COMPOSITE SANDWICH-TYPE PANEL MADE OF FOAMGYPSUM

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Abstract. Sandwich type panels are popular building materials with low weight and high strength. Sandwich-type panels nowadays are mostly used in high thickness as elements for external walls or roofs. But in most cases modern building panels contain lots of combustible additives, which can produce toxic fumes and expedite fire in buildings. In this paper, sandwich-type panels are discussed with structural, acoustic, fire and heat insulation properties made of foamed gypsum core with an open and close cellular structure and higher strength lining on both sides made of regular plasterboard. Gypsum is used as a fire protection and acoustical material with excellent fire protection, because it dehydrates at a temperature around 100 ºC absorbing energy and acting as a heat barrier. This research shows that combining desirable properties of gypsum as a high density composition and low density composition can improve the overall material properties and variety of application. It was found that a thinner and lighter composite sandwich panel made of gypsum can resist fire for longer time than rigid gypsum boards with complex structure.

Keywords: plasterboard, heat distribution, fire, acoustic, foam gypsum, sandwich.

Introduction

Most of the existing buildings are responsible for high energy consumption and CO_2 emission in the EU [1]. The costs of heating and management rise every year, which can be reduced using construction materials smartly. Nowadays, not only energy efficiency but also the demands for better living comfort highly increase the sound and fire safety requirements of building components.

Gypsum as a natural and ecologic raw material is used in building for centuries. Plasterboard is one of the first innovative composite building materials based on gypsum and it has been produced almost for hundred years in the territory of Latvia. Easy production and low energy consumption make gypsum based construction products very sustainable. Today lots of construction materials for acoustic and fire safety characteristics are made of gypsum based, which can still be improved changing the properties of the material and making composite building materials. Building materials that can provide more than one basic requirement at the same time are more attractive for consumers.

Composite light weight panels are used for almost a century in building, aircraft and ship industries [2; 3]. Composite sandwich panels are manufactured from a high strength thin layer facing material such as steel sheet, paper or metal and a core with a low density material, which often has low bending and compression strength, but has low thermal conductivity or sound insulation characteristics such as mineral wool. The idea of making a sandwich structure panel is combining of desirable characteristics of each material. Outer facing sheets or skins must be with high structural strength but the core material can be with low structural strength and low density. Combining both material desirable characteristics, sandwich panel structures additionally are essential for fire resistance, thermal insulation, sound insulation and impact resistance.

Often sandwich type panels are made of combustible materials for outer facing or core material. To bond the outer facing material and core material high consumption of combustible adhesive is used. Combustible sandwich type panels show good thermal and sound insulation characteristics, but when the panel is exposed to fire, it can resist for 30 to 60 minutes [4; 5]. But, as the panel contains a lot of combustible materials, which release toxic fumes of flaming droplets, it is the reason for deaths in fire.

In this paper a sandwich type panel is made from two non-combustible materials thin layer plasterboards with A2-s1,d0 reaction to fire class and foam gypsum core material with A1 fire resistance class according to the European classification. Sandwich type panels made of gypsum based material with different density can be used as thermal insulation boards for external walls, non-loadbearing partitions or fire resistant ceiling constructions [6]. Material properties can be changed by adding additional ingredients to its composition, but when we look at gypsum based materials, then pure gypsum has the best behaviour at elevated temperatures [7]. Or changing the structure of pores can affect sound absorption of porous materials [8; 9].

By mathematical modelling it is possible to express the temperature changes in every layer for multi layered gypsum products exposed to fire [10].

Previous research shows good fire resistance and good sound absorption characteristics for a simple foam gypsum material and two layered composition [11; 12].

Materials and methods

Composite sandwich type panel samples were produced using regular 0.0065 m thick plasterboard with the density of 800 kg·m^{-3} as outer facing layer and the core material made of foam gypsum with three different thicknesses of 0.02, 0.03 and 0.04 m and the density of 450 ± 15 kg·m^{-3} Outer facing plasterboards were used as stay-in formwork filled with foam gypsum composition produced using the three-stage method. As the main ingredient for the production of foam gypsum β $CaSO_4 \cdot 0.5H_2O$ industrial gypsum and the foam concentrate STHAMEX®–AFFF 3 % F-15 were used as the surface active substance (SAS).

Sandwich type panels of size 0.300×0.600 m and thickness of 0.033, 0.043 and 0.053 m were produced. Smaller samples of size 0.300×0.300m for fire resistance tests and beams of size 0.040×0.16 m for bending and compression strength tests were cut by a circular saw, but the samples of Ø40 mm for sound absorption tests were cut by a holesaw.

Bending and compression strength tests of the sandwich type panels were carried out using a device Shimadzu AGS-X 10 kN. Samples were tested on three points, bending with 100 mm distance between the supports and compression with compression area of 40×62.5 mm. The results were processed by the computer programme TRAPEZIUMX single.

The furnace for fire resistance tests was produced from high temperature resistant vermiculite boards, Figure 1. The furnace of the volume 0.07290 m3 was heated with BOCHEM Meker-Ficher laboratory burner connected to a propane-butane gas cylinder with a maximum temperature of 1,300 ºC. The lower part of the furnace has an Ø40 mm opening for insertion of a Meker type burner, but the top of the furnace has an opening of 0.270×0.270 mm for placement of a sample.

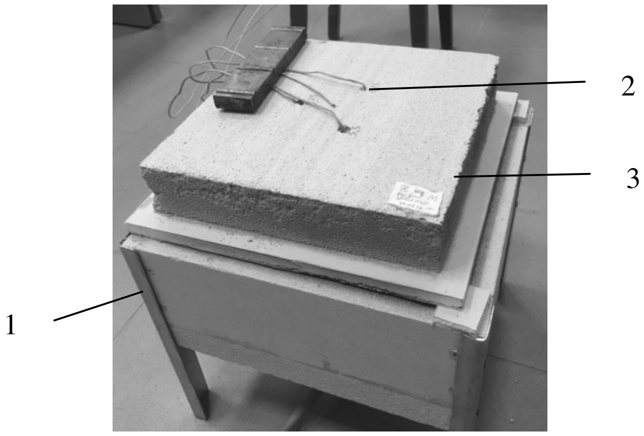

Fig. 1.**Test furnace:** 1 – furnace; 2 – thermocouples; 3 – sample

The furnace was heated with the temperature close to the standard cellulosic fire curve according to ISO 834, where temperature rise is expressed by formula 20 + 345 lg(8t + 1) ºC, where t is the time in minutes. The furnace temperature was measured at the exposed side of the sandwich type panel and unexposed surface, contact surface of two different layers and in the middle of material thickness with the K type thermocouples Omega 5TC-GG-KI-20-1M, with the accuracy measurement of ± 0.5 %. At the exposed side of the sample surface in the furnace K type thermocouple Omega 5TC-GG-KI-20-1M was installed, accuracy measurement of ± 0.5 %. The readings of the thermocouples were registered every 10 seconds by the data recorder OM-DAQPRO-5300. Fire resistance tests were performed based on the EN standard methodology.

The sound absorption measurements were carried out using the company "Sinus" impedance tube produced in this specific industry. The sound absorption coefficient was measured in the range of frequencies from 250 Hz up to 4000 Hz. The impedance tube has two different diameters Ø100 mm and Ø40 mm. In the tube part of Ø100 mm – the sound source was placed, but in the Ø40 mm part, two measuring-microphones and a sample of Ø40 mm to be measured were located.

The determination procedure for the sandwich panel sound absorption properties was carried out for 3 parallel samples from each panel and the obtained values were averaged, and the relative error of measurements was less than ±5 %.

The measurements of the sound absorption coefficient (α_w) in frequency ranges 250; 500; 1000; 2000; 4000 Hz were performed in an impedance tube (Ø 40 mm) by applying the two microphone transfer function method according to ISO 10534-2:2001 and ISO 11645:2000.

Results and discussion

The small-scale test furnace was used to determine the thermal insulation in fire for sandwich type panels. Totally six types of samples were produced, summarized in Table 1. Two types of panels were tested to determine temperature rise on the unexposed side. Two samples E and F were produced as a two layered system – 0.030 ± 0.001 and 0.040 ± 0.001 m foam gypsum layer applied on regular plasterboard 0.0065 ± 0.0005 m thick. Three samples A, B and C were produced as a three layered system – regular plasterboard 0.0065 ± 0.0005 m thick as outer facing and foam gypsum 0.020 ± 0.001, 0.03 ± 0.001 and 0.040 ± 0.001 m thick as the core material. Sample D as pure core material of foam gypsum was produced 0.040 ± 0.001 m thick with density 450 ± 15 kg·m^{-3} for bending and compression strength tests and sound absorption tests.

Table 1

The prepared samples

Sample	Layer 1 plasterboard thickness, m	Layer 2 foam gypsum thickness, m	Layer 3 plasterboard thickness, m	Total thickness, m
Sample A	0.0065 ± 0.0005	0.020 ± 0.001	0.0065 ± 0.0005	0.033 ± 0.0005
Sample B	0.0065 ± 0.0005	0.030 ± 0.001	0.0065 ± 0.0005	0.043 ± 0.0005
Sample C	0.0065 ± 0.0005	0.040 ± 0.001	0.0065 ± 0.0005	0.0535 ± 0.0005
Sample D	-	0.040 ± 0.001	-	0.040 ± 0.001
Sample E	-	0.030 ± 0.001	0.0065 ± 0.0005	0.0365 ± 0.0005
Sample F	-	0.040 ± 0.001	0.0065 ± 0.0005	0.0465 ± 0.0005

Two layered system samples with total thickness of 0.0365 ± 0.0015 and 0.0465 ± 0.0015 m show lower fire resistance than the samples of the three layered system with total thickness of 0.033 ± 0.0015, 0.043 ± 0.0015 and 0.053 ± 0.0015 m. Samples, which were covered with high density layer on both sides, show slower heating than the samples, which were exposed by fire from the low density layer side. The experiment results show that the thin layer facing with higher density than the core material can prolong fire resistance of foam gypsum composite structures. Addition of a plaster board layer of 0.0065 ± 0.005 m thickness can reduce temperature on the unexposed side by 45 °C after 60 minutes for the sample with 0.040 ± 0.001 mm thick foam gypsum layer and 50 °C after 45 minutes for the sample with 0.030 mm thick foam gypsum layer.

Analysing the data form thermocouples inside the three layered system samples of 0.03 and 0.04 m, which are shown in Figure 3, shows that the first layer of the regular plaster board, which is exposed to fire, works for 20 minutes. After 20 minutes the temperature behind the plasterboard layer increases rapidly. After 50 minutes from starting the test, the fist layer of the plaster board drops off. Temperature rise in the middle of 0.043 and 0.053 m thick samples is very similar and shows the same results as the previous research.

In normal environment contact the surface between two different materials did not show any problems, but increasing the temperature, materials with different densities and the combustible layer of paper show problems with adhesion. Figure 4 shows the combustible layer after 60 minutes of the fire resistance test.

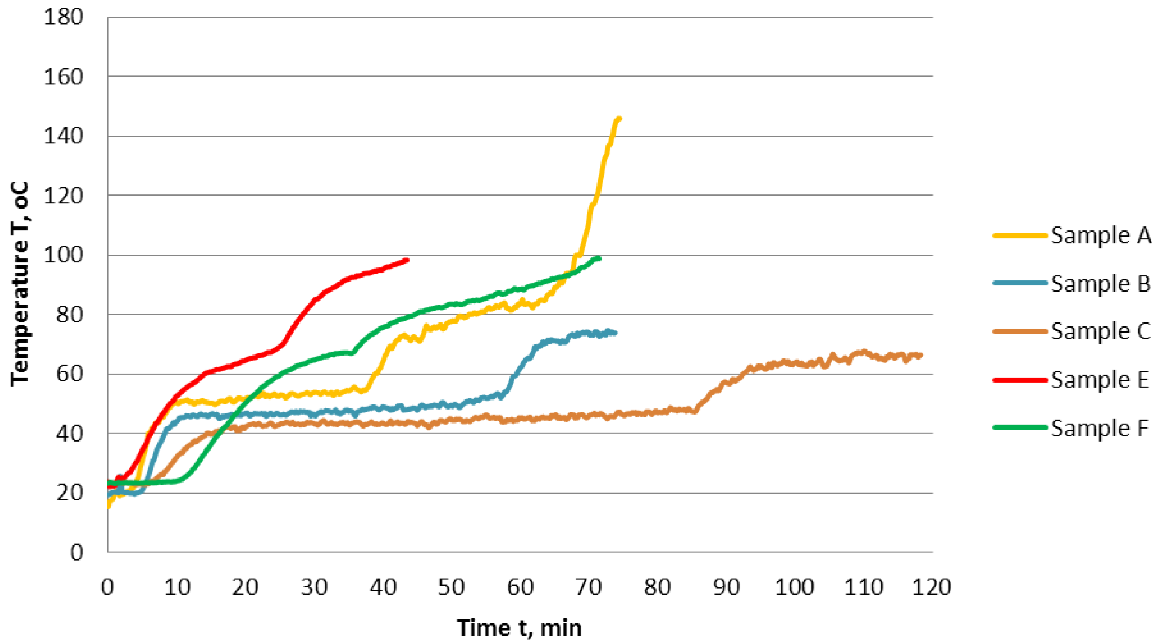

Fig. 2.**Fire resistance test. Temperature rise on unexposed surface**

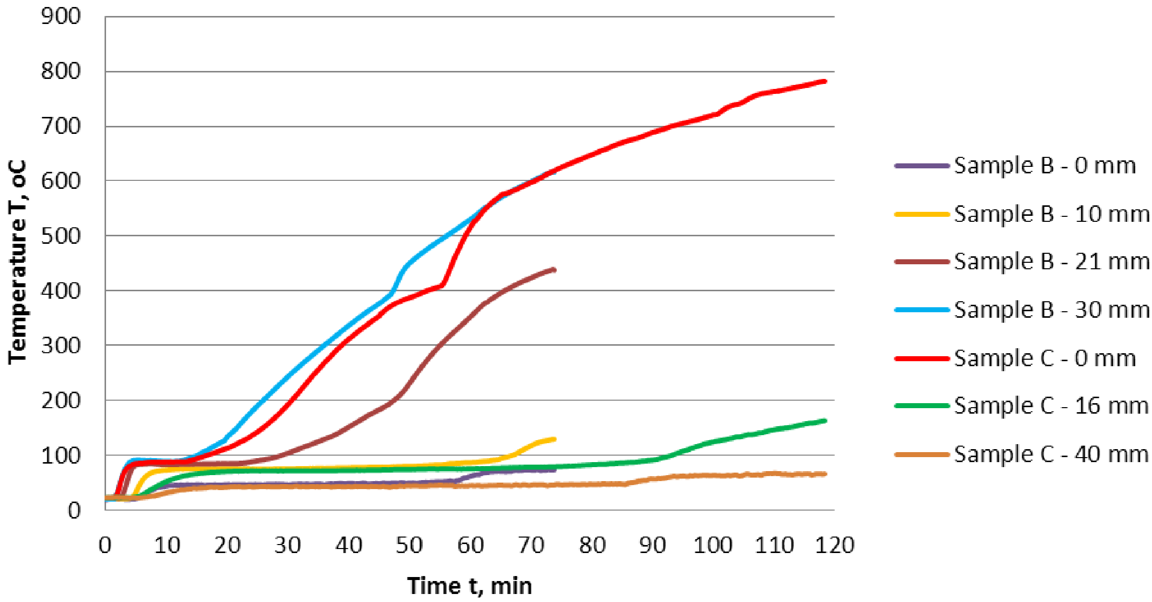

Fig. 3.**Fire resistance test. Temperature rise inside three layered samples with foam gypsum layer of 0.03 and 0.04 m**

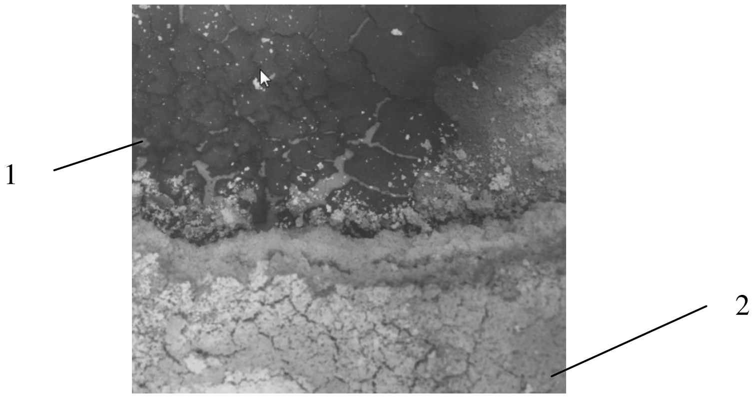

Fig. 4.**Combustible layer of paper after fire resistance test:** 1 – paper; 2 – layer of foam gypsum

Results of bending strength are shown in Figure 5. Tests were carried out for simple foam gypsum beam, a two layered system with a plasterboard layer on top and a three layered system with the plasterboard as the outer lining and foam gypsum as the core material.

Foam gypsum material reinforced with 0.0065 ± 0.005 m thick plasterboard on the upper side increases the bending strength by 44 %, but adding plasterboard reinforcement on the upper and lower side of the foam gypsum sandwich type board, the bending strength increases by 196 %. Compression strength did not change for reinforced and non-reinforced samples.

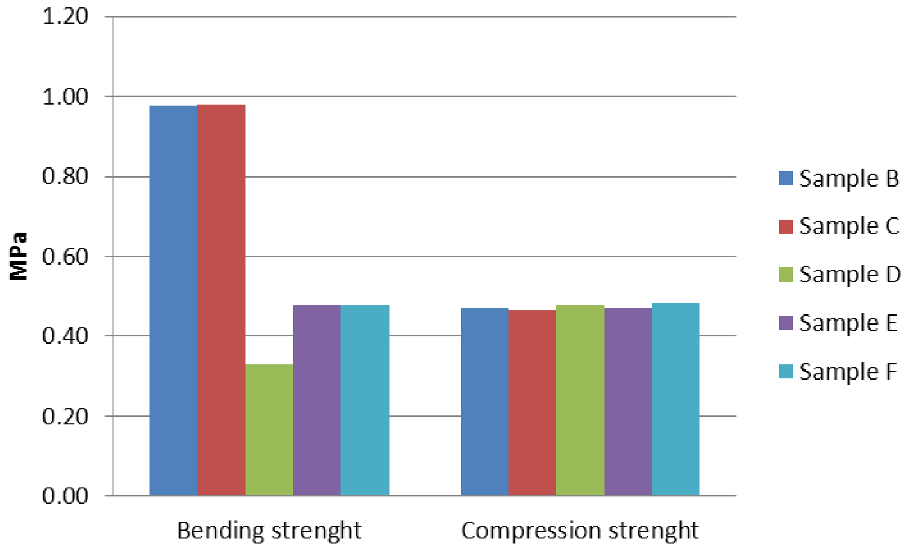

Fig. 5.**Bending strenght and compression strenght of foam gypsum composit panels**

The sound absorption coefficient for the improvement of the weight average of the addition of the gypsum layer on the opposite side and plate board on both sides of the panel was observed, summarized in Table 2. There were no significant changes with regard to the gypsum layer on one side of the sound absorption coefficient, but panels with plasterboard on both sides show significant changes in decrease of the absorption coefficient. The sandwich panel with plaster board facing on both sides shows that in this material the sound absorption results depend on the plasterboard layer and have no influence on the foam gypsum core structure. Simple foam gypsum panel without the plasterboard layer average sound absorption coefficient is balanced in all frequency range, but adding one layer of plasterboard on the opposite side of sound source lowers the sound absorption coefficient. Two layered board is effective in combination of middle and high (MH) frequencies, but the three layered board is effective in low (L) frequencies.

Table 2

Sound absorption results

	250 Hz	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**Average**
Sample B	0.15	0.20	0.15	0.15	0.15	0.15L
Sample C	0.20	0.15	0.15	0.15	0.15	0.15L
Sample D	0.40	0.65	0.65	0.70	0.70	0.65
Sample E	0.15	0.40	0.70	0.75	0.70	0.4MH
Sample F	0.15	0.55	0.80	0.65	0.70	0.45MH

Conclusions

1. Sandwich type panel with plasterboard of 0.0065 ± 0.0005 m as the outer facing and foam gypsum as the core material show significant increase in fire resistance and increase of the bending strength.
2. Sound absorption coefficient dramatically decreases for sandwich type panels with plasterboard facing on both sides. Sound absorption coefficient for sandwich type panels depends only on the outer layer structure and has no influence on the core material.

3. For further research optimal thickness of the outer layer, which can be reduced or perforated for acoustical reasons, needs to be investigated.
4. Bonding of two different materials as foam gypsum with low density and outer facing with high density needs to be investigated.

References

[1] Energy Efficiency. Buildings. [online] [15.01.2018]. Available at: https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings
[2] Gibbons H. B., Composite structure for use in aircraft constructions, U.S. Patent 2,479,342, issued August 10, 1949.
[3] Raynes B. F., Prefabricated modular home construction, U.S. Patent 3,203,145, issued August 31, 1965
[4] Wang Y.C., Foster A., Experimental and numerical study of temperature developments in PIR core sandwich panels with joint. Fire Safety Journal. Vol. 90, 2017, pp. 1-14.
[5] Pereira D., Gago A., Proença J., Morgado T., Fire performance of sandwich wall assemblies. Composites Part B, vol. 93, 2016, pp. 123-131;
[6] Pedreno-Rojas M.A., Morales-Conde M.J., Perez-Galvez F., Rodríguez-Linan C.,Eco-efficient acoustic and thermal conditioning using false ceiling plates made from plaster and wood waste. Journal of Cleaner Production. Vol. 166. 2017. pp. 690-705.
[7] Doleželová M., Scheinherrová L., Krejsová J., Vimmrová A, Effect of high temperatures on gypsum-based composites. Construction and Building materials. Vol. 168, 2018, pp. 82-90.
[8] Laukaitis. A, Fiks B., Acoustical properties of aerated autoclaved concrete. Applied Acoustics, vol. 67, 2006, pp. 284-296.
[9] Elkhessaimi Y., Tessier-Doyen N., Smith A., Effects of microstructure on acoustical insulation of gypsum boards. Journal of Building Engineerin, vol. 14, 2017, pp. 24-31.
[10] Aboltins A., Kalis H.,Pulkis K.,Skujans J.,Numerical Simulation of Heat Transfer problem for layered gypsum products exposed to fire. Proceedings of intentional conference "Engineering for Rural Development" Jelgava 2017, May 24.-26., pp. 1369-1376.
[11] Pulkis K., Iljins U., Skujans J., Gross U. Research on Fire Safety Parameters on Foam Gypsum Products. CHEMICAL ENGINEERING TRANSACTIONS, Volume 43, 2015, p. 1765-1770.
[12] Pulkis K., Soloveiko S., Brencis R., Skujans J.,Research on Improvement of Safety and Durability of Foam Gypsum Acoustic Plate by Using Multilayered Board. Proceedings of the 7th International Conference on Safety and Durability of Structures ICOSADOS 2016, May 10 - 12, 2016, UTAD, Portugal.