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Nondestructive determination of mechanical properties of the flue gas desulphurization gypsum

Hana Němcová[1], Tomáš Plachý[2], Andrea Hájková[3], Pavel Tesárek[4] & Michal Polák[5]

Abstract: Nondestructive method was used for determination of mechanical properties of gypsum specimens. The dynamic modulus of elasticity, shear modulus and Poisson's ratio were determined using impulse excitation method. The specimens were cut from the gypsum block which was a part of the building envelope for four years. The weather influence on changes of gypsum material properties was investigated.

Keywords: Nondestructive method, Dynamic modulus of elasticity, Gypsum block

1. Introduction

The strength characteristics correspond mainly with physical properties of hardened gypsum as total open porosity, arrangement of gypsum crystals, and type of used the gypsum binder. On the other hand, properties of the hardened gypsum depend on conditions where the hardened gypsum is placed [3]. Temperature and moisture (relative humidity but especially a liquid water content) prejudice mechanical properties of gypsum.

The main aim of this research is to determine the mechanical properties of block from gypsum (flue gas desulphurization gypsum - FGD), which was the part of the building envelope for four years and was exposed to outdoor and indoor climate conditions.

For the determination of dynamic modulus of elasticity, shear modulus and Poisson's ratio, non-destructive method was used currently for a short preparation time and mainly for the matter of fact that it is possible to test one sample several times.

2. Materials and specimens

The gypsum block of dimensions 350 × 250 × 600 mm were cast from gypsum (flue gas desulphurization gypsum), which was made in the power plant Počerady (Czech Republic). Water/gypsum ratio was 0.627 and the material was not modified. According to ČSN 72 2305, the gypsum classified as G-7 BIII were used.

One month after the production, the block was inserted into the building envelope. The block was tested using probes, thermal sensors and humidity sensors on the surfaces and inside the gypsum block, the temperature and relative humidity were monitored. Exterior

[1] *Ing. Hana Němcová, DiS.; Department of Mechanics, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29 Prague 6, Czech Republic;hana.nemcova@fsv.cvut.cz*
[2] *Ing. Tomáš Plachý, Ph.D.; Department of Mechanics, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29 Prague 6, Czech Republic; plachy@fsv.cvut.cz*
[3] *Ing. Andrea Hájková; Department of Mechanics, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29 Prague 6, Czech Republic; hop.hop@seznam.cz*
[4] *Ing. Pavel Tesárek, Ph.D.; Department of Mechanics, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29 Prague 6, Czech Republic; tesarek@fsv.cvut.cz*
[5] *doc. Ing. Michal Polák, CSc; Department of Mechanics, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, Praha 6, 166 29, Prague, Czech Republic; polak@fsv.cvut.cz*

conditions such as temperature, relative humidity, rainfall intensity, direction and wind speed and indoor conditions such as temperature, relative humidity and atmospheric pressure were recorded using a small weather station. This experiment was conducted from 20th December 2005 till 25th February 2010, when the block was placed at laboratory conditions.

The block was cut into dimensions 40 × 40 × 165 mm, which were subjected to a non-destructive examination using the impulse excitation method. The dynamic modulus of elasticity, shear modulus and Poisson's ratio have been measured for each specimen using this method.

3. Impulse excitation method

The test procedure was performed in accordance with ASTM C215 [4]. At first, the dimensions of all specimens were measured and the mass were weighed.

3.1. Dynamic modulus of elasticity

The dynamic modulus of elasticity was calculated twice. The first calculation was done based on measured basic longitudinal resonant frequency and the second one was done based on measured basic transversal resonant frequency.

The specimen was supported in the middle of its span for measuring the longitudinal resonant frequency. The acceleration transducer was placed at the centre of the end face of the specimen and the opposite end face of the specimen was struck by the impact hammer. The measured excitation force and the response were transformed from time domain to the frequency domain using Fast Fourier Transform (FFT). The fundamental natural frequency of longitudinal vibration f_l [Hz] was determined as the basic resonant frequency of the Frequency Response Function (FRF). The dynamic modulus of elasticity E_{dl} can be determined using the relation:

$$E_{dl} = \frac{4lmf_l^2}{bt} \tag{1}$$

where l [m] is the length of the specimen, m [kg] is the mass of the specimen, f_l [Hz] is the fundamental natural frequency of the longitudinal vibration of the specimen, b [m] is the width of the specimen and t [m] is the thickness of the specimen.

The specimen was simply supported in the distance 0.224×l of the span on both ends for measuring the transversal resonant frequency. The acceleration transducer was placed at the end of the specimen on the upper face and the opposite end of the specimen was struck by the impact hammer. The first transversal resonant frequency was evaluated using the same procedure as the above described longitudinal one. The dynamic modulus of elasticity E_{df} can be determined using the relation:

$$E_{df} = \frac{0.9465ml^3T_1f_f^2}{bt^3} \tag{2}$$

where f_f [Hz] is the fundamental resonant frequency of the traverse vibration of the specimen and T_1 is the correction factor for fundamental flexural mode to account for finite thickness of bar, Poisson's ratio μ, and so forth. If the Poisson's ratio is not known a priory, an iterative procedure should be applied for determination of E_{df} and μ.

3.2. Dynamic shear modulus

The specimen was supported in the middle of its span for measuring the torsional resonant frequency. The acceleration transducer was placed at the end of the specimen in the right upper corner of the side face and in the opposite lower corner the specimen was struck by the impact hammer. The first torsional resonant frequency was evaluated using the same procedure as the above described longitudinal one. The dynamic shear modulus G_d can be determined based on the equation

$$G_d = \frac{4lmf_t^2}{bt}[B/(1+A)] \tag{3}$$

where f_t is the fundamental torsional resonant frequency of the specimen [Hz], A is an empirical correction factor dependent on the width-to-thickness ratio of the specimen defined in [4] and B is defined as

$$B = \left[\frac{b/t + t/b}{4(t/b) - 2.52(t/b)^2 + 0.21(t/b)^6}\right] \tag{4}$$

3.3. Dynamic Poisson´s ratio

The dynamic Poisson's ratio μ_d can be calculated for an isotropic solid

$$\mu_d = \frac{E_d}{2G_d} - 1 \tag{5}$$

where E_d [GPa] is the dynamic modulus of elasticity, G_d [GPa] is the shear modulus. The dynamic Poisson's ratio μ_d can be determined by two manners using E_{dl} or E_{df}

4. Results

The gypsum block was cut to 20 specimens of dimensions 40 × 40 × 165 mm; four specimens in the direction parallel to the face of the building envelope (marked as 1 - 4) and five specimens perpendicular to the face of the building envelope (marked as I – V, I – exterior, V – interior). All dimensions and weights of all specimens were measured and then the dynamic material properties were determined. The Fig. 1 and Fig. 2 show the evaluated dynamic Young's modulus determined based on the longitudinal resonant frequency (E_{dl}) and based on the transversal resonant frequency (E_{df}). The Fig. 3 shows the values of the evaluated dynamic shear modulus and the graph of the Poisson's ratio μ_d is visible in Fig. 4.

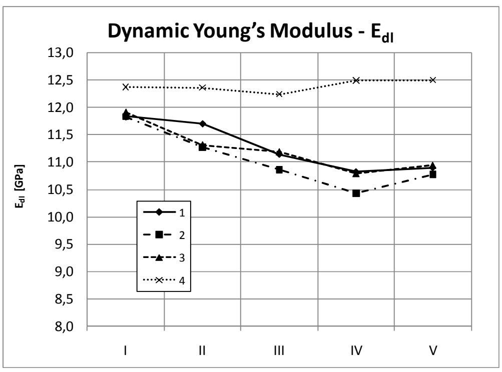

Fig. 1. The dynamic Young's modulus E_{dl} determined based on the basic longitudinal resonant frequency

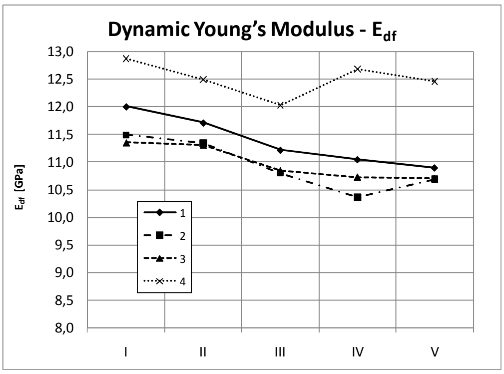

Fig. 2. The dynamic Young's modulus E_{df} determined based on the basic transversal resonant frequency

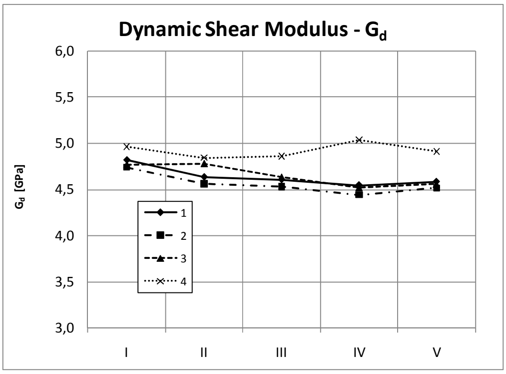

Fig. 3. The dynamic shear modulus G_d determined based on the torsional resonant frequency

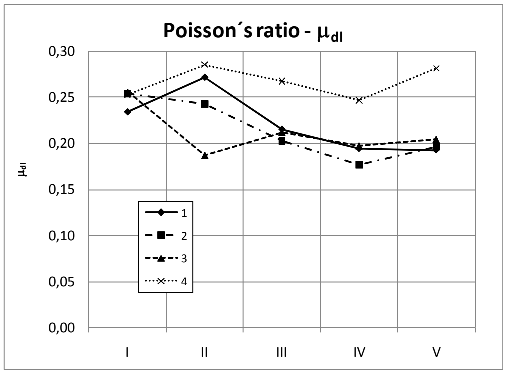

Fig. 4. The Poisson's ratio μ_d determined based on longitudinal and torsional vibration μ_{dl}

5. Conclusion

The paper presents measurement of dynamic material properties (dynamic Young's modulus E_d, dynamic shear modulus G_d and Poisson's ratio μ_d) of the gypsum block, which was for four years a part of the building envelope. It can be seen from the presented results that the weather actions (sunshine, wind, rain, frost) have not influenced the mechanical properties (E_d, G_d, μ_d). Their values did not decreased on the exterior side of the block as it is supposed generally for gypsum materials exposed to weather conditions [1]. The values of dynamic material properties (Figs. 1 – 4) even seem to be higher on the exterior side (I) then on the interior side (V). It would be good to complete results with values of other material parameters obtained from destructive testing – compression strength, tensile strength from bending test – to ensure if there are not any marked differences between material properties of the gypsum on the interior and exterior sides of the block.

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