STUDY OF FLEXURAL AND YIELD STRENGTH OF GYPSUM COMPOSITE BOARDS

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Abstract. The material under study in this paper is a gypsum composite board, which is a sustainable material, and therefore attracts scientists' attention in the recent years. This material is of a great importance for Latvian economy, since Latvia has gypsum mining sites and has developed a tradition of gypsum manufacturing. The goal of the study was to compare the mechanical properties of gypsum boards from different manufacturers. For comparison of strength one cement board was tested as well. To complete the study a specific experimental setup was developed and is demonstrated in this paper. The results obtained are experimental values, useful for a scientific community because these can be used for CAD modelling in the future. In this paper the experimental results were used to create FEM models in ANSYS program and complete simulation. It was discovered that some gypsum boards have different physical properties in longitudinal and transverse directions, while for other properties do not differ depending on the direction. In this study, the cheapest board had the yield stress of 2.76 MPa in the longitudinal direction, 1.87 MPa in the transverse direction, while the more expensive board was homogeneous, and the physical properties did not change depending on the direction and the average yield stress was 2.19 MPa. The values obtained in the tensile test in other studies of gypsum boards for other manufacturers are even lower - 1.10 MPa in the longitudinal direction and 0.64 MPa in the transverse direction.

Keywords: gypsum board, cement board, flexural strength, yield strength, testing.

Introduction

Gypsum is a building material that has a long-lasting manufacturing tradition in Latvia, and it is getting a recognition today as a sustainable construction material. The manufacturer of gypsum has a logo which tells: "Gypsum is genius". Indeed, this material, used to produce building gypsum, gypsum boards, and blocks has many advantages. Depending on manufactured options, it has good fire resistance. Other researchers reported that it has low energy consumption, high cost performance and efficient thermal and sound insulation [1].

Previously it was believed that gypsum has a fragile nature [2-5], so manufacturers today improved the impact resistance properties to a great extent. Today, visitors of gypsum manufacturing facility are welcomed to test gypsum boards hitting them with box gloves, as well as do a balance exercise (standing on a board that is put on a rolling element) and thus see that a board is very strong. Therefore, it is not only a sustainable material [6], but also strong. To further increase the sustainability of gypsum, researchers introduce a solution, when different waste materials are used for gypsum production [7-10]. Consequently, the strength of a gypsum board varies greatly depending on the product, manufacturer, and quality. The goal of this study therefore was to experimentally test, numerically simulate and compare the mechanical properties of different boards, obtaining values for the boards that were not available before and comparing them to the values available in the literature. The main novelty of the study lies in the experimental setup, which is demonstrated in Materials and methods section.

There are number of standards in the area that manufacturers should respect. In this work we refer to the standards [11] and [12]. Particular attention is paid to the property of a yield stress of the tested materials, the amount of stress at which the material begins to deform plastically.

Experimental tests and statistical analysis of the mechanical properties of gypsum boards were previously described in the literature in the study [13], where tensile and compression experiments were performed on 302 samples with the aim of determining the mechanical properties of gypsum boards. Both tensile and compressive tests were performed according to EN 789 (CEN 2004b). Tension and compression tests [13] were performed for different boards: two different thicknesses of 12.5 and 18 mm and two different densities – standard (standard plasterboards 12SB with a density of 720 $kg \cdot m^{-3}$ and 18SB with a density of 862 $kg \cdot m^{-3}$) and increased density with three different thicknesses (high density plasterboards, 12HDB, 15HDB and 18HDB, and respectively densities of 831, 893 and 920 $kg \cdot m^{-3}$). Such plates are commonly used for partitions, cladding systems and ceilings that require excellent fire, impact and acoustic resistance.

Materials and methods

To determine the mechanical properties products that meet and are harmonized with the EN 520: 2004 + Al:2009 [11] standard were used.

- The following boards were purchased to fulfil the task:
- gypsum board SINIAT, size 12.5x1200x2000 mm, white (alternative 1 BELGIPS), hereinafter – SINIAT;
- gypsum board GKB HRAK, KNAUF, size 12.5x1200x3000 mm, white (2nd alternative BELGIPS), hereinafter – KNAUF;
- fiber cement board Cembrit Multi Force LW, fireproof, manufacturer Cembrit Holding AS, Denmark, size 9x1200x2550 mm, hereinafter – CEMBRIT.

The usual tensile test procedure was not possible to organise, because of the difficulty of creating quality samples for the tensile test and reducing the effect of clamping in the jaws. Therefore, an alternative setup was created in the laboratory for the frame construction of the wall element samples (gypsum boards and cement board cladding) as shown in Fig.1, which corresponds to the average board structure (profile) frame used in small construction objects e.g. elevator cabins, i.e. the support of the sample width is 60 cm, the board length is 120 cm. Accordingly, two loading machines were set up: one with a tube, diameter 30 cm, the other with a square box, section 30 x 30 cm^2, in accordance with the provisions stipulated in the contract. Further, 3 point bending test according to ISO 14125 [14] was made to determine material properties to be used later in FEM computer simulations. Testing speed was controlled by displacement. A speed of 10 mm/min was used to determine the modulus of elasticity, yield stress and strain. Zwick/Roell Z600 equipment was used for the work (calibration certificate for force sensor No. K1906271UH and displacement meter No. T1906262UH). Example of a setup is given in Fig.1.

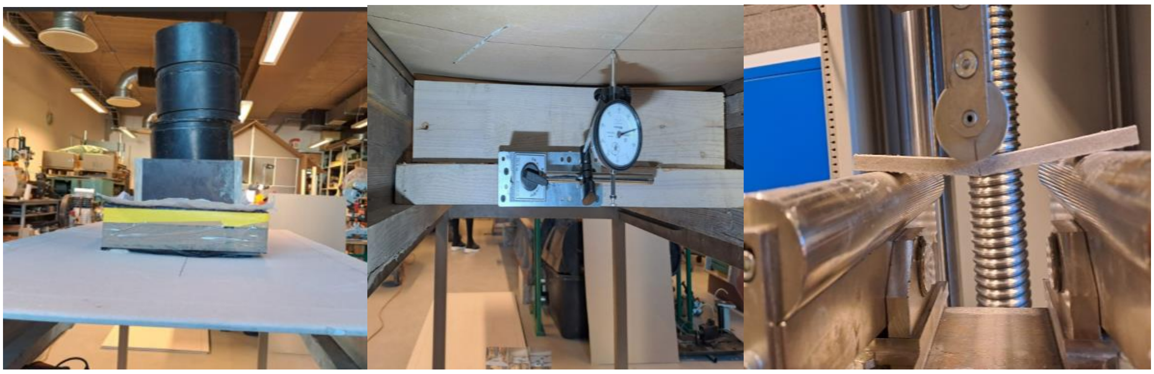

Fig. 1. **Setup of the experiment:** left – view from the top; middle – view from the bottom; right – three-point bending test setup on a Zwick/Roell Z600

Since in the first experiment series not all plates allowed to test the full range of loading due to the cracks which appeared in some plates, additional experiments were repeated with a higher quality sand pad that filled the corners of the square more completely. In Fig.1. the dial indicator (Mitutoyo, Dial Indicator No. 99MAG014M10, Certificate No. 4452274541) is mounted at the center of the plate.

To conclude the work, the FEM analysis was done. 3D simulations were performed with the Ansys Mechanical computer program. The physical properties of the boards were defined using the values determined in the three-point bending test, see Table 1.

Simulation configurations were as follows: board I: 700x1200 mm, considered case with the dimensions of the sheet tested in the laboratory; board II: 700x2000 mm, standard sheet length, one side viewed; board III: 1250x2000 mm, standard sheet; board IV standard sheet: 1250x2000 mm and metal profile frame; board V standard sheet: 1250x2000 mm with defect (a hole) and metal profile frame. All 3 plate types were simulated:

1. SINIAT and KNAUF with a thickness of 12.5 mm;
2. CEMBRIT with a thickness of 9 mm.

The price of one SINIAT board in a local department store was 5.66 EUR, further referred as "cheap", the price of the KNAUF board was 8.30 EUR, the price of the CEMBRIT board was 44.89 EUR and, further referred to as "more expensive".

A force applied at the center of the right side of the horizontal axis of symmetry of the plate is 1000 N on the area of a circle with a diameter of 300 mm, with the same dimensions as in case No. III. The plates are fixed to the frame of the metal profiles, for which the symmetry condition is used, and half of the profile is shown in the z-axis direction. The geometry is simplified according to the UW-type profile with a standard thickness of 0.6 mm (profiles comply with EN 14195 standards). The minimum requirements for material yield stress are 140 MPa. A material with a yield stress of 250 MPa is used in the simulations, which is the average structural steel class value. Modulus of elasticity E = 200 GPa. Finite Element Meshing was as follows (example of board IV): 44677 elements and 190950 node points (SINIAT/KNAUF); 63383 elements and 232659 node points (CEMBRIT).

Results and discussion

First the results of the experiment demonstrated in Fig.1. are presented. The result plot in Fig.2 contains 3 graphs, 3 tests for each material:

1. 01/12/22 is the first test with a round tube with a diameter of 30 cm;
2. 07/12/22 is the second test, where there is a 0.3x0.3 m square, both gypsum board sheets broke;
3. on 09/12/22, the loading test of a 0.3x0.3 m square area was repeated, but with a more evenly spread loading area.

Here, for example, 07/12/22 means that the test was performed on December 7, 2022. Similarly, the others indicate the December date.

After the last two tests it has been found that the gypsum board is not homogeneous. For example, for the KNAUF board test on 09/12/22 a crack appeared relatively far from the center.

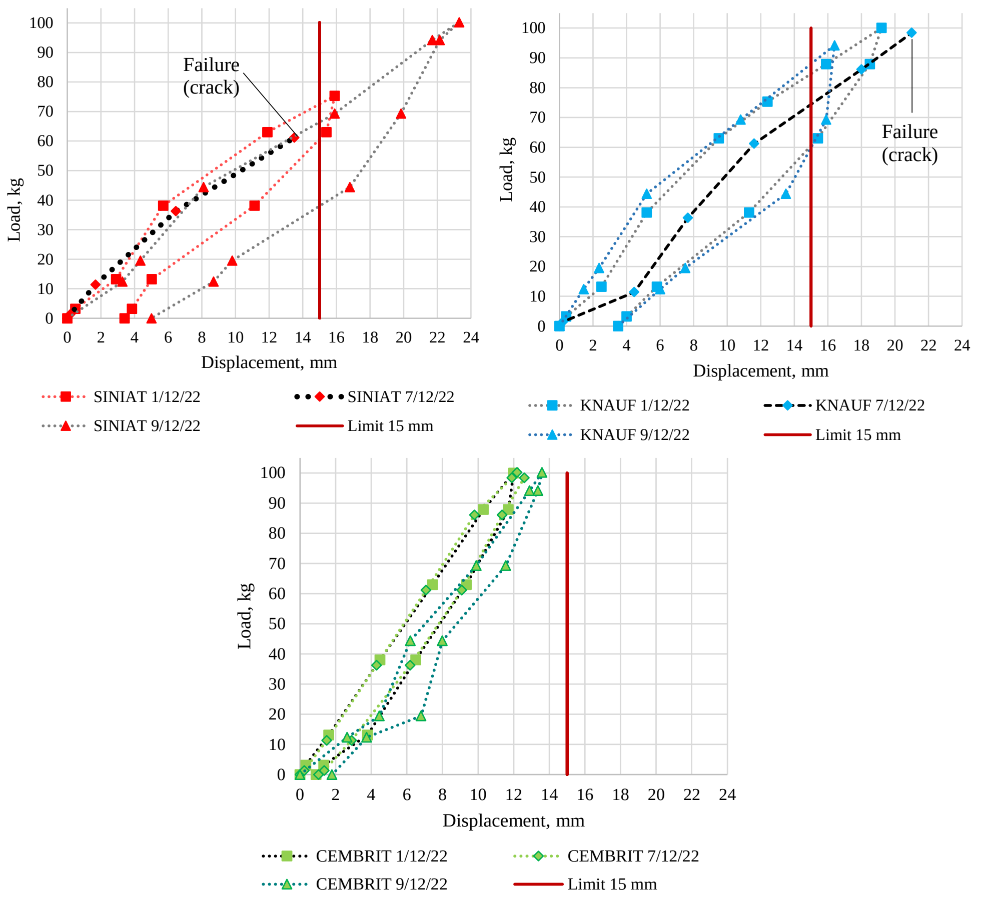

Fig. 2. **Displacement under load:** three tests: 1st December, in a tube with a diameter of 30 cm; 7th December in a square box 30x30 cm^2; 9th December in a square box 30x30 cm^2

Fig. 2. shows that all experiments for KNAUF boards reached maximum deformation of 15 mm, at a maximum load of around 100 kgf (1000 Newtons), although one board cracked at 98.4 kgf applied to it. The permanent deformations exceeded the required limit (1.5 mm) several times. In all experiments for CEMBRIT the maximum deformation was less than 15 mm limit, at a maximum load of around 100 kgf (or 1000 Newtons). In all experiments for CEMBRIT, the permanent deformations did not exceed 1.5 mm. Gypsum plasterboards with enhanced strength are referred as Type R [11]. These boards with specific thickness of 12.5 mm must sustain a flexural breaking load of at least 300 N in transverse direction and 725 N in longitudinal direction. Looking at Fig.2, these values were achieved.

To conclude, from the laboratory experiment setup we observed the following:

1. For gypsum board SINIAT and KNAUF maximum deformation of 15 mm was exceeded, at a maximum load of around 100 kgf (or 1000 Newtons); in all experiments, the residual deformations exceeded the required limit (1.5 mm) several times.
2. For cement fiber board CEMBRIT: in all experiments it was possible to achieve a maximum deformation of less than 15 mm, at a maximum load of around 100 kgf (or 1000 N); in all experiments the remaining deformations did not exceed the required limit (1.5 mm).

Table 1 summarises the mechanical properties obtained from the 3 point bending test, which are as follows:

Table 1

Mechanical properties determined from 3 point bending tests

Property	SINIAT		KNAUF	CEMBRIT
	Longit.	Transv.	Long./Transv.	Long./Transv.
E, MPa	1331.86		1633.96	5119.29
σ_t, MPa	2.76	1.87	2.19	9.33
σ_m, MPa	4.84	2.73	2.65	10.21

Table 1 illustrates that for the SINIAT board, which is a cheapest one, properties in longitudinal and transverse directions are different, while for KNAUF and CEMBRIT boards, which are more expensive, the properties are the same in both directions. The values obtained in the tensile test in other studies of gypsum boards [13] for other manufacturers are even lower - 1.10 MPa in the longitudinal direction and 0.64 MPa in the transverse direction.

Finally, in Fig.3 an example of the simulation results for one version of the board fitted with a frame is given:

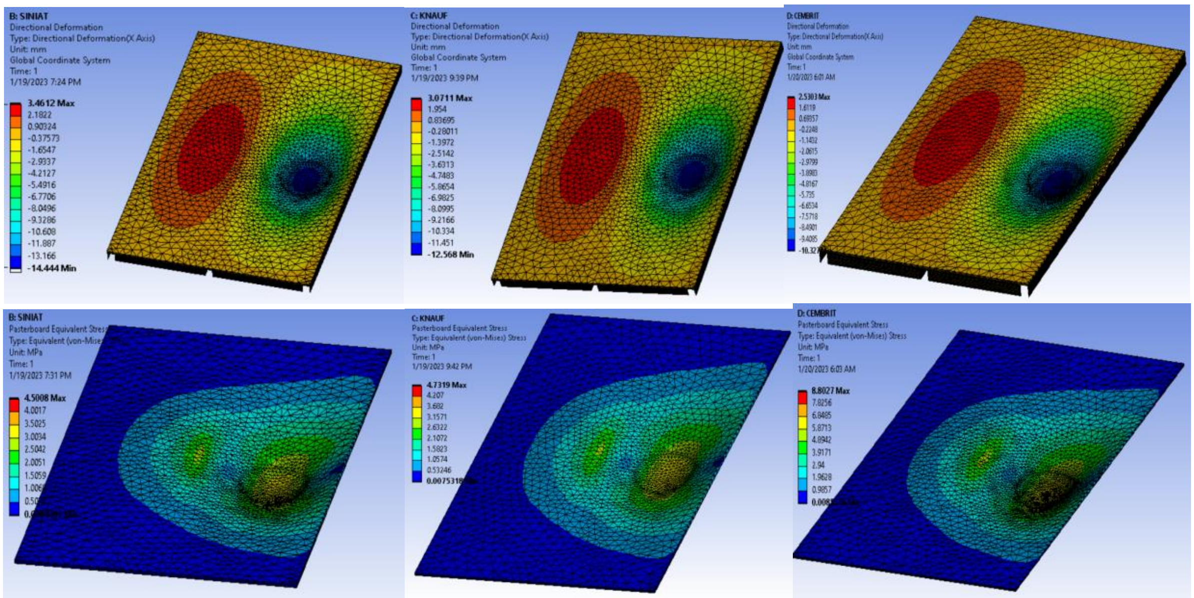

Fig. 3. **Example of simulation results for board version IV:**
1250x2000 mm and metal profile frame

The created FEM model allows to calculate different reinforcements of plate edges, for example, the ends are not supported (this is used in the next task section). Full simulation results are available from the authors. The summary of the simulation results and comparison with the experimental values obtained from the 3 point bending test (referred as "Test") are provided in Table 2.

Table 2

Results of 3D simulation of structural plate loading – maximum stresses in MPa

Manufacturer		**SINIAT**		**KNAUF**		**CEMBRIT**	
Method		**Test**	**FEM**	**Test**	**FEM**	**Test**	**FEM**
Plates	**Nr. I**	1.87	4.87	2.19	4.87	9.33	9.39
	Nr. II	1.87	5.00	2.19	5.00	9.33	9.65
	Nr. III	1.87	4.56	2.19	4.56	9.33	8.82
	Nr. IV	1.87	4.50	2.19	4.73	9.33	8.80
	Nr. V	1.87	6.53	-	-	-	-
Profiles	**Nr. IV**	250.00	265.83	250.00	239.69	250.00	203.86
	Nr. V	250.00	277.45	-	-	-	-

The results of the FEM analysis and experimental tests fit best for CEMBRIT boards, which proved to be the strongest one. FEM results cannot trace the quality of manufacturing, therefore the values obtained from the computer simulation are the same for SINIAT and KNAUF, whereas the bending tests, performed on real boards, show the difference.

Calculations of maximum deformations and maximum forces confirm the results of laboratory experiments on compliance or non-compliance of various plates with the standard.

Conclusions

1. This study confirmed that gypsum boards may have different physical properties in the transverse and longitudinal direction, and the difference depends on the quality of the board and consequently on the price of the board.
2. The cheapest board had the yield stress of 2.76 MPa in the longitudinal direction, 1.87 MPa in the transverse direction, while the more expensive board, was much more homogeneous and the physical properties did not change depending on the direction and the average yield stress was 2.19 MPa.
3. The cement board has more than 4 times higher yield stress of 9.33 MPa than gypsum boards, but it is the most expensive one, and the values in the longitudinal and transverse direction are the same.
4. The more expensive gypsum board tested meets all requirements of the standard and is competitive in terms of superior strength performance.

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Author contributions:

Conceptualization: J.V., methodology: M.I. software: M.I., validation: M.I. formal analysis: V.B, writing – original draft preparation: M.C., writing – review and editing: V.B., visualization, M.I.

References

[1] Li Z., Wang X., Yan W., Ding L., Liu J., Wu Z., Huang H. Physical and mechanical properties of gypsum-based composites reinforced with basalt, glass, and PVA fibers. Journal of Building Engineering, vol. 64, 2023, pp. 105640, DOI: 10.1016/j.jobe.2022.105640

[2] Hernandezolivares F., Oteiza I., Devillanueva L., Experimental-Analysis of toughness and modulus of rupture increase of sisal short fiber reinforced hemihydrated gypsum. Compos. Struct. 22 (3), 1992, pp. 123-137. DOI: 10.1016/0263-8223(92)90001-S

[3] Bijen J., Vanderplas C. Polymer-Modified glass-fiber reinforced gypsum. Mater. Struct., vol. 25 (146), 1992, pp. 107-114.
[4] Chen X.-Q., Xia K., Hu W., Cao M., Deng K., Fang S. Extraction of underwater fragile artifacts: research status and prospect. Herit. Sci., vol. 10 (1), 2022, pp. 1-9. DOI: 10.1186/s40494-022-00645-1
[5] Suknev S. (Ed.). Fragile and quasi-brittle fracture of gypsum boards with circular hole with unevenly distributed compression. International Symposium "Engineering and Earth Sciences: Applied and Fundamental Research", Atlantis Press, 2019. DOI: 10.2991/isees-19.2019.63
[6] Lushnikova N., Dvorkin L. Sustainability of gypsum products as a construction material. Sustain. Constr. Mater., 2016, pp. 643-681. DOI: 10.1016/ B978-0-08-100370-1.00025-1.
[7] Balti S., Dammak A.B.L., Hamdi N. Mechanical and thermophysical characterization of gypsum composites reinforced by different wastes for green building applications. Construction and Building Materials, 372, 2023, 130840. DOI: 10.1016/j.conbuildmat.2023.130840
[8] Romero-G´omez M.I., Silva R.V., Costa-Pereira M.F., Flores-Colen I. Thermal and mechanical performance of gypsum composites with waste cellulose acetate fibres. Constr. Build. Mater. 356, 2022, 129308. DOI: 10.1016/j.conbuildmat.2022.129308
[9] Vidales-Barriguete A., Santa-Cruz-Astorqui J., Pi˜na-Ramírez C., Kosior-Kazberuk M., Kalinowska-Wichrowska K., Atanes-S´anchez E. Study of the mechanical and physical behavior of gypsum boards with plastic cable waste aggregates and their application to construction panels. Materials (Basel), vol. 14 (9), 2021, 2255. DOI: 10.3390/ma14092255
[10] Ejaz M.F., Riaz M.R., Azam R., Hameed R., Fatima A., Deifalla A.F., Mohamed A.M. Physico-Mechanical Characterization of Gypsum-Agricultural Waste Composites for Developing Eco-Friendly False Ceiling Tiles. Sustainability, vol. 14, 2022, 9797. DOI: 10.3390/su14169797
[11] EN 520:2004 + A1:2009 Gypsum plasterboards - Definitions, requirements and test methods
[12] EN 12467:2012 + A1:2016 Fibre-cement flat sheets - Product specification and test methods
[13] Petrone C., Magliulo G., Manfredi G. Mechanical Properties of Plasterboards: Experimental Tests and Statistical Analysis. Journal of Materials in Civil Engineering, vol. 28 (11), 2016, 04016129. DOI: 10.1061/(ASCE)MT.1943-5533.0001630
[14] ISO 14125:1998. Fibre-reinforced plastic composites – Determination of flexural properties.