Compressive behavior of vacuum insulation panels according to EN 826

Difficulties with the measurement results for VIP and possible solutions

The study was carried out on behalf of VIPA International, 1140 Brussels

FIW München

Final Report FO-2015/04

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1 Definition of tasks

The Vacuum Insulation Panel Association VIPA authorized FIW München on behalf of it's member companies to carry out a study concerning the compressive behavior of vacuum insulation panels. As a member of VIPA International and CEN TC 88 WG 11 "VIP", FIW was involved in the discussion about the compressive behavior of VIPs and the comparability and reproducibility of the test. FIW has therefore made a proposal to investigate the compressive behavior on specimens of all VIPA members and to derive a possible testing procedure.

From their work on VIPs within the German surveillance system for many years, FIW pointed out that carrying out measurements of compressive behavior arises some concerns on comparability and reproducibility of the test results of VIPs. The test results depend strongly on the software algorithms used by the various manufacturers of the test machines and on personal judgement of the person carrying out the test. The given test procedure in EN 826 has to be interpreted by the testing personnel and is not a proper description for VIPs.

To find a suitable testing procedure and define a proper description is also important for the standardization work for the European VIP product standard currently under development.

1.1 Problem definition

Test results of compressive behavior according to EN 826 of vacuum insulation panels are difficult to evaluate. With the current testing procedure, a comparability among different producers is not ensured.
Even tests with specimens of the same producer show a high diversity concerning the stress-deformation graph and a non-linear behavior. In addition, the test results are strongly depending on the skills and the judgement of the lab personnel carrying out the test. The following list contains the reasons for this irregular and not reproducible compressive behavior

- Design of the flaps
- Number and design of surface seams
- The way the surface seams are folded and attached to the surface
- Warping of the panel
- Thickness of the panel
- Different introduction of the force caused by warping and seam design
- Non-linear compressive behavior of an inhomogeneous product

All these points lead to very different results, mainly at thin panels, which need a professional interpretation of the testing laboratory – and a lot of experience at the lab personnel. Especially the absence, or the very small portion, of a nearly linear range of the stress-deformation graph makes it difficult to define a theoretical “zero-deformation point”. This point is defined as the intersection of the linear extension of the linear part of the stress-deformation graph with the x-axis (deformation). Sometimes this “zero deformation point” is beyond 10 % of deformation, which can be seen in fig. 1. As the determination of the linear part is automatically done by the software of the testing machine, it is not ensured, that consistent algorithms are used to define the linear part. This could lead to variations of the starting point of the deformation and therefore to differing results – even for identical panels if tested on different machines or at different labs.

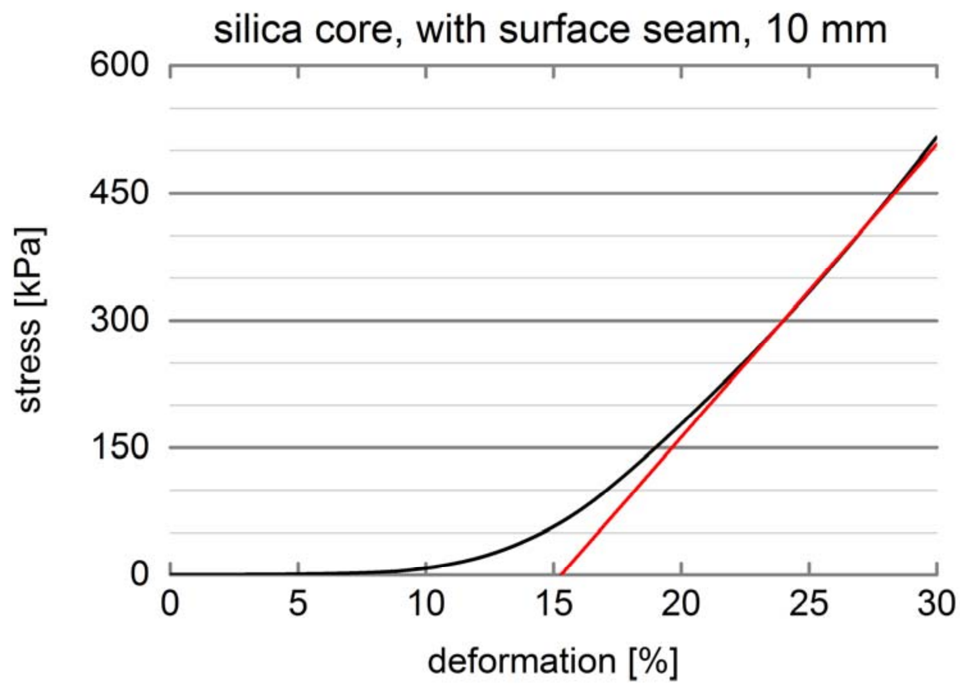

fig. 1: stress-deformation graph of a vacuum insulation panel with a thickness of 10 mm and a theoretical “zero deformation point” of 15 %

The mentioned problems also lead to results with a very wide range of diversity, especially at thin panels. This diversity is not so striking at thicker panels, e.g. 30 mm, but for smaller ones. This effect is illustrated by fig. 2, which show an array of test results for 10 mm and 30 mm vacuum insulation panels with silica core of different producers. These results were achieved within the German surveillance on vacuum insulation panels with silica core.

As no German surveillance with fiber core panels occurred, comparable results relating to silica core panels with surface seam were achieved with panels without surface seam within this study, see fig. 3.

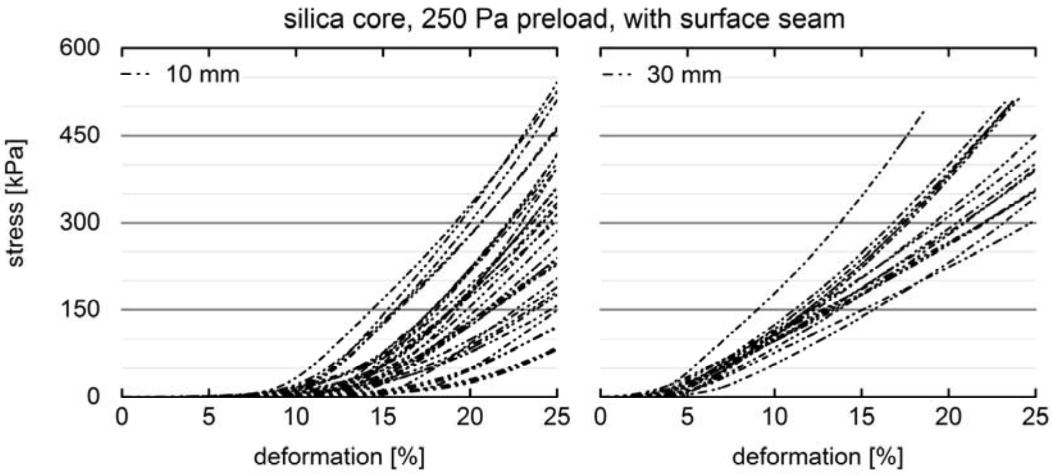

fig. 2 Compressive behavior of vacuum insulation panels with a thickness of 10 mm and 30 mm, silica core. Overview of panels with surface seam, different producers. Results made within the German surveillance 2013-2016. Graphs with a very long initial range and no linear behavior.

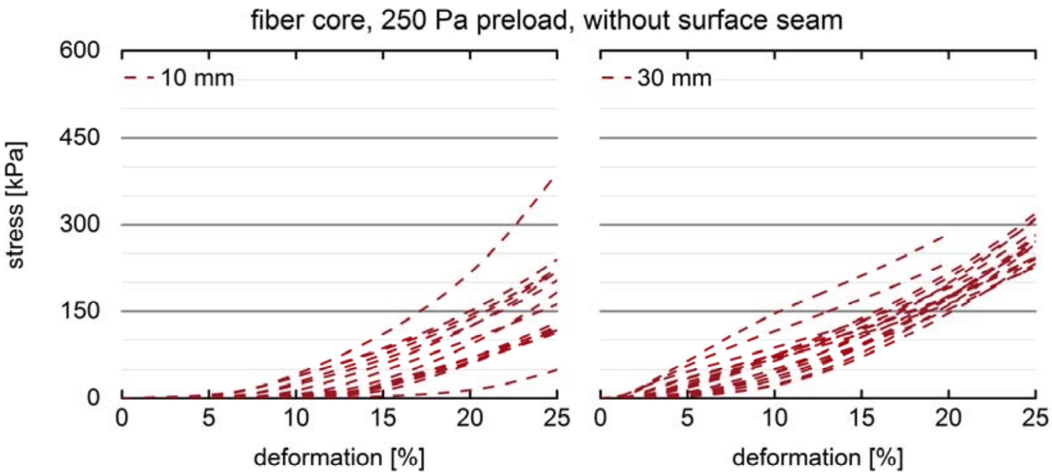

fig. 3 Compressive behavior of vacuum insulation panels with a thickness of 10 mm and 30 mm, fiber core. Overview of panels without surface seam, different producers. Graphs with a long initial range and different nonlinear behavior.

Another way to demonstrate the wide distribution of the results can be seen in fig. 4. All results are calculated with a zero-deformation point corresponding to the deformation at 250 Pa of stress (see chapter 2).

On the left side, the results for every single test on specimens with a thickness of 10 mm are illustrated. The values are very low, even not visible, for both core types and nearly every test yield a different result.

As expected the results for the 30 mm panels are higher. For panels with silica core the value tend to scatter around a value of 100 kPa – with a minimum value of ca. 50 kPa and a maximum value of ca. 180 kPa. Fiber core panels have a mean value about 60 kPa – with a minimum of ca. 20 kPa and a maximum value of ca. 140 kPa. Although the variation of the test results is still large, at least the results are more reasonable and comparable in between different manufacturers.

For all thicknesses and core materials, the aim should be to get lower distribution (smaller bandwidth), better reproducibility and preferably higher values.

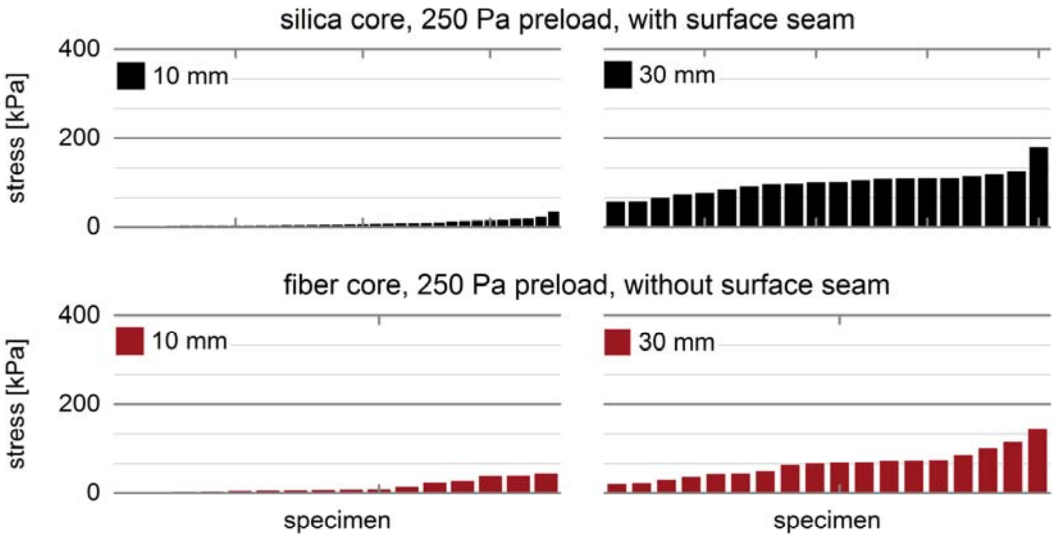

fig. 4 Results of the compressive stress at 10 % relative deformation (zero-deformation point corresponding deformation at 250 Pa, see chapter 2) for each tested specimen with silica and fiber core. The values for the 10 mm panels are very low and vary very much. Values for 30 mm panels are higher and distributed around 100 kPa for silica panels and 60 kPa for fiber panels. Tested specimens from different producers.

1.2 Aim of the study

The aim of this study is to find a testing procedure, which is adjusted to the special requirements caused by the layout of a vacuum panel. The main components that are responsible for the amount of deformation under compressive load on a vacuum panel are the density and the reinforcement (mostly by fibers) of the silica core material, the density and the fiber length of the mineral fiber core material, the compressibility of the fleece used in between foil and core (if there is any), the supporting effect of the foil and it's edge design and the level of the vacuum.

With the standard testing procedure according EN 826 the quality of these components can't be measured. In addition, the uneven surface caused by warping and possible surface seams lead to an even higher deviation of test results, although these layout issues have almost no effect in a real assembly situation. They only lead to variations in the assessment of test results and declared properties.
It's important to make adjustments to the test procedure to be able to show the compressive behavior of the vacuum panel itself, without the layout effects. The new testing procedure or the new way of evaluating the results needs to fulfil the following criteria

- Reproducible test results,
  - o independent of testing apparatus,
  - o independent of the laboratory,
  - o independent of the examiner and
  - o independent of the specimen design
- Comparable measurement results
- Easy feasible testing procedure
- Normative easy implementable

1.3 Approach

The following points give a short overview of the tests done within this study. The scope of the first part is, to examine the influence of the specimen design on the test results. The second part is taking a closer look to the method of testing the specimens. All tests are done on specimens with fiber and silica core.
During the conference call on the 30th of June VIPA members suggested to take a closer look to the relation between compressive behavior and the bulk density of the core material with regard to the indirect measurement method mentioned in the standardization process. This aspect is examined in part three.

Specimen Design

Specimen dimensions

Within this study, specimens of the size of 100 mm x 100 mm, 200 mm x 200 mm and 300 x 300 mm are tested (only panels with silica core). To examine the influence of the dimensions and to find a possible correlation, it is important to look at the results of each producer separately, because the results vary among the producers.

Surface seam

The influence of the surface seam is depending on the layout and the stiffness of the used foil, both having a striking effect on the initial range of the stress-deformation graph.

Testing Procedure and Boundary Conditions

Preload

Changing the initial load can lead to a shortening of the initial range, especially at thin panels. The influence of this measure can be illustrated with an array of stress-deformation curves showing which part of the curves are below a certain preload level.

Testing area smaller than panel size

Testing the compressive behavior on a standard panel with dimensions larger than the testing area has the advantage, that it is not necessary to produce special specimens. Tests are done on specimens with a size of e.g. 500 mm x 500 mm and a testing area of 100 mm x 100 mm. This way of testing can allow more than one compressive stress test on one specimen; the problem with a long initial range could remain.

Suitable coating of specimen

The influence from the warping of the panel and the surface seams could be controlled by a suitable coating, which improves the coupling of the force from the test machine to the surface of the panel and ensures a more even distribution of the load. The initial range of the graph could be shortened, which leads to higher results for the relative deformation at 10 %.

Relation between compressive behavior and bulk density of the core

Finding a relation between the compressive behavior and the bulk density could make indirect assessment in factory production control possible. In order to find such a relation, it is important to look at the results of each producer and each core material separately.

2 Principles

The following chapter gives a short overview about the principles of a compressive behavior measurement. The problem with the evaluation of compressive behavior results at VIPs are clarified by means of a comparison of a stress-deformation graph between EPS and a vacuum insulation panel.

2.1 Definitions

Relative deformation: Ratio of the reduction in thickness of the test specimen compared with its initial thickness

Compressive strength: Ratio of the maximum force to the initial surface area of the test specimen reached when rupture occurs at a relative deformation less than 10 %

Compressive stress at 10 % relative deformation: Ratio of the compressive force to the initial surface area of the test specimen at 10 % relative deformation. This value is used on products when rupture lies beyond 10 % relative deformation.

Compression modulus of elasticity: Compressive stress divided by the corresponding relative deformation below the proportional limit, when relationship is linear.

2.2 Comparison of compressive behavior

To outline the problem of evaluating the compressive behavior of a vacuum insulation panel, a comparison is given between a conventional insulation product (here EPS) and a VIP with silica core.

fig. 5 shows both stress-deformation graphs. On the left side, a clear linear range is given which is necessary to find the zero-deformation point (here named P_{zd}). According to EN 826 this point is given by extending the linear range of the stress-deformation curve until it intersects with the x-axis (deformation). All displacements for calculations of relative deformation are measured from this zero-deformation point. For the calculation of the deformation, the non-linear part of the graph in front of the zero-deformation point is not taken into account. The zero-deformation point of conventional insulation materials is usually found at less than 2 %.

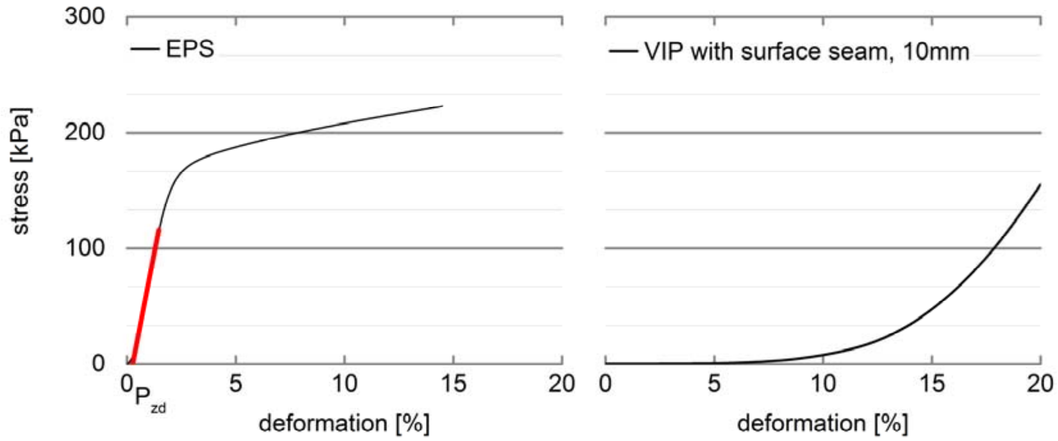

fig. 5 Comparison of the compressive behavior of EPS to a silica core VIP of 10 mm thickness. The linear range of the EPS curve is clearly visible. The zero-deformation point P_{zd} can be determined easily. The stress-deformation curve of the vacuum panel has no linear range and cannot be detected by the measurement device software.

This linear range and therewith the zero-deformation point is normally calculated by a software (depending on the testing apparatus) based on mathematical principles. The stress-deformation graph of the vacuum panel shown on the right side of fig. 5 has no linear range and cannot be found automatically with mathematical principles. Many small parts of the graph seem to be linear and could be used for a definition of a theoretical “zero-deformation point”, but this method is very subjective and depends on the testing expert. Furthermore these nearly linear ranges are very small compared to length of the curve and do not represent an elastic behavior of the insulation material.

2.3 Evaluating compressive behavior of vacuum insulation panels according to EN 826

Vacuum insulation panels do not show an elastic compression behavior. In this case, the testing standard EN 826 defines the zero-deformation point as the deformation corresponding to a stress of 250±10 Pa. This value is the defined preload.

All values for the compressive stress at 10 % deformation that are presented in this study are calculated with a zero-deformation point corresponding to a stress of 250 Pa, except the results presented in section 3.3 Preload.

3 Conduction of the tests

3.1 Specimen dimensions

The following paragraph describes the influence of the specimen dimension on the compressive behavior. The tests are performed without any changes concerning the testing method according EN 826.

Conduction

Specimens with a thickness of 10 mm and 30 mm are tested according EN 826. The dimensions of the specimens were 100 mm x 100 mm, 200 mm x 200 mm and 300 mm x 300 mm for panels with silica core. Fiber core panels were only tested in the dimension of 100 mm x 100 mm and 200 x 200 mm. As 300 mm x 300 mm silica core panels did not lead to very different results, it was decided to put the focus more on the relation between compressive behavior and bulk density. This action was discussed with the VIPA members during the latest conference call and is based on the fact that almost none of the manufacturers are able to measure dimensions of 300 x 300 mm for their FPC.

Concerning the evenness, some specimens had a deviation of maximum 2 mm, which has no impact on a real assembly situation (as they are installed underneath a concrete slab or fixed with anchors to a wall or a roof) but for the measurement in the laboratory - see fig. 6 as an example. According to EN 826 the preload was 250 Pa.

fig. 6 VIP with silica core and without surface seam, size 300 mm x 300 mm x 10 mm, in the testing machine before applying the initial force

Results

<u>Silica core panels</u>

The results are shown in the following figures, separately for the specimens of one producer and for the thicknesses 10 mm and 30 mm without surface seam.

In fig. 7 the graphs for the 10 mm specimens show nearly the same spread for every dimension, except one outlier with the dimension of 200 mm x 200 mm. The highest values at 10 % deformation are achieved with the dimension 100 mm x 100 mm. The 30 mm specimens show a very small spread for the dimension of 100 mm x 100 mm and 200 mm x 200 mm.

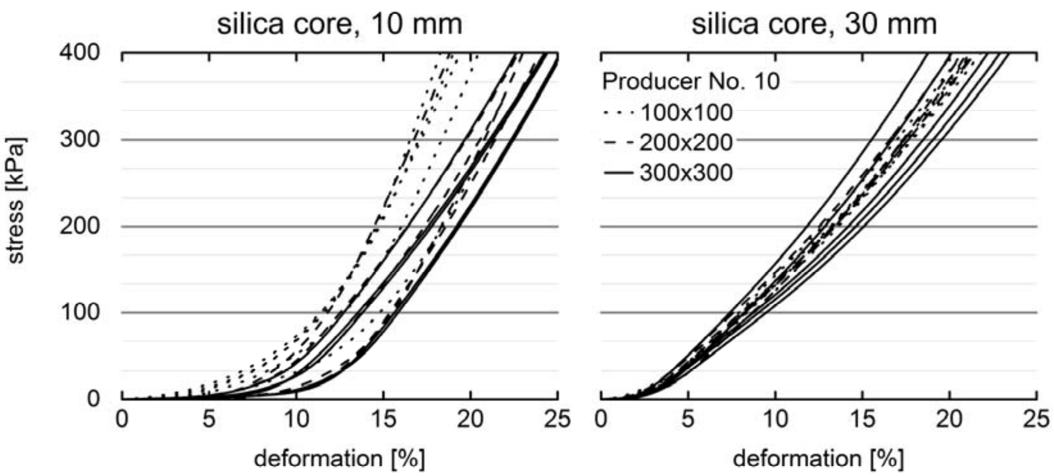

fig. 7 Compressive behavior curves for the thicknesses 10 mm and 30 mm, silica core, without surface seam, producer no. 10. At 10 mm, spread nearly the same for all dimensions, higher results can be achieved with smaller dimension. At 30 mm, spread for smaller dimensions is narrower.

The 10 mm panels in fig. 8 show a smaller spread for 100 mm x 100 mm and 200 mm x 200 mm. The results for these two dimensions are unremarkable and show no particular tendency. The results for the panels with a thickness of 30 mm are closely together. The 100 mm x 100 mm specimens tend to have the highest values at 10 % deformation.

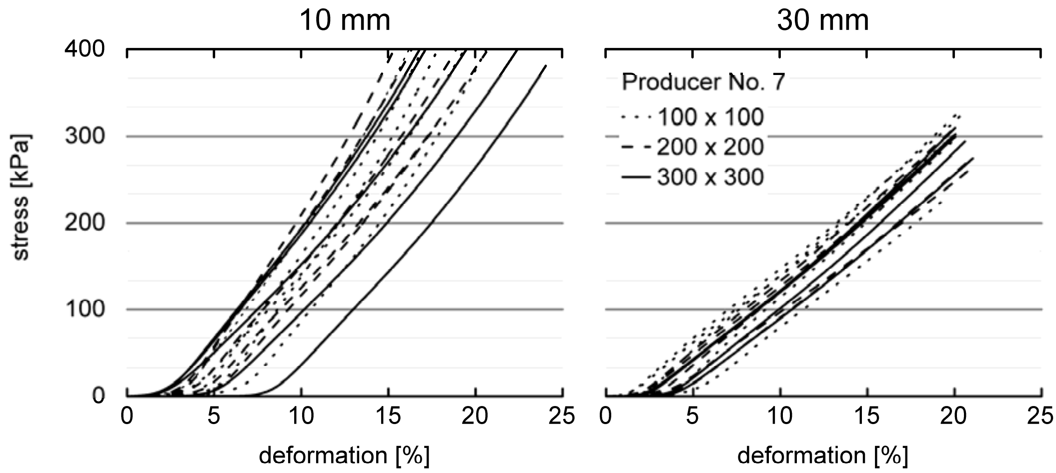

fig. 8 Compressive behavior curves for the thicknesses 10 mm and 30 mm, silica core, without surface seam, producer no. 7. At 10 mm, the spread is smaller for the dimensions 100 mm x 100 mm and 200 mm x 200 mm and higher results can be obtained for these dimensions. At 30 mm, spread is small and equal for all dimensions, higher values can be achieved with 100 mm x 100 mm specimens.

fig. 9 shows for the 10 mm specimens a different distribution of the results. The 100 mm x 100 mm panels have the widest spread, the 200 mm x 200 mm the lowest. The highest results for the compressive stress at 10 % deformation are mainly achieved with the panel dimension of 200 mm x 200 mm. The curves for the 30 mm panels are closely together and show nearly the same behavior like in the figures before. The 100 mm x 100 mm specimens have the smallest spread, the highest result are measured on a 200 mm x 200 mm panel.

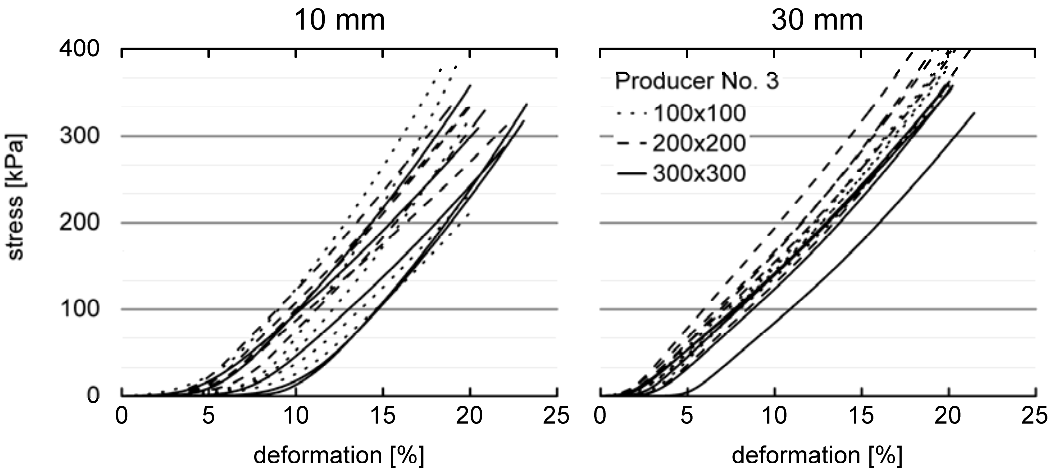

fig. 9 Compressive behavior curves for the thicknesses 10 mm and 30 mm, silica core, without surface seam, producer no. 3. At 10 mm, the spread is smaller for the dimension 200 mm x 200 mm, and highest results can be obtained for this dimension. At 30 mm, spread smaller for the dimension 100 mm x 100 mm, highest results can be obtained from 200 mm x 200 mm specimen.

Fiber core panels

The influence of the specimen dimensions at fiber core panels is shown for two producers in fig. 10.

Without consideration of the best (100 mm x 100 mm) and the worst (200 mm x 200 mm) result, the 10 mm panels of producer No. 1 have nearly the same distribution for both dimensions. The results for the 200 mm x 200 mm panels are slightly higher compared to the others. For producer No.9 the 100 mm x 100 mm panels deliver higher results, but they are really close to the results of the 200 mm x 200 mm specimens. The compressive behavior curves of the 30 mm panels for both producers are quite similar and show a higher value for the dimension 100 mm x 100 mm. 200 mm x 200 mm are close below the smaller panels and show the same spread.

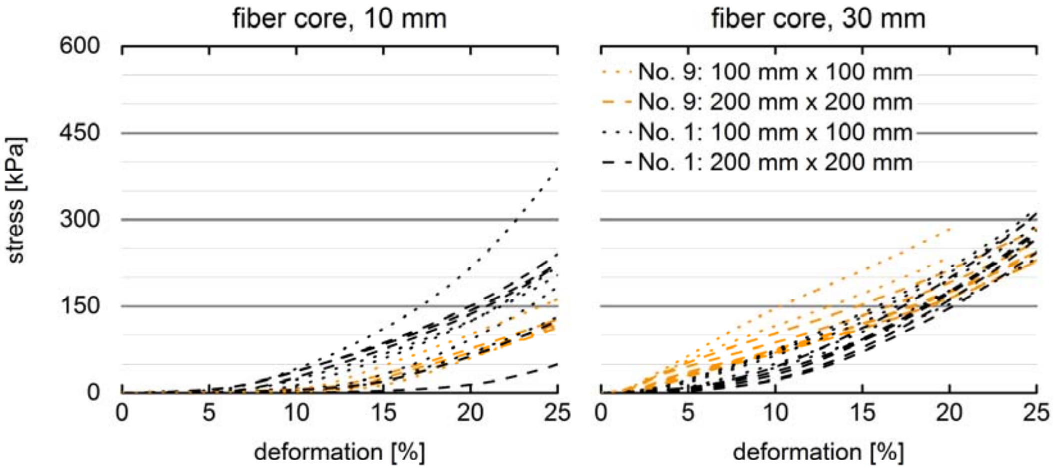

fig. 10 Compressive behavior curves for the thicknesses 10 mm and 30 mm, fiber core, without surface seam, producer no. 1 and no. 9. At 10 mm, the spread is smaller for the dimension 100 mm x 100 mm, and the results are nearly equal with the 200 mm x 200 mm panels. At 30 mm, slightly higher results for the dimension 100 mm x 100 mm with the same spread like 200 mm x 200 mm panels.

Summary

The tests on the panels with a thickness of 30 mm show no specific tendency for silica core panels. Fiber core panels show higher results for the dimension 100 mm x 100 mm, but do not differ very much from the 200 mm x 200 mm panels. The curves are all in a small area considering the product-specific spread and have a similar initial range for each core material, which lead to comparable results concerning the compressive stress at 10 % deformation.

The results for the more critical thickness of 10 mm at silica core panels show, that the spread for the 300 mm x 300 mm specimens is bigger, than for the other thicknesses. Furthermore, the values for the compressive stress at 10 % for both core materials tend to be higher for smaller dimensions, which can be a result of the fact that the warping of the bigger panels is much more pronounced compared to the small panels.

The investigation of the influence of the panel size shows, that there is no measureable correlation between the different dimensions for this test setup.

The dimensions 100 mm x 100 mm and 200 mm x 200 mm provide similar results, and as most of the producers are not able to measure specimens with a size of 300 mm x 300 mm anyway, it can be noted, that tests according to EN 826 can be carried out either on specimen sizes of 100 mm x 100 mm or 200 mm x 200 mm without significant impact on the test results.

As mentioned 300 mm x 300 mm panels are normally too big to measure and, furthermore, lead to a wider spread, no tests are performed with fiber core panels in this dimension.

3.2 Surface seam

The influence of the surface seam is investigated and it's dependence from stiffness of the foil and from the seam layout.
Additionally the influence depends on the number of surface seams, which can vary between one, one of each side or two on one side. The protrusion of the foil at the seam and how it is affixed on the surface has further impact on the initial range of the stress-deformation graph.

Conduction

The tests are performed with a preload of 250 Pa. Similar to the tests before most of the specimens are slightly uneven. The dimensions of the specimens are 100 mm x 100 mm and 200 mm x 200 mm in a thickness of 10 mm and 30 mm.

In the past, many results were achieved for silica core panels with surface seam within the German surveillance. For fiber core panels no such data are available and within this study too less panels are tested to show the influence of the surface seam regarding to panels without surface seam. This chapter presents only results without surface seam for fiber core panels, but it can be assumed that the effect of the seam is comparable to silica core panels.

Results

<u>Silica core panels</u>
For the evaluation of the results, it is reasonable to extend the test results available for assessment by including the results of panels from VIPA members made within the German surveillance during the last years. These results are used anonymously within this study. All specimens tested within the surveillance had a surface seam and mostly had the dimension of 200 mm x 200 mm. The following figures show the comparison of panels with and without a surface seam in a thickness of 10 mm and 30 mm.

The results for the critical 10 mm panels are shown in fig. 11. Except of a few outliers the initial range of the stress-deformation graph is shorter compared to the panels with surface seam, but still long with a deformation between 2.5 % to 10 %. The spread of the curves without surface seam is still wide and the characteristics as well as the gradients are different.

The values at 10 % deformation vary from approximately 20 kPa to 200 kPa. The graphs of the panels without surface seam are similar to the panels with surface seam, shorter initial range but still without a linear range, which makes it not possible to find a compression modulus of elasticity. In this case, according to EN 826 point 8.4, the zero-deformation point is the deformation corresponding to a stress of 250 Pa (see chapter 2).

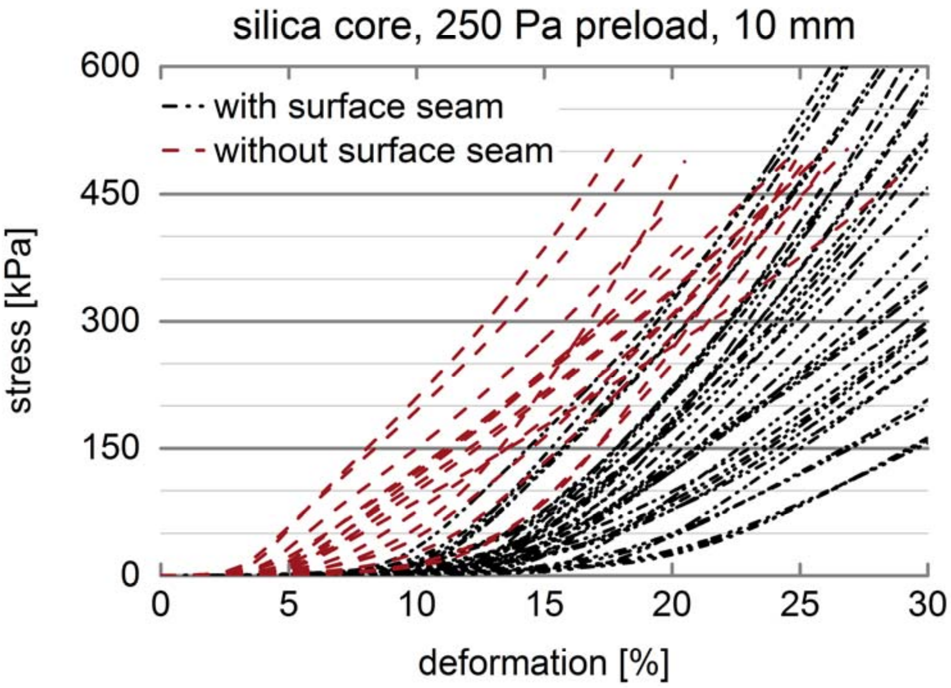

fig. 11 Comparison of the compressive behavior of vacuum insulation panels with a thickness of 10 mm and silica core. Overview of test results for panels with and without surface seam, preload 250 Pa and from different producers.

The curves for the 30 mm panels are illustrated in fig. 12. As expected, the spread of the graphs is not as wide as for the 10 mm panels. The initial range is shorter without surface seam and has a length of 1 % to 4 % of deformation. The curve progression is similar to the graphs with surface seam and the values of compressive stress at 10 % deformation are higher and vary between 80 kPa and 200 kPa.

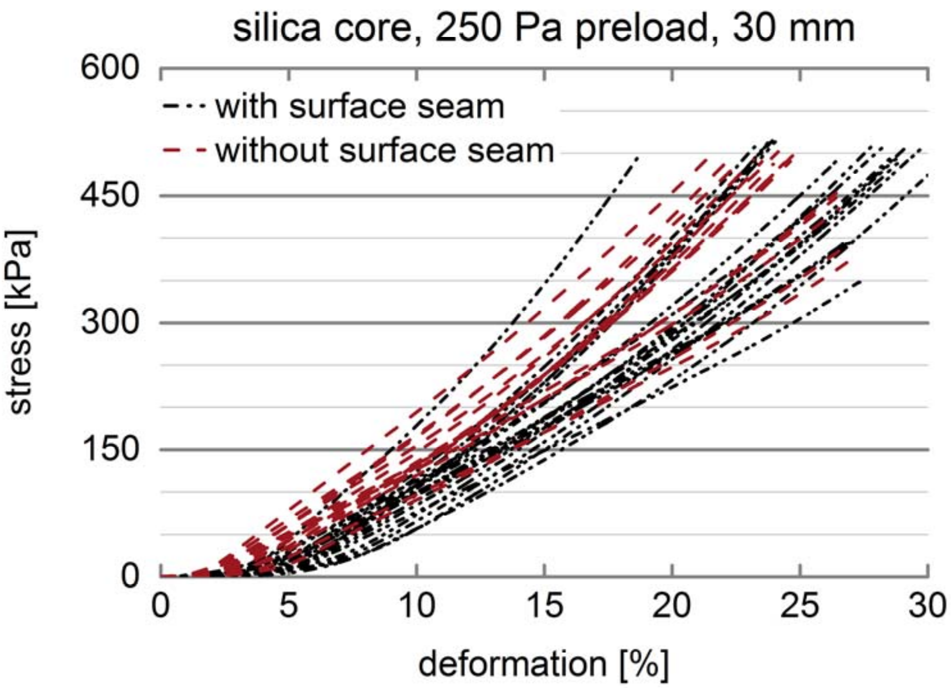

fig. 12 Comparison of the compressive behavior of vacuum insulation panels with a thickness of 30 mm and silica core. Overview of test results for panels with and without surface seam, preload 250 Pa and for different producers.

Fiber core panels

As no data for fiber core panels with surface seam are available, all results measured for 10 mm panels without surface seam and 250 Pa preload within this study are presented in fig. 13. The initial range is more pronounced compared to the silica core panels and has a length of 8 % to 15 %. The progress of the curves is also nonlinear and the compressive values at 10 % deformation are all under 50 kPa for every producer. All in all the results are comparable the silica core panels with a long initial range.

The results for panels with surface seam are expected to be even lower, which could be confirmed by tests.

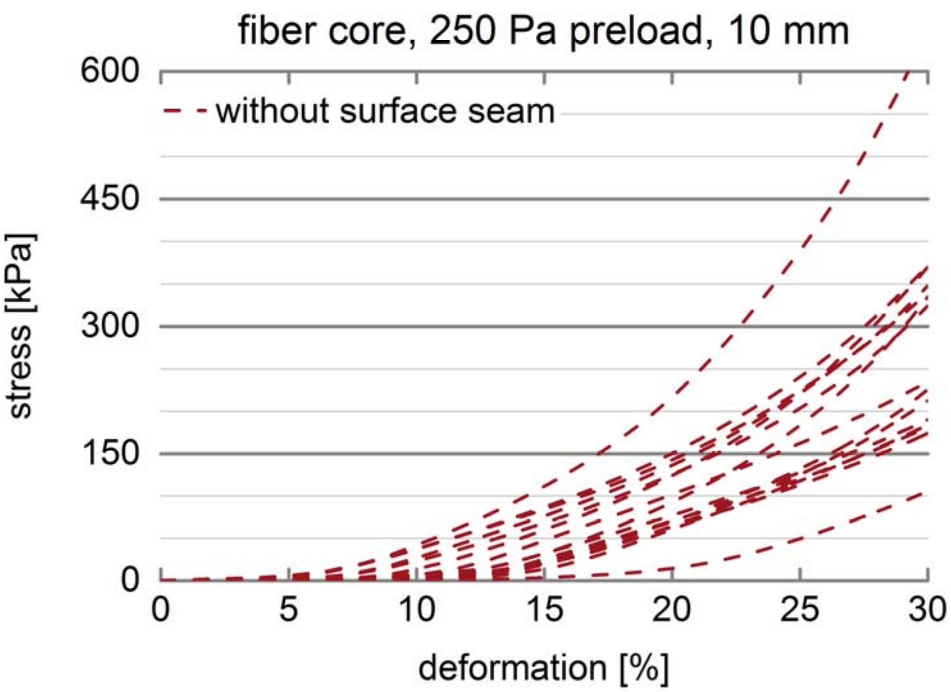

fig. 13 Overview of test results for panels with a thickness of 10 mm and fiber core, without surface seam and from different producers.

Comparable to silica core panels the 30 mm fiber core specimens, fig. 14, achieve higher results of 50 kPa to 150 kPa at 10 % deformation. The initial range is shorter, the slope of the curve quite flat and the spread is, as expected, also narrower in comparison to the 10 mm panels.

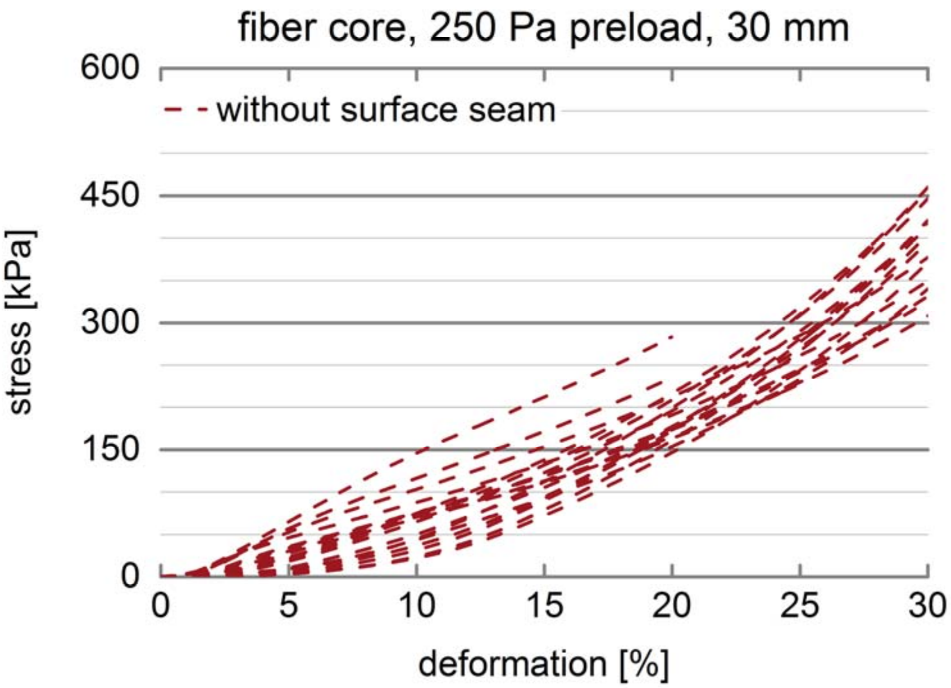

fig. 14 Overview of test results for panels with a thickness of 30 mm and fiber core, without surface seam and for different producers.

Summary

The absence of the surface seam improves the compressive behavior of vacuum insulation panels. The initial range is shortened; especially at thin panels, the difference between specimens without and with surface seam is clearly visible. The values for the compressive strength are also higher. Even if no test results for fiber core panels with surface seam are presented, the authors assume that the compressive behavior is comparable between fiber and silica panels.

The compressive behavior of panels with a thickness of 30 mm improved too, but not as clearly as for the 10 mm panels.

The graphs still do not have a linear range, which makes it impossible to find a compression modulus of elasticity. The graphs still show a very irregular progression depending on the thickness and the producer. The results for compressive strength at 10 % deformation are wide-ranging, especially for the thin panels, and vary between 20 kPa and 200 kPa for silica core panels and 0 kPa to 150 kPa for fiber core panels.

fig. 15 illustrates the increase of the compressive stress values for silica core panels without surface seam compared to the panels with seam. The distribution of the values is still very high with a very high difference between lowest and highest value. It needs to be considered that fig. 15 presents results of different producers.

The results for fiber core panels are illustrated in the same way by fig. 16, only for panels without surface seam (consider the different y-axis scaling compared to fig. 15). Even though no comparison is possible, like for silica core panels, this graph is necessary, to be able to compare this way of testing with the next approach.

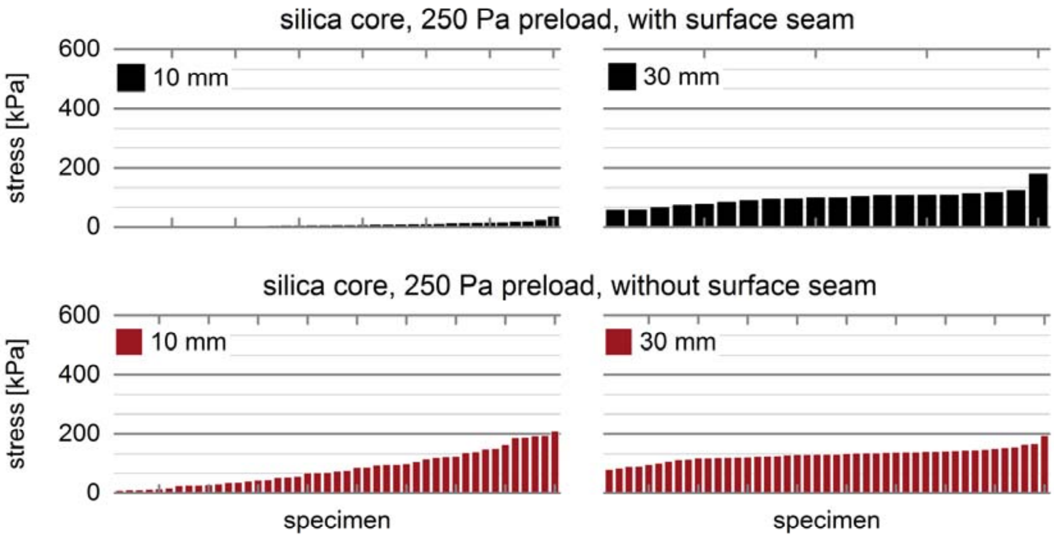

fig. 15 Results of the compressive stress at 10 % relative deformation (zero-deformation point corresponding deformation at 250 Pa, see chapter 2) for each tested specimen. The values in the upper graphics represent panels with surface seam, the lower graphics panels without surface seam. The values increase for both thicknesses without surface seam (shorter initial range). The distribution of the values of the 30 mm panels is narrower. At 10 mm, the wide distribution concerning the values remains and test results are much higher. Tested specimens are from different producers with silica core.

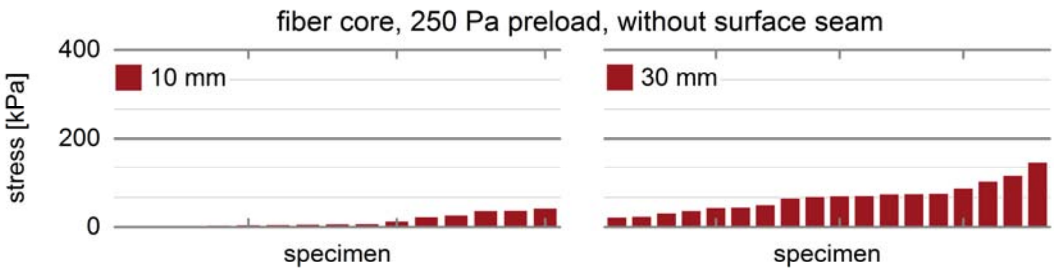

fig. 16 Results of the compressive stress at 10 % relative deformation (zero-deformation point corresponding deformation at 250 Pa, see chapter 2) for each tested specimen. The values in the graphic represent panels without surface seam. Compared to silica core panels the values are lower while the compressive behavior is nearly equal. Tested specimens are from different producers with fiber core.

3.3 Preload

Changing the preload can be an opportunity to equalize the influence of the warping and of the surface seam, which means a shorter initial range in the graph and a higher result for the compressive stress at 10 % deformation.

Conduction

No special tests with additional preloads are performed. All results are calculated from the data created within the tests of vacuum panels without a surface seam.

An appropriate value for the higher preload is considered based on a real assembly situation with a high demand on the compressive behavior under floating floor. The density of screed was assumed with 2100 kg/m³ and a floating floor thickness of 4-5 cm.
These estimations lead to a load of approximately 100 kg/m², which leads to a stress of 1 kPa.

An even higher preload would exclude many applications in the flooring sector, thus the initial range would be reduced further.

Results

Silica core panels

fig. 17 presents the results for the 10 mm panels with a preload of 1 kPa. The initial range is significantly shorter. The characteristic of the further curve progression is the same, which means still a wide range of results. The shorter initial range leads to higher values at 10 % relative deformation starting from a zero-deformation point of 1 kPa, which can be seen in fig. 21**Fehler! Verweisquelle konnte nicht gefunden werden.**.

Values increase for the 30 mm panels, but the change of the preload has not a striking effect on the 10 mm panels, see fig. 18.

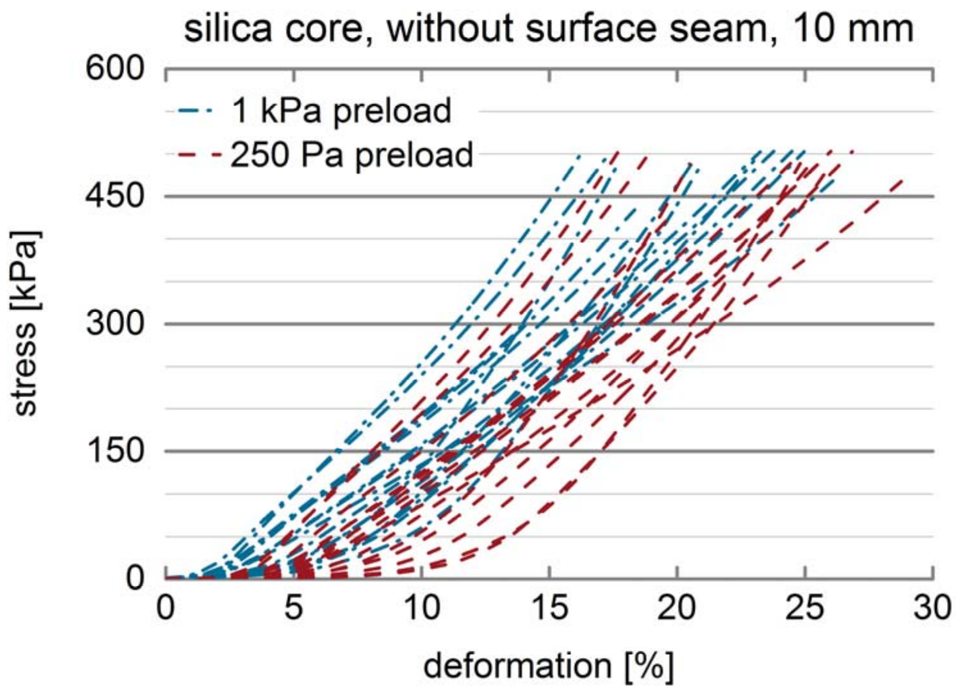

fig. 17 Deformation curves of 10 mm vacuum panels with different preloads. A preload of 1 kPa reduces significant the initial range, characteristics of the curves remain. Panels from different producers, silica core, without surface seam.

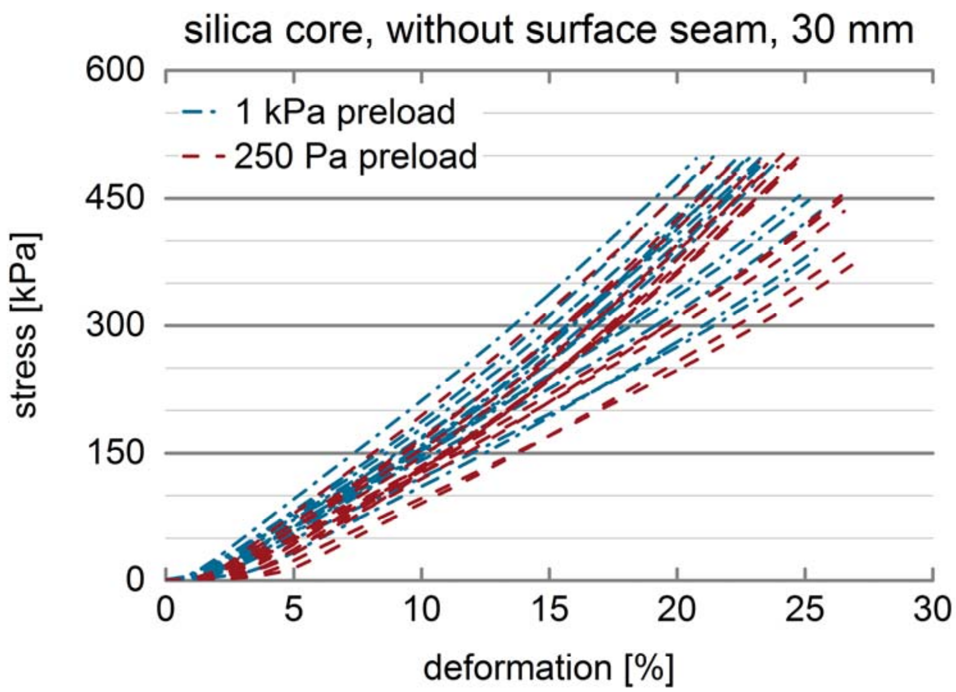

fig. 18 Deformation curves of 30 mm vacuum panel with different preloads. A preload of 1 kPa reduces initial range, characteristics of the curves remain. The difference to a preload of 250 Pa is not very striking. Panels from different producers, silica core, without surface seam.

Fiber core panels

fig. 19 and fig. 20 present the results for a higher preload applied on fiber core panels. All in all this action leads to the same results, similar to silica core panels. The values at 10 % deformation for the 10 mm panels improve a little bit while for 30 mm panels a preload of 1 kPa has nearly no effect.

The distribution and the progression of the curves are still the same.

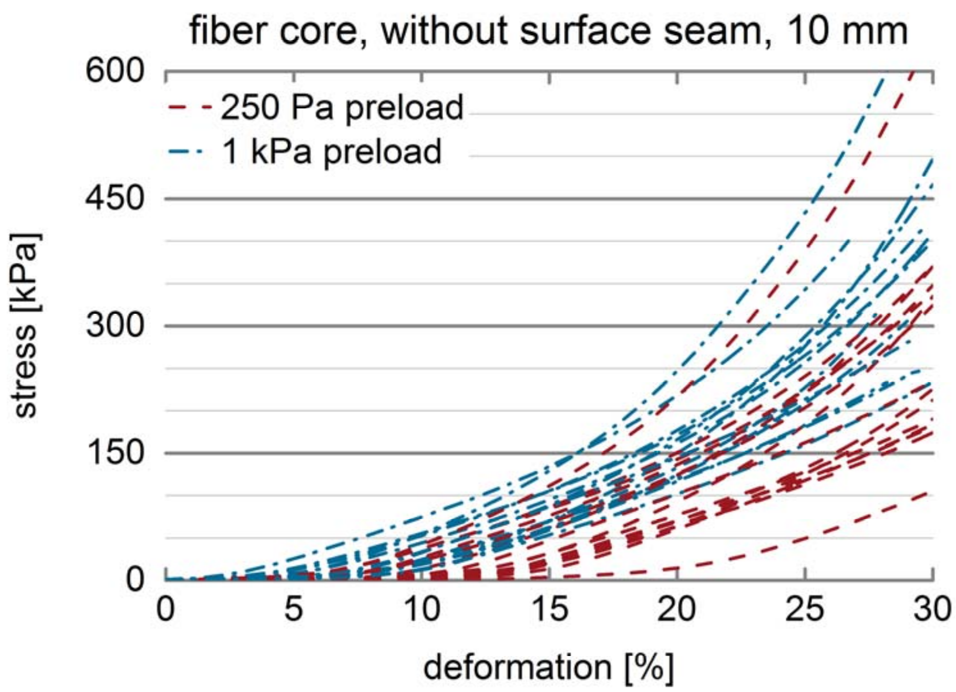

fig. 19 Deformation curves of 10 mm vacuum panels with different preloads. A preload of 1 kPa reduces the initial range slightly, characteristics of the curves remain, values still low. Panels from different producers, fiber core, without surface seam.

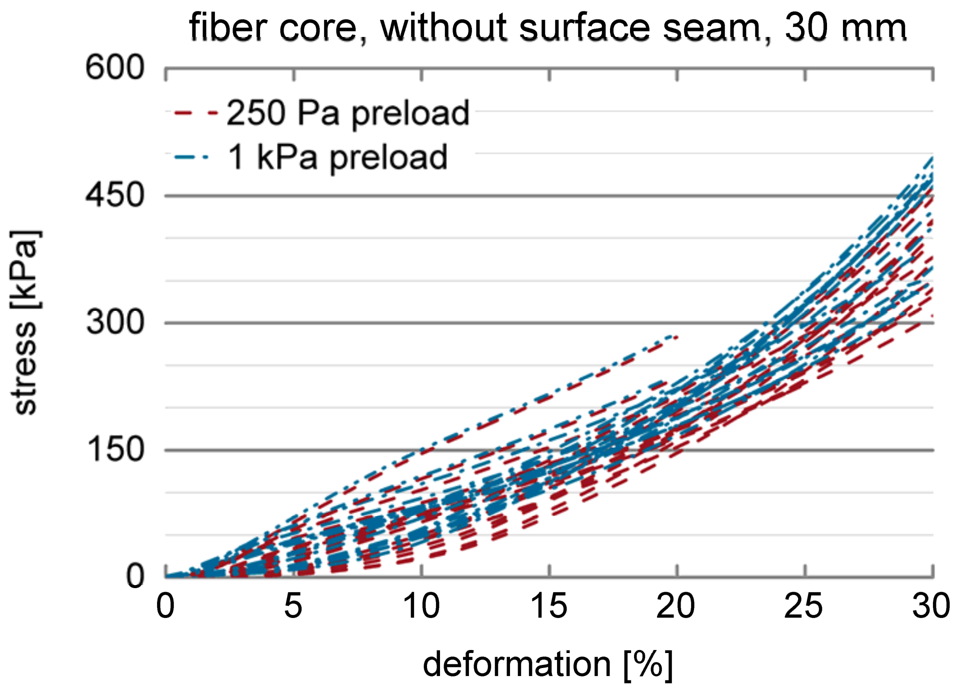

fig. 20 Deformation curves of 30 mm vacuum panel with different preloads. A preload of 1 kPa has nearly no influence compared to 250 Pa. Initial range and characteristics of the curves remain. Panels from different producers, fiber core, without surface seam.

Summary

By changing the preload, an increase of the compressive stress values at 10 % deformation of about 50 kPa is possible for 10 mm silica core panels, see fig. 21. 20 kPa can be achieved for fiber core panels with the same thickness, see fig. 22 (consider the different y-axis scaling compared to figure 21). Especially specimens with a very low compressive stress value benefit from this action.

The distribution of the curves for the thin panels remains the same for both core materials, which also means no comparability among the producers.

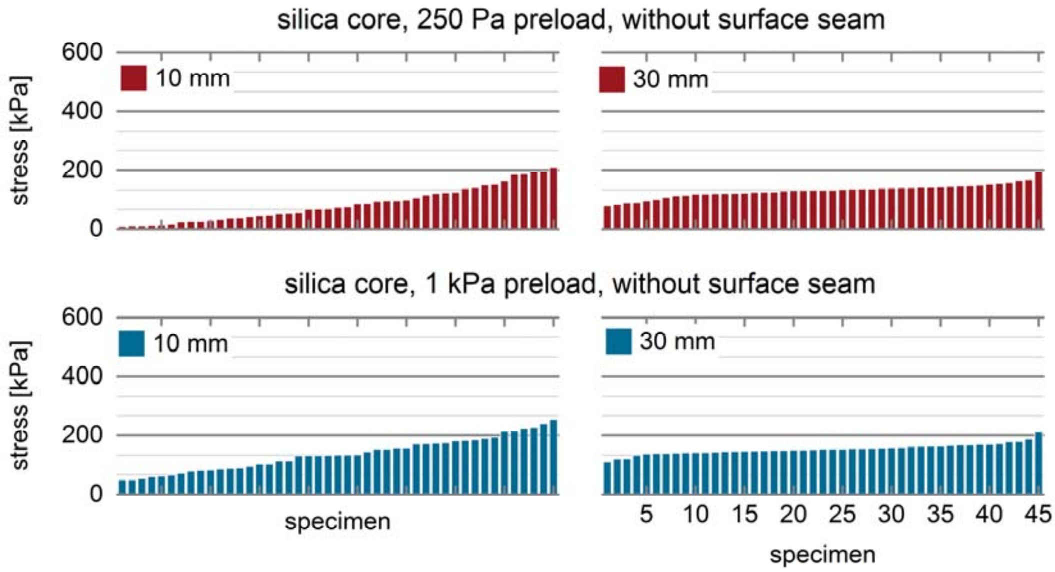

fig. 21 Results of the compressive stress at 10 % relative deformation (zero-deformation point corresponding deformation at 250 Pa / 1 kPa, see chapter 2) for each tested specimen. The higher preload reduces the initial range and increases especially the lower values for both thicknesses. The distribution of the values stays nearly the same. Tested specimens are from different producers with silica core.

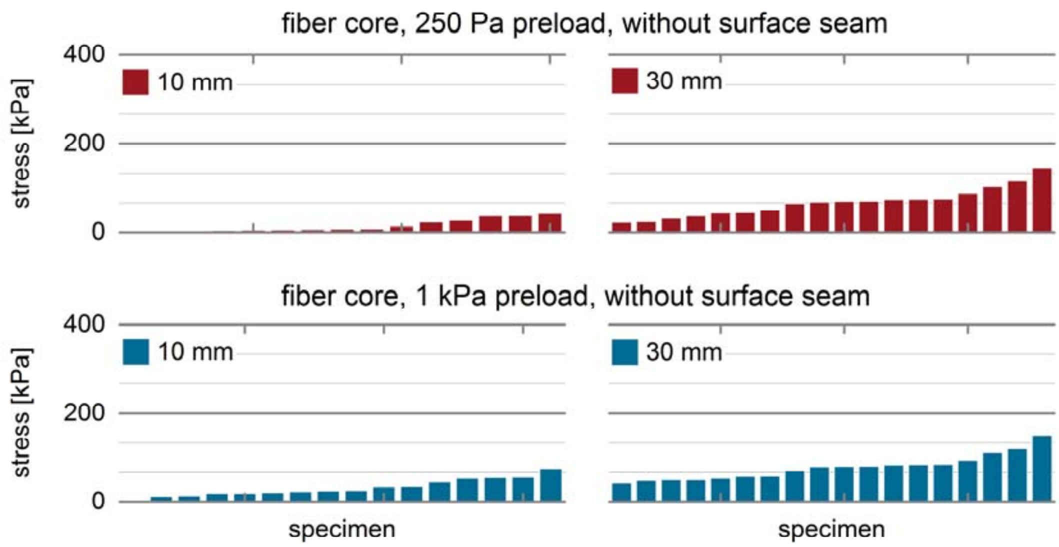

fig. 22 Results of the compressive stress at 10 % relative deformation (zero-deformation point corresponding deformation at 250 Pa / 1 kPa, see chapter 2) for each tested specimen. Overall, the higher preload has no very striking effect; the low values are still very low. The distribution of the values stays nearly the same, comparable to silica core panels. Tested specimens are from different producers with fiber core.

3.4 Testing area smaller than specimens sizes

Testing a small area of a panel with a normal size could be a great advantage for the compressive behavior measurements within the factory production control, because no additional specimens need to be produced and more tests can be done on a specific panel.

It turned out that the test results are similar to the test results of the small specimens with or without surface seam. Furthermore, it is very difficult to define a position on the panel, which would lead to a reproducible result. Besides, the result would be at low level as well and the compressive behavior would not be independent of the panel layout. As every producer has another layout, it is nearly impossible to define certain boundary conditions that lead to comparable results. Besides, the width in between the studs of the testing machines used in FPC need to be big enough to insert a panel with a width larger than the one of the usual specimen sizes.

These difficulties were presented to the VIPA members during the last conference call, and it was decided to put the focus on the relation between compressive strength and bulk density. Therefore only a brief overview of the results on larger panels is summed up. All results are for panels with fumed silica core only.

Conduction

As it has a big influence where the testing area is located on the panel, a few positions were defined, see fig. 23, to investigate the impact of the following criteria.

- Distance to the seams
- The density distribution in the panel
- Number of fleece layers under the foil (silica core panels)
- Distance in between metering areas
- Distance to the edge

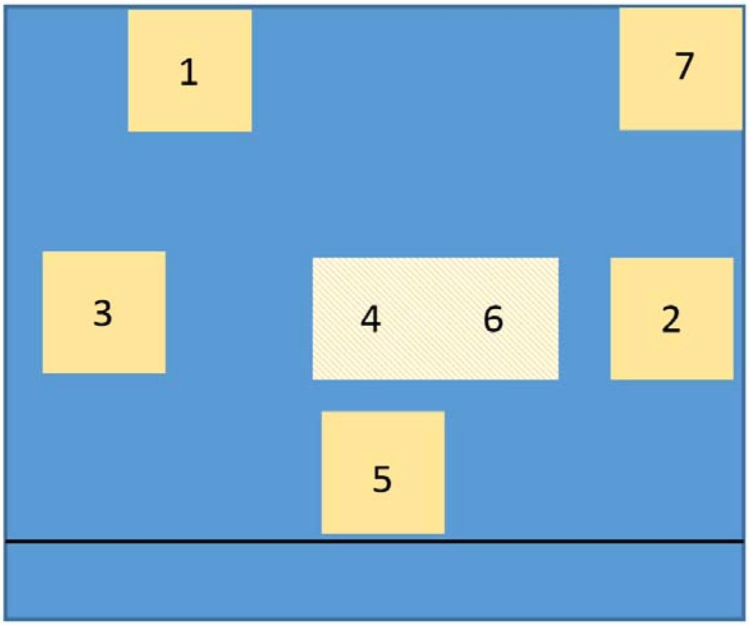

fig. 23 Necessary testing areas, to investigate the influence of the position. Black line symbolizes surface seam, panel dimension 500 mm x 600 mm.

The dimension of the testing area is 100 mm x 100 mm, panel dimension is 500 mm x 600 mm. The dashed testing areas in **Fehler! Verweisquelle konnte nicht gefunden werden.** were examined on another panel, to avoid influence of the testing areas too close to each other.

Results

The test results show the same compressive behavior like tests on specimens without surface seam. Thin panels show an initial range of 5 % to 15 % depending on the position of the testing area, see fig. 24 (positions described in fig. 23). Thicker panels, as expected, have a shorter initial range and the results are nearly not depending on the testing area.
Overall, this way of testing is not leading to an improvement of compressive behavior. The progress of the curves is still nonlinear and the values at 10 % deformation are quite low, especially for thin panels.

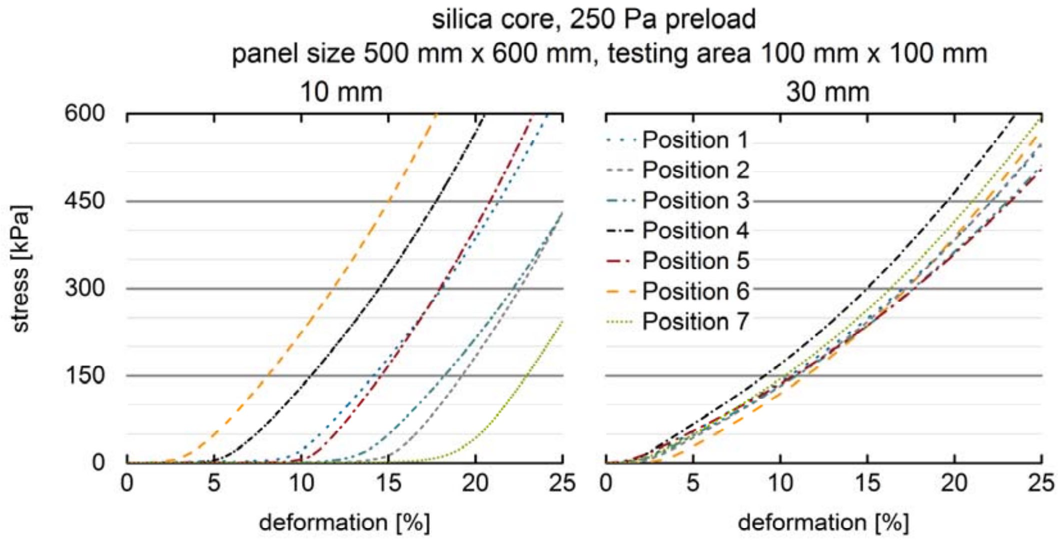

fig. 24 Compressive behavior depending on the position of the testing area on a regular sized silica core panel. The initial range varies very much with the position of the testing area. Tests on a 30 mm panel do not show such a dependency.

Summary

This way of testing does not lead to an improvement of the measurement. Test results are similar to the results presented the chapters before. Additionally, the influence of the individual layout issues regarding to the position of the testing can be very striking, especially at thin panels. As the panel layouts vary very much depending on the producer, it is not possible to define a testing area position that will lead to comparable und reproducible results among the different producers.

3.5 Suitable coating of specimens

To guarantee a plane surface the testing standard EN 826 recommends a suitable coating. The coating should fulfil the following criteria

- Workability (expenditure of time, harmless, waste)
- Availability
- Low price
- Low viscosity (to eliminate slightest unevenness)
- Incompressible (otherwise superimposition with the stress-compressive curve of the panel)
- Already mentioned in a harmonized standard

The decision was made to use gypsum as a suitable coating. Gypsum fulfils all mentioned criteria and is already mentioned in the testing standard EN 826 for another harmonized insulation product.

Conduction

The specimens are coated with a gypsum layer of approximately 3-5 mm. To achieve the testing setup shown in fig. 25**Fehler! Verweisquelle konnte nicht gefunden werden.**, the following steps, illustrated in fig. 26, need to be done.

Before starting the coating procedure, the dimensions of each panel have to be determined. The initial value of thickness is needed for the testing apparatus to define the relative deformation at 10 %. No further measurement is conducted after the application of the gypsum layers as it is not possible to guarantee a 100 % parallel setup of panel and metal plates.

fig. 25 Specimen preparation of a vacuum insulation panel, 30 mm, silica core. Specimen with gypsum coating on both sides

<u>Step 1:</u>
Gypsum (stucco plaster) should be mixed with less liquid as indicated to be able to apply a gypsum layer of approximately 1 cm, especially at the edge of the metal plate. If there is too less gypsum on the edges, it is possible that there is no gypsum between vacuum panel and metal plate, which would reduce the testing area and would lead to a wrong compressive strength result. Furthermore, ensure that there are no air bubbles under the gypsum.

<u>Step 2:</u>
To place the VIP on the gypsum layer, put one edge of the VIP on the gypsum and "roll out" the panel onto the gypsum layer to avoid air pockets between panel and gypsum. Press on the panel with circular movements until the gypsum layer has a thickness of 2-3 mm and the panel is parallel to the metal plate.

<u>Step 3:</u>
Remove the excess gypsum at the edge of the vacuum panel with a blunt object (fig. 26 back of a spoon) to avoid a linkage of gypsum from one surface to the other,

which would lead to an unwanted additional supporting effect concerning the compressive behavior.

<u>Step 4:</u>
Apply gypsum on the other plate as described in step 1.

<u>Step 5:</u>
After 2 minutes of drying the connection of panel and metal plate is sufficiently stable to put it on the other, with gypsum applied, metal plate. Proceed as described in step 2 with pressing on the panel-metal plate with circular movements. The panel should be as parallel as possible to the plate. To allow optimal transmission of forces it is important to have a closer look on the testing apparatus and its self-aligning joint head. Make sure that the plate of the testing apparatus is parallel to the plate of the specimen.

<u>Step 6:</u>
Remove the excess gypsum again and dry the whole specimen setup for approximately 30 minutes. Afterwards the panel can be tested.
The duration for creating this specimen setup is approximately 5 minutes, each.

All tests with gypsum coating where performed with a preload of 250 Pa as described in the compressive behavior standard EN 826.

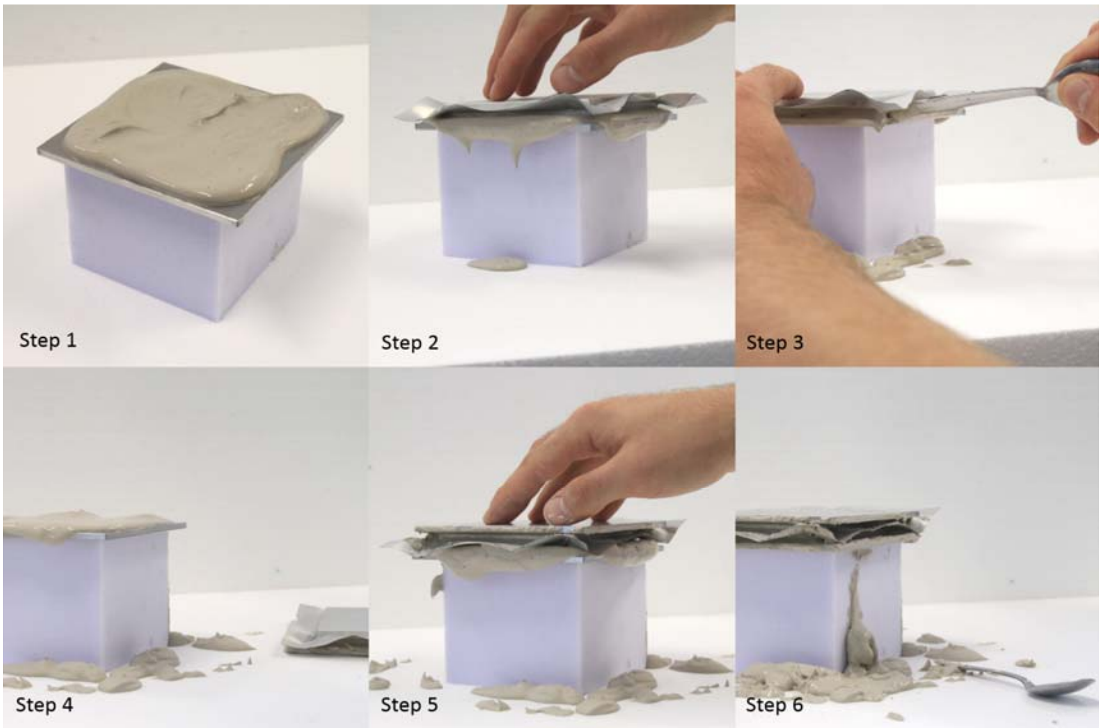

fig. 26 Instruction for coating a vacuum insulation panel with gypsum. Description of the single steps see chapter 3.5 / Conduction

Results

<u>Silica core panels</u>

fig. 27 and fig. 28 present the results for the tested panels with gypsum coating in comparison with panels tested without coating and a preload of 1 kPa.

Especially for the thin panels the effect of the coating is very striking. The initial range is much shorter, which means that the influence of surface seam and warping can be equalized quite well. The results among the different producers are now more comparable and are not affected by individual layout issues, which can be seen by the lower distribution of the graphs. Further tests on 20 mm panels with a surface seam show values for the compressive strength at 10 % in the same range or just a little bit lower as for the panels without surface seems.

For the 30 mm panels the initial range as a percentage value of the initial thickness does nearly not exist with this testing procedure. The spread of the curves is very small.

fig. 31**Fehler! Verweisquelle konnte nicht gefunden werden.** shows a comparison of the 10 % values for both tests and for both thicknesses and illustrates the lower spread of the results and the increase of the 10 % value for the deformation.

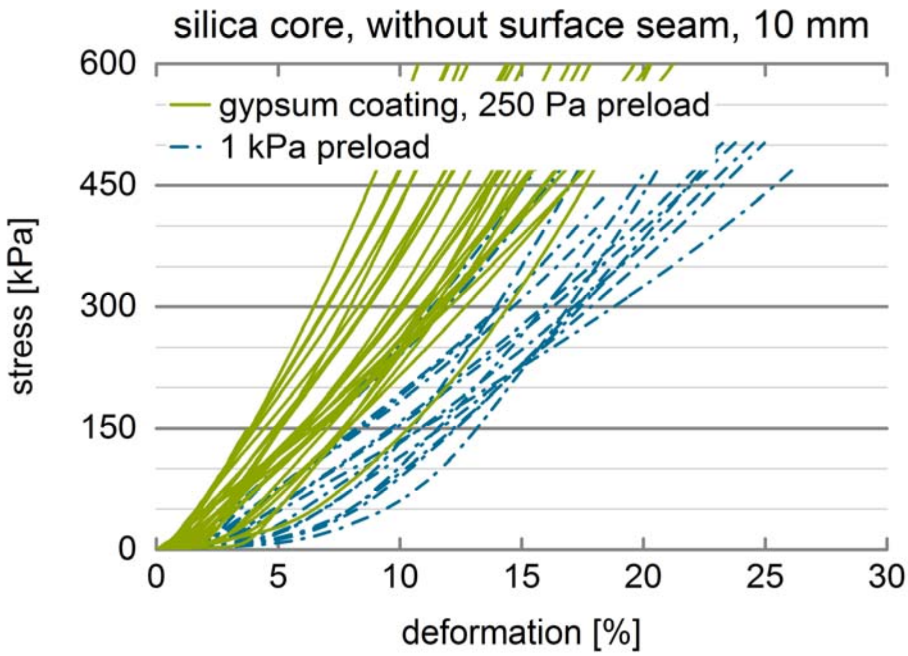

fig. 27 Deformation curves of 10 mm vacuum panels with gypsum coating compared to tests without coating and a preload of 1 kPa. The initial range of panels with gypsum coating is much shorter, consequently the values at 10 % deformation are higher. The spread of the curves is narrower compared to the test procedures before, except the curves with the very high results. Panels from different producers, silica core.

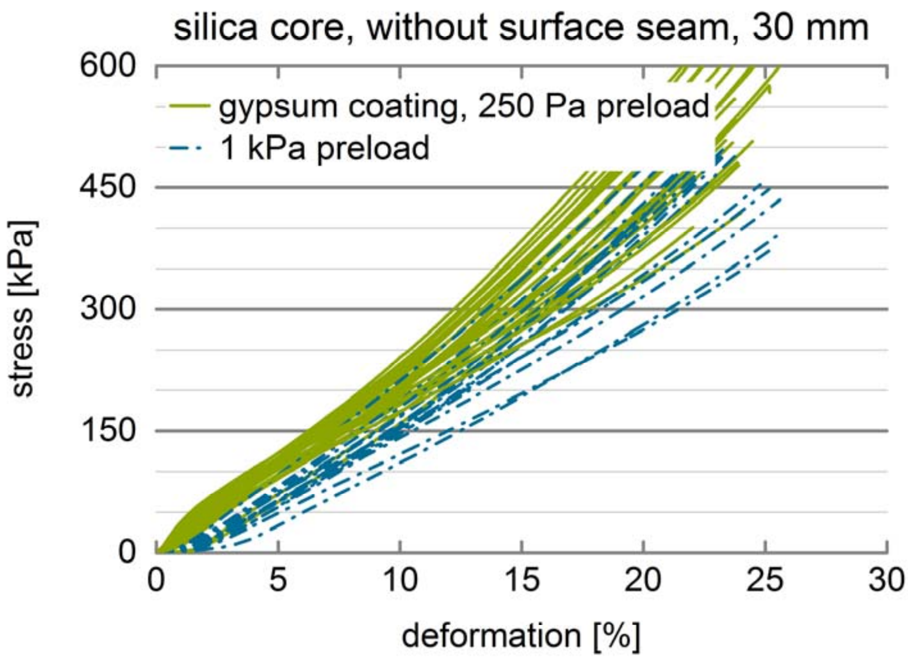

fig. 28 Deformation curves of 30 mm vacuum panels with gypsum coating compared to tests without coating and a preload of 1 kPa. The initial ranges of panels with gypsum coating is shorter, consequently the values at 10 % deformation are higher. The spread of the curves is narrower compared to the test procedures before. The gypsum coating effect at thicker panels is not as striking as for the 10 mm panels. Panels from different producers, silica core.

Fiber core panels

Tests on fiber core panels with gypsum coating lead to similar results compare to silica core panels. For panels with a thickness of 10 mm, see fig. 29, values improve significant for compressive strength at 10 % deformation. Without coating, the results vary between 10 kPa and 70 kPa, with gypsum coating between 90 kPa to 220 kPa. The distribution of the compressive strength values at 10 % deformation increases a little bit, because of higher results of one producer.
fig. 30 shows the test results for 30 mm panels. With that testing method and at this thickness the curves can clearly be separated according to the different producers. The spread of the curves for each producer is narrower than before and the values for compressive stress higher. As expected, the values increase not so much and the absolute values are not as high as at 10 mm panels.

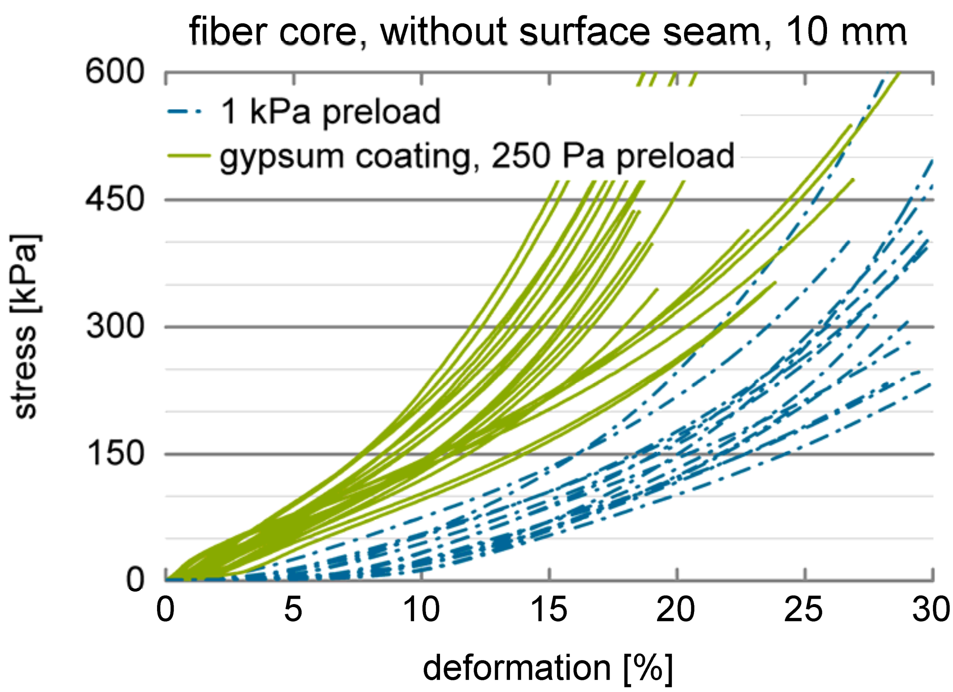

fig. 29 Deformation curves of 10 mm fiber core vacuum panels with gypsum coating compared to tests without coating and a preload of 1 kPa. The initial range with gypsum coating is much shorter, compressive values at 10 % deformation are higher. The spread of the curves is similar to the testing procedure before. Panels from different producers.

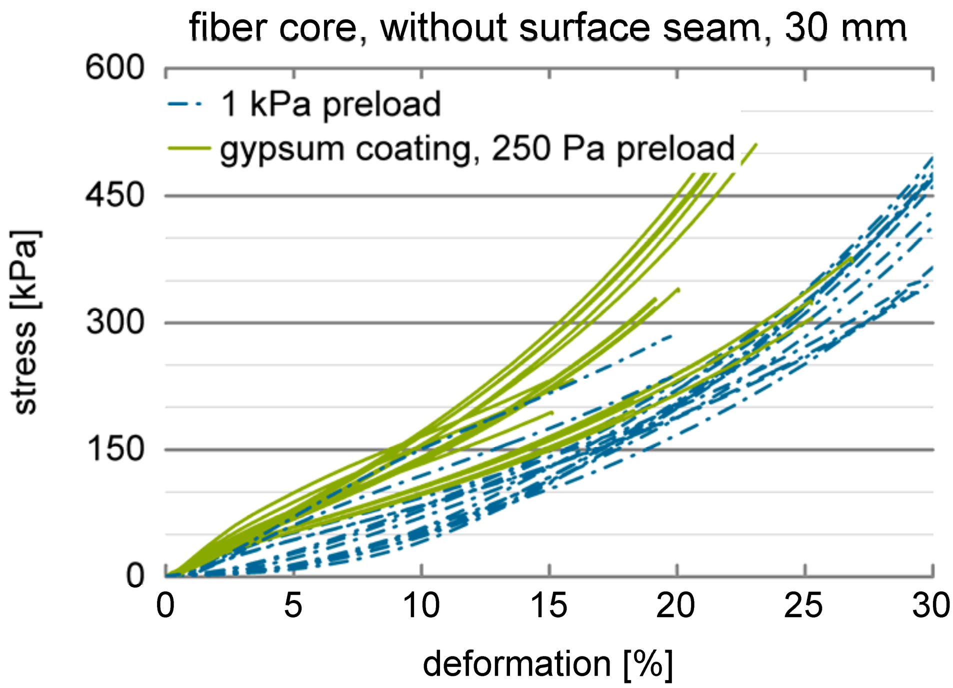

fig. 30 Deformation curves of 30 mm fiber core vacuum panels with gypsum coating compared to tests without coating and a preload of 1 kPa. The initial ranges of panels with gypsum coating is shorter, consequently the values at 10 % deformation are higher. The spread of the curves is narrower for each producer compared to the test procedures before. The spread of the curves in total is the same as before. Panels from different producers.

Summary

Testing the specimens with a gypsum coating improves the results concerning the values of the compressive stress at 10 % deformation as well as the distribution of the values (at least for separate producers).
The influence of the individual layout issues like seam and warping are nearly equalized which lead to a very short initial range.

With this test setup, it is possible to analyze the compressive behavior of the panel itself.

Because of this testing method, it can be noted that the results for a specific producer are closer together and more comparable. Furthermore, it is possible to evaluate the difference between different producers.

The values for the compressive stress at 10 % deformation with a zero deformation point at 250 Pa for silica core panels, see fig. 31, improved significantly and now ranges from 200 to 250 kPa for 10 mm panels and around 180 kPa for 30 mm.

For fiber core panels, see fig. 32, it is difficult to make a conclusion over all producers, because the properties of the core material vary a lot. Nevertheless, it can be noted that the compressive behavior improved significantly from ca. 20 kPa for 10 mm panels and ca. 60 kPa for 30 mm panel to approximately 150 kPa for both thicknesses with small deviations depending on the producers.

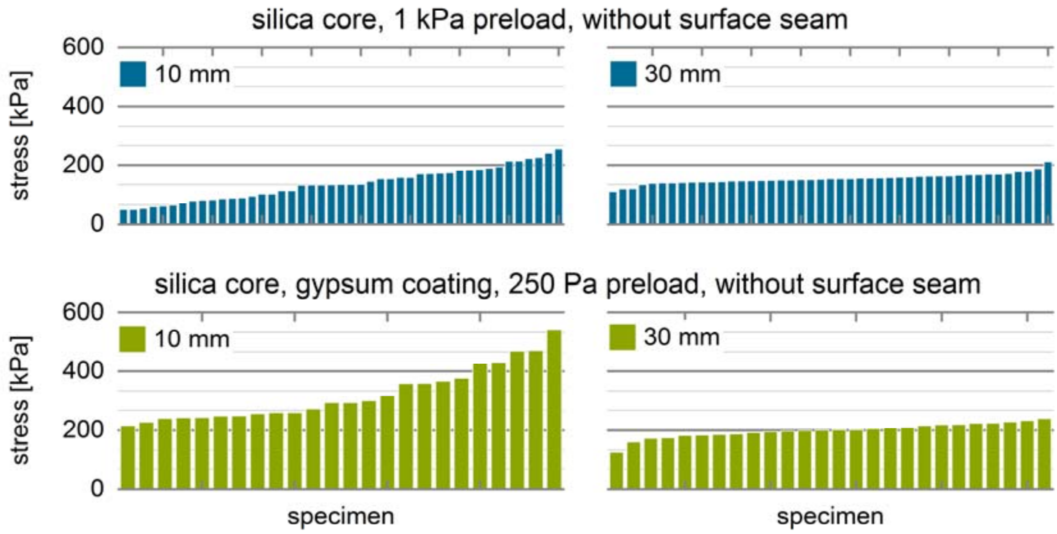

fig. 31 Results of the compressive stress at 10 % relative deformation for each tested specimen. The values in the upper graphics represent panels without surface seam, tested with a preload of 1 kPa. The lower graphics show panels with gypsum coating. The shorter initial range increases the results for the tests with gypsum coating significantly. The distribution of the values for 10 mm is lower compared to the tests before. Especially for the 10 mm, it needs to be considered, that the presented results are from different producers (very high values are from one producer) Tested specimens with silica core.

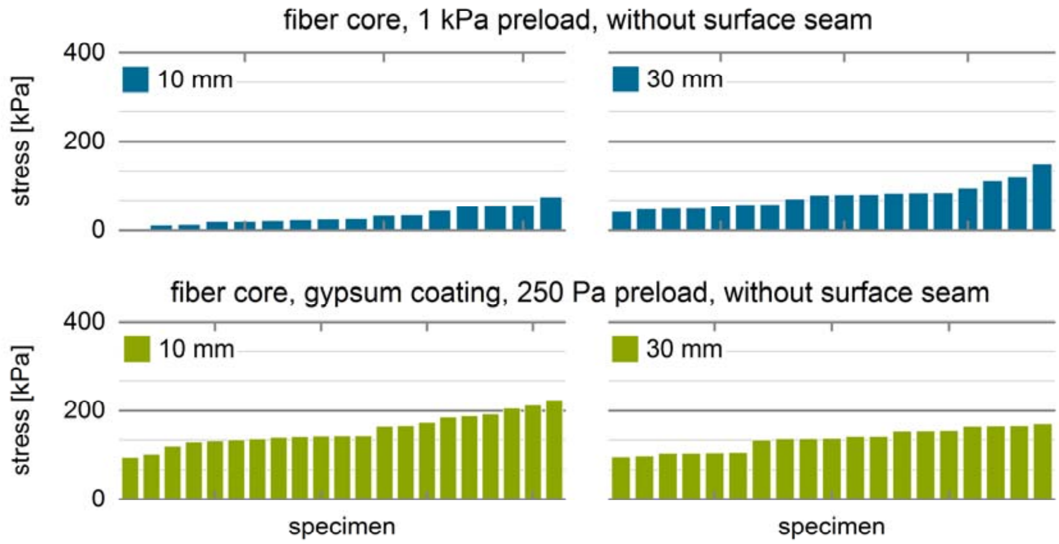

fig. 32 Results of the compressive stress at 10 % relative deformation for each tested specimen, like in fig. 30 (consider different y-axis scaling). The results for the tests with gypsum coating increased significantly. The distribution of the values for 10 mm is nearly same at a higher level. For both thicknesses it needs to be considered, that differing results are mostly from different producers (more significant compared to silica core panels). Tested specimens with fiber core.

3.6 Influence of the bulk density on the compressive behavior

As already mentioned in chapter 1.3 VIPA members suggested to take a closer look to the relation between compressive behavior and the bulk density of the core material. This correlation is considered as an indirect measurement method for the compressive behavior mentioned in the draft standard.
Compressive behavior is influenced by the core material itself as a mixture of numerous components and depends on the percentage of the components and how they are processed. Furthermore, by properties like level of the vacuum, stiffness of the foil and the supporting effect of the fleece, if there is one. As all these properties differ among the manufacturers, the correlation between bulk density and compressive behavior will be done separately for each producer.

Conduction

For the correlation between bulk density and compressive behavior, it is necessary to measure compressive behavior with a gypsum coating, to avoid an affection of the results by layout issues like warping or surface seam.

To determine the bulk density the dimensions of all specimens were measured before testing and with the foil. For every dimension 0.2 mm were subtracted to exclude the thickness of the foil.

After the compressive strength measurement, the foil and the fleece (just silica core panels) were removed and the weight of the core determined. Especially for fiber core panels the volume of the core increases very much. Therefore, the determined density of the core material shown in the following figures could be higher, than the values determined by the producer within the FPC.

Results

Silica core panels

The compressive stress results shown in the following figures are separated for each producer and plotted over bulk density. Every dot is marked with a different shape and color depending on the thickness and the size of the specimen.

fig. 33 shows the results for producer No. 10. For specimens thicknesses of 30 mm and 20 mm a linear dependence of compressive stress and bulk density can be assumed. For 10 mm specimens the results are widely distributed for both properties and a correlation between bulk density and compressive stress does not exist.

As expected and already seen in chapter 3.5, results of compressive stress at 10 % deformation for 10 mm are usually higher than for lower thicknesses at silica core panels. Reasons could be a stronger supporting effect of the foil compared to the higher thicknesses and a higher bulk density.

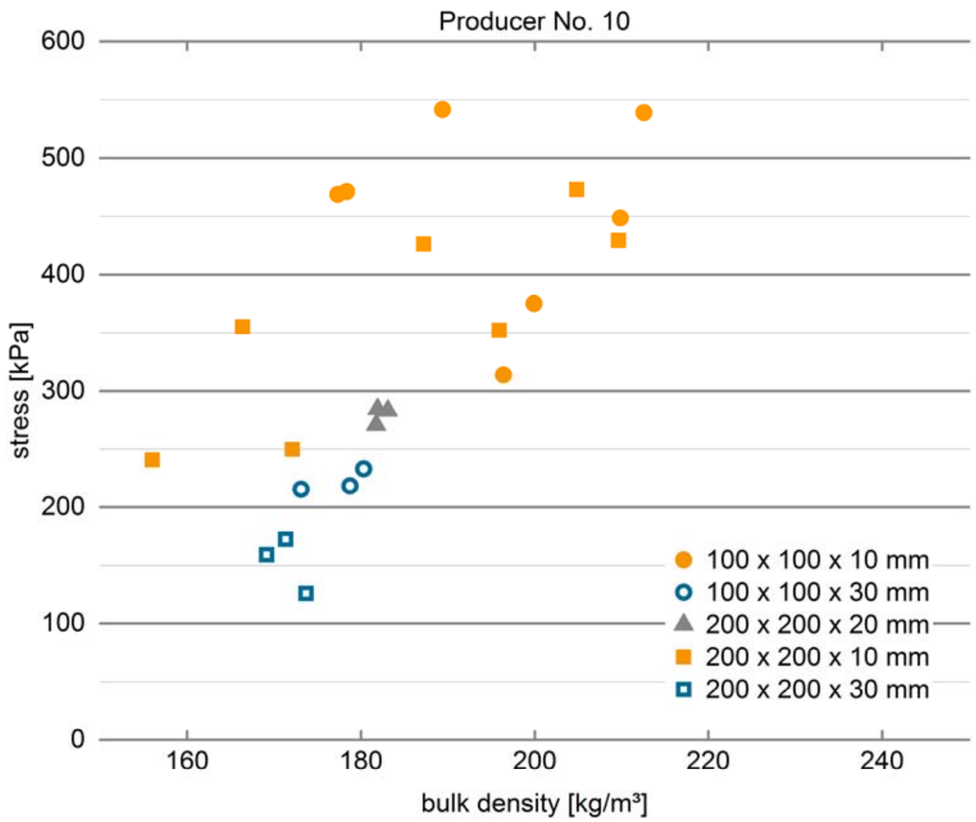

fig. 33 Compressive behavior results versus bulk density for producer No. 10, silica core. Compressive behavior measured with gypsum coating (see chapter 3.5). Compressive behavior nearly linearly dependent on bulk density for thicknesses 30 mm and 20 mm. 10 mm panels vary very much for both properties and achieve higher values. Compressive results for 100 mm x 100 mm specimens tend to be higher.

Results for producer No. 7 are presented in fig. 34. The compressive stress for the thicknesses 30 mm and 20 mm is depending on the bulk density; the gradient of the dependence is completely different compared to producers mentioned before.
The results for 10 mm panels are wider distributed but they seem to have a linear dependence. More results would be necessary to prove this conjecture.
The specimen dimensions have not such a major impact on the compressive stress results, especially at 30 mm specimens, like at the producer before.

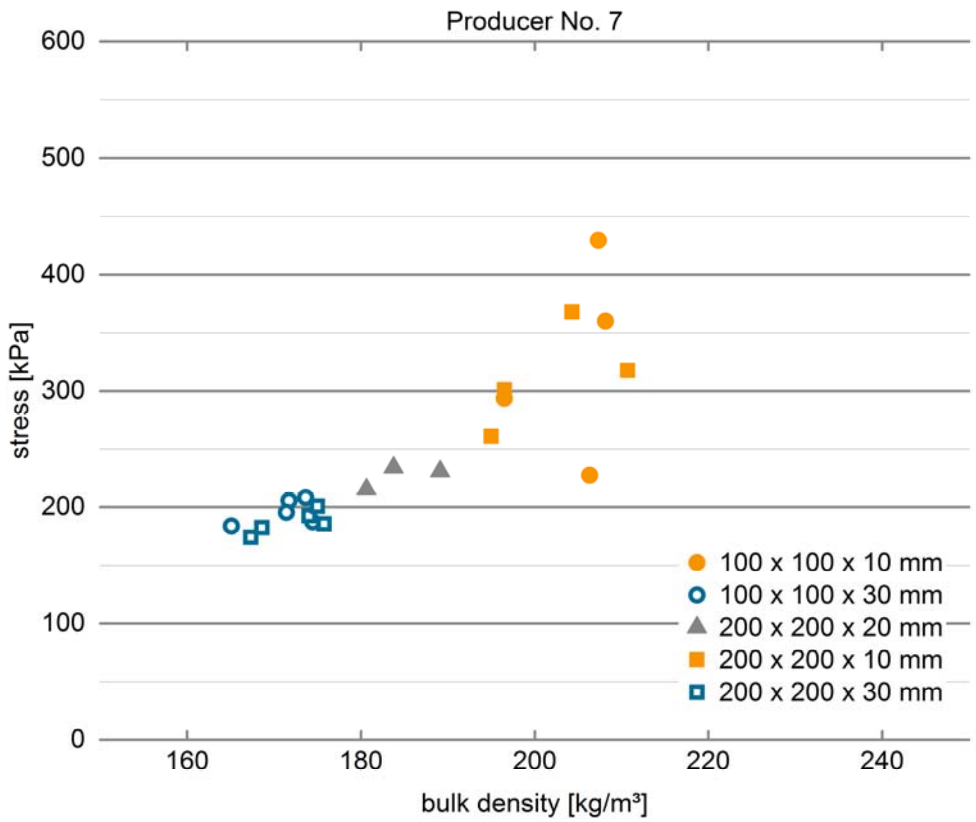

fig. 34 Compressive behavior results versus bulk density for producer No. 7, silica core. Compressive behavior measured with gypsum coating (see chapter 3.5). Compressive behavior nearly linearly dependent on bulk density for thicknesses 30 mm and 20 mm. 10 mm panels vary for both properties, achieve higher values and have a linear dependence with a greater gradient compared to the other thicknesses. Specimen size has nearly no influence on compressive behavior.

Producer No. 3, see fig. 35, has a completely different distribution of the results. Nearly all thicknesses are in the same bulk density range of approximately 160 kg/m³ - 190 kg/m³, except the 20 mm panels. To derive statement about the correlation of compressive strength and bulk density over all thicknesses more results would be necessary. The specimen dimensions have no influence on the compressive strength but the thickness of the panels.

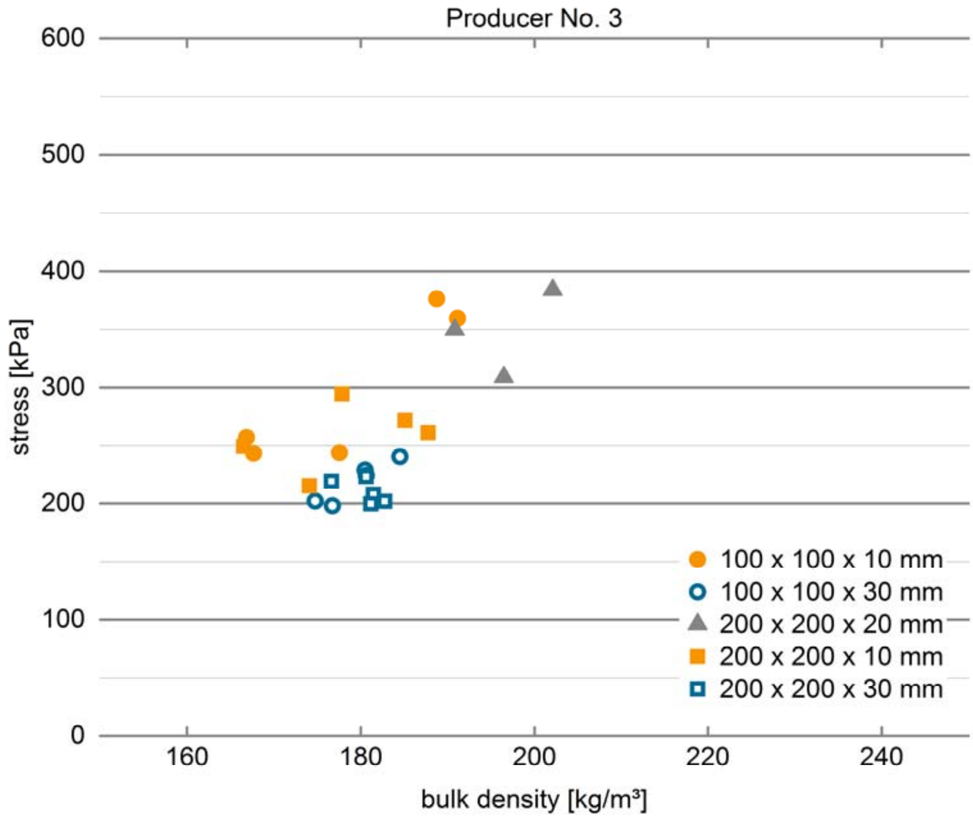

fig. 35 Compressive behavior results versus bulk density for producer No. 3, silica core. Compressive behavior measured with gypsum coating (see chapter 3.5). Compressive behavior nearly the same within a narrow density range of 160 kg/m³-190 kg/m³ for thicknesses 30 mm and 10 mm. The results for 20 mm panels lie outside this density range. Results for 10 mm panels have the greatest variation. Linear dependence can be assumed over all thicknesses. To confirm this linearity more results are necessary. Specimen size has nearly no influence on compressive behavior.

Fiber core panels

The results for fiber core panels are completely different compared to silica core panels. Even the results between the two fiber core producers whose panels were tested within this study are not comparable, because of different fiber core materials.

The material of producer No. 9, see fig. 36, leads to low compressive strength values within a small density range for most of the results. The compressive behavior is not depending on the bulk density even though the highest values were achieved with the highest density. The specimen size and thickness have no influence.

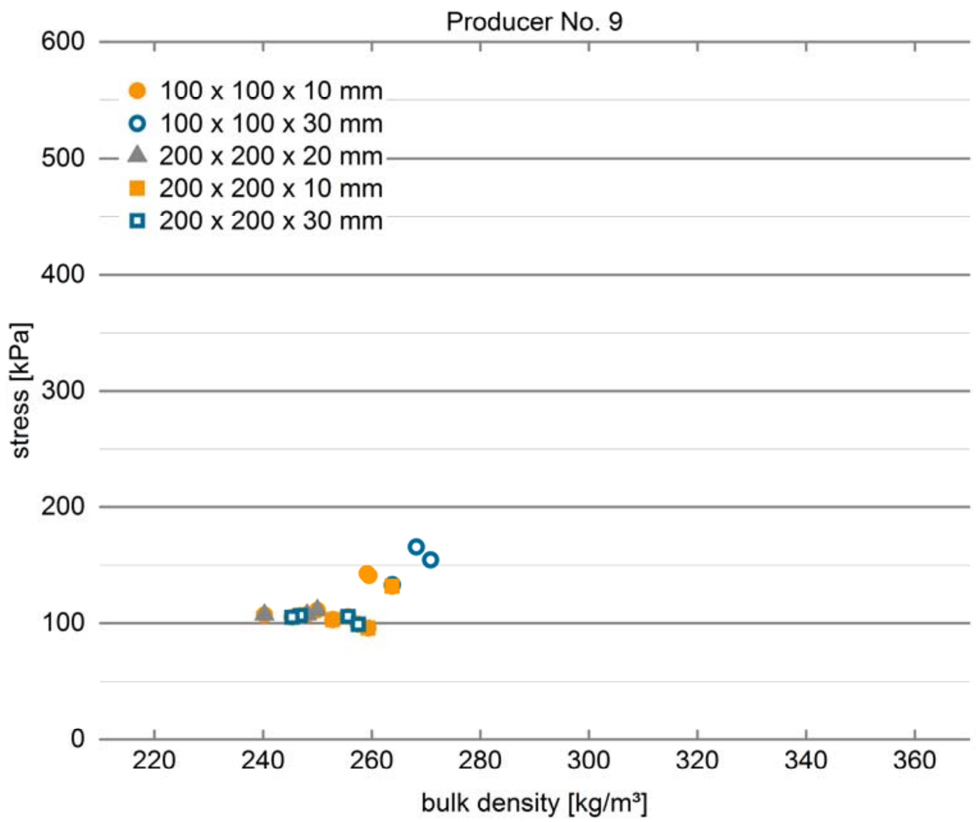

fig. 36 Compressive behavior results versus bulk density for producer No. 9, fiber core. Compressive behavior measured with gypsum coating (see chapter 3.5). Compressive behavior the same for a density range of 240 kg/m³-260 kg/m³ (density is too high; see point Conduction within this chapter). No linear dependence existing for all thicknesses. Specimen size has nearly no influence on compressive behavior.

The panels of producer No. 1, fig. 37, show a completely different compressive strength behavior compared to silica core panels or also producer No. 9. Nearly all specimens have a compressive stress value between 100 kPa and 200 kPa for a density range of 260 kg/m³ to 360 kg/m³. The bulk density seems to depend on the specimen size, especially for 10 mm panels. It is not possible to predict the compressive stress value based on the bulk density.

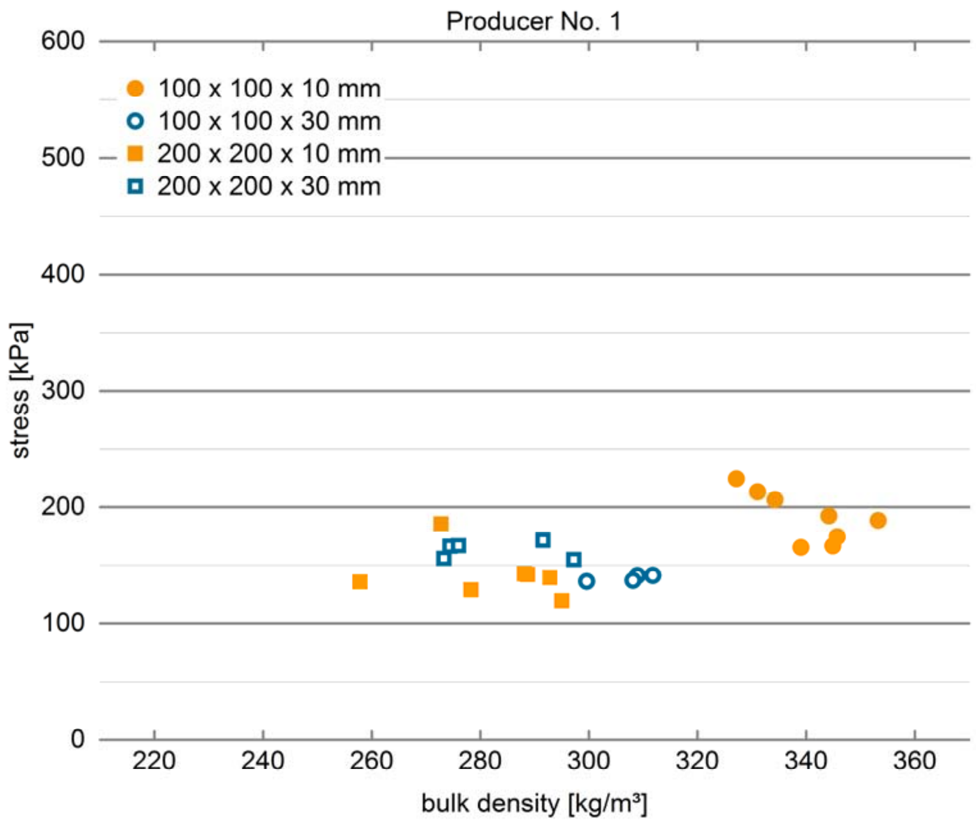

fig. 37 Compressive behavior results versus bulk density for producer No. 1, fiber core. Compressive behavior measured with gypsum coating (see chapter 3.5). Compressive behavior scatter around 150 kPa for a density range of 260 kg/m³-360 kg/m³ (density is too high; see point Conduction within this chapter). Compressive behavior is not depending on the bulk density. Specimen size has nearly no influence on compressive behavior.

Summary

A correlation between compressive stress at 10 % deformation and bulk density can roughly be shown for silica core panels. In order to find a clear dependence, more results for each thickness are necessary. Especially the results for thin panels are widely distributed. The compressive behavior does not depend only on the bulk density, also the mixture of the core, the supporting effect of the foil and the level of vacuum seem to have an influence on the results.

For the fiber core panels tested within this study no dependence can be found. The results are significantly lower and it seems that the compressive behavior is more influenced by the properties of the core material in compressed state and by the stiffening effect of the foil, rather than by the density.

4 Summary

All test setups lead to improved results, but just the testing procedure with gypsum could reduce the spread of the curves and make the compressive behavior results more comparable.

fig. 38 and fig. 39 illustrate the difference between the results of silica core panels with surface seam and without coating and the results of the test with gypsum coating. Comparable results for fiber core panels are presented in fig. 40 and fig. 41.

For both core materials, the improvements can be seen clearly, especially for the 10 mm panels with an average length of the initial range of approximately 2 %, which correspond to an absolute value of 0.2 mm. The curves for the 30 mm panels have an initial range of approximately 1 % with leads to an absolute value of 0.3 mm. These absolute values for both thicknesses proof, that testing with a gypsum coating is applicable for all thicknesses and layout characteristics.

Furthermore, all tests show that vacuum insulation panels with silica core or fiber core do not have a linear compressive stress behavior. According to EN 826 in such cases, the zero-deformation point shall be the deformation corresponding to the preload.

The VIPA members asked to investigate the correlation between bulk density and compressive behavior to simplify the factory production control (FPC). The results are presented in chapter 3.6 and show a different dependence for each producer and each thickness. In addition, the specimen size needs to be taken into account. For silica core panels it could be possible to find a linear dependence for each thickness. To be able to find this dependence, additional tests with gypsum coating for each thickness within the FPC are necessary. Because of other influences like the supporting effect of the foil, level of vacuum and mixture of the core, it might not be possible for some producers to find a correlation between compressive behavior and bulk density. These influences have a major impact especially at thin panels.

Based on the results achieved within this study, it is not possible to monitor the compressive behavior by such a correlation for fiber core panels. This property depends more on the core material itself, than on its density, which leads to same compressive values within a wide density range.

It is recommended to measure the compressive strength within the FPC directly with a gypsum coating. If a correlation is wanted, it must be ensured that a dependence with a clear confidence range is existing; otherwise, a direct testing cannot be omitted.

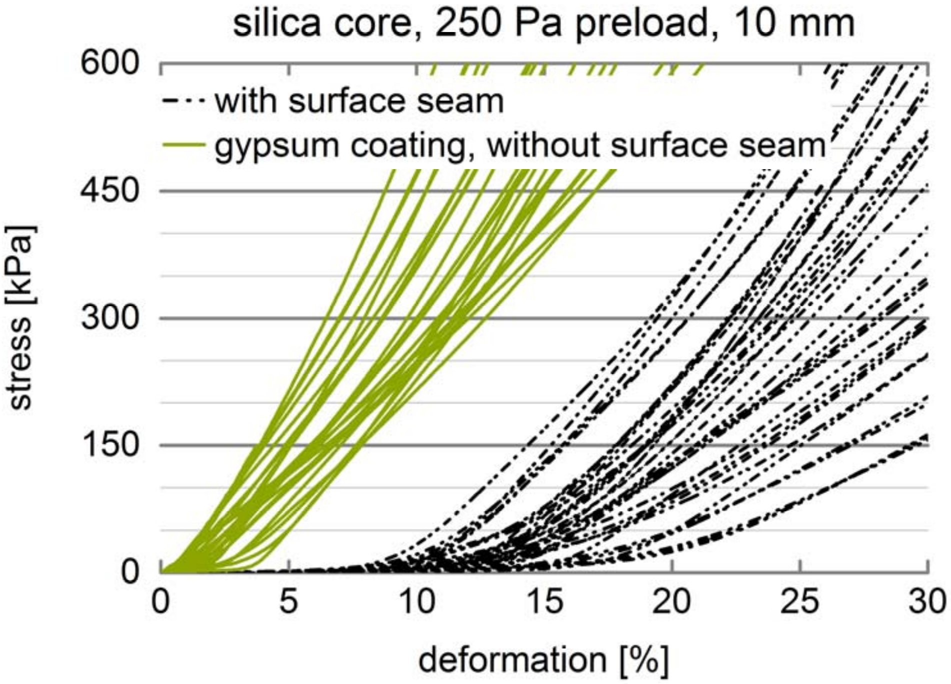

fig. 38 Deformation curves of 10 mm silica core vacuum panels with gypsum coating compared to specimens with surface seam, both tests 250 Pa preload. Compared to the starting position the initial range is significantly shorter and the spread of the curves lower. An evaluation of the compressive stress at 10 % deformation is now possible.

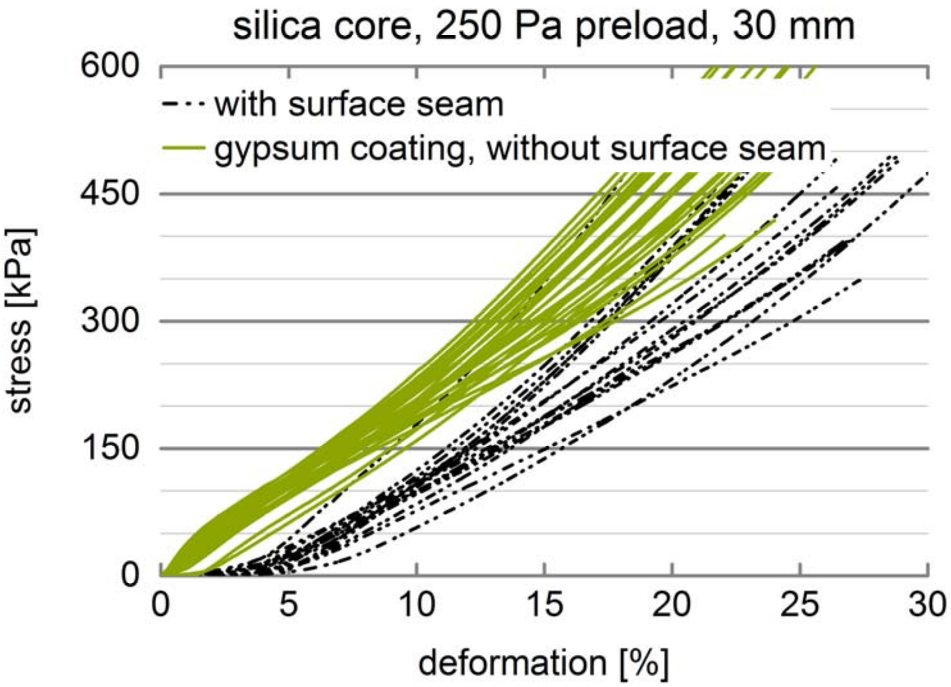

fig. 39 Deformation curves of 30 mm silica core vacuum panels with gypsum coating compared to specimens with surface seam, both tests 250 Pa preload. Compared to the starting position the initial range is significantly shorter and the spread of the curves lower. The values at 10 % deformation are lower compared with 10 mm thick panels.

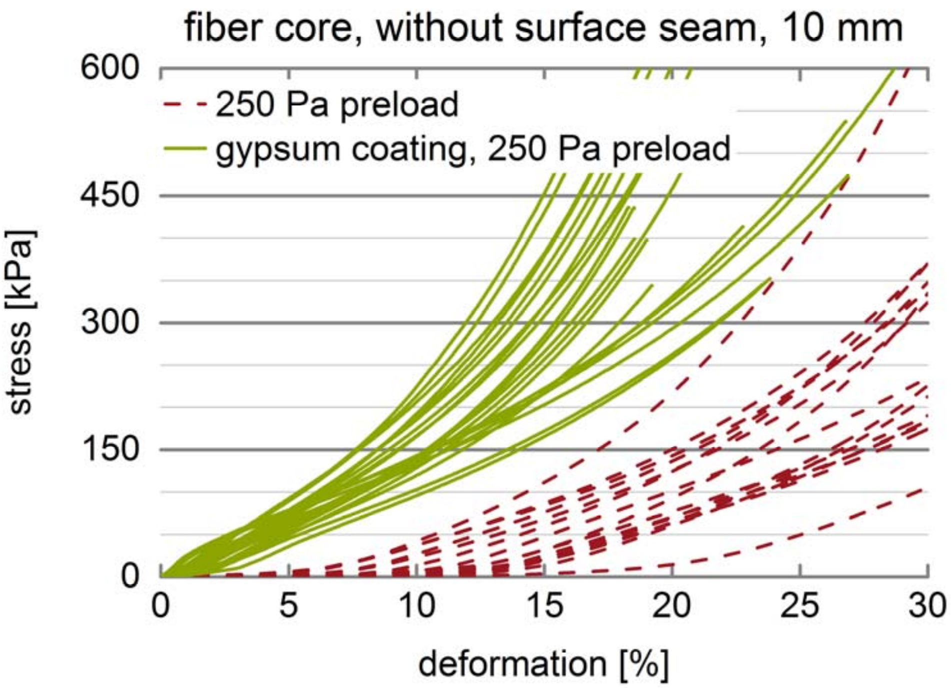

fig. 40 Deformation curves of 10 mm fiber core vacuum panels with gypsum coating compared to specimens without surface seam, both tests 250 Pa preload. Compared to the tests without gypsum coating the initial range is significantly shorter and the spread of the curves lower. An evaluation of the compressive stress at 10 % deformation is now possible.

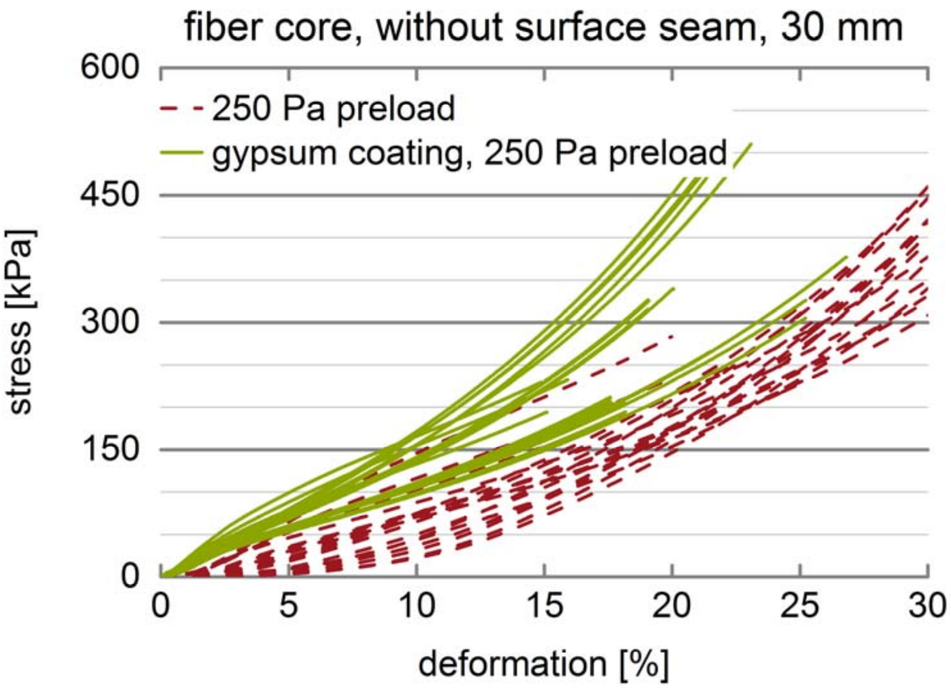

fig. 41 Deformation curves of 30 mm fiber core vacuum panels with gypsum coating compared to specimens without surface seam, both tests 250 Pa preload. Compared to the tests without gypsum coating the initial range is significantly shorter and the spread of the curves lower.

5 Outlook

If agreed by the members of VIPA, the results of this study can be processed to describe the methodology for the compressive behavior measurement within the product standard VIP currently under development.

After approval from the Tech WG the results and findings can be presented either in the ISO or the CEN committee responsible for the development of the product standard.

If the VIPA technical working group agrees, FIW could ask the IVIS Scientific committee if it is possible to present the results at the upcoming IVIS 2017 in Paris (deadline for abstracts is Dec. 16th 2016).

In addition to that, the findings could be implemented in the GSH document which is the basis for the private quality label for VIP.

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