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EXAMINATION AND ANALYSIS OF INFLUENCE OF COMPACTION DEGREE ON DIELECTRIC PROPERTIES OF MOULDING SAND COMPONENTS

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In the paper, presented are results of a research on influence of compaction degree on dielectric properties of components of moulding sands. During recent years, intensive research works on possibilities of using microwave heating in foundry technique are carried-out. However, introduction of such innovative, environment-friendly and efficient heating processes to foundry technologies is accompanied by a shortage of basic knowledge about behaviour of components of moulding sands in microwave field. In this case, of particular importance becomes knowledge of electrical properties of components of moulding and core sands, i.e. their permittivity εr and dielectric loss factor tgδ that characterise efficiency of absorbing electromagnetic radiation and thus prove effectiveness of the heating process.

Key words: mould, sand, electrical properties, permittivity, dielectric loss factor

INTRODUCTION

In foundry practice, synthetic sandmixes are those being most commonly applied from among the traditional moulding sands. This is related, first of all, to the possibility of controlling composition and thus technological properties of these sandmixes. Main components of a synthetic sandmix are sand base and a binder. The sand base of a synthetic sandmix is generally composed of high-silica sand and less frequently of other sands, like olivine, chromite, zirconite or magnesite sands. Sand-based moulding sands are characterised by small ability to be compacted uniformly. The main purpose of compacting a sandmix is obtaining exact representation of the mould cavity shape, corresponding to the model shape, and proper resistance of the mould cavity to pressure of liquid metal, with maintained possibly high permeability of the sandmix [1].

In foundry practice, continued are the works on improving effectiveness of the methods aimed at removing humidity from moulding and core materials or at their hardening. Pressure put on speed and effectiveness of the dehydration processes intensifies interest in the microwave heating process and extends the possibilities it creates. Thanks to its specificity, this way of using microwaves in the drying and/or hardening processes of moulding and core sands can significantly contribute to automation and modernisation of foundries. Electromagnetic waves are more and more commonly used in foundry practice, making to some extent an alternative for energy consuming methods of traditional heating [2 - 6]. Energy of microwave radiation can be absorbed by a material in two ways. One of them consists in dielectric losses, mainly resulting from dipole polarisation.

Knowledge of electrical properties of a selected material, like relative permittivity ε_r and loss tangent $tg\delta$, makes it possible to determine its application in electromagnetic field unequivocally, as well as gives information about its radiation absorption ability. This paper presents experimentally determined relation between compaction degree and dielectric properties of the main component of a moulding sand that is its sand base.

MEASUREMENT STAND

When selecting a suitable method of measuring permittivity ε_r and loss tangent $tg\delta$, one should be guided first by types of the examined materials and next by size and shape of the examined samples, and frequency and bandwidth of the planned working frequencies should be also considered. Selection of a suitable measuring method should be supported by estimating the expected range of the measured quantities.

Considering the above-mentioned requirements concerning selection of a suitable measurement method for the materials containing water molecules in their structure, chosen was the perturbation method used for examinations of dielectric materials. It permits the samples to be measured in a wide range of temperature and humidity, as well as complex values of permittivity and loss tangent to be determined precisely within microwave frequency range.

In the perturbation method, shapes of the examined samples are unimportant, provided that their volumes are significantly smaller than volume of the resonance

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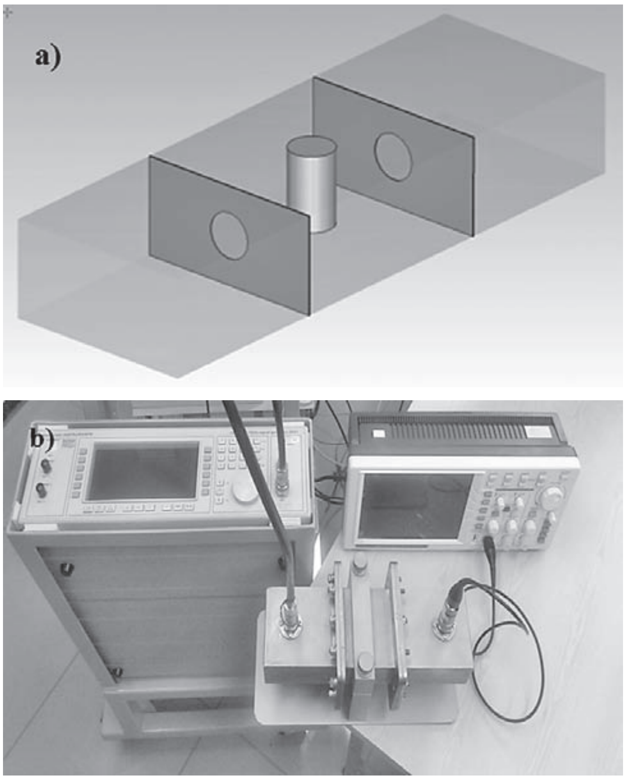

Figure 1 Measurement stand: a) schematic presentation of rectangular waveguide resonator with cylindrical sample of the examined material; b) general view of the stand

cavity. The basic phenomena utilised in the perturbation method are changes of resonance frequency and of quality of the resonance cavity Q caused by introducing lossy materials into the resonator. In measurements of permittivity and loss tangent of selected sand bases applied was a measurement stand composed of a high-frequency signal source (10 kHz to 2,7 GHz), a rectangular resonator with a diode array detector (Figure 1a) and an oscilloscope. General view of the stand is shown in Figure 1b.

Measurements of permittivity and loss tangent

Properties of dielectric materials in variable electric field are described by relative complex permittivity ε_r determined by the formula (1):

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

In order to measure electrical properties of non-magnetic materials, a small sample of the examined material was placed in the waveguide cavity in the place where intensity of the electric field reaches its maximum [7]. At that time, resonance frequency f and quality of the cavity Q change as a result of changing electrical capacity of the resonator cavity. Quality of the resonance cavity is determined by measuring width of the resonance curve on the grounds of the relationship (2) [7]:

$$Q = \frac{f}{\Delta f} \tag{2}$$

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

$$\varepsilon' = \frac{V_c(f_0 - f_s)}{2V_s f_s} + 1 \tag{3}$$

The real ε' and the imaginary ε" components of permittivity ε_r can be determined from the relationships (3) and (4) that, in turn, permit loss tangent $tg\delta$ to be calculated from the equation (5) [7].

In the mentioned relationships:

f_0 – resonance frequency of the cavity / GHz, f_s – resonance frequency of the cavity with a sample / GHz, V_c – volume of the resonance cavity / m^3, V_s – volume of the sample / m^3, Q_c – quality of the cavity, Q_s – quality of the cavity with a sample.

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

$$tg\delta = \frac{\varepsilon''}{\varepsilon'} \tag{5}$$

PREPARATION OF SAMPLES

For the measurements, 3 kinds of standardised sand bases with various physico-chemical properties were selected, namely medium-grained high-silica sand, coarse-grained chromite sand and medium-grained olivine sand. The individual bases were placed in cylindrical moulds dia. 20 mm and 33 mm high, made of a material with dielectric properties close to those of air. The samples were next compacted on a laboratory rammer LU-1 using the weight 6,667 ± 0,01 kg. The examinations were carried-out in several phases. The initial phase was measurement of uncompacted samples and the next phases were measurements of dielectric properties of the samples compacted on the laboratory rammer in the range from 1 to 10 strokes. Then, the samples were placed in the rectangular resonator with a diode array detector, as shown in Figure 1a. Measurements of dielectric properties of the selected sands were carried-out at 20 °C and at constant air humidity of 60 %.

EXPERIMENTAL RESULTS

Measurement results of permittivity ε_r and loss tangent $tg\delta$ for high-silica base are shown in Figures 2a and 2b, for chromite sand in Figure 3a and 3b and for olivine sand in Figures 4a and 4b.

The presented results are average values of three measurements for each sand base. Analysis of the values ε_r and $tg\delta$ for all the examined sand bases indicates that dielectric properties, i.e. permittivity and loss tangent become stable at fivefold compaction of the examined samples using a laboratory rammer. Further increase of the compaction degree does not affect measurement results significantly. So, it can be said that fivefold compacting the samples with a laboratory rammer gives guidelines for further research works on utilisation of dielectric properties of traditional moulding sands.

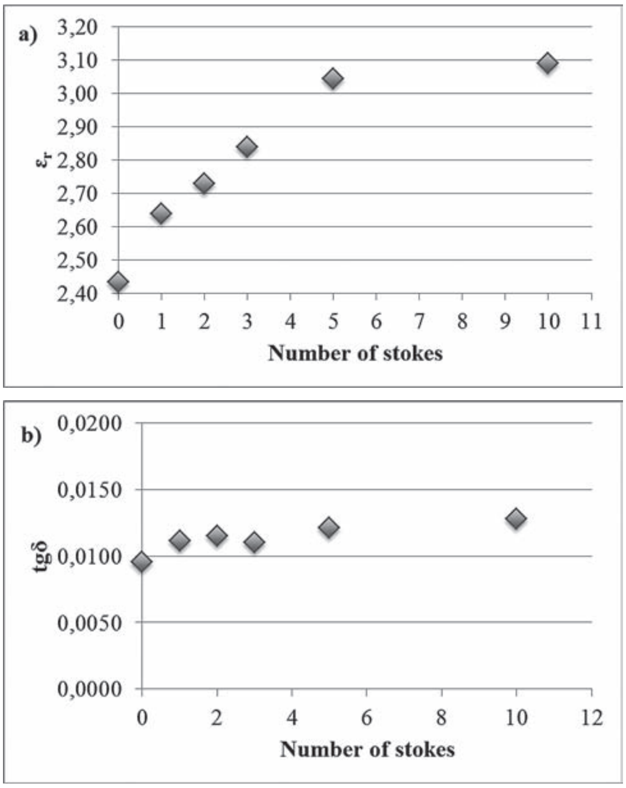

Figure 2 Measurement results for high-silica base with humidity W = 0,88 %: a) permittivity ε_r; b) loss tangent $tg\delta$

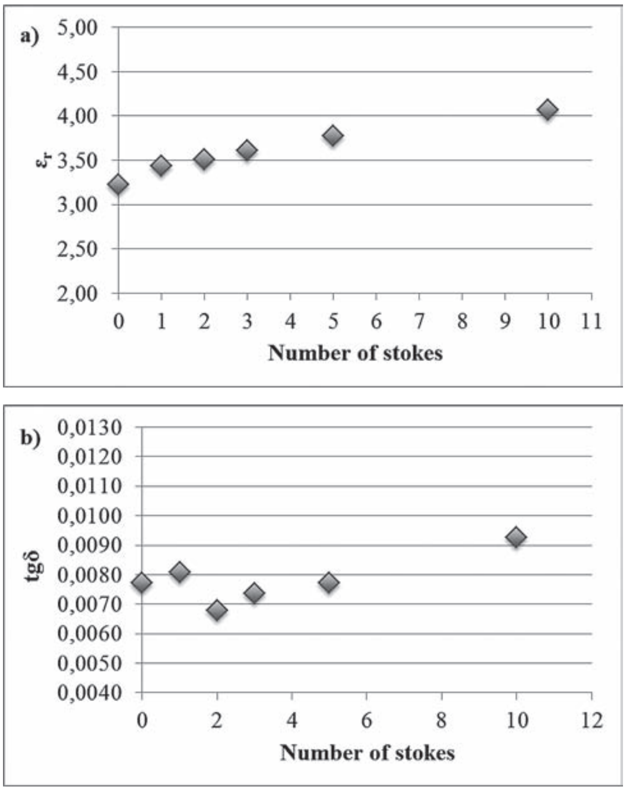

Figure 3 Measurement results for chromite base with humidity W = 0,71 % : a) permittivity ε_r; b) loss tangent $tg\delta$

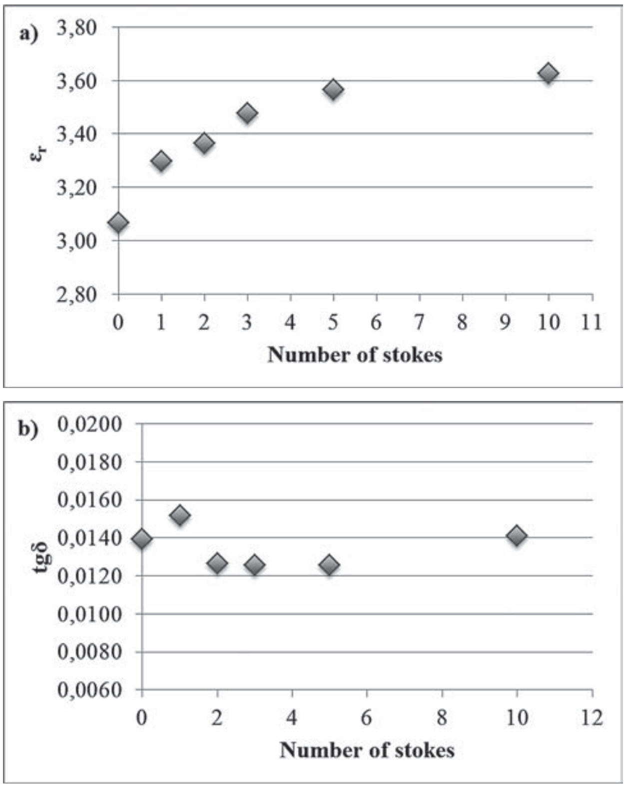

Figure 4 Measurement results for olivine base with humidity W = 2,72 % : a) permittivity ε_r; b) loss tangent $tg\delta$

CONCLUSION

The presented measurement results of permittivity ε_r and dielectric loss tangent $tg\delta$ for the examined sand bases permit the following conclusions to be drawn:

It is already after fivefold compacting with a laboratory rammer that compaction degree does not affect significantly dielectric properties of the examined sand bases.

The most favourable for microwave processes in foundry practice appears chromite sand, so the moulding sands based on chromite sand can be successfully dried and/or hardened in microwave field.

The experimentally obtained relations between compaction degree of sand bases and their dielectric properties establish guidelines for further research works with use of electromagnetic field in foundry practice and especially for determining permittivity ε_r and dielectric loss tangent $tg\delta$ with the perturbation method.

List of physical characteristic and factors:

Symbol	Name/ Unit	SI-unit
f	Frequency/ GHz	$10^9 \cdot s^{-1}$
f_0	Resonance frequency of the cavity / GHz	$10^9 \cdot s^{-1}$
f_s	Resonance frequency of the cavity with a sample / GHz	$10^9 \cdot s^{-1}$
ε_0	Permittivity of free space/ dimensionless	

ε_r	Permittivity/ dimensionless
ε'	Real component of complex relative permittivity/ dimensionless
ε''	Imaginary component of complex relative permittivity/ dimensionless
$tg\delta$	Dielectric loss factor/ dimensionless
Q_c	quality of the cavity/ dimensionless
Q_s	quality of the cavity with a sample/ dimensionless
V_c	volume of the resonance cavity/ m^3 m^3
V_s	volume of the sample/ m^3
W	humidity / %

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