Experiment in real conditions: mechanical properties of gypsum block determined using non-destructive and destructive methods

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Abstract: - The paper presents long-term experiment. One side of the gypsum block was exposed to the weather conditions and the other side was inside the building. After four years exposure to weather (sunshine, rain, snow, temperature changes), the gypsum block was sawed to standard samples 40×40×160 mm. At first, these samples were tested using non-destructive method – impulse excitation method- to obtain Dynamic Young's Modulus of gypsum. Then the samples were tested using destructive methods – three point bending test and standard compression test - to obtain static mechanical properties (tensile and compression strength, Young's Modulus of gypsum) of each sample. Based on the results, distribution of mechanical properties of the gypsum block and dependence of mechanical properties on position into the gypsum block were evaluated.

Key-Words: - Mechanical properties, gypsum block, destructive methods, non-destructive methods, Modulus of Elasticity.

1 Introduction

At present time, gypsum is used only for interior applications as plasterboards, blocks for bathroom walls or as fire safeguards [1].

Only few research workers deal with utilization of materials on gypsum basis for exterior applications. These materials are modified using different types of admixtures as:

- plasticizers
- water proof (hydrophobization)
- setting regulators (retardants or accelerators)

or fillers as:

- fibers
- clay
- fly ash
- sand
- thermal insulation (polystyrene, perlite, vermiculite) [2]

Combination of various admixtures of fillers types is very frequent. Gypsum composite materials are frequently marked as GBCM (Gypsum Based Composite Materials) in foreign countries. For an example, a new material of this type was tested in Mexico, where Rubio-Avalos et al. [3] modified a gypsum binder by means of styrene-butadiene resin (SBR) in a resin/gypsum proportion of 0.05–0.2. The volume density, the bending strength and the modulus of elasticity were measured on different types of samples. The effect of resin on the microstructure was also observed by the ESEM electron microscope. The results were compared with the values measured on unmodified gypsum. Colak [4] modified gypsum by adding foaming agents supporting this reaction by the addition of citric acid as a retardant and carboxylmethylcellulose (CMC) as an addition increasing the viscosity supporting the formation of foam and gas during the reaction. In final products, he compared the volume density and the compressive strength. Tazawa [5] used gypsum-polymer composites, which were at first vacuum-treated and then impregnated with methylmetacrylate (MMA) and azobisisobutyronitrile applied in a bath for a period of 20 hours at 60 °C, comparing the bending strength, the compressive strength and the modulus of elasticity. Other modifications using polymers were made by Bijen and Plas [6]. They reinforced gypsum with fibreglass of E-glass type (up to 13 % of the matrix by weight) and modified the binder, which was α-gypsum in this case, by means of polymers of the Forton type based on acryl polymers. One is produced specifically for use in gypsum binders, while the other is added to cement. The other components were a plasticizer – Melamine, a setting retardant, a catalyst and an addition preventing foaming. The volume density and the relationships of strength characteristics (bending strength, tensile strength and long-term fatigue strain) under variable placement – the temperature and moisture content effects, were determined for three materials with variable compositions. This material, marked as Forton-Jesmonite PGRG (Polymer-modified glass fiber reinforced gypsum) in the Netherlands, is presumed for exterior applications as well.

Inspired by their research, it leads us to the experiment in real conditions. The term "real conditions" means influence of weather, and testing the material with practical dimensions, e.g. not only standard samples 40×40×160 mm.

2 Non-destructive methods

The dynamic non-destructive methods can be divided into two groups: pulse and resonance methods. Pulse methods are based on measuring the travel time of the ultrasonic pulse. It is the time between inducing the pulse on one side of the specimen and receiving the signal on the other side of the specimen. If the dimensions and the mass of the specimen are also known, it is possible to determine elastic properties of the specimen.

The resonance methods are based on measuring the resonance frequency. The specimen is usually excited by mechanical vibration using drivers or impact hammers (Fig. 1). Vibration of the specimen is monitored by acceleration transducers (Fig. 1) and characteristic resonance frequencies are evaluated. If the dimensions and the mass of the specimen are also known, it is possible to determine elastic properties of the specimen.

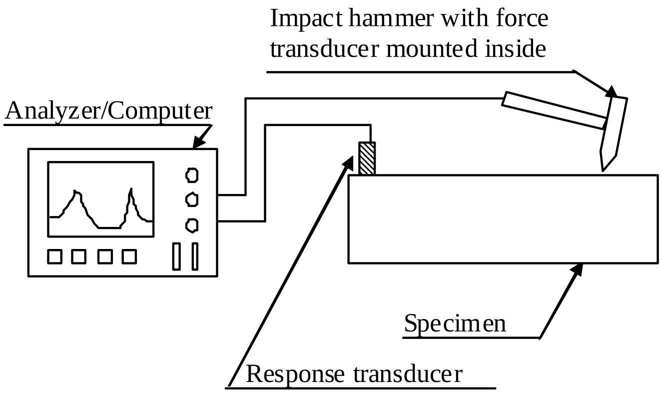

Fig. 1 The schema of the measurement line for impact resonance method

The advantages of dynamic methods over static methods are their nondestructive character, wide variety of specimen shapes and sizes, which can be used, better accuracy of the results, the wide temperature interval, in which these methods can be used, portable measurement equipment and inexpensiveness of the measurement.

For the determination of the Dynamic Young's Modulus of the gypsum block, the impulse excitation method was used, which is based on measuring the fundamental resonant frequencies [7], [8]. The test arrangement was done for longitudinal vibration (Fig. 2).

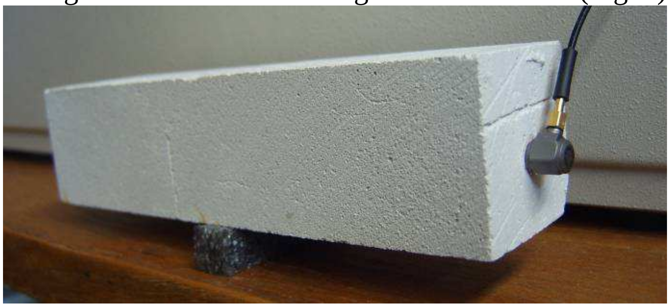

Fig. 2 The test arrangement for measuring the fundamental longitudinal resonant frequency of the gypsum specimen

The specimen was supported in the middle of its span (Fig. 2), the fundamental longitudinal nodal position. The acceleration transducer Bruel&Kjaer of Type 4519-003 was placed at the centre of one of the end faces of the specimen (Fig. 2- the right end face). The end face of the specimen opposite to the face, where the transducer was located, was struck by the impact hammer Bruel&Kjaer of Type 8206. Both signals, the excitation force and the acceleration, were recorded and transformed using Fast Fourier Transform (FFT) to the frequency domain and the Frequency Response Functions (FRF) (Fig. 3) were evaluated from these signals using the vibration control station Bruel&Kjaer Front-end 3560-B-120 and program PULSE 14.0. The FRF is defined as

$$H(f) = \frac{a(f)}{F(f)}, \tag{1}$$

where $H(f)$ is FRF, $a(f)$ is measured acceleration in frequency domain and $F(f)$ is the excitation force in the frequency domain. In order to prevent errors due to zeros in the denominator, the program PULSE calculates FRF differently

$$H_1(f) = \frac{G_{aF}(f)}{G_{FF}(f)}, \tag{2}$$

where $G_{aF}(f)$ is cross-spectrum of input (force) and output (acceleration) signals and $G_{FF}(f)$ is autospectrum of the input signal.

The test was repeated five times for each specimen and resultant readings were averaged. From an averaged FRF, the fundamental longitudinal resonant frequency was determined for each specimen (Fig. 3).

Based on the equation for longitudinal vibration of the beam with continuously distributed mass with free-free boundary condition, the Dynamic Young's Modulus can be determined using the relation

$$E = \frac{4lmf^2}{bt}, \tag{3}$$

where *l* is the length of the specimen, *m* is the mass of the specimen, *f* is the fundamental longitudinal resonant frequency of the specimen, *b* is the width of the specimen and *t* is the thickness of the specimen.

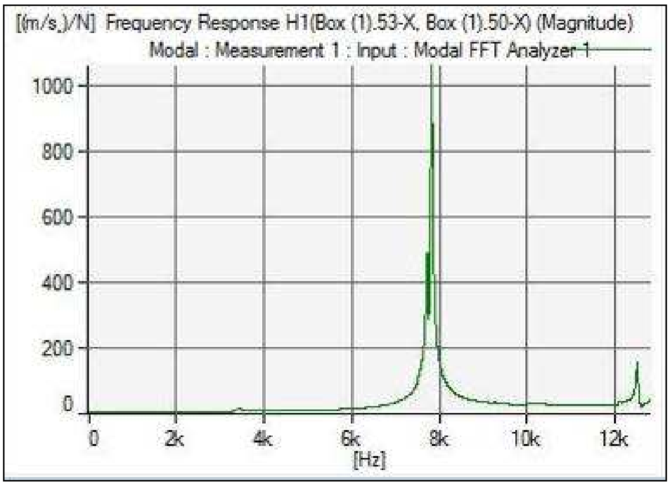

Fig. 3 The Frequency Response Function of the specimen VI-3 – the longitudinal resonant frequency $f_{(1)}$= 7800 Hz.

3 Destructive methods

Bending strength, compressive strength and Young's modulus of gypsum samples were measured using standard methods, namely ČSN 72 2301 [10].

The compressive strength was tested on six halves of samples, obtained after the bending test. The samples were placed between two steel plates (with dimensions 40×50 mm). The value of the maximal force *F* [kN] corresponded with the used press loading area was read on the devices and was continuously recorded to the PC. The compressive strength was calculated using the known relations, see [10]. The resulting compressive strength value of one set of the gypsum samples (3 times 2 sample halves) was calculated according to Czech standard ČSN 72 2301 as the average of the results of the six tests (respectively four tests) with the elimination of the highest and the lowest values reached.

Bending strength was provided after ČSN 72 2301 too [10]. The test was performed on the MTS Alliance device, with a scale of 30 kN. The sample was placed so that its edges, which were horizontal during its preparation, would be in a vertical position. The test involved three-point bending, with a distance of the supporting rollers of 120 mm. The value of the force *F* [kN] was read on the apparatus and continuously recorded to the PC. The tensile bending strength was calculated using the standard evaluation procedure as the average of three values of the three tests.

4 Experiment in real conditions and the gypsum block

The experiment in real-life conditions was carrying out at Faculty of Civil Engineering, CTU in Prague. The advantages of this test are real exterior and interior conditions. The exterior weather conditions contain the effects of wind, rain, solar radiation and changes of temperatures and values of relative humidity. The interior conditions are predominantly invariable – temperature 20 °C and relative humidity 30-50 %.

The part of building envelope (the outer glazing) was removed, and the gypsum block from material S0 with a thermal insulation, were placed in this position (Fig.4 and Fig.5). The gypsum block (Fig.6) was prepared from FGD-gypsum (Flue gas desulphurisation gypsum) FGD-gypsum was produced in the Počerady Power Plant (ČEZ Company), during calcinations process at temperatures of 110 to 160 °C, for more information about this gypsum see [10]. The gypsum material was non-modified by additions and was made only from the water and gypsum, with the water gypsum ratio 0.627. This material was called S0. The water gypsum ratio was used according to Czech standard ČSN 72 23 01 Gypsum binders and is defined as gypsum with standard consistence and corresponded with a spillage 180 ± 5 mm. Used gypsum was classified as G13 BIII (G13 – compressive strength after two hours is minimally 13 MPa for gypsum samples prepared with normal consistence, it means for the standard water gypsum ratio, B – is gypsum with normal-setting (B) and III is slightly ground.

The experimental gypsum blocks were cast in wooden moulds with dimensions of 350×250×600 mm. The free space between the block and the load-bearing structure of the building envelope was completed with thermal insulation. The block was placed so that its exterior edge would be aligned with the glazing of the building envelope. Sensors for reading temperature and relative moisture contents were located inside the gypsum block. The interior and exterior surfaces of the block were fitted with thermal elements. Exterior conditions – temperature, relative humidity, rainfall intensity, wind direction and velocity – as well as interior conditions – temperature, relative humidity and atmospheric pressure – were read using a small weather station. Data from the all sensors were recorded in a digital form and transferred to PC. The arrangement of the experiment shows Fig. 4. Schematic views on experiment show Fig. 4 and Fig. 5, where 1 – the gypsum block, 2 – the thermal insulation, 3 – the building envelope (a window with aluminum elements), 4 – the table, 5 – the exterior thermal sensors, 6 – the interior thermal sensors, 7 – the combined thermal and relative humidity sensors and 8 – the weather station.

This experiment started 20. 12. 2005 and the gypsum block was removed 25. 2. 2010. The lowest temperature of -14.1 °C was measured in January 2006. The highest day-time temperature in May 2006 was amounting to 30.1 °C. This temperature pattern implies that the blocks were exposed to exterior temperatures ranging from -14 to 30.1 °C. The condition of the gypsum block after four years long exposure to real conditions shows no visible damage. The exterior surface of the block was in an absolutely identical state as the interior surface.

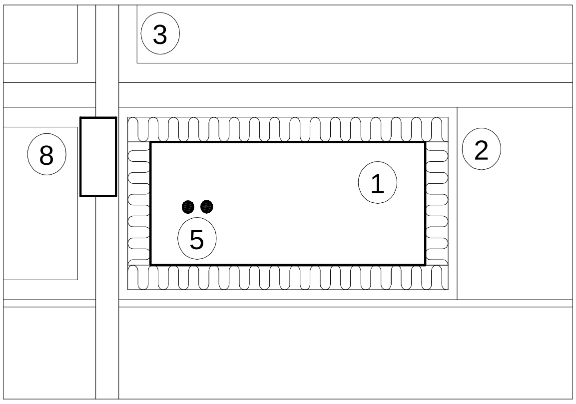

Fig. 4. Schematic view on the experiment from exterior

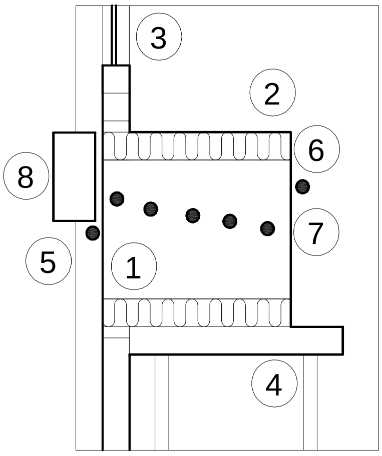

Fig. 5. Schematic view on the experiment

For the further study of the gypsum block behavior after four years of experience to outdoor weather conditions, the block was sawed on specimens with dimensions of 40×40×160 mm (Fig. 6). And the gypsum samples were tested by mechanical tests using non-destructive and destructive methods to determine a set of mechanical properties of the gypsum block. The samples were marked (Fig. 6) and the position of the samples are known – a distance from the exterior side of the gypsum block.

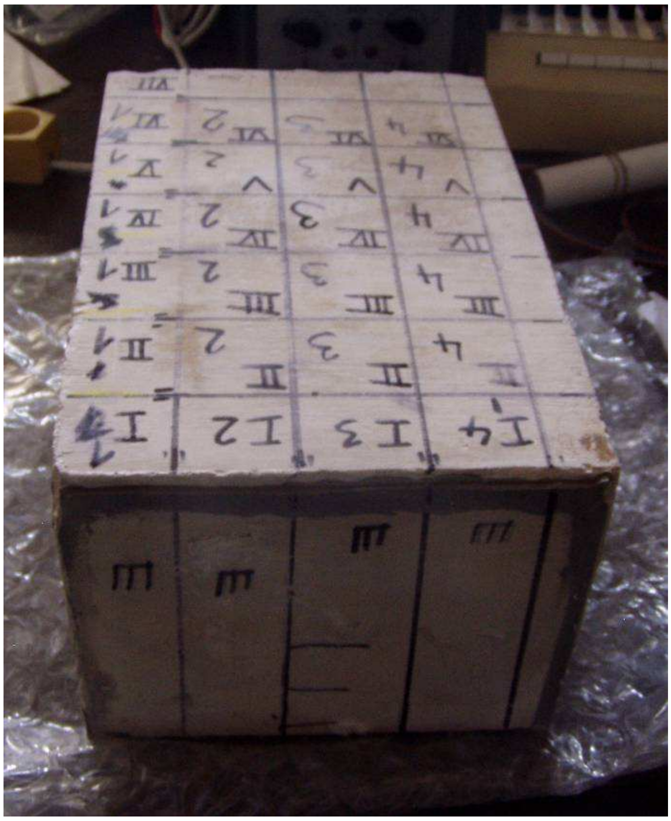

Fig. 6. The view on the tested gypsum block from the exterior side.

This proceeding allows us from all results set together a distribution of gypsum block mechanical properties and a dependence of mechanical properties on position into the gypsum block. A basic question is how exterior behavior (weather conditions) influenced mechanical properties of the gypsum block.

5 Experimental results and discussions

The first used method for Young's Modulus determination was non-destructive method – the impulse excitation method.

Before starting measurement, all dimensions and weight of each specimen were measured. Based on these measured values, mass densities of the specimens were evaluated (Fig. 7). As it can be seen in the Fig. 7, there are no big differences in mass densities of the specimens. The values are a little bit larger on the exterior side.

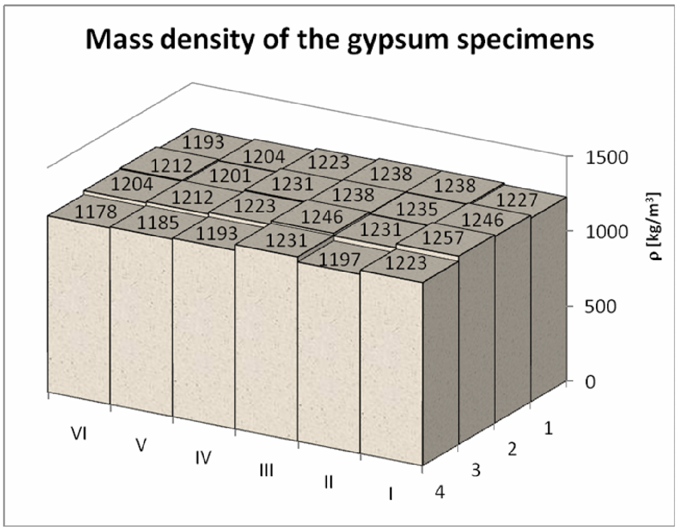

Fig. 7. The mass density of the tested gypsum specimens.

The fundamental longitudinal frequencies (Fig. 8) of the specimens were determined as the peaks of the evaluated FRFs (2) (Fig. 3). The differences of the resonant frequencies of the samples at the interior and exterior sides are small. Only values of the frequencies of the samples cut off from the middle of the block are smaller than the frequencies at the sides.

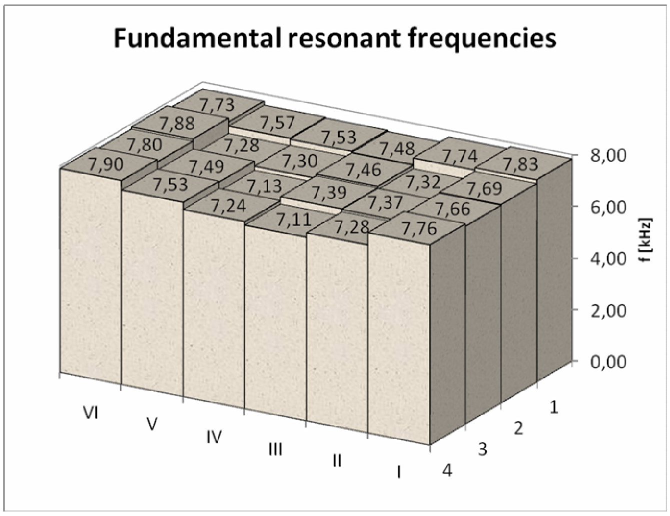

Fig. 8. The fundamental resonant mass density of the tested gypsum specimens.

The Dynamic Young's Moduli of the tested gypsum specimens was calculated based on (3). The distribution of the Dynamic Young's Moduli in the gypsum block is presented in the Fig. 9. There are no big differences in Moduli between interior and exterior sides.

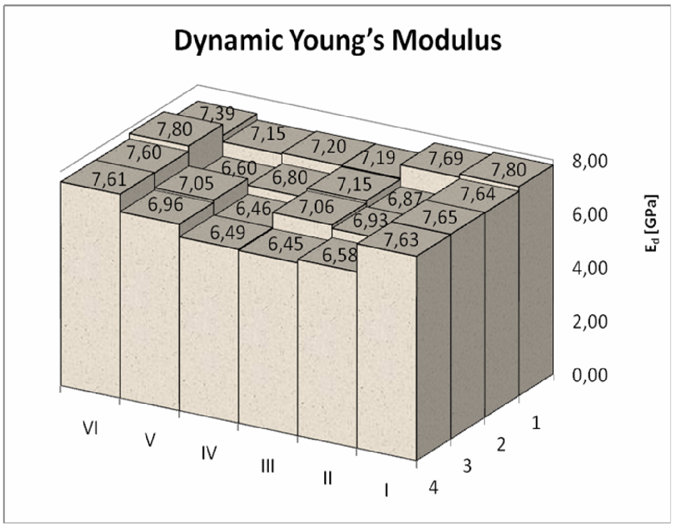

Fig. 9. The Dynamic Young's Moduli of the tested gypsum specimens.

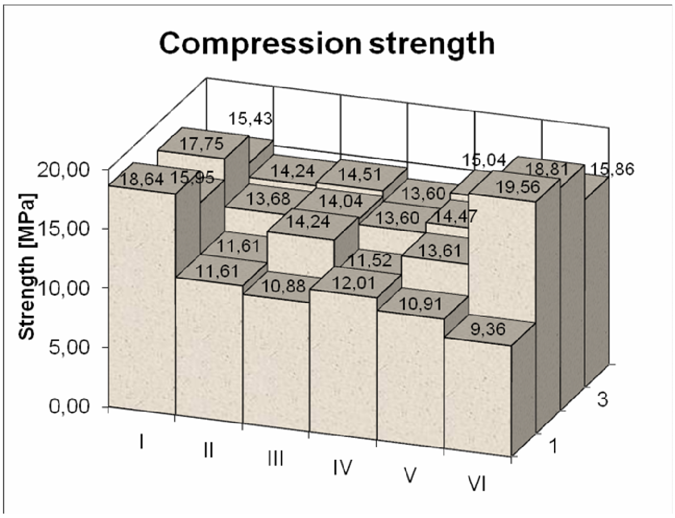

Fig. 10. Compression strength of the specimens.

Figure 10 displays the values of compression strength of 24 specimens. Lines 1 and 4 represent the results of boundary parts of specimen. These curves are not different from curves 2 and 3 which representing middle part of specimens. The interior side of block (I) has the values of compression strength more close than the exterior side of the block (IV). In comparison of the Figures 9 and 10, it is possible to see that specimen VI1 has the lower value of the Dynamic Young's Modulus and the compressive strength.

Values of compression strength are between 11 and 19.5 MPa. Compression strengths are higher in cross-sections I and VI than values in cross-sections from II to V. This difference is about 3.4 MPa. Similar difference can be seen for the Dynamic Young's Moduli, see (Fig. 9).

Nevertheless, average compression strength is 14.2MPa. This material property is comparatively high and is achieving the values of ordinary concrete.

4 Conclusion

The paper presents long-term experiment. One side of the gypsum block was exposed to the weather conditions and the other side was inside the building. After four years exposure to weather conditions, the distribution of mechanical properties of the gypsum block was evaluated.

The results of both non-destructive and destructive methods show that the mechanical properties of the gypsum material on both interior and exterior sides are very similar. From these results, it can be concluded that the four years exposure of the gypsum block to the weather conditions did not influenced mechanical properties of the gypsum.

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