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StandardBoard – A product standard for earth panels

In recent years. the utilization of modern building materials made from soil has extended considerably. For building principals and designers. this decision is often determined by their extremely low carbon dioxide equivalent. A paradigm is the application of earth panels in the conversion of the former House of Representatives in Bonn to the secretariat of the United Nations Framework Convention on Climate Change. The choice of earth panels was determined not only by considerations of indoor climate and acoustic insulation issues. but particularly by an endeavour to attain a high level of sustainability.

The lack of a standard causes producers of earth panels to experience considerable competitive disadvantages. With the absence of test certificates. designers as well as implementers refrain from using earth materials. The project StandardBoard has been initiated with the purpose of developing the basis for a product standard for earth panels. being realized at the BAM. where also standards for earth blocks and earth mortars have been developed. The BAM is cooperating with the project partner Conluto. a manufacturer of earth panels. The object of the standard being in development is to guarantee the usability of earth panels by stating quality requirements and testing procedures and thereby to achieve safety for designers and users as well as competitiveness with established panels. Furthermore. a standard allows to emphasize the special ecological and climatic features of earth materials. The drafting of the standard is coordinated in close relation to the German Association for Earth Construction (DVL).

Earth panels are plate-shaped earthen materials used for planking or panelling indoor frame works or wall surfaces. They may contain reinforcements situated beneath the surface or in the core and are mounted by gluing or using mechanical fixing materials. In comparison to other earthen materials their specialties consist in a high degree of prefabrication and the fast and dry application. This is of high importance when it comes to components that are sensitive to moisture. as for example frame work. As earth panels require only a thin-layer plastering according to TM 06 [4]. the total amount of water being introduced by plastering is very low. In addition to this. it hardly gets in contact with the loadbearing structure itself. According to type of application earth panels must fulfil different requirements. ranging from dimensional accuracy to resistance against mechanical loads.

The earth panels that are presently available differ in size. structure. composition and mode of application (see Tables 1 and 2). Some of the earthen bulk materials contain expanded clay or hemp chaff in order to decrease their density. thereby allowing larger sizes. Many products aim at increasing their tensile strength by reinforcements. such as fibre grids. reed tubes and fibres. Currently the proposed draft of the standard allows for the following additions and reinforcements:

- Mineral aggregates (natural aggregates according to DIN EN 13139 [1]. ground brick free of mortar residues. lightweight aggregates according to DIN EN 130551 [2].
- Organic additions (vegetal components and fibres. animal hair. chopped chemically untreated wood).
- Up to 1 m-% water soluble stabilizers (polysaccharides).
- Inorganic pigments according to DIN EN 12878 [3] or vegetal colorants.
- Bound vegetal components.
- Weaves and grids of vegetal. artificial or glass fibres.

Earth panels are manufactured by filling. ramming or pressing the material in a mould or by pressing

Product	Length mm	Width mm	Thickness mm	Weight kg/m²
Earth panels	625 – 1500	250 – 625	12.5 – 35	11.2 – 38.5
Gypsum boards [6]. [7]	1200 – 3040	400 – 1250	9.5 – 25	7.0 – 21.1
Wood fibre boards [8]				
– porous	1700 – 2600	600 – 1700	6 – 80	1.4 – 32.0
– medium	2440	1220	6 – 25	2.1 – 20
– hard	2500	1250	3 – 8	2.4 – 6.4

Table 1 Characteristics of various panel products currently available in Germany

it through a die in a strand. Special panels contain water pipes for cooling and heating or encapsulated paraffin. to increase the heat storage capacity. Those panels are to label as special products.

After mounting. the panels are plastered to achieve an even surface. Usually the plastering consists in two layers with a total thickness of 3 mm (in accordance to TM 06 [4]. First the panels are being joined by earth slurry and strips of grid. It is also possible to do the same with the whole surface. Next a levelling layer of fine plaster is being added. which is to be reinforced as well and constitutes the basis for the finish layer. Panels. fixing materials. grid and plaster form a system. The components of that system are prescribed by the manufacturers and are adapted to one another.

In the project StandardBoard. currently available panels undergo material and component tests to verify their suitability for the intended purpose and to create for the first time a comprehensive data basis. Available standards for comparable materials serve as models for the development of plausible and realistic requirements and for the necessary test procedures. Those are to be applied to all non-load bearing earth panels produced in factories that can be used indoor and in the non-weather faced outdoor as planking. panelling or facing shell. The standard will not apply to panels that. made of other materials. carry an earth plaster.

This article presents preliminary results of the ongoing project.

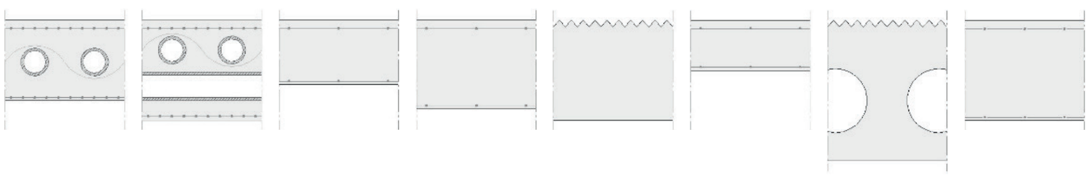
Requirements and test procedures

General remarks

Earth panels that are used for planking or panelling should fulfil the following requirements:

1. Easy handling and application
2. Serviceability and security after implementation
3. Suitability as render ground.

Table 2 Cross section of several earth panels



Thickness	20	25	16	22	25	35	25	12.5
Width	625	625	625	625	250	250	600	600
Length	1500	1500	1250	1250	1250	1250	1200	1200
Structure	Earth mesh reed single layer	Earth mesh reed two layer	Earth mesh	Earth mesh	Earth	Earth	Earth mesh	Earth mesh
Use	Planking and panelling							Planking

Dimensional accuracy class DAC	Acceptable deviation ± from nominal value mm				
	Orthogonality	Length l	Width w	Thickness t	Evenness
I	2.0	2.0	2.0	1.0	1.0
II	3.0	4.0	4.0	2.0	2.0
III	4.0	6.0	6.0	3.0	3.0

Table 3 Levels of dimensional accuracy as proposed

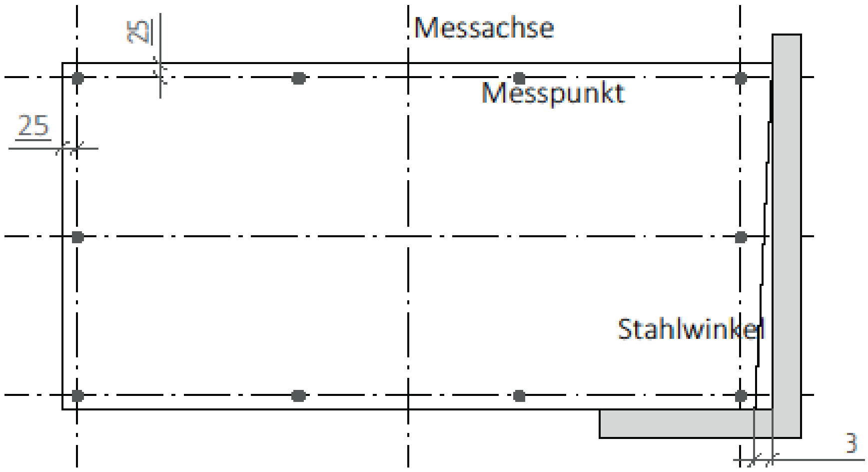


Fig. 1 Situation and number of measuring points and axes

The test procedures that are proposed as follows are designed to test those features of earth panels that are crucial to fulfil the demands listed above. If possible. test procedures were adopted from other standards covering earth and panel shaped materials and were modified whenever necessary. Some points. however. have shown to be generally critical.

- Dimensions:
  The dimensions of the available products differ from other panel products being smaller and thicker than for example gypsum [5]. [6]. [7] or wood panels [8]. as their density is higher. Therefore. test samples cannot be prepared out of those earth panels which are less wide than the smallest dimension required.
- Missing references for requirements:
  For some requirements that are to be defined for earth boards no reference values do exist. especially concerning the acceptable deformation under the influence of humidity. This is of utmost importance as swelling and shrinking after the implementation may lead to permanent deformations or cracks of the panels and / or the rendering.

All panelling products come within DIN 4103-1 [9] and have to meet the requirements applicable to non-loadbearing partitions. Those regard. between others. the limit bending strength and the resistance to soft and hard impacts. Tests have shown that the latter seems to be influenced considerably by the reinforced thin-layer rendering. The proposed requirements and test setups are to ensure the suitability of earth panels for use in the system specified by the manufacturer. The compliance with the regulations for earth panels however does not induce the suitability of the complete system.

Test procedures

Dimensional accuracy and evenness

Like any other building material earth panels are subject to variations due to production factors. Those are particularly noticeable in the dimensions and can cause considerable expenditure. While deviations of length. width. orthogonality and density rarely present relevant issues in practice. others can effect additional efforts. For example. the excessive length of a panel must be compensated by one of the following methods:

- Offset the following panels in the row
- Shorten the panel with a lattice plaster plane or saw
- Shorten of a following panel
- Combine with a short panel

The excessive thickness of a panel. however. requires a thicker plastering on the complete wall surface. For example. to level a local deviation of 1 mm on a surface of 10 m^2. approximately 14 kg (dry weight) of plaster are necessary. As thin layer plastering usually have a thickness of 2 to 3 mm. this equals an additional effort of 30 to 50 %. not to mention the time delay. Therefore. in the draft standard classes of dimensional accuracy are proposed. which must be declared by the manufacturer.

Length. width. orthogonality and thickness of five panels are determined with metallic meters. callipers and angles. Length and width are documented with an accuracy of 1 mm. angles and thickness are documented with an accuracy of 0.1 mm. Location and number of measuring points and axes are shown in figure 1.

To determine the evenness. the specimens are laid on an even surface. A straightedge is put upon all edges and the two diagonals of the panel. The widest gap between the panel and the straightedge is measured with a measuring wedge.

Bulk density

The knowledge of the bulk density of an earth panel is important. not only for quality and production control. but also for load assumptions in the context of static calculations and the estimation of acoustic insulation. Similar to [12]-[14] the classes of bulk density can be defined as follows.

To determine the bulk density. two rectangular specimens are cut out of three panels each. Each has to measure at least 10 × 10 cm and has to be conditioned at (23 ± 2) °C/ (50 ± 5) % RH until constant weight is reached. All specimens are weighted. and lengths. widths and thicknesses are measured on the central axes and the central point. The bulk density is the ratio of weight and volume.

The average of the six values indicates the bulk density class according to Table 4. given that the six single values do not differ more than ± 10% from the average value.

Bulk density class	**Average bulk density** kg/dm^3
0.8	0.30 to 0.80
1.0	0.81 to 1.00
1.2	1.01 to 1.20
1.4	1.21 to 1.40
1.6	1.41 to 1.60
1.8	1.61 to 1.80
2.0	1.81 to 2.00
2.2	2.01 to 2.20

Table 4 Proposed bulk density classes of earth panels

Bending strength

The bending strength of earth panels is especially relevant relating to their resistance to static loads. Moreover. it influences the handling of the panels and their reaction to console loads. Therefore it is important to both panelling and planking.

Several sources provide test procedures for the determination of the bending strength or limit bending load of panels that are suited for light partitions. Four different methods to determine bending strength have been chosen. The differences consist in the size of the specimens or in the requirements.

The first tests were done according to DIN EN 520 [5]. As the dimensions required for the specimens were too large for some earth panel products. the tests were repeated with modified dimensions. The results have shown that the requirements for gypsum panels are mostly not fulfilled by earth panels.

The procedures included in DIN 4103-1 [9] and DIN EN 310 [15] have shown to be more appropriate for the intended purpose. DIN 4103-1 [9] requires orthogonal specimens with a length and width corresponding to the distance of the construction studs. Likewise. this distance is factored into the calculation of the failure load that is to be reached. The standard distinguishes two application areas 1 and 2 with different requirements.

$$F'/\gamma_{s.B} \geq 1.5 \times q_{1.2} \times b \qquad (1)$$

F' is the average of the determined failure loads. $\gamma_{s.B}$ a factor that involves the variation of the test results and *b* the width of the specimen. The reference load *q* depends from the application area and equals in case of vertical studs to

- application area 1: q_1 = 0.25 kN/m.
- application area 2: q_2 = 0.50 kN/m.

Use category (ETAG 003)	Application area (DIN 4103-1)	Impact force	Fall height of the pendulum
I	1	100 Nm	0.2 m
II	1	200 Nm	0.4 m
III	2	300 Nm	0.6 m

Table 5 Procedure for the testing of the resistance against soft impact

DIN EN 310 [15] on the other hand defines specimens with a constant width of 50 mm and a length twenty times the thickness. Requirements are defined in DIN 622-4 [16]. distinguishing three ranges according to the thickness. As all tested earth panel products belong into the same range. the minimum bending strength is uniformly 0.80 N/mm^2. All panels were tested only in the situation (horizontally or vertically) indicated by the producers.

Surface tensile strength

The tensile strength of the panel surfaces has high influence on the connection between panel and plastering. Therefore. the surface tensile strength has to reach at least the same minimum value of 0.10 N/mm^2 as earth plasters according to DIN 18947 [14]. Those are determined with the same test procedure which is to be found in DIN 1015-12 [17]. A steel cylinder with a diameter of 50 mm is glued to the specimen and pulled off with a test machine. The maximum load is documented as failure load. Differing from the standard procedure. earth panels are tested without drilling ring grooves.

Console loads

Partitions must allow to fix light console loads on every spot on their surface. given suited fixtures are being used. DIN 4103-1 [9] describes a component test with a console load of 0.4 kN/m and a minimum bending moment of 0.12 kN/m. By each fixture. a horizontal tensile force and a vertical force of minimum 0.4 kN/m each is acting on the system. Tests can conceivably be carried out with smaller specimens instead of whole panels. Currently. pull-out tests and shear tests are ongoing.

Resistance again soft impact

While many other tests are used to verify the serviceability of the panels. impact tests simulate situations that can constitute safety issues and display the ultimate limit state. According to DIN 4103-1 [9]. sufficient resistance against the brunt of a human body (soft impact) must be proven. According to the standard impacts may damage but must not destroy a partition. i.e. pull them off the fixtures or push through the complete wall. Applied to earth panels on frameworks. the most suggestive criterion is tear of the panels off their fixtures. as this allows the whole panel or parts of it to collapse. To test the resistance to soft impact. a bag with 50 kg of glass spheres is swung against the partition. If the distance of two studs is lower or equal to 0.625 m. the partition can be tested upon the studs. Otherwise. the bag has to hit the most vulnerable location. Table 5 shows the test modalities and how to transfer from use categories according to ETAG 003 [18] to application areas as stated in DIN 4103-1 [9].

Resistance against hard impact

The test of the hard impact corresponds to the test of the soft impact. Again the whole panels are fixed on a sub construction. but tested with a steel ball of

Fig. 2 Test stand for the conduct of the soft impact according to DIN 4103-1 [9].

1 kg weight. This is swung to the vertical surface or is dropped from 1 m height on the horizontal surface. Each panel is tested on 15 spots that are situated in the least stable areas of the panel. Up to 15 specimens can be used to create enough test spots. The weak areas are. if unknown. to be determined experimentally. The failure criteria are the same as in the case of the soft impact.

Surface hardness

Wall surfaces, especially in corridors and areas with increased public business, are exposed to frequent strain, for example by luggage pieces or prams. Therefore, earth panels have, besides reaching a minimum value, to fulfil a higher requirement if used in areas like schools or dormitories.

The test procedure is based on DIN EN 520 [5]. A steel ball with a mass of 500 g is dropped from a height of 0.5 m to a specimen that is covered with coal paper. The fall leaves a circular imprint of earth on the surface of the paper. The diameter of this imprint is documented.

One specimen has to measure at least 200 x 300 mm. The average diameter of the imprints must not exceed 25 mm. If it remains under 15 mm, the panels can be declared as possessing an increased surface hardness.

Humidity influence

Sometimes, earth plastering on earth panels can show cracks, often following the bed joints. This may be caused by tensions that are formed during the drying of the plaster. Similar to the contact test with earth blocks according to Din 18947 [14], the reaction of earth panels to the water introduced by plaster is investigated.

A specimen of 200 x 250 mm is covered with humid medical fleeces that cede part of the contained water to the panel. This causes a humidity gradient that leads to flexing and restraint stresses. The deformation is documented with transducers. The test is to be performed under standard climate.

Preliminary results and discussions

Dimensional accuracy and evenness

The evaluation of dimensional accuracy and evenness follows DIN EN 520 [5] and DIN EN 722-20 [11]. Both average and extreme criteria are applied. The average of the single values of one panel must not exceed the acceptable deviations stated in Table 3. The difference of the extreme values must not exceed the range given by the positive and negative deviations. To declare a specific DAC, 4 of 5 panels must fulfil those requirements. Table 6 gives an ex-

Table 6 Evaluation of thickness measurement results

Product	Specimen	Average deviation	Maximum single deviation	Minimum single deviation	Difference of extreme values	DAC to declare
F	Specimen 1	0.5	2.3	-1.1	3.4	2
	Specimen 2	0.3	1.9	-1.2	3.1	
	Specimen 3	-0.9	0.3	-2.6	2.9	
	Specimen 4	-1.0	0.2	-2.2	2.3	
	Specimen 5	-0.8	0.6	-2.3	2.9	
G	Specimen 1	0.0	1.4	-1.3	2.7	Beyond the DAC limits
	Specimen 2	0.8	4.6	-1.0	5.6	
	Specimen 3	1.3	5.4	-1.8	7.3 !	
	Specimen 4	2.1	5.6	-0.7	6.3 !	
	Specimen 5	1.5	3.5	0.1	3.4	
D [1]	Specimen 1	0.2	0.7	-0.9	1.6	1
	Specimen 2	0.2	0.9	-0.9	1.8	
	Specimen 3	0.1	0.4	-1.0	1.4	

[1] *At the time of publication, results for only three of the samples of product D were available.*

Product	Position	Normative failure load kN	Requirement kN	
			Stress Situation 1	Stress Situation 2
A	T	0.22	0.12	0.23
B	T	0.46	0.23	0.47
	L	0.64	0.23	0.47
C	L	0.18	0.09	0.19
D	L	0.29	0.09	0.19
E	T	0.65	0.23	0.47
F	T	0.74	0.23	0.45
	L	0.72	0.23	0.45
G	T	0.23	0.12	0.24
	L	0.23	0.12	0.23
H	T	0.48	0.12	0.24
	L	0.50	0.12	0.23

Table 7 Comparison of normative failure loads and requirements according to DIN EN 4103-1 [9]

ample for the evaluation of the results of thickness measurements.

The absolute average deviation from the nominal value of product F does not exceed 1.0 mm (DAC I according to Table 3). The differences of the extreme values, however, show values between 2.3 mm to 3.4 mm and cause the product to range in DAC II. The average deviation values of product D remain below 1.0 mm, the differences of the extreme values with a maximum of 1.8 mm are in the range of DAC I as well. 4 of the 5 average values of product G allow to be classed with DAC II, but 2 specimens carry differences of the extreme values that exceed 6.0 mm and are therefore not acceptable.

Bulk density

The upper chart in Figure 3 includes 11 different earth panel products and shows the maximum deviation of the single values from the average value. Only the deviation of product G exceeds the acceptable deviation of 10%. In the lower chart of Figure 3 the measured bulk densities are compared with the nominal values. The products G, H and I clearly exceed the nominal densities, thereby causing their assignment in higher density classes according to Table 4. Instead of class 1.4 (1.21 to 1.40 kg/dm^3), both range in class 1.6 (1.41 to 1.6 kg/dm^3). Product K, on the other hand, has to be assigned to class 1.4 instead of class 1.6.

Bending strength

Table 7 lists the normative failure loads of 8 earth panels and the corresponding requirements in the application areas 1 and 2 according to 4103-1 [9]. Figure 4 shows the bending strengths determined according to DIN EN 310 [15] in comparison to the requirements of DIN 622-4 [16].

Both procedures are suited for the testing of earth panels. The minimum requirements are in both cases fulfilled by all products. The decision for one of these procedures will be guided by considerations of practicability, effort and comparability of the results.

Surface tensile strength

To drill ring grooves into earth panels requires a lot of efforts. The panels are easily damaged, but also the wearout of the drills very high. A few tests have shown that specimens with ring grooves provide a clearly reduced surface tensile strength. This is probably due to failure of the reinforcement grid that is cut in the process of drilling. Therefore, testing without ring grooves is recommended. Apart from this modification, the tests can be done according to DIN 18947 [14]. Figure 5 shows the results of the tests without ring grooves. While product A fails the proposed threshold of 10 N/mm^2 only slightly, the products C, D and E remain clearly below this value. All products exceed a value of 0.05 N/mm^2, which cor-

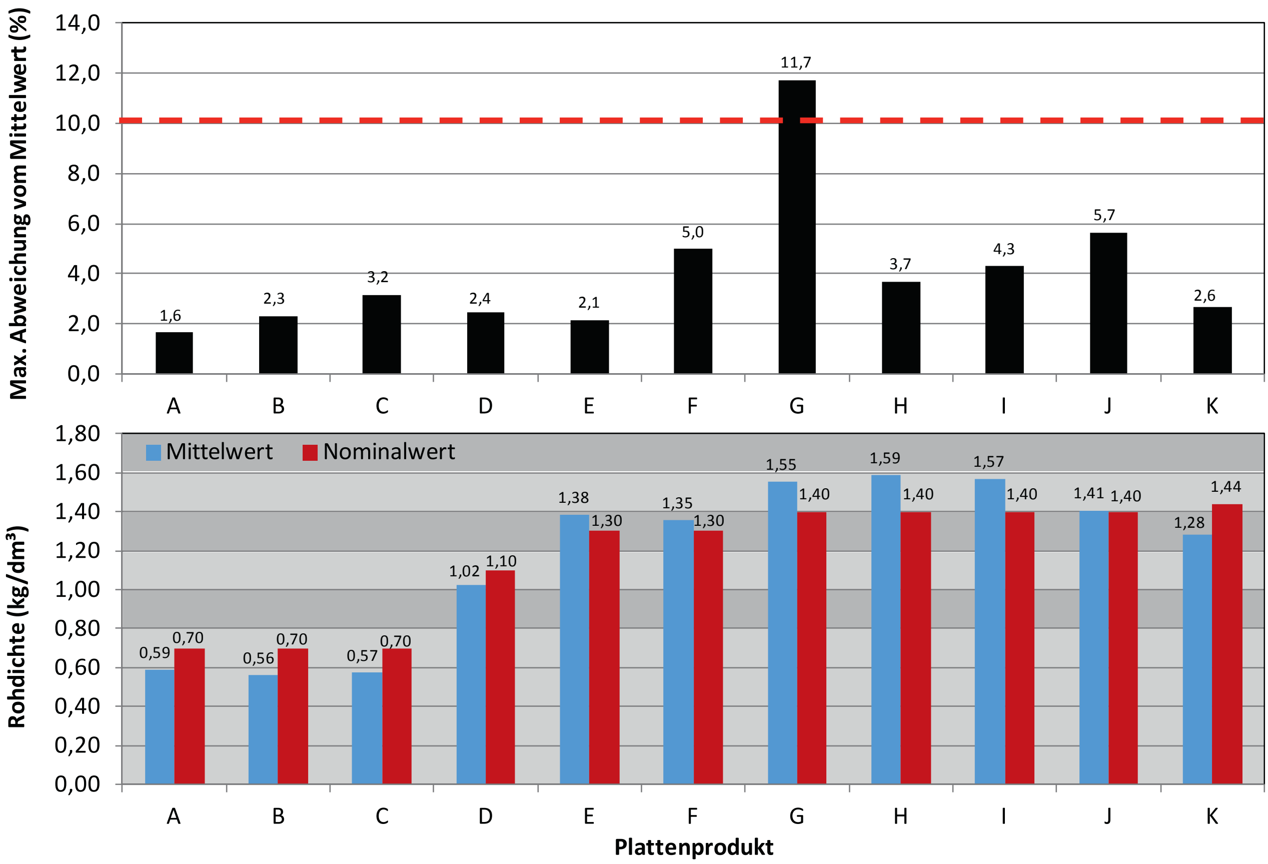


Fig. 3 Bulk density of earth panels. Maximum deviation of the single values from the average value (above) and comparison of the test results with the nominal values indicated by the producers (below).

responds to the minimum adhesive pull-off strength of earth plasters class S I according to DIN 18947 [14].

Resistance against soft impact

All panels were first tested without plastering. The impact bag always hit upon the stud. With one exception, no product failed in use category I and II according to ETAG 003 [18] or application area 1 according to DIN 4103-1 [9]. This one product showed failure in form of fracture. The other products only failed exposed to a hit force corresponding to use category III, generally tearing off one or several fixtures.

The resistance of earth panels seems to be influenced positively by the application of reinforced plastering. The product that had failed in the tests with low impact loads did now resist even to the highest impact loads without damage.

Resistance against hard impact

The resistance against hard impact has shown to resemble the resistance against soft impact. Again, only one product showed failure in form of fracture and passed the test after the application of reinforced plastering.

Surface hardness

The test results have shown that all products fulfil the minimum requirements, i.e. the diameter of the imprint caused by the steel ball remained below 25 mm (Figure 6). It was observed again that the surface hardness is increased by plastering (see products B and E in figure 6).

Summary and outlook

At present, earth panels come within the Rules of Earth Construction [20], which do not describe some of the essential requirements and features. However, earth panels that are used for planking of inner non load-bearing partitions have to meet the demands of DIN 4103-1 [9].

To further establish earth panels, it is necessary to increase the product quality, to define features and to control these characteristics adequately. The investigations presented in this contribution and the proposed draft standard form for the first time a solid basis for this purpose. The publication of this draft as a technical bulletin of the DVL is scheduled for 2017, to test the proposed procedures in practice. Afterwards it is planned to be transferred into a DIN standard.

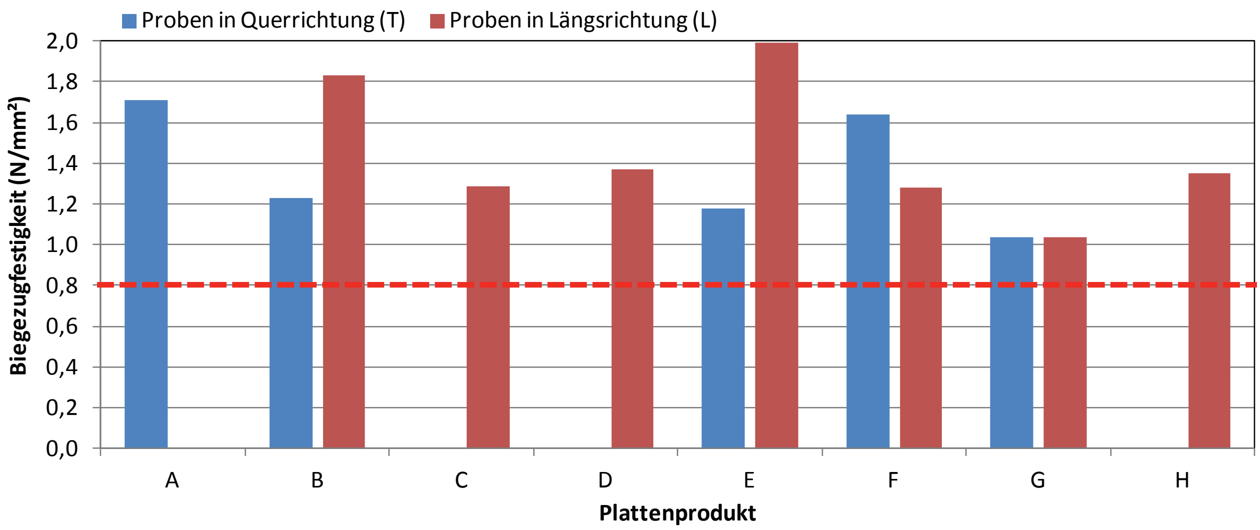


Fig. 4 Results of bending strength tests following DIN EN 310 [15].

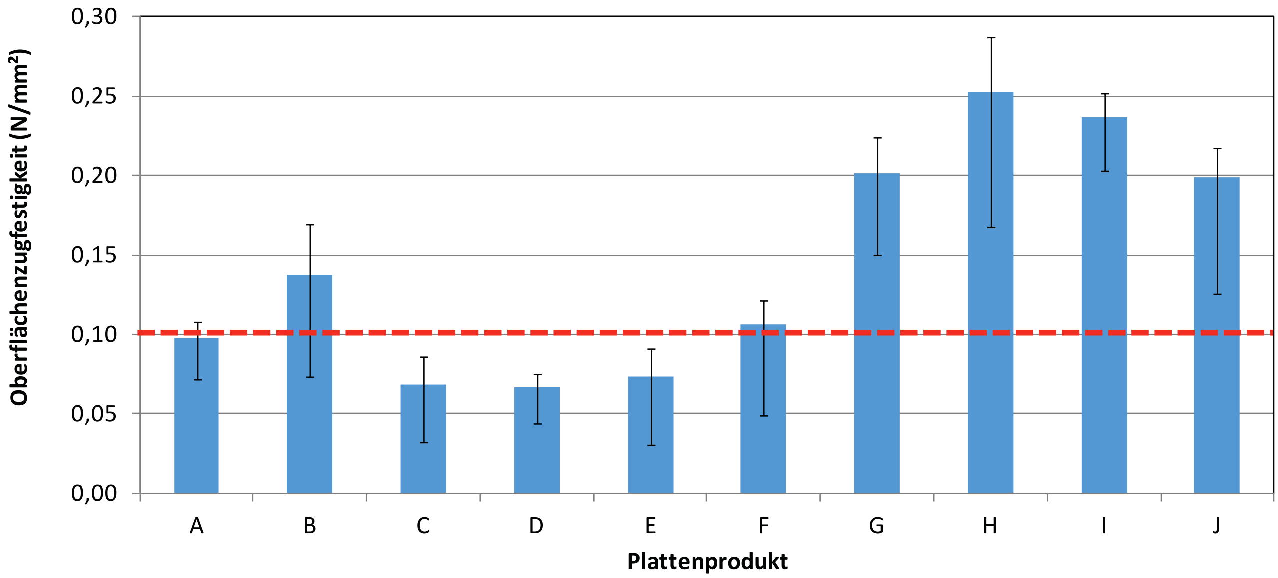


Fig. 5 Average values of the surface tensile strength without ring grooves. The error bars indicate the maximum and minimum single values

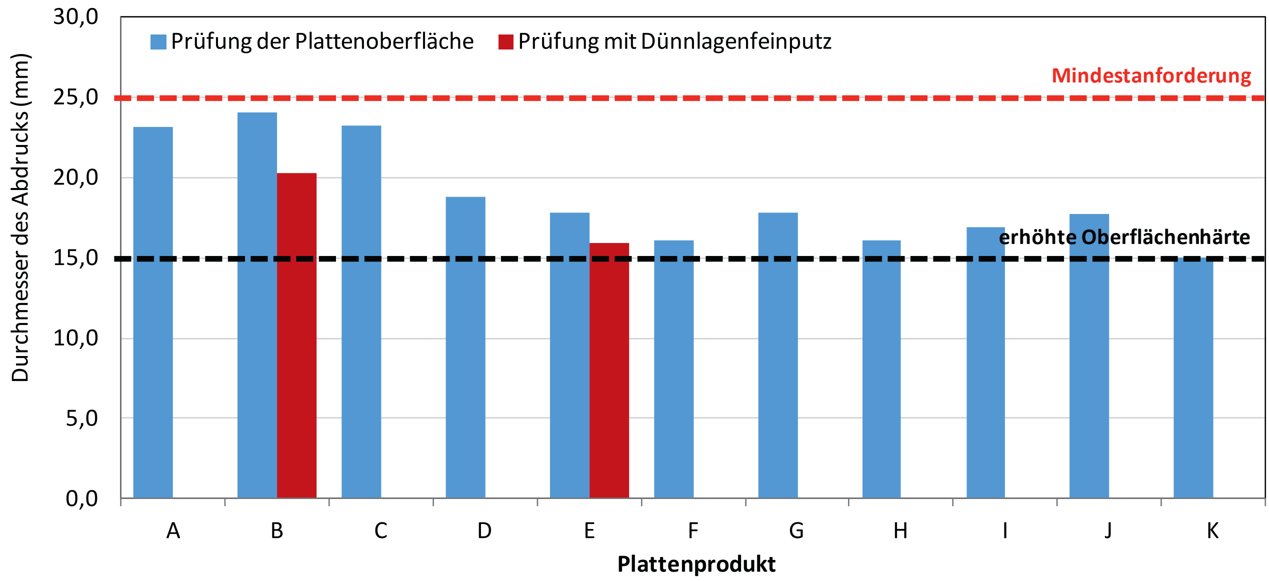


Fig. 6 Results of surface hardness tests

The weakest feature of the currently available earth panels is generally their low tensile strength. This can cause damages during processing or also afterwards, during use. Most panels are reinforced with fibres, grids beneath the surfaces or reed in their core that improve the tensile strength considerably. Nonetheless, careless handling often leads to damages. In some cases the spacing of the framework sub-construction is small and causes high material and time effort.

Furthermore, the knowledge about the mechanism of adsorption and desorption – as in general about earthen building products– needs to be extended to prevent damages and to allow for the full benefit of their climate regulation potential. This is maybe one of the most pressing needs for further research in this field. Similar findings applies to the adsorption of odours, heat storage capacity and acoustic insulation. Those features belong to the strongest arguments when the advantages of earthen materials are emphasised in comparison to conventional building products. But, there is still a need for detailed research that quantifies these features in comparing investigations. Nevertheless, the presented studies have shown that earth panels can equal the quality of other commercially available products.

Acknowledgements

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