European Association for
Panels and Profiles

RULES FOR TESTING, EVALUATION AND FIELD OF APPLICATION OF TEST RESULTS, FOR SANDWICH PANELS

DECEMBER 2024

Content

1 INTRODUCTION

The assessment of the essential properties of sandwich panels is widely based on testing. Experimental verification covers most of the mechanical, fire and thermal insulation properties. The Testing Rules (TR) for Sandwich Panels support the QR by giving detailed explanations and advices about the execution of the tests and about the analysis of the test results. The current version of TR is based mainly on the Practical Guide to EN 14509 The TR have been revised to correspond to the requirements given in the harmonized European standard EN 14509:2013 for self-supporting sandwich panels.

The document introduces appropriate ways to perform the tests and to analyse and evaluate the test results. It shows a good practice of experimental verification of the mechanical and building physics properties for type testing, factory production control and regular external quality control. The TR are under continuous development due to the systematic review of the standards and improvement of practices in laboratories.

2 DETERMINATION OF RELEVANT MECHANICAL AND PHYSICAL PROPERTIES

2.1 Content

Necessary mechanical and physical properties in general and depending on the intended application are presented in the following table.

No.	Characteristic		External walls	Internal walls	Ceilings	Roofs
1	Density of core material		yes	yes	yes	yes
2	Thickness of core and faces		yes	yes	yes	yes
3	Mass of panel		yes	yes	yes	yes
4	Tensile strength and thickness of face material (or declaration acc. to EN 14509:2013, 6.3.4.2)		yes	yes	yes	yes
5	Mechanical properties of the panel	Shear strength and modulus of core material	yes	yes	yes	yes
6		Creep coefficient	no	no	yes	yes
7		Compressive strength and modulus of core material	yes	yes	yes	yes
8		Shear strength after long-term loading	no	no	yes	yes
9		Cross-panel tensile strength (with faces) and modulus	yes	yes	yes	yes
10		Bending resistance and wrinkling stresses				
10.1		Bending resistance in span and at internal support				
10.1.1		- positive bending	yes	yes	yes	yes
10.1.2		- positive bending, elevated temperature	yes	no	no	yes
10.1.3		- negative bending	yes	yes	yes	yes
10.1.4		- negative bending, elevated temperature	yes	no	no	yes
10.2		Wrinkling stresses				
10.2.1		Wrinkling stress, external face				
10.2.1.1		- in span	yes	yes	yes	yes
10.2.1.2		- in span, elevated temperature	yes	no	no	yes
10.2.1.3		- at internal support	yes	yes	yes	yes
10.2.1.4		- at internal support, elevated temperature	yes	no	no	yes
10.2.2		Wrinkling stress, internal face				
10.2.2.1		- in span	yes	yes	yes	yes
10.2.2.2		- at internal support	yes	yes	yes	yes
11	Dimensional tolerances		yes	yes	yes	yes
12	Thermal transmittance		yes	where applicable		yes
13	Fire characteristics	Reaction to fire – classification	yes	yes	yes	yes
14		Fire resistance – classification	When the performance is intended to be declared			
15		External fire performance – classification	no	no	no	yes

16	Water permeability		yes	When the performance is intended to be declared	yes
17	Air permeability		yes	When the performance is intended to be declared	yes
18	Airborne sound insulation		When the performance is intended to be declared		
19	Sound absorption		When the performance is intended to be declared		
20	Durability	Reduction of tensile strength with time as a consequence of ageing (durability), depending on the core type	yes	When the performance is intended to be declared	yes
21		Wedge tests (only in case of core-glued panels)	yes	When the performance is intended to be declared	yes
22	Resistance to point loads		no	no	When the performance is intended to be declared
23	Resistance to repeated loads		no	no	When the performance is intended to be declared
24	Dangerous substances		Where required (depending on the national regulations)		

Table 1: Necessary mechanical and physical characteristics

3 MECHANICAL PROPERTIES

3.1 Task

The subjects of consideration in chapter 3 are all tests concerning the mechanical values, the reduction of tensile strength with time as a consequence of ageing, durability, long-term effects on shear strength and modulus, the resistance to point loads and repeated loads.

The focus is on typical panel types. Unusual panel types need special, sometimes modified consideration.

3.2 Composition of required values for mechanical resistance

3.2.1 External walls (see EN 14509:2013, ZA.3.3 and Fig. ZA.3)

For external walls, all necessary mechanical values for the CE-marking (see EN 14509:2013 ZA.3) and the accompanying documents need to be determined according to table 1, point 1 to 10, 20 and 21.

3.2.2 Internal walls (see EN 14509:2013, ZA.3.2 and Fig. ZA.4)

The same values as under 3.2.1 are necessary, however without properties for elevated temperature, when determining wrinkling strength. The durability investigations are needed when the performance is intended to be declared.

Note:
In many countries, there are national regulations considering the determination of impact loads on internal walls (e.g. in Germany DIN 4103). Such standards need to be considered additionally.

3.2.3 Roofs (see EN 14509:2013, ZA.3.4 and Fig. ZA.2)

Same values as in 3.2.1 and additionally:

- Shear strength after long-term loading
- Creep coefficient (value at t = 2,000 h and t = 100,000 h)
- Resistance to point loads and access loads, when the performance is intended to be declared

3.2.4 Ceilings (see EN 14509:2013, ZA.3.2 and Fig. ZA.4)

The same values as under 3.2.3 are necessary, however without properties for elevated temperature, when determining wrinkling strength. The durability investigations are needed when the performance is intended to be declared.

3.3 General references for testing procedures and evaluation of test results

In the following, all necessary tests including evaluation for a panel with flat or lightly profiled faces and for a panel with profiled faces are discussed.

This includes then all necessary testing for internal walls and ceilings, where the tests mentioned above can be neglected.

I. All mechanical properties shall be stated as characteristic values (5% - fractile values) and mean values (see EN 14509:2013, 6.2.4 and 6.4). The mean values are particularly necessary for moduli and density because the mean value is taken into account for design (see EN 14509:2013, E.7.1 and EN 14509:2013, E.7.6). The mean values of tension and compression moduli are eventually used for required standardi-zations.

For normal sandwich panels, $\bar{\chi}$ = mean value of χ_i.

$$\bar{x} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_i \tag{3.1}$$

II. The 5% - fractile values should result from a statistic evaluation in accordance with EN 14509:2013, A.16.3 following the subsequent formulae (log. distribution!)

$$x_p = e^{(\bar{y} - k\sigma_y)} \tag{3.2}$$

where:

χ_p = 5% - fractile value of population χ

$\bar{y}$ = mean value of y_i

$$\bar{y} = \frac{1}{n} \cdot \sum_{i=1}^{n} y_i \tag{3.3}$$

$$y_i = L_n(\chi_i) \tag{3.4}$$

k = fractile factor given in EN 14509:2013, table A.5

σ_y = standard deviation of y

Number of specimens (n)	3	4	5	6	7	8	9	10	15	20	30	60	100
k	3.15	2.68	2.46	2.34	2.25	2.19	2.14	2.10	1.99	1.93	1.87	1.80	1.76

Table 2: Fractile factor k assuming a confidence level of 75%

For clarification, the evaluation is displayed for 3 virtually assumed test results for wrinkling stresses (x_i):

x_1 = 80 MPa

x_2 = 100 MPa

x_3 = 120 MPa

mean value → $\bar{\chi}$ = 100 MPa

y_1 = ln χ_1 = ln 80= 4.38203

y_2 = ln χ_2 = ln 100= 4.60517

y_3 = ln χ_3 = ln 120= 4.78749

mean value → $\bar{y}$ = 4.59156

$$\sigma_y = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^{n} (y_i - \bar{y})^2} \tag{3.5}$$

$$= \sqrt{\frac{1}{3-1} \cdot [(4.38203 - 4.59156)^2 + (4.60517 - 4.59156)^2 + (4.78749 - 4.59156)^2]} = 0.20307$$

k = 3.15 (factor in accordance to EN 14509:2013, table A.5)

III. Calculation of the 5% - fractile and related material safety factor for mechanical strength for the ultimate limit state (ULS), subject to EN 14509:2013, E.6.3.2:

$$y_p = \bar{y} - k \cdot \sigma_y = 4.59156 - 3.15 \cdot 0.20307 = 3.95189 \quad (3.6)$$

$\chi_p = e^{y_p} = e^{3.95189} = 52.03$ MPa

$$\gamma_M = 1.05 \cdot e^{2.115 \cdot \sigma_y} = 1.05 \cdot e^{2.115 \cdot 0.1099} = 1.32 \; (\sigma_y = 0.1099) \quad (3.7)$$

IV. Advice on number of tests:

The minimum number of tests is indicated for type testing (TT) in EN 14509:2013, table 5 and 6 and for factory production control (FPC) in EN 14509:2013, table 7. It is, however, strongly recommended to accomplish more than only the minimum numbers of tests for some mechanical properties. This does not necessarily apply to full scale tests (EN 14509:2013 A.5 wrinkling tests, A.4 shear tests and A.7 simulated internal support tests). For these, the minimum number of 3 or 4 tests is expected to result in reasonable 5 % - fractile values of the mechanical properties (e.g. wrinkling stresses).

Since the determination of material values (e.g. shear, compressive and tensile strength of the core material) is carried out with small samples and relatively small effort and costs, a larger series of tests (e.g. 10 tests) can be of great benefit. This is described in the following example:

Due to really measured ultimate loads of 10 shear tests (short beam, see also chapter 3.5.3.1), the following shear strength values were determined. Thereby it is emphasized that these values are determined on samples of a good polyurethane (PUR) core quality (all values range from 0.100 to 0.123) and, therefore, they do not have a great statistical scatter.

Sample no.	1	2	3	4	5	6	7	8	9	10
f_{Cv} [MPa]	0.123	0.121	0.104	0.108	0.113	0.106	0.107	0.109	0.113	0.100

Table 3: Example shear strength values

Assuming that only 3 tests instead of 10 were carried out and duly evaluated (minimum number according to EN 14509:2013, table 5) and this coincidentally with the samples no. 1, 3 and 10, a very low 5% - fractile value would have been found.

$f_{Cv}^{5\%}$ = 0.076 MPa with a standard deviation of "$\sigma_y = 0.1099$"

This result could possibly have a decisive impact on design, so that as a result, smaller permissible spans or loads were determined. All calculations with these small characteristic values would be uneconomic.

This is additionally intensified by the fact that the material safety factor is specified depending on the deviation found in the evaluated tests. Due to the standard deviation according to EN 14509:2013, E.6.3.2:

$\gamma_M = 1.05 \cdot e^{2.115 \cdot \sigma_y} = 1.05 \cdot e^{2.115 \cdot 0.1099} = 1.32 \; (\sigma_y = 0.1099)$ for ultimate limit state.

The design value of shear strength would then only be $f_{Cvd} = \frac{0.076}{1.32}$ = 0.057 MPa and, for the entire design, very uneconomic.

Assuming once more that only 3 tests were carried out and duly evaluated instead of 10, and, this time, coincidentally with the samples no. 1, 2 and 5, a very high 5% - fractile value would have been found:

$f_{Cv}^{5\%}$ = 0.103 MPa with a standard deviation of "$\sigma_y = 0.0449$"

This result indeed would be an advantage for the design but the probability that this value is always confirmed by FPC, is very small and that would cause substantial problems. The consequence in most occasions is that all tests belonging to this test series must be repeated.

These examples clearly show that it is of advantage to accomplish more tests (e.g. n = 10) than the minimum number required in EN 14509:2013, table 5, 6 and 7, particularly with the small test specimens. In doing so, one receives a sufficiently well 5% - fractile value which can be kept with steady quality also throughout FPC. A large number of test results gives also a more realistic picture about the real distribution of the concerned strength.

It follows with the 10 values given above:

$f_{Cv}^{5\%}$ = 0.096 MPa with a standard deviation of "$\sigma_y = 0.0648$" and with that, a material safety factor for the ultimate limit state of

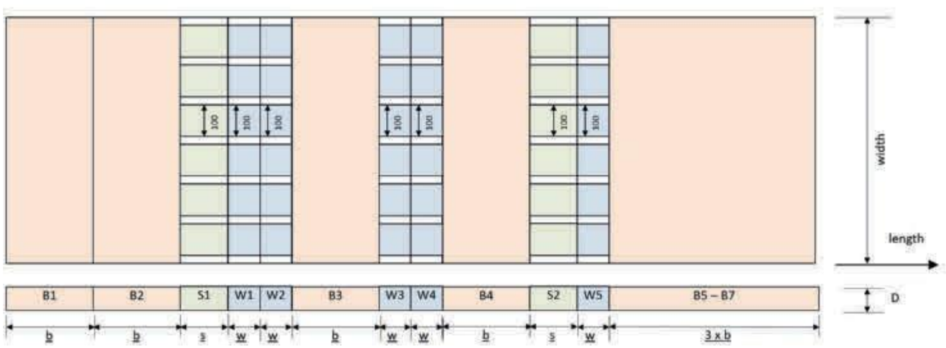
$$\gamma_M = 1.05 \cdot e^{2.115 \cdot \sigma_y} = 1.05 \cdot e^{2.115 \cdot 0.0648} = 1.20\ (\sigma_y = 0.0648)$$

$$f_{Cvd} = \frac{0.096}{1.2} = 0.080\ \text{MPa}$$

V. For TT, all panels and specimens shall be from the same batch (see EN 14509:2013, 6.2.3.1). Therefore, all test specimens must be from one „batch“ of the current production. This is of great importance since all mechanical properties depend on each other in principle (e.g. wrinkling stresses depend on shear modulus, compression modulus and tensile modulus of core and the elasticity modulus of the face) and the defined specifications of the characteristic values are only sensible if the core material is from one and the same batch.

The extraction and cutting of the samples is normally based on explicit „cutting sketches“. An example is presented below:

b = 6000 mm, w = 100 mm, s = 1000 mm



b → full scale tests
w → small scale tests (compression, tension, density etc.)
s → short beam tests

Note: The drawing is not in scale.

Figure 1: Sampling plan

The required samples w and s may also be taken from the unharmed areas of a panel subject to a full scale test. It is important to include both, samples from the edge as well as from the centre region of the panel (EN 14509:2013, 6.2.3.1).

VI. Development of product families

In order to reduce the number of necessary tests, it is sensible and in most cases also easy, to define product families as described in EN 14509:2013, 6.1.

In the following, the expression „family" is described more thoroughly by giving the relevant criteria, which the panels belonging to one family have to fulfil.

Products sharing the same cross section, meaning that the face geometry is the same.

- The faces may consist of different steel thicknesses as long as they are within the same steel grade.
- All products are produced implementing the same polyurethane (PUR) / polyisocyanurate (PIR) or phenolic foam (PF) formulation, or the same type of mineral wool (MW) or expanded polystyrene (EPS), with the same mechanical properties.
- For panels with slab stock or lamella cores, it is necessary that all elements are produced with the same amount of glue, the same type of glue as well as the same orientation and layout of longitudinal joints of the lamellas or slab stock within the panel.
- If there are several thicknesses belonging to a product family, it is only necessary to test the smallest, one middle range and the biggest thickness (see EN 14509:2013, table 5). For any thickness between those tested, the obtained results can either be interpolated or the lowest values may be used for all thicknesses.
- If for one family, both, flat and lightly profiled („as if flat") face geometries (according to definition in EN 14509:2013) are included, the results obtained for the completely flat panels may also be used for the lightly profiled panels.

3.4 General references for technical correct recording of test results

The requirements of EN 14509:2013, A.16.1 need to be considered and followed essentially:

For each TT series, a formal documentation (inspection report), that contains all relevant data, needs to be developed so that the test series can be reproduced accurately. In addition to test results, the specimens need to be described fully and accurately, particularly in terms of dimensions and material properties. Furthermore, any observations during testing must be recorded. All equipment used in tests shall be calibrated.

The following information shall be recorded in all TT inspection reports:

I. Date and time of production;
II. Method of production and orientation of the panel during production e.g.:
    - For foamed PUR elements: which face was on top, which was the leading edge during continuous foaming, etc.;
    - For EPS panels: joints in the core, gluing of slabs etc. or
    - For MW panels: width and length of the lamellas, if necessary gluing of the lamellas and orientation of the fibres, etc.
III. Date of testing;
IV. Conditions during testing (temperature and humidity);
V. Method of loading and details of testing - including gauging device;

VI. Support conditions (number and length of spans, width and details of supports, number and details of connections to supporting structure, etc.);
VII. Orientation of panel during testing (e.g. full scale tests: positive or negative orientation);
VIII. Type and properties of face material (thickness, yield stress, geometry, etc.);
IX. Type and properties of core material (density, strength, modulus, etc.);
X. Type and details of adhesive;
XI. Measurements made during testing (load, deflection readings, temperature, etc.);
XII. Mode of failure (if possible with photo documentation).

The analysis of results for a test shall be based on measured dimensions and material properties of the specimen, unlike the design, where nominal values are assumed.

General notes:
The data provided from II to XII is normally acquired directly during individual test series.

The requirement of employing measured dimensions and material properties for the evaluation of test results is of high importance. First of all, this means that every specimen must be measured exactly, i.e. the exact width, thickness, and length but also the depth of stiffeners and light profiling; the position of stiffeners and profiles, together with the height and width of ribs and valleys in trapezoidal profiled faces must be documented.

In addition, the metal sheet thicknesses need to be determined for each coil used in specimens. For arithmetical evaluations based on sandwich theory, the determined test results, e.g. tested shear modulus of core material, must be included.

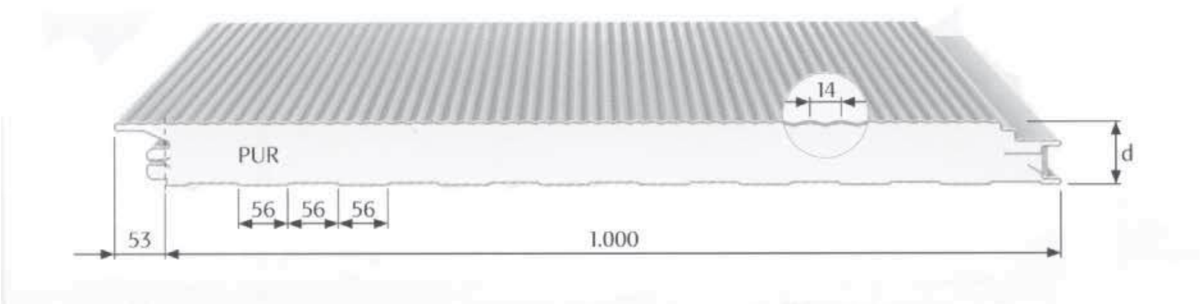


Figure 2: Example of a panel with lightly profiled faces (dimensions in mm)

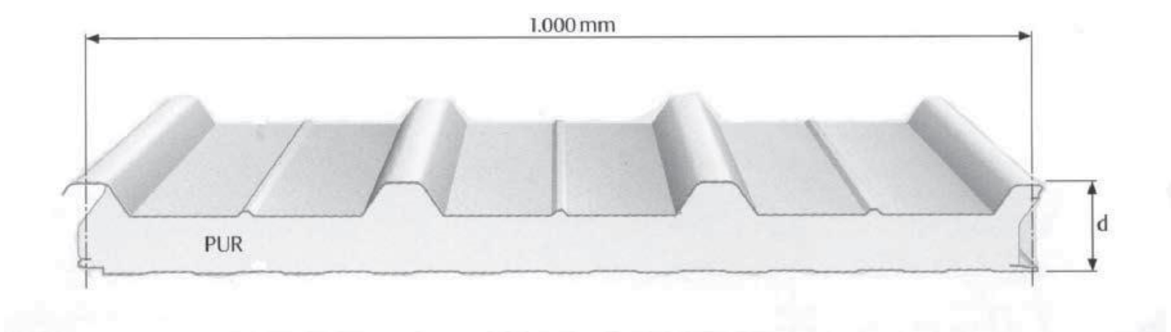


Figure 3: Example of a panel with one profiled face and one lightly profiled face

3.5 Presentation and explanation of tests in detail

3.5.1 General

In the following, the necessary tests according to EN 14509:2013, 5.2.1 and 6.2 (in particular EN 14509:2013, table 5) are explained in detail. Important notes on how to conduct the tests are given for each case. Furthermore, explanations on which parameters are needed for accurate evaluation of characteristic properties and how these should be acquired are given. References to related standards can be found. Additionally, examples of real-life test results are provided. Calibrated test equipment has to be used.

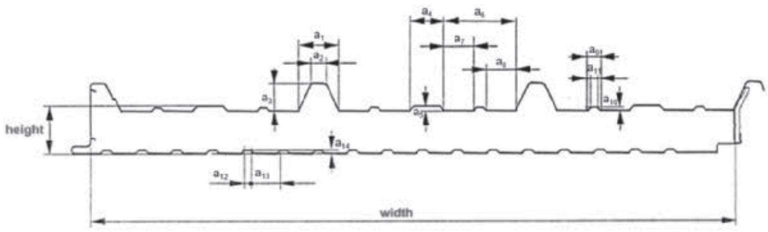


Figure 4: Typical roof panel with dimensions to be checked

The dimensions indicated in Figure 4 need to be measured at both ends at least 50 to 200 mm away from the cut edges.

The minimum number of test specimens is based on EN 14509:2013, table 5.

3.5.2 Mechanical properties of metal faces

Based on: EN 14509:2013, 5.1.2 and EN ISO 6892-1:2016

Comments:

I. Test specimens:
   - Test pieces according to EN ISO 6892-1:2016, type 1 or type 2.
   - The coatings must be removed either in part or totally before measuring the steel thickness. The removal of metallic coating must be in accordance with EN 10346, Annex A.

II. Test procedure is exactly defined in EN ISO 6892-1:2016.

III. Number of tests:
   - For each coil, 3 tests are sufficient.
   - Two of the samples must be taken from the edge area (however with a minimum distance of 50 mm from the edge) and one sample must be taken from the centre of the face. All samples must be oriented parallel to the lengthwise direction of the panel.

IV. Important test results:
   - Metal sheet thickness tobs (accuracy 0.01 mm, micrometre shall be used), yield stress fyobs, ultimate tensile strength fu and elongation shall be determined on test specimen.
   - If another test method is used, the equipment has to be calibrated and the test method has to be validated.

V. Aim of evaluation of test results:
   - The values are necessary for interpretation of test results (e.g. see EN 14509:2013, 5.2.1.2, 5.2.1.7, 5.2.1.8) and for determination of correction factors (e.g. EN 14509:2013, A.5.5.4, equation A.23a).

3.5.3 Shear strength and shear modulus

Based on: EN 14509:2013, 5.2.1.2 and A3 (in particular EN 14509:2013, A.3.1 to A.3.5), A.4 and A.5.6

Comments:

There are two different kinds of tests which can be conducted alternatively:

I. Test on short beams (see EN 14509:2013, A.3.1 to A.3.4)
II. Test on a complete panel (see EN 14509:2013, A.4)

In this context, it should also be remembered that the tests for type testing and the FPC tests must be identical, i.e. if the shear tests for type testing are accomplished with full scale panels, the FPC shear tests must also be conducted on full scale panels.

3.5.3.1 Test procedure on short beams

The exact test procedure is described in EN 14509:2013, A.3.2 to A.3.4.

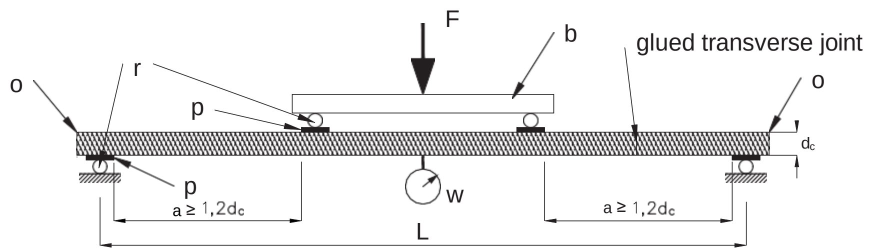
Comments:

I. To get a shear failure it is important that:
   a) the width of the load spreading plates both at the supports and below the loading points and
   b) the span length

   are appropriate.

   The recommended values in the standard may not be suitable for all types of panels.
II. Shear failure mode:

   With PUR, PIR, EPS core, clear shear failure (shear crack, see Figure 6, or delamination between core and lower face at support) should be observed, as a correct value of the shear strength can only be achieved by a shear failure of the specimen. With MW core, the shear failure mode is displayed in Figure 7.



Key

F	applied load	w	measured deflection
b	loading beam / quad hollow profile	a	distance between the loading point and support
r	rollers, radius ≥ 15 mm		
p	metal load spreading plates ≥ 60 x 10 mm.	d_c	continuous thickness of the core
		L	span length
o	overhang not exceeding 50 mm		

Figure 5: Test arrangement for the shear test with two load points

- A smooth material (e.g. rubber or plywood) can be placed between the metal load spreading plates and panel face.

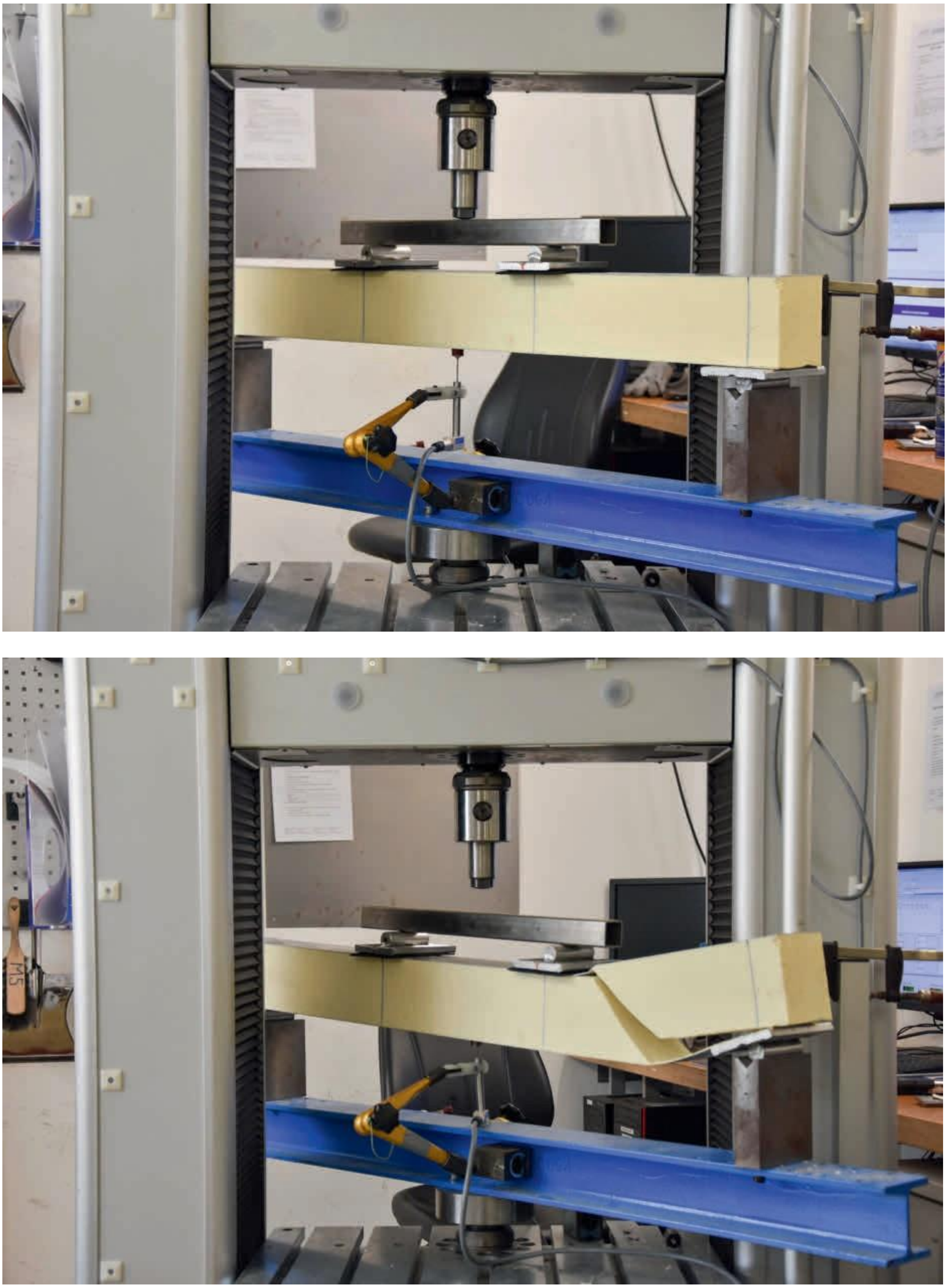


Figure 6: Shear tests on short beams of PU cored panels

Failure due to wrinkling or delamination of upper face does not deliver real shear strength.

With MW also shear hinges (no clear shear cracks) which correspond to real shear strength can be found (see Figure 7).

For some configurations, the failure mode may be a compressive failure either at the support or under the load introduction area. The test evaluation then does not give realistic shear strength properties.

Figure 7: Shear tests on short beams of MW cored panels

III. Deflection recording:
For determination of the shear modulus, the exact load-deformation curve must be recorded. The displacement has to be measured at the lower face of the specimen. The displacements measured in the upper and lower face do both include the compressive deformation at the supports. The displacement measured in the upper face may include local deformation at the loading point, which may cause difference in the measured data of lower and upper face.

IV. Sampling of test specimens:
- For panels with profiled faces, the specimens shall be cut out of the predominant thickness (see Figure 8), which mostly occurs between the ribs. Possibly existing light profiles or micro linings should be symmetrically distributed over the width of specimens if possible. The width of specimens shall be ≥ 100 mm.

Figure 8: Cutting of specimens in case of panels with profiled faces

- For specimens with PUR, PIR, EPS, PF and CG, it just needs to be kept in mind that a span must be selected with which the above mentioned shear failure mode occurs. The clear distance between the plate of support and point of load introduction must be respected (at least 1,2 of d_c).
  Note: *Tests on thick panels (>250 mm) require wide supports and the compressions on supports can be high.*
- With MW and EPS, the followings need to be considered additionally:
  - With a core of prefabricated slabs (e.g. MW or EPS plates) and transverse joints within the core, glued together at the front side, a short beam needs to be removed so that the transverse joint is situated between the support and the first loading point during the test.

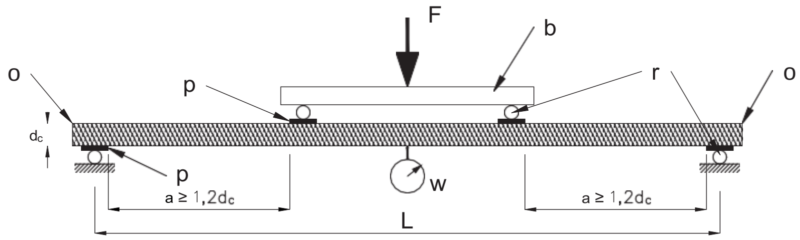


Figure 9: Test arrangement for the shear test with two load points in case of cores of prefabricated slabs with glued transverse joints

  - With lamellas (MW) where longitudinal and transversal joints are not glued together, the arrangement of joints is of decisive importance for the shear strength and shear modulus. Therefore, the joints are normally not in one line. The following procedure is recommended: Sampling of a short beam in such way that no transverse joints are present, if possible. If not possible otherwise, a part of the cross section can include a joint as long as the joint is situated between the two single loads.
    For evaluation of tests (also see EN 14509:2013, A.3.5.1. equation A6), the influence of transverse joints is then considered arithmetically (also see EN 14509:2013, 6.2.1 and 6.2.3).
- Special care must be taken when cutting the specimens. Considerations concerning the cutting are given in chapter A.1.3 in EN 14509:2013.

V. Number of tests:
It is recommended to perform 10 instead of the required 3 tests per thickness (see chapter 3.3). This leads generally to a smaller but reliable scatter of results and thus to better values when determining the characteristic values and the material safety factors γ_M.
When evaluating a variety of panel thicknesses, it is only necessary to test the lowest, a middle range and the largest thickness. This procedure is in accordance with the full scale tests (see chapter 3.3).

VI. Documentation and test results:
The individual test specimens must be measured exactly and the results must be documented in detail. Important test results: failure load, load-deflection curve and details on failure mode.

VII. Aim of evaluation of test results:
- Shear strength f_{Cv} (characteristic value)
- Shear modulus G_C (mean value and characteristic value)

Shear strengths are needed for design against ultimate and serviceability limit states (see e.g. EN 14509:2013, table E.2).
The single values for the shear modulus are to be determined from the linear slope of the load-deflection curve and with the measured core thickness of the faces.

Note: *The linear part of the graph should be chosen so that it is in the beginning (under approximately 50 % of the maximum force) and all possible disturbances in the very beginning are excluded.*
The mean shear modulus is necessary for application of the sandwich theory (design by calculation) e.g. according to EN 14509:2013, tables E.3 and E.10. The characteristic shear modulus is used to set limits in FPC.

3.5.3.2 Test procedure on full panel
The exact test procedure is presented in EN 14509:2013, A.4. The principle of partial vacuum method is shown in 3.5.7.

<u>Comments:</u>

I. To get a shear failure, it is important that:
   a) the width of the load spreading plates, both at the supports and below the loading points (if not using air pressure loading) and
   b) the span length

   are appropriate.

   The recommended values in the standard may not be suitable for all types of panels.

II. The deflection recording, the number of tests, the documentation of test results and the evaluation of test results are in principle according to 3.5.3.1.

III. When the shear strength and modulus are determined with a complete panel, the effects of the possible joints in the core material are included in the test results. It is therefore important that the sampling of the test panels is done in such way that the joints are situated in the most critical pattern in the shear failure area. The joint pattern in the core material must always be delivered by the manufacturer so that an evaluation of the influence can be done. It should also be noted if the joints are glued or if there is any other type of connection. The measured complete width of the core has to be taken into account for evaluation.

IV. In this test set-up, it is also possible to test panels with profiled faces. However, the evaluation determining the shear strength and shear modulus has to be undertaken on the basis of the sandwich theory (see EN 14509:2013, A.4.5). If type testing is performed on the full panel, the same test set-up has to be used also for FPC, as well as for external quality control (EQC).

V. The clear distance between the plate of support and point of load introduction must be respected (at least 1.2 of d_c).

   Notes:
   Tests on thick panels (> 250 mm) for the shear strength are difficult and require wide supports (up to 500 mm, minor eccentricity of the support plates is acceptable). The failure mode can still be combination of compression failure on support and shear failure at the end of the support plate.

   In case of panels with profiled faces, the clear distance between the support plates and loading plates might be larger than 1.2 d_c in order to get a shear failure.

VI. In case of tests on the complete panel width with load applied by air pressure, the deflection has to be measured at the mid-span and at the supports, on the upper side of the panel.

Because the remainder after subtraction of the deflection caused by the bending deformations from the total deflection results in the deflection caused by shear deformations, the total deflection has to be measured very exactly.

3.5.4 Reduced shear strength after long-term loading

Based on: EN 14509:2013, 5.2.1.5 and A.3.6

Comments:

I. In general:

The tests shall be carried out as tests on short beams as described in chapter 3.5.3.1, however with long-term loading. In terms of test procedure, all notes in chapter 3.5.3.1 need to be considered. A general description of the tests is presented in EN 14509:2013, A.3.6.2.

If the shear tests have been carried out according to 3.5.3.2 (EN 14509, A.4), reduced shear strength tests can be carried out using this test method and applying the principles of EN 14509, A.3.6.2.

The test specimens have to be from the same batch as the test specimens for the short-term tests (see chapter 3.5.3).

It is recommended to apply a maximum load of approximately 90 % and a minimum load of approximately 50 % of the mean failure load, determined in the short-term tests (see chapter 3.5.3).

The long-term loading is usually applied with weights.

II. Number of tests:

Based on experience, a set of 10 tests on short beams, taken from the greatest panel thickness, is sufficient.

III. Documentation:

The individual test specimens must be measured exactly and the results must be documented in detail.

IV. Important test results:

- Time of shear failure after the load was applied for different loads

The results are necessary to determine the long-term shear strength at t = 100,000 h.

V. Note:

According to EN 14509:2013, A.3.6.1, no tests need to be accomplished if a long-term shear strength of $f_{Cv,long\text{-}term}$ = 0.4 x $f_{Cv,short\text{-}term}$ (at $\varphi_t \leq 2.4$ at 2000 h) or $f_{Cv,long\text{-}term}$ = 0.3 x $f_{Cv,short\text{-}term}$ (at $\varphi_t > 2.4$ at 2000 h) is specified, where φ_t is the creep coefficient according to EN 14509:2013, A.6.5.

However, it must be noted that higher long-term shear strengths, which can be determined with the help of the described tests, lead to significant advantages for the design of panels.

3.5.5 Compressive strength and compressive E-modulus

Based on: EN 14509:2013, 5.2.1.4 and A.2

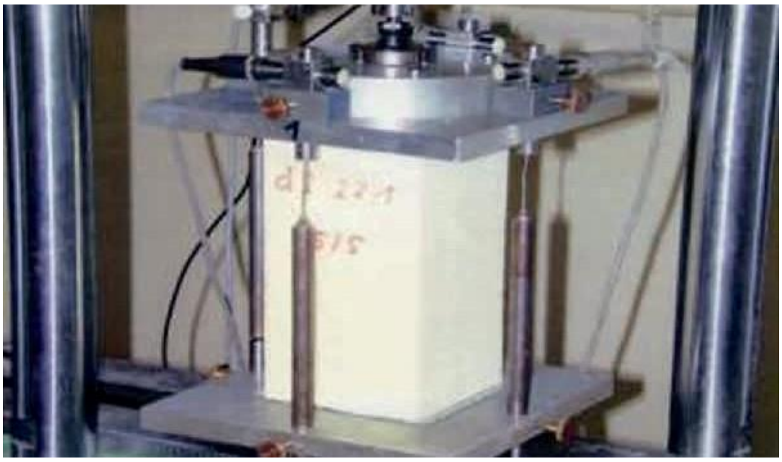


Figure 10: Test of compressive strength and compressive modulus

Comments:

I. Test procedure:

When accomplishing the tests, it is important to have centric and constraint free load introduction (e.g. spherically seated mounting device). Regarding the test arrangement, one ball bearing plate is sufficient

Note:
One ball bearing plate and one stiff plate are recommended. In case of test-set-ups with two stiff plates (see Figure 11), the additional bending moment can cause wrong results for the compressive strength and modulus.

Figure 11: Test of compressive strength and compressive modulus

II. Number of tests:

It is recommended to accomplish 10 instead of 6 tests (see EN 14509:2013, table 5 and 6) for each panel thickness (for explanations see 3.3, point VI).

III. Sampling of test specimens:

In case of panels with profiled faces, the specimens shall be cut out of the predominant thickness (analogue to EN 14509:2013, A.1.3) that mostly occurs between the high profiles. Possibly existing light profiles or micro linings should be symmetrically distributed over the width of samples, if possible.

IV. The individual test specimens must be measured exactly and the results must be documented in detail.

When accomplishing the tests, it is important to have centric and constraint free load introduction (e.g. spherically seated mounting device).

Regarding the test arrangement, one ball bearing plate is sufficient.

Wrong results caused by bending of the faces during the compression phase can be avoided by filling the gaps between the faces and the compression plates with gypsum or other suitable filling materials.

V. Important test results:
   - Failure load and load-deformation curve

VI. Aim of evaluation of test results:
   - Compressive strength f_{Cc} (5% - fractile value and mean value)
   - Compressive E-modulus E_{Cc} (mean value and 5% - fractile value)

Compressive strengths are needed for proof of ultimate and serviceability limit states of stresses at the supports (see EN 14509:2013, E.2 and E.4.3.2).

The single values of compressive E-modulus are to be determined from the linear slope of the load-deflection curve.

The mean compressive E-modulus is necessary for standardization and for the case that the wrinkling stress should be determined arithmetically without tests (such procedure is however conservative and gives low values) (see EN 14509:2013, A.5.5.3, equations A20 and A21).

Figure 12: Compression test failed specimen

Notes regarding Figure 12:
- *Pinned connection on top.*
- *The failure has taken place before "buckling". When the area is small and the height is big, it is vitally important that the specimen is cut precisely to avoid skewness. Two displacement transducers give accurately the average strain.*
- *EN ISO 844 also foresees a procedure with additional displacement transducers which is more accu- rate for determination of the ECc modulus.*

3.5.6 Tensile strength and tensile E-modulus

Based on: EN 14509:2013, 5.2.1.6 and A.1

Comments:

I. Test procedure:

- At accomplishment of tests, it is absolutely important to have centric load introduction (tensile force). Therefore e.g. metal plates, plywood or similar are glued to the faces of the specimen and these are gimbal mounted into the test device. Regarding the test arrangement, one ball bearing plate is sufficient. Pinned connections are also suitable.

  In the cross-panel tensile test, it is important to determine the accurate deformation between the two plates. When using the cross head movement for evaluation, the deformation of the mounting devices is always included in the results. The elastic modulus cannot be then deter- mined accurately.

  If needed, the cross-panel tensile modulus has to be determined at an elevated tempera- ture of +80° C. The tensile test specimen shall be heated and stored according to A.1.6 of EN 14509:2013. The instructions given to the temperature limits and to the duration of the heating shall be followed. The test shall be started immediately (≤ 3 minutes after removal of the spec- imen from the thermal box). The load-displacement curve, the maximum load and the type of failure shall be recorded.

Figure 13: Cross-panel tensile test - measurement of the movement from loading bridge

Notes regarding Figure 13:
- *The measured displacement includes also extension in plywood, screw connection and steel parts and the calculated strain is higher than the actual strain in panel. The obtained E-modu- lus is thus lower than the actual one.*
- *Pinned connections on top and bottom*

Figure 14: Cross-panel tensile test - measurement of the movement directly from specimen

Notes regarding Figure 14:

- It is enough to have two displacement transducers to obtain average strain.
- This method gives E-modulus correctly.
- Pinned connections on top and bottom

Figure 15: Cross-panel tensile test specimens after failure

It is in any case necessary to use the same type of test set-up for both, type testing and quality control (FPC and external). Different test set-ups can have an effect especially on the modulus. If no displacement transducers are used, the measured displacement is the sum of the deformation of the sample and that of the test apparatus. These can be in the same range. If the test set-up is changed (e.g. between type testing and FPC) a verification has to be performed.

- During sampling and cutting of samples, it is important that the faces are not peeled off, not even in small areas at the edges (see EN 14509:2013, A.1.3).

II. Number of tests:

It is recommended to accomplish 10 instead of 6 tests (see EN 14509:2013, table 5 and 6) for each panel thickness (for explanations see 3.3, point VI).

III. Sampling of test specimens:

In case of panels with profiled faces, the specimens shall be cut out of the predominant thickness (analogue to EN 14509:2013, A.1.3) that mostly occurs between the high profiles. Possibly existing light profiles or micro linings should be symmetrically distributed over the width of samples, if possible.

IV. Documentation and test results:

- The individual test specimens must be measured exactly and the results must be documented in detail.
- Important test results:
- Tensile strength f_{Ct} at 20^0C and 80^0C (see EN 14509:2013, A.1.6)
- Tensile E-modulus E_{Ct} at 20^0 C and 80^0 C (see EN 14509:2013, A.1.6)

V. Aim of evaluation of test results:

The tensile strength values are needed as control values (FPC) and for determination of the correction factor k_2 (see EN 14509:2013, A.5.5.5) of the wrinkling stress at low tensile strengths.

The single values of tensile E-modulus are to be determined from the linear slope of the load-deflection curve.

Note: *The single values of tensile E-modulus are to be determined as secant modulus from the linear slope of the load-deflection curve.*

The characteristic tensile E-modulus is necessary for determination of the correction factor k_1 for the wrinkling stress at increased temperature (see EN 14509:2013, A.5.5.5, equation A.24) and the mean value is needed if the wrinkling stress should be determined arithmetically without tests (such procedure is however conservative and gives low values) (see EN 14509:2013, A.5.5.3, equation A.20 and A.21).

3.5.7 Bending moment capacity and wrinkling stresses of simply supported panels

Based on: EN 14509:2013, 5.2.1.7 and A.5.1 to A.5.5

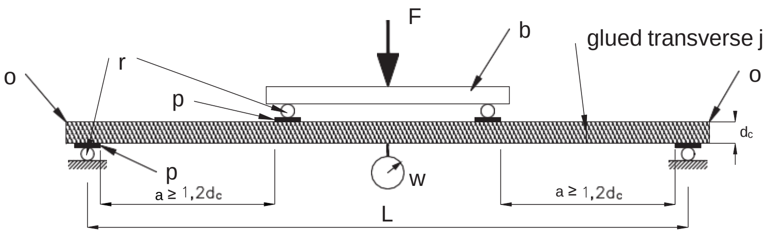


Figure 16: Test set-up - bending moment capacity and wrinkling stresses of simply supported panels

Figure 17: Bending test arrangements based on line loads. Loads shall be introduced on the lower parts of the face profile.

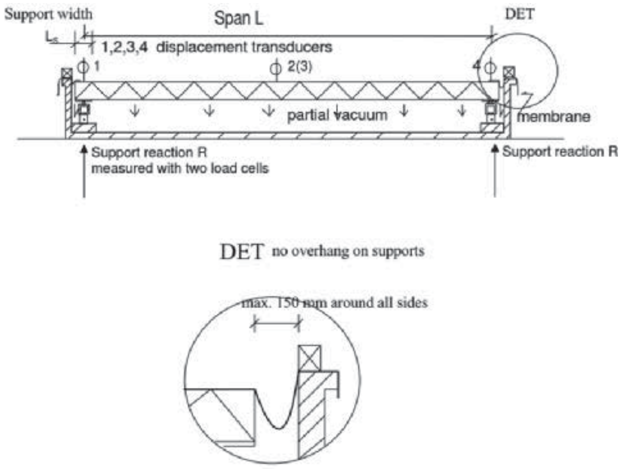


Figure 18: Principle of partial vacuum method

Figure 19: Test set-up in partial vacuum bending test

Comments:

I. In general:

The aim of this test set-up is to define the wrinkling stresses σ_w for each type of face. The determination of the bending moment capacity (M_u) is automatically included with the evaluation of the test results, even though these values are not necessary for the design calculations.

II. Test procedure:

The exact test procedure is described in EN 14509:2013, A.5.1 to A.5.4.

- In principle, there are two ways in which the test loads can be applied to the system (see EN 14509:2013, A.5.2.1):
- By 4 line loads (linear distributed loads) or
- By air pressure in a vacuum chamber.

Note:
Air bags are not recommended as the real load application is unknown. This leads to wrong results.

Only when loading with uniformly distributed load such as vacuum chamber, air bag or similar, the correction factor k_2 (see EN 14509:2013, A.5.5.5) needs to be considered in the evaluation

Principle of partial vacuum method and overpressure box method:

In a vacuum chamber, the load is almost uniform on the panel different from line loads where local compression on the upper face may cause it buckle under line loads. Around the panel, there are small line loads because of the bends in membrane between the panel and the walls. This distance should be limited and the bends should allow the panel to deflect freely. During the deformation, the foil may not be detached from the panel as this causes severe errors. The actual uniform load w is little less than $_{F/L}$ ($F = 2 \cdot R$ total load), but in practice, in bending tests, one can assume that $F = w \cdot L$. In shear tests, a more accurate analysis may be needed (see EN 14509:2013, A.4.5.2). Thin (0.2 ÷ 0.4 mm) transparent plastic film is recommended as membrane because it allows to observe buckling in the upper face. Gaps between panel sides and chamber walls which are greater than 50 mm need to be taken into account for calculation. If the panel is shorter than the box, the empty space should be filled with e.g. EPS blocks so that the gap between them and the panel end is less than 50 mm.

It is accurate enough to have one displacement transducer in mid-span.

It is accurate enough to measure only the support reaction on one of the supports. Because of symmetry, one can assume that it is half of the total load. The load cannot reliably be based on the air pressure and area.

The contact area of the air bag shall cover the whole area of the face, which is intended to be loaded by a uniformly distributed load. However, the size of the air bag shall be limited to the intended loading area. This can be done using the rigid side walls like in vacuum box method. The gap between the edge of the test panel and the side wall shall be limited equally as in the vacuum box method.

The air pressure and the support reaction at least on one support shall be measured simultaneously. The comparison of the air pressure and the support reaction shows the area exposed to the load.

III. Test results:

- After the ultimate load is reached, the failure mode needs to be determined and documented exactly. A pure bending failure must always be obtained. This is virtually always recognizable (in the face under pressure) by wrinkling of the flat or lightly profiled faces or by buckling of the upper chord areas of the trapezoidal faces (see figures 20 and 21). The failure must occur in the centre part of the panel. If not, the test should be repeated. A failure can also occur through yielding of the faces (in the face under tension). This can be determined e.g. by measuring the strains (and thus the stresses) with strain gauges and possibly also through the load-deflection curve.

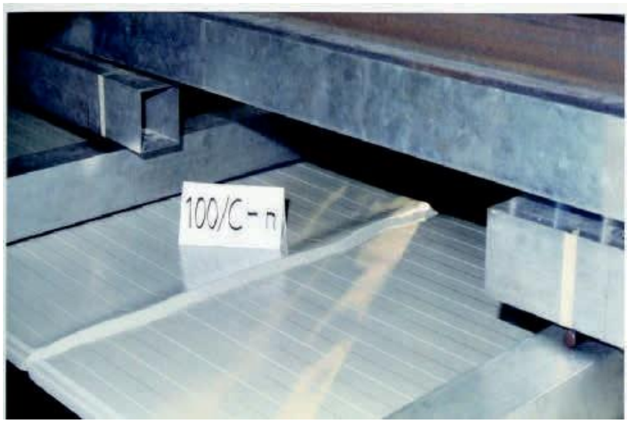


Figure 20: Wrinkling of a lightly profiled face (negative orientation)

Figure 21: Buckling of the trapezoidal face (positive orientation)

- In addition to the determination of the failure load, the deflection at mid-span must be determined in any case and displayed in a load-deflection curve. Furthermore it is recommended to measure strains (and thus stresses) with strain gauges at the middle of the span. The obtained results should also be displayed in a load-stress curve. Compared to calculated deflections and stresses (design by calculation) both curves serve for confirmation of the calculation method with which allowable span tables are determined in the end.

IV. Number of tests:

For each face with a defined geometry (depth of stiffeners and profiles, pitch of stiffeners and profiles) and for each panel thickness, 3 full scale tests (single span panel) need to be accomplished. In these tests, the face under investigation must be in the compression area (upper side) during the test.

Since the geometry of exterior faces and interior faces differs, also for panels with lightly profiled faces on both sides, 3 tests need to be accomplished in positive orientation and in negative orientation; i.e. the exterior face and the interior face must be in the compression area during the tests.

If the faces are identical concerning the geometry and if it is clear which side is decisive, e.g. for panels with known auto-adhesive polyurethane (PU) cores, testing of one face is sufficient; the faces that were on the upper side during production (lower properties, possibly blowholes, unfavourable bonding) must be in the compression area (upper side during test). It is recommended for verification that one additional test is also accomplished on the face that has been on the lower side during production. On this, a higher value should be obtained.

Within the product portfolio of one company, the geometry of the inner, lightly profiled face is often valid for more panel types. The test results of the inner, lightly profiled face, of a panel type, can be also used for the other panel types that have the same inner, lightly profiled face. In this case, the wrinkling stress of the face is already known, in principle, from the initially performed tests. It is recommended however to accomplish one test with each panel thickness respectively for confirmation.

No tests need to be arranged with different face thicknesses as long as the tests were accomplished with the lowest intended thickness and the wrinkling stresses for further face thicknesses are determined according to EN 14509:2013, A.5.5.3, equation A.19.

V. Documentation:

The dimensions of the test specimens must be measured exactly and the results must be documented in detail.

The metal face geometry and the panel thickness need to be measured, so that the cross-sectional values (distance between centroids of faces, areas etc.) can be determined for each individual test specimen.

VI. Important test results:

- Achieved ultimate load for each test, deflection at the middle of span

  Recommended: *results of strain (stress) measurement at mid-span, possibly only in few, defined tests.*

VII. Aim of evaluation of test results:

The failure stresses for the upper chord of the profiled (trapezoidal) faces, respectively wrinkling stresses (σ_w) of the lightly profiled faces within span for individual types of faces at different panel thicknesses, including the related values for increased temperature by application of the evaluation process according to EN 14509:2013, A.5.5.5, equation A.24

By comparing theoretical and tested deformation, the shear modulus determined in the small scale test can be validated. In some cases, the shear modulus can also be determined directly from the full scale bending test, but the value may be inaccurate if the shear part of deformation is small.

3.5.8 Bending moment capacity and wrinkling stresses at an internal support

Based on EN 14509:2013, chapter 5.2.1.8 and A.7

Comments:

I. In general:

For the design of continuous beam panels, ultimate (see EN 14509:2013, E.5.2) and serviceability (see EN 14509:2013, E.5.4) limit states need to be checked.

It is allowed to assume „wrinkling hinges" above the internal support for the design of the ultimate limit state. The static system then changes to a chain of simple beam panels for which the ultimate limit state can be determined individually (see EN 14509:2013, E.7.2.3).

For the serviceability limit state (see EN 14509:2013, E.5.4 and E.7.2), it needs to be ensured through calculation that no yielding or wrinkling in the faces occurs above the internal support. In the area of internal supports an explicit reduction of the wrinkling stresses can arise due to additional deformations caused by support pressure or (under uplifting loads) due to point bearing in the area of the screw heads.

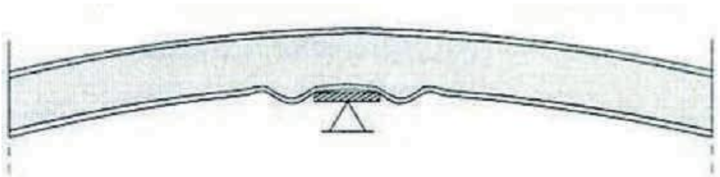


Figure 22: Wrinkling of the face at internal support, under regular loading

Therefore, the aim of simulated internal support tests is to analyse the effects on the ultimate capability (see EN 14509:2013, 5.2.1.8) and to determine the relevant wrinkling stresses for design in the area of internal supports. The wrinkling stresses can be expected to be clearly lower compared to those within the span.

With the help of the simulated internal support test, load configurations that are comparable with those in the area of internal support of a double span panel, shall be achieved in an economic way. Therefore, simply supported beam panels are loaded until failure in such way, that a line load is introduced at the middle of the span either directly through a bending stiff beam or through a beam connected with screws.

Additional tests using wider support plates (as used in practice) may be carried out. The minimum condition for the width of the internal support is 40 mm in France and Finland and 60 mm in Germany. The result of testing on a less wide support is also valid for a wider support.

For the load case „uplifting loads“, the uplifting support reactions in the area of the internal support of the continuous sandwich panel are normally transferred to the substructure with the help of a screw fastening.

For flat or lightly profiled exterior faces, the support reactions of the panel must be transferred into the screws via the elastically supported, flexible faces. A punctual support arises in the area of the screw heads and causes relatively high, locally limited additional stresses in the exterior face.

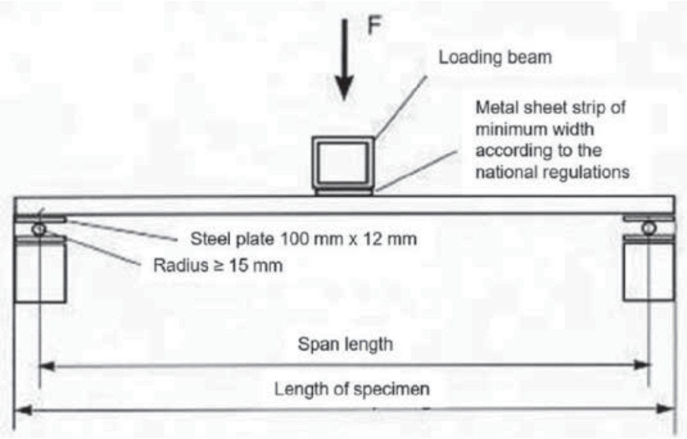


Figure 23: Internal support bending test - test set-up with regular loading

Figure 24: Internal support bending test with regular loading

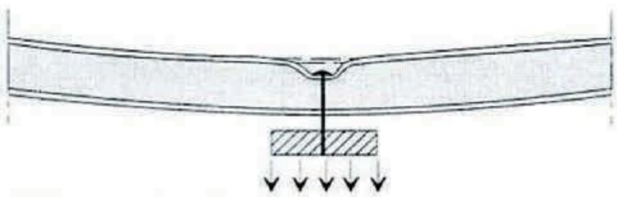


Figure 25: Wrinkling of the face at internal support, under uplifting loading

For panels with profiled external faces, the support reactions can be transferred without a problem via the webs of the trapezoidal metal faces and the narrow upper chord.

The resulting triangular shape of the moments in the simulated internal support tests approximately corresponds to the moments on a continuous beam (in reverse orientation of the points of zero-moments). Here, the transverse loading beam simulates the internal support.

Note:
The following conclusions have been reached based on the current practical experience:

- *For panels with profiled faces, simulated internal support tests with regular loading are not necessary, as long as the geometry of the inner, lightly profiled face is similar to that of panels without profiled faces, on which simulated internal support tests were already conducted.*
- *For panels with profiled faces, simulated internal support tests with uplifting loading (fixed with screws) will not be necessary if yielding stress is reached in the upper chord of the profiled face (e.g. in the single span panel full scale tests).*

II. Test procedure:

The exact test procedure is described in EN 14509:2013, A.7.

The test set-up must be chosen in a way that, in compliance with these verifications, the faces in the internal support area fail at about the same loading as the compressive strength (f_{Cc}) respectively when the tensile capacity of the screws is reached. At least the loads should be in the same range.

Because of this relativity, long spans usually need to be provided for the tests. These spans do not have to correspond with the point of zero-moments in a double span beam.

III. Number of tests:

Three tests with regular loads and three tests with uplifting loads need to be accomplished for the minimum and maximum panel thickness of one family. It is recommended that tests with uplifting loads are carried out with different numbers of screws (with a defined distribution over the panel's width), e.g. 1 test with 3 screws, 1 test with 4 screws and 1 test with 5 screws, on the basis of the end use indicated by the manufacturer.

For each panel thickness, the test specimens shall be taken from the same batch as the test specimens for simple beam test. Normalization can be undertaken implementing the material properties used for the single span bending tests.

IV. Documentation:

The test specimens shall be measured exactly, analogous to the single span bending tests.

V. Important test results:

- Achieved ultimate load and load-deflection curve per test

  Recommended: *measuring of sinking and crushing of the support (loading beam) and the screw heads.*

VI. Aim of evaluation of test results:

- Wrinkling stresses (σ_w) over an internal support for regular loads and for uplifting loads for individual types of faces at different panel thicknesses
- Related values for increased temperature by application of the evaluation according to EN 14509:2013, A.5.5.5, equation A.24.

The values are necessary for verification of serviceability limit state over internal support for continuous beam panels.

VII. Failure mode:

If the panel fails in shear at the internal support (load introduction area) and not in wrinkling, this has to be noted. The calculation model must then be adjusted when determining the resistance at the ultimate and serviceability limit state (plastic hinge at internal support is no longer an accurate model).

3.5.9 Creep coefficient

Based on: EN 14509:2013, 5.2.1.3 and A.6

Since long-term loadings do not occur in wall panels, verifications concerning creep are not necessary and therefore no creep coefficients need to be determined.

Comments:

In general:

Since creep actions can occur under constant mechanical loading, the deflection of the panel can increase without an increase of the loading. Such an effect may also lead to a rearrangement of stresses within the metal faces. These shall be considered in the design of panels.

Note: *In single span lightly profiled panels, stresses are not affected.*

Because of this, long-term tests need to be undertaken in which a uniformly distributed load or at least four linear loads are applied to a panel. Note that the formulae used in the analysis are based on uniform load, but in practice one has to use line loads caused by death weight and the increase of deflections over time is measured. The test is not easy to perform. It requires constant circumstances and accuracy. Deviations in temperature and relative humidity distort the measurements. Even very small temperature difference between faces can cause considerable deflection that distorts the results.

The load must be arranged so that it will not have effect on the bending stiffness. A good possibility is to use many steel weights and distribute them equally over the panel. If sandbags are laid tightly on top of the panel, they will work as a supporting arch and cause wrong results. They are also not recommended especially if the relative humidity cannot be kept constant i.e. sand can absorb or release moisture and change in weight. Long boards (plywood etc.) on the panel may work together with the upper face and cause wrong test results.

Note that it is vitally important to measure correctly initial deflection w_0 (at t=0). For this, the panel must be temporarily supported during the time that is needed to lay the weights on it. The supports are released instantaneously and the deflection w_0 due to the applied load q is read when the movement is stabilised after some seconds. However, this needs to be multiplied by (1+g/q) to include self-weight g. After that, the panel starts to creep under load g+q. One can also eliminate the deflection caused by g by lifting panel horizontally straight. Then w_0 includes also g.

The deflection at mid–span of a simply supported beam measured in defined time intervals; graph showing deflection over time (up to 1000 h) can be drawn. As a minimum, deflections shall be recorded at 30 seconds, one hour and 24 hours after removal of the props and then at intervals of 24 hours for the first week and 48 hours thereafter. It is recommended to measure the compression deflection of the core at the two supports.

An example of test with stone wool cored panel is given below.

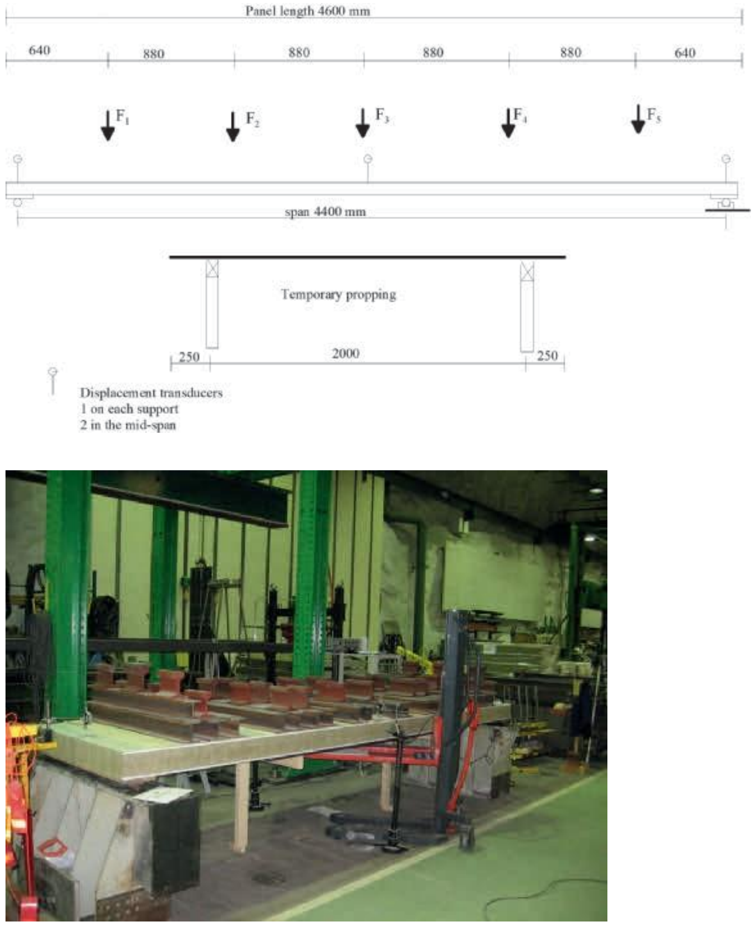


Figure 26: Creep coefficient test set-up

Line loads are chosen to simulate uniform load. Steel sections are used for the line loads. For propping, 25 mm thick plywood and two timber props are used. The propping system is shown in Figure 26. An elevator with zero hydraulic pressure is used to smoothen the drop of the panel after removing the props.

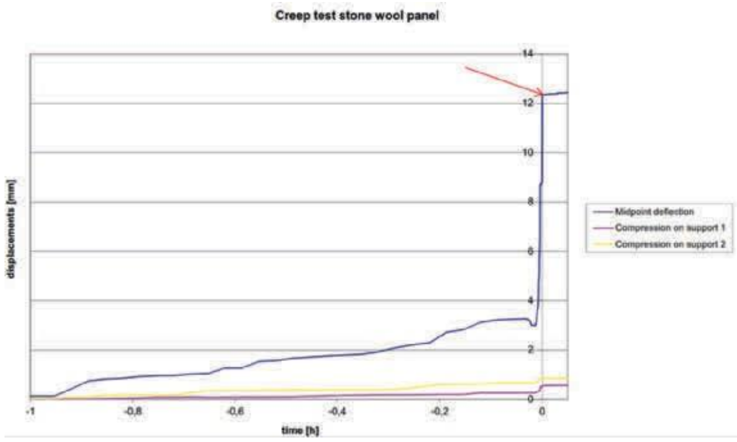


Figure 27: Creep coefficient test - start of the loading

It took about one hour to lay load on the panel and there is some midpoint deflection despite of the propping. For mineral wool cored panels, there is however practically no creep in this pre-release deflection. Panels with plastic foam cores would need more propping (props under each line load). The transducers are set to 0 after propping and before the loading, to eliminate the deformation due to self-weight. The props were released at t = 0. In panels with plastic foam cores, deflection starts to increase significantly immediately after the release of propping.

w_0 (about 12.5 mm) can be easily identified on the graph (indicated by the red arrow). Midpoint deflection before the release of the propping (about 3 mm) is part of w_0.

In practice it is impossible to avoid small deviations from the theory, where the loading should start to act instantaneously and there are no deformations prior to that.

Note: *The test time was here 2000 h instead of 1000 h (minimum required in EN 14509).*

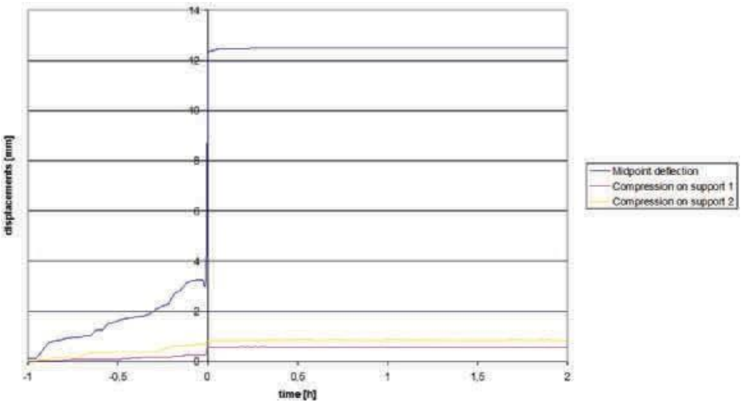


Figure 28: Creep coefficient test - test data in logarithmic scale

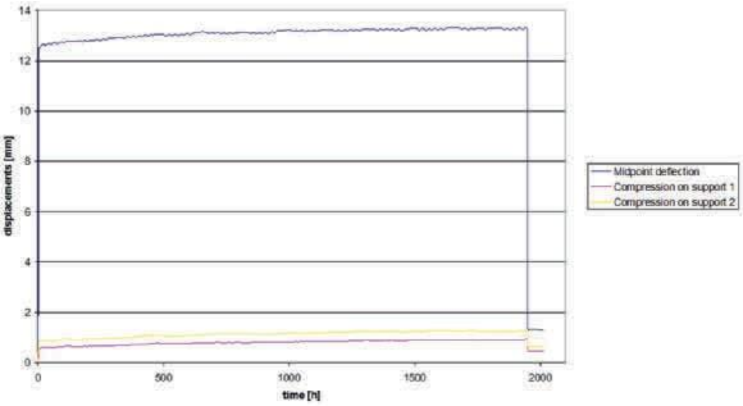


Figure 29: Creep coefficient test - displacements in linear time scale

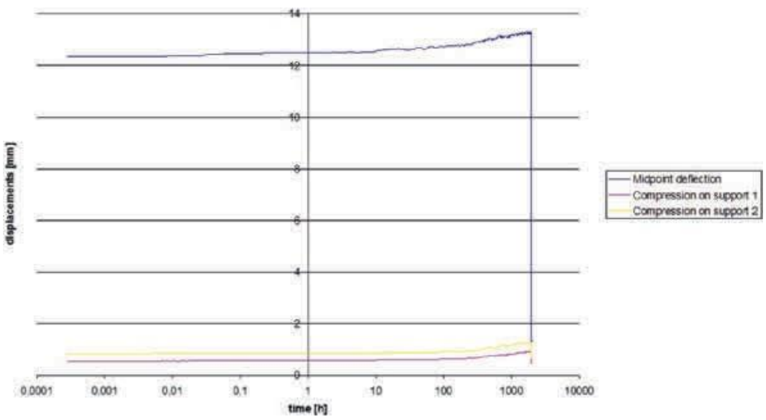


Figure 30: Creep coefficient test - displacements in logarithmic time scale

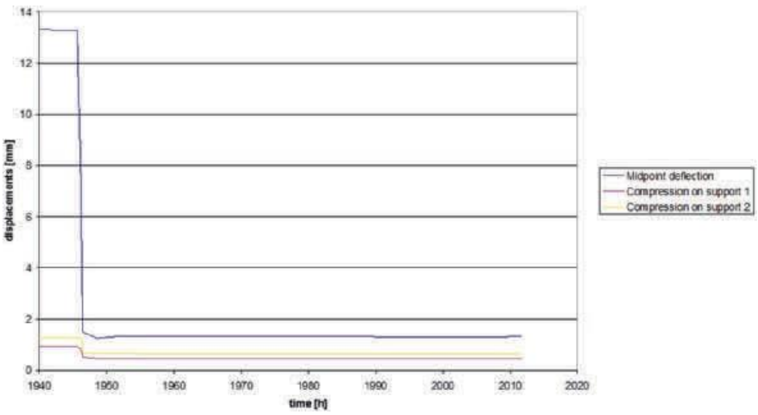


Figure 31: Creep coefficient test - end of the loading

It is recommended to record also the recovery after removing the load.

VIII. Test procedure:

In principle, the tests need to be accomplished according to chapter 3.5.7 (respectively EN 14509:2013, A.5), whereas instead of an increasing load, a long-term constant load shall be applied.

The amount of loading must be chosen in such way, that a maximum shear loading on the core of approximately 30 % to 40 % of the shear strength to be declared according to 3.5.3 (respectively EN 14509:2013, A.3) is reached. Minor deviations from the required loading are acceptable (see EN 14509:2013, A.6.4). The loading time shall be at least 1000 h.

IX. Number of tests:

For all range of panel thicknesses, one test on the greatest panel thickness is sufficient (according to EN 14509:2013, A.6.1). Because of problems that may occur when determining the panel deformation, it is recommended to perform 2 tests.

X. Documentation:

The dimensions of the test specimens must be measured exactly and the results must be documented in detail.

XI. Important test results:

The deflection at mid-span of a simply supported beam measured in defined time intervals; graph showing deflection over time (up to 1000 h) can be drawn.

3.5.10 Density of the core and mass of the panels

Based on: EN 14509:2013, A.8 and EN 1602

Test specimen and test procedure is exactly described in EN 14509:2013, A.8 or in EN 1602 respectively.

<u>Comments:</u>

- The density shall be determined for each panel type.
- The mass of the panels shall be determined arithmetically with the nominal values of the density according to EN 14509:2013, A.8.

- The weight of the samples for evaluation of the tests shall be measured directly (by weighing) according to chapter 3.5.7 and 3.5.8.
- In terms of sampling of the specimens for determination of the density, see EN 14509:2013, A.8.1.3.
- For panels with profiled faces, the specimens shall be cut out of the predominant thickness.

3.5.11 Dimensional tolerances

Based on: EN 14509:2013, 5.2.5, table 4 and annex D

3.5.12 Support reaction capacity at the end of a panel

Based on EN 14509:2013, A.15

I. In general, end support reaction capacity tests are used to determine the value of the parameter k that is used in the calculation of support reaction capacity in cases where a plain or lightly profiled face is in contact with the support (see EN 14509:2013, E.4.3.2). The principle of test arrangement is shown in EN 14509:2013, Figure A.21. 3 tests should be carried out for each support width. The analysis of the test results is given in EN 14509:2013, A.15.5.

II. Test arrangement and comments

The support reaction F_R should be measured directly with load cells placed under the support beam to achieve better accuracy (see Figure 32).

The support beam should be aligned with the lower face of the panel so that the crushing is uniform along the support.

The other support should be wide enough to avoid failure there.

The loading rate should be slow enough (preferably 1%/minute to 3%/minute) so that the test reflects the true nature of crushing failure on a support in practice. Crushing of MW fibres is an irreversible slow process in panels (fibres break gradually). The ultimate compressive strains are only some percentages. Plastic foams are more resilient and the deformation somewhat reversible.

It is not always possible to obtain crushing failure in the tests because the ratio between shear and compression strengths may be low. The use of thick panels lowers the possibility of shear failure. The failure may start as crushing of the core but may then turn into shear failure (see Figures 34 and 35). This can be seen if the rate of deflection is also monitored.

The assumption that the parameter k is a material constant is not actually true. While repeating the same test series, one might get different results.

It is advisable to determine the compression strength of each end tested, using 3 compression test specimens. These should be taken as close to the end as possible (from undamaged parts) and to use the average of the test results as f_C, while adjusting the test results. It is also advisable to determine the density.

The following data shall be given in the test report:

– The results of the 3 tests;
– Identification of the tested panels;
– Geometry of the cross section of the specimen and that of the faces, thickness of the faces and type of the core;
– Test arrangement (test set-up, loading, measurements) and procedure (rate of loading);

– Results of the compression tests (place of the specimens, loading rate, compression strengths),
– Analysis of the test results (the obtained values of k).

III. The principle of testing when using vacuum chamber is shown in Figure 32. Three or four tests are recommended for each panel thickness. The minimum, mid-range and maximum thicknesses should be tested. The support width should be chosen to coincide with the minimum one used in practice and there shall be an inclination of 1:20 according to EN 14509:2013. The duration of test is about 5 – 10 minutes so that the compression of 10 % is reached. The compression on the support is measured by two displacement transducers. A third displacement transducer 200 mm away from panel end is used to monitor shear failure. The load is measured with two load cells on one support. The test arrangement is shown in Figure 33.

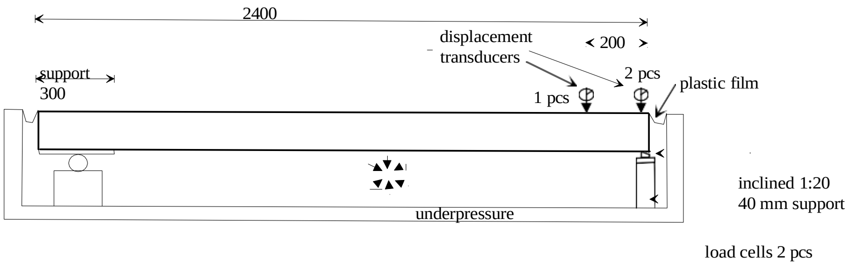
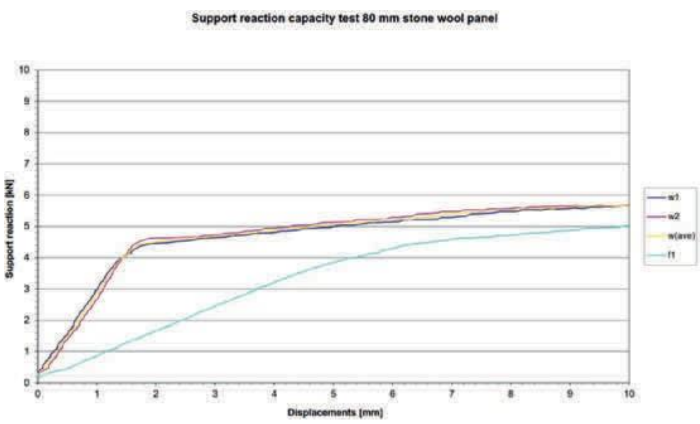
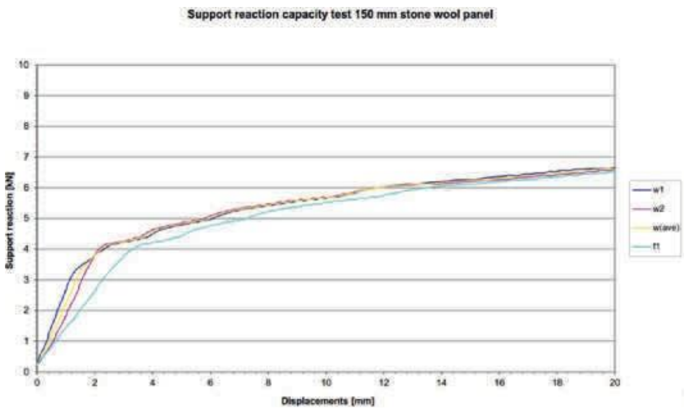


Figure 32: Principle when using a vacuum chamber in support reaction tests. The displacements w_1 and w_2 are on the support and f_1 in span.

Figure 33: Test arrangement when using a vacuum chamber in support reaction tests





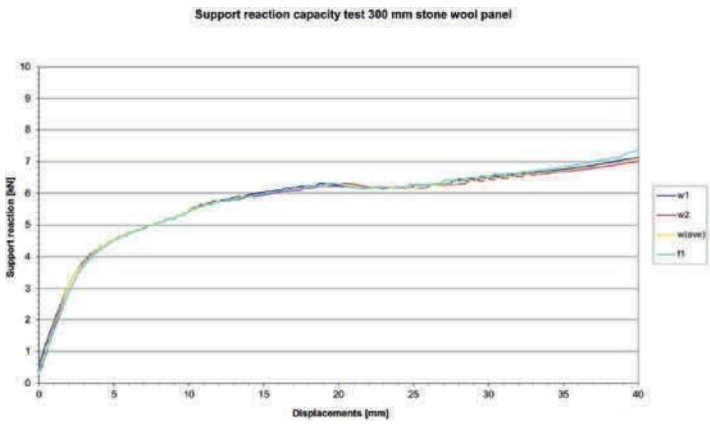


Figure 34: Results of support reaction tests on 3 panel thicknesses

In the first graph of Figure 34, it can be seen that the 80 mm thick panel failed in shear (displacement f_1 200 mm away from the support starts to increase at once).

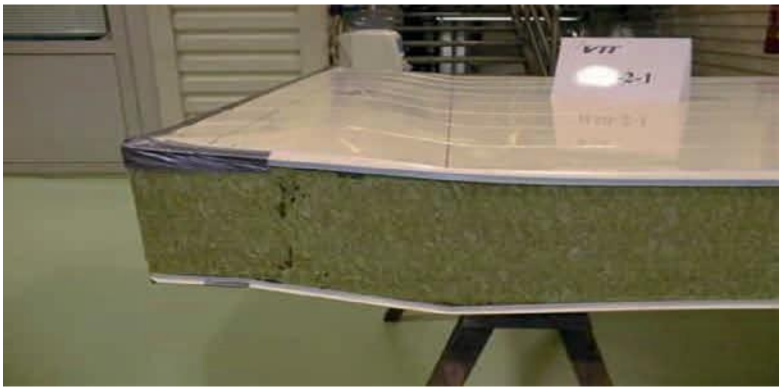


Figure 35: Failure of a specimen in a support reaction test (the final failure was shear)

The relative force is $F_{REL} = \frac{F_{R1}}{f_{Cc} \cdot L_S \cdot B}$ (3.8)

3.5.13 Durability and other long-term effects

Based on: EN 14509:2013, 5.2.3 and Annex B

Comments:

I. In general

Altogether, there are 5 different test methods in this chapter:

a. DUR 1 (see EN 14509:2013, B.2)
b. DUR 2 (see EN 14509:2013, B.3)
c. Wedge test (see EN 14509:2013, B.5)
d. Repeated loading test (see EN 14509:2013, B.6)
e. Thermal shock test (see EN 14509:2013, B.7)

II. Necessary testing for different material combinations

The necessary testing is defined in EN 14509:2013, chapter 5.2, table 3 and also presented in the following table:

Test according to method:	**a)**	**b)**	**c)**	**d)**	**e)**
MW		x	x		
EPS/XPS	x		x		
PUR (auto adhesive)	x				
PUR (bonded)	x		x		
PF	x		x	x	x
CG	x		x	x	x

Table 4: Necessary testing of durability and other long-term effects for different core materials

For PUR foam systems that are included in EN 13165 and which do not employ CO_2 as a blowing agent, the tests according to DUR 1 can be omitted.

Note: *At the moment, predominantly employed, PUR foams are within the scope of EN 13165 and therefore no durability testing is needed in most cases.*

III. Test accomplishment

The influence of ageing on sandwich panels or their constituent materials is tested by measuring changes in the cross-panel tensile strength of the panel. The durability is defined by the change in the tensile strength of a test specimen that is subject to climatic test cycles, which are denoted as DUR 1 and DUR 2 and have to be chosen depending on the core material employed.

The cross-panel tensile tests are, in principle, performed as described in 3.5.6 (see EN 14509:2013, 5.2.1.6 and A.1).

3.5.13.1 DUR 1 based on EN 14509:2013, B.2

The test accomplishment, as well as the corresponding test conditions (e.g. choice of temperature according to the colour group of panel face) and the necessary evaluations are defined in EN 14509:2013, B.2.

Notes:

- *With the temperatures required in the test, it can be assumed that the relative humidity is always lower than the requested 15 %. In most cases it is not necessary to control this parameter.*

- *It is recommended to age more than the requested 5 specimens per set. Specimens that are excluded from the evaluation can easily be replaced without having to repeat the complete test cycle.*
- *It is requested to perform the test on the thickest and thinnest panel planned for one product family (procedure analogous to DUR 2).*

3.5.13.2 DUR 2 based on EN 14509:2013, B.3

The test accomplishment, as well as the corresponding test conditions (e.g. 65 °C air temperature and 100 % relative humidity) and the necessary evaluations are defined in EN 14509:2013, B.3.

Notes:

- *It is strongly recommended to protect the cut edges of the samples by applying a silicone layer. This layer then protects the sample from moisture penetration into the adhesive layer between face and core. Such penetration can lead to oxidation of the zinc layer (formation of „white rust“) which reduces the cross-panel tensile strength in an unnatural way.*
- *It is recommended to include one set for 56 days of ageing from the beginning of the test. If the test becomes necessary during the evaluation process, this reduces testing time as the necessary results are at hand.*

3.5.13.3 Adhesive bond between faces and prefabricated core material (wedge test)

Based on EN 14509:2013, B.5

I. In general, this test is used to assess the suitability of the glue on the back-coat (“primer coating”) of the steel sheet. It is of qualitative nature, it gives an indication whether the bond between the glue and the primer coating and the adhesive layer itself are resilient enough.

II. Test procedure and comments

a. Cut at least 10 steel sheet strips of size 20 x 100 mm^2. Clean the surfaces well.
b. Weight five (or more) pairs of strips.
c. Mix the components according to the instructions from the glue manufacturer and apply glue on the surfaces aiming at the real amount of glue used in the production of panels.
   Note:
   This has to be done manually in a very short time. It is of great importance to have the right ratio between the components and the amount of glue as close to the target amount as possible.
d. Keep the strips in pressure for the time given by the glue manufacturer. Let the specimens cure for the time given by the glue manufacturer.
e. Remove excessive glue (burrs) along the edges.
f. Weight the specimens and calculate the amount of glue per area.
g. Smoothly insert the wedges between the strips, measure the initial crack length l on both edges using a loupe. It should not be more than 30 mm.
h. Immerse the specimens for 24 h in water heated at 70 °C while loading the wedges with force of 3 N.
   Note: *This may be done with plummets (see Figure 36).*
i. Remove the specimens and measure the crack growth Δ_2. It should not be more than 20 mm (see Figures 37 and 38).
j. Examine the type of cracking. It should be cohesive (in glue only).
k. Give the following data in the report:

- The details of the metal sheet: grade, thickness, manufacturer, identification (coil/charge number), type and thickness of back coating;
- The details of the glue: trade names of components, ratio of mixture, identification (batch number);
- The test results: cure time used, amount of glue, initial crack length l, crack growth Δ_2, type of cracking for each specimen
- The conclusions (test passed/failed).

Figure 36: Wedge test arrangement

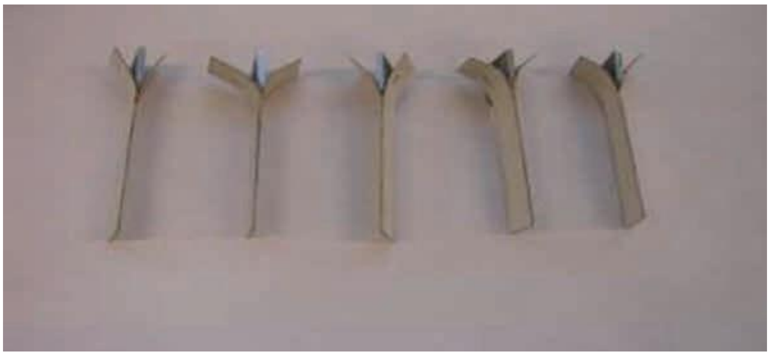


Figure 37: The specimens after exposure

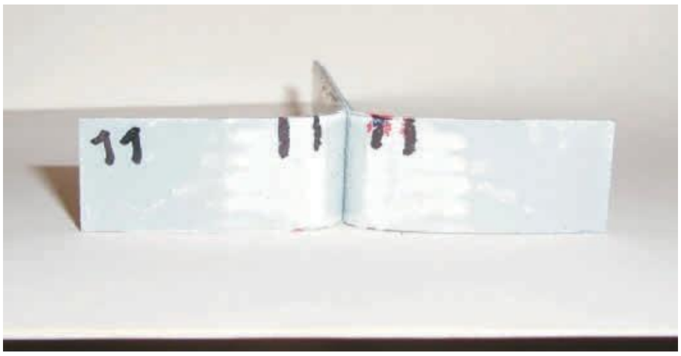


Figure 38: The specimen after exposure (the crack tips are marked on the strips)

3.5.14 Resistance to point loads and repeated loads

The ability of a sandwich panel to resist point loads and access loads shall be determined in accordance with EN 14509:2013, A.9.1. For applications where the access is more frequent than occasional foot traffic (see the note), the procedure described in EN 14509:2013, A.9.2 shall also be carried out.

Note: *Point loads are loads resulting from a single person walking on the panel, for occasional access both during and after erection.*

The span capabilities of a ceiling panel and its supporting system should be checked before access is allowed.

Note: *Ceiling panels are generally unsuitable for regular foot traffic.*

Ceiling and roof panels should be protected when used on regular walking routes or working areas both, during installation and in end use.

Panels should allow a safe support for a foot and should not be subject to permanent deformations under occasional foot traffic for access or maintenance. For maintenance purposes, only one person at a time should be allowed to walk on a panel.

I. General

Panels within the scope of EN 14509:2013 with thin metal faces are generally considered as unsuitable for regular foot traffic and applications of this type (like floors) are outside of the scope of the standard. For applications like ceilings and roofs, where there is occasional or repeated access on the panel, there are rules for classification for which type of access the panels are suitable. The rules in EN 14509:2013, chapters 5.2.3.2 and A.9 are written for ceilings and roofs (Figure 39).

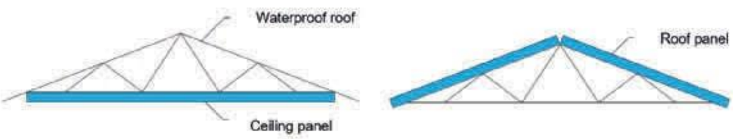


Figure 39: Insulated sandwich panels used in ceilings and roofs

The resistance to point loads and repeated loads is subject to type testing only. The FPC is covered by the control of the compressive strength. Therefore, also the compressive strength of the panel tested for repeated loads is recommended to be determined according to the procedures in EN 14509:2013, A.2 (see chapters 3.5.5 and 3.6.5).

The resistance to point loads and repeated loads of the panel shall be noted on the CE-marking, based on a pass/fail criteria given in chapter A.9 of EN 14509:2013. There are two cases for type of application:

Case 1: occasional access to be tested according to A.9.1 in EN 14509:2013 or
Case 2: repeated access to be tested according to A.9.2 in EN 14509:2013.

There is no further information given in EN 14509:2013 on the definition of occasional access and repeated access. Based on experience, the following guidelines can be used if nothing else is specified (see Figure 40):

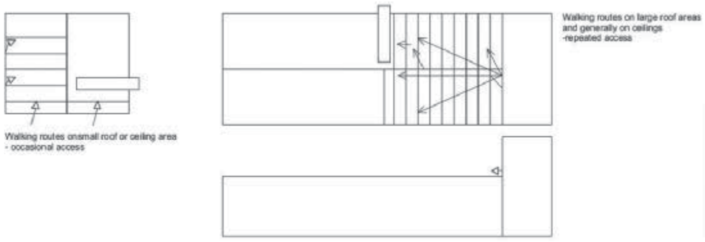


Figure 40: Walking pattern on ceilings, small roofs and on large roofs

- If there is access on the panels during erection, only on the area which is to be mounted, an area that is moving during the progress of the installation and regular service of devices placed on the top of the panels is not foreseen, this type of access is occasional.
- If the access to the erection area of the panels is given by permanent ladders or doors and the area is more than approximately 1000 m^2 (for roofs) and if for the service of the devices placed on the top of the panels, the access is regular, this type of access is of repeated nature.

Generally, the case for repeated access is more frequent for roofs than for ceilings, as the frame structure above the ceiling hinders free access on the ceiling.

In EN 14509:2013, there is no recommendation on the loads for ceilings.

Protection: In chapter 5.2.3.2 of EN 14509:2013, it is noticed generally, that the panel should be protected where repeated walking is expected. This should be a general recommendation. In the figure from below, one example from one producer's manual on the need for protection is shown:

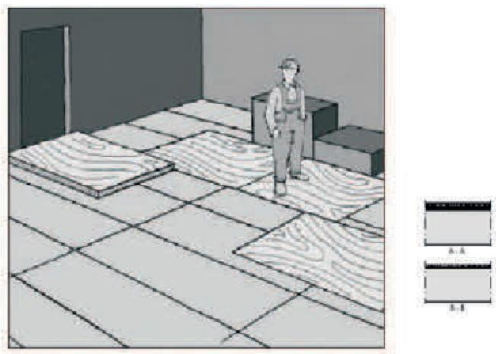


Figure 41: Example of protection of the panels

Practical recommendations:

Recommendation on core material to be used:

There are no requirements on the materials used in roof and ceiling panels from the accessibility point of view in EN 14509:2013. The principle is to determine the resistance of the panel by testing.

The test methods described in EN 14509:2013 are anyhow not frequently used and especially the test method in A.9.2 is new and there is little experience so far on its suitability. Therefore, it is recommended from a practical point of view and based on experience and in order to increase the safety of ceiling and roof panels for access, to use core materials with compressive strength not lower than 100 kPa (characteristic value) in all other cases than non-walk-on ceiling panels.

Fixing of panel ends

In order to avoid panels falling down, it is highly recommended to use screws penetrating the panel, fixing both skins to the frame or fixing both skins directly with metal stripes and screws to the frame. This makes membrane action possible which is also of great importance with regard to fire safety.

II. Testing case 1: Occasional access during erection and service (EN 14509:2013, A.9.1)

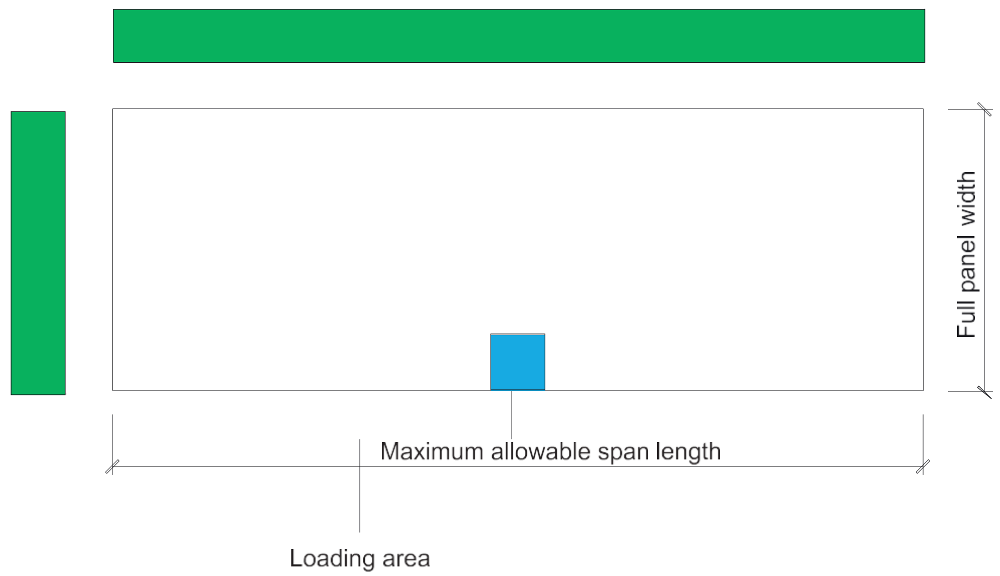


Figure 42: Test arrangement for testing panel resistance to point loads

a. Sampling
The sample is of full panel width. The samples chosen for testing are checked for the compressive strength of the core not to be higher than 10 % over the declared compressive strength of the panel (see Figure 42).
At least the following two panels per each core type are recommended to be tested:
   - A panel with the minimum panel thickness and minimum sheet thickness and
   - A panel with the maximum panel thickness and minimum sheet thickness.

b. Testing
A test report according to chapter A.16.1 (TT) in EN 14509:2013 shall be written.
The testing procedure is the following:
   - Cut a minimum of three specimens from the undamaged zone of the panel close to the loaded area for determining the compressive strength of the core in the tested panel. The procedure for determining the compressive strength shall follow chapter A.2 in EN 14509:2013 (see 3.5.5).
   - Place the panel on two end supports (simply supported; i.e. free to rotate and one end free to move in the direction of the span) with the greatest length (span) envisaged in practice.
   - Apply a point load of 1.2 kN, unless otherwise required by national regulations. The load shall be applied through a 100 mm x 100 mm timber block on the edge of the panel in the middle of the span (see Figures 43 and 44):
      – Measure the deflection at the midpoint of the panel under the loading point by using e.g. a line spanning in the middle of the upper surface from support to support and measuring the midpoint deflection before and after the testing. An accuracy of ± 1 mm is sufficient.

- Place the timber block on the edge rib if this is closer than 100 mm to the edge or place the timber block close to the edge of the panel in case of flat surfaces. A 10 mm thick layer of rubber or felt shall be placed between the timber block and the panel.
- Keep the maximum load for 6 s and release the load. Release the timber block and the soft layer underneath. Make visual inspection of the loaded area.

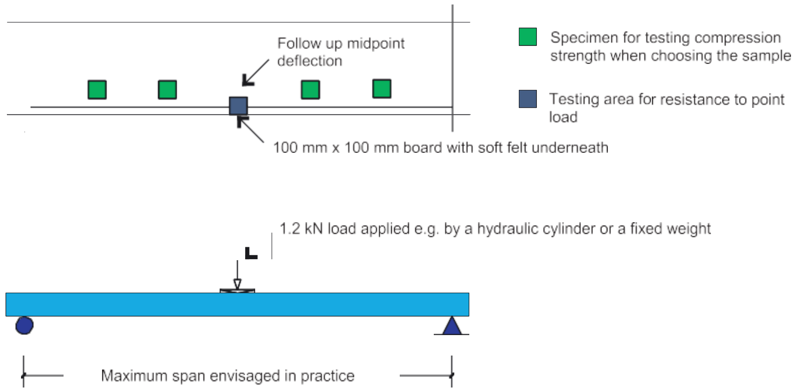


Figure 43: Test arrangement for testing panel resistance to point load (case 1)

Details are shown below:

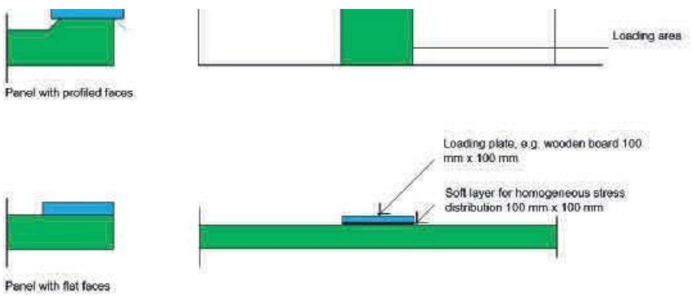


Figure 44: Details on loading arrangement for testing the resistance to point load

III. Testing case 2: Repeated access for erection and service (EN 14509:2013, A.9.2)

The purpose of this test is to check the safety and serviceability of roof or ceiling panels, with respect to a single person walking on the panel for repeated access, both, during and after erection. This can be the case where installation groups are walking over already installed panels to areas to be installed, or where the routes to the erection area is passing through doors, fixed ladders. Such may also be applicable in case of necessary service work on devices on the top of the panels, after erection, where the personnel is expected to repeatedly pass along one and the same route.

a. Specimen
The specimen consists of a single panel with approximately 5.7 m length and full cover width. This panel shall be conditioned for at least 24 h under normal laboratory conditions prior to the test.

A line shall be drawn underneath the centre line of the panel and eight squares, each measuring 100 mm × 100 mm, shall be clearly marked on the upper face of the panel at a distance of 600 mm, as shown in Figure 45. Rigid lines of support, each providing a bearing width of 75 mm ± 5 mm shall be provided at a distance of 1200 mm between centres, as shown in the figure. Sufficient restraint shall be provided to ensure that the panel cannot move with respect to the points of support, as a person walks on the panel.

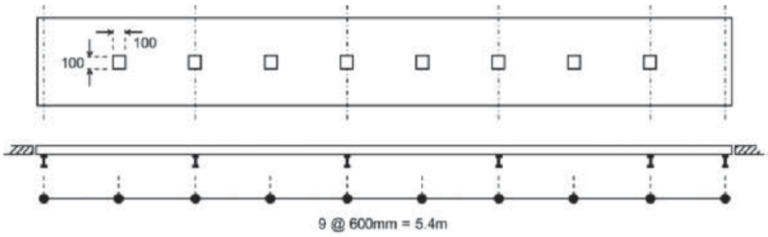


Figure 45: General arrangement for testing the panel resistance to repeated loads (case 2)

b. Testing
The test shall be carried out by a person carrying a toolbox (if required). The total weight of the person plus toolbox shall be at least 90 kg and the person shall wear standard protective footwear with no significant wear at the heel where it impacts the panel when walking. The person shall walk forwards and backwards across the panel, turning at each end on a platform that is clear of the panel. During each passage of the panel, care shall be taken to ensure that a heel impact takes place within each of the squares drawn on the surface of the panel. The actual location of these impacts within the squares should be random, i.e. it is important that the heel does not impact the same points on each passage.
One passage is, when a person walks from one end to another.
After 500 passages, a plywood sheet of minimum thickness 12 mm shall be placed over two of the squares, one in a span and the other over a support, so that these are protected from any further direct heel impact. After a total of 1000 passages, a further two such squares shall be similarly protected. This part of the test shall be terminated after a total of 2000 passages across the specimen. The eight marked squares shall then be carefully cut out from the panel. Three similar squares shall also be cut out from random parts of the panel remote from the line of walking.
The metal faces of the 11 panel samples shall be bonded to tensile plates with an adhesive and they shall be tested to determine their cross-panel tensile strength in accordance with EN 14509:2013, A.1.4.

3.6 Evaluation of test results (type testing)

In the following, the evaluation of the test results (according to chapter 3.5) is demonstrated according to the guidelines in EN 14509:2013. This is achieved by performing the necessary evaluation steps on the basis of the previously determined test results. In the document, general notes for accurate evaluation with references to the corresponding chapters in EN 14509:2013 are given. In addition, examples about the analyses are given.

3.6.1 In general

The task is to determine all necessary mechanical values for the CE-marking and for the information accompanying the CE-marking by evaluating the test results of accomplished type testing for one panel type with different panel and face thicknesses.

Notes:

- The following systematics of test numbering and corresponding notes are directly based on the information given in chapter 3.5.
- The representative part of the graph should be chosen so that it contains the beginning (under approximately 50% of the maximum force), excluding all possible disturbances in the very beginning (below approximately 5% of the maximum force). The range for the evaluation shall at least contain more than 20% of the maximum force. Secant modulus or regression can be used. Similar procedure can be used in the determination of compressive, tensile and shear moduli.

3.6.2 Mechanical properties of metal faces

Based on: EN 14509:2013, 5.1.2 and EN ISO 6892-1:2016

Note:

Due to the test results according to chapter 3.5.2, the metal grade and the thickness of the face material must be determined on the basis of the relevant standards (in this case, for steel EN 10346).

A question of great importance is the classification of the steel grade in principle, since normally, the tensile tests provide clearly higher values compared to the normative values of the ordered steel.

Therefore, it needs to be clarified which steel grade shall be the basis for the CE-marking.

For panels with flat or lightly profiled faces (profile < 5 mm, see EN 14509:2013, E.1.1), it is not necessary to perform normalization with regard to the yield strength of the faces. For panels with profiled faces, the normalization should be in accordance with chapter 3.6.7.2, point V.

3.6.3 Shear strength and shear modulus

Based on: EN 14509:2013, 5.2.1.2 and A.3 (in particular A.3.1 to A.3.5), A.4

I. On shear strength:

a. For cores without joints or glued joints, the shear strength is easy to determine from the shear test on short beams (or the full scale test) with:

$$f_{Cv} = \frac{F_u}{2 \cdot B \cdot e}$$

(see EN 14509:2013, A.3.5.1, equation A.5)

where:

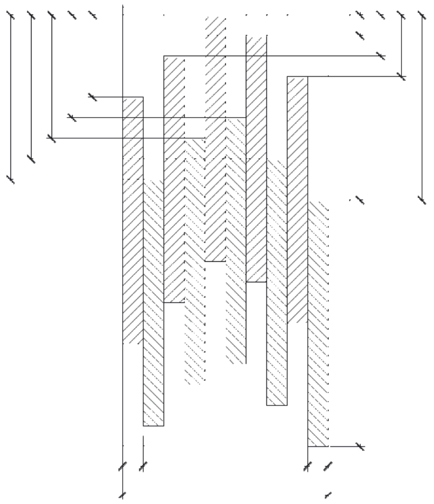
F_u = failure load
B = width of test specimen
e = distance between centroids of faces

With the individual values, the fractile value needs to be determined according to EN 14509:2013, A.16 and stated as the characteristic value of the shear strength.

b. For cores including joints, e.g. not glued mineral wool lamellas, the evaluation must be undertaken as above, as long as samples without joints (or joints in the shear force free area) were used in the shear test. But the characteristic value, then, needs to be reduced with the factor k_v (see EN 14509:2013, A.3.5.1 and equation (A.6)).

$$k_v = \frac{minimal\ width\ of\ uncut\ core\ along\ a\ line\ of\ cut\ ends}{overall\ panel\ width} \quad (3.10)$$

e.g. in the following case:



$k_v = \frac{900}{1000} = 0.9$

Figure 46: Example of the arrangement of MW lamellas

Comments:

- If the shear strength has been determined including the appropriate amount of core joints, no further reduction is necessary.
- Where the cut ends are more than 5 cm close to each other in longitudinal direction, they shall be treated as one cut end.

II. On shear modulus

The shear modulus is to be determined on the basis of the shear test on short beams (or the full scale test) according to EN 14509:2013, A.3.5.2 and equation (A.7).

The shear modulus G_C needs to be determined for each test specimen from the linear part of the load-deflection curve $\left[\frac{\Delta F}{\Delta w}\right]$ as shown below:

Flexural rigidity: $B_S = \frac{E_{F1} \cdot A_{F1} \cdot E_{F2} \cdot A_{F2}}{E_{F1} \cdot A_{F1} + E_{F2} \cdot A_{F2}} \cdot e^2$ (3.11)

Bending deformation: $\Delta w_B = \frac{\Delta F \cdot L^3}{56.34 \cdot B_S}$ (3.12)

Shear deformation: $\Delta w_S = \Delta w - \Delta w_B$ (3.13)

Shear modulus: $G_C = \frac{\Delta F \cdot L}{6 \cdot B \cdot d_C \cdot \Delta w_S}$ (3.14)

where:

E_{F1} = Young's modulus of the upper face;

E_{F2} = Young's modulus of the lower face;

A_{F1} = cross-sectional area of the upper face based on measured steel thickness;

A_{F2} = cross-sectional area of the lower face based on measured steel thickness;

e = determined distance between centroids of faces;

Δw = deflection at mid-span for a load increment ΔF taken from the linear part of the load-deflection curve;

d_C = thickness of the core material

$$d_C = D - (t_1 + t_2) \qquad (3.15)$$

(see EN 14509:2013, D.2.1)

t_1, t_2 are the thicknesses of the faces

A_C = cross-sectional area of the core based on measured thickness d_C;

L = span of test specimen (in shear failure).

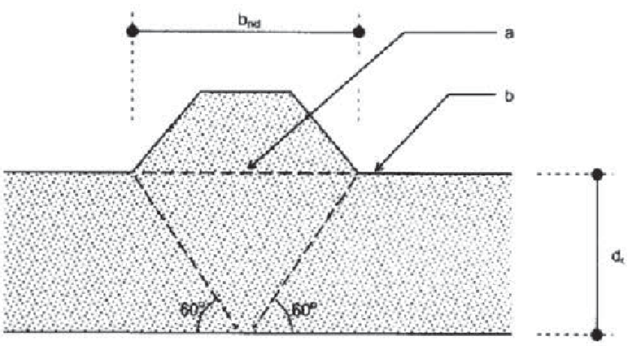
With the single values, the mean and fractile value need to be determined in accordance with EN 14509:2013, A.16. Both values must be specified for the shear modulus.

Comment:

- A reduction of the shear modulus due to unglued core joints is in principle not necessary if the percentage of cut end joints is less than 20. In doing so it is however assumed, that the theoretically determined deformation for the single span test shows good correlation with the obtained test results. If the stiffness determined in the A.5 test is in the same range, then a reduction is not necessary.

III. Incompletely bonded panels

If the core is not completely bonded with the faces, the declared values shall be calculated using the following procedures based on the dimensions illustrated in Figure 47:



Key
a unbonded area (bnd = unbonded width)
b bonded area
d_C the continuous thickness of the core

Figure 47: Dimensions relevant for incompletely bonded panels

Where $b_{nd} > 2 \cdot d_C \cdot 0.58$, the declared values shall be reduced in accordance with the following equations:

$$f_{Cv,red} = f_{Cv} \cdot \left(1 - \frac{b_{nd} - 1.16 \cdot d_C}{p}\right) \quad (3.16)$$

$$G_{C,red} = G_C \cdot \left(1 - \frac{b_{nd} - 1.16 \cdot d_C}{p}\right) \quad (3.17)$$

where:

f_{Cv} and G_C are determined using the equations from the previous points, I and II.

p is the pitch (see EN 14509:2013, chapter A.10.3, Figure A.18)

Comment:

- The reduction using the above expressions shall be made if f_{Cv} and G_C have been determined using completely bonded specimens. If the shear strength and shear modulus have been determined using incompletely bonded specimens, no reduction shall be made.

IV. EN 14509:2013, A.4 test:

Alternatively, shear strength and shear modulus on full-scale specimens can be determined according to EN 14509:2013, A.4.

3.6.4 Shear strength after long term loading

Based on: EN 14509:2013, A.3.6.3

Comments:

For determination of the long term shear strength, the obtained test results shall be evaluated in such way, that the „time to failure" values obtained in the long term shear strength tests are displayed in a diagram. Here, the shear stresses (t_i) determined on the individual test specimens shall be compared with the short term shear strength (f_{Cv} as mean value).

In these diagrams, this ratio (t_i / f_{Cv}) is shown at the ordinate and the „time to failure" value is shown on the abscissa in a logarithmic scale.

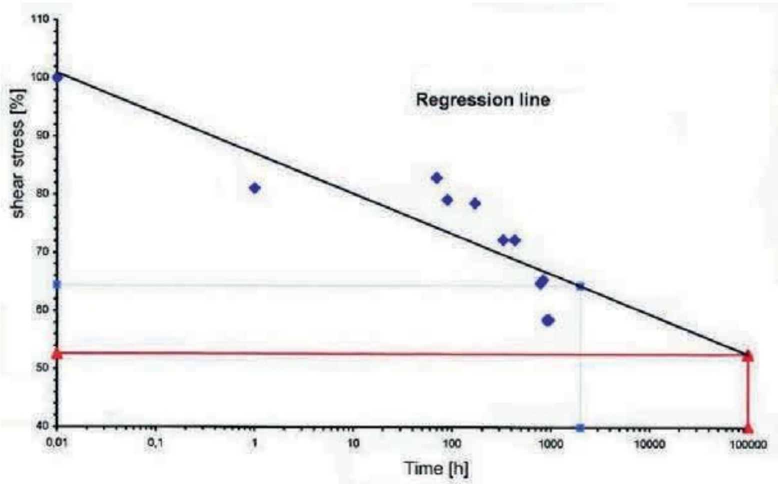


Figure 48: Graph of long term shear strength values

On the basis of the obtained points in the diagram, a regression line can be calculated which allows an extrapolation for 2,000 and 100,000 hours.

The result of the test is the relation $\frac{f_{Cv,long\ term}}{f_{Cv}}$.

The shear strengths of short term loads are to be multiplied by this factor and declared as long term value on the CE-marking.

3.6.5 Compressive strength and compressive E-modulus

Based on: EN 14509:2013, 5.2.1.4 and A.2

<u>Comments:</u>

I. On compressive strength:

The compressive strength is determined with:

$$f_{Cc} = \frac{F_u}{A} \tag{3.18}$$

where:

F_u = failure load, respectively the load at a defined compressive strain (see EN 14509:2013, A.2.5.1) e.g. with PUR at 10 % of the core thickness

A = cross-sectional area = $B \cdot L$ (3.19)

II. On compressive E-modulus:

The compressive E-modulus must be determined from the linear part of the load-deflection curve $\left[\frac{\Delta F}{\Delta w}\right]$ from the compression test.

$$E_{Cc} = \frac{\Delta F \cdot d_C}{\Delta w \cdot B \cdot L} = \frac{\Delta_\sigma \cdot d_C}{\Delta w} = \frac{\Delta \sigma}{\varepsilon_c} \tag{3.20}$$

where:

Δ_σ = stress increment within linear part

d_C = thickness of the core

ε_c = compression strain

3.6.6 Tensile strength and tensile E-modulus

Based on: EN 14509:2013, 5.2.1.6 and A.1

<u>Comments:</u>

I. On tensile strength:

The tensile strength is determined with:

$$f_{Ct} = \frac{F_u}{A} \tag{3.21}$$

where:

F_u = failure load, respectively the load at a defined strain (see EN 14509:2013, A.1.5.1. note 1) e.g. with PUR at 10 % of the core thickness.

A = cross-sectional area = $B \cdot L$

On tensile E-modulus:

The tensile E-modulus must be determined from the linear part of the load-deflection curve $\left[\frac{\Delta F}{\Delta w}\right]$ from the tensile test.

$$E_{Ct} = \frac{\Delta F \cdot d_C}{\Delta w \cdot B \cdot L} = \frac{F_u \cdot d_C}{w_u \cdot A} = \frac{\Delta \sigma \cdot d_C}{\Delta w} = \frac{\Delta \sigma}{\Delta \varepsilon_t} \tag{3.22}$$

where:

$\Delta\sigma$= stress increment within linear part

d_C = thickness of the core

ε_c = tensile strain

3.6.7 Bending moment capacity and wrinkling stresses at a simple beam

Based on: EN 14509:2013, 5.2.1.7 and A.5.5

3.6.7.1 Panels with flat or lightly profiled faces:

I. In general

One of the most important values for the design against ultimate limit state is the wrinkling stress σ_w at which the flat or lightly profiled face under compression fails. Therefore, the aim is to determine the:

- wrinkling stress within span
- wrinkling stress within span at increased temperature, for each type of exterior and interior face.

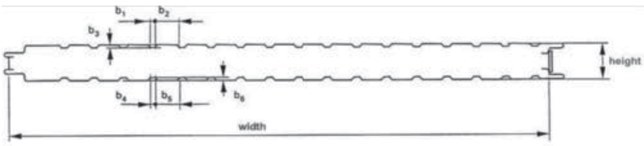


Figure 49: Example of a panel with lightly profiled faces

The wrinkling stresses may depend on the thickness of the core. In the case of panels of the same type, the minimum requirement is that the smallest and the largest thicknesses shall be tested, together with a thickness from the middle range. If only three thicknesses are tested, the values for products of intermediate thickness and of greater thickness up to 20 % but not exceeding 30 mm may be interpolated or extrapolated linearly.

However, it is recommended that interpolation and extrapolation is carried out by treating the results as a family according to EN 14509:2013, 6.4. If more than three thicknesses are tested, the same extrapolation limits apply but interpolation and extrapolation shall be carried out by treating the results as a family.

The wrinkling stresses may, in addition to the thickness of the core, also depend on the metal sheet thickness and the temperature of the face. These values shall be determined by an appropriate evaluation of the determined wrinkling stresses (see following chapter).

II. Evaluation of test results

In the following, it is assumed that the faces for wall panels are either flat or lightly profiled (depth of profile < 5 mm, see EN 14509:2013, E.1.1). For profiled faces, the evaluation needs to be undertaken in accordance with chapter 3.6.7.2.

The determination of wrinkling stresses of flat or lightly profiled faces is described in EN 14509:2013, A.5.5.2 and A.5.5.3.

$$M_u = \frac{F_u \cdot L}{8} \tag{3.23}$$

where:

M_u = ultimate bending moment

F_u = failure load, including possible existing transverse loading beams and the self-weight of test specimen.

If the face under tension is flat or lightly profiled, the wrinkling stress σ_w shall be determined from the bending moment in accordance with the equation given below:

$$\sigma_w = \frac{M_u}{e \cdot A_{F1}} \tag{3.24}$$

where:

M_u = ultimate bending moment

e = distance between centroids of faces

For lightly profiled faces, the centroids of the faces must be determined under consideration of the geometry.

A_{F1} = cross-sectional area of the face under compression

The wrinkling stress σ_w is directly relevant only for panels where the face in compression is fully bonded and either flat or lightly profiled.

Determination of wrinkling stresses for metal sheet thicknesses that were not experimentally analysed

For larger metal sheet thicknesses ($t_2 > t_1$), the wrinkling stress must be reduced.

$$\sigma_{w,t2} = f \cdot \sigma_{w,t1} \tag{3.25}$$

where:

$\sigma_{w,t2}$ = wrinkling stress of a larger metal sheet thickness t_2

$\sigma_{w,t1}$ = wrinkling stress of metal sheet thicknesses determined in tests

$$f = \frac{A_1 \cdot \sqrt[3]{I_2}}{A_2 \cdot \sqrt[3]{I_1}} \tag{3.26}$$

A_1, I_1 = cross-sectional area and moment of inertia of a face with thickness t_1

A_2, I_2 = cross-sectional area and moment of inertia of a face with thickness t_2

Alternatively, the simplified formula can be used:

$$f = \sqrt[3]{\left(\frac{t_1}{t_2}\right)^2} \tag{3.27}$$

III. Wrinkling stresses at increased temperature (see EN 14509:2013, A.5.5.5) are determined with the help of the factor k_1:

$$k_1 = \min\left(\sqrt[3]{\left(\frac{E_{Ct,+80^0 C}}{E_{Ct,+20^0 C}}\right)^2}; \sqrt[3]{\left(\frac{f_{Ct,+80^0 C}}{f_{Ct,+20^0 C}}\right)^2}\right) \leq 1 \tag{3.28}$$

(see EN 14509:2013, A.24)

where:

$E_{Ct,+20^0 C}$ = mean value of the tensile cross-panel E-modulus at 200 C

$E_{Ct,+80^0 C}$ = mean value of the tensile cross-panel E-modulus at 800 C

$f_{Ct,+20^0 C}$ = mean value of the tensile cross-panel strength at 200 C

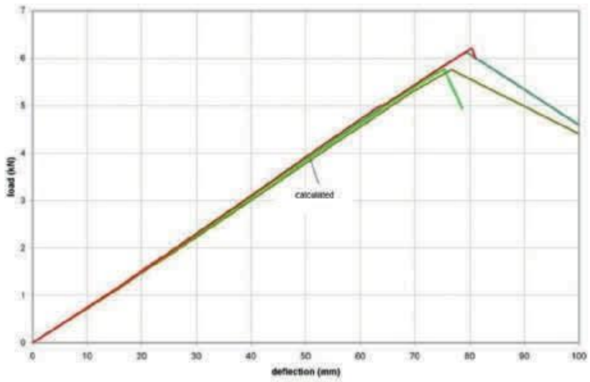
$f_{Ct,+80^0 C}$ = mean value of the tensile cross-panel strength at 800 C

$$\sigma_w^{80^0 C} = k_1 \cdot \sigma_w \tag{3.29}$$

where:

$\sigma_w^{80^0 C}$ = wrinkling stress at increased temperature

IV. Reference to the factor k_2 (EN 14509:2013, A.5.5.5):



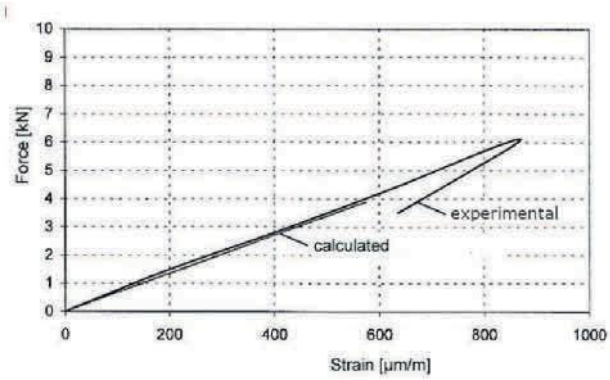


Figure 50: Load / deflection diagram and load / strain diagram

With the factor k_2, the wrinkling stress must be additionally reduced if the characteristic tensile strength of the core is less than f_{Ct} = 0.1 MPa. This must only be taken into account as long as the loading in the tests was applied with air pressure, e.g. in a vacuum chamber or by air bags. For tests with 4 line loads (transverse loading beams) the factor k_2 is not needed.

3.6.7.2 Panels with profiled faces:

I. In general

The most important values for the design against ultimate limit state are the failure stress (compressive stress) in the upper chord of the profiled face under regular loading together with the wrinkling stress σ_w of the lightly profiled face under uplifting loads. Therefore, the aim is to determine the:

- failure stress of the profiled face
- wrinkling stress of the lightly profiled face, within span for each type of exterior and interior face.

The wrinkling stresses may depend on the thickness of the core. In the case of panels of the same type, the minimum requirement is that the smallest and the largest thicknesses shall be tested, together with a thickness from the middle range. If only three thicknesses are tested, the values for products of intermediate thickness and of greater thickness up to 20 % but not exceeding 30 mm may be interpolated or extrapolated linearly.

However, it is recommended that interpolation and extrapolation is carried out by treating the results as a family according to EN 14509:2013, 6.4. If more than three thicknesses are tested, the same extrapolation limits apply but interpolation and extrapolation shall be carried out by treating the results as a family.

The wrinkling stresses may, in addition to the thickness of the core, also depend on the metal sheet thickness and the temperature of the face. These values shall be determined by an appropriate evaluation of the determined wrinkling stresses (see following chapter).

II. Evaluation of tests

For the determination of the failure stresses in the upper as well as in the lower face on the basis of the achieved test results, the sandwich theory (consideration of the shear flexibility of the core) shall be applied (see EN 14509:2013, A.5.5.3).

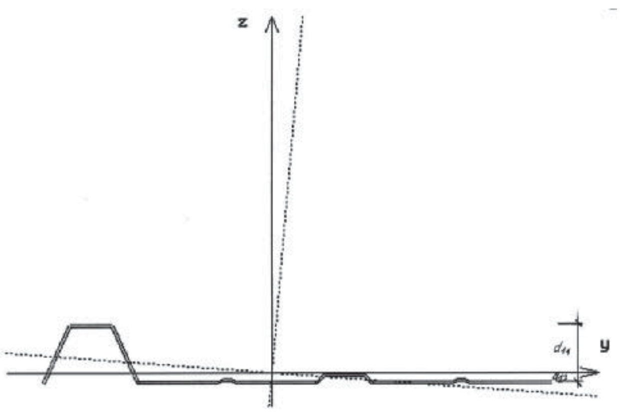


Figure 51: Computer printout; example

The following principle procedure is recommended:

- First of all, the stresses in the faces caused by unit load of $\bar{q}$ = 1 kN/m shall be determined. Here the cross-sectional values of the measured geometry and the t hickness of the metal faces shall be applied.
- The failure stresses measured in a test can than easily be determined by multiplying the obtained failure loads by the ratio of failure load to unit load.

III. Determination of stresses caused by unit load

- The stresses due to the unit load for panels with profiled faces can be calculated directly according to EN 14509:2013, E.7.5.2 and making use of table E.10.2 in EN 14509:2013 or according to EN 14509:2013, A.5.5.3 or using special purpose software, developed for sandwich panels.
  Compilation of formulae according to EN 14509:2013, table E.10.2:

$$M_{F1} = \frac{q \cdot L^2}{8} \cdot \beta \qquad (3.30)$$

$$M_S = \frac{q \cdot L^2}{8} \cdot (1 - \beta) \qquad (3.31)$$

$$w = \frac{5 \cdot q \cdot L^4}{384 \cdot B_S} \cdot (1 + 3.2 \cdot k) \cdot (1 - \beta) \qquad (3.32)$$

where:

M_{F1} = Face bending moment fraction at mid-span

M_S = Sandwich bending moment fraction at mid-span

w = Maximum deflection at mid-span

For a uniform load:

$$\beta = \frac{B_{F1}}{B_{F1} + \frac{B_S}{1+3.2k}} \qquad (3.33)$$

Flexural rigidity:
(for terms, see also EN 14509:2013, E.1.2)

$$B_{F1} = E_{F1} \cdot I_{F1} \qquad (3.34)$$

$$B_S = \frac{E_{F1} \cdot A_{F1} \cdot E_{F2} \cdot A_{F2}}{(E_{F1} \cdot A_{F1} + E_{F2} \cdot A_{F2}) \cdot B} \cdot e^2 \qquad (3.35)$$

$$k = \frac{3 \cdot B_S}{L^2 \cdot G_C \cdot A_C} \qquad (3.36)$$

- The bending moment is divided in two parts, the sandwich part M_S and the part of the face profile M_{F1}. The bending moments at the mid-span of a one-span simply supported sandwich panel loaded with uniformly distributed load are:

$$M_S = \frac{F_u \cdot L}{(1+\alpha)} \cdot \left[\frac{1}{8} - \frac{cosh(\lambda/2) - 1}{\lambda^2 \cdot cosh(\lambda/2)}\right] \qquad (3.37)$$

$$M_{F1} = \frac{F_u \cdot L \cdot \alpha}{(1+\alpha)} \cdot \left[\frac{1}{8} + \frac{cosh(\lambda/2) - 1}{\alpha \cdot \lambda^2 \cdot cosh(\lambda/2)}\right] \qquad (3.38)$$

where:

$$F_u = q_u \cdot L \tag{3.39}$$

F_u is the ultimate load including the self-weight of the panel, weight of the loading arrangements and the ultimate load caused by the external uniformly distributed pressure. The parameter α has the following values:

$$\alpha = \alpha_1 + \alpha_2 \tag{3.40}$$

$$\alpha_1 = \frac{B_{F1}}{B_S} \tag{3.41}$$

$$\alpha_2 = \frac{B_{F2}}{B_S} \tag{3.42}$$

$$B_{F1} = E_{F1} \cdot I_{F1} \tag{3.43}$$

$$B_{F2} = E_{F2} \cdot I_{F2} \tag{3.44}$$

$$\beta = \frac{B_S \cdot d_C}{{B_e}^2 \cdot G_C \cdot L^2} \tag{3.45}$$

$$\lambda = \sqrt{\frac{1+\alpha}{\alpha \cdot \beta}} \tag{3.46}$$

- Stresses in faces:
  Stresses in the upper chord of the profiled face:

$$\sigma_{F1} = -\frac{M_s}{e \cdot A_{F1}} - \frac{M_{F1}}{I_{F1}} \cdot d_{11} \tag{3.47}$$

Stresses in the lower, flat or lightly profiled face:

$$\sigma_{F2} = +\frac{M_s}{e \cdot A_{F2}} \tag{3.48}$$

Stresses in the upper, flat or lightly profiled face:

$$\sigma_{F1} = -\frac{M_S}{e \cdot A_{F1}} \tag{3.49}$$

IV. Determination of failure stresses

The determining failure stresses in the upper chord of the profiled face σ_{F1}^u and the wrinkling stress σ_w in the lightly profiled face shall be determined by multiplying the calculated stresses caused by a unit load by the following factor:

$$f = \frac{failure\ load}{unit\ load} = \frac{q_u + weight\ of\ panel\ [kN/m]}{1} \tag{3.50}$$

where:

$$q_u = \frac{F_u}{L} \tag{3.51}$$

F_u = failure load measured in the test

L = span

$$\sigma_{F1}^u = f \cdot \sigma_{F1} \text{ (profiled face)} \tag{3.52}$$

$$\sigma_w = f \cdot \sigma_{F2} \text{ (flat or lightly profiled face)} \tag{3.53}$$

In doing so, it must be mentioned that in principle only the failure stresses of the face under compression is of interest. This means that for σ_{F1}^{u}, only tests with positive orientation and for σ_w only tests with negative orientation must be evaluated.

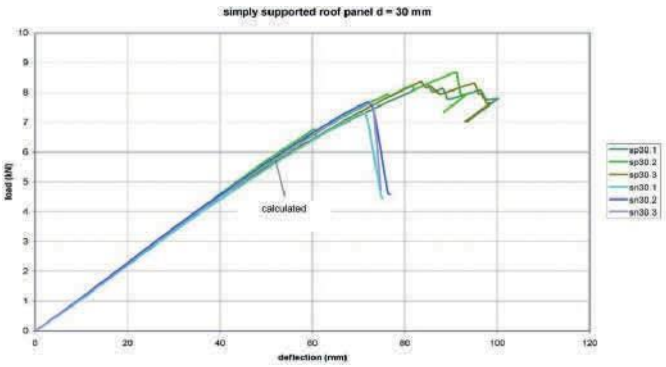


Figure 52: Load / deflection diagram

Notes:

- *In most cases, the yield stresses of metallic materials can be applied as failure stresses for the faces under tension.*
- *The lightly profiled lower faces of roof panels often equal those of wall panels. For cases with similar material properties, only confirmation tests with negative orientation must be accomplished, to proof that the wrinkling stresses measured in such tests are higher than those values determined in wall panel tests. The values for wall panels are then also applied as the wrinkling stresses of the lower face of roof panels, if all panels are produced on the same production line.*

V. Correction coefficient for the profiled face

For normalization of the failure stress, determined in the tests, with regard to the standard values of the face material, the formulae in EN 14509:2013, A.5.5.4 are to be implemented:

$$R_{adj,i} = R_{obs,i} \cdot \left(\frac{f_y}{f_{y,obs}}\right)^{\alpha} \cdot \left(\frac{t}{t_{obs}}\right)^{\beta} \qquad (3.54)$$

where:

$R_{obs,i}$ = result of test no. i

$R_{adj,i}$ = test result modified to correspond to the design values of metal thickness and yield stress

f_y = design yield strength

$f_{y,obs}$ = yield stress measured in the test specimen

t = design metal thickness

t_{obs} = metal thickness measured on the test specimen

$\alpha = 0$ if $f_{y,obs} \leq f_y$ and for flat and lightly profiled faces

$\alpha = 1.0$ if $f_{y,obs} > f_y$

except that, for the compression failure mode of a profiled face:

$$\alpha = 0.5 \text{ if } f_{y,obs} > f_y \text{ and } \frac{b}{t} > 1.27\sqrt{\frac{E_F}{f_y}}$$

For β applies:

$\beta = 0$ when calculating the wrinkling stress from test results, or

$\beta = 1.0$

except that, for the compression failure mode of a profiled face:

$$\beta = 1.0 \text{ if } t_{obs} > t \text{ and } \frac{b}{t} \leq 1.27\sqrt{\frac{E_F}{f_y}}$$

$$\beta = 2.0 \text{ if } t_{obs} > t \text{ and } \frac{b}{t} > 1.27\sqrt{\frac{E_F}{f_y}}$$

where:

$\frac{b}{t}$ = width to thickness ratio of the relevant part (crown or valley) of the profiled face

b = width of the top of the profiled face (rib)

t = thickness of flange material.

Notes:

- *The normalisation and the declaration of the bending moment capacity of panels with profiled faces shall be done in accordance with A.5.5 in EN 14509:2013.*
- *A reduction of the wrinkling stresses due to elevated temperature needs to be considered only for roof panels with flat or lightly profiled faces on the external side.*

3.6.8 Bending moment capacity and wrinkling stresses at an internal support

Based on: EN 14509:2013, 5.2.1.8 and A.7, in particular A.7.5

General comments:

One of the most important values for the design against serviceability limit state is the wrinkling stress σ_w at which the flat or lightly profiled face under compression fails directly in the area of the internal support due to regular or uplifting loads (for more detailed explanations about ultimate capacity over an internal support, see chapter 3.5.8). Therefore, the aim is to determine the wrinkling stress under regular and uplifting loads at first of each type of exterior and interior faces.

In terms of dependency on the thickness of panels and the thickness of metal sheets, the same information as in chapter 3.6.7 applies.

The factor k_1 implementing the effect of the increased temperature can be applied analogous to chapter 3.6.7.

The interaction test is carried out using a line load. Thus, the factor k_2 is not needed to be taken into consideration.

The determination of the wrinkling stress is described in EN 14509:2013, A.7.5. The ultimate bending resistance of panels with flat or lightly profiled faces is as follows:

$$M_u = \left[\frac{F_u}{4} + \frac{F_G}{8}\right] \cdot L \tag{3.55}$$

where:

F_u = failure load including transverse loading beams

F_G = self-weight of panel

$$\sigma = \frac{M}{e \cdot A_i} \tag{3.56}$$

where:

A_i = cross-sectional area of face under compression

For a panel with one or both faces fully profiled, the test can be evaluated as follows:

The sandwich component of bending moment M_S:

$$M_S = \frac{F_u \cdot L}{1+\alpha} \cdot \left(\frac{1}{4} - \frac{\sinh\left(\frac{\lambda}{2}\right)^2}{\lambda \cdot \sinh(\lambda)}\right) + \frac{F_G \cdot L}{1+\alpha} \cdot \left(\frac{1}{8} - \frac{\cosh\left(\frac{\lambda}{2}\right) - 1}{\lambda^2 \cdot \cosh\left(\frac{\lambda}{2}\right)}\right) \tag{3.57}$$

The face component of bending moment M_{F1}:

$$M_{F_1} = \frac{F_u \cdot L \cdot \alpha}{1+\alpha} \cdot \left(\frac{1}{4} + \frac{\sinh\left(\frac{\lambda}{2}\right)^2}{\alpha \cdot \lambda \cdot \sinh(\lambda)}\right) + \frac{F_G \cdot L \cdot \alpha}{1+\alpha} \cdot \left(\frac{1}{8} + \frac{\cosh\left(\frac{\lambda}{2}\right) - 1}{\alpha \cdot \lambda^2 \cdot \cosh\left(\frac{\lambda}{2}\right)}\right) \tag{3.58}$$

The values of and are defined in the formula A.11 in EN 14509:2013.

The components of bending moment capacity determined in this way shall be corrected using the procedures given in EN 14509:2013, A.5.5.4 and A.5.5.5 prior to the determination of the characteristic values to be used in design (see EN 14509:2013, E.4.2). The wrinkling stress of the face in compression shall then be determined from the components of ultimate moment using the formula given in 3.6.7.2 and in EN 14509:2013, E.7.2.5.

3.6.9 Creep coefficient

Aim of evaluation of test results:

- For sandwich panels with flat or lightly profiled faces:

$$\varphi_t = \frac{w_t - w_0}{w_0 - w_b} \tag{3.59}$$

where:

w_t = deflection measured at time t

w_0 = initial deflection at time $t = 0$

w_b = deflection caused by the elastic extension of the faces (without shear deformation)

- For sandwich panels with one or both faces profiled:

$$\varphi_t = \frac{\beta \cdot (C_D - 1)}{\beta_1 \cdot (1 - \beta - \beta \cdot \rho \cdot (C_D - 1))} \quad (3.60)$$

where:

$$C_D = \frac{W_t}{W_0} \quad (3.61)$$

C_D is the relationship between the deflection after the loading time t and the initial deflection

$\rho = 0.5$ = relaxation coefficient, having here the value of 0.5

$$\beta = \frac{I_F}{I_W} \quad (3.62)$$

$$I_W = I_F + \frac{I_S}{1+k} \quad (3.63)$$

where:

I_F = moment of inertia of the profiled face(s) (sum if both faces are profiled)

I_S = moment of inertia of the sandwich part (see Annex E in EN 14509:2013)

$$k = \pi^2 \cdot \frac{E_{F2} \cdot A_{F2}}{G_C \cdot A_C} \cdot \frac{A_{F1}}{A_{F1} + A_{F2}} \cdot \left(\frac{e}{L}\right)^2 \quad (3.64)$$

$$\beta_1 = \frac{k}{1+k} \cdot \beta \quad (3.65)$$

where:

e = measured distance between centroids of the faces

L = span of panel used in creep test

The creep coefficients φ_t at 2,000 h and at 100,000 h are obtained using the following formulae:

$$\varphi_{2000} = 1.2 \cdot (1.43 \cdot \varphi_{1000} - 0.43 \cdot \varphi_{200}) = 1.7 \cdot (\varphi_{1000} - 0.3 \cdot \varphi_{200}) \quad (3.66)$$

$$\varphi_{100000} = 3.86 \cdot \varphi_{1000} - 2.86 \cdot \varphi_{200} \quad (3.67)$$

Instead of using the expression for sandwich panels with one or both faces profiled, the creep coefficient of the panel with profiled faces may be determined numerically on the basis of the analytical or numerical methods. In the procedures, the experimental and calculated deflections are equated by varying the shear modulus used to describe the shear deformations of the core. Iterative methods are required to find shear modulus G_{Ct} for different moments of time.

The following example may depict the procedure based on the analytical expression of the deflection.

It is assumed that the test specimen is loaded by a uniformly distributed load F. The experimental deflection w_exp at time t is compared to the calculated deflection $w(G_{Ct})$.

$$w(G_{Ct}) = \frac{F\,L^3}{B_S + B_F}\left(\frac{5}{384} - \frac{\cosh(0.5\lambda(G_{Ct})) - 1}{\alpha\,\lambda(G_{Ct})^4 \cosh(0.5\lambda(G_{Ct}))} + \frac{1}{8\,\alpha\,\lambda(G_{Ct})}\right) := w_{exp} \quad (3.68)$$

The shear modulus G_{Ct} in the expression 3.68 is varied until the calculated deflection equals the experimental deflection.

The experimental creep coefficient is calculated as:

$$\varphi_t = {}^{G_{0i}}/_{G_{ti}} - 1 \tag{3.69}$$

where G_{0_i} is the imaginary initial shear modulus of the core and which corresponds to the initial deflection w (0.1 h) measured in the creep test at t = 0.1 h and G_{ti} corresponds to the measured deflection w_i measured in the creep test at t_i. These procedures can only be used if $G_{0i} \geq G_C$, where G_C is the mean value out of the belonging shear tests according to EN 14509:2013, A.3 or A.4.

The iteration to find out the shear modulus and the creep coefficient is repeated for every measured deflection of the test specimen. If the deflection has not been measured at t = 200 h and t = 1000 h, either the deflection or the creep coefficient at t = 200 h and t = 1000 h have to be interpolated using logarithmic time scale (lnt). Using the experimental creep coefficients φ_{200} and φ_{1000}, the creep coefficients φ_{2000} and φ_{100000} for the design can be calculated using the above expressions.

3.6.10 Density of the core and mass of the panels

Based on: EN 14509:2013, A.8

Comments:

The density according to EN 1602 shall be stated as mean value based on the obtained test results presented in chapter 3.5.10. Furthermore, the smallest and greatest values shall be documented according to EN 14509:2013, table 5.

The mass of the panels shall be determined arithmetically (value shown on CE-marking) based on the nominal geometry and the nominal density of the core and face material.

3.6.11 Dimensional tolerances for the most important geometrical dimensions

Comments:

The maximum allowed dimensional deviations are shown in EN 14509:2013, 5.2.5, table 4. These need to be checked according to EN 14509:2013, annex D.

For panels with lightly profiled faces on both sides, the geometrical dimensions are in particular the depth and width of profiling together with the thickness of the panel.

3.6.12 Determination of material safety factors

Based on: EN 14509:2013, E.6.3.2

Comments:

The variation coefficient obtained from the determined values of shear, compressive and wrinkling strength is the basis for the determination of the material safety factors (see EN 14509:2013, E.6.3.2).

3.6.13 Durability and other long-term effects

3.6.13.1 DUR 1 based on EN 14509:2013, B.2

The evaluation must be undertaken in accordance with EN 14509:2013, B.2.5 and is recapitulated in the following:
The lowest average value (f_{Ct42} or f_{Ct84}) found in a set of specimens is denoted as f_{CtDUR1}. The test is passed, if the following requirements are met:

- $f_{CtDUR1} \geq 0.5\ f_{Ct0}$
- $f_{CtDUR1} \geq 0.02\ MPa$
- change in dimension ≤ 5 %, in the most affected area.

3.6.13.2 DUR 2 based on EN 14509:2013, B.3

The evaluation must be undertaken in accordance with EN 14509:2013, B.3.5 and is recapitulated in the following:

- $f_{Ct7} - f_{Ct28} \leq 3 \cdot (f_{Ct0} - f_{Ct7})$
- $f_{Ct28} \geq 0.4 \cdot f_{Ct0}$
- change in dimension ≤ 5 %, in the most affected area

or, if one of the previous criteria is not met:

- $f_{Ct28} - f_{Ct56} < f_{Ct7} - f_{Ct28}$ and $f_{Ct56} \geq 0.4 \cdot f_{Ct0}$

3.6.14 Resistance to point loads and repeated loads

3.6.14.1 Testing case 1: Occasional access during erection and service (EN 14509:2013, A.9.1)

There are three possible outcomes that can be reached based on this test:

- If the panel bears the load without permanent visible damage after releasing the timber block and the soft layer (possible damages are: yielding of the face or a permanent deformation of the face; e.g. over 0.1 mm), there is no restriction for occasional access onto the roof or ceiling neither during the erection phase nor during occasional service work on the panel or other devices on top of the panel. In this case, the notation on the CE-marking is:
  Resistance to point and access loads: Suitable for occasional access for erection and service
- If the panel bears the load, but with permanent visible damage, the access on the panel can only be allowed during erection if protection boards are used. For further access, permanent walking ways supported by the frame structure of the building are to be installed. In this case, the notation on the CE-marking is:
  Resistance to point and access loads: Suitable for occasional access for erection, only when using protection of the surface. Unsuitable for service and repeated access without permanent walking ways installed
- If the panel fails to bear the load, i.e. there is a clear collapse of the panel (a permanent deflection at the loading point of the panel, of size e.g. greater than span/100, measured e.g. with the help of a line spanning over the panel length in the middle of the upper face, is noticed), no access on the panel neither during erection nor thereafter is allowed. Access on the panel is allowed only via walking ways fixed to the supporting frame of the building. In this case, the notation on the CE-marking is:
  Resistance to point and access loads: Access not allowed, suitable as non-walk-on ceilings only

3.6.14.2 Testing case 2: Repeated access for erection and service (EN 14509:2013, A.9.2)

For each specimen, the cross-panel tensile strength (f_Ct) shall be determined as

$$f_{Ct} = F_u / A \qquad (3.70)$$

according to EN 14509:2013, A.1.5.1.

The average tensile strength (f_{Ct0}) shall be calculated for the three specimens taken from points extracted from the walking route.

The test results shall be plotted on a graph of tensile strength versus number of heel impacts including f_{Ct0}. The test series is valid if there is a progressive deterioration of the tensile strength with number of cycles.

Note:
In the nature of this test, a significant scatter of test results is to be expected. The results may also be influenced by the care taken to cut test specimens from complete panel, which may have already been weakened by repeated impacts. It would be, therefore, optimistic to expect that the test results give rise to smooth curves; a generally decreasing trend with number of cycles is all that is required.

The test shall be interpreted on the basis of the four results for specimens subjected to 2 000 cycles of load. If these form a compact block of results, the characteristic value of the reduced tensile strength f_{Ct2000} shall be taken as the mean of the four relevant values of f_{Ct} minus 2.68 standard deviation. If the results for specimens from above of support are significantly different from those for specimens in the span, f_{Ct2000} shall be taken as the lowest of the four values of f_{Ct}. If the pattern of results does not allow a rational interpretation, then the complete test series shall be repeated with a different panel.

If $f_{Ct2000} > 0.8\, f_{Ct}$, the panels shall be deemed to be suitable for repeated foot traffic for access or maintenance without additional protection. In this case, the notation on the CE-marking is:

Resistance to repeated loads: Suitable for repeated access

If $f_{Ct2000} \leq 0.8\, f_{Ct0}$, the panels are not suitable for repeated access. In this case, the notation on the CE-marking is:

Resistance to repeated loads: Unsuitable for repeated access without additional protection

4 BUILDING PHYSICS PROPERTIES

4.1 General

All properties that are handled and described in this section are not only dependent on the sandwich panel, but the function of the whole system consisting of panels, fixings, sealants, flashings, details and workmanship during installation. There are different options for the manufacturer to deal with these aspects.

Generally, the specimens should therefore include both longitudinal joints between the panels and transversal joints with fixings to connect the panels to the building frame. Normal sealant systems and details should be used in the joints mentioned above according to the end use conditions the manufacturer will use in practice.

All details used in the different tests shall be recorded in the test reports and the test results are valid only for the same family of structure with the tested one, according to the field of direct and/or extended applications given for the different test methods.

Openings (windows, doors, etc.) shall not be included in the test specimen.

4.2 Installation on the building site

Because the installation will affect the properties of the system, the installation of a quality marked product shall always be done by an installation company that has enough knowledge of the product and its function. The manufacturer is obliged to give clear installation rules and details to ensure a correct installation on the building site (see PPA-Europe's Rules for Good Practice). These rules must also be followed to ensure the properties declared.

4.3 Determination of product properties in final applications

4.3.1 Reaction to fire

Based on: EN 14509:2013, 5.2.4.1 and C1

Family of products shall be established using the rules for direct field of application given in the product standard.

The tests shall be made according to the relevant test methods and the additional instructions given in the product standard.

Where the test EN ISO 11925-2 is needed, the method for unprotected applications without flashings shall be used.

In case of A1 or A2 classified panels, the amount of adhesive shall be checked at least once per day and the rolling mean value of the amount shall be below the value given in the classification report. This shall also be checked together with the strength properties in TT and third party control tests.

4.3.2 Fire resistance

Based on: EN 14509:2013, 5.2.4.2 and C2

For sandwich panels used in wall applications, the field of application of the fire resistance test results shall be in accordance with EN 15254-5 together with the additional direct field of application given in Table C.2 of the product standard.

For sandwich panels used in ceiling applications, family of products shall be established using the rules for direct field of application given in the product standard

For sandwich panels used in roof applications considered loadbearing, EN 14509:2013 does not provide rules for direct field of application of fire resistance test results.

The tests shall be made according to the relevant test methods and the additional instructions given in the product standard.

Additional measurements can be used for further EXAP examinations and classifications.

4.3.3 External fire performance for roofs

Based on: EN 14509:2013, 5.2.4.3 and C.3

Family of products shall be established.

The tests shall be made according to the relevant test methods and the additional instructions given in the product standard if the panels do not have a classification without further testing (CWFT). It is up to the manufacturer to choose what test method(s) he wants to use depending on the requirements in the different countries.

4.3.4 Thermal transmittance

Based on: EN 14509:2013, 5.2.2 and A.10

The declared thermal conductivity shall be determined in accordance with the procedures described in the appropriate product standard for the core material in the direction used in the sandwich panel. In order to ensure an adequate level of quality, for preformed CE-marked core materials (such as MW, EPS), the values and the results from the manufacturer of the core material can be used without any further testing, if the manufacturer has a quality system that respects the requirements of EN 13172, the CE-marking provides the λ values for the orientation used in the panel manufacturing process and these core material performances are controlled under responsibility of a third party, in a system equivalent with the AVCP system 1+. For materials other than core materials (e.g. metal sheets), tabulated values in accordance with EN ISO 10456 shall be used.

Design thermal conductivity shall be determined and the thermal transmittance value (U) for the panel system excluding the end fixings but taking into account the effects of all joints shall be calculated according to EN 14509:2013.

The influence of the fixings shall be given separately and calculated according to standard EN ISO 10211.

For all standards, the reference shall be made to the current edition, as modifications in the next editions are not foreseeable.

4.3.4.1 Common test methods for determination of the thermal conductivity
Based on: EN 12667 and EN 12664

As only the heat flow meter and the guarded hot plate apparatuses can reach the required accuracy, only these two methods are regarded here.

Measuring devices that deviate from the test standard EN 12667 (e.g. one plate measuring devices with cooling circuit on the warm side) are not automatically usable for products with targeted thermal conductivity. If such devices are used, these have to be explicitly proven under the engagement of the EPAQ IE for thermal characteristics for the products to be measured.

l. Heat flow meter (HFM)

To measure the thermal conductivity of plate-shaped products, the HFM can be applied. A grid of thermocouples generates a voltage proportional to the heat flux through the element.

Calibration and accuracy of the equipment:

- Calculation of the measuring uncertainty (requirement on the measuring uncertainty: ≤ 3%, according to EN 12667, Annex C.2) has to be available for each test apparatus and can be provided by the producer of the device.

Implementation of:

- First calibration:
  - The calibration has to be performed for the complete thickness range.
  - Certified reference material IRMM 440 or verified reference material (e.g. with EPS samples) provided by an independent laboratory for thermal conductivity or by the manufac- turer of the test apparatus shall be used.
  - The measuring uncertainty (under consideration of the extended measuring uncertainty according to EN 12667, EN 1946-2 and EN 1946-3) has to be calculated.
  - As a result of the first calibration, the requirements for the two weeks internal control, including tolerances have to be defined.

- Two weeks internal control:
  - The apparatus shall be controlled according to the requirements defined during the first calibration, using IRMM 440 or reference material provided by an independent laboratory for thermal conductivity or by the manufacturer of the test apparatus and shall comply with the requirements.

- Annual calibration:
  - The calibration has to be performed for the greatest and smallest thicknesses.
  - Certified reference material IRMM 440 or verified reference material (e.g. with EPS samples) provided by an independent laboratory for thermal conductivity or by the manufacturer of the test apparatus shall be used.

- External Quality Control:
  - The third party has to check the calibration certificates, the documentation of the certified reference material and the internal control records.
  - Accepted deviation of the calibration measurements using either IRMM 440 or a reference material provided by an independent laboratory for thermal conductivity or by the manufacturer of the test apparatus is ± 1%.

The HFM measurement is suitable for components consisting of homogenous layers perpendicular to the heat flow. In steady state, with a constant temperature gradient through the subject, the equivalent thermal conductivity can be derived directly from heat flux, the thickness of the specimen and the temperatures of the surfaces only (as described for laboratory methods in EN 12664, EN 12667, EN 12939 or EN 1934). For thermal transmittance, the environmental temperatures and/or surface thermal resistances are required.

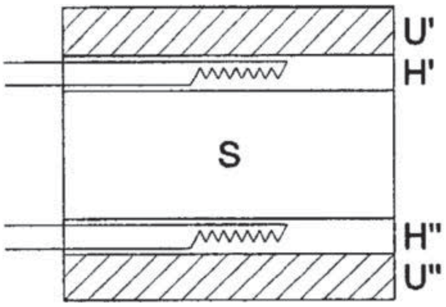


Figure 53: Schematics of heat flow meter apparatus with symmetric alignment and single specimen (source: EN 12667)

Key
U´, U´´ heating and cooling plate
H´, H´´ heat flow meter

HFM apparatuses are in most cases easy to maintain and will reach steady state conditions often-times faster than guarded hot plate apparatuses. On the other hand, the measurement uncertainty is connected to the quality of the calibration standard and in general higher than for GHP, because also the measurement uncertainty of the calibration standard has to be taken into account.

II. Guarded hot plate (GHP)

The reference method with highest accuracy (± 2% according to EN 12667, Annex B.2) for determining thermal resistance and thermal conductivity results of building- and insulating materials is the GHP measurement. The measurement is carried out by measuring the energy consumption of a hot plate, when using it to apply a defined temperature gradient to a specimen.

Implementation of:

- First calibration:
  - The calibration has to be performed for the complete thickness range.
  - Certified reference material IRMM 440 or verified reference material (e.g. with EPS samples) provided by an independent laboratory for thermal conductivity or by the manufac- turer of the test apparatus shall be used.
  - The measuring uncertainty (under consideration of the extended measuring uncertainty according to EN 12667, EN 1946-2 and EN 1946-3) has to be calculated.
  - As a result of the first calibration, the requirements for the three weeks internal control, including tolerances have to be defined (this is optional, but recommended).

- Three weeks internal control (this is optional, but recommended):
  - The apparatus shall be controlled according to the requirements defined during the first calibration, using IRMM 440 or reference material provided by an independent laboratory for thermal conductivity or by the manufacturer of the test apparatus and shall comply with the requirements.

- Annual calibration:
  - The calibration has to be performed for the greatest and smallest thicknesses.
  - Certified reference material IRMM 440 or verified reference material (e.g. with EPS sample) provided by an EPAQ independent laboratory for thermal conductivity or by the manufacturer of the test apparatus shall be used.

- External Quality Control:
  - The third party has to check the calibration certificates, the documentation of the certified reference material and the internal control records, if applicable.
  - Accepted deviation of the calibration measurements using either IRMM 440 or a reference material provided by an independent laboratory for thermal conductivity or by the manufacturer of the test apparatus is ± 1%.

The method requires plane and plate-shaped specimens, which are installed between heating (A, C) and cooling plates (D). The installation is thermally decoupled to avoid outward heat flows perpendicular to the heat flow to be measured. This is achieved by an insulating guard ring, surrounding the installation with a small gap and temperature controls that zero out any differences in temperature between the specimen and the guard ring (E). When reaching a stationary temperature state, the heat flow becomes constant. At this point, the temperature gradient and the heat flow can be used to calculate the equivalent thermal conductivity of the specimen directly from thermal resistance using the thickness of the specimen.

The test is very similar to the HFM in matters of test conditions and specimen preparation.

The duration of the test is mainly dependent on the size and the thermal properties of the specimens and ranges between several hours and days (until steady state conditions are sufficiently met).

Compared to HFM, the GHP is more accurate because all necessary values for calculation of the thermal conductivity are measured directly.

On a laboratory scale, the method is described in EN 12667 and EN 12664.

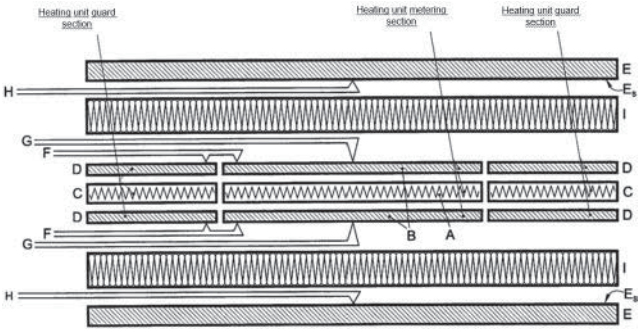


Figure 54: Guarded hot plate - two specimen apparatus (source: EN 12667:2001)

III. Conclusion on the common test methods
The GHP method can be seen as the reference method for calibrating and verifying other methods – stationary and transient.
Most of the sophisticated methods are characterized by sensitive laboratory setups and small-sized samples. Especially for insulation materials with often times inhomogeneous distribution of cell-sizes or fibre/particle classes, the measurement of thermal conductivity on boards and plates in real thickness is recommendable in any case. Also production related variations in the density over the thickness of the panel are common for many products, therefore again, the measurement on the whole panel is mandatory to get correct results.

4.3.4.2 Basic sampling and test specimen preparation in general and for determination of the initial lambda value

I. Specimen preparation in general

As the specimen thickness can have a big influence on the testing result, specimen shall be cut out of the sample directly below the facing, to minimize the differences between nominal and specimen thickness and to have a representative result (except specimen for normality test, see the following chapter).

According to EN 12667:2001, 6.3, depending on the type of apparatus (GHP apparatus or HFM apparatus), one or two specimens shall be chosen from each sample; the thickness difference shall be less than 2% for GHP. The faces of the specimen shall be parallel over the total surface area within 2% of the specimen thickness and shall be made as flat as the apparatus surfaces and so that the accuracy in the measurement of specimen thickness is within 0.5%.

The specimen(s) shall be of such size as to cover the heating unit surfaces completely including the guard section, without exceeding the overall linear dimension of the heating unit or flow meter by more than 3%. They shall have a thickness according to the relevant product standard and additionally, the relationship between the thickness of the used test specimen and the dimensions of the heating unit shall be restricted so as to limit the sum of imbalance error (GHP apparatus only) and edge heat loss errors to 0,5%, see thickness limits in Table A.1 of EN 12667:2001.

An accurate saw cut normally satisfies the requirements for the flatness and parallelism of the sample surfaces in EN 12667:2001, A.3. If grinding is used, it should be realised by machine, in order to prevent cupping.

II. Factory made rigid polyurethane foam (PU) products according to EN 13165:2016 as core layer of a double skin metal faced insulating panel according to EN 14509:2013

Based on: EN 13165:2016, 4.2.1, 5.3, C.2, C.3 and EN 12667:2001, 6.3

The aging effect by cell-gas diffusion or exchange has a negative influence on the thermal conductivity of PU products over lifetime. As a result, a careful specimen handling is very important. For a reliable information on the thermal performance, the aged values of thermal conductivity are needed. EN 13165 deals with two possible ageing procedures, the fixed increment procedure in annex C.5 and the accelerated ageing procedure in annex C.4.

Regarding sampling and specimen preparation, the following points shall be taken into account:

- To minimize the aging effect by cell-gas diffusion, tests for the fresh value of the thermal conductivity shall be performed within one and eight days after manufacturing of the panels.
- The test specimen shall be cut from the central area of the product sample.
- As facings of panels can influence the thermal conductivity measurement by their geometry, facings shall be removed. The impact of the faces is taken into account by calculation of the U-value.
- The removal of the metal faces and the cutting of samples from the central area shall be done directly before the testing, to minimize the distortion by aging effects by cell-gas diffusion or exchange. It is recommended that the lambda values are obtained within 24 hours after removal of the metal facings.
- Samples of complete thickness shall be measured. If this is not possible, an alternative FPC procedure can be established together with an EPAQ independent expert for thermal characteristics. In order to validate the FPC procedure, when the manufacturer is not able to measure with his device the complete thickness, he has to measure a sample of a smaller thickness according to FPC procedure. At the same time, the EPAQ independent laboratory for thermal

conductivity has to measure a sample of complete thickness. The results of the manufacturer and of the EPAQ independent laboratory have to be within the tolerances given in the EPAQ Quality Regulations.

III. Factory made mineral wool (MW) products according to EN 13162+A1 as core layer of a double skin metal faced insulating panel according to EN 14509:2013

No special conditioning of the test specimens is needed, unless otherwise specified in the test standard. In case of dispute, the test specimens shall be stored at (23 ± 2) °C and (50 ± 5) % relative humidity for at least 6 h prior to testing. For FPC no special conditioning of the test specimens is needed.

The correct orientation of the used MW products according to the mounting conditions is important for the measurement process, as the fibre orientation has an essential influence on the test result.

The MW lamellas used in sandwich panels are usually narrow (with a width of about 100 mm). In order to reach the needed measuring width and to avoid any air gap between the fitting products, more lamellas have to be fixed together by tape surrounding edges.

IV. Factory made expanded polystyrene (EPS) products according EN 13163:2012+A1:2015 as core layer of a double skin metal faced insulating panel according to EN 14509:2013

The specimen shall be conditioned for 3 weeks at (23 ± 3) °C and (50 ± 10) % relative humidity, due to the out-diffusion of pentane.

4.3.4.3 Determination of the cell-gas composition for PU core materials

As the used blowing agent is very important for the correct calculation according to the fixed increment procedure (see 3.3.4.8. II) or according to the accelerated aging procedure (see 3.3.4.8. III), determination of the cell-gas composition according to the gas chromatograph method (see "Cell-gas Composition – An Important Factor in the Evaluation of Long-term Thermal Conductivity in Closed-cell Foamed Plastics" in the document "Cellular Polymers", Vol. 19, No. 5, 2000, of Dipl.-Ing. W. Albrecht, FIW e.V. München) is required.

I. Methods for determination of the cell-gas composition

Cell-gas composition is usually determined using a gas chromatograph with a packed column and a thermal conductivity detector. Thermal conductivity detectors can determine all blowing agents currently in use and gaseous compositions in the Vol.-%- range. The carrier gas used for the gas chromatograph is one which is not present in the cellular plastic to be examined (usually helium).

Samples are taken using a gas-tight syringe with a long hollow needle, from around the middle of the cellular plastic material to be examined. It is expedient to determine the cell-gas composition with the same specimen that was used to determine thermal conductivity in order to eliminate material variations. The specimens are not destroyed in the process, so that further measurements of thermal conductivity can be made.

Before samples are taken, the gas-tight syringe is rinsed three times with the carrier gas.

The needle of the syringe is then inserted approximately half-way through the thickness of the specimen. During insertion, cell-gas samples are taken from several foam cells by slowly drawing back the syringe piston. This process is repeated twice in order to rinse the syringe; the third cell-gas sample is injected through the septum into the carrier-gas stream of the gas chromatograph.

The taking of cell-gas samples requires great care and some practice in order to ensure that the cell-gas samples are not contaminated with the ambient air. It is easy to check whether the sampling technique employed effectively prevents the penetration of ambient air: the cell-gas composition in a foamed plastic specimen with gas-diffusion-tight facings manufactured shortly before testing is determined. Normally such foams contain practically no air.

With a good sample-taking technique, measured values of < 1 Vol.-% air are obtained. The relative cell-gas composition of the sample is then determined using a gas chromatograph by retention period comparison and peak surface determination.

The sensitivity of the gas chromatograph detector must be set for each cell-gas component with appropriate gas-calibration mixtures (wherever possible within the concentration range of the subsequent measurements).

The obtained cell-gas percentages are multiplied by the sensitivity value of the detector and the cell-gas composition is expressed in Vol.-%.

It is usual to examine three cell-gas samples from each test specimen. The result is expressed as a mean value in 1 percent gradations. If the results exhibit a high degree of dispersion, further cell-gas samples must be examined.

II. Detection limit

In the process described, the detection limit is at about 0.5 Vol.-%. The detection limit can be significantly reduced by using a flame-ionisation detector. In this case, however, the detector is able to measure only certain gas components, but not oxygen, nitrogen or CO_2. However, for thermal properties, only quantities in the Vol.-% range are relevant. For this reason, the process as previously described is completely adequate for routine examinations.

III. Variation of measured results

As a result of gas exchange processes, the cell-gas composition is to a large extent dependent on the thickness of the specimen. Therefore, cell-gas samples are as far as possible always taken from the middle layer of the thermal insulation material specimen. In a more or less homogeneous insulation material, the dispersion of measured values amounts to approx. < 5 Vol.-%. For this reason, only the mean value is to be expressed in 1 percent gradations.

If the test specimens are either thin (insulation thickness 5 ÷ 20 mm) or not homogeneous, it may be advisable to state the measuring range.

4.3.4.4 Determination of the closed cell content for PU core materials

A further quality characteristic is the closed cell content in accordance with EN 13165, C.5.1 and in conjunction with Table 11, determined according to method 2 a (volume expansion) in EN ISO 4590. The closed cell content shall not be less than 90 %.

The specimens shall be cut with a sharp cutter and taking care not to change the original cell structure, except on the surface. The specimens must be free from dust, cavities and foaming skins.

The specimen size including its fragmentation rules shall be taken over from EN ISO 4590.

It is important to avoid any air pressure fluctuations during the measurement, e.g. by drafts or wind gusts. The specimens shall be conditioned at least 16 h before the test at (23 ± 2) ° C and (50 ± 5) % relative humidity. It is important that the test is conducted at (23 ± 2) ° C and preferably at controlled and moderate humidity of (50 ± 5) %.

The characteristic dimensions of the specimens are: 100 mm x 30 mm x 30 mm.

According to Boyle-Mariotte's law, increasing the volume of an enclosed gas causes a proportional reduction in pressure. If the size of a chamber is increased equally, with and without specimens, the pressure drop for the empty chamber is lower. By this method, the relative pressure drop, which was previously calibrated to standard volumes, is determined by the difference display values on the scale of a tube manometer that is open to the atmosphere.

I. Additional provisions

The surface correction procedure according to EN ISO 4590, chapter 10 shall be taken into account, as during the preparation of the specimens, the surface cells are opened.

4.3.4.5 Specimen preparation of PU products for the normality test
Based on: EN 13165:2016, 4.2.1, C.2, C.5

The specimen dimensions for the normality test of EN 13165:2016, C.5, differ from those for the initial test of thermal conductivity. Thus, the specimen shall have minimum dimensions 200mm x 200mm x 20mm (+ 2/-0) (length x width x thickness) and shall be cut out of the central area of the sample.

Hereafter the whole process is described. First step is determination of initial value of thermal conductivity of the test specimen in accordance with C.3 directly after cutting. After that the test specimen has to be stored at (70 ± 2) °C for (21 ± 1) days. After reconditioning the specimen for 16 h at (23 ± 3) °C and (50 ± 10) % relative humidity, the aged value of thermal conductivity of the test specimen has to be determined in accordance with EN 12667, EN 12939 and 5.3.2 in EN 13165.

4.3.4.6 Specimen preparation of PU products for the accelerated aging test
Based on: EN 13165:2016, 4.2.1, C.2, C.4

Process: Specimen storage at (70 ± 2) °C for (175 ± 5) days, reconditioning for 16 h at (23 ± 3) °C and (50 ± 10) % relative humidity, measuring thermal conductivity.

During the accelerated aging test, the test specimen shall be stored the complete time ((175 ± 5) days) with facings at (70 ± 2) °C. After reconditioning for 16 h at (23 ± 3) °C and (50 ± 10) % relative humidity, the accelerated aging conductivity value of the specimen shall be measured. For determination of the thermal conductivity in accordance with C.3, all facings shall be removed directly before starting the measurement.

Due to the fact that guidelines regarding specimen sizes and metering area are not available in EN 13165, the following requirements shall be fulfilled to obtain reliable and comparable results. The specimen sizes shall be 500 mm x 500 mm and in complete thickness during the entire test procedure. The metering area for recording the thermal conductivity shall be 300 mm x 300 mm. Due to the big standard dimensions of a complete sandwich panel, the relation between specimen sizes and metering area appears suitable. As the aging effect begins on the edges of the specimen, it is very important to have a reasonable relation between the specimen size and the metering area, as indicated above. The regulations of EN 12939 shall be taken into account. For testing PU foam with these dimensions, up to 200 mm thick, the GHP apparatus shall have a dual guard section and the HFM shall have a symmetrical design (symmetrical heat flow meter). For thicknesses ≥ 200 mm, a validation of the specimen sizes is necessary.

At the beginning of the test, the samples shall not be younger than one day or older than fifty days since the manufacturing.

4.3.4.7 Testing conditions and measuring procedure of thermal conductivity

The measurement of the thermal conductivity shall be carried out in accordance with EN 12667, EN 12939 for thick products, EN 13165 for PU products, EN 13162 for MW products and EN 13163 for EPS products. Minimum number of measurements to get one test result is one.

Thermal conductivity shall be specified to the nearest 0,001 W/(m · K).

Thermal conductivity shall be determined directly for the measured thickness.

When measured thickness is used for testing of thermal conductivity, the tested thickness should be the smallest of the measured points on the tested specimen. If air gaps are observed, the specimen must be reworked.

The mean temperature shall be (10 ± 0.3) °C.

In case of PU panels, the effect of ageing according EN 13165:2016, Annex C shall be taken into account. The used blowing agent shall be proven as permanent.

4.3.4.8 Interpretation and requirements

I. General

Determination of the cell-gas composition in accordance with the gas chromatograph method and determination of the closed cell content in accordance with the closed cell content method (as described in EN 13166, annex D.3 and EN 13165:2016, annex C.5.1) should be carried out in the frame of the type testing, to detect the used blowing agent in EN 14509. Only in this way, prohibited blowing agents (e.g. CFC, HCFC), as well as blowing agents that are not covered by EN 13165:2016 (e.g. HFO) can be detected, the aging methods according to EN 13165:2016, annex C.4 and C.5 can be used reliably, lambda declared be calculated correctly for closed cell PU products and durable quality of the foam be ensured.

The procedures of fixed increment and accelerated aging are only valid for the blowing agents for which aging increments are stated in EN 13165. In case of other blowing agents, a national or European approval is needed or the procedure in the position paper "SG19 of the Thermal insulation products Sector Group of the Group of Notified Bodies for the CPR" has to be followed.

II. Interpretation and requirements for the fixed increment procedure

The fixed increment procedure is the common method regarding ageing increment for sandwich products with PU core, as it suits especially for diffusion tight products and it is faster than other methods.

Using blowing agents that are described in EN 13165:2016, C.1 and C.5, Table C.2, the fixed increment method in accordance with EN 13165:2016, C.5 can be applied, if the normality test in accordance with C.5.2 was carried out successfully. The lambda value of the normality test shall be near the initial value of the full core thickness. In dependence of the blowing agent, the fixed increment lies between 0,0015 and 0,0060 W/(m K) for diffusion tight facings.

The fixed increment (ageing increment) together with the initial value of thermal conductivity (according to EN 13165:2016, C.3, at the complete thickness) results in the aged value of thermal conductivity.

III. Interpretation and requirements for the accelerated aging procedure

The accelerated aging procedure is the alternative method for determining the aged value of thermal conductivity. The procedure is described in EN 13165:2016, C.4 and Figure C.1.

Using blowing agents that are described in EN 13165:2016, C.1, the accelerated aging procedure in accordance with EN 13165:2016, C.4 can be applied. It has to be applied, if the requirements of the normality test are not fulfilled.

The aged lambda value shall be calculated by applying the safety increments in EN 13165, C.4.

4.3.5 Water permeability

Based on: EN 14509:2013, 5.2.6 and A.11
Test standard: EN 12865:2001

No tests in addition to those required by EN 14509 are foreseen. In case of water and air tightness, the weakest point of the building element is usually not the longitudinal joint of the panels. Water and air permeability tests should be performed especially for building sites with demanding weather conditions. Water permeability tests can be performed on the same assembly used for air permeability.

The tests shall be carried out according to the relevant test methods, the additional instructions given in the product standard and the following rules:

- The dimensions of the test assembly shall be large enough to be representative of the intended use.
- If sandwich panels for wall application, are used in practice, in both, horizontal and vertical orientations, both configurations shall be tested – see figures 55 and 56.
- For horizontal orientation, the test assembly shall consist of at least one full-width panel and two cut panels (width > 300 mm) to include a minimum of two longitudinal joints. The height H of the assembly shall not be less than 2400 mm and the length L of the assembly shall be at least 1200 mm based on the test-standard requirement, but from the practical experience, it is recommended to use a test assembly which is at least 2000 mm long. See figure 55.
- For vertical orientation, the test assembly shall consist of at least one full-width panel and one or two cut panels (width > 300 mm) to include a minimum of one longitudinal joint. The height H of the assembly shall not be less than 2400 mm and the length L of the assembly shall be at least 1200 mm based on the test-standard requirement, but from the practical experience, it is recommended to use a test assembly which is at least 2000 mm long. See figure 56.
- If sandwich panels include both, factory-made longitudinal and transversal joints (bi-directional joints), the test assembly shall include both joints - see figure 57 and 58.

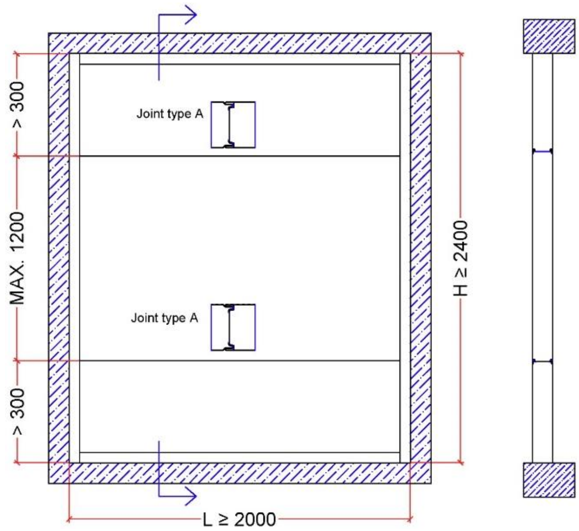


Figure 55: Arrangement of the water / air permeability test for sandwich panel wall in horizontal orientation

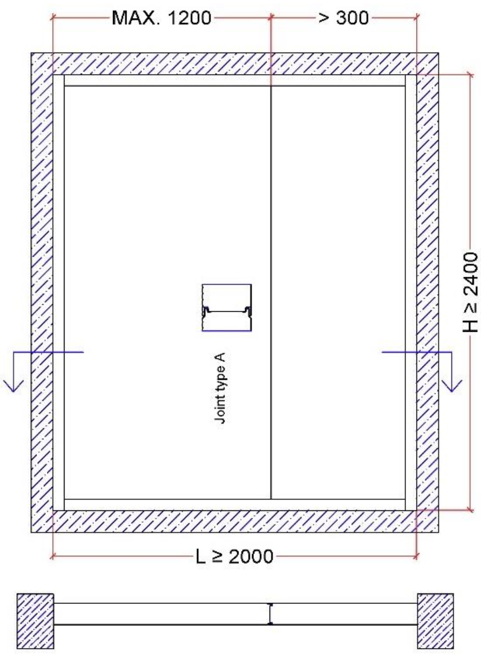


Figure 56: Arrangement of the water / air permeability test for sandwich panel wall in vertical orientation

- For panels with bi-directional joints, the test assembly shall consist of all elements typical for the end use. The height H of the assembly shall not be less than 2400 mm and the length L of the assembly shall be at least 1200 mm based on the test-standard requirement, but from the practical experience, it is recommended to use a test assembly which is at least 2000 mm long.

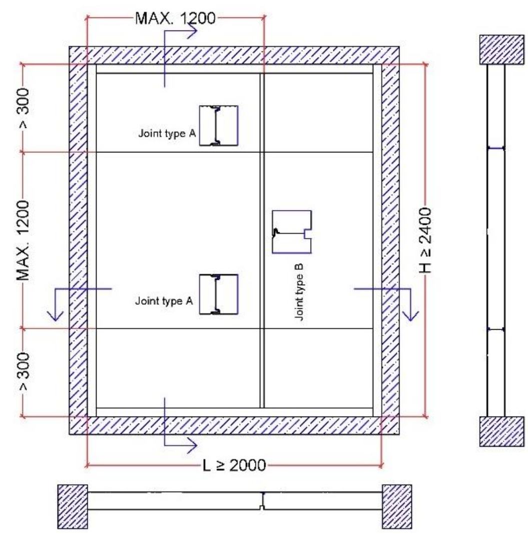


Figure 57: Arrangement of the water / air permeability test for installation type 1: joint type A horizontal, joint type B vertical

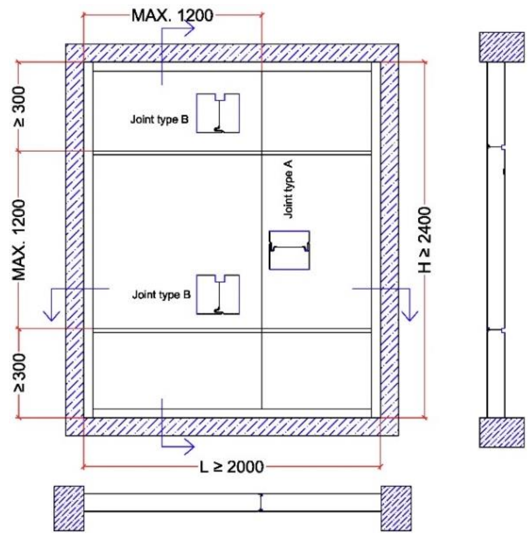


Figure 58: Arrangement of the water / air permeability test for installation type 2: joint type B horizontal, joint type A vertical

Note:
The provisions for sandwich panels with factory-made bidirectional joints are only based on the experience of one manufacturer.

- Roof sandwich panels shall be tested under the minimum allowed roof slope given by the panel producer – see Figure 59.
- For roof installation, the test assembly shall consist of at least one full-width panel and one or two cut panels (width > 300 mm) to include a minimum one longitudinal joint. The length L of the assembly shall not be less than 2400 mm. From the practical experience, it is recommended to use a test assembly which is at least 2000 mm wide.
- For roof panels used on large area roofs, it is recommended to test a combination of both roof panel joints: longitudinal joint (type C) and transversal overlapping joint (type D) – see figure 59.
- The overlapping joint (type D) shall be executed on drip distance of maximum 1200 mm. The assembly including all sealing parts shall be executed according to the instructions of the producer, in compliance with building practice.

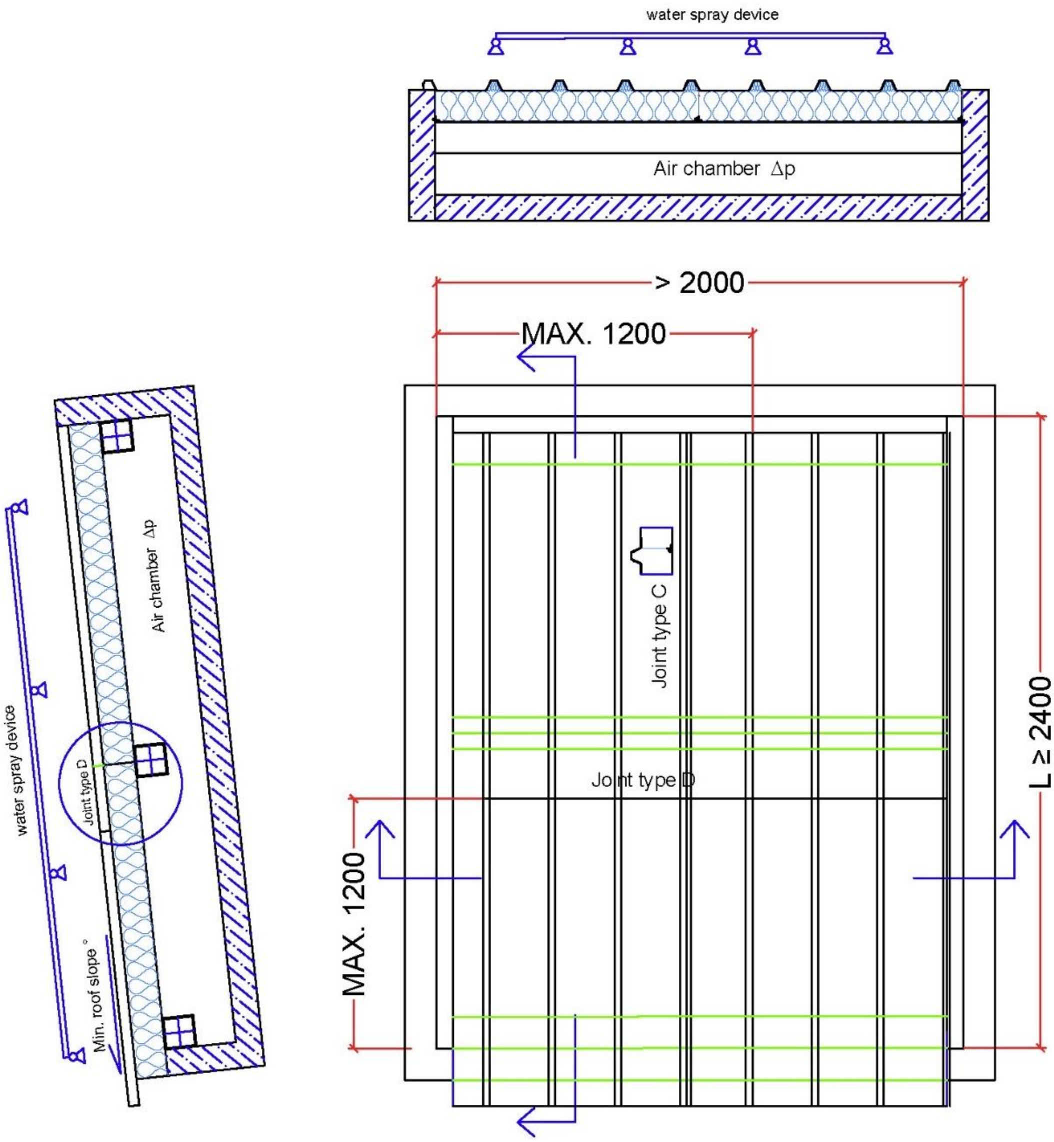


Figure 59: Arrangement of the water / air permeability test for roof panels

Note:
These water permeability tests based on EN 12865 do not include junctions or connections, such as corner junctions, junctions at the wall base and between wall and roof. To test real project related details, other full-scale water permeability test standards as EN 12155 can be used.

4.3.5.1 Evaluation of test results and field of application

Family of products shall be established taking into account the following base criteria: the core material, the metal face material, the sandwich panel joint design / geometry, the type of joint sealant, the sealant material.

- Results for horizontally installed wall panels are not valid for vertically installed panels and vice versa.
- For panels produced with joint sealant on the core material – see Figure 60 *a*, only the thinnest panel shall be tested, and results are valid for all thicker panels. It is not possible to use the results from a test with a thick panel for thinner panels.
- For panels produced with joint sealant at the junction between the metal faces – see Figure 60 *b*, results from one test are valid for the entire thickness range of the tested panel.

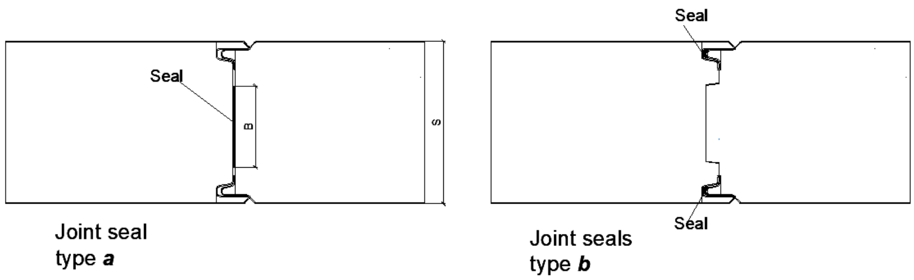


Figure 60: Sandwich panel joint seal type *a* and type *b*

- Lowest amount of fixings / panel end used in practice shall be used in the test. Results are then valid for all higher amounts of fixings.
- Results for one type of core material are only valid for that type of core material (e.g. if PUR/PIR is tested, results are only valid for PUR/PIR cores, and not for MW or others).
- If different variations of core materials are used within the same family (e.g. different densities), only the material with the lowest stiffness needs to be tested and the results are valid for all other stiffer materials within the same family.
- If different thicknesses of face materials are used, only the thinnest type needs to be tested and the results are valid for all other thicker materials within the same family. For different types of metals, a result for a metal giving a lower panel stiffness is always valid for a metal face giving a higher stiffness.
- Because the permeability is totally depending on the joint system, a result for one type of joint is valid for that joint type only within the tolerances for the joint in question.
- Results for one type of sealant are valid for other sealants within the same family with same material properties within given tolerances.
- A joint system can be constructed with or without sealants. Results for joints without sealants are always valid for the same type of joints with sealants.

4.3.6 Air permeability

Based on: EN 14509:2013, 5.2.7 and A.12
Test standard: EN 12114:2000

The tests shall be carried out according to EN 12114. Additional instructions are given in the product standard and underneath:

- The dimensions of the test assembly shall be in accordance with the instructions given in 4.3.5.
- The test specimen shall be tested for both, under and over pressure. Worst result can be used as single value set of air permeability for the test specimen.
- The test results shall be given in such way that the air permeability for the longitudinal joints in horizontal or vertical orientation are measured (in m^3/m h).
- The test results for sandwich panels with bi-directional joints shall be given in such way that the air permeability for the tested longitudinal and transversal joints are measured in m^3/m h. Length of longitudinal and transversal joints shall be recorded.
- The recommended way to do this is first to measure the air permeability for the complete assembly totally sealed, to determine the air leakage of the equipment. Then, unseal the panel joints to get a result for the longitudinal joints between the panels only. From these results, the air permeability (m^3/ m^2 h) for the assembly can be calculated for different applications. The air permeability test should begin with a pressure difference Δp_{max} of at least 200 Pa between inside and outside of the test assembly. The values *n* and *C* shall be declared on the basis of the test results (according to EN 12114, Annex B, formula (B.8)). The air loss *V* can be calculated using:

$$C = \exp(\alpha) \quad (4.1)$$

and

$$V = C \cdot \Delta p^{\,n} \quad (4.2)$$

(EN 12114, Annex B, formula (B.1))

Family of products shall be established taking into account the rules given in 4.3.5.

4.3.7 Airborne sound insulation

Based on: EN 14509:2013, 5.2.9 and A.13
Test standards: EN ISO 10140-1:2016, EN ISO 10140-2:2010, EN ISO 10140-4:2010, EN ISO 10140-5:2010
Evaluation standard: EN ISO 717-1:2013

The tests shall be carried out according to the relevant test methods and the additional instructions given in the product standard.

Family of products shall be established taking into account the following rules:

- Base criteria for establishing of product family: core material, metal face material, sandwich panel joint design / geometry, type of sealant, sealant material.
- Longitudinal joints between the panels and end fixings shall be incorporated into the test assembly.

4.3.7.1 Evaluation of test results and field of application

- Results for horizontally installed wall panels are valid for vertically installed panels and vice versa.
- If panels of different thicknesses are manufactured, the thinnest panel shall be tested, and test results are valid for all thicknesses.
- Results for one core material are valid for the tested core material only.
- If different thicknesses of face materials are used, only the thinnest type needs to be tested and the results are valid for all other thicker materials within the same family. For different types of metals, a result for a metal with lower density is always valid for a metal with a higher density.
- Tests should be carried out for one type of joint construction. Results are then valid for other joint constructions with the same type of sealing system. Results for joint constructions without sealants are also valid for constructions with sealants.
- Tests should be carried out for one type of joint sealant. Results for one type of sealant are valid for other sealants within the same family with same material properties within given tolerances.

4.3.8 Sound absorption

Based on: EN 14509:2013, 5.2.10 and A.14

Perforated panels are not within the scope of the standard. For non-perforated panels it can be assumed that the sound absorption for normal metal faces and coatings is 0 without any tests.

5 BIBLIOGRAPHY

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