Journal of Casting & Materials Engineering Vol. 1 No. 4 (2017) 80–84
http://dx.doi.org/10.7494/jcme.2017.1.4.80

Determination of Binder Content in Traditional Sandmixes by Microwave Method

Daniel Nowak[a]*

[a] Wrocław University of Science and Technology, Department of Foundry Engineering, Plastics and Automation, Łukasiewicza 5, 50-371 Wroclaw, Poland
e-mail: daniel.nowak@pwr.edu.pl

Received: 25 September 2017/Accepted: 13 December 2017/

Abstract

This paper presents preliminary research on the possibility of determining the binder content in traditional sandmixes by the microwave method. The research included examinations of three kinds of bentonite. The presented measurements were carried-out with the use of a special stand – the so-called slot line. The concentration of the binder in molding sand was determined on the grounds of measurements of a parameter; i.e., absorbed power or output power of the electromagnetic wave. One of the main advantages of the suggested new method is the short time of the measurement.

Keywords:

molding sand, binder, microwaves

1. INTRODUCTION

From among traditional molding sands, synthetic sandmixes are most-commonly used in foundry practice. This initially results from the possibility of controlling the composition and, thus, the technological properties of these sandmixes. The main components of synthetic molding sand are the sand base and a binder. The sand base is most often composed of high-silica sands and less frequently of other sands (e.g., zircon, chromite, or magnesite sands). From among the binders used in foundry practice, the most-important are bentonites (with respect to their cementing power) [1, 2].

The technological properties of a molding sand are mostly decided by its type and composition. In the case of a specific kind of molding sand, its technological properties are decided by the quantity and quality of the binder (bentonite) and by its moisture content. Knowing the binder content (especially of an active one and, in the case of reclaiming, a circulating sandmix) is important information about the technological properties of such a sandmix.

Therefore, there is a necessity to determine the binder content in molding sands as precisely as possible and, consequently, in a possibly short time. The currently used measuring methods are both time- and labor-consuming.

An analysis of the preliminary results of laboratory examinations carried out using the microwave slot line at the Department of Foundry Engineering and Automation at Wroclaw University of Technology showed that it is possible to develop a new method of quantitative identification of a binder in traditional molding sand using an electromagnetic field [3, 4].

Microwaves are extensively used in such fields as telecommunication, agriculture, automotive, the building industry, meteorology, or chemistry. In foundry engineering, works on improving the effectiveness of removing moisture from molding and core materials or their hardening are continuously being developed. The emphasis put on the speed and effectiveness of dehydration processes resulted in an increasing interest in and extending the possibilities offered by the microwave-heating process. Thanks to its specificity, this way of using microwaves in the processes of drying and/or hardening molding and core sands can constitute a modern, economical segment in the mechanization, automation, and modernization of casting houses. In foundry practice, the application of electromagnetic waves has become more and more common, which presents an alternative to some extent for the energy-consuming methods utilizing traditional heating [5–8].

2. TEST STAND

The phenomenon of a standing wave occurring in a waveguide (resulting from the superposition of the wave reflected from the given medium and the wave incident on that medium) is often used in microwave metrology. With its use, it is possible to determine the standing wave ratio (SWR) that plays a very important role in the heating processes as well as absorption attenuation. Measurements were taken using microwave slot lines [9–12]. In the SWR examinations of selected foundry materials, a test stand consisting of an electromagnetic wave source, rectangular waveguide with movable probe, and SWR meter was applied.

The waveguides were prepared in a way that enabled us to introduce a measuring probe inside through a specially made slot. The movable probe makes it possible to measure the distribution of electromagnetic field intensity inside the waveguide. On the grounds of this distribution, a relationship between the wave reflection coefficient and the load impedance (of the substrate) can be determined.

Figure 1 shows a view of the test stand. As the source of electromagnetic wave applied was a device made by MARCONI INSTRUMENTS equipped with a frequency synthesizer. The device generates a constant-power signal of 3.98 mW during the whole measurement cycle.

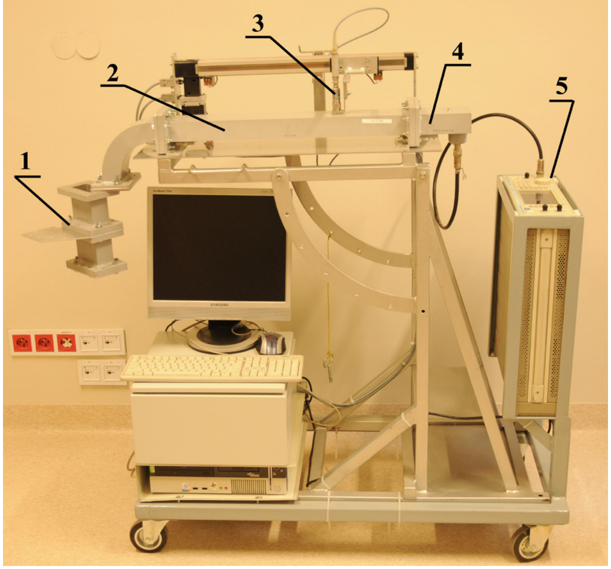

Fig. 1. View of test stand: 1 – load chamber with exchangeable substrates; 2 – measuring waveguide line; 3 – probe with detector; 4 – transition of waveguide to concentric system in WR340 standard; 5 – microwave generator

The value of the measured standing wave ratio was read on the meter. Before starting the examinations, wavelength λ_f in the waveguide for measurement frequency 2.45 GHz was calculated using Equation (1), in that λ_0 is the wavelength in a vacuum [9–11]:

$$\lambda_f = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_{gr}}\right)^2}} \quad (1)$$

Wavelength λ_{gr} for the limit frequency (equal to 188 m) was calculated on the grounds of the dimensions of the waveguide and for the accepted kind of field TE10. The wavelength in waveguide λ_f = 174 mm was determined from Equation (1). The positions of taking measurements of the minimum and maximum signal values were repeated in the waveguide every half wavelength; i.e., every 87 mm. In addition, reading the positions of at least one minimum and one maximum requires that the condition of minimum waveguide length $L >> 0{,}5\ \lambda_f$ is met [12].

3. MEASUREMENT OF MICROWAVE ABSORPTION

The examinations were aimed at precisely determining which part of input microwave power P_{in} is absorbed by the examined material. In the considered case, knowing the selected components of this parameter enables us to determine the binder content in the molding sand.

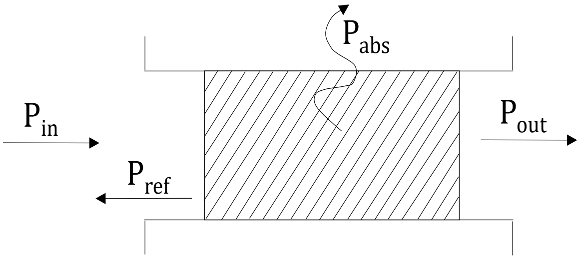

Fig. 2. Power balance of microwaves affecting sample

The power balance of the microwaves acting on the examined sample (shown in Figure 2) is as follows:

$$P_{in} = P_{ref} + P_{abs} + P_{out} \quad (2)$$

from that:

$$P_{ref} = 10^{\left(\frac{RL}{10}\right)} \cdot 100\% \quad (3)$$

$$P_{abs} = \left(1 - \left(10^{\left(\frac{IL}{10}\right)} + 10^{\left(\frac{RL}{10}\right)}\right)\right) \cdot 100\% \quad (4)$$

$$P_{out} = 10^{\left(\frac{IL}{10}\right)} \cdot 100\% \quad (5)$$

where:

P_{in} – input power,
P_{ref} – reflected power,
P_{abs} – absorbed power,
P_{out} – output power,
RL – reflection loss,
IL – insertion loss.

The parameter directly related to the attenuation resulting from absorbing power in the examined material is absorption attenuation A_a [9].

$$A_a := \frac{P_{out}}{\left(P_{in} - P_{ref}\right)}, A_a := 10 \cdot log\left[\frac{1-\left(\left|s_{11}\right|\right)^2}{\left(\left|s_{21}\right|\right)^2}\right] \quad (6)$$

where s_{11}, s_{21} – elements of the scattering matrix.

In order to determine scattering parameters s_{11} and s_{21}, it is necessary to measure the reflection coefficient for the examined sample with an adjusted load and with a shorting at the end of the slot line.

The input reflection coefficient for a symmetrical two-port loaded by impedance *ZL* is described by the following relationship:

$$\Gamma_{in} = s_{11} + \frac{s_{21}^2 \cdot \Gamma_L}{1 - s_{11} \cdot \Gamma_L} \tag{7}$$

Parameter s_{11} is determined directly from the measurements of the reflection coefficient for the examined sample with adjusted load, for that $\Gamma_L = 0$.

Therefore:

$$\Gamma_{in} = s_{11} \tag{8}$$

is a complex quantity that can be written in the following form:

$$\Gamma_{in} = \left|\Gamma_{in}\right| \cdot e^{i\theta_{in}} \tag{9}$$

where:

$$\Theta_{in} = \pi + \frac{4\pi}{\lambda} \cdot dL \tag{10}$$

$$\left|\Gamma_{in}\right| = \frac{SWR - 1}{SWR + 1} \tag{11}$$

and

$$SWR = \frac{U_{\max}}{U_{\min}} \tag{12}$$

where:

$U_{\max}$ – maximum voltage,
$U_{\min}$ – minimum voltage of standing wave,
dL – displacement of minimum of standing wave,
λ – wavelength.

Quantities $U_{\max}$, $U_{\min}$, and dL are determined during the measurements on the test stand (see Fig. 1). For the examined sample and the line shortened at the end ($\Gamma_L = -1$), the following expression for parameter s_{21} is obtained from Formula (7):

$$s_{21} = \sqrt{\left(s_{11} - \Gamma_{in2}\right)\left(1 + s_{11}\right)} \tag{13}$$

where Γ_2 is the measured reflection coefficient and s_1 is determined from Formula (5).

$$\Gamma_{in2} = \frac{SWR_2 - 1}{SWR_2 + 1} \tag{14}$$

$$SWR_2 = \frac{U_{\max}}{U_{\min}} \tag{15}$$

Therefore, to determine absorption attenuation A_a, it is necessary to obtain measurements of the maximum and minimum voltages of the standing wave (see Formulas (12) and (13)), wavelength, and wave displacement (see Formula (10)) for the sample with the adjusted load and with the shortened slot line.

4. PREPARATION OF TEST SAMPLES

The test samples were introduced to the constant volume chamber fitted at the end of the waveguide. The chamber was made of a material with a very low attenuation coefficient of microwaves, guaranteeing that they could be transmitted through the chamber walls and penetrate the molding sand present inside. The sandmixes to be examined had a constant fixed humidity and ambient temperature. The examined samples were composed of 0.5% water, 5–10% bentonite, and silica sand in proportion of the bentonite content. The samples were preliminarily compacted with a laboratory rammer type LU to ensure a regular compaction degree. Next, the compacted samples were dried.

5. RESULTS

Before starting the examinations, preliminary measurements were taken that were aimed at determining the correlations between the bentonite content and insertion losses (*IL*) as well as between the bentonite content and reflection losses (*RL*) of microwave energy. The examinations consisted of determining the *IL* and *RL* values for the dried molding sand with various contents of the Specjal, Bentomak, and Geco bentonites are presented in Table 1 and illustrated graphically in Figures 3 and 4.

Table 1
Results of insertion losses and reflection losses for three types of bentonite

Bentonite	*IL*, mV	*RL*, mV
Specjal	0.60	0.27
	0.58	0.27
	0.52	0.29
	0.45	0.30
	0.42	0.31
	0.41	0.28
Geco	0.69	0.23
	0.66	0.25
	0.63	0.21
	0.58	0.24
	0.52	0.25
	0.50	0.24
Bentomak	0.75	0.22
	0.73	0.22
	0.71	0.22
	0.61	0.27
	0.54	0.29
	0.50	0.30

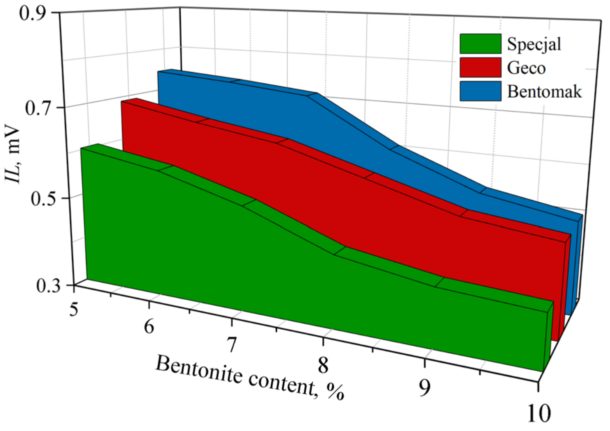

Fig. 3. Effect of bentonite content in traditional molding sand on insertion losses (*IL*)

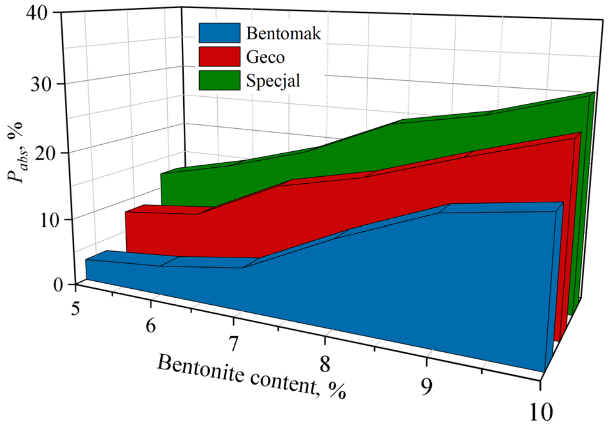

Fig. 5. Effect of bentonite content in traditional molding sand on absorbed power P_{abs}

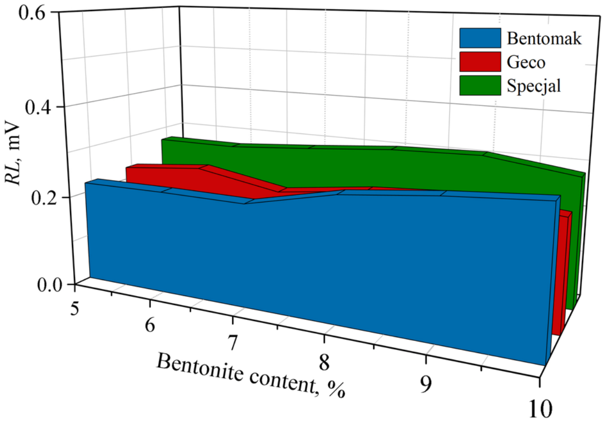

Fig. 4. Effect of bentonite content in traditional molding sand on reflection losses (*RL*)

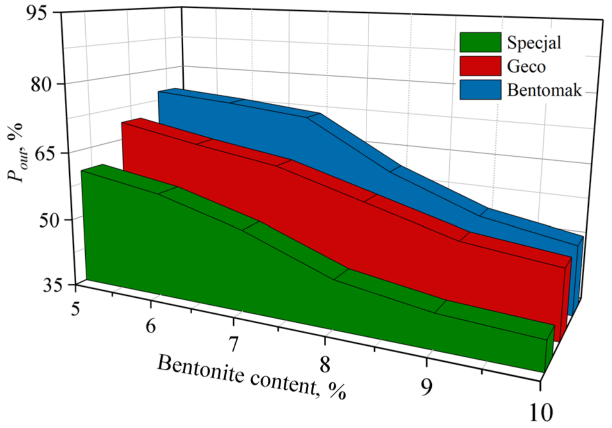

Fig. 6. Effect of bentonite content in traditional molding sand on output power P_{out}

Next, the selected components of microwave input power P_{in} were determined on the grounds of the Formulas (4) and (5). The results of the absorbed and output power parameters are illustrated graphically in Figures 5 and 6 and presented in Table 2.

The analysis of the impact of bentonites content in the classical molding sand on absorbed power P_{abs} shows a linear relationship for all three types of bentonite in the entire research field. It can be observed that, when the bentonite content of Bentomak is doubled, there is a six-fold increase in the absorbed power, whereas for the Special bentonite, the increase is only two-and-a-half times higher. The results of the Specjal bentonite tests also show an increased capacity for absorbing microwave energy. Investigations of the impact of the bentonite content on the P_{out} output power also show a linear relationship, but with a two-fold increase in the bentonite content in the molding sand for the three bentonites selected for the research, there is a one-and-a-half-fold decrease in the output power. Molding sand based on the Specjal bentonite has the smallest initial power. Summarizing the results of the absorbed and initial power tests, it can be concluded that it is possible to determine the binder content in classic molding sands using the microwave method.

Table 2
Results of absorbed and initial power for three types of bentonite

Bentonite	**P_{abs}, %**	**P_{out}, %**
Specjal	12.44	60.39
	15.29	57.54
	18.94	52.48
	24.40	45.39
	26.80	42.36
	30.47	41.20
Geco	8.17	69.02
	9.57	65.76
	15.57	62.95
	18.46	57.54
	22.64	52.11
	26.45	49.88
Bentomak	3.17	74.64
	4.33	73.28
	6.266	71.40
	12.43	60.95
	17.64	53.57
	19.61	50.11

6. CONCLUSIONS

The following conclusions can be drawn from the presented research:

- The binder content in molding sand can be measured using microwave radiation by a new measurement method consisting of determining one of two parameters; (i.e., ab--sorbed power or output power) on a slot-line test stand.
- An advantage of the newly developed method of determining the binder content in molding sand is the short measuring time resulting from the specificity of microwave radiation.
- The presented preliminary examination results with use of a microwave lot line (consisting of measuring absorbed power or output power) make an introduction to developing a method of determining the quantity of active binder in circulating sandmixes, identifying type of the binder, and (in a further phase) determining the humidity of molding sand.

In future research work, it is planned to determine the effect of variable temperatures on molding sands reclaimed to a fixed value of R_c [13].

REFERENCES

[1] Lewandowski J.L. (1998). *Tworzywa na formy odlewnicze.* Kraków: Akapit.

[2] Żymankowska-Kumon S., Holtzer M., Olejnik E. & Bobrowski A. (2012). Influence of the changes of the structure of foundry bentonites on their binding properties. *Materials Science (Medžiagotyra)*, 18(1), 57–61.

[3] Pigiel M., Granat K., Nowak D. & Florczak W. (2006). Utilisation of microwave energy in foundry processes. *Archives of Foundry Engineering,* 6(21), 443–452.

[4] Granat K., Nowak D., Pigiel M., Stachowicz M. & Wikiera R. (2008). Measurement of standing wave ratio for efficiency assessment of microwave absorption by moulding materials. *Archives of Foundry Engineering,* 8(spec. iss. 3), 31–34.

[5] Granat K., Stachowicz M. & Nowak D. (2010). Application of innovative method of microwave hardening in manufacturing processes of cast steel castings for machine-building industry. *Archives of Mechanical Technology and Automation,* 30, 19–27.

[6] Wang J., Fan Z., Zan X. & Pan D. (2009). Properties of sodium silicate bonded sand hardened by microwave heating. *China Foundry,* 6(3), 191–196.

[7] Che G., Liu X. & Li J. (2006). Effects of water-glass tensile strength and collapsibility of water-glass cured by microwave heating. *China Foundry Machinery and Technology,* 6, 18–19.

[8] Li H. & Xie W. (2002). Study on the materials used for making models of sodium silicate bonded sand core heating by microwave energy. *Journal of Chongqing University (Natural Science Edition)*, 25(1), 116–119.

[9] Galwas B. (1985). *Miernictwo mikrofalowe.* Warszawa: Wydawnictwo Komunikacji i Łączności.

[10] Litwin R. & Suski M. (1972). *Technika mikrofalowa.* Warszawa: Wydawnictwa Naukowo-Techniczne.

[11] Garczyński W. (2003). *Podstawy techniki mikrofalowej.* Wrocław: Oficyna Wydawnicza Politechniki Wrocławskiej.

[12] Thomas H.E. (1978). *Techniki i urządzenia mikrofalowe.* Warszawa: Wydawnictwa Naukowo-Techniczne.

[13] Holtzer M., Bobrowski A. & Żymankowska-Kumon S. (2011). Temperature influence on structural changes of foundry bentonites. *Journal of Molecular Structure.* 1004(1), 102–108. doi: 10.1016/j.molstruc.2011.07.040