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Effect of Electrical Properties of Materials on Effectiveness of Heating Their Systems in Microwave Field

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Abstract

In the paper presented are results of a research on influence of electrical and physico-chemical properties of materials being parts of multicomponent and multimaterial systems used in foundry practice on efficiency and effectiveness of microwave heating. Effectiveness of the process was evaluated on the grounds of analysis of interaction between selected parameters of permittivity and loss factor, as well as collective index of energy absorbed, reflected and transmitted by these materials. In the examinations used was a stand of waveguide resonance cavity for determining electrical properties and a stand of microwave slot line for determining balance of microwave power emitted into selected materials. The examinations have brought closer the possibility of forecasting the behaviour of multimaterial systems like e.g. model, moulding sand or moulding box in microwave field on the grounds of various electrical and physico-chemical properties. On the grounds of analysis of the results, possible was selecting a group of materials designed for building foundry instrumentation to be effectively used in electromagnetic field.

Keywords: Innovative casting technologies, Microwaves, Moulding sands, Foundry instrumentation, Electrical properties

1. Introduction

In industrial practice, a technologically conditioned set of materials with various physico-chemical properties, composing a determined system like e.g. foundry instrumentation and moulding sand, permits influencing its electrical properties and creates a possibility to predict a response of such a system in electromagnetic field.

Description of materials behaviour in microwave field can be based on their electrical properties, however these properties are generally determined separately for each component of the considered system [1]. According to literature data, behaviour in microwave field depends on relative permittivity (ε_r) and loss factor (tgδ) of the materials [2,3]. The first quantity describes the way how the material is polarised in electrical field and the second (tangent of loss angle) determines the part of energy that is converted to heat as a result of microwave action.

So, in the case of a given set of various materials it is necessary to adapt the existing measurement methods to determining its dielectric properties in a way enabling complex evaluation of behaviour of multimaterial systems in electromagnetic field. From among many methods [3,4] described in literature, the most often suggested for measurements of these properties are: perturbation method [5,6] and measurement of standing wave ratio on a stand of microwave slot line [3].

2. Selection of materials and methodology of examinations

2.1. Research issues

In foundry processes, the phenomenon of dissipation of electromagnetic wave energy should be considered comprehensively. On one hand, moulding sands dried and/or hardened in microwave field should show possibly highest capability of energy dissipation (absorption) that conditions high effectiveness of e.g. removing water from them. Another aspect is referring this phenomenon to behaviour, in the same conditions, of the materials for foundry instrumentation (models, core boxes, moulding boxes) that should be characterised by lowest lossiness (high transparency), decisive for transmitting possibly largest quantity of electromagnetic radiation deep into moulding sands.

Considered could be also the system in that moulding sand with very small water content and low lossiness requires – to initiate crosslinking – heat energy that should be delivered through foundry instrumentation. In such a case, high capability of microwave absorption is required from the materials for foundry instrumentation.

2.2. Objective of the research

The presented research is aimed at determining influence of physico-chemical properties of materials used for foundry instrumentation on efficiency and effectiveness of the process of microwave heating. This can be determined on the grounds of known values of permittivity and loss factor of the used materials, which influence also the collective index of energy absorbed, reflected and transmitted by the systems built of them, like e.g. the system "foundry instrumentation – moulding sand".

In the future, introducing on an industrial scale the innovative and quick-acting microwave-heating process that guarantees measurable economical and environmental results is conditioned by recognition of physical basics of behaviour of electromagnetic radiation in complex multimaterial systems like "moulding box – moulding sand" or "core box – core sand".

2.3. Selection of materials

From among the materials used in foundry processes, designed for industrial application in microwave field, two groups can be distinguished, i.e. moulding/core sands and materials for foundry instrumentation. These groups are connected with each other during production of casting moulds and cores, since their manufacture requires models and core boxes made of such materials like plastics, wood, composites etc. [9,10].

The system "moulding (core) sand and moulding (core) box", placed in microwave field, on one hand should permit correctly run process of drying and hardening moulding sand by effective removing water steam from its inside, and on the other hand should ensure obtaining proper, high surface quality, as well as shape and dimensional accuracy.

2.4. Methodology

The stand for measurements of electrical properties by the perturbation method consists of a source of high-frequency signal, diode detector, oscilloscope and a rectangular resonator transmission-included in the waveguide line and coupled with the line through round openings. In the presented solution employing the perturbation method, a small sample of the examined material is placed in the resonance cavity at the point where intensity of electric field reaches its maximum value. Then, electrical capacity of the resonator cavity changes resulting in a change of basic parameters of the cavity, like resonance frequency f and quality factor Q of the cavity, as described in [7]. The above-mentioned parameters of the cavity serve for determining basic electrical properties of the examined materials and, in the future, also properties of complex multimaterial systems.

A properly adapted stand of microwave slot line, described in [8], permits measuring collective percentage indices of power absorbed, reflected and transmitted through multimaterial systems like a batch of moulding sand in foundry instrumentation and also multicomponent systems like e.g. moulding sands. In the research used was a microwave signal emitted by the generator, with frequency 2.54 GHz.

3. Results

3.1. Measurements of electrical properties by perturbation method

Methodology of measurements of electrical properties is strictly determined, since they depend on both physico-chemical properties of the materials and external factors [2,11]. The measurements were performed at 20 °C and air humidity 60 % on five samples of each material designed for building foundry instrumentation. The examined materials were preliminarily subdivided acc. to their density to two groups: the first one with low density below 1 g/cm^3 (Table 1) and the other one with high density over 1 g/cm^3 (Table 2). Arithmetical averages of individual results are compared in Tables 1 and 2, together with selected information about the examined materials.

Analysis of the measurements indicates that the highest permittivity ε_r is revealed by textolite and the lowest permittivity – by plates of polymeric foam. These values indicate ability of individual materials to be polarised under microwave radiation. Measurements of the loss factor permits complete characterisation of the materials. According with expectations, the lowest loss factor is demonstrated by polymeric foam (tgδ = 0.00022). The basic structural disadvantage of polymeric foam is its very low mechanical strength and relatively high price. In the group of materials with density below 1 g/cm^3, the highest loss factor (0.0405) demonstrates pine wood. Among the materials with density over 1 g/cm^3, polytetrafluoroethylene (PTFE) and recycled polytetrafluoroethylene (rPTFE) show low loss factors of 0.00095 and 0.0011, respectively. They are characterised by good machinability, mechanical strength and thermal resistance [12]. Textolite, whose loss factor tgδ = 0.049, can show big inclination to become heated.

Table 1.
Characteristics of materials with density below 1 g/cm^3: price, machinability, averaged electrical properties

Material	Density [g/cm^3]	Price for 1 dm^3 [PLN]	Machinability	Real component of permittivity ε'	Imaginary component of permittivity ε''	Permittivity ε_r	Loss factor tgδ
Polymeric foam	0.032	100.00	Sufficient	1.053	0.00023	1.053	0.00022
Plates of aluminosilicate fibres	0.350	37.88	Sufficient	1.451	0.01260	1.451	0.00870
Pine wood	0.820	4.32	Good	2.324	0.09410	2.330	0.04050

Table 2.
Characteristics of materials with density over 1 g/cm^3: price, machinability, averaged electrical properties

Material	Density [g/cm^3]	Price for 1 dm3 [PLN]	Machinability	Real component of permittivity ε'	Imaginary component of permittivity ε''	Permittivity ε_r	Loss factor tgδ
Textolite	1.300	56.00	Very good	3.465	0.1699	3.469	0.04900
Polytetrafluoroethylene (PTFE)	2.160	207.54	Very good	2.054	0.0020	2.054	0.00095
Recycled polytetrafluoroethylene (rPTFE)	2.180	129.58	Very good	2.043	0.0022	2.043	0.00110

3.2. Attenuation measurements

Examinations of the selected materials (Tables 1 and 2), intended for manufacture of foundry instrumentation to be used in microwave field, were performed on diaphragm plates 86.36 x 43.18 x 5 mm. Figure 1 shows the chamber filled with a sample, composed of a diaphragm plate and the reference moulding sand. Averaged values of indices of absorbed P_{abs}, reflected P_{ref} and transmitted P_{out} power are compared on graphs, see Figs. 2 and 3.

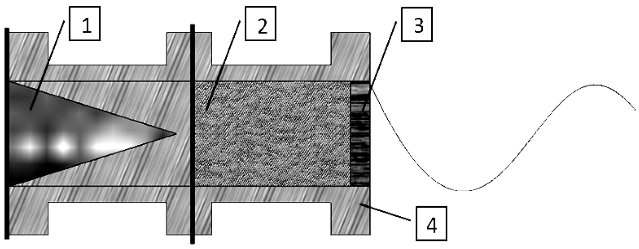

Fig. 1. Measuring assembly of the stand of microwave slot line: 1 – waveguide attenuator of microwaves; 2 – reference moulding sand; 3 – diaphragm plate; 4 – chamber filled with the examined multimaterial system

In the examinations used was a 40-gram sample of the reference moulding sand prepared of high-silica medium-grained sand to that 1.5 % of water was added during stirring. Water used in this quantity well replaced hydrophilic binders absorbing microwaves, as well as permitted forming and compacting the reference sample in the measuring chamber.

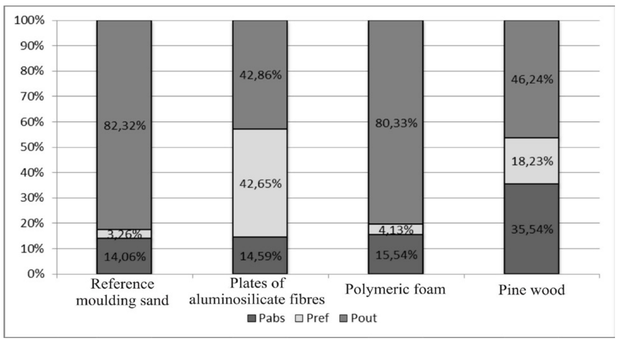

Fig. 2. Collective comparison of power indices P_{abs}, P_{ref} and P_{out} measured for multimaterial systems with diaphragms made of the materials mentioned in Table 1

The quantity significant for the entire microwave heating process performed after forming the sandmix is power reflected from the multimaterial system. The smaller part of P_{ref}, the more microwave radiation penetrates deep into the moulding (core) material, as determined by the index P_{out}. The not-reflected microwave energy can be also converted to heat energy and thus support the heating process but, at the same time, causing difficulties at handling hot elements. Heated-up instrumentation can also unfavourably reduce working life of the formed sandmixes. Analysis of the measurement results (Fig. 2) indicates that, in comparison to the reference moulding sand, the plate of aluminosilicate fibres is the material that reflects most part of microwaves (42.65 %). This value decidedly restricts penetration of microwaves deep into the sandmix, which can be important in the case of big-volume moulds. For the other materials, percentage power indices P_{ref} are smaller. The smallest value of the index was determined for the system with polymeric foam (4.13 %). The measured indices P_{ref} do not show any direct relation with individual coefficients given in Table 1.

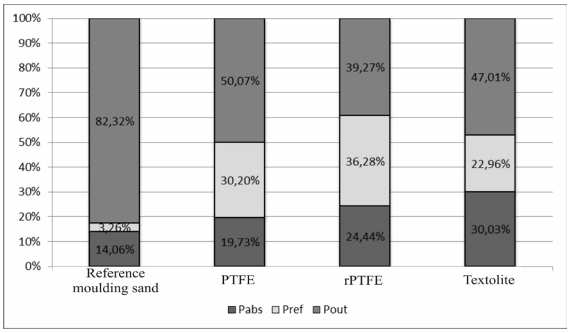

Fig. 3. Collective comparison of power indices P_{abs}, P_{ref} and P_{out} measured for multimaterial systems with diaphragms made of the materials mentioned in Table 2

In the second group of materials with density over 1 g/cm^3 (Fig. 3) observed was strong relationship between the values of loss factor (Table 2) and quantity of absorbed power P_{abs}. Along with increasing tgδ, measured for the materials for foundry instrumentation, increased also ability to become heated of the multimaterial system containing moulding sand. Comparison of these data imposes the suggestion that an advantageous effect of microwave heating appears not only in moulding sand, but also in the instrumentation material. The system most absorbing radiation is that with textolite diaphragm (30.03 %). A special attention deserves the system with the diaphragm made of PTFE. In that case observed is slight increase of the absorbed power factor by 5.6 % in relation to the sample with reference moulding sand. On the background of the other materials used for diaphragms in this group, the system with PTFE is characterised by high value of the index P_{out} that informs of high ability to transmit microwave radiation deep into the mould (core).

4. Conclusions

Analysis of the above-presented research on relationship between electrical properties of materials designed for foundry instrumentation to be used in microwave field leads to the following conclusions:

- Measurement of electrical properties of materials by perturbation method permits their preliminary selection from the viewpoint of their use for foundry instrumentation to be used in electromagnetic field.
- Measurements on the stand of microwave slot line can complement and confirm credibility of the obtained measurements of electrical properties obtained by the perturbation method.
- The stand of microwave slot line permits performing measurements of multicomponent systems like moulding sand, as well as multimaterial systems like "moulding sand – foundry instrumentation" used in the processes of forming and microwave heating.
- Polymeric foam, characterised by minimum lossiness, absorbs and reflects the smallest portion of the emitted microwave power, which results from its porous structure containing large quantity of air transparent for electromagnetic radiation.
- From among the examined materials, textolite and wood, adequately to their loss factor value, absorb the largest part of microwave field energy. This creates a possibility to use them for foundry instrumentation for sandmixes requiring heat energy to initiate the crosslinking process.
- The effect of reflecting microwave radiation by the material containing aluminosilicate fibres that shows relatively low lossiness, is undesirable due to high energy consumption, thus reducing effectiveness of the heating process.
- Polytetrafluoroethylene (PTFE) and recycled polytetrafluoroethylene (rPTFE) used for foundry instrumentation absorb little more microwave power than absorbs the applied reference moulding sand.
- It is expected that measurements of electrical properties combined with measurements of attenuation permit determining quantitative and qualitative composition of the considered systems.

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