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# Effect of Porosity on Mechanical Properties of High Strength Gypsum

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**Abstract:** The mechanical properties of material on gypsum basis are mainly influenced by the water/gypsum ratio. The mechanical properties of hardened gypsum depended on the total open porosity and pour distribution curve. These parameters affect macromechanical properties of gypsum because gypsum micromechanical properties are from the same source material. In this case a relationship between open porosity and macro mechanical properties were studied on high strength gypsum, which is used for dental purposes.

**Keywords:** Porosity, Mechanical properties, High strength gypsum

## 1. Introduction

Secondary sources for the production of gypsum are now more than sufficient and they could be appropriately used to expand the utilization of this cheap and easy-to-use material in a much larger scale in building industry. However, some basic knowledge of the nano- and sometimes also macro-level properties is still lacking and obstructs gypsum wider application, for example at building industry as building envelope [1].

Some basic dependencies of the material properties on thermal and hygric conditions is lacking as well. Understanding of the gypsum behavior during hydration and dehydration would lead to an easier way of designing modifications of gypsum binders to be used more efficiently. Appropriately, the design of gypsum modifications would allow expanding the use of this secondary raw material. With respect to its chemical composition (e.g. in comparison with cement), the processes and behavior of other silicate binders could be deduced based on processes and relations between macro- and nano-mechanical properties of the gypsum [2]. Determination of gypsum mechanical properties using by destructive method on the macro level is usually presented [3], [4].

Nondestructive method is possible to apply commonly for determination of mechanical properties, e.g. as a function of different material characteristics [5]. At first, non-destructive methods for determination of macro mechanical properties were applied for homogenous materials without porous (as metal), but presently they are used for heterogeneous porous building materials as concrete.

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## 2. Experimental method

Dynamic Young's modulus was determined as basic mechanical property using by a non-destructive method, in this case the ultrasonic method was used. Ultrasonic pulse tester made by the company Matest (Italy) was used for measuring the dynamic Young's modulus, respectively for measuring the required time (μs) by the ultrasonic impulse to go through the tested material, which depends on the physical and material properties of tested samples. Firstly, the tester was reset and calibrated using an etalon (a calibrating cylinder) with the value of 42.5 μs. The time values were selected as the material value for description of one of the material properties. The tester set contained two 55 kHz probes with connecting cables. The probes were attached to the surface of tested samples, facing each other, during the measurement. A contact paste (an ultrasonic gel) caused an ideal contact between the probe and the sample. The samples were measured three times and an average value was then calculated. After ultrasonic measuring, samples were weighted and dimensions of samples were provided.

Dynamic Young's modulus $E$ [MPa] was calculated using followed equation:

$$E = v^2 \rho \tag{1}$$

Bulk density $\rho$ [kg.m$^{-3}$] of the samples was calculated using a basic equation. Velocity $v$ [km.s$^{-1}$] was calculated based on measured time and the length of samples, respectively the distance between the probes.

Total porosity $\psi$ [-] was calculated using relation (2), density of the matrix was 2500 kg.m$^{-3}$, bulk density was known individually for all samples.

$$\rho = \rho_{mat}(1-\psi) \tag{2}$$

## 3. Material and samples

The high strength gypsum material was used for determination of dependence between dynamic Young's modulus on water/gypsum ratio or total porosity. Commercially available dental gypsum Interdent® (with compressive strength 250 MPa after 24 hours) was used in our study. It was assumed that water to gypsum (w/g) ratio will have influence on its macromechanical properties. Therefore, five different types of samples with w/g = 0.18, 0.19, 0.20, 0.21 and 0.22, were prepared. Dimensions of samples were 40 × 40 × 160 mm. Table 1. shows common types of dental gypsum, clearly is visible effect of the water/gypsum ratio).

**Table 1. Types of dental gypsum**

| Type of dental gypsum | Description | Expansion rate [%] | Water/gypsum ratio |
|---|---|---|---|
| Type I | Expression plaster | 0.15 | 0.50 |
| Type II | Model plaster | 0.30 | 0.50 |
| Type III | Hard stone | 0.20 | 0.30 |
| Type IV | Super hard stone (low expansion) | 0.10 | 0.22 |
| Type V | Super hard stone (high expansion) | 0.30 | 0.22 |

Every type of gypsum is described from a view point of strength (compressive) of hardened gypsum and expression during/after hardening. It is clearly visible dependence of macromechanical properties on water/gypsum ratio [6].

## 4. Experimental results

Obtained results are summarized in Fig. 1 to 4. Fig. 1 shows the dependence between dynamic Young's modulus of gypsum samples on the water/gypsum ratio. It is clearly visible that with increasing value of the water/gypsum ratio decreases the values of dynamic Young's modulus of tested samples. Error bars in Fig. 1 present 5 % deviation from the measured values. The dependence has character as letter "S", and used regression is polynomial of the fourth order, but the used regression for the initial and the final part of the dependence is not too ideal. Fig. 2 shows similar regression as Fig. 1, but in this case as a function of total porosity, obtained wave is like as in Fig. 1.

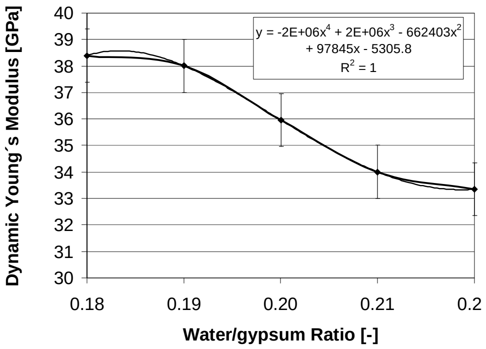

**Fig. 1.** Dependence of dynamic Young's modulus on water/gypsum ratio

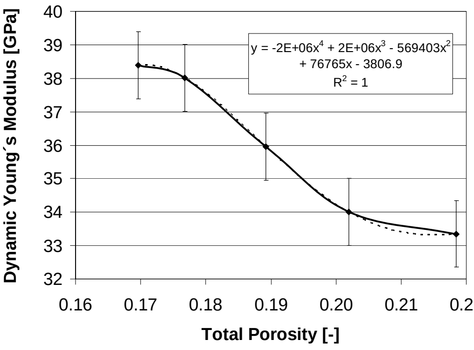

**Fig. 2.** Dependence of dynamic Young's modulus on total porosity

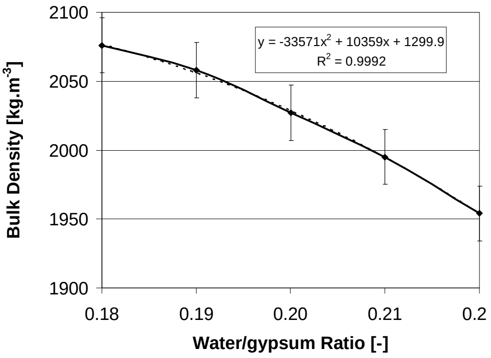

**Fig. 3.** Dependence of bulk density on water/gypsum ratio

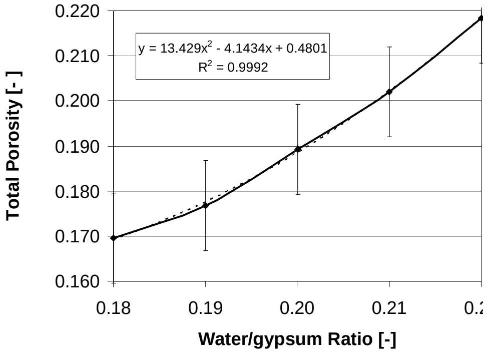

**Fig. 4.** Dependence of total porosity on water/gypsum ratio

Fig. 3 and 4 present dependence between water/gypsum ratio and bulk density or total porosity of the tested gypsum materials.

From all of the four presented dependences, it results that materials with w/g ratio between 0.19 and 0.21 are almost linearly dependent – one parameter on another. Whereas, all dependences changed significantly for w/g ratios 0.18 and 0.22. This fact could be described that both border values of w/g ratios are far from the value of the ideal workability of the gypsum paste. The gypsum material with the w/g ratio 0.18 was mixed very hardly and the whole amount of binder could not be hydrated. On the contrary, gypsum paste with the w/g ratio 0.22 was too rare.

## 5. Conclusion

The usage of nondestructive methods for testing of material properties of porous building materials is relatively new but it can be supposed that these methods will find wider use in the field of testing these materials. The previous limited usage of these methods only for homogenous materials seems to be baseless. Measurement of several phases, from which the common porous building material is composed (matrix, porous system, air or moisture in porous system), seems to be troublefree. Nevertheless, the most of authors have measured samples in natural state and not e. g. in dependence on the moisture content.

Destructive methods are then suitable used as a supplement for verification of nondestructive methods [7], [8].

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