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Evaluation of the Microwave Absorbing Effectiveness by the Selected Molding Sands Matrixes

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Abstract

The paper presents the results of the absorption effectiveness measured for electromagnetic waves with a frequency of 2.45 GHz penetrating selected quartz mold and core sands matrixes. Research was conducted with a usage of the unique microwave slot line for assessing, on the basis of the measured parameters of looseness, the effectiveness of microwaves absorbing capacity by the matrixes of molding sands. Examinations were focused on the high-silica quartz matrixes from various mines with a different grain size composition and humidity. Usage of the unique measuring device, designed especially for this type of research, has made possibility to systematize knowledge of the dynamics and efficiency of microwaves absorption while penetrating humid matrix of molding sands. Analysis of the study results indicate, that the process of microwaves absorbing is affect, in addition to water located on the matrix grains surfaces, by the grain size distribution and the origin of the quartz sand.

Keywords: Foundry, Microwaves, Quartz sand, Absorption, Water

1. Introduction

Previously shown in many publications such as [1-3], microwave heating is a competitive process, which can be enabling technology for traditional solutions intended the treatments of forming cavities and cores for casting ferrous and non-ferrous metals. Earlier studies have been mainly focused on demonstrating possibilities of applying this technology to hardening molding sands containing various organic [4] and inorganic binders, described in the context of significant benefits [5], which are specific to the rapid curing process during microwave heating.

To evaluation the effectiveness of microwave heating process of molding sands, became necessary determination of the effectiveness of electromagnetic radiation absorbing capacity by the matrix, which is a major component of molding sands. Presently, particularly important is to clarify, which one of the commonly used materials provides: profitable, effective and efficient process of the hardening with the use of microwaves at frequency of 2.45 GHz.

In the practical application of electromagnetic waves for hardening molding and core sands, take on a new meaning the parameters of this process, such as: growth rate and curing time. Mentioned parameters mainly depend on the effectiveness of the microwave absorption of the sandmixes components. On the absorption of microwaves, which is the ability of their acceptance by dielectric materials, has influence electrodynamics' forces which cause dipoles rotation and parallel setting them to the direction of the applied, external electric field. Result of such behavior of dipoles is the reduction of their electric field intensity inside the dielectrics. In this way, under the influence of the alternating electric field, continues-changing of the electric field direction results in permanent movement of electric charge and mutual friction of the particles [6], from which the material is built. As a result of this process, is warming up the material.

In the previously studies have been used generally one model kind of molding, high-silica quartz sand [1-8]. During the preparation of the foundry molds and cores production process, in which will be applied the microwave heating to hardening sandmixes, is necessary to know about the microwave heating process' progress of different kinds of matrix, including the most widely used quartz sands.

Main component of foundry high-silica sands is quartz dioxide SiO_2. In the highest quality class, named 1K content of the SiO_2 should be greater than 98%, while for the lower classes: 2K and 3K - 96%. Other classes of foundry high-silica sands aren't normalized. Foundry quartz sand matrix cannot contain more than 2% of natural binder. In addition, the composition of quartz foundry sands may include other minerals, such as: silicates, carbonates (for 1K class may be <0.3%) and the iron compounds (for 1K class may be <0.3% Fe_2O_3) [9].

The results of the measurements of electromagnetic waves absorption by the selected types of quartz matrix will expand the knowledge of the selection of most suitable composition of the molding and core sands for hardening in the microwave heating process.

2. Measuring device

To determine the effectiveness of microwave absorption by the selected molding sand matrixes have been used prototype measuring device shown in Figure 1 [7-8, 10-13]. As the electromagnetic wave source in microwave slot line device was used a low power microwave generator, model M 2031. Signal generated by this unit was inserted into a rectangular waveguide, which was made with the WR 340 standard.

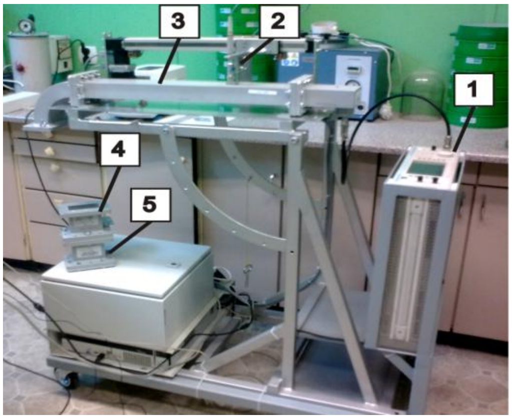

Fig. 1. View of a microwave slot line device: 1 - low power microwave generator (f = 2.45 GHz), 2 - diode detector, 3 - rectangular waveguide with a slot, 4 - chamber for tested materials, 5 - microwave waveguide damper

During the measurements with a diode detector, model 423A, were registered maxima of the standing wave amplitudes (SWR) as a function of voltage. Mentioned detector model was characterized by a level of sensitivity, which was not less than 0.4 mV.

At the time, while the measurements were making, presented in Figure 1 detector, was moving along the slot made in the waveguide. Measuring device was also included with additional elements, such as: waveguide test chamber in which the substrate is placed and the waveguide with a material which damping microwaves. To improve the methodology of the measurement the measuring device was equipped with the automatic elements for fully automated data registration. For this purpose, a stepper motor have been used to drive the detector 423A along the waveguide slot. Furthermore, to the data acquisition was used a computer program made by the company „AMT" Zakład Elektroniczny Usługowo – Wdrożeniowy, which was supported by a data acquisition board installed in the suitable to measuring device computer set.

In the preliminary tests, carried with the short circuit of microwave slot line, has been determined the value of a sinusoidal signal parameter at ≈ 3.98 mW, which allowed to a very precise identification of SWR level. Thanks to this preliminary tests, the possibility of warming-up tested substrate, under the influence of microwave energy, was limited to a minimum.

3. Purpose and scope of the research

The purpose of the research was the determination of the level of microwaves absorption by selected from various mines, quartz sands used for matrixes of molding and core sandmixes. To determine the differences in the absorption of microwaves with a frequency of 2.45 GHz by the molding sands with various grain size matrixes was added, while stirring, the portion of water. Results of these tests will be useful in further discussions on ways of intensification the microwave process of hardening foundry molds and cores.

Microwaves absorption researches (P_{abs}) were carried out using the laboratory device, which is designed to measure the standing wave ratio (SWR) of molding materials (see Fig. 1).

To determine the effect of microwave absorption by different grain size matrixes from various places of origin have been selected four quartz sands from three mines, with the main fraction presented in Table 1, which were determined during the sieve analysis.

Table 1.
Sand qualification by size of quartz grains (PN-85/H-11001)

Sand qualification:	Mine:	Main fraction [mm]:
Coarse silica sand	Nowogród Bobrzański	0.40/0.32/0,20
Coarse silica sand	Grudzeń Las	0.40/0.32/0.20
Medium silica sand	Szczakowa	0.32/0.20/0.16
Medium silica sand	Grudzeń Las	0.32/0.20/0.16

Next, to determine the differences between the examined sands derived from several mines have been made SEM observations and EDS chemical composition analysis with the usage of "table - top" scanning electron microscope Hitachi TM-3000.

4. Results

Figures 2 to 5 shows the topography of the surface of the grains of examined quartz matrixes. On the views of matrixes made with the usage of a scanning electron microscope were marked places in which have been done the determination of the chemical composition. The EDS analysis were made to determine the amount of oxygen, silicon and iron in tested sands.

Figure 2 and 3 shows a view of the selected coarse quartz matrixes, respectively from the mine: Novgorod Bobrzański and Grudzeń Las.

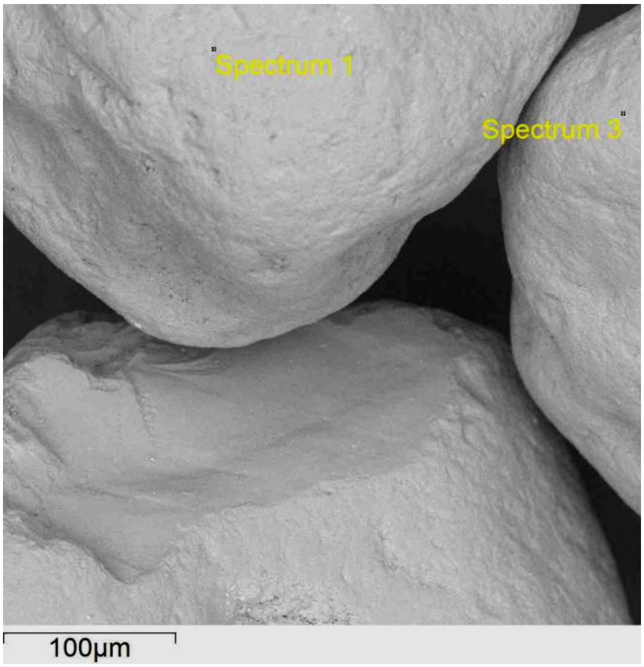

Fig. 2 View of the grains surface of coarse silica sand from the Nowgoród Bobrzański mine

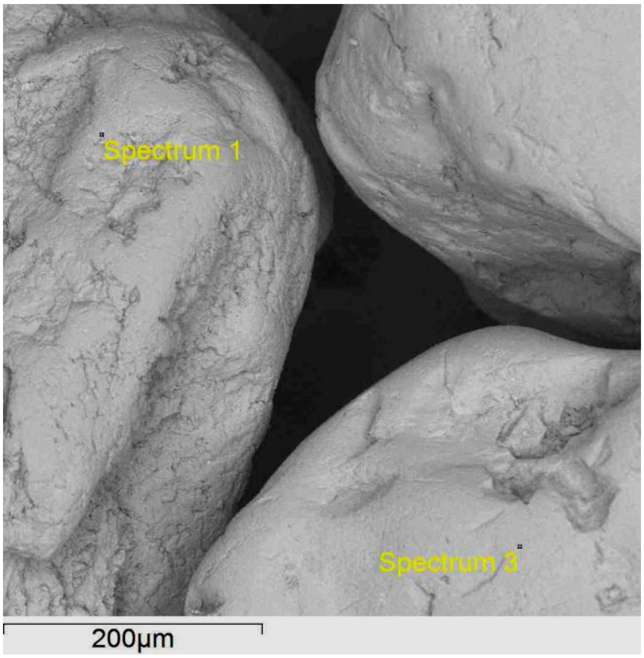

Fig. 3. View of the grains surface of coarse silica sand from the Grudzeń Las mine

Similarly, Figures 4 and 5, taken with a scanning electron microscope, shows the surface of matrix grains of medium silica sands from the mines: Grudzeń Las and Szczakowa.

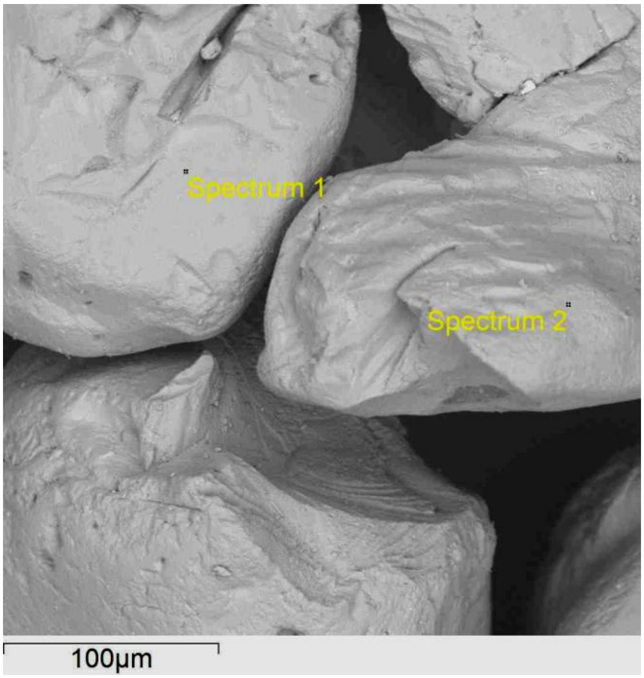

Fig. 4. View of the grains surface of medium silica sand from the Grudzeń Las mine

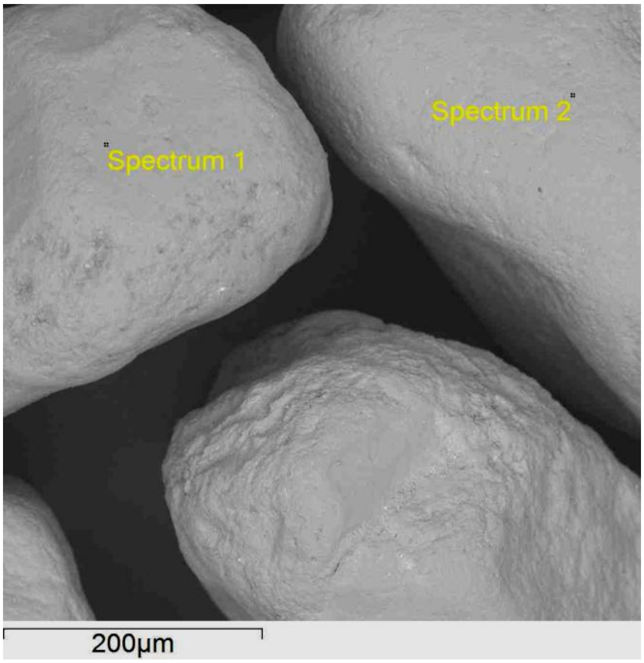

Fig. 5. View of the grains surface of medium silica sand from the Szczakowa mine

Table 2 shows the average results of the chemical composition analysis of the examined quartz sands.

Table 2.
The EDS analysis of the chemical composition of examined silica sands

Sand qualification:	Mine:	O vol. %	Si vol. %	Fe vol. %
Coarse	Nowogród Bobrzański	63.04	27.52	**9.45**
Coarse	Grudzeń Las	65.26	32.37	2.37
Medium	Grudzeń Las	65.06	30.74	4.19
Medium	Szczakowa	71.01	28.42	0.57

Analyzing the results of the chemical composition of the examined dry quartz sands it was found that, noted differences are not only in the grain size (see Table 1), but also in some chemical extent composition (Table 2). Most visible differences are in the content of iron and formed with their participation compounds, for example: Fe_2O_3. Probably, the content of this element, will have also an impact on the further measurement of microwaves absorption by the humid quartz matrixes.

In the next stage of the research were treated with microwaves at a frequency of 2.45 GHz and power ≈ 3.98 mW, mixed with a determined quantity of water, selected for these tests, four quartz sands.

Absorption of microwaves P_{abs} was calculated with the measured, expressed in units of loss [dB] quantities of: reflection from the substrate (*RL*) and the dispersion in the rectangular waveguide (*IL*), using the formula (1):

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

To validate the formula (1) was used equation numbered (2), which explains the balance of the microwave power, while acting the sample during the measurement:

$$P_{wej} = P_{odb} + P_{abs} + P_{wyj}, \quad (2)$$

where P_{odb} shows the level of the reflected power, and P_{wyj} determines the level of output power after passing through the examined substrate, which were expressed by formulas 3 and 4:

$$P_{odb} = (10^{\left(\frac{RL}{10}\right)}) * 100 \ [\%] \quad (3)$$

$$P_{wyj} = (10^{\left(\frac{IL}{10}\right)}) * 100 \ [\%] \quad (4)$$

Results of the P_{abs} power calculations after determining the *RL* and *IL* losses for the selected quartz matrix have been graphically compiled in Figure 6. To determine the relationship between the level of absorbed power P_{abs}, and water content in sand matrix was used the linear regression. The results of the statistical analysis of correlation between the level of P_{abs}, and water content are summarized in Table 3.

Analyzing the results of the microwave absorption capacity (Fig. 6) has been noted that each one of quartz matrixes has a characteristic point, in which was reached the lowest level of P_{abs}, located in the area of about 10% for a small water content from 1.0% to 1.5%. Low value of P_{abs} providing a low effectiveness of microwaves absorption during heating process.

As a result of increasing water content in examined sands have been reached a maximum value of 30 % of microwaves absorption. To the sand derived from the Nowgoród Bobrzański mine, which contains the most of iron (see Table 2), value of P_{abs} was even at 37 %.

Comparing the two types of "coarse" silica sand matrixes was found, that the microwave absorption of radiation is affected by the chemical composition of the sand.

It has been observed that the application of "coarse" sand matrix from the Nowgoród Bobrzański mine has more preferably impact on the effectiveness of microwave heating process, than the other quartz sands.

On the basis of these observations has been verified earlier, the incorrect assumptions that the efficiency of the microwave heating process entirely depends only on the amount of water added into the sand and do not depend on the other properties of the quartz matrix.

Moreover, it has been observed that the matrixes classified as a coarse silica sands absorbs the microwaves greater than the medium ones.

Probably, the fine and the very fine sands for molding matrixes will indicated similar, downward trend in the absorption of microwaves, influencing the reduction of the effectiveness of microwave heating during hardening molds and cores.

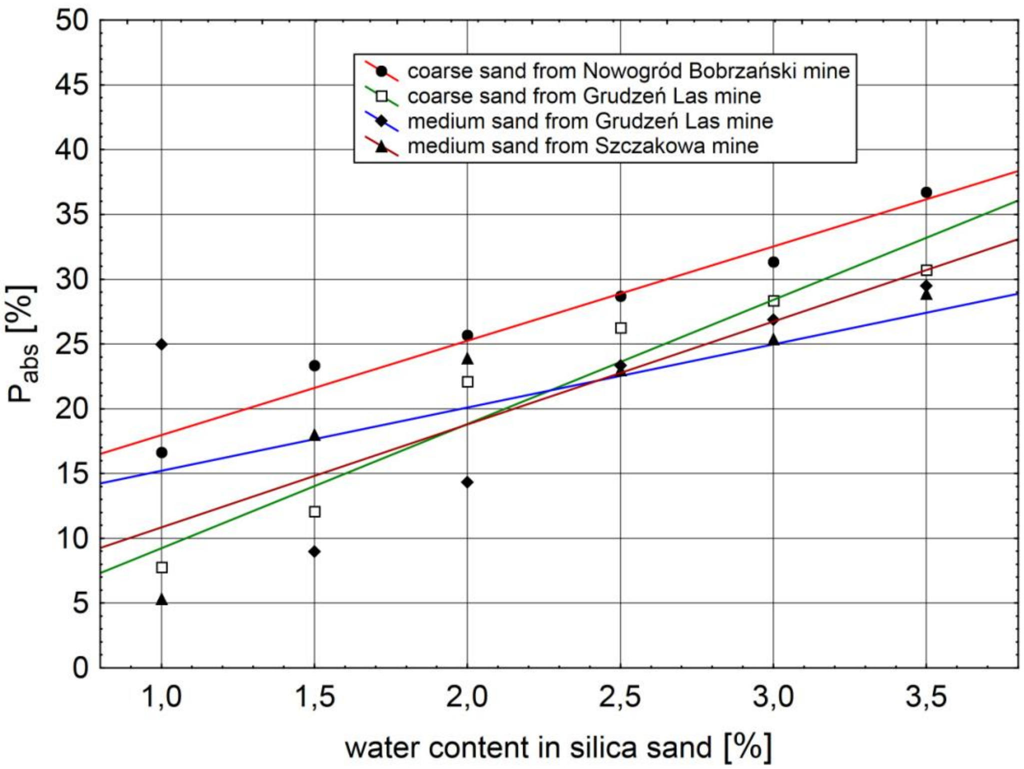

Fig. 6. Correlation graph between the level of P_{abs} power and the amount of water added to examined quartz sands

Descriptions of the dependence between the level of P_{abs} and the content of H_2O explained by linear regression (Figure 6) are presented in Table 3. Degree of dependence between P_{abs} and H_2O content has been described by Pearson's correlation coefficient "r".

Table 3.
Results of the statistical analysis of correlation between the level of absorbed power, and the water content

Sand qualifica-tion:	Mine:	Correlation between P_{abs} and H_2O:	coefficient of correlation „r":	coefficient of slope:
Coarse	Nowogród Bobrzański	yes	almost full	7,28
Coarse	Grudzeń Las	yes	almost full	**9,58**
Medium	Grudzeń Las	very low	almost full	4,88
Medium	Szczakowa	yes	almost full	7,95

On the basis of the calculated slope coefficients of the linear regression curves (Table 3) it was found, that the highest level of dynamism of microwaves absorption (9.58) is attributed to coarse sand from the Grudzeń Las mine. However, the lowest level of dynamism of microwaves absorption (4.88) is attributed to medium quartz sand from the same mine.

5. Conclusions

Analyzing the results of the tests made with a prototype microwave slot line device, which is used for the evaluate, on the basis of the values of P_{abs}, an influence of size distribution, humidity and quartz sand extraction site, can be concluded that:

- measurements of the microwave signal loss parameters *RL* and *IL* enable to predict, on the basis of calculated absorbed power (P_{abs}), the effectiveness of the microwave heating and/or hardening process of the quartz molding and core sands with organic and inorganic binders;
- more preferably absorption of microwaves, in range of the humidity from 1.0% to 3.5%, is characterized to coarse quartz sand from the Nowgoród Bobrzański mine;
- regression curves of the correlation between the level of P_{abs} and the content of H_2O, described by the slope coefficients, may be useful as an informing indicators about the effectiveness of microwave heating of quartz matrixes used to molding sands;

- the strongest factor influencing the microwave absorption by the quartz matrix is the quantity of water added during the mixing process;
- influence on the absorption of microwaves by quartz molding sands also has their chemical composition, for this example, the quantity of iron compounds;
- further research should give an answer to question: whether the grain size and type of their surface have a decisive effect on the effectiveness of microwave heating;
- presented in the paper mobile measuring device - microwave slot line - can be used to carry out a thorough research on the ways of intensification microwave hardening process for the molding sands prepared of quartz matrixes and selected organic and inorganic binders.

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