EXPERIMENTAL STUDY ON SHEAR BEHAVIOUR OF FOUR DIFFERENT THERMAL INSULATING MATERIALS

EXPERIMENTELLE STUDIE ZUM SCHERVERHALTEN VON VIER VERSCHIEDENEN WÄRMEDÄMMSTOFFEN

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SUMMARY

The results of an experimental study on the shear behaviour of different thermal insulating materials are presented for discussing the applicability of the test method described in the standard EN 1606 [1]. The chosen test specimens were 60 mm thick boards made of wood fibres and of mineral fibres as well as expanded and extruded polystyrene.

ZUSAMMENFASSUNG

Es wird über das Ergebnis einer vergleichenden Prüfung zum Verhalten bei einer Scherbeanspruchung von vier verschiedenen Wärmedämmstoffen berichtet und die Anwendbarkeit des Prüfverfahrens nach EN 1606 [1] für diese Art der Dämmstoffmaterialien diskutiert. Die ausgewählten 60 mm dicken Dämmstoffplatten bestehen aus Holzfasern oder Steinwollefasern bzw. aus expandiertem oder extrudiertem Polystyrol.

KEYWORDS: Shear strength, shear stress, shear modulus, thermal insulating material

1. SIGNIFICANCE

The consideration of the shear behaviour of thermal insulating materials is an important property of thermal insulating material in the construction of External Thermal Insulation Compound System (ETICS) due to gravitational force by the mass of the construction, which results in shearing stress in the thermal insulating layer. Furthermore, shear stress can arise in the perimeter insulation (at basement walls or under foundation slab) due to vertically or horizontally effected forces in the insulating layer (e.g. thermal insulating material under loadbearing foundation slabs of concrete). Another field of application is in the field of manufacturing of multi-layered boards, whose single layers are bonded to one another by an adhesive. In this case shear strength tests are used for quality checks of the bonding strength.

2. TEST METHOD

The European standard EN 12090 [1] defines the test method for the shear behaviour of thermal insulating materials. There are two different arrangements regulated: two double test specimen arrangements and one single test specimen arrangement. The double test specimen arrangement depicted in the schematic sketch 2 b) was implemented at the MPA laboratory (Fig. 1).

The test machine works in the pull-mode (number 1). Each single test specimen (number 2) is seated between two stiff wooden chipboards (number 5) and fixed by means of an adhesive (number 3). Number 4 points at the steel frame of the test rig. While the test machine is pulling up the middle part shear forces are generated within the test specimens parallel to the axis of the force.

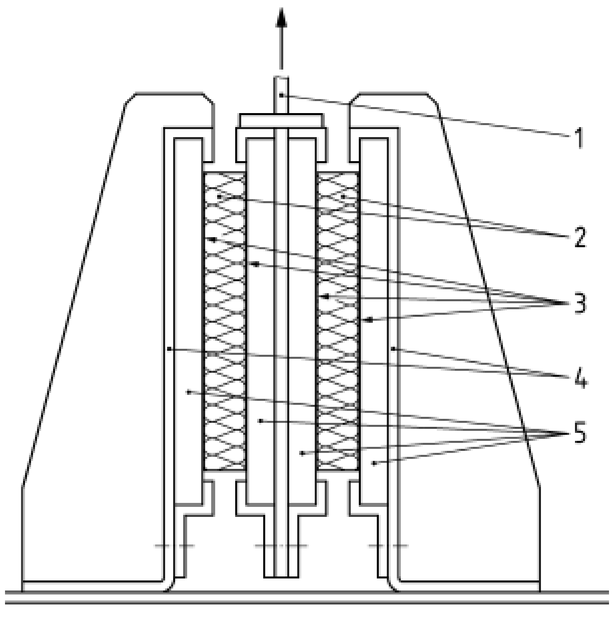

Fig. 1: Schematic sketch of the double test specimen arrangement

An important rule in the standard is to be respected and is related to the evaluation: a test result is only usable in case the shear fracture occurs inside the material. A break in the adhesive or between adhesive and mounting plate (wooden or steel plate) is not acceptable, - the result has to be discarded.

3. CHARACTERIZING OF THE CHOSEN MATERIALS

Table 1 informs about the selected thermal insulating materials with regard to the thickness of the boards and the density of material. All tests boards had the equal thickness of 60 mm. The density was more or less in a medium range related to each product type. Furthermore, the table gives a brief description of structure and the general mechanical behaviour against the exposure of forces under load.

The general behaviour of the material made of MW (mineral wool) or of WF (wood fibre) can be described as brittle in contrast to boards from EPS (expanded polystyrene) and XPS (extruded polystyrene), which exhibit significantly elastic behaviour.

Table 1: Thermal insulating materials

type thickness mm density kg/m³	WF 60 140	MW 60 157	EPS 60 16	XPS 60 35
structure	3-dimensional disordered netting	2- dimensional layers	foam (cellular) with open cells	foam (porous) with closed pores
general behaviour	„brittle“	„brittle“	elastic	elastic
size of specimen mm	200 x 200	200 x 200	100 x 100	100 x 100

The following Tables 2 and 3 provide the results of the strength properties on compression stress/strength [2] and on tensile strength [3]. All the results are as expected and typical for each of the chosen materials. Comparing the ratio of the results of compressive stress/strength and tensile strength, it can be recognized that the tensile strength of the fibrous materials is clearly lower compared to their compressive stress at 10% strain. By contrary the tensile strength of the elastic materials EPS or XPS is twice higher than the respective the compressive stress/strength.

Concerning the tests with XPS, the cross section of the test specimens had to be reduced to 50 mm x 50 mm by notching near the middle of their thickness (predetermined breaking point) in order to obtain a proper tear-off in the thermal insulating material XPS. Fig. 2 shows the cohesion break of the test specimens. If the testing is carried out without this notching, the breakage will be found within the adhesive bonding or between adhesive and connecting plate (wooden chipboards).

Table 2: Compression behaviour [2]

product type		WF	MW	EPS	XPS
		length and width			
test specimen	[mm x mm]	200 x 200	200 x 200	100 x 100	100 x 100
1	[kPa]	151	63	85	536
2		148	66	78	530
3		127	75	78	502
4		147	98	81	534
5		152	91	86	506
mean value		145	72	81	522
		compressive stress at 10% strain			compressive strength

Table 3: Tensile strength [3]

product type		WF	MW	EPS	XPS *
		length and width			
test specimen	[mm x mm]	200 x 200	200 x 200	100 x 100	100 x 100
1	[kPa]	23	14	175	1120
2		22	17	168	1160
3		20	14	175	1180
4		14	16	165	1100
5		16	22	173	1220
mean value		19	17	171	1160
* reduced cross section of 50 mm x 50 mm by notching midst of test specimen as predetermined breaking point					

Fig. 2: Test specimens of XPS after the tensile strength test (cohesion break)

4. COMPARING TEST ON SHEAR BEHAVIOUR

Shear test is totally different from tensile or compression test as the forces applied are parallel to the upper and lower faces of the object and moving in opposite directions under test. Shearing stress affects in the material a sliding motion until failure happens in the so-called shear plane.

In all test runs under shear stress the specimens of the fibrous materials always resulted a failure along the shear plane largely within the material. Thus, all results could be used unrestrictedly under consideration of the no-detachment-rule of the standard EN 12090. Their behaviour can be compared to that of brittle materials, which in relation to their compressive strength have often a clear lower tensile strength.

In contrary to this behaviour the reducing of the area of shear plane was needed with the elastic materials EPS and XPS in order to avoid detachment at the specimen surface from the mounting plate. The ratio of the cross section of bonding area to area of shear plane was 2,5 : 1 for EPS and 8 : 1 for XPS, respectively.

In Table 4 are listed the results on the shear strength and in Table 5 the results of the shear modulus, respectively.

Table 4: Shear behaviour [1]

product type		WF	MW	EPS *	XPS *
		length and width			
test specimen	[mm x mm]	200 x 200	200 x 200	200 x 100	200 x 100
1	[kPa]	29	39	106	469
2		22	44	98	496
3		29	50	93	563
4		33	---	---	429
5		---	---	---	419
mean value		28	45	99	475

* notching midst of test specimen as predetermined breaking point
EPS: dimensions of reduced cross section of 200 mm x 40 mm
XPS: dimensions of reduced cross section of 200 mm x 12 mm

Table 5: Shear modulus [1]

product type		WF	MW	EPS	XPS
		length and width			
test specimen	[mm x mm]	200 x 200	200 x 200	200 x 200	200 x 100
1		1,0	1,1	1,6	15
2		1,1	1,2	1,6	14
3	[kPa]	0,8	1,2	1,6	15
4		1,1	---	---	13
5		---	---	---	12
mean value		1,0	1,2	1,6	14

The series of the following pictures shall give an impression about the typical failure modes of the test specimens after the shear test.

The specimens of the two fibrous materials experienced a clear breakage plane within the material (Fig. 3 and 4).

However, the testing for the specimens from EPS and XPS was much more complicated. The picture shown in Fig. 5 identifies the difficulties both with EPS and with XPS because of detachment from the mounting plane, in the picture for XPS even with a 50% reduction of the area of shearing in the thermal insulating material. Only after enlarging of the notching until a residual web of 12 mm width for XPS and a residual web of 40 mm for EPS it was possible to prevent the detachment.

The pictures of Fig. 6 and 7 show the breakage and the pictures of Fig. 8 and 9 the shear plane after failure. In a more macroscopic way the development of this kind of fracture may be described as a joint action of pulling and pressing forces in the elastic material. Thus, in the shear plane many short sections of elements alternating are forming under test once consisting of tear-outs and secondly consisting of compacting material (see Fig. 9).

Fig. 3: Specimen from wood fibres after failure

Fig. 4: Specimen from stone fibres after failure

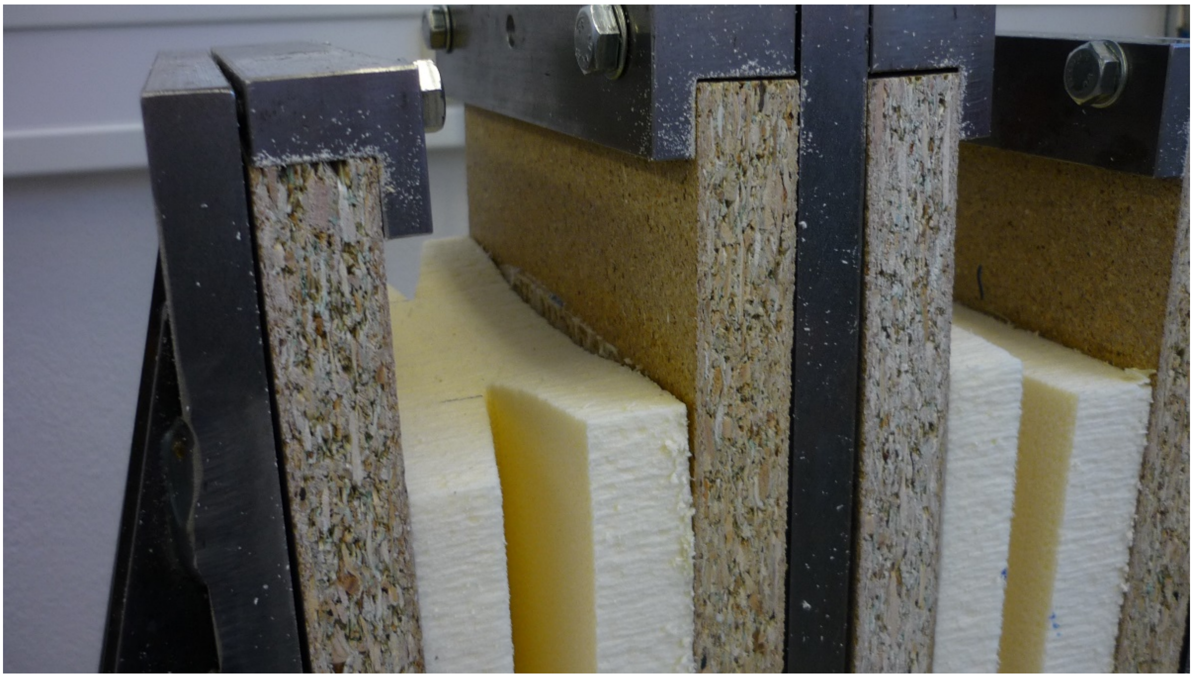

Fig. 5: Detachment in the bonding plane

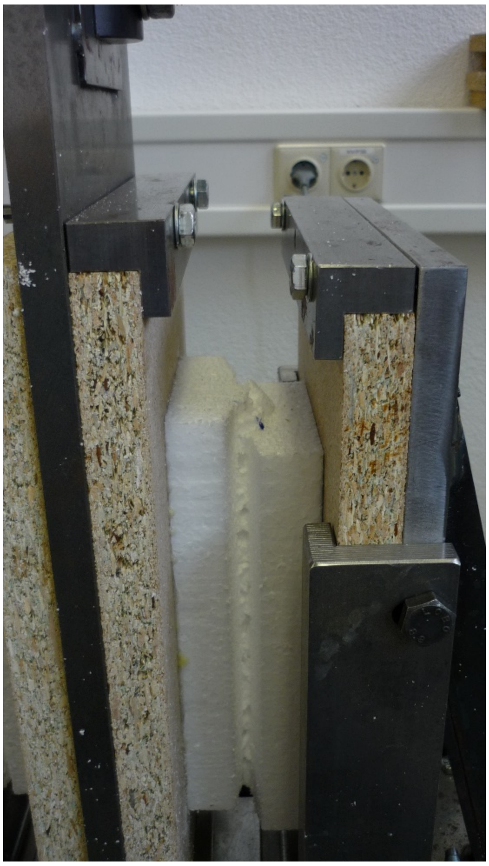

Fig. 6: Specimen from EPS under test

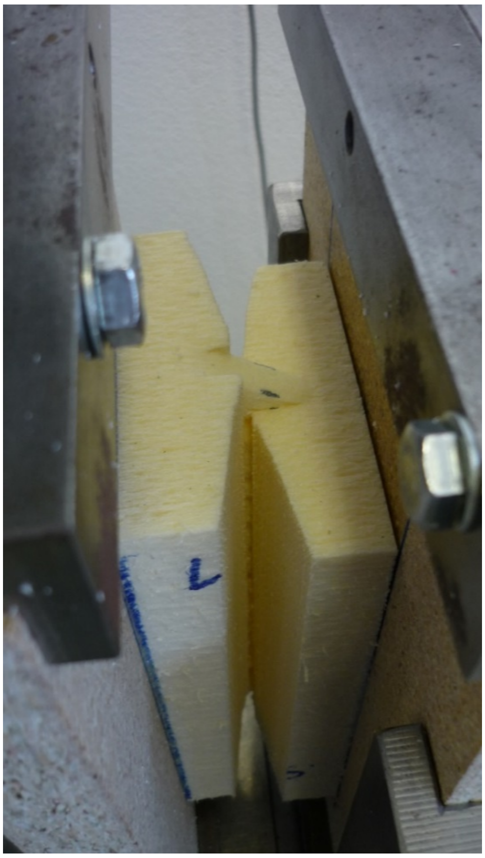

Fig. 7: Specimen from XPS under test

Fig. 8: Fracture zone in the EPS material (dimensions of reduced cross section of 200 mm x 40 mm)

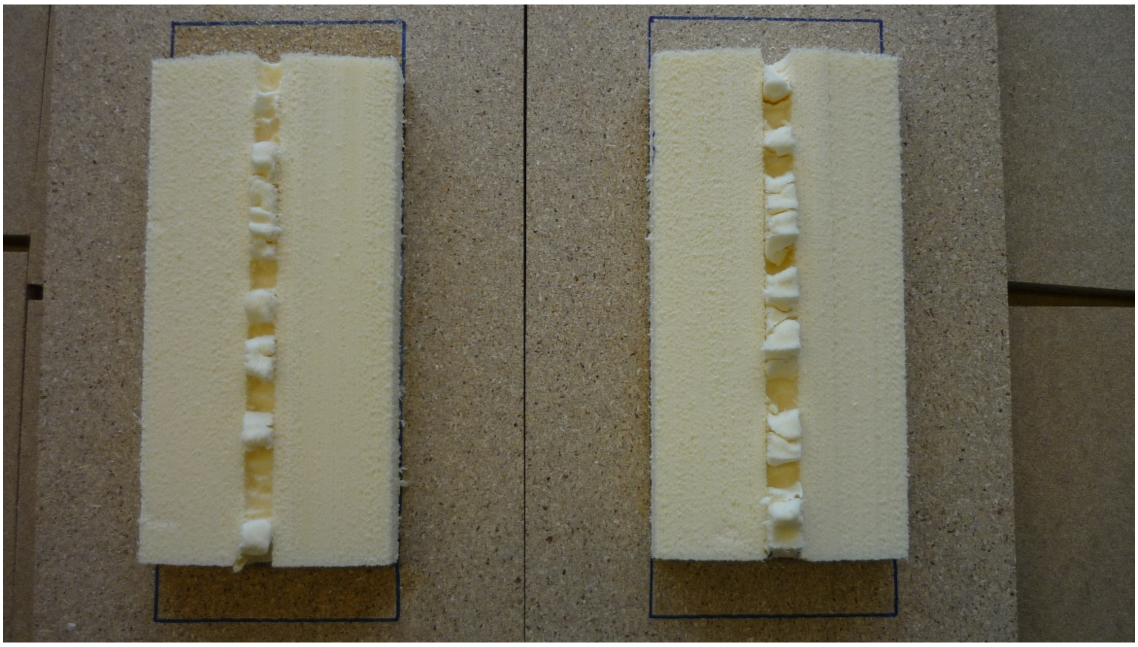

Fig. 9: Fracture zone in the XPS material (dimensions of reduced cross section of 200 mm x 12 mm)

5. CONCLUSIONS

The test standard EN 12090 defines the shear strength as the ratio of maximum force that breaks the material along the shearing plane parallel to the direction of the applied force to the area of the plane of rupture. The breakage plane needs to lie in the thermal insulating material (cohesion break).

The test experiences and the results of all the comparing test runs suggest that the test method as defined the standard EN 12090 was probably meant to thermal insulting materials with a generally brittle behaviour against force effect, such as fibrous materials or glass foam boards or autoclaved aerated concrete blocks.

Thermal insulating materials as EPS and XPS which exhibits an elastic behaviour against force effects under loading make the application according to this test method difficult in regard of the avoiding of detachment of the specimen from the mounting plate.

One hint for a possibly “problematic” material is the ratio of the tensile strength versus compressive strength if is

$$TR >> CS(10/Y).$$

In this case the test is likely not to be able to be carried out properly without detachment from the mounting plate. It was not possible to find a suitable adhesive, which was able to generate a sufficient strength of bonding. It is possible to avoid this problem by introducing a predetermined breaking point in the material by notching of the specimen. This way leads indirectly to a strengthening of the adhesive bonding.

REFERENCES

[1] EN 12090:2013 *Thermal insulating products for building applications – Determination of shear behaviour*
[2] EN 826:2013 *Thermal insulating products for building applications – Determination of compression behaviour*
[3] EN 1607:2013 *Thermal insulating products for building applications – Determination of tensile strength perpendicular to faces*