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Experimental Stress Analysis

Nondestructive Determination of Young's Modulus of Gypsum Specimens Using Impulse Excitation Method

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Abstract: The paper presents a nondestructive impulse excitation method for Young's modulus determination of gypsum specimens. The dynamic Young's modulus is calculated based on the measured resonant frequencies of longitudinal vibration of the gypsum specimens. The major advantage of this method is its nondestructive character. Thus, the time dependent changes of dynamic Young's modulus can be monitored on the same specimen. At the end of the paper, time dependence of dynamic Young's modulus changes of gypsum material is presented.

Keywords: Gypsum, Non-destructive methods, Dynamic Young's Modulus

1. Introduction

The mechanical characteristics – strengths and modules – of gypsum after its hydration rely on some conditions applied during the development of its own solid structure, but also on the successive placement of the unit (for example, the difference between a placement in a water environment and in the air, pressured under atmospheric, etc) [1]. The strength values of hardened gypsum significantly depend on the water-gypsum ratio, which commonly takes the value for total open porosity in the interval of 0.6 to 0.8. In the Czech Republic, these issues were studied by e.g. Šatava [2], [3]. He concludes that, for example, the strength of hardened gypsum mixes is most affected by the water-gypsum ratio. This ratio particularly affects the shape, size and distribution of particles (crystals). Another significant factor is the increase in the number of interfaces in a volume unit. This factor may be affected by the temperature at which the mix hardens, or by the mechanical processing of the gypsum suspension.

On effects as moisture of samples, draying temperature, time – initial 14 days – influenced mechanical properties of hardened gypsum. After Czech standard ČSN 72 23 01 Gypsum binders – Classification, General technical specifications, Test

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methods of 1979 [4] gypsum binder is classified and divided into several groups. The basic classification of gypsum is based on its compressive strength after two hours. And gypsum may be classified into the total of 12 groups (G-2 to G-25). In this case 2 hours compressive strength is certain conventional strength. Because this strength is lower than e.g. 28 days compressive strength. The same effect holds for bending strength.

2. Material and samples

Tested samples were made according to Czech standard CSN 722301 from the commercial gypsum grey which is produced by company Gypstrend. This binder is made from two different dehydrates, namely naturally gypsum and gypsum from chemistry industry, ratio is half to half.

Used water-gypsum ratio was 0.71 and corresponded with normal consistence of gypsum paste after standard CSN 722301; gypsum is classified after this standard as G2 BII.

Young's modulus of gypsum was determined on specimens with dimension of 40×40×160 mm (Fig.1) which were prepared in a stainless mould with three sections. In each set, three bars were made.

The one set of gypsum specimens were prepared from a gypsum binder with a mass of 1.0 kg and 0.71 kg of water. Water was poured into a plastic vessel and then gypsum binder was spilled, gypsum paste was homogenised, after 60 seconds gypsum paste was poured into the stainless mould. Consequently the gypsum paste in the mould was solidifying using five standard tapping. As soon as the paste started to set, outside surface of gypsum samples was cut off in the direction parallel to the mould face. Approximately after 15 minutes of the samples preparation beginning the mould was removed and the samples were marked and placed in different conditions for further testing.

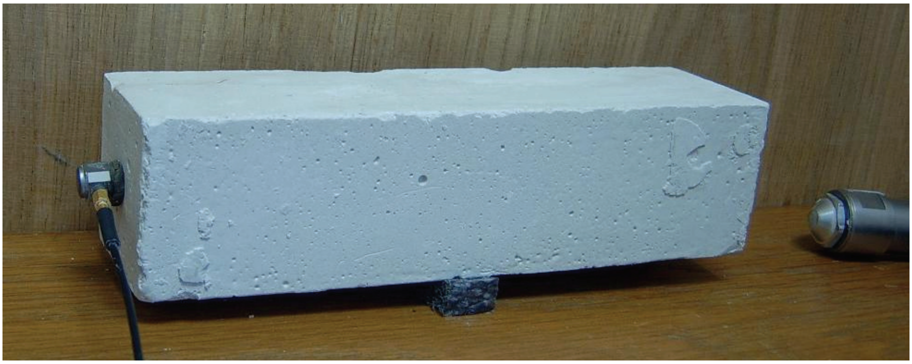

Fig. 1. The test arrangement for measuring the fundamental longitudinal resonant frequency of the gypsum specimen.

3. Impulse excitation method

The impulse excitation method for Young's modulus determination of the gypsum specimens is based on measuring the fundamental resonant frequencies. The test arrangement was done for longitudinal vibration (Fig. 1).

The specimen was supported in the middle of its span (Fig. 1), 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. 1- the left 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 Function (FRF) were evaluated from these signals using the vibration control station Bruel&Kjaer Front-end 3560-B-120 and program PULSE 14.0. 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. Based on the equation for longitudinal vibration of the beam with continuously distributed mass with free-free boundary condition, the Young's modulus can be determined using the relation

$$E = \frac{4lmf^2}{bt} \qquad (1)$$

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.

4. Evaluation of dynamic Young's modulus

The time dependent changes of dynamic Young's modulus were monitored during tests. The prepared specimens were divided into three groups. The first group of specimens was dried in dryer, where the temperature was maintained at 40°C. The second group of specimens was put to the water and the third one was placed in the test room at an average temperature of 25 °C and a relative humidity of 50 %.

The first five hours after preparation of specimens, they were tested approximately every 20 minutes. After five hours, the specimens were tested daily and after five days, they were tested after 7 days and 14 days. At each test time, the same six specimens from the third group were tested using impulse excitation and time dependent changes of the dynamic Young's modulus were monitored. Three more specimens from the third group were tested using the same non-destructive method at each test time. Then they were taken out of the group for making other types of tests (e.g. bending tests, compression tests). The dimensions and weight of every tested specimen were measured before starting each testing.

The specimens from the first and the second groups were tested starting from the second day of measurement. Three specimens from each of these two groups were tested at each test time.

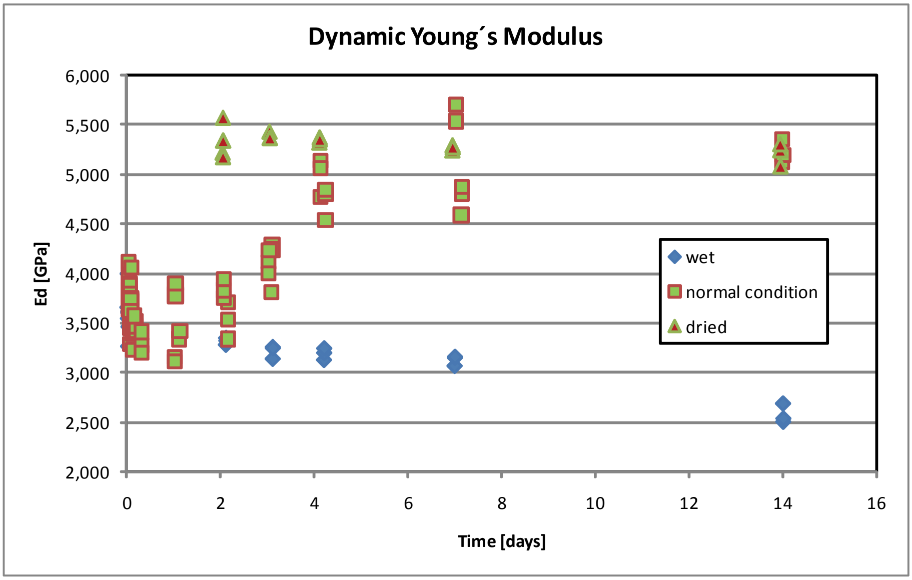

Fig. 2. The time dependent changes of Dynamic Young's modulus of all tested specimens.

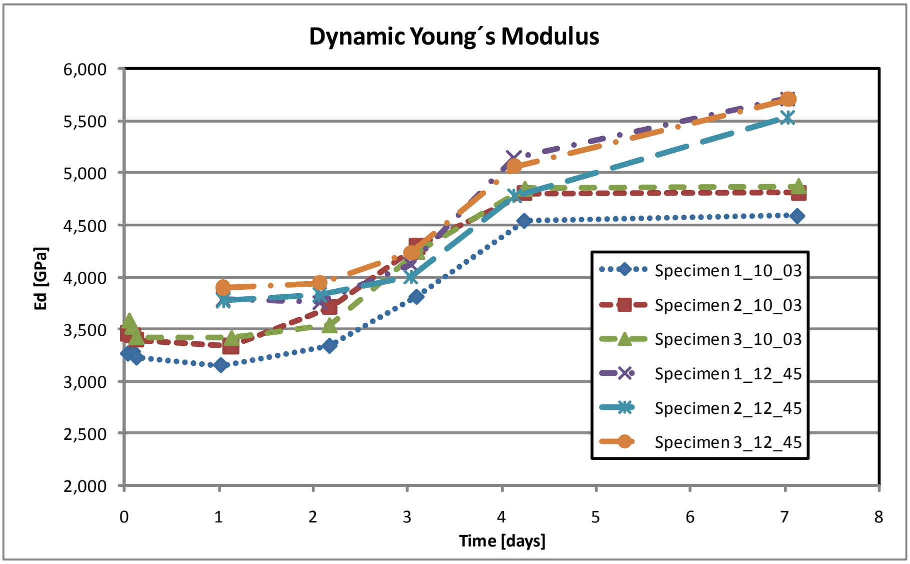

Fig. 3. The time dependent changes of Dynamic Young's modulus of chosen six specimens.

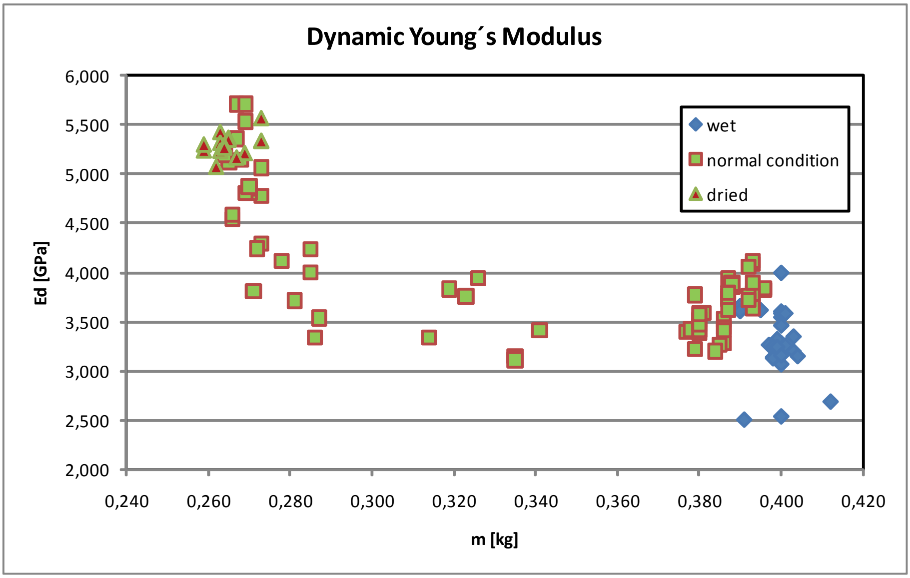

Fig. 4. The changes of Dynamic Young's modulus of all tested specimens in dependence on weight of the specimens.

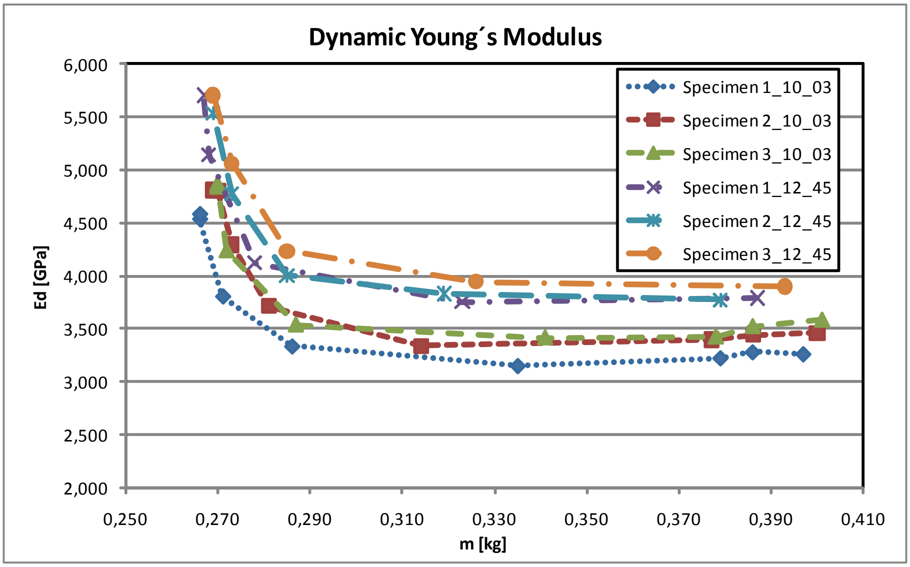

Fig. 5. The changes of Dynamic Young's modulus of chosen six specimens in dependence on weight of the specimens.

5. Conclusions

The changes of the dynamic Young's modulus in dependence on time were presented in this paper. From the time dependence of these changes (Fig. 2) it is obvious that dynamic Young's modulus of gypsum specimens increases in time, especially during the first week. Nevertheless, differences between the dynamic Young's moduli of the specimens at the same time instant are not negligible, especially at the beginning (Fig. 2). These differences can be seen more clearly in Fig. 3, where the dynamic Young's moduli of two sets of three specimens were monitored in time.

From the weight measurement of the specimens during the time, it results that specimens dried differently. Therefore the graphs of the changes of the dynamic Young's moduli of the specimens in dependence on their weight were made (Fig. 4 and Fig. 5). From these graphs, it results that the dynamic Young's moduli of the specimens increases especially at the end of their drying. Based on the comparison of the results of the specimens from the first and the third groups obtained from the graph in Fig.2, this process, which took seven days at room temperature, can speed up by putting the specimens to the dryer.

Acknowledgements

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