

EXPERIMENTAL ANALYSIS OF PHYSICAL PROPERTIES OF LIGHTWEIGHT GYPSUM PLASTERBOARD

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ABSTRACT. This article presents an experimental analysis of a newly developed gypsum plasterboard for dry construction. The new board has a density that is 40 kg m^{-3} lower than existing boards and was created with an emphasis on conserving resources and reducing the energy consumption required for its production. Because gypsum is the most energy-intensive raw material, the research team focused on minimizing its content. As a result, the new board uses 12 % of mass less gypsum, which translates into an approximately 6 % reduction in CO₂ emissions from the annual production process. Crucially, this was achieved while meeting the relevant standard requirements for mechanical, thermal-technical, and fire performance, and maintaining the board's "sustainable" user properties. The article details the experimental analysis conducted on key mechanical and thermal-technical parameters of the board.

KEYWORDS: Gypsum plasterboard, lightweight, mechanical properties, experiments.

1. INTRODUCTION

Dry construction in the Czech Republic has seen significant growth since the turn of the 20th and 21st centuries, when this technology underwent substantial refinement at the national level. Today, it is used not only for temporary structures but also for renovations and new buildings. Gypsum plasterboard finds application in both vertical and horizontal structures, offering key advantages such as rapid installation, the avoidance of wet processes, and favourable acoustic and fire performance. Its main drawback is heightened sensitivity to moisture, where a special type of board must be used [1].

Several major producers of plasterboard operate in the Czech Republic, across Europe, and worldwide, including Knauf Praha, spol. s r.o. All these manufacturers continually strive to improve and innovate their products, with particular attention to principles of the circular economy and energy efficiency.

This article introduces a new, lighter plasterboard for sustainable construction (from the current density of 760 kg m^{-3} down to 720 kg m^{-3}). The manufacturer's aim is to make the production process more environmentally friendly while maintaining, as far as possible, the same user and technical properties. A research team at the Czech Technical University (CTU) validated the key parameters of the newly developed board and compared them with the original formulation. The main innovation lies in reducing the board's

gypsum content; in the next phase, there will be a focus on maximizing the use of organic (and therefore renewable) additives.

The new board must comply with the mandatory requirements for performance properties under EN 520:2004+A1:2009 [2], which include aspects such as strength, acoustics, and thermal performance. Dry construction continues to increase its market share, with plasterboard serving as its core component. Moreover, the advent of multi-story timber buildings will further boost the role of plasterboard in providing fire protection.

2. WEIGHT REDUCTION IN GENERAL, RESEARCH BACKGROUND, AND PRACTICAL APPLICATION

Reducing the weight of the board, conserving gypsum (a strategic raw material), and thereby lowering CO₂ emissions during production all address market demands and evolving legislation, while still meeting the requirements of applicable building standards. In the context of plasterboard innovation, the specifications of EN 520:2004+A1:2009 [2] are both authoritative and limiting. Failure to comply with these standards would necessitate obtaining a standalone European Technical Approval for the new board a protracted process.

For the practical use of new boards, it is essential to describe and quantify their key properties so that

it is clear which structural requirements they fulfil or do not fulfil, as well as the performance range they will achieve. Experience from abroad shows that such a board simply represents a new market segment that complements the existing one. Similar boards have the longest history in the United States, where they have been in use for several decades and where it first became evident how technologically and financially demanding it is to manufacture them. Any “weight reduction” i.e., decreasing the gypsum content must go hand in hand with ensuring usability for future customers.

3. TESTING METHODOLOGY

Testing mechanical and other physical properties is therefore one of the basic ways to verify the quality and required resistance of newly developed plasterboards [3–5] and also how to certify a new product and bring it to the market. It is possible to combine small-format and large-format tests, which can then be used, for example, for validating computational models [6]. The laboratories of the University Centre for Energy-Efficient Buildings and the Faculty of Civil Engineering at the Czech Technical University in Prague tested the mechanical and thermal-technical properties of plasterboard. This was a comparative study of standard and lightweight boards, both with a uniform thickness of 12.5 mm. The set labelled A represented the standard board, while set B contained the lightweight board. The company Knauf Praha, spol. s r.o. supplied samples with standard dimensions to the laboratories: 10 samples from one set for mechanical tests and 8 samples from one set for determining the thermal conductivity coefficient. The samples for mechanical testing were conditioned at a temperature of 20 °C and a relative humidity of 65 %.

3.1. DETERMINATION OF EMBEDMENT STRENGTH AT THE FASTENER LOCATION

The purpose of this test is to determine the embedment strength at the fastener location. During the test, a continuous record was taken of both the applied load and the vertical displacement of the plasterboard.

The board was attached by means of a Knauf TN 55 drywall screw to two anchoring L-profiles, which form part of the testing apparatus. Both L-profiles are made of P8 steel sheet (strength class S235) and are connected to a P8 steel base plate by four M6 bolts of grade 8.8. The TN 55 screw passed through the center of the board’s height and through pre-drilled holes in the anchoring L-profiles. To reduce friction between the steel L-profiles and the board, a polyamide strip was placed on both sides. The load was applied to the board’s centroid via a loading cylinder acting on a P4 S235 distribution plate.

Testing of the specimens followed the procedure specified in EN 383:2007 [7]. The load was controlled according to the standardized load diagram: first, the

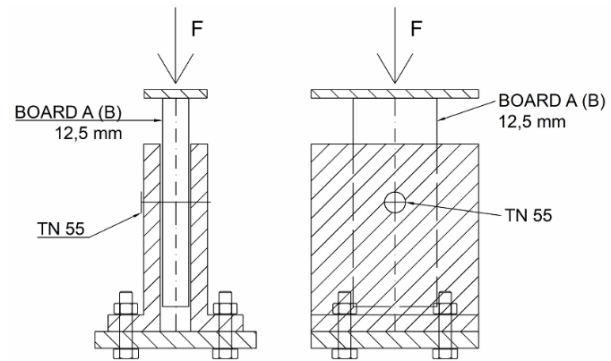


FIGURE 1. Schematic of the embedment strength test at the fastener location.

board was loaded to 40 % of the estimated maximum load (F_{est}), then the load was reduced to 10 % of F_{est} , and finally increased until the specimen breaks or reached the limit displacement. The specimen was positioned in the testing apparatus so as to allow vertical deformation of the board and thus embedment at the fastener location. The test setup, including the applied load, is illustrated in Figure 1. Testing of all specimens was terminated either after 300 ± 120 s or upon reaching the 5 mm deformation limit in accordance with [7].

For all specimens, the applied load and the corresponding deformation of the board were monitored. Deformation was measured continuously by inductive LVDT sensors installed on both side edges of the board at the fastener’s height. The average reading from these LVDT sensors was used for data evaluation.

3.2. HEAD PULL-THROUGH RESISTANCE TEST

The purpose of this test was to determine the load capacity of the screw connection under axial loading – i.e., in the same direction that the screw is driven into the material.

This test is essential for evaluating the resistance of the board against localized failure caused by the screw head pulling through the surface. In practical applications, such as suspended ceilings, cladding systems, or other constructions where boards are fastened using screws, this type of failure is a critical mode of concern. A high pull-through resistance ensures a secure and long-lasting connection between the board and the supporting structure, particularly under long-term loads or dynamic effects. Therefore, the results of this test directly reflect the reliability and performance of the board in real-life installation scenarios. The test was performed in accordance with the standard EN 14566:2008+A1:2009 [8], which specifies the requirements and testing procedures for mechanical fasteners used in gypsum plasterboard systems.

The test specimen was placed in the apparatus so that the plasterboard was fully supported. A portion of the screw was secured into a polyamide plate, which forms part of the testing setup and is attached to the hydraulic cylinder via steel side plates and an M6

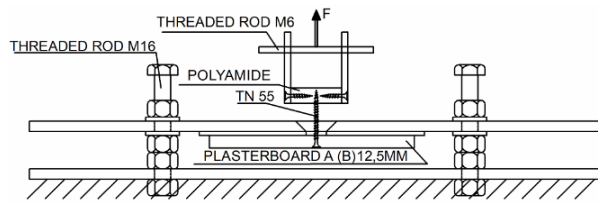


FIGURE 2. Schematic of the head pull-through resistance test.

threaded rod. A schematic of the test arrangement is shown in Figure 2.

Throughout the experiment, the tensile force was recorded, and its maximum value served as the primary test outcome. The vertical displacement of the loading device was also monitored.

3.3. FLEXURAL STRENGTH TEST

One of the fundamental mechanical properties specified by EN 520:2004+A1:2009 [2] is the minimum flexural strength (flexural breaking load). According to the standard, test specimens measure 400×300 mm and are tested in both the longitudinal and transverse directions, with the longitudinal direction being decisive. Testing follows a three-point bending method with a 350 mm support span (see Figure 3). The load is increased at a rate of 250 ± 50 N min⁻¹, and the total duration from the start of loading until failure must exceed 20 seconds. The test continues until the specimen breaks and is carried out under displacement control, with a verified speed of 2 mm min⁻¹.

We can use the optical correlation to evaluate tensile strength in bending of plasterboard [9].

A supplementary test of strength is the shear strength test [10], but this test was not part of this test block.

3.4. THERMAL CONDUCTIVITY COEFFICIENT

The thermal conductivity coefficient (λ -value) is a fundamental parameter that describes the ability of a material to conduct heat. Its value depends on various factors, such as the chemical composition, moisture content, temperature, density, and porosity of the material. This parameter is typically determined using experimental methods. Generally, effective insulation will have a λ -value as low as possible to minimize heat loss.

In this study, a commercially available portable heat transfer analyser, the ISOMET 2104 from Applied Precision Ltd. (Figure 4), was used, which comes with interchangeable needle and surface sensors of various ranges supplied by the manufacturer. This device is suitable for measuring heat transfer properties across a wide range of isotropic materials and offers several advantages, including the direct measurement of thermal-technical properties, portability, and a relatively short measurement time. The λ -value measurement is based on the temperature analysis response of the analysed test specimen to heat flow

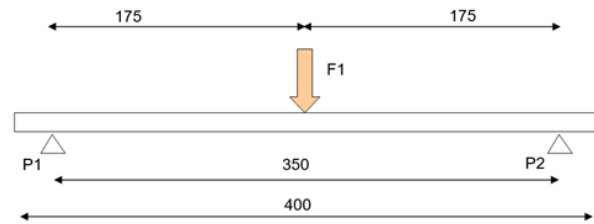


FIGURE 3. Static schematic of the flexural tension strength test.



FIGURE 4. Measurement of thermal properties using the ISOMET 2104.

impulses. For accurate measurements, a surface probe with a 60 mm diameter was placed in proper contact with a flat sample (300×300 mm), and measurements were taken at multiple locations on the sample.

4. RESULTS COMPARISON

In this section, there are present a comparison of the results for the above-described properties of standard and lightweight boards based on the experimental analysis.

4.1. EMBEDMENT STRENGTH AT THE FASTENER LOCATION

All ten specimens were break in the expected manner – by embedment of the board at the fastener location (see Figure 5). Compared with the standard boards in set A, the lightweight boards in set B exhibited an 11.5% decrease in the characteristic embedment strength $f_{h,k}$. With regard to the average foundation modulus $K_{s,mean}$, there was a 5.1% reduction for the lightweight boards, and a 5.3% reduction for the elastic foundation modulus.

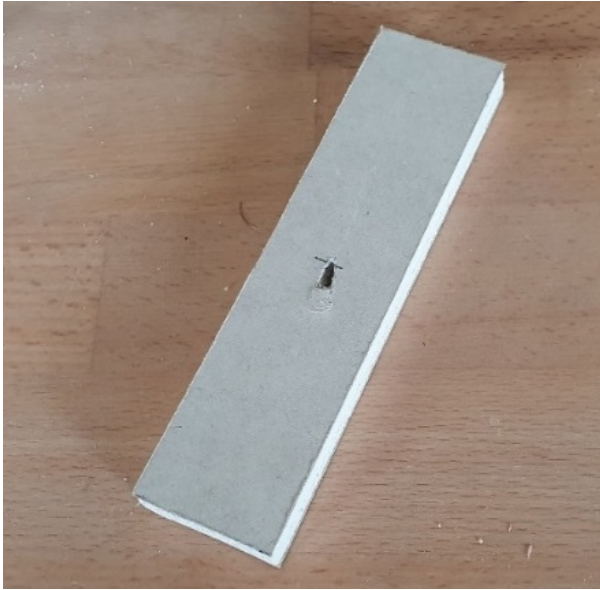


FIGURE 5. Typical failure mode of an experimental specimen via indentation at the fastener location.

4.2. AXIAL LOADING OF THE FASTENER

The primary result of this test was the maximum load reached during loading – that is, the screw’s pull-through resistance. Compared with the standard boards in set A, the lightweight boards in set B showed a 15.4% decrease in their characteristic pull-through capacity.

4.3. FLEXURAL STRENGTH TEST

According to EN 520:2004+A1:2009 [2], 12.5 mm gypsum plasterboards must achieve a minimum flexural breaking load of 210 N in the transverse direction and 550 N in the longitudinal direction. The crucial parameter is the longitudinal bending strength (in the direction of flow of mixture during production). Both boards satisfy the longitudinal strength requirement, and the strength values for the standard and lightweight boards are nearly identical. The original (standard) board, made using the existing formulation, exceeds 610 N, while the lightweight boards attain flexural breaking loads only 3.5% lower on average. The process of the test can be seen in Figure 6.

4.4. THERMAL CONDUCTIVITY MEASUREMENT

The thermal conductivity measurement results for both the standard and lightweight boards are presented in Table 1. The average value is calculated based on all eight samples from a single set of test specimens.

In the comparison between standard and lightweight gypsum boards, standard boards typically have a higher bulk density, which results in a higher thermal conductivity coefficient. This means they transfer heat more efficiently but provide less insulation. In contrast, lightweight gypsum boards are designed with a lower bulk density, often incorporating air pockets

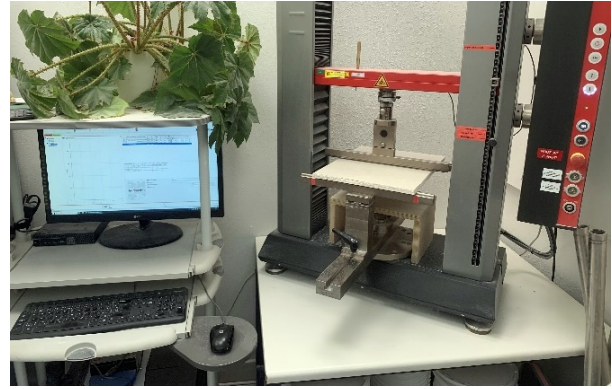


FIGURE 6. Flexural strength test.

	λ_A [W (mK)^{-1}]	λ_B [W (mK)^{-1}]
1	0.181	0.171
2	0.180	0.172
3	0.185	0.176
4	0.185	0.175
5	0.192	0.176
6	0.194	0.175
7	0.189	0.172
8	0.182	0.171
Average	0.1860	0.1735
STDev	0.0048	0.0021

TABLE 1. Results of thermal conductivity coefficient measurements for standard and lightweight boards.

or lightweight fillers. These modifications reduce their thermal conductivity coefficient.

5. CONTINUITY TO FULL-SCALE CONSTRUCTION EXPERIMENTS

The initial motivation for this project stemmed from comparative bending tests on full-scale wall assemblies, designed to show how altering the plasterboard type would affect partition wall performance. Identical wall sections were fabricated from both board types and tested horizontally to assess their flexural stiffness. However, it became clear that to ensure identical conditions for both sets of specimens – and thus derive valid results a large number of production steps had to be carefully controlled, making the entire process much more time-consuming than anticipated. Therefore, as part of this project, methods were developed to enable faster, more efficient, and above all more meaningful comparisons of the boards’ parameters.

The results from these bending tests on the same wall panels confirmed that one cannot reliably infer the actual behavior of gypsum boards built into a partition from their similar flexural tensile strength values per EN 520:2004+A1:2009 [2]. Moreover, preparing completely identical test specimens for partition walls with different boards proved both technically challenging and time intensive.

Consequently, the focus shifted to simpler tests on smaller samples – specifically, embedment strength tests at the fastener location and axial loading of the fastener. By applying an appropriate schematic model, these tests can predict how gypsum boards and steel framing interact, thus providing a fairly precise estimate of how partitions made from different boards will ultimately perform.

The findings from this project now serve as a valuable foundation for planning, conducting, and evaluating the results of large-scale structural tests.

6. CONCLUSION

The use of circular economy principles in material design is increasingly important for advancing sustainability in the building sector. Lightweight gypsum plasterboard is an alternative to standard gypsum board, designed to reduce weight and make transportation, use and installation easier. This reduces costs and time by increasing the quantity of gypsum boards transported in a container or truck, thereby enhancing overall efficiency and logistics. It also improves worker safety during handling. It can be manufactured in standard sizes and thicknesses and features an easy score and snap-cutting method, making it a preferred choice for both residential and commercial construction projects and ensuring straightforward and efficient installation.

In summary, this experimental analysis demonstrates the potential of lightweight gypsum plasterboard to improve sustainability and resource efficiency in dry construction. By reducing the density by 40 kg m^{-3} compared to conventional boards, the new product becomes lighter and easier to handle, offering potential savings in transportation and installation costs, as well as generating less waste. Moreover, reducing the gypsum content by 12% of mass results in an approximately 6% decrease in CO_2 emissions from annual production. This reduction is a significant step toward decreasing the energy consumption typically required for gypsum production, making the new board more energy-efficient than its traditional counterparts.

Additionally, the shift towards using organic additives derived from renewable chemical substances, replacing some of the non-renewable inorganic materials, further enhances the environmental sustainability of the product. This change reduces reliance on finite resources and promotes a circular economy within the construction industry, potentially contributing to certifications such as LEED by supporting environmentally sustainable practices.

This study emphasizes the importance of developing gypsum boards that not only adhere to current standard requirements for production but also maintain sustainable performance characteristics. These include essential mechanical, thermal, and fire-resistant properties. Balancing these factors is crucial to achieving both environmental and functional goals.

In conclusion, this study demonstrates that lightweight, resource-efficient gypsum boards offer a viable solution for advancing sustainability in dry construction, balancing environmental benefits with functional performance, without compromising established standards or functional performance.

LIST OF SYMBOLS

λ thermal conductivity coefficient [W (mK)^{-1}]

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