ARCHIVES of FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 15
Special Issue
1/2015

136 – 139

28/1

Dielectric Properties of High-Silica Sand at 2.45 GHz

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Received 28.04.2015; accepted in revised form 05.05.2015

Abstract

In the paper, presented are measurements of permittivity (ε_r) and dielectric loss factor (tgδ) of high-silica moulding sand, determined at 2.45 GHz by perturbation method on a stand of waveguide resonance cavity. Determined were electrical properties of the main component of moulding sands, i.e. high-silica base, critical for their heating kinetics. The measurements were carried-out for six kinds of high-silica sand with diverse grain size distribution. Analysis of the results indicates that both permittivity and loss tangent values are similar for all kinds of high-silica moulding sand. Irrespective of their grain size analysis, neither of the examined sandmixes shows susceptibility to action of 2.45 GHz microwave field. The presented results make a ground for developing a mathematical model of microwave heating of technological systems composed of moulding sand and foundry tooling.

Keywords: Innovative foundry technologies, Microwaves, Moulding sand, High-silica sand

1. Introduction

Application of microwave heating of frequency 2.45 GHz in foundry processes is possible at drying and hardening of casting moulds and cores made of eco-friendly sandmixes containing inorganic binders [1-3]. Effectiveness of microwave heating of sandmixes is decided by the factors related to their qualitative and quantitative composition, as well as to parameters of the microwave field. Electrical properties of all the materials, including those applied in foundry practice, depend on chemical, mineralogical, quantitative and qualitative composition of these materials, deciding the possibility to use them in microwave field [4-6].

The main component of moulding and core sands is high-silica base, selected depending on the requirements posed to finished castings. To that end, high-silica sand is commonly applied, mainly because of its accessibility, relatively low price and sufficient resistance to high temperatures [7]. Application of microwave heating of high-silica-based moulding sands requires determining their electrical properties that condition effectiveness and efficiency of drying and hardening processes [5] of casting moulds and cores.

An objective of this work is determining electrical properties of high-silica sand used as the base of moulding and core sands containing inorganic binders. The scope of the work includes the commercially available types of high-silica sands having diverse grain size distributions. Results of the examinations will contribute to developing a mathematical model of microwave heating of moulding and core sands.

2. Methodology of the research

2.1. Materials

Six kinds of high-silica sand were selected for the examinations, with density 2650 kg/m^3 and various grain size distributions (see Fig.1), coming from the high-silica sand mine „Grudzeń Las". Table 1 shows basic properties of the selected materials.

Electrical properties of sandmixes, decisive for effectiveness and efficiency of microwave heating, individually depend on mineralogical composition and macroscopic parameters (shape, size and regularity of grains, surface topography).

Table 1.
Properties of high-silica moulding sands

Designation	Name of high-silica sand	Chemical analysis			Grain size (sieve number)	Main fraction F_g [%]	Clay content [%]	Average grain diameter d_L [mm]	Coefficient of homogeneity logW
		SiO_2 [%]	Fe_2O_3 [%]	Carbonate [%]					
P1	High-silica sand, very fine-grained	99.20	0.10	0.08	0.10/0.16/0.071	93	0.45	0.12	49.54
P2	High-silica sand, fine-grained	99.24	0.10	0.07	0.10/0.16/0.20	94	0.20	0.15	51.98
P3	High-silica sand, fine-grained	99.34	0.08	0.07	0.20/0.16/0.10	93	0.17	0.20	53.22
P4	High-silica sand, medium-grained	99.25	0.07	0.08	0.2/0.315/0.16	96	0.15	0.24	48.40
P5	High-silica sand, coarse-grained	99.30	0.06	0.08	0.20/0.315/0.40	90	0.12	0.28	59.78
P6	High-silica sand, coarse-grained	99.35	0.05	0.08	0.40/0.315/0.20	90	0.11	0.32	62.39

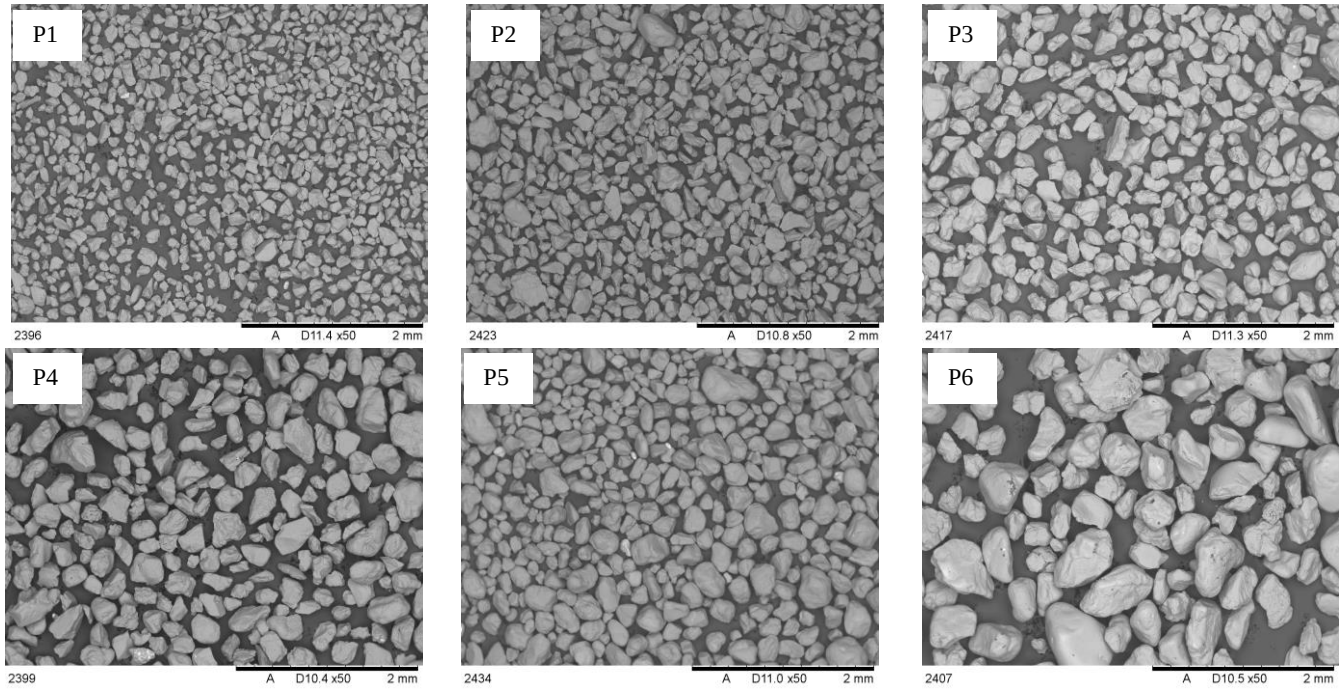

Fig. 1. Grains of high-silica sand with diverse size analysis SEM

2.2. Scope and methodology

Behaviour of materials in variable electric field is described by two main parameters. The first one is relative permittivity ε_r that determines the way how the material is polarized in electric field. The other parameter is loss tangent tgδ that determines fraction of energy transformed to heat in the material subject to action of microwaves [4,5].
In order to determine electrical properties of loose materials like high-silica moulding sand at 2.45 GHz, applied was the stand of waveguide resonance cavity, described in [8]. The perturbation method and the applied stand of waveguide resonance cavity permit measuring electrical properties of samples with widely varying physico-chemical properties (in liquid or loose state or in form of mixtures). Moreover, the perturbation method was selected because of its numerous advantages like high accuracy of measurement, possibility of measuring materials with low lossiness and simple measurement system [9].

In this research, constant volume of the examined specimens was applied, equal to 5 cm^3. The high-silica sand, as a grainy material with diverse grain size analysis, was characterised by its apparent density (kg/m^3), expressed by the weight-to-volume ratio [7]. This property is important, since fraction of free space in the structure of a microwave-heated system is decisive for penetration of electromagnetic waves through a given medium. The relations between electrical properties of grainy materials and their apparent densities will be examined in the subsequent research works.

3. Achieved results

Measurements of electrical properties were carried-out at 20 °C and air humidity 60 %, on three specimens of each sand, previously dried at 105 °C. Average results compared with apparent density of the examined sands are shown in Figs. 2 and 3.

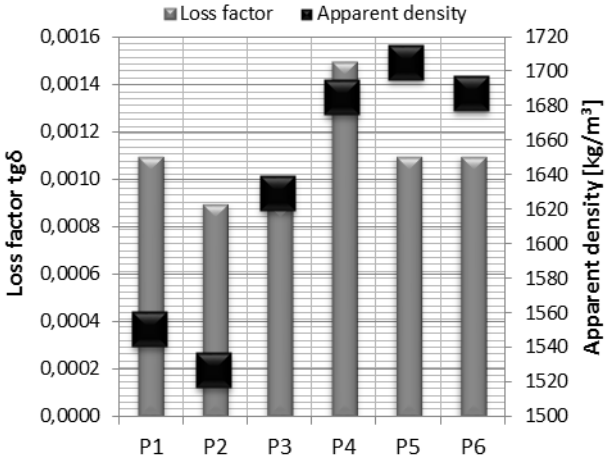

Fig. 2. Loss factor and apparent density values of selected kinds of high-silica sand

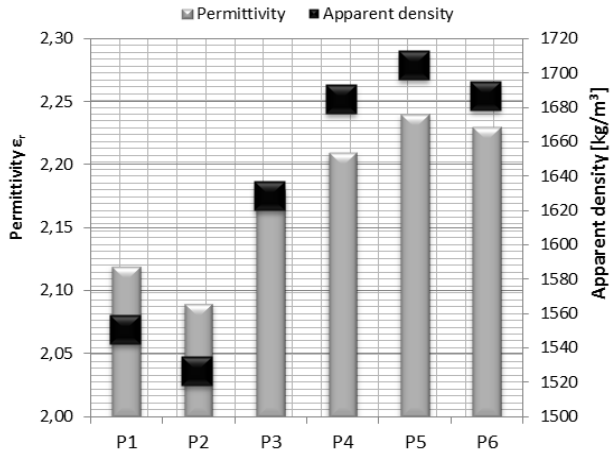

Fig. 3. Permittivity and apparent density values of selected kinds of high-silica sand

Analysis of the measurement results permits the statement that both loss factor and permittivity values of all kinds of the examined sandmixes are similar, irrespective of their grain size analysis. The measured loss factor values indicate that high-silica sand is a material with low lossiness (tgδ = 0,0009 ÷ 0,0015), and thus with low susceptibility to heating by microwaves of frequency 2.45 GHz.

4. Conclusions

Analysis of the measured values of permittivity ε_r and loss factor tgδ of high-silica sand leads to the following conclusions:

- Measuring electrical properties by the perturbation method permits preliminary selection of types of high-silica sand from the viewpoint of their application for bases of moulding sands to be microwave-heated.
- Irrespective of its grain size analysis, high-silica sand does not show susceptibility to action of 2.45 GHz microwave field.
- The obtained measurement results will make a ground for determining electrical properties of sandmixes based on high-silica sand.

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