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MEASUREMENT OF ELECTRICAL PROPERTIES AS EFFECTIVENESS APPRAISAL OF MICROWAVE ABSORPTION BY MOULDING AND CORE SANDS SUBJECT TO MICROWAVE UTILIZATION

POMIAR WŁAŚCIWOŚCI ELEKTRYCZNYCH JAKO OCENA SKUTECZNOŚCI POCHŁANIANIA MIKROFAL PRZEZ MASY FORMIERSKIE I RDZENIOWE PODDAWANE PROCESOWI MIKROFALOWEJ UTYLIZACJI

Within the research, carried-out were examinations of foundry rejects in form of waste moulding and core sands in order to determine effectiveness of the microwave utilization process. Presented are measurements of permittivity and loss tangent that determine behaviour of materials in electromagnetic field. Measurements were performed on a stand of waveguide resonance cavity that permits precise determination of the above-mentioned parameters with the perturbation method. Examination results of five waste moulding sands confirm that effectiveness of microwave utilization depends on electrical properties of the sandmixes (permittivity and loss tangent).
Keywords: nnovative foundry technologies, microwaves, utilization, permittivity, loss tangent

W pracy podjęto badania odpadów odlewniczych w postaci zużytych mas formierskich i rdzeniowych w celu określenia skuteczności procesu mikrofalowej utylizacji. Przedstawiono wyniki pomiarów przenikalności elektrycznej oraz tangensa kąta stratności, które określają zachowanie materiałów w polu elektromagnetycznym. Pomiary przeprowadzono na stanowisku falowodowej wnęki rezonansowej, która umożliwia precyzyjne wyznaczenie metodą perturbacyjną wymienionych parametrów. Badania pięciu zużytych mas formierskich i rdzeniowych potwierdzają, iż skuteczność mikrofalowej utylizacji jest zależna od ich właściwości elektrycznych (przenikalności elektrycznej oraz tangensa kąta stratności).

1. Introduction

Waste materials created in manufacturing processes and in everyday life can constitute a danger for natural environment. However, their utilization can be complicated with technical point of view and is generally expensive.

In foundry industry applied are many materials that should be utilized after the manufacturing process is completed. Very often, during the binding process, irreversible reactions (sandmixes with binders bonding chemically or thermally) occur in the materials binding together matrix grains of moulding and core sands and this is why they can not be reused at all or can be reused in some cases only, so they become waste sandmixes after one circulation cycle only. It is just these sandmixes and a part of traditional sandmixes worn-out after many refreshing cycles that should be first of all subject to the reclamation process and the reacted binder should be disposed, for both economical and ecological reasons [1].

So far, research works concerning utilization of foundry wastes, performed in the Foundry and Automation Group of Institute of Production Engineering and Automation of Wroclaw University of Technology, were focused on kinetics of the utilization process. The carried-out measurements and analyses prove that possible is thermal utilization and/or reclamation of moulding and core sands in the process of microwave heating [2-4].

In literature, no basic data are available on electrical properties of the materials applied in foundry processes, determining in details their behaviour in electromagnetic field. This results, first of all, from the fact that neither moulding materials nor foundry wastes were created with a view to be used in electromagnetic field. In the light of the above-mentioned issues, the presented research work is aimed at determining electrical properties of foundry wastes, which define effectiveness of their utilization process in electromagnetic field.

2. Utilization of foundry wastes in electromagnetic field

A material subject to action of alternating electrical field with intensity E and frequency f partially attenuates this field and converts energy to heat that is dissipated in the whole material volume. This phenomenon is quantitatively expressed by the formula (1) showing that loss of the field energy for heating the material is directly proportional to intensity E and frequency f of the field, as well as to electrical parameters (permittivity of free space ε_0, relative permittivity ε_r and loss factor tgδ) [5]. Therefore, to evaluate possibilities of applying

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the heating process it is necessary to determine electrical properties of the materials used in the given technology, since they condition efficiency and effectiveness of microwave heating.

$$P \approx f\mathrm{E}^2\varepsilon_0\varepsilon_r \,\mathrm{tg}\,\delta[W/m^3] \tag{1}$$

Electrical properties of the materials used in foundry processes are extremely important from the viewpoint of both kinetics of the microwave heating process and designing the foundry instrumentation. Behaviour of materials in alternating electrical field is described by two main parameters. The first one is relative permittivity ε_r determined by the formula (2) [6], describing the way how the material is polarised in electrical field. The other parameter is loss factor (tangent of loss angle tgδ) determined by the formula (3) describing the part of energy converted to heat in the material subject to action of microwaves [5].

$$\varepsilon_r = \varepsilon' - j\varepsilon'' \tag{2}$$

where: ε' – real component of complex relative permittivity,
ε" – imaginary component of complex relative permittivity.

$$tg\delta = \frac{\varepsilon'}{\varepsilon''} \tag{3}$$

In the thermal method of reclamation of moulding and core sands, basic removing the binding material from surfaces of matrix grains occurs, first of all, by its burning or decomposition (organic binders), but is not excluded that the reacted binder can be separated by intensive microwave heating, using the difference of thermal expansion coefficients of the matrix and the covering it envelope of worn-out binder [7].

Of particular importance in the microwave heating process of loose materials is reaching the temperature uniform in the whole volume of the substrate, guaranteeing efficiency and effectiveness of the process. The most advantageous would be action of such quantity of thermal energy, concentrated on surfaces of grains of sand matrix, that the layer of binder only was heated to the required temperature. Specific nature of influence of electromagnetic radiation can ensure such course of the heating process in the case when there is a difference between microwave energy absorption by matrix grains and by the binder layer [8].

It was observed in course of the research works on possibility of using microwaves in the utilization process that, depending on kind of the sandmix, the binder envelope is burnt at the final stage of the process and adheres to the grain surfaces (sandmix with phenolic resin), and thus the reacted binder gets utilized, see Fig. 1. In the case of a moulding sand containing phenol-formaldehyde resin, the envelope was incinerated, peeled-off and separated from the matrix surface, see Fig. 2. Then, the process may be regarded as utilization with simultaneous reclamation of the sandmix [8].

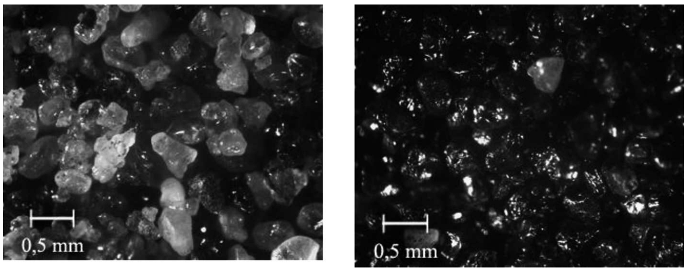

Fig. 1. Sandmix with phenolic resin before (left) and after utilization (right)

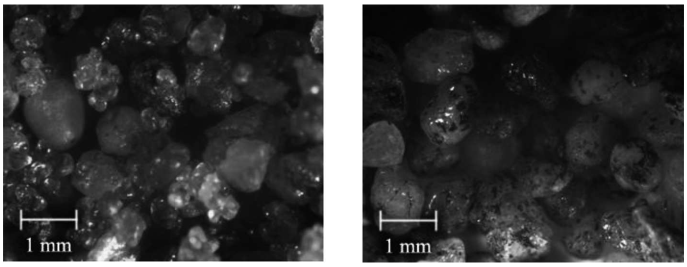

Fig. 2. Sandmix with phenol-formaldehyde resin before (left) and after utilization (right)

Possibilities of using microwave radiation in utilization processes is decided by knowledge of the process parameters and properties of the materials used in this process. Knowledge of electrical parameters of the material, like relative permittivity (ε_r) and loss factor (tgδ) is necessary for developing and characterising the process of microwave utilization.

3. Measurements of electrical properties of waste moulding and core sands

Waste moulding material composes a mixture of incinerated moulding sand located close to the mould cavity during pouring and various size residues of partially burnt or charred fragments of moulds and cores containing irretrievably reacted binder, which should be utilized [7].

Effectiveness of the process of heating with microwave energy decidedly depends on dielectric parameters of the thermally processed material (permittivity and loss factor) and these parameters can change during heating even by a few orders of magnitude. This fact is confirmed, as often observed in researches on application of microwave heating, by very dynamical increase of effectiveness of the process, which appears after a slow initial period till reaching a specific temperature [3].

For examinations of electrical properties of the materials used in foundry technique, designed and produced was a stand of waveguide resonance cavity. The stand for measurements of electrical properties by the perturbation method consists of a high-frequency signal source, cuboidal resonator, diode array detector and oscilloscope.

In the perturbation method, a small sample of the examined material is placed in the resonance cavity at the point where electric field intensity 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.

Quality factor of the resonance cavity can be determined by measuring width of the resonance curve from the relationship (4). The real ε' and the imaginary ε" components of permittivity ε_r can be determined from the relationships (5) and (6) [6].

$$Q = \frac{f}{\Delta f}, \quad (4)$$

where:

f – resonance frequency,

$\Delta f = f_g - f_d$ – difference between upper f_g and lower f_d frequency for the bandwidth 3 dB.

$$\varepsilon' = \frac{V_c (t_0 - t_s)}{2V_s t_s} + 1 \quad (5)$$

where:

f_s – resonance frequency of the cavity with a sample, f_0 – resonance frequency of the cavity,

V_c – volume of the resonance cavity, V_s – volume of the sample,

$$\varepsilon'' = \frac{V_c}{4V_s}\left(\frac{1}{Q_s} - \frac{1}{Q_c}\right) \quad (6)$$

where:

Q_c – quality factor of the cavity, Q_s – quality factor of the cavity with a sample.

4. Results of own examinations

It was found on the grounds of laboratory examinations on a possibility of thermal utilization and/or reclamation of waste sandmixes with organic binders containing phenolic, phenol-formaldehyde and urea-furfuryl resins, as well as water-glass, that possible is their efficient and effective incineration in facilities employing electromagnetic radiation.

In order to determine behaviour of individual moulding sands in electromagnetic field completely, taken were measurements of electrical properties by the perturbation method. Examined were five various sandmixes whose designations and compositions are given in Table 1.

TABLE 1

Designation and composition of waste sandmixes selected for measurements of electrical properties

Designation	Composition
M1	Sandmix with phenolic resin Fenotec P439
M2	Thermosetting sandmix coated with phenol-formaldehyde resin type Nowolak
M3	Core sand with phenolic resin and protective coating Novanol 165
M4	Sandmix with water-glass R145 hardened with Flodur
M5	Sandmix with urea-furfuryl resin Kaltharz U404

Before examination, the sandmixes were initially disintegrated in a roll mixer, because granulation of the substrate influences process parameters and distribution of thermal field at microwave heating and thus effectiveness of utilization [9].

Measurements of electrical properties of moulding and core sands were taken at 20°C and air humidity of 60%. Before starting examinations of electrical parameters, measured was resonance frequency and quality of empty resonance cavity. Measurements of permittivity and loss factor of the selected moulding and core sands, as well as maximum temperatures reached by the samples during microwave utilization (total power of generators was 6.0 kW) are presented in Table 2. Measured were three samples of each material. The table contains arithmetic averages of individual measurements.

TABLE 2

Measurements of permittivity, loss factor and maximum temperature reached by the samples during microwave utilization

	M1	M2	M3	M4	M5
ε_r	2.295	1.865	1.875	1.963	2.042
tgδ	0.0048	0.0139	0.0097	0.0063	0.0290
T [°C]	525	810	670	665	900

The measurements of electrical properties, specified in Table 2 and in the diagram (Fig. 3) indicate that the sandmix containing urea-furfuryl resin (M5) demonstrates the highest value of loss factor tgδ = 0.029. The next one is the thermosetting sandmix coated with phenol-formaldehyde resin type Nowolak (M2) showing loss factor by half lower than that of the sandmix M5. The other sands (containing phenolic resin, phenolic resin with protective coating, water-glass) show relatively low loss factor.

Electrical properties, in particular loss factor deciding the part of energy that is converted to heat in the material heated by microwaves, exactly determine behaviour of moulding sands in a microwave field. This is reflected in the measurement of temperature reached by the samples during microwave utilization. Results of preliminary examinations indicated that the heating process ran dynamically and, in the case of the sandmix containing phenol-formaldehyde resin, temperature of the sample equal to 810°C was measured as early as after 4 minutes. Less dynamically was heated the sandmix containing urea-furfuryl resin, whose temperature reached 900°C after 10 minutes. So, both of the mentioned sandmixes reached the temperature effective for the utilization process [8].

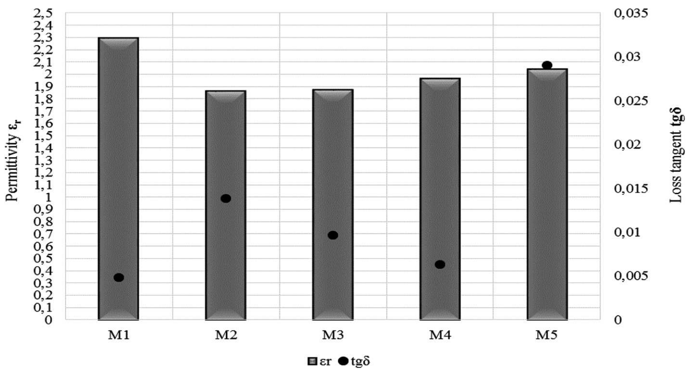

Fig. 3. Permittivity and loss factor for waste moulding and core sands

5. Conclusions

The following conclusions result from analysis of the measurements of electrical properties of waste moulding and core sands, as well as from preliminary examinations on a possibility of microwave utilization of moulding sands:

- The stand of waveguide resonance cavity enables precise determination of electrical properties of loose materials with diverse granulation.
- From among the examined sandmixes, those containing phenol-formaldehyde resin and urea-furfuryl resin show the highest lossiness values conditioning effectiveness of heating, as confirmed by preliminary measurements of maximum temperatures reached by the two sands.
- Relatively low lossiness values of the sandmixes containing phenolic resin, phenolic resin with protective coating and water-glass predispose them to further research works on the agents intensifying the process of microwave utilization (increasing the dielectric loss factor).
- Electrical properties of foundry materials examined at ambient temperature permit evaluating usefulness of sandmixes for the process of microwave utilization.

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