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EFFECTS OF MOISTURE AND CONTENT OF MOULDING SAND BENTONITE ON THE ELECTRIC PROPERTIES

The paper presents the results of laboratory tests into the effects of moisture and the content of two types of bentonite on dielectric properties of moulding sand. The use of electromagnetic waves in foundry industry is becoming more and more popular, which provides to some extent alternatives to conventional drying methods. Experimental studies published so far have shown the validity of using microwaves for drying classic moulding sands with bentonite. However, these studies lack data on the effect of moisture or bentonite content in moulding sand on the real component ε' or imaginary component ε'' of the relative complex electrical permittivity. The presented results may become in the future the basis for the evaluation of the composition of moulding sands, taking into account the phenomena occurring under the influence of electromagnetic field, which directly translates into the quality of the castings made and may constitute an attempt to develop a mathematical model of electric properties of moulding sands.

Keywords: moulding sand, eletric properites, moisture, bentonit

1. Introduction

The term 'moulding sands' refers to a number of processed mixtures prepared from various moulding materials selected in an appropriate ratio. Depending on the alloy used, the wall thickness of the casting, its shape, size, required dimensional accuracy surface smoothness, and quantity the type of components varies, but each moulding sand can be considered as a mixture of two main components, i.e. the matrix and the binding material. The matrix is made up of various types of sand, but due to the availability of raw materials and the low price, silica sand is the most widely used. Binding materials are added to the matrix to give it sufficient strength, which translates into a casting of the desired shape and size. Among the binding materials available in the foundry industry, it is moulding clays, in particular bentonites, mostly composed of montmorillonite, which continue to be popular. The distinguishing feature of montmorillonite is its ability to swell and its susceptibility to water dispersion. Structurally, bentonite minerals are composed of three-layer packets, i.e.: an aluminosilicate layer closed between two silicon-oxygen layers. Figure 1 shows the structure of montmorillonite [1].

Taking into consideration the structure of the packets, dioctahedral (montmorillonite, beidellite, nontronite) and trioctahedral (saponite) montmorillonites are distinguished, while depending on exchangeable (inter-packet) cations we distinguish sodium, calcium, ammonium and other montmorillonites. The distances between the packets depend on the exchangeable cations and change under the influence of water. As the degree of water saturation increases, the distances increase. The effect of changing the distance is the swelling of montmorillonites and the formation of stiff network inter-packet water. The process of saturation and elimination of packet water is very easy, as montmorillonite absorbs and releases water from the air. Increasing the water content will make the rigid water film more plastic. The plasticity depends on the type of exchangeable cations. The ability of montmorillonite to swell depends on the type of inter-packet cations. Strong swelling is caused by Li^+ and Na^+, while weaker swelling is caused by Ca^{2+}, Mg^{2+}, Al^{3+}, H^+, Fe^{3+} and K^+. The higher the charge of the cation, the stronger the bond. Highly charged ions attract the packets more strongly to each other, pumping water out of them in a way [1].

In the experimental works published so far, it has been demonstrated that the use of microwaves for drying classic masses with bentonite or sodium silicate is appropriate, however, there is no knowledge about the influence of moulding sand components on their dielectric properties [2-6]. Complementing this knowledge will help to eliminate problems occurring during the heating of the sands, such as a rapid increase in steam pressure inside the material or the phenomenon of uneven heating of samples. [7]. Since moulding sand, in which the main component is sand, is characterised by a low conductivity, it can be classified as a group of materials called dielectrics. Solid dielectric are an important group of electrotechnical materials. The most important electrical parameters of dielectrics are cross- and surface resistivity, electrical permittivity and dielectric loss coefficient, electrical strength, incomplete discharge resistance,

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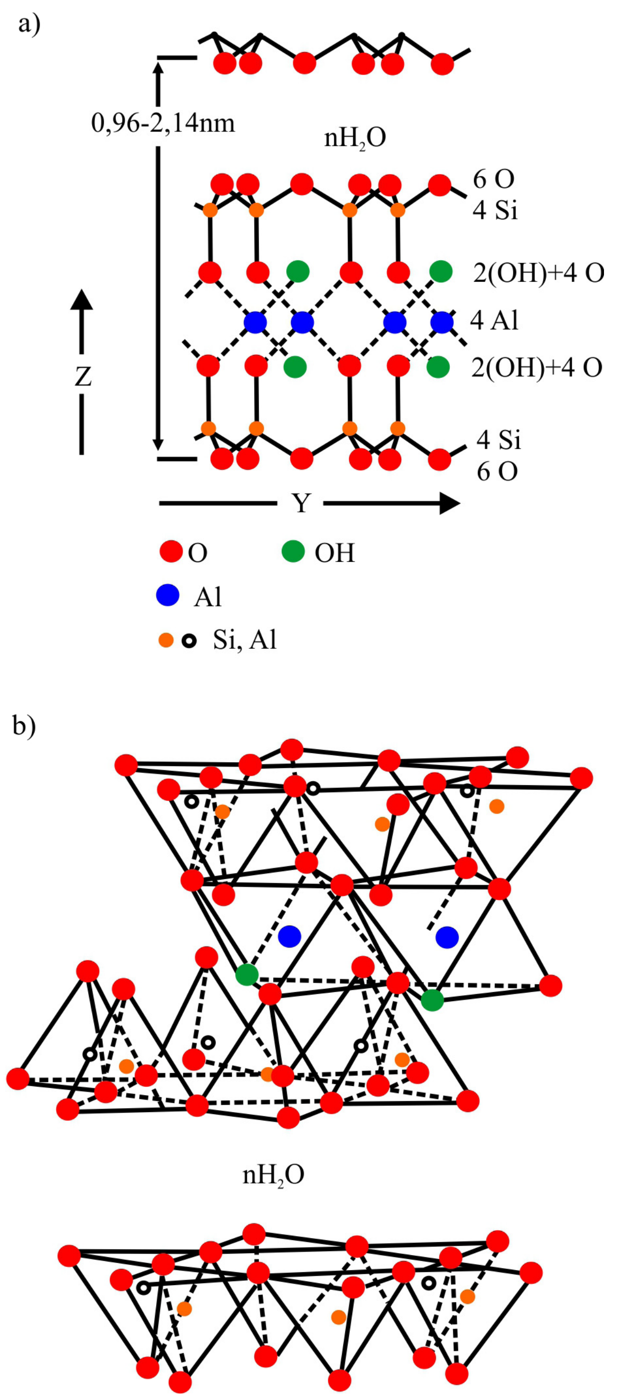


Fig. 1. Montmorillonite network packets: a) flat diagram, b) spatial diagram [1]

and electrical susceptibility [8]. One of the most important electrical parameters involved in the process of microwave heating of moulding and core sands and their components is electrical permittivity. This parameter became the focus of research carried out by scientists from several world research centres, where the research concerned both sands and binders [9-11] and mixtures whose main component is sand [12-14].

The macroscopic properties of dielectrics in an alternating electric field are described by a relative complex electrical permittivity ε_r defined by formula (1). It should be noted that this property is not a material constant, because it changes depending on both the parameters of electrical materials and the frequency of electromagnetic wave

$$\varepsilon_r = \varepsilon' - j\varepsilon'' \tag{1}$$

where:

ε' – the real component of the relative complex electrical permittivity,

ε'' – the imaginary component of the relative complex electrical permittivity.

Both quantities are measured experimentally. The real component of relative complex electrical permittivity corresponds to a situation where the system response does not involve field energy absorption and the imaginary component describes a situation where a medium absorbs energy [15]. Changes in moisture content or sand composition affect the real and imaginary component of the relative complex electrical permittivity. Therefore, it is advisable to conduct analyses of changes in moisture content or moulding sand composition to dielectric properties, as this significantly affects the course of the microwave heating process.

2. Methodology and test stand

Our own research concerned moulding sands made of moulding materials, which are most often selected and used by domestic foundries. The first group of these materials was sand. Medium sand of class 1K from the mine "Grudzeń Las" with the main fraction 0.20/0.16/0.315 was used. Two types of bentonites, differing mainly in montmorillonite content, were selected for the study. Table 1 demonstrates the physicochemical parameters used in the preparation of bentonite moulding sand.

TABLE 1

Physicochemical parameters of bentonites [16,17]

	Bentonite A "Specjal"	**Bentonite B "Geko S"**
Water content max. [%]	12	14
Montmorillonite content min. [%]	75	90
Carbonate content max. [%]	5	5
Swelling index min. [cm^3/2g]	17	20

For the purpose of the study, the water content in individual moulding sand was selected in the range from 1% to 6%. Moulding sand were prepared in accordance with the literature recommendations [18]. Samples with a diameter of 16 mm and a height of 43 mm were prepared for testing. In the paper [19] it was shown that the value ε_r of synthetic moulding sands depends on apparent packing degree. For this reason, on the basis of weight and volume measurements of each of the packed fittings, the apparent packing degree was determined, which ranged from 1,420 to 1,580 kg/m^3 depending on the composition of the sand. The moisture content in individual moulding sands was determined by the gravimetric method using laboratory dryer Lap-3 on samples of 50 g, dried for 15 minutes at a temperature of ca. 120°C [18].

Relative dielectric permittivity ε_r of materials is measured by various methods, which are selected depending on: type of material, size and shape of tested samples, frequency, as well as expected range of measured values. From among many test methods, the perturbation method was chosen to measure the relative dielectric permittivity of classic moulding sand. It allows the measurement of samples within a wide temperature and humidity range and precisely determine the ε_r value of a composite at an industry-standard frequency of 2.45 GHz. The measurement time of ε' and ε'' values using the perturbation of for one sample was about 45 seconds. A detailed description of the measurement methodology and the dependencies on the basis of which the value of the real and imaginary component was determined has been described in item. The measurements were carried out at a temperature of 20°C and relative humidity of 40%. The measurement results were analysed in an integrated system for statistical data analysis.

3. Test results and analysis

The results of the tests are presented in Table 2 together with the composition of the tested moulding sand. The studies were performed for various bentonite contents within the range of 5-11% by weight.

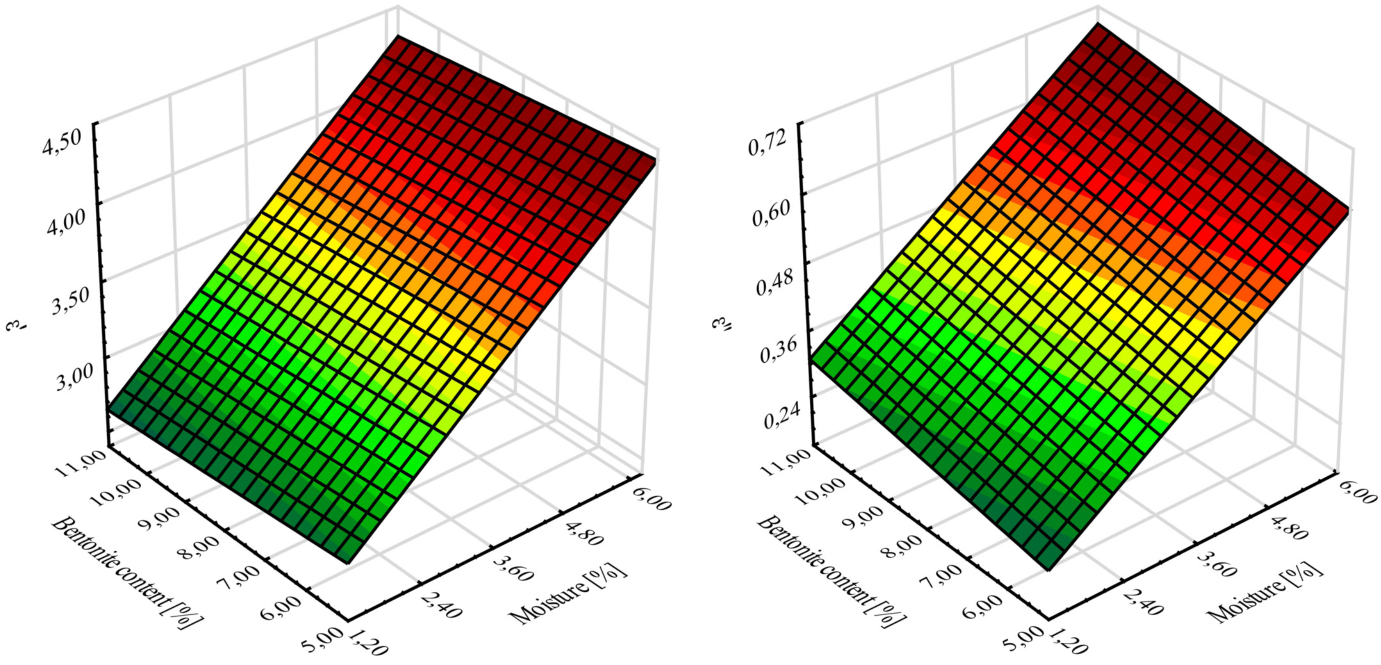
Graphically illustrated results for sands from Table 2 are shown in Figures 2 and 3.

In previous studies, a very significant influence of moisture on dielectric properties of moulding sand was demonstrated [15]. Therefore, when describing the test results for the real (ε') and imaginary (ε'') component of the relative complex permittivity

TABLE 2

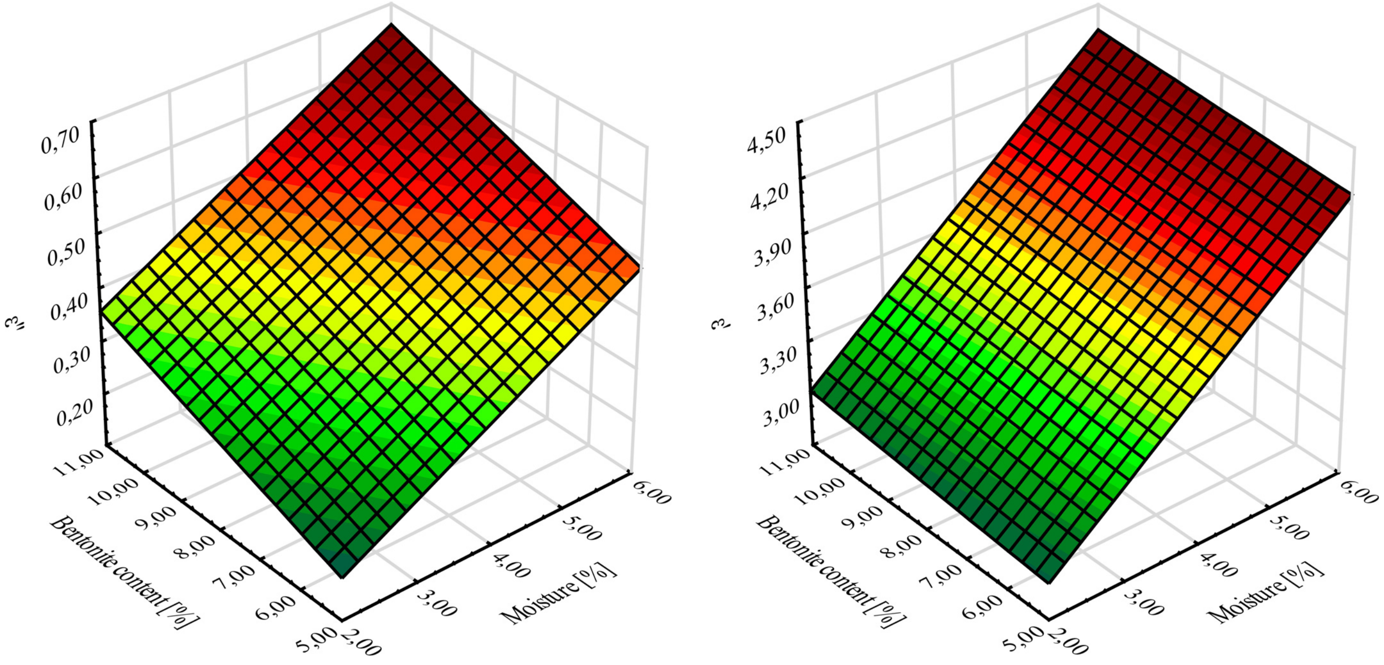
Composition of moulding sands under investigation with test results for the real (ε') and the imaginary component (ε'') of the relative complex electrical permittivity

Type of bentonite	Sand matrix [%]	Bentonite [%]	Moisture [%]	Real component ε'	Imaginary component ε''
A	95	5	1.28	2.79	0.17
A	95	5	2.00	2.90	0.37
A	95	5	2.95	3.41	0.41
A	95	5	5.20	4.21	0.52
A	92	8	2.23	3.10	0.31
A	92	8	2.65	3.17	0.43
A	92	8	3.46	3.43	0.46
A	92	8	5.63	4.19	0.63
A	89	11	2.65	3.38	0.43
A	89	11	3.17	3.42	0.46
A	89	11	3.30	3.44	0.49
A	89	11	3.97	3.46	0.51
B	95	5	2.16	2.85	0.22
B	95	5	3.55	3.46	0.25
B	95	5	3.73	3.47	0.26
B	95	5	5.64	4.22	0.53
B	92	8	2.37	3.12	0.33
B	92	8	3.57	3.44	0.35
B	92	8	4.46	3.81	0.44
B	92	8	5.68	4.19	0.57
B	89	11	2.57	3.38	0.44
B	89	11	3.60	3.42	0.46
B	89	11	5.20	4.16	0.61
B	89	11	5.72	4.16	0.61



a) b)

Fig. 2. Effects of sand moisture and bentonite content on the real (a) and imaginary (b) components of the relative complex electrical permittivity for moulding sands with bentonite A



a) b)

Fig. 3. Effects of sand moisture and bentonite content on the real (a) and imaginary (b) components of the relative complex electrical permittivity for moulding sands with bentonite B

for moulding sand, it is necessary to analyse both the bentonite content in moulding sand composition and the moisture content of moulding sand simultaneously. Observing the influence of moisture one can notice changes in the values of the real component. For example, for 5% content of bentonite A, at a fourfold increase in moisture content, we note a 1.5-fold increase in value ε'. For bentonite B, a 1.5-fold increase in this value is observed at a 2.5-fold increase in moisture content. The effect of the bentonite content on the real component for both bentonite A and B is practically imperceptible, as can be seen graphically in Figures 2a and 3a.

The test results for the imaginary component (ε'') of relative complex electrical permittivity reveal a significant impact of moisture content. For sand containing 5% of bentonite A, at a four-fold increase in moisture, one can observe a 3-fold increase in ε'', and for sand containing bentonite B, at a 2.5-fold increase in moisture content one can observe above 2.5-fold increase in the imaginary component. In contrast to the real component, the composition of moulding sand and, in particular, the content of bentonite is important for the imaginary component. For example, for sands with 5 and 11% of bentonite B and a constant moisture content of approx. 3.60%, the value ε'' is almost doubled, as shown graphically in Fig. 3b.

4. Conclusions

Microwave absorption is one of the indicators of the degree of conversion of microwave energy into heat during the microwave heating process. Therefore, it is very important to analyse the phenomena influencing this process. For bentonite moulding sand, the influence of moisture and bentonite content was analysed. The conclusions are as follows:

1. The sand moisture, which is the main absorber of the microwave energy, has a significant impact on the dielectric properties, both the real and the imaginary components.
2. For both types of bentonite no actual effect of bentonite content on the real component of the relative complex electric permittivity was observed.
3. The process of microwave heating is significantly influenced by the imaginary variable, which is responsible for the conversion of microwave energy into heat, and its influence at the changing content of bentonite in moulding sand.
4. A much higher influence on the imaginary variable is exerted by moulding sand containing bentonite B, which may be associated with a higher content of montmorillonite in the bentonite.
5. The assessment of the influence of montmorillonite in bentonite on electric properties becomes therefore important.
6. 6. The test results concerning the influence of moisture and bentonite content may be useful for the selection of sand composition with regard to the phenomena occurring as a result of electromagnetic field and may constitute the basis for the development of a mathematical model of electric properties of bentonite moulding and core sands.

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