Fixings of sandwich panels in building applications

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ABSTRACT: The paper introduces briefly the European Recommendations for Testing and Design of Fastenings of Sandwich Panels, written by the Joint Committee of ECCS TC7.9 and CIB W056. The Recommendations can be seen as an annex to the standard EN 14509 (2006), which concern the factory made sandwich panel products. The paper gives background information about the mechanical behavior and explains the effects of important parameters of a fastening loaded by tensile forces. A design formula is presented, which shows the influence of the essential mechanical parameters in the load-bearing capacity.

1 INTRODUCTION

The standard EN 14509 provides information about the requirements of the factory made sandwich panels used in civil engineering and further, about the determination of material parameters and the methods of the verification of the load-bearing resistance. EN 14509 does not give information about the joints and fasteners of the sandwich panels. In order to close the gap, the European Joint Committee consisting of ECCS TWG 7.9 “Sandwich Panels and Related Structures” and of CIB W056 “Lightweight Structures” has produced a recommendation, which introduces the experimental determination of the load-bearing resistance of fastenings, the evaluation of the test results and finally, the principles of the design of fastenings. The ECCS/CIB guidelines are based on the earlier version of the European Recommendations for Sandwich Panels, completing and updating it for today.

The paper summarizes briefly the content of the Recommendations. It introduces the essential parameters, which have influence on the load-bearing resistance of fastenings loaded by tensile loads. The results given in the paper allow also the comparisons of the load-bearing resistance of fastenings in the sandwich panels and in steel sheetings and sections.

2 OBJECT

2.1 *Sandwich panels and their loads*

Sandwich panels used in civil engineering consist typically of two faces and of an insulating core layer. The faces are normally made of thin metal sheets possibly having been profiled in order to increase the load-bearing capacity of the panel. Thicknesses of the steel sheet faces vary from 0.4 to 1.0 mm. The core layer is build up today of structural foams such as PUR or ESP or of a mineral wool. The thickness of the core layer is in the range from 40 mm to 300 mm.
Sandwich panels are typically self-supporting roof and wall claddings in industrial and office buildings or in the constructions of cold storage houses and cooling chambers. The sandwich panels are usually loaded by permanent loads like self-weight and by variable loads like the wind and snow loads and further, by the temperature differences between internal and external faces. The loads cause distributed stresses over the thin metal sheet facing and the core, to which stresses the resistance of a sandwich panel is rather high. The area of the connections and of the supports to a load-transferring substructure, however, turns out to be problematic. In this area, the local stresses in the face and core increase for which a sandwich panel is sensitive and which may result in a failure. Further, the additional elements and coverings are often attached to one face only, which cause large local stresses and imperfections.

2.2 *Fasteners and their load*

To fasten the sandwich panels to the substructure, mostly self-tapping screws or self-drilling screws are used. The both are able to make the threads in the substructure themselves. However, the self-tapping screws require a pre-drilling. The screws have a formed drilling bit which allows the screwing and drilling in one working operation. In order to produce a rainproof joint, sealing washers with an vulcanized EPDM layer are used between the screw head and the face. The washers of the screws fixed to the upper flange of the trapezoidal profiled facing, may also have saddle washers to tighten and support the profile. Screw fastenings may be visible fastenings drilled through the sandwich panels, or invisible fastenings placed in the joints between the panels.
The fasteners between the sandwich panel and the substructure may be loaded by tensile and shear forces as well as by bending moments due to the thermal movements. Tensile forces are result of a wind suction load and, in continuous multi-span systems, also of a temperature difference between internal and external face. The tensile force has to be introduced into the screw via the head and the washer of the screw, which causes local compressive stresses in the face and the core under the washer. The distribution of the local stresses inside the panel depends on the structure of the face and the core. The resulting tensile force of the shaft of the screw will be introduced into the substructure via the threads in the screw end. Failure of the screw fastening may take place due to the pull-through failure of the head and the washer through the outer face (figure 1), due to a failure of the fastener or due to the pull-out failure from the substructure. Since the thickness of the facing is small compared to the thickness of the substructure, the mode of failure is most likely the pull–through failure.
Shear forces mostly result in from the self-weight of the sandwich panels and additional elements fixed to the panel, and from the stabilizing forces and shear diaphragm effects. Shear forces are predominantly introduced into the screw via the internal facing. The external face below the screw head and washer shares in load transfer to a small proportion (< 5%), only. Thus, the influence of the core thickness can be disregarded as it is shown in the documented investigations of Baehre & Ladwein (1994) for example. As a rule, the failure occurs through the formation of an enlarged hole in the internal facing. An inclination or formation of the enlarged holes in the substructure can be observed extremely rarely.

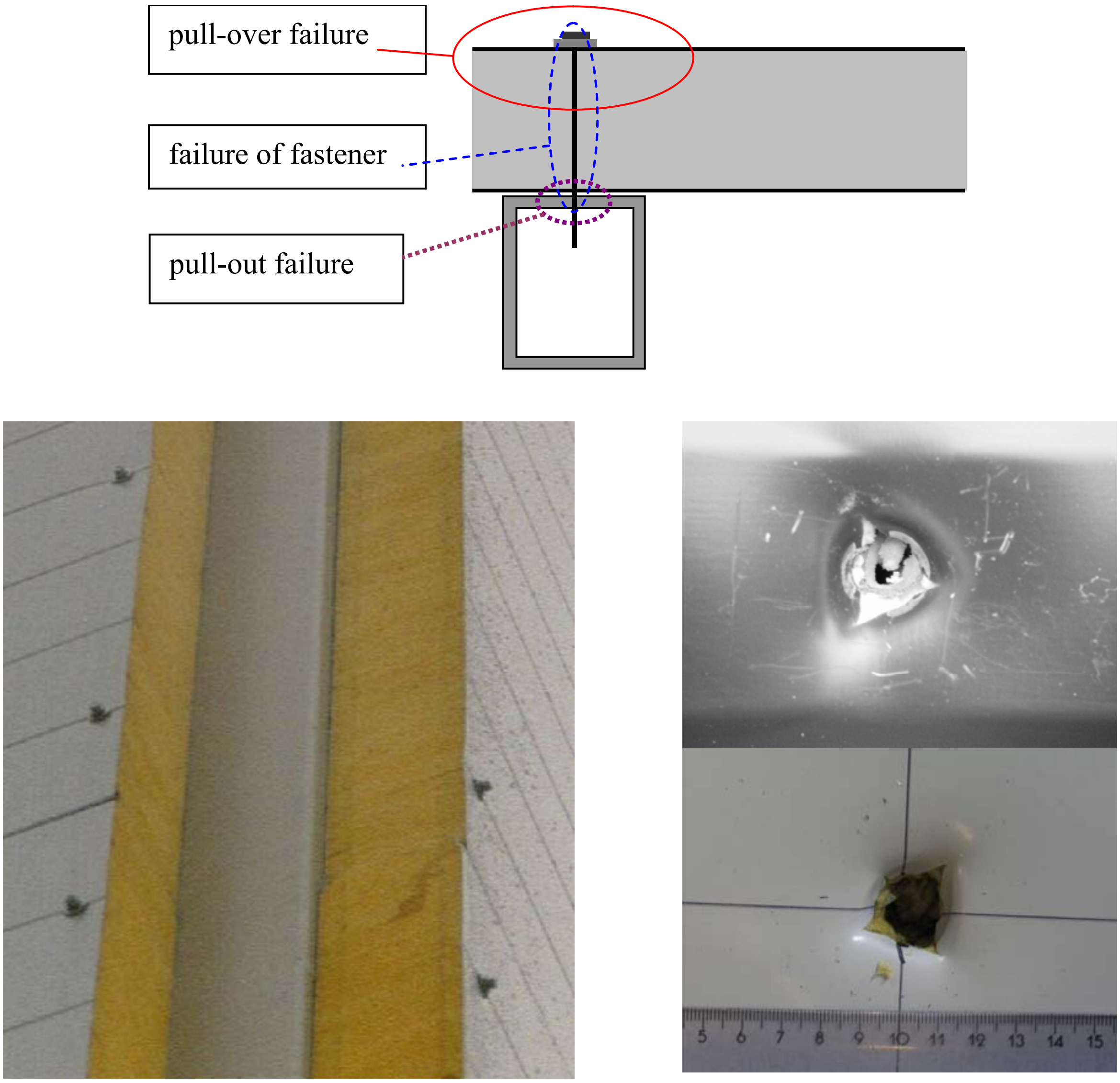

Figure 1. Potential failure modes of a direct screw fastening of a sandwich panel, typical screw fastenings in wall panels and typical pull-through failure modes in faces of PUR-foam and mineral wool sandwich panels.

The difference of the temperatures between the external and internal facing as well as the substructure results in relative displacements of the faces and the substructure against each other and thus, produces a bending moment in the shaft of the screw. The daily changes of the temperatures cause alternating repeated loads, thus subjecting the screw to a risk of a fatigue failure or loosening of the screw. Obviously, the resistance of the screw to the temperature movements increases with the thickness of the sandwich panel and decreases with the thickness of the substructure based on the increasing restraint.

3 EUROPEAN RECOMMENDATIONS

3.1 *Testing of fastenings*

3.1.1 *Tensile resistance*

The tensile resistance of a fastener represents the minimum value of the pull-through resistance and the pull-out resistance. The load-bearing capacity of the screw does normally not play any role in the case of the sandwich panels. The recommendations ECCS & CIB (2008) deal with the pull-through resistance only. For determining the pull-out resistance a reference is given to ECCS

(2008). As an alternative, the pull-out resistance of self-tapping screws and drilling screws from metallic substructures can be also verified through calculation according to Hettmann (2007).
For the determination of the pull-through resistance altogether three test arrangements are available. Tests on small specimens from sandwich elements, tests on complete full-scale components and tests on U-shaped steel sheet strip specimens according to ECCS (2008). Most typical are today the tests with small-scale specimens cut from the sandwich panels (figures 2 and 3). The following dimensions are applied:

e_1 corresponds the minimum edge distance defined by the manufacturer
$e_2 \geq \max\{e_C, 100 \text{ mm}\}$
$e_3 \geq B/4$ where B is the overall width of the panel
$e_4 \geq 400$ mm

In addition to the static tests, supplemental tests to determine the influence of the repeated load caused by the wind suction are necessary. Tests based on complete full-scale components include also cyclic loading phases. Tests on U-shaped steel sheet strip specimens do not reflect the load-bearing behavior and thus the performance of the fastenings to repeated loads can not be gained on the basis of them.

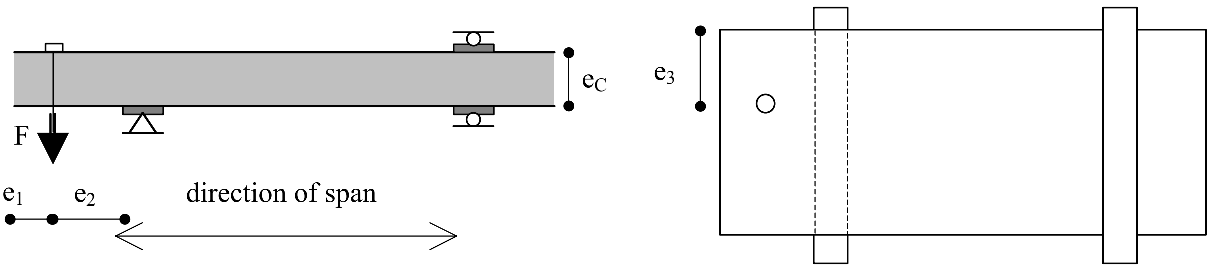

Figure 2. Test arrangements for pull-trough resistance with small-scale specimens at an end support.

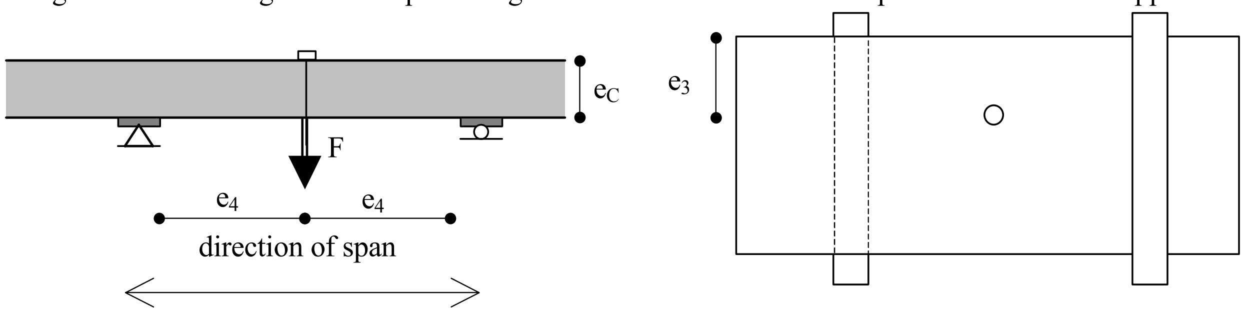

Figure 3. Test arrangements for pull-trough resistance with small-scale specimens at an intermediate support.

3.1.2 *Shear resistance*

Figure 4 shows the principal set-up of a test for the determination of the shear resistance of a screw fastening. Since the influence of the external face decreases with the increasing thickness d of the core layer, the tests are to be performed with the largest envisaged panel thickness. As an alternative, the sole direct load transmission between the internal face and the substructure is investigated. In this case, however, the tests should be performed with the smallest envisaged panel thickness in order to minimize the influence of the support regarding the screw pile shaft.

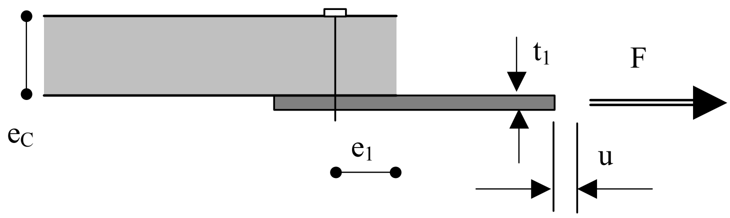

Figure 4. Shear test assembly for screws passed through the panel.

3.1.3 *Bending resistance*

For the determination of the resistance of a screw to the deflection of the screw head, the fastener is subjected to a repeated deflection of u. The deflection spectrum comprises as follows: 20.000 cycles with a deflection of 4/7 u, 2.000 cycles with a deflection of 6/7 u and 100 cycles with a deflection of u. The load spectrum to be assessed is based on the assumption of a service life of 50 years in a location in Central Europe. During the test, the screw shall not fail and after the test, the screw has to achieve at least 80 % of the mean value of the pull-out resistance without the cyclic load.

3.2 *Evaluation of test results*

Since the load-bearing capacity of the joint depends on the mechanical properties of the facing as well as on the core layer, the load-bearing resistance determined in the tests, has to be adjusted to the guaranteed minimum values or to the values used in the design. The adjustment to the tensile strength and thickness of the metal sheet facing in based on a linear model. Influence of the core layer is described using the square root of the relation of the characteristic and the measured compression strength of the core

$$F \sim \sqrt{\frac{f_{Cck}}{f_{Cc,obs}}} \tag{1}$$

The model can be compared to the approach of a plate on an continuous elastic support. In adjustments, only the smallest ratio of the properties of the face and core is to be assessed. Furthermore, the shear modulus G_C of the core layer is irrelevant in case of direct fastenings.
The characteristic value of the tensile resistance is evaluated on the basis of the statistical analysis on logarithmic distributed variables as shown EN 14509 (2006). The characteristic value is a 5 % fractile value.

3.3 *Design of fastenings*

The design value of the load-bearing capacity of a fastening corresponds the characteristic value divided by the material safety factor γ_M. The material factor can be derived from the deviation of the test results. However, it is recommended to assess at least the value of γ_M = 1,33 in the verification of the load-bearing capacity of fastenings.
Since the inner face adjacent to the substructure is used for the transfer of shear forces and the external face and the core layer for the transfer of tensile forces, no verifications of the interaction between the tensile and shear are necessary for a combined load.
Annex D of ECCS/CIB (2008) shows ways to calculate the head deflection, caused by the relative displacement of the faces of a panel due to a temperature gradient. The calculated deflection has to be compared with the value sustainable by the screw.
The deformations and stresses in the point of a fastening cause imperfections in the sandwich panels which might reduce the resistance of the facings to compression (wrinkling failure) and of the core to shear.

3.4 *Fastening on a facing*

A special case regarding the fastening of sandwich panels represents screwing in a sole one face layer. In the case, the face obviously represents the substructure for the screw. This joint is inasmuch non-favourable as the thread of the screw is normally screwed into a very thin sheet plate. Failure can also occur through a delamination of the facing from the core layer, e.g. the tensile strength of the core layer is to be considered. Nevertheless, the determination of the load-bearing capacity through tests can be carried out analogously.

4 PULL-THROUGH-RESISTANCE: LOAD-BEARING MECHANISMS

4.1 *Investigations*

For quantifying the effects, the tests on PUR wall panels with quasi-flat facing presented in Misiek et al. (2008) were recalculated using the Finite Element Method. For the purpose, a part of the sandwich panel including the screw head and the EPDM washer was modeled. Multi-linear constitutive equations with hardening were assessed for the steel facings. The foam core was assumed to follow the isotropic material model described with bilinear constitutive equations. This model corresponds to the stress-strain behaviour that can be effectively observed if loading PUR-foam core with compressive stresses f_{Cc}. This model was transferred to tensile stresses based on the comparatively small tensile stresses. The load was applied gradually using a displacement-control. The equivalent stress of von Mises was regularly determined in the elements representing the face sheet. If the equivalent stresses were above the uniform extension A_g, the relevant element was regarded as cracked and was eliminated. The definition of an uniform extension as reference value was done at random, but proved of value. Obviously, the fineness of the integration of the facing under the EPDM washer is relevant for this procedure. The following illustrations introduce results of two calculations and the comparison with the test results.

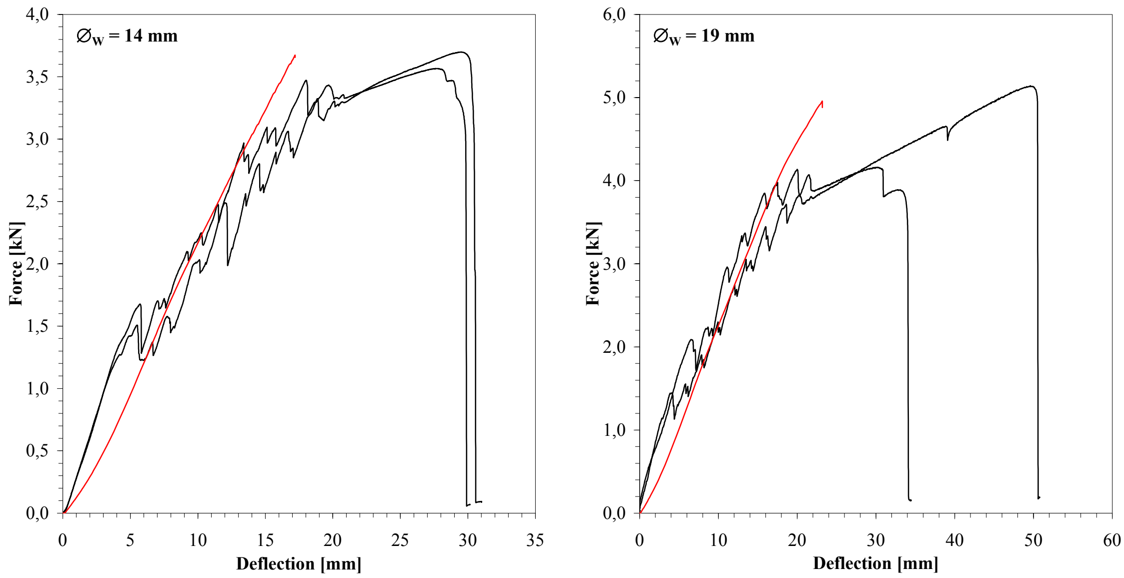

Figure 5. Comparison of load-deflection-curves of tests and numerical investigations.

The strongly increasing deformations beginning from a force of about 3.5 kN to 4.0 kN are attributed to a beginning bending failure of the PUR-foam cored sandwich panel, which is not registered in the FE-model.

4.2 *Influencing parameters*

4.2.1 *Facing*

The load-bearing capacity of the direct screw fastening increases nearby linear with the tensile strength and thickness of the facing. The influence of the thickness is shown in Figure 6.

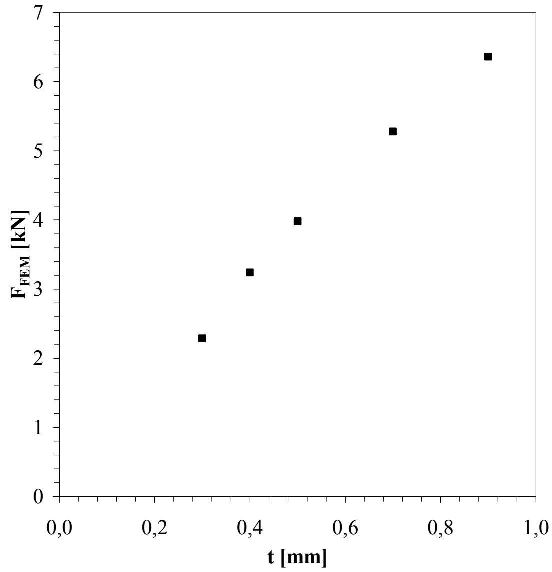

Figure 6. Influence of the thickness of the facing on the tensile resistance of direct screw fastening.

4.2.2 *Core layer*

A high compression strength f_{Cc} and a high modulus of elasticity E_{Cc} obviously increase the pull-through resistance. The latter one results in a reduction of deformations and thus, a concentration of the load distribution close to the fastener and relieving of the bending stresses in the face sheet (see figure 7 left). With a small thickness of the core layer, the influence of bending effects of the beam-type test specimen on the load-bearing capacity increases. The negative influence of the bending deformations on the pull-through resistance naturally looms to be large (see figure 7 right).

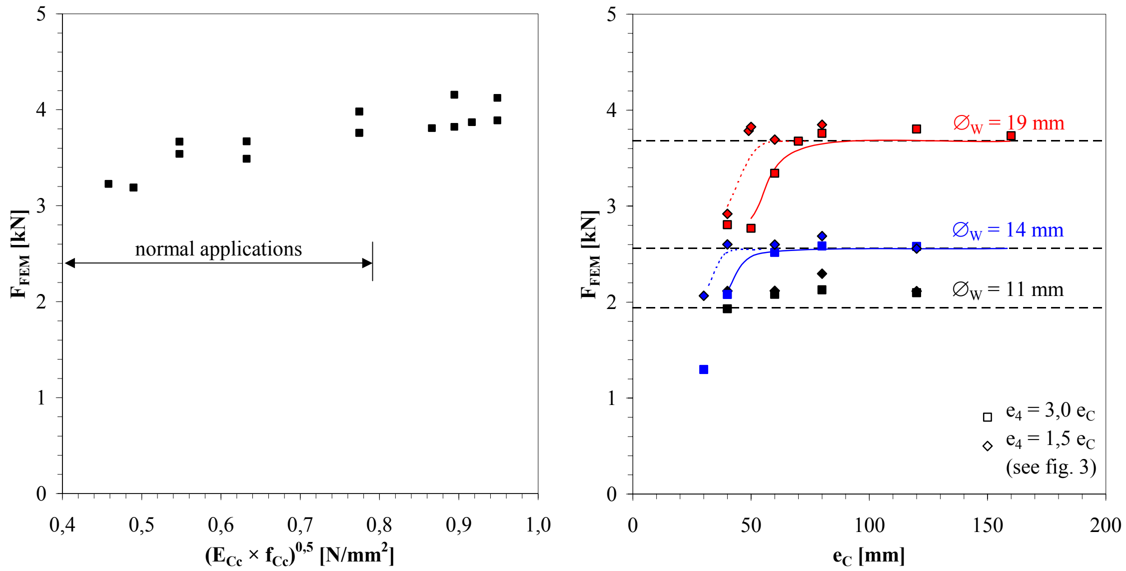

Figure 7. Influence of the mechanical properties of the core material and of the thickness e_c of the core.

4.3 *Design model*

4.3.1 *Load-bearing capacity*

The numerical investigations resulted in the fact that the pull-through resistance of direct screw fastenings of PUR-foam cored wall panels can be determined using a simple two-part expression describing the contributions of the core and the face layers.

$$F_{mean} = F_{C,mean} + F_{F,mean} = c_{C,mean} \cdot \sqrt{E_c \cdot f_c} \cdot \varnothing_W^2 + c_{F,mean} \cdot t \cdot R_m \cdot \varnothing_W \qquad (2)$$

In the expression, R_m is the tensile strength of the face. The constant $c_{C,mean}$ has a value of 2.87, the constant $c_{F,mean}$ is 0.84. More complex approaches comprising the distribution of load based on the theory of the elastically supported plate result in far worse estimates to the calculated results. Comparison between the resistances based on numerical simulations and the values evaluated on the basis of the expression (2) is shown in Fig. 8, which shows also the relation between the numerically simulated values and the characteristic values based on expression (3). The prerequisite is that the distance of the fastener to the end of the specimen is irrelevant.

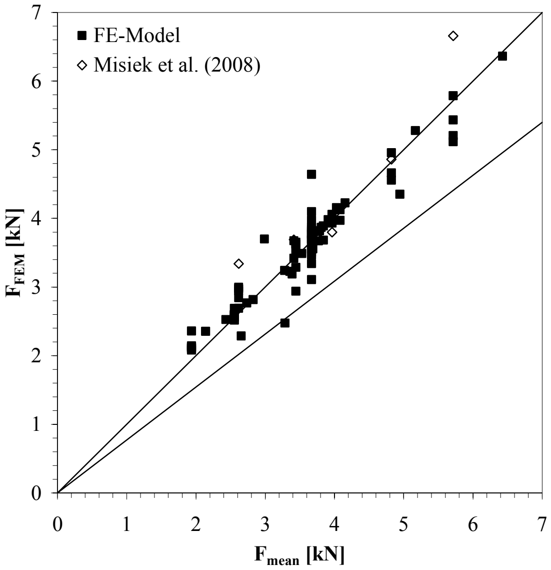

Figure 8. Comparison of pull-trough-resistance according to equation 3 and numerical investigations.

Characteristic values of the pull-trough resistance are evaluated from

$$F_k = F_{C,k} + F_{F,k} = c_{C,k} \cdot \sqrt{E_c \cdot f_c} \cdot \varnothing_W^2 + c_{F,k} \cdot t \cdot f_{u,k} \cdot \varnothing_W \qquad (3)$$

in which $c_{C,k}$ = 2.21 and $c_{F,k}$ = 0.65. Pull-through of the screw head through the washer itself as this could be observed for $\varnothing_W$ = 29 mm has to be excluded.

4.3.2 *Distance of edge and fastener*

A small distance between the fastener and the end of the specimen e_1 can result in a reduction of the load-bearing capacity, the influence of which can be seen figure 9.

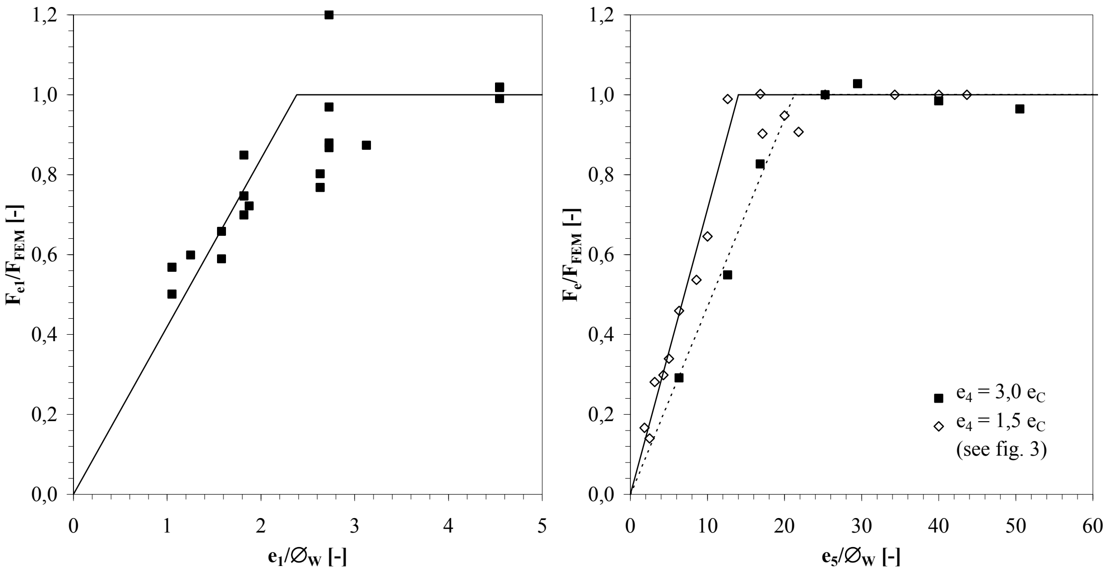

Figure 9. Influence of distances e_1 and e_5.

To estimate the influence of the distances, the functions

$$f_{e1} = 0{,}4 \cdot \frac{e_1}{\varnothing_W} \leq 1{,}0 \qquad (4)$$

for the edge distance and – depending on the influence of the bending moments –

$$f_{e5} = 0{,}04...0{,}08 \cdot \frac{e_5}{\varnothing_W} \leq 1{,}0 \tag{5}$$

for the distance of the two neighboring fastener can be applied as multipliers in expression 4. Obviously the influence of the two neighboring fasteners is far bigger than the influence of the end distance. The result based on PUR-foam cored specimens is in contrary to the observations on mineral wool cored sandwich panels, in which the strongly oriented core layer distributes the load effectively in one direction, only. The influence of the end distance seems to be larger but on the other hand due to the higher compression modulus, the influence of the two neighboring fasteners smaller than those in the panels with PUR-foam cores.

4.3.3 *Repeated load*

The influence of the repeated load for small washer diameters plays a minor role according to results of Misiek et al. (2008). The share of load transfer via the foam core increases with increasing washer diameter, which results in higher compression stresses in the core layer and thus also larger deformations in the face layer. They enhance the crack growth. The influence of the repeated load doubtlessly necessitates further investigations. As a simplification, the value of the pull-through resistance determined according to equation (3) can be reduced to 75 % in those cases, in which the foam core has a share of more than 20 % in the load bearing capacity.

5 CONCLUSIONS

The new document introducing the testing and design of fastenings of sandwich panels is a useful addition to EN 14509 (2006). The basic test methods and the principles of the design are briefly presented in the paper. The influence of the main parameters on the tensile resistance of the direct screw fastenings have been studied experimentally and numerically. The work has resulted in an expression to evaluate tensile resistance by calculations. The expression is a useful tool to extend the area of the application of the experimental values and to adjust the experimental values to the nominal values of the essential parameters. Further studies are needed to extend the expression to take into account the properties of structurally oriented an-isotropic core layers such as mineral wools and the influence of the repeated loads.

6 REFERENCES

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