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Applying Conduct – Metrical Method to Research of Foam Gypsum with Hemp Fibrous Reinforcement Drying Process

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Foam gypsum is a perspective material in construction. According to the requirements for the manufacturing process of foam gypsum, the initial moisture content should be very high. The drying of these products is an obligatory requirement to obtain material with sufficient mechanical and heat conductivity properties. This study provides the experimental measurements of electrical properties – resistance and capacitance during the drying process. The results show, that electrical measurements are a useful tool for characterizing moisture content in foam gypsum. The optimal frequency of electric measurements at the kilo- and megahertz range has been determined.

1. Introduction

Electrical measurements are a useful nondestructive method for the drying process control in porous materials (Iljins et al. 2009). Foam gypsum with hemp reinforcement is a complex heterogeneous media, containing gypsum, pores, moisture and cellulose. Electrical properties are investigated in many porous materials: sands and clays (Lounev et al. 2002), sand–clay mixtures (Roberts et al. 2004), black soils (Ahire et al. 2012) and cellulose (Sugimoto et al. 2008). It has been observed that the dielectric constant of material decreases and conductivity increases with an increase in frequency. The dielectric constant is directly related to the electronic, atomic and orientation polarization of material.
There are indications that in porous materials the dielectric dispersion at low frequencies depends on the moisture content (Sugimoto et al. 2008). Within a low-humidity region the dielectric relaxation process is insignificant. While within a high-humidity region dielectric relaxation is more pronounced. The analysis of electrical measurements of water saturated sand-clay materials shows that the porous medium contains at least two types of water – bound water, strongly adsorbed on substrate pores, and free water, which belongs to free volume (Lounev et al. 2002). According the results of the analyses they conclude, that at humidity less than 12 %, water is completely transformed into a bound state. Therefore the dielectric relaxation methods are very convenient for studying the drying process.

2. Materials and methods

Conduct – metrical measurements were performed during the drying process on a foam gypsum sample with hemp fibrous reinforcement. The sample's final density in the dry condition was 415 kg/m^3. According to our theoretical calculations, the drying time of the sample is inversely proportional to the thickness squared (Iljins et al. 2009). Therefore, the thickness of the sample was chosen d = 10 cm, so that the drying time would be within 2 months. All the surfaces of the sample, except the top surface through which the moisture evaporates, were covered with a vapor barrier.
During the process of drying, the average moisture content in the sample was determined by weighing the sample with scales manufactured by the company KERN, the maximum allowable weight of which is 16,100.0 g, but sensitivity $\pm$ 0.2 g. In order not to exceed the maximum allowable weight value, the surface area of the sample was 0.16 m^2. To electrically check the moisture changes in the sample, four pairs of electrodes with different immersion depths were inserted in the sample during the manufacturing process

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with the distance between the electrodes being α=15 mm, the height β=15 mm and the length 120 mm (Figure 1). Electrical resistance and capacitance were measured with a HIOKI alternate current bridge HIOKI 3532-50 at frequencies of 0.5, 5, 50, 500 and 5,000 kHz in a parallel equivalent scheme. RF signal level was 1 V. During the drying process of the samples the resistance and the capacitance between the electrodes were measured. Above this frequency range the system capacitance was determined to be 18 – 22 pF. The data presented are corrected for this capacitance. We have used an automatic set-up with a PC-based control and data register every 6 hours during the sample drying.

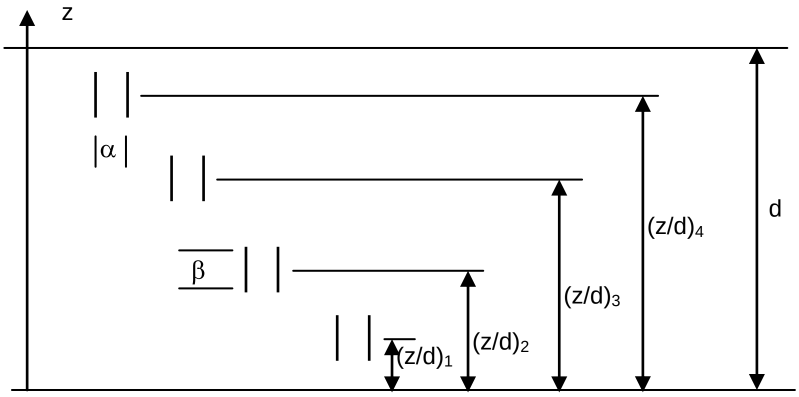

Figure 1: Cross section of sample with inserted electrodes. Average immersion depth $(z/d)_i$ were i: 1 – 0.2230 (bottom); 2 – 0.4015; 3 – 0.5750; 4 – 0.7675 (upper pair)

3. Experimental results

Sample weighing gives an average change of mass for drying time. Each pair of electrodes is present in the sample at different depths in different humidity conditions (Figure 1). These humidity conditions do not coincide with the average moisture content according to the sample weighing results. Our theoretical drying process model (Iljins et al., 2009) makes it possible to calculate local humidity conditions for each pair of electrodes during drying time (Figure 2).
Using the theoretical calculations for different immersion depths in the sample (Figure 2), it is possible to recalculate the experimentally obtained electrical resistance R = f (t) and capacitance C = f (t) versus time to the dependence on the humidity R = f (w) and C = f (w). It is appropriate to use dependence R = f (w) to control the humidity of the sample at the beginning of the drying process for high moisture content W > 30 kg/m^3. At lower moisture content resistance measurements can become unstable. Figure 3 shows the dependence of resistance on the moisture content at a frequency of 0.5 kHz for all 4 pairs of electrodes with different immersion depths (Figure 1). Dependence approximation is described by Eq(1) (Moik et al., 1988). The results obtained from the measurements in the frequency range of 1 - 500 kHz are very close to the results shown in Figure 3.

$$R = 4 \cdot 10^6 \cdot W^{-1.9595} \qquad (1)$$

Capacitance measurements of moisture for the pairs of electrodes (Figure 1), shown in Figure 4 and Figure 5, can be used at a low moisture content of the sample W < 30 kg/m^3. It is particularly important in the case of foam gypsum and modifications with hemp fibrous reinforcement to detect the moment, when the moisture content during drying is about 10 kg/m^3, because under these conditions the material very quickly changes its physical - mechanical characteristics (reach design values): mechanical strength and thermal conductivity. It is then possible to design a technological processing of foam gypsum constructions.

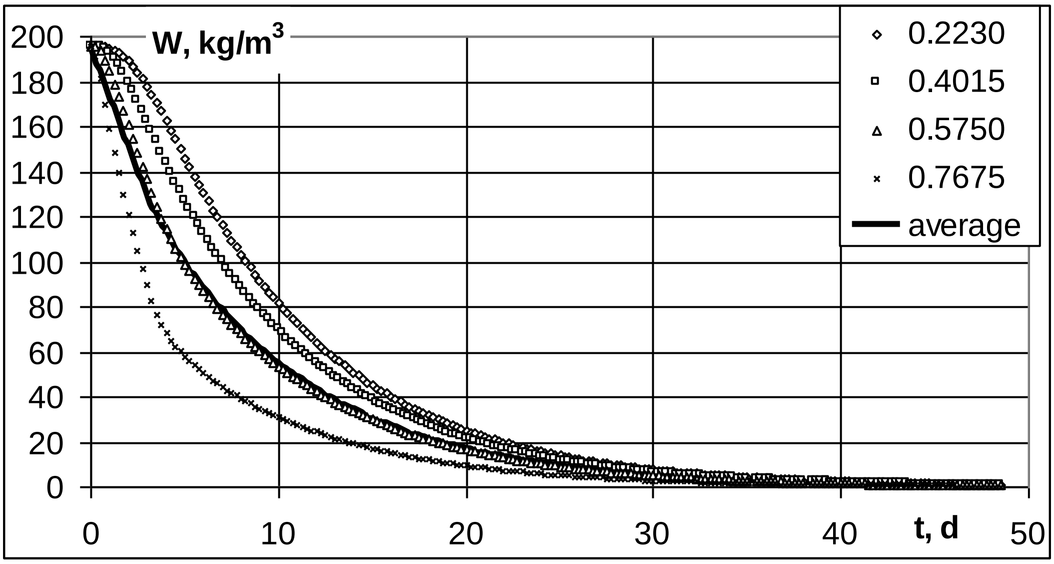

Figure 2: Plots showing theoretical moisture content in different sample depths z/d and average moisture versus drying time, were i: i = 1 – 0.2230 (bottom); 2 – 0.4015; 3 – 0.5750; 4 – 0.7675 (upper pair)

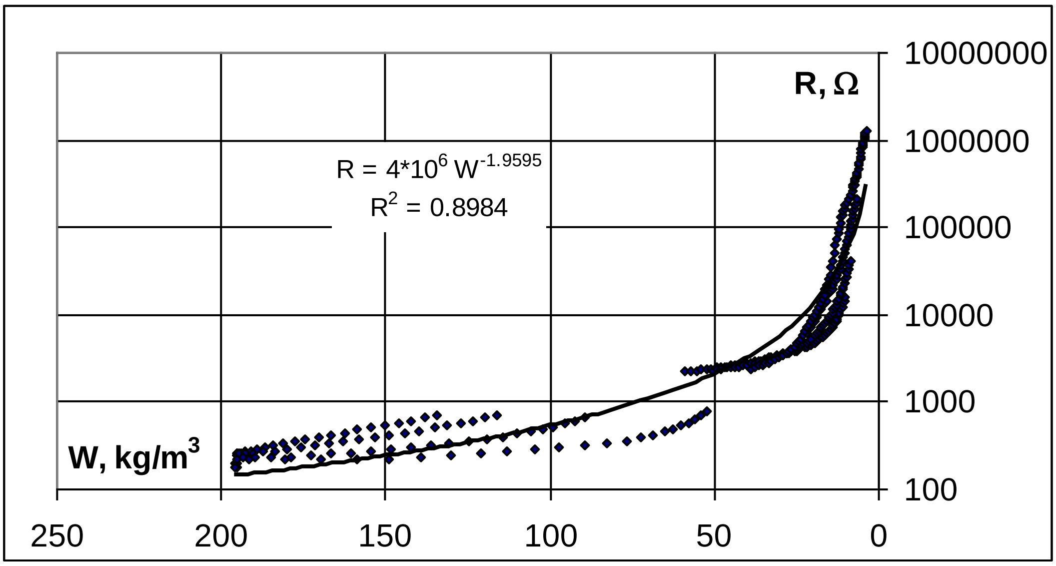

Figure 3: Resistance dependence on local moisture content at a measurement frequency of 0.5 kHz

Figure 4 shows the capacitance of pairs of electrodes on the moisture content at a frequency of 5 MHz. In this frequency range measurements are stable and repeatable, but the capacitance values are less than 20 pF, which requires more sensitive instrumentation. Dependence of capacity (pF) approximation is described by the Eq(2).

$$C = -0.0107W^2 + 0.7347W + 4.9628 \quad (2)$$

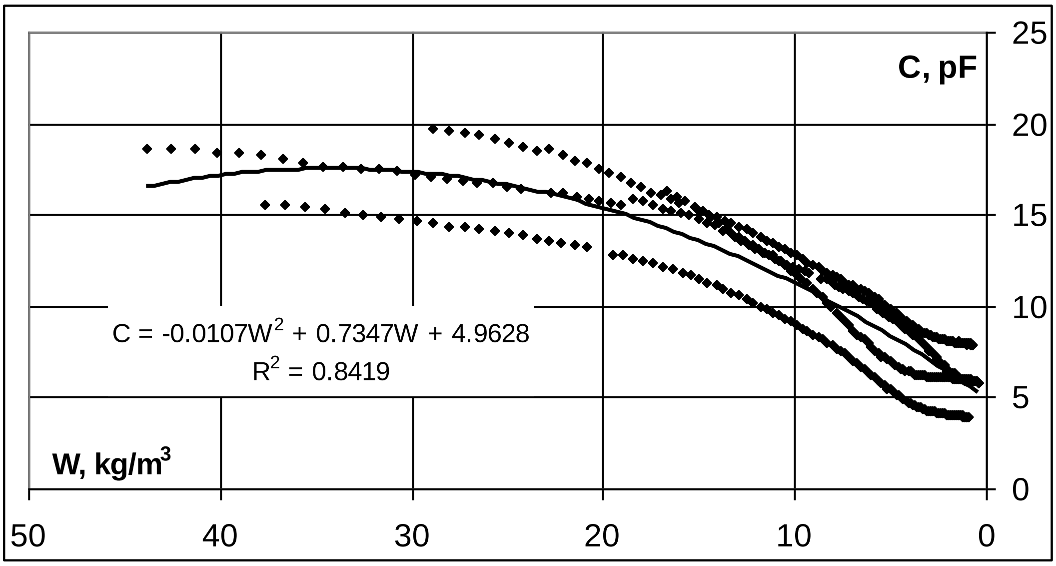

Figure 4: Capacitance of the pairs of electrodes on the humidity of the sample at the measurement frequency of 5 MHz

At lower frequencies, the measured capacitance value grows, however, the stability of the measurement decreases. Figure 5 shows the capacitance on moisture content at a measuring frequency of 0.5 kHz. Dependence of capacity (pF) approximation is described by Eq.(3).

$$C = -0.317W^3 + 25.37W^2 - 194.63W + 279.77 \qquad (3)$$

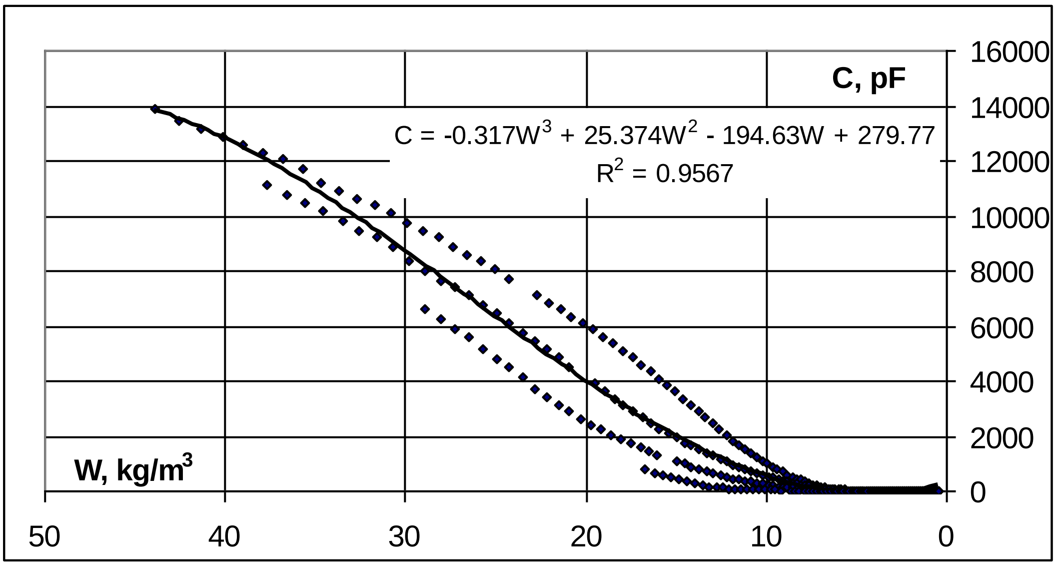

Figure 5: Capacitance of the pairs of electrodes on the humidity of the sample at the measurement frequency of 0.5 kHz

If the electrode geometry (size) is not given values (Figure 1), the values of resistance and capacitance values will differ. This can be avoided by switching measurements of resistance and capacitance to the measurements of the resistivity and dielectric permittivity (Grove et al. 2005). The confirm mapping (Iljins et al. 2008) can perform this conversion subject taking in account the electrode edge effects. Thus, resistance and capacitance can be found from Eq.(4).

$$R = \frac{\rho}{f}\Gamma_R \text{ and } C = \varepsilon\varepsilon_0 f\Gamma_C \quad (4)$$

were ρ – sample resistivity, Ωm;

ε, ε_0 - the sample dielectric permeability and dielectric constant ε_0 = 8.85 pF/m;

f – lengh of electrodes, m;

Γ_R un Γ_C – geometric factors of the resistance and capacitance $\Gamma_R = 1/\Gamma_C$;

Figure 6. shows the capacitance and resistance geometrical factors dependence on geometrical factor of electrode system $\xi = \alpha/\beta$ (Figure 1). For example, the current electrode sizes α=β=15 mm, ξ=1 and Γ_C = 2.116. Then we find, that the dielectric permeability of foam gypsum ε = 2.0-2.4. Taking into account the porosity of the sample (72 %) it is in proper agreement with the literature data for rock gypsum ε = 5.7 (Kaye and Laby, Table of Physical and Chemical Constants, 2013).

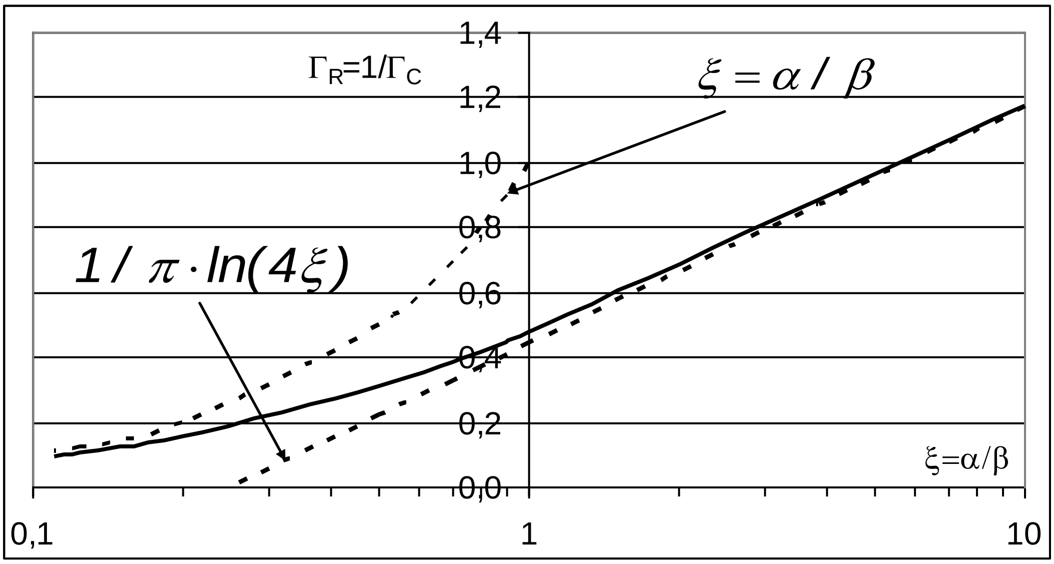

Figure 6: Dependence of resistance and capacitance geometrical factors Γ_R and Γ_C on geometrical factor of electrode system $\xi=\alpha/\beta$. The formulas in figure are asymptotic expressions of geometric factor Γ_R

4. Conclusions

Conduct–metrical method is a useful tool for moisture content control in foam gypsum. Resistance measurements of moisture content in the sample can be used for high moisture content W > 30 kg/m^3. Capacitance measurements can be used for low moisture content W < 30 kg/m^3. However there is a considerable need for additional experiments aimed at verifying the results and understanding the physical mechanisms causing the observed electrical results.

Acknowledgements

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