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EFFECT OF COMPACTION DEGREE ON PERMITTIVITY OF WATER-GLASS CONTAINING MOULDING SAND

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The presented basic research was aimed at determining a correlation between compaction degree of moulding sand and its permittivity ε_r at $2{,}45 \cdot 10^9$ s^{-1}. The measurement results make a basis for mathematical description of a multilayer technological system as is a combination of moulding sand and foundry instrumentation. Analysis of the results shows that compaction significantly influences permittivity of the sandmix containing water-glass, because permittivity value increases with increasing compaction degree.

Key words: casting, moulding sand, permittivity, compaction degree, microwaves

INTRODUCTION

As an innovative solution in manufacture of moulds and cores prepared of moulding sands containing organic and inorganic binders, microwave heating is a still developing research area [1-6]. Knowing the merit of microwave drying of binder-containing moulding sands requires determining basic cause-and-effect relationships between quality or technological properties of moulding sands and the applied parameters of electromagnetic field.

When placed in electromagnetic field, moulding sand being a granular mixture [7-8] containing water molecules is considered as a material containing a dielectric component in that, as a results of absorption, energy of microwaves is converted to heat that is next spent for removing water from the material structure. As the main property of the material, indicating whether it may be effectively heated in microwave field, relative permittivity ε_r [9] described by the formula (1) is determined.

$$\varepsilon_r = \varepsilon_r' - j\varepsilon_r'' \quad (1)$$

where: ε_r' – real part,
j – unit imaginary number,
ε_r'' – imaginary part.

A value of this parameter defines the way how the material is polarized when supplied by microwave energy [9]. It depends on several parameters related to the dried material [10-11] and, in particular, to water content that is the main absorber of microwaves. Analysis of previous examination results permits the statement that permittivity of moulding sands containing water-glass does not depend on quantity of water-glass in a linear way [12].

With respect to action of a microwave field, three phases can be distinguished in unhardened binder-containing moulding sand: solid (sand base), liquid (hydrated sodium silicate) and gaseous (air, steam) phase [7-9], which is schematically shown in Figure 1. Each of the specified phases of a moulding sand shows different electrical properties, and, as a result, reacts to the applied microwave field in another way. Sand base is a material with low absorbing capacity of microwaves. Hydrated sodium silicate, as a dielectric, absorbs microwave energy. Free spaces between these phases, as areas with high transparency to microwaves [9].

The compaction process of moulding sands, which consists in relocating sand grains in volume units V under action of external forces [7-8], is basically aimed at precise reproduction of the casting shape in form [8,13]. With regard to three-phase structure of moulding sands, the compaction process consists in eliminating pore (volume V_p, mass m_p) [7-8] between loosely poured base grains (volume V_s, mass m_s) coated with binder layers (volume V_b, mass m_b). The factors decisive for

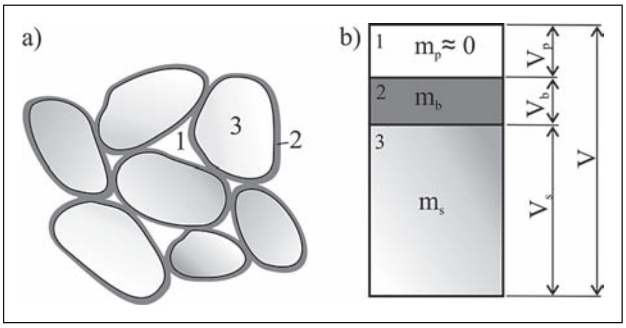

Figure 1 Schematic presentation of three-phase structure of moulding sand (a) 1 – gaseous phase (air), 2 – liquid phase (binder), 3 – solid phase (sand); (b) volumetric fractions of individual phases

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compactibility of a moulding sand include shape and size of base grains, as well as kind and quantity of the bonding material [7,13].

The purpose of the presented basic research was determination of the relationship between compaction degree of a moulding sand containing water-glass and relative permittivity ε_r determined for microwaves with frequency $2,45 \cdot 10^9$ s^{-1}. Analysis of the results makes a ground for building a theoretical mathematical model of microwave hardening of binder-containing moulding sands and multilayer technological systems as a combination of moulding sand and foundry tooling.

METHOGOLOGY OF THE RESEARCH

Moulding sands were prepared in a paddle mixer. Time of stirring sand base with water-glass, equal in each case to 300 s, was chosen on the grounds of literature recommendations [8,13]. After 20 s from pouring sand base in the mixer chamber, a fixed quantity of water-glass was dosed.

Moulding sands containing water-glass are characterised by relatively good flowability [8,13] that makes it possible to obtain a proper compaction degree during forming, with no need of a very big amount of work. Cylindrical samples dia. 0,016 m x height 0,042 m were vibration compacted on an apparatus Luz - 2e at vibration frequency 50 s^{-1} and time 20 s. As the variable parameter directly decisive for the compaction degree, vibration amplitude was modulated between $4 \cdot 10^{-4}$ and $1,6 \cdot 10^{-4}$ m.

Density ρ and apparent density ρ_o of the sandmix was determined in indirect way. Density ρ, as an additive property, was calculated for each prepared water-glass containing sandmix on the grounds of known weight fractions and densities of individual components. Apparent density ρ_o that measure considers three-phase structure of moulding sand, being the ratio of its mass m / kg to sample volume V / m^3, was determined for each vibration compacted laboratory shape. Compaction degree of each sample was calculated as the ratio of apparent density ρ_o to density ρ of the sandmix.

Relative permittivity of compacted samples at microwave frequency $2,45 \cdot 10^9$ s^{-1} was measured by the perturbation method on a stand of waveguide resonance cavity. Methodology of the measurement is described in [14-15].

EXAMINED MATERIALS

Influence of compaction degree on permittivity was determined for water-glass containing sandmixes with variable composition with respect to quality (grades of base and water-glass) and quantity (concentration of binder and volumetric fractions of individual phases).

Components of moulding sands were chosen with respect to variable density that decides their volumetric fractions in a compacted sample. From among all the commercially available base materials, three grades of sand were selected: high-silica, chromite and olivine sand. As the binder, three grades of hydrated sodium silicate were used: 137, 145 and 150. Concentrations of the binder were chosen from the range between 2 and 6 wt %, as recommended for preparation of quick-setting moulding sands [13]. Densities of the base ρ_s and of water-glass ρ_b, as well as weight percentages of individual components and densities of the prepared moulding sands are given in Table 1, where the sandmixes are designated by grades of sand base (K – high-silica, O – olivine, C – chromite) and of water-glass (137, 145 and 150).

Table 1 **Components of sodium water-glass containing sandmixes**

Designation	Sand base		Binder –water-glass		Density of sandmix ρ / kg/m^3
	Density ρ_s / kg/m^3	Fraction / wt %	Density ρ_b / kg/m^3	Fraction / wt %	
K137	2 650	98	1 400	2	2 625
K145	2 650	97	1 480	3	2 615
O140	3 300	96	1 430	4	3 225
O145	3 300	94	1 480	6	3 191
C145	4 400	96	1 480	4	4 283
C150	4 400	96	1 540	4	4 286

EXPERIMENTAL RESULTS

Results of the measurements are shown in Figure 2 in form of an approximating function and a determination coefficient that describe the relationship between permittivity values and compaction degrees for individual moulding sands, see Figures 2, 3 and 4.

It was found that permittivity of a given moulding sand containing water-glass is linearly dependent on compaction degree, irrespective of kind of sand base, grade and weight concentration of water-glass. In the case of a high - silica based moulding sand containing 2 wt % of water-glass grade 137, changing compaction degree of samples from 0,31 to 0,50 resulted in increas-

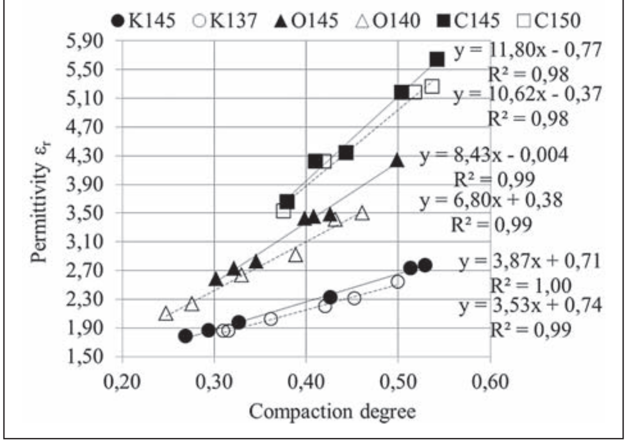

Figure 2 Relationship between permittivity and compaction degree of moulding sands

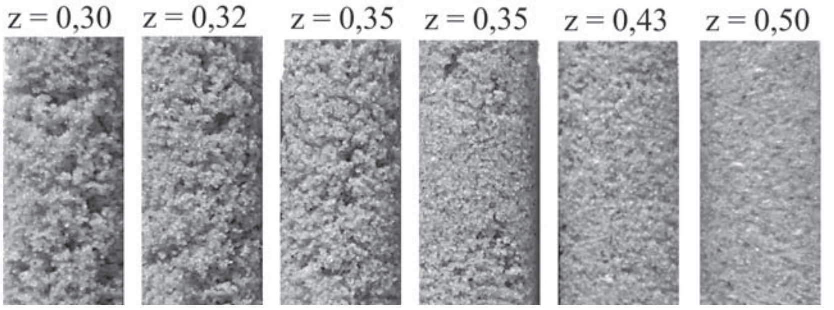

Figure 3 Side surfaces of cylindrical samples of sandmix O145 (z - compaction degree)

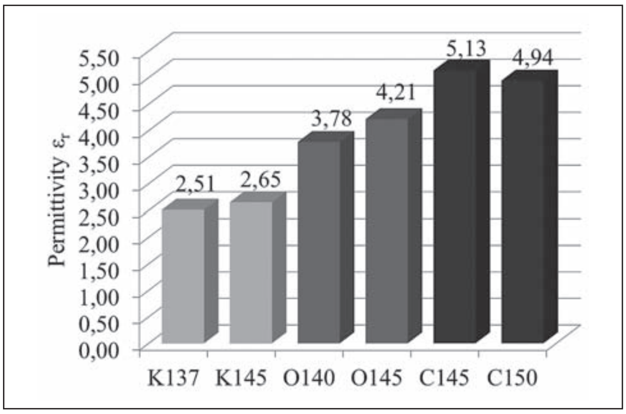

Figure 4 Relative permittivity of samples with compaction degree 0,5

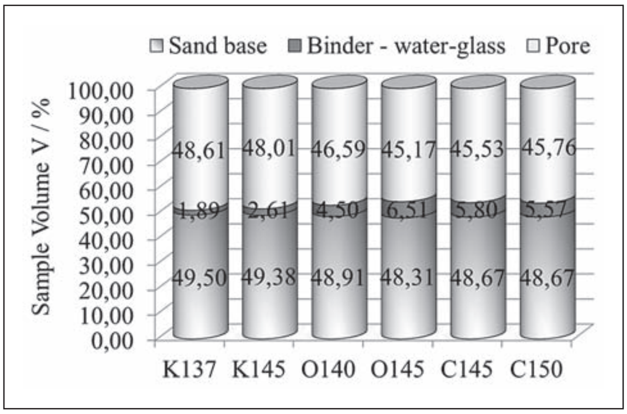

Figure 5 Volumetric percentage of individual phases in a cylindrical sample of moulding sand with volume $8{,}44 \cdot 10^{-6}$ m^3 at compaction degree 0,5

ing the ε_r value from 1,85 to 2,54, respectively. For the sandmix based on olivine sand with 4 wt % of water-glass grade 140, changing compaction degree from 0,25 to 0,46 resulted in increasing the ε_r value from 2,10 to 3,50, respectively. For the sandmix based on chromite sand with 4 wt % of water-glass grade 145, changing compaction degree from 0,38 to 0,54 resulted in ca. 1,5-fold increase of the ε_r value.

In all the cases, value of the determination coefficient R^2 was ca. 0,99, which means that the chosen models of linear regression are statistically significant. It can be said that the determined regression equations are well fitted and will be used for predicting relative permittivity on the ground of compaction degree of a sandmix with known quantitative and qualitative composition.

Visual evaluation of compacted samples indicates that, for all the examined sandmixes, compaction degree below 0,45 does not guarantee proper dimensional accuracy and quality of surface reproduction of the foundry tooling. An exemplary view of surfaces of the samples with various compaction degree for the sandmix based on olivine sand containing 6 wt % of water - glass grade 145 is shown in Figure 3. Comparison of permittivity values of moulding sands with various compositions requires elimination of variable factors, in this case various compaction degrees. It is important to determine permittivity values of moulding sands at constant compaction degree.

On the grounds of the obtained regression equations, permittivity of selected sandmixes was determined at compaction degree 0,5, as shown in Figure 4. The highest permittivity value was measured for the sample C145 and the lowest value – for the sample K137. It was observed that, at constant compaction degree of 0,5, ε_r values for the sandmixes prepared with the same base but with various kinds and contents of water-glass are close to each other, e.g. the sandmixes K137 to K145 and C145 to C150, see Figure 4.

For exactly known quantitative and qualitative compositions and compaction degrees, volumetric fractions of individual phases in the sandmixes were calculated.

Figure 5 shows volumetric percentages of solid phase (base), liquid phase (water-glass) and gaseous phase (air) in sandmixes with compaction degree of 0,5. The sandmix based on olivine sand is characterized by the highest volumetric percentage of water-glass (6,51 %) but, contrary to expectations, it does not show the highest of the ε_r values determined in the examinations, see Figure 4. Thus, it is confirmed that, at constant compaction degree, relative permittivity of moulding sand depends on volumetric fraction, properties and permittivity values of all the components.

Difference between ε_r values for the sandmixes based on chromite sand (C145 and C150), differing from each other in kind of the applied water-glass only, is 0,19. It was found that, at the same compaction degree, the same base and the same binder content but with different kind of water-glass (145 or 150), relative permittivity value results from volumetric fraction of water-glass being an absorber of microwave radiation.

CONCLUSION

On the grounds of measurements of relative permittivity ε_r depending on compaction degree of water-glass containing sandmixes, the following conclusions can be formulated:

- Relative permittivity εr of a moulding sand with known composition depends linearly on its compaction degree.
- Increase of permittivity value along with increasing compaction degree results from changing volumetric fractions of base and binder in moulding sand.
- Knowledge of quantitative and qualitative composition and compaction degree of a water-glass containing sandmix makes it possible to forecast its permittivity value.
- Comparison of relative permittivity values of granular mixtures, significant for microwave heating practice, should be carried-out at constant compaction degree of the materials.
- Considering the examined moulding sands as three-phase mixtures and knowing their quantitative and qualitative composition as well as compaction degree, will permit a complex analysis of the relationship between permittivity and other factors related to methodology of preparing moulding sands.

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Note: The responsible translator for English language: "INTER-TK" Translation Office, Wrocław, Poland