Electrical Properties of Multilayer Systems Composed of Foundry Tooling and Moulding Sand

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Abstract

Within the research, selected multilayer technological systems created as combinations of water-glass containing moulding sand with foundry tooling, were characterised on the grounds of their electrical properties. By measuring resonance frequency and quality factor of a waveguide resonance cavity, real component of permittivity ε_r' and loss tangent tgδ were determined for multilayer foundry systems with various qualitative and quantitative compositions. It was demonstrated that combination of a sandmix and foundry tooling with known dielectric properties results in a system with different physico-chemical properties, whose relation to the parameters of individual components of the system is undefined at this research stage. On the grounds of measurement results, theoretical value of microwave heating power, dissipated in unit volume of the selected multilayer foundry system, was determined. Knowledge of theoretical heating power and evaluation of physical, chemical and structural changes occurring in moulding sands exposed to microwaves in such a technological system makes a ground for empirical modelling of the process of microwave heating of foundry moulds and cores.

Keywords: Innovative foundry technologies, Microwaves, Electrical properties, Multilayer foundry system

1. Introduction

Use of microwaves, as an innovative solution in manufacture of moulds and cores of sandmixes hardened by microwave radiation, is drawing more and more attention [1-4]. In the aspect of microwave technique and mechanics of disintegrated media, a moulding sand containing water-glass is described as a three-phase dielectric mixture of sand base, binding material and air [5-6]. Compacted moulding sand with water-glass can be hardened in 2.45 GHz microwave field both in foundry tooling and after being previously removed. The first method requires that models, moulding boxes and core boxes are transparent for microwave radiation. On the other hand, hardening of moulding sands free of

foundry tooling is only limited to moulds and cores with simple shapes, because they could get damaged when being removed before hardening. With regard to efficiency and effectiveness of microwave-aided manufacture of foundry moulds and cores, the first method seems more favourable. For this reason, the subject of direct microwave hardening of water-glass containing sandmixes in foundry tooling was taken up.

A material system formed by moulding sand compacted in foundry tooling is defined on the grounds of literature data [7-10] as a technological multilayer foundry system schematically shown in Fig. 1. This results from the fact that microwaves in a heating appliance, generated in a magnetron and transmitted by a waveguide to such a system, arrive successively to the layers with different dielectric properties (ε_r', tgδ). At the initial

propagation phase, microwaves reach the layer of air, then the layer of foundry tooling and finally the layer of moulding sand. At the interface of two media, microwave radiation is subjected to reflection and refraction, so that a part only of microwave power is transferred deep into the subsequent layer [8-9].
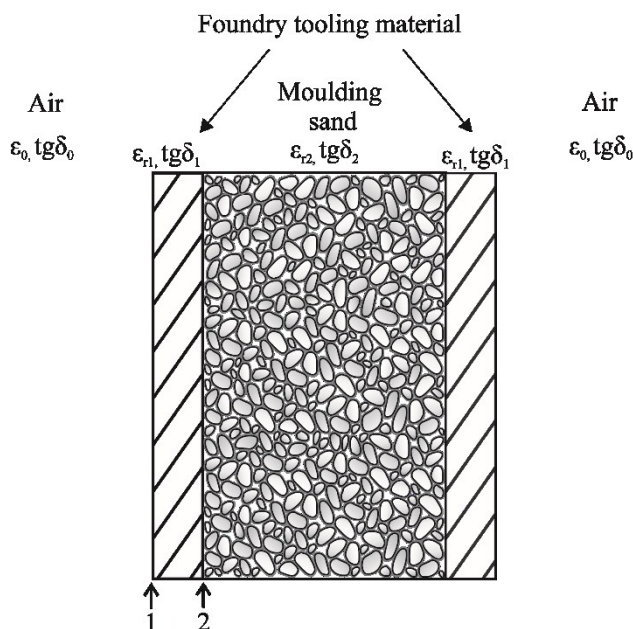

Fig. 1. Schematic presentation of the multilayer foundry system: 1 – interface air / tooling material, 2 – interface tooling material / moulding sand

Volumetric heating of a dielectric material, which is water contained in the binding material, leads to rotation of dipoles and, consequently, to emission of heat due to intermolecular friction. Thermal power P_V emitted in unit volume depends directly on microwave frequency f, square electric field strength E, real component of permittivity ε_r' and loss tangent tgδ [11] of moulding sand, as expressed by the formula:

$$P_V = 55.6325 \cdot 10^{-12} f \varepsilon_r' \, \mathrm{tg}\delta E^2 \quad [W/m^3] \tag{1}$$

Selection of microwave field parameters, as well as knowledge of dielectric properties of moulding sands, decide the possibility of microwave application in manufacture of foundry cores and moulds and, in the future, they will condition obtaining high effectiveness of this process. It becomes justified to determine electrical properties of sandmixes in relation to the industrially applied microwave frequency of 2.45 GHz, as well as to examine relationships between electrical properties and selected physico-chemical and technological properties of moulding sands and materials for foundry tooling.

The presented research of basic nature was aimed at determining the ε_r' and tgδ values of a multilayer foundry system with water-glass containing moulding sand for the microwave frequency of 2.45 GHz. Determined was theoretical heating power P_{Vtheor} to be dissipated in unit volume of a selected multilayer system. In the future, it will be possible to determine the most favourable parameters of microwave heating of variable

foundry materials on the grounds of the P_{Vtheor} value, as well as of the physical, chemical and structural changes occurring in foundry multilayer systems under microwave radiation.

2. Idea and methodology of the research

2.1. Materials used in the research

Permittivity was determined for three moulding sands with various dielectric properties, based on high-silica, olivine and chromite sands. As binders, three kinds of hydrated sodium silicate (water-glass) were applied. According to the assumption that the moulding sand is the better, the less binding material it contains, fractions of water-glass were chosen within the range of 2 to 6 weight parts, as recommended for quick-setting moulding sands [10]. Qualitative and quantitative compositions of the three examined sandmixes are given in Table 1, where designations are related to the base type: K = high-silica sand, O = olivine sand or C = chromite sand, and to the water-glass grade: 145, 137 or 150.

Table 1.
Quantitative composition, dielectric properties and theoretical heating power of selected moulding sands

Designation	Fraction of water-glass [wt %]	ε_r' [dimensionless]	tgδ [dimensionless]	P_{Vtheor} [W/m³]
K145	4	2.99	0.0717	0.029
O137	3	3.57	0.0929	0.045
C150	2	6.10	0.0460	0.038

The materials for foundry tooling, used in the examinations, were selected on the grounds of their diverse density and dielectric properties. From among the commercially available materials designed for models and core boxes, two plastics with known physical and dielectric properties were selected: polytetrafluoroethylene and polyethylene. On the background of the commonly applied metal alloys and wood, their advantages are, first of all: low absorptivity of microwaves, good machinability and relatively low price [12]. In the previous researches on foundry tooling materials the following dielectric properties of the plastics used in the examinations were determined:

- polytetrafluoroethylene: $\varepsilon_r' = 2.04$; tg$\delta = 0.0011$,
- polyethylene: $\varepsilon_r' = 2.33$; tg$\delta = 0.0024$.

2.2. Scope and methodology of the research

Sandmixes were prepared in a paddle mixer. Time of mixing the base with water-glass, in each case equal to 300 s, was chosen on the grounds of literature recommendations [6, 10] and technological trials. After 20 s of stirring dry sand in the mixer chamber, the established amount of water-glass was dosed.

According to the presumptions of the measurement method [13], total volume of cylindrical shape of the multilayer foundry system was each time 8.44 cm^3. In a sleeve OD 16 mm, ID 14 mm and 42 mm high, made of polytetrafluoroethylene or polyethylene, moulding sand was vibration compacted on the apparatus Luz-2e using constant parameters like vibration frequency 50 Hz, vibration time 20 s and vibration amplitude 0.13 mm. For individual multilayer systems, this resulted in various compacting degree of the sandmix, being 0.55 for O137, 0.58 for K145 and 0.66 for C150.

Either in literature or in foundry practice, no comprehensive characteristics of electrical properties or measuring methodology of their dielectric properties could be found for both moulding sands and foundry multilayer systems. From among the methods of measuring electrical properties, the perturbation method was selected as the only one that permits measurements for the frequency of 2.45 GHz. This is an indirect method in that real ε_r' and imaginary ε_r'' components of relative permittivity ε_r and loss tangent tgδ are calculated on the grounds of measurements of resonance frequency f and quality factor Q of the waveguide resonance cavity [13-14].

The P_{Vtheor} value was calculated from the formula (1), accepting the following factors as constant values:

• volume of specimens of both moulding sand and the multilayer system equal to 8.44 cm^3,
• microwave frequency equal to 2.45 GHz,
• electric field intensity E equal to 100 V/m.

The examinations were carried-out at ambient temperature of 20 °C and relative humidity of the air of 40%. For the measurements, 7 to 10 specimens of each multilayer foundry system were prepared. The results shown in Figs. 2 and 3 are average values of minimum three specimens with identical compaction degree.

3. Results

Real component values of permittivity and loss tangent of multilayer systems with water-glass are shown in Figs. 2 and 3, in that the values determined for each selected moulding sand are additionally presented. Figure 4 shows values of theoretical heating power dissipated in unit volume of a given multilayer foundry system.

The highest value of real component of permittivity (5.33) is shown by the multilayer system C150 with chromite-based moulding sand containing 2 wt% of water-glass 150, compacted in a polyethylene sleeve. The lowest value of this parameter (2.80) is shown by the system K145 compacted in a polytetrafluoroethylene sleeve. Comparison of ε_r' values determined for water-glass containing moulding sands and for multilayer foundry systems composed with their use proves that the foundry tooling material causes reduction of this parameter value. For the sandmixes K145 and O137, ε_r' values of the multilayer systems with polytetrafluoroethylene and polyethylene layers are 5% lower than the values determined for the sandmixes alone. A similar comparison of the results for the sandmix C150 shows that ε_r' value of the multilayer system is ca. 14% lower than that for the sandmix alone. Application of polytetrafluoroethylene and polyethylene for foundry tooling used with one selected

moulding sand results in similar ε_r' values. This evidences that individual multilayer systems have similar polarizability in 2.45 GHz microwave field, regardless of the used plastic.
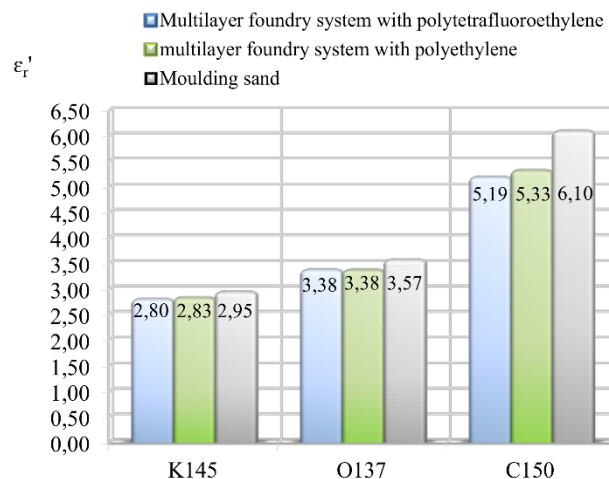
Fig. 2. Permittivity values for moulding sands C150, O137, K145 and for multilayer foundry systems containing these sandmixes

The multilayer foundry system with polyethylene and O137 sandmix is characterised by the highest tgδ value (0.108) among the examined systems, which results in the highest ability to generate power losses in form of heat. Analysis of loss tangent values indicates that combination of moulding sand with foundry tooling results in a change of this parameter value: decrease for the systems with K145 sandmix or increase for the systems with O137 and C150 sandmixes. In the latter case, this reduces the ability of power generation under microwave radiation.
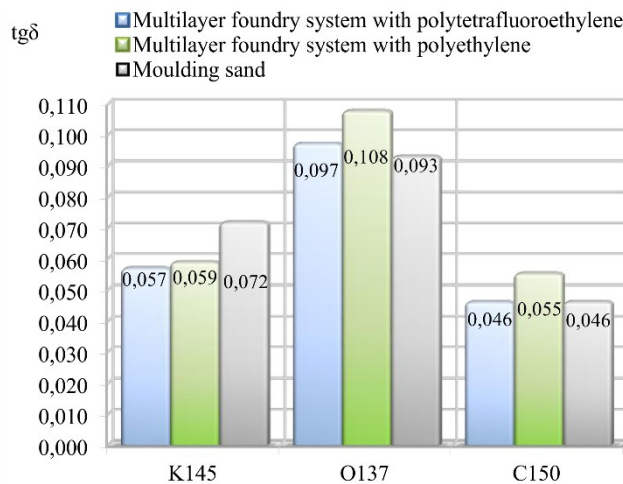
Fig. 3. Loss tangent values for moulding sands C150, O137, K145 and for multilayer foundry systems containing these sandmixes

Values of theoretical heating power dissipated in unit volumes of multilayer systems with water-glass containing moulding sands are shown in Fig. 4. It was observed that, at constant parameters of microwave field and constant volumes of multilayer foundry

systems, the largest P_{Vtheor} value (4.95 W/cm^3) is shown by the system O137 in polyethylene. The system K145 in polytetrafluoroethylene is characterised by the lowest value of this parameter (2.17 W/cm^3). For each moulding sand, application of polytetrafluoroethylene for foundry tooling results in a multilayer system with lower P_{Vtheor} value than in the case of using polyethylene. In the future, this will permit complex selection of a tooling material that would enable microwave hardening of moulding sands in an effective and economically favourable way.
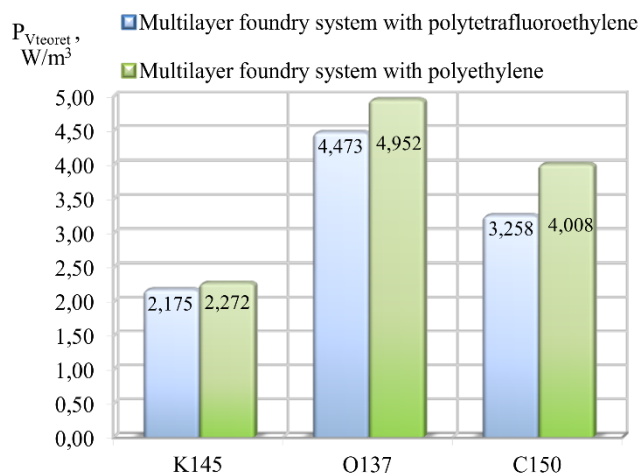

Fig. 4. Theoretical heating power values for multilayer foundry systems containing sandmixes C150, O137 and K145

4. Conclusions

The presented results of measurements and calculations made for multilayer foundry systems with water-glass containing moulding sand lead to the following conclusions:

- A combination of moulding sand and foundry tooling material with known dielectric properties results in a system with different dielectric properties that – at this stage of the research – cannot be related to the values of its individual components;
- A multilayer system created of water-glass containing moulding sand and foundry tooling made of a plastic shows ε_r' and tgδ values different in comparison to the sandmix alone;
- Determination of dielectric properties of a multilayer foundry system by the perturbation method permits effective selection of materials for foundry tooling to be used with a given moulding sand;
- Among multilayer systems containing one moulding sand with known dielectric properties, the system with polyethylene tooling shows the most intensive dissipation of microwave power;
- The obtained values of dielectric properties and theoretical heating power make a ground for empiric modelling the process of microwave heating of moulding sands.

Acknowledgements

References

[1] Wang, J., Fan, Z., Zan, X. & Pan, D. (2009). Properties of sodium silicate bonded sand hardened by microwave heating. *China Foundry*. 6(3), 191-196.

[2] Stachowicz, M., Granat, K. & Nowak, D. (2013). Dielectric hardening method of sandmixes containing hydrated sodium silicate. *Metalurgija*. *52*(2), 169-172.

[3] Kaczmarska, K., Grabowska, B. & Drożyński, D. (2016). Potential of the application of the modified polysaccharides water solutions as binders of moulding sands. *Metalurgija*. 55(1), 15-18.

[4] Liu, F., Fan, Z., Liu, X., Huang, Y. & Jiang, P. (2016). Effect of surface coating strengthening on humidity resistance of sodium silicate bonded sand cured by microwave heating. M*aterials and Manufacturing Processes*. 31(12), 1639-1642. DOI: 10.1080/10426914.2015.1117631.

[5] Szymański, A. (2007). *Soil Mechanics*. Warsaw: SGGW Publisher.

[6] Perzyk, M., Waszkiewicz, S., Kaczorowski, M., Jopkiewicz, A. (2000). *Foundry Practice*. Warsaw: Publishing House "Wydawnictwa Naukowo-Techniczne".

[7] Ratanadecho, P., Aoki, K. & Akahori, M. (2009). Influence of irradiation time, particle sizes, and initial moisture content during microwave drying of multi-layered capillary porous materials. *Journal of Heat Transfer*. 124, 151-161. DOI: 10.1115/1.1423951.

[8] Chen, M., Zhu, Y., Pan, Y., Kou, H., Xu, H. & Guo, J. (2011). Gradient multilayer structural design of CNTs/SiO2 composites for improving microwave absorbing properties. *Materials and Design*. 32, 3013-3016. DOI: 10.1016/j.matdes.2010.12.043.

[9] Yeh, P., Yariv, A. & Hong, Chi-S. (1977). Electromagnetic propagation in periodic stratified media. I. General theory, *Journal of the Optical Society of America*. 67(4), 423-438.

[10] Lewandowski, L. (1997). *Materials for casting moulds*. Kraków: Akapit.

[11] Mujumdar, S.A. (Ed.) (1995). *Handbook of Industrial Drying*. New York: Marcel Decker.

[12] Saechtling, H. (1955/2000). *Polymeric materials, Handbook*, Warsaw: WNT Scientific and Technical Publishing.

[13] Granat, K., Opyd, B., Stachowicz, M., Nowak, D. & Jaworski, G. (2013). Usefulness of foundry tooling materials in microwave heating process. *Archives of Metallurgy and Materials*. 58(3), 919-922. DOI: 10.2478/amm-2013-0101.

[14] Lisowski, M., (2004). *Measurements of resistivity and permittivity of solid dielectrics*. Wrocław: Publishing House of Wroclaw University of Technology.