ARCHIVES of FOUNDRY ENGINEERING
DOI: 10.1515/afe-2016-0059
Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences
DE GRUYTER OPEN
ISSN (2299-2944)
Volume 16
Issue 3/2016
103 – 108

Effect of Sand Base Grade and Density of Moulding Sands with Sodium Silicate on Effectiveness of Absorbing Microwaves

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Received 31.03.2016; accepted in revised form 04.05.2016

Abstract

In the paper, presented is a research on effectiveness of absorbing electromagnetic waves at frequency 2.45 GHz by unhardened moulding sands prepared of three kinds of high-silica base and a selected grade of sodium silicate. Measurements of power loss of microwave radiation (P_{in}) expressed by a total of absorbed power (P_{abs}), output power (P_{out}) and reflected power (P_{ref}) were carried-out on a stand of semiautomatic microwave slot line. Values of microwave power loss in the rectangular waveguide filled with unhardened moulding sands served for determining effectiveness of microwave heating. Balance of microwave power loss is of technological and economical importance for manufacture of high-quality casting moulds and cores of various shapes and sizes. It was found that relative density influences parameters of power output and power reflected from samples of moulding sand placed in a waveguide. Absorption expressed by the parameter P_{abs} is not related to granularity of high-silica base: fine, medium and coarse. It was found that the semiautomatic microwave slot line supports evaluation of effectiveness of microwave absorption on the grounds of power loss measurements and enables statistic description of influence of relative density of the sandmix on penetration of electromagnetic waves in unhardened moulding sands.

Keywords: Foundry, Microwaves, Sodium silicate, High-silica sand, Lossiness measurements

1. Introduction

In previous research works on absorption of 2.45 GHz microwaves, used also in foundry practice, selected were the materials making grounds for further works on economical aspects of this technology [1-2]. It was found in [3] that, for moulding sands (sandmixes) containing up to ca. 3.5 wt% of water, the base materials most favourable from the viewpoint of microwave absorption expressed by P_{abs} are (in order): chromite (30-45%), zirconium (25-30%), high-silica (15-30%), magnesite (17-20%) and corundum (10-20%) sands. It was also found that, at water content over 3.5 wt%, the best results are ensured by chromite (45-65%), high-silica (30-45%), zirconium (30-35%), corundum (20-33%) and magnesite (20-22%) sand. Summarising, the most favourable base of moulding and core sands for applications involving microwave heating are chromite, zirconium and high-silica sands. As is known, from the economical point of view, the most beneficial base of moulding sands is high-silica sand.

Hitherto, research works on absorption of 2.45 GHz microwaves were carried-out on wet moulding sands because of polar structure of water molecules. Water, being a component of moulding materials, e.g. of eco-friendly binders like sodium silicate (water-glass) [4,5], is still composed of dipoles even being a part of water-glass structure [6]. It was found in research works on absorption of microwaves containing inorganic hydrophilic binders [7] that microwaves are best absorbed by water-glass grade 137 because of the biggest fraction of water in the colloidal solution.

In the case of using electromagnetic microwaves for hardening of moulding and core sands, basic parameters informing about effectiveness of the process should be determined, like value of losses related to incidence and reflection of microwaves from the surface on their propagation way, losses related to dissipation of microwaves inside the waveguide and transmission losses related to instrumentation materials, in particular waveguides and microwave chambers (Fig. 1). The examinations presented in this paper are a continuation of the trials aimed at evaluating influence of composition of sandmixes [4,5,7] on the process of absorbing microwaves, carried-out using a prototype stand of semiautomatic microwave slot line for measurements of the standing wave ratio (SWR).

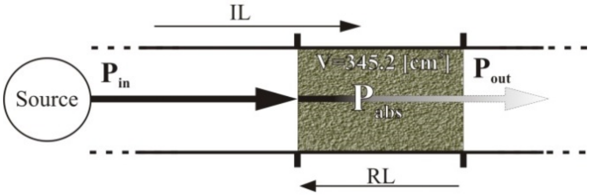

Fig 1. Propagation of electromagnetic wave in a waveguide filled with 345.2 cm^3 of moulding sand

The applied stand of semiautomatic microwave slot line makes it possible to determine the above-mentioned parameters by measuring maximum amplitude of the standing wave generated in a rectangular aluminium waveguide with a slot. Amplitude values are recorded in a function of voltage (mV) using a diode detector with sensitivity level not below 0.4 mV. The losses caused by the substrate present in the waveguide (sample of moulding sand) are determined by two equations (1) and (2) below. The equations express two parameters of lossiness:

RL – Return Loss is the microwave energy lost by primary reflections from the surfaces present on propagation way of microwave standing wave; IL – Insertion Loss is the microwave energy dissipated in the transmission line.

A measure of these losses is attenuation expressed in dB. Indexes of the dissipation matrix s_{11} and s_{21} are related to the above-mentioned parameters:

$$RL = 20\log|s_{11}| \quad [\text{dB}] \qquad (1)$$

$$IL = 10\log|s_{21}| \quad [\text{dB}] \qquad (2)$$

On these grounds, microwave absorption P_{abs} can be calculated with use of the equation (3):

$$P_{abs} = \left(1 - (10^{\left(\frac{IL}{10}\right)} + 10^{\left(\frac{RL}{10}\right)})\right) \cdot 100\ [\%] \qquad (3)$$

To check correctness of the equation (3), the equation (4) was applied, presenting power balance of microwaves acting on the specimen during measurements [8]. A part of output power P_{in} of microwaves propagating in the waveguide filled with the examined material, is lost by the components:

$$P_{in} = P_{ref} + P_{abs} + P_{out} \qquad (4)$$

where P_{ref} means reflected power and P_{out} means output power after transition through the examined substrate located in the waveguide (Fig. 1), as expressed by the expressions (5) and (6):

$$P_{ref} = \left(10^{\left(\frac{RL}{10}\right)}\right) \cdot 100\ [\%] \qquad (5)$$

$$P_{out} = \left(10^{\left(\frac{IL}{10}\right)}\right) \cdot 100\ [\%] \qquad (6)$$

In the preliminary research, power value of sinusoidal microwave was established that facilitates very precise determination of SWR value for calculations of RL and IL on the level of ca. 3.98 mW, thus reducing to a minimum the possibility of heating the examined substrate. This way, initiation of the process of hardening samples of water-glass containing sandmixes is also limited to a minimum. Thanks to semiautomatic construction of microwave slot line [7] reached was the repeatability of the measurements results for specific relative density of unhardened moulding mixtures.

2. Purpose and scope of the research

In order to determine effectiveness of microwave absorption depending on relative density of moulding sands, three commercially available high-silica bases coming from the mine Grudzeń Las Sp. z o.o. were selected, as well as a grade of non-modified sodium silicate from Chemical Plant Rudniki S.A. with the properties given in Table 1. On the grounds of conclusions of [9], measurements of iron content that, in compounds with other elements, can affect absorption of microwaves by the examined high-silica bases, were also considered. Measurements of iron content, carried-out with an EDS analyser, clearly indicate that the sands originate from the same deposit. Selected inorganic binder (Table 1) thanks to physical methods of hardening can be classified to the highest 1st quality class binders [10,11], determined by bending R_g^U and tensile R_m^U strength calculated per 1 wt% of the binder.

Table 1.
Measured parameters of examined moulding materials

High-silica sand acc. to PN-85/H-11001:	**Fine:**	**Medium:**	**Coarse:**
Fraction 1:	0.10	0.20	0.20
Fraction 2:	0.16	0.315	0.315
Fraction 3:	0.20	0.16	0.40
Fe / wt% max.	0.1	0.1	0.1

Binder (sodium silicate) grade 137:				
Molar module SiO_2/Na_2O	**Oxide content (SiO_2+Na_2O) % min.**	**Density (20 °C) g/cm^3**	**Fe_2O_3 % max.**	**Dynamic viscosity (P) min.**
3.4	36.3	1.37	0.02	1

6-kg portions of moulding sands for the examinations were prepared in a laboratory ribbon mixer in the following proportions (by mass, per 100 parts of moulding sand): 0.5 part of water were dosed to the base [10,11], then 1.5 parts of binder 137 were dosed in 60 s after starting the mixer and stirring was continued for 4 min. Temperature of the moulding sand was equal to ambient temperature of 23 ±2 °C.

During thickening on the apparatus LUZ-2e vibration frequency 50 Hz was and applied amplitudes (A) amounting to: 80%, 60% or 40% of the maximum value 2 mm. In the tests, constant process time of 120 s and constant volume of measuring chamber of 345.2 cm^3 were accepted. By applying various settings of the thickening device, indirect control (through relative density) of the important technological parameter, i.e. permeability of the moulding sand, was possible. In consequence, this would influence production economics, since lower density of a moulding sand means less consumption of high-silica base.

It is supposed that the research on absorption of microwaves during initial phase of microwave heating will make it possible to determine a relationship between relative density of the sandmix and maximum effectiveness of the process in that water has the highest permittivity (ε_r). Results of this research will bring nearer development of a complex mathematical model to facilitate determining the most beneficial parameters of microwave heating, optimum for a specific composition of the moulding mixture and its thickening process.

3. Results

Measurement results of lossiness parameters RL and IL, determined on the microwave slot line and expressed in attenuation units dB, were converted according to the formulas (3), (5) and (6) to components of output power P_{in} expressed by the formula (4). For the unhardened moulding sands with various high-silica bases after their thickening, power balance of microwaves P_{in} is shown in the diagrams, see Figs. 2, 3 and 4. Component values of P_{in} are presented according to decreasing amplitude of vibrations.

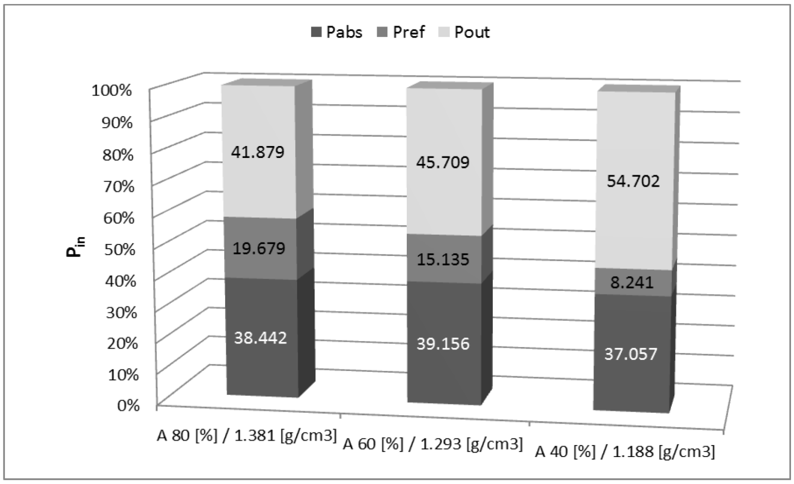

Fig. 2. Relationship between thickening degree (amplitude value / relative density) and effectiveness of microwave heating of a moulding sand with fine-grained high-silica base

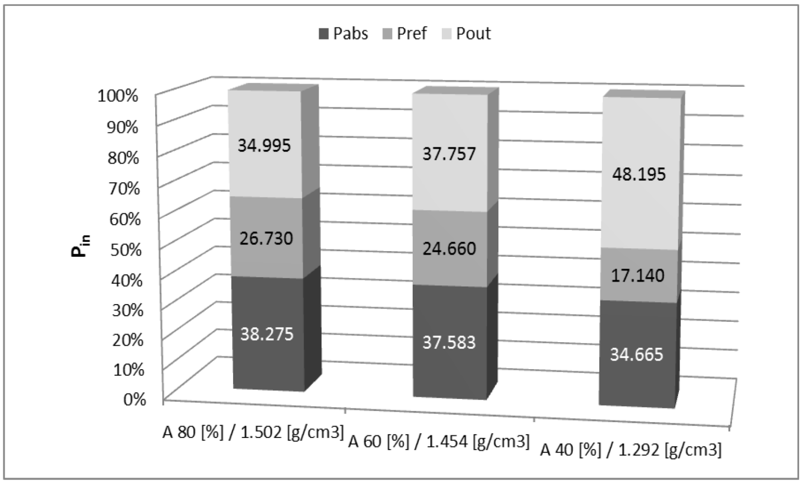

Fig. 3. Relationship between thickening degree (amplitude value / relative density) and effectiveness of microwave heating of a moulding sand with medium-grained high-silica base

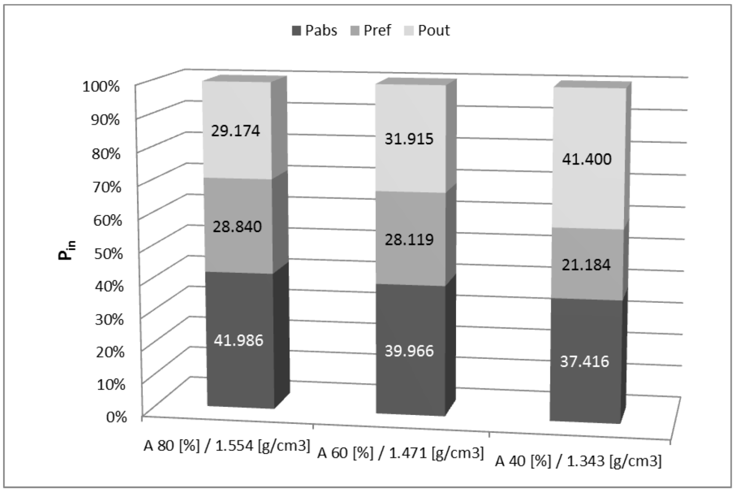

Fig. 4. Relationship between thickening degree (amplitude value / relative density) and effectiveness of microwave heating of a moulding sand with coarse-grained high-silica base

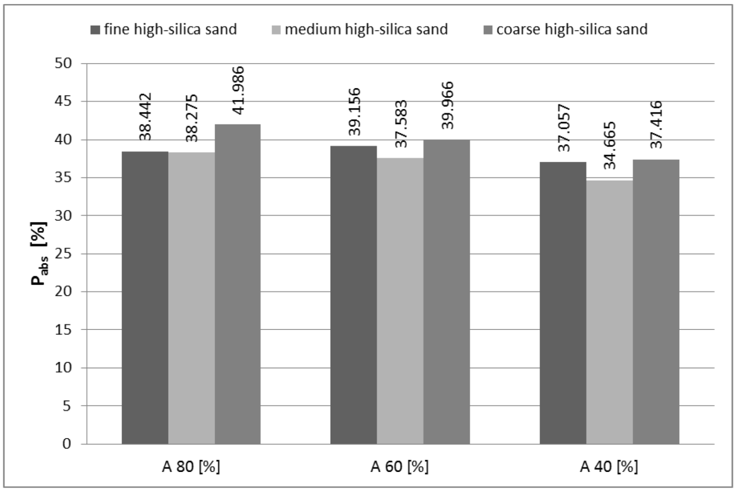

Fig. 5. Relationship between thickening degree (amplitude value) and absorption of microwaves expressed by P_{abs} value for moulding sands prepared of various high-silica bases

Of the greatest importance for effectiveness of microwave heating are the determined fractions of power absorbed by moulding sand, describing the part of energy to be converted to heat. Analysis of the examination results shows that the fraction P_{abs} is practically invariable regardless of the applied high-silica base and vibration amplitude. For better visualisation, fractions of absorbed power from Figs. 2, 3 and 4 are shown together in Fig. 5. It can be said on the grounds of Fig. 5 and literature data [3,4,7,9] that absorption of 2.45 GHz microwaves is mostly affected by fractions of the materials containing molecules with polar structure, e.g. water. If mass fractions of the sandmixes containing water and thickened by vibration are invariable, at constant conditions of the tests the observed values of microwave absorption ranging between 34.7% and 42% could be hardly related to application of high-silica base with various granularities but coming from the same sand mine.

The most distinct differences resulting from using various vibration amplitudes (relative thickness values) (Figs. 2, 3 and 4) and various main fractions of high-silica base are visible in values of the components P_{ref} and P_{out} of the P_{in} value. Because of small variability of P_{abs}, it is possible to observe changes of the reflected P_{ref} and transmitted P_{out} fractions of microwave energy. It was found that, in each of three moulding mixtures with various main fractions of base sands, relative density decreased along with decreasing vibration amplitude. As a result of decreasing relative density (1.554 to 1.188 g/cm^3), fraction of reflected power P_{ref} also decreased from 29% to even 8% in the case of fine-grained base sand, see Fig. 4 and 2. In the general power balance P_{in}, decline of reflected power fraction was compensated by changes of the fraction P_{out} measured after transition of microwaves through the sample. Decreasing density of the material is conducive to propagation of microwaves in the waveguide filled with moulding sand and to increase of P_{out} from 29% to 55% for the moulding sand with fine sand base.

On the grounds of the carried-out examinations and the observed changes resulting from various amplitudes of vibration thickening, an attempt was made to describe the relationship between relative density and effectiveness of microwave heating of moulding sands. Values of components of the P_{in} power are shown in Fig. 6 for all the three high-silica bases. Values of the components are arranged according to increasing relative density of the moulding sands. It was initially assumed that, for high-silica bases with various main fractions, the power balance values P_{in} will not be associated with relative density after vibration thickening. To this end, required calculations were performed using the program STATISTICA 12. For all the cases, significance level of 0.05 was accepted. Results of linear approximation of the components P_{abs}, P_{ref} and P_{out} are given in Table 2 and Figure 6.

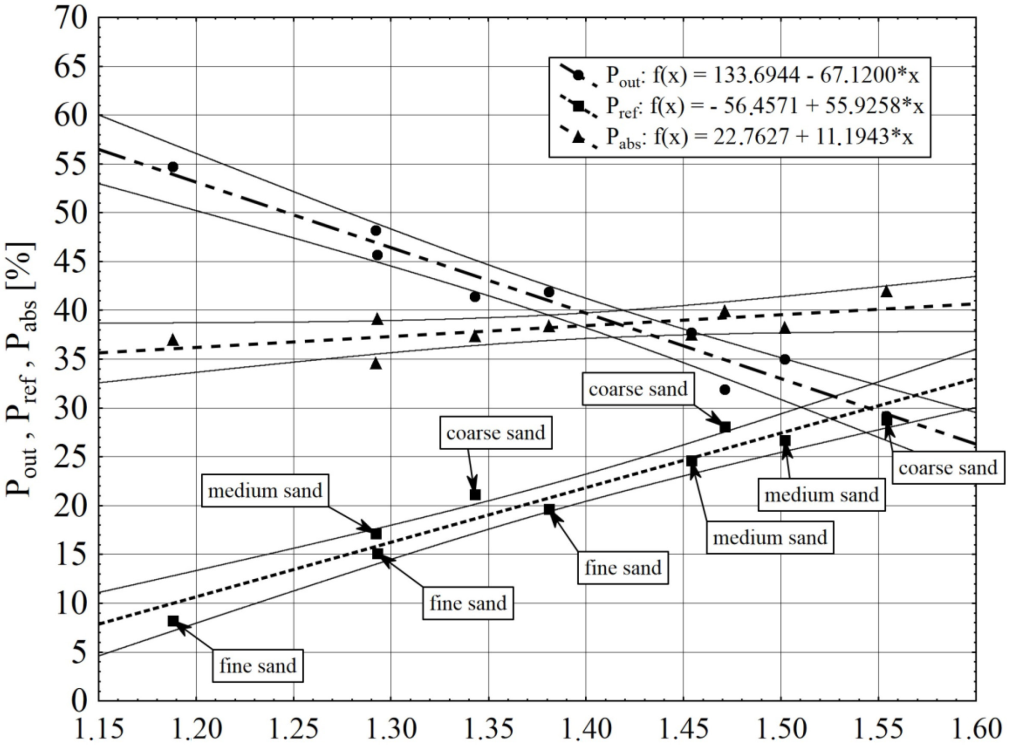

Fig. 6. Relationship between relative density and power components P_{abs}, P_{ref} and P_{out} for moulding sands containing sodium silicate grade 137 and various high-silica bases from the same sand mine

The applied method of linear approximation is reflected in the data given in Table 2, containing information on possible linear relationship (correlation P/density) between moulding sand density and components of P_{in} (P_{abs}, P_{ref} and P_{out}).

Table 2.
Correlation parameters between components of P_{in} and relative density of moulding sands with water-glass 137 and various high-silica bases from the same sand mine

P_{in}	Correlation: *P* / density	Correlation coeff. „*r*”	„r2”	p
P_{abs}	No	0.6508	0.4235	**0.0577**
P_{ref}	Yes	0.9705	0.9420	0.00001
P_{out}	Yes	-0.9757	0.9521	0.00001

The performed analysis made it possible to reject the initial hypothesis assuming that no linear correlation exists in the case of the components P_{ref} and P_{out}.

The calculated correlation coefficients given in Table 2 indicate a very good matching of the linear function between P_{ref} or P_{out} and relative density of moulding mixtures. Because of this good matching of regression values to empirical data for P_{ref}, it can be assumed that quantity of energy reflected from the unhardened moulding sand depends on its relative density. Similarly, good matching makes it possible to relate P_{out} value with relative density of the moulding sand. In the case of P_{abs}, the applied linear approximation method did not reveal a strong relationship between absorption of microwaves and density of the moulding mixture.

4. Conclusions

The presented results of the research on influence of base grade and density of sodium silicate containing moulding sand on effectiveness of absorbing microwaves lead to the following conclusions:

- Measurements of lossiness parameters RL and IL of microwave radiation make it possible to forecast, on the grounds of calculated absorbed power (P_{abs}), effectiveness of heating with microwaves 2.45 GHz at the level between 35% and 42% of P_{in} power for density of unhardened moulding sands between 1.2 and 1.6 g/cm^3.
- No significant changes of absorbed power fraction P_{abs} are connected with decrease of relative density of moulding sands with fine, medium and coarse base sand from 1.6 to 1.2 (g/cm^3).
- With respect to penetration of microwaves to moulding sands containing water-glass 137, thickening resulting in proper mechanical parameters at low relative density is favourable.
- Fractions of reflected power P_{ref} and transmitted power P_{out} change with density of the moulding sands.
- Decrease of reflected power fraction (P_{ref}) is most noticeable in the case of fine-grained high-silica base sand. Along with increasing granulation of main fraction of base sand, the change of reflected (lost) microwave power becomes less beneficial.
- From the viewpoint of effectiveness of microwave heating of moulding sands, decreasing P_{ref} value in favour of P_{out} can be of high practical importance for hardening large-size moulds and cores.
- A mathematical description of the relationship between P_{ref} and P_{out} and relative density of high-silica based moulding sands is possible. This would facilitate proper selection of base materials to be used for high-quality moulding and core sands, e.g. acc. to the permeability criterion.
- Research should be extended to sands from different mines to determine the effect of surface morphology and particle shape of grains on the components of P_{in}.
- The semiautomatic test stand used in the research, i.e. the microwave slot line, can be used for detailed examinations of intensification of heating high-silica based moulding sands with selected organic and inorganic binders.

Acknowledgement

The research was financially supported from the grant for statutory activity No. B50120/K1012.

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