www.czasopisma.pan.pl PAN www.journals.pan.pl

ARCHIVES of FOUNDRY ENGINEERING

DOI: 10.2478/v10266-012-0086-x

ISSN (2299-2944)
Volume 12
Issue 3/2012

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

83 – 86

Application of Microwaves for Binder Content Assessment in Moulding Sands

D. Nowak
Foundry and Automation Team, Wroclaw University of Technology,
ul. Łukasiewicza 5, 50-371 Wrocław, Poland
Contact: daniel.nowak@pwr.wroc.pl

Received 16.04.2012; accepted in revised form 02.07.2012

Abstract

The paper presents results of preliminary examinations on possibility of determining binder content in traditional moulding sands with the microwave method. The presented measurements were carried-out using a special stand, the so-called slot line. Binder content in the sandmix was determined by measurements of absorption damping A_d and insertion losses I_L of electromagnetic wave. One of main advantages of the suggested new method of binder content measurement is short measuring time.

Key words: Innovative foundry technologies, Moulding sand, Binder, Microwaves

1. Introduction

In foundry practice, the most commonly applied among traditional moulding sands are those with synthetic binders. This is first of all related to the possibility of controlling composition and thus also technological properties of these sandmixes. The main components of a synthetic sandmix are sand base and a binder. The sand base of synthetic sandmixes most often consists of high-silica sands and less often of other sands, e.g. zircon, chromite or magnesite sand. From among the binders used in foundry practice, the most important with respect to binding capacity are bentonites [1].

Technological properties of a sandmix are first of all decided by its kind and composition. In the case of a specific sandmix grade, its technological properties are decided by quantity and quality of the binder (bentonite) and humidity. Knowledge of the binder content, especially of an active one and especially in the case of rebonding the circulating sandmix, is an important information about technological properties of this sandmix.

Analysis of the results of preliminary laboratory examinations carried-out using a microwave slot line in the Foundry and Automation Team of Wroclaw University of Technology proved that it is possible to develop a new method of qualitative identification of a binder in the traditional moulding sand [3-5].

2. Test stand

The phenomenon of a standing wave present in a wave-guide, resulting from superposition of the wave reflected from the given medium and the wave incident on this medium, is often used in microwave metrology. With its aid, it is possible to determine the standing-wave ratio (SWR) that plays an important role in heating processes, and the absorption loss. Microwave slot lines [2,6-8] are used in these measurements. Investigation of SWR of selected moulding materials was carried-out using a test stand composed of an electromagnetic wave source, rectangular wave-guide with movable probes and a SWR meter.

The wave-guide was so made that a measuring probe connected to the detector could be introduced inside through a specially made slot. The movable probe permits measuring distribution of the electromagnetic field inside the waveguide. On the ground of this distribution, the wave reflection coefficient can be determined as a function of the load impedance (of substrate).

Figure 1 shows layout of the test stand. A device made by Marconic Company, equipped with a frequency synthetizer, was used as the electromagnetic wave source. The signal generated by this device has constant power of 3.98 mW during the entire measuring cycle.

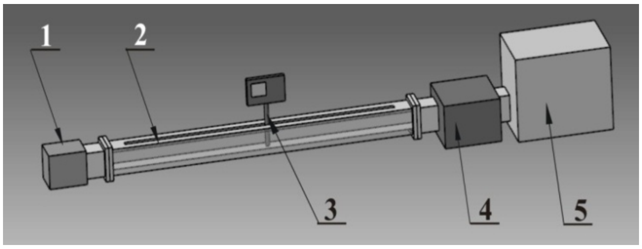

Fig. 1. Layout of the test stand: 1 - load chamber with exchangeable substrates, 2 - wave-guide measuring line, 3 - probe with detector, 4 - transition of the wave-guide to the coaxial system in the WR340 standard, 5 - microwave generator

Modulus of the measured standing-wave ratio was read-off on the meter. Before the measurement, calculated was wavelength λ_f in the wave-guide for the measurement frequency 2.45 GHz. To this end, the equation (1) was applied, in that $\boldsymbol{\lambda_o}$ is wavelength in vacuum [6-8]:

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

The wavelength $\boldsymbol{\lambda_{gr}}$ of 188 mm for the limit frequency was calculated on the ground of the wave-guide dimensions and the accepted kind of field TE_{10}. The wavelength $\boldsymbol{\lambda_f}$ in the wave-guide was determined from the equation (1) as 174 mm. Places of the measured signal minimum and maximum values are repeated every 0.5 wavelength in the wave-guide, i.e. exactly every 87 mm. In addition, in order to allow reading-off the position of at least one minimum and one maximum, the condition of minimum wave-guide length should be met: L >> 0.5 $\boldsymbol{\lambda_f}$ [1].

3. Measurement of microwave absorption

The performed research was aimed at determining precisely the part of microwave power input P_{in} that is absorbed by the examined material. Knowledge of this parameter permits, in the considered case, determining quantity of a binder in the sandmix.

Figure 2 shows balance of microwave power affecting the examined specimen.

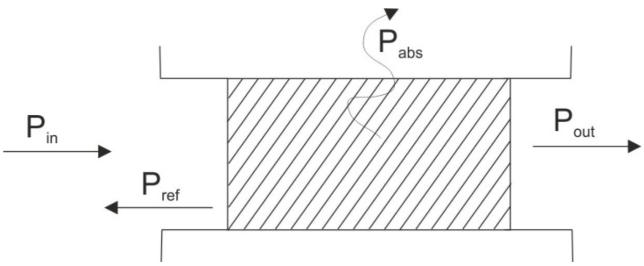

Fig. 2. Balance of microwave power affecting the specimen

The respective equation is as follows:

$$P_{in} = P_{ref} + P_{abs} + P_{out} \tag{2}$$

where:
- P_{in} = power input,
- P_{ref} = reflected power,
- P_{abs} = absorbed power,
- P_{out}= power output.

The parameter directly related to the losses resulting from power absorption in the examined material is absorption damping $\mathbf{A_d}$ [6]:

$$Ad = \frac{P_{out}}{(P_{in} - P_{odb})} \qquad Ad = 10 \cdot log\left[\frac{1-(|s_{11}|)^2}{(s_{21})^2}\right] \tag{3}$$

where:
$\mathbf{s_{11}, s_{21}}$ – coefficients of the scattering matrix.

To determine the scattering parameters $\boldsymbol{s_{11}}$ and $\boldsymbol{s_{21}}$ properly, it is necessary to measure the reflection coefficient for the examined specimen with matched load and with shorting at the end of the slot line.

The input reflection coefficient for a symmetrical two-port loaded by impedance $\boldsymbol{Z_L}$ is described by the relationship:

$$\Gamma_{in} = s_{11} + \frac{s_{21}^2 \cdot \Gamma_L}{1 - s_{11} \cdot \Gamma_L} \tag{4}$$

The parameter $\boldsymbol{s_{11}}$ id determined directly from a measurement of the reflection coefficient for the examined specimen at matched load, for that $\boldsymbol{\Gamma_L} = 0$,

and thus $\Gamma_{in} = s_{11}$ (5)

where Γ_{in} is a complex quantity that can be written as:

$$\Gamma_{in} = |\Gamma_{in}| \cdot e^{i\Theta_{in}} \tag{6}$$

where:

$$\Theta_{in} = \pi + \frac{4\pi}{\lambda} \cdot dL \tag{7}$$

$$|\Gamma_{in}| = \frac{wsf - 1}{wsf + 1} \tag{8}$$

and

$$wfs = \frac{U_{max}}{U_{min}} \tag{9}$$

where: $\boldsymbol{U_{max}}$ – maximum voltage, $\boldsymbol{U_{min}}$ – standing wave minimum voltage, dL – standing wave minimum displacement, $\boldsymbol{\lambda}$ – wavelength.

The quantities $\boldsymbol{U_{max}}$, $\boldsymbol{U_{min}}$ and $\boldsymbol{dL}$ are determined during measurements on the test stand, see Fig. 1.

For the examined specimen and the line shorted at the end (Γ_L=-1), the following expression for the parameter s_{21} is obtained from (4):

$$s_{21} = \sqrt{(s_{11} - \Gamma_{in2})(1 + s_{11})} \quad (10)$$

where Γ_{in2} is the measured reflection coefficient and s_{11} is determined from (5):

$$|\Gamma_{in2}| = \frac{wsf_2 - 1}{wsf_2 + 1} \quad (11)$$

$$wfs_2 = \frac{U_{max2}}{U_{min2}} \quad (12)$$

Therefore, determining absorption damping A_d requires obtaining measurements of maximum and minimum standing wave voltage (see formulae 9 and 12), wavelength and wave displacement (see formula 7) for the specimen with matched load and with shorted slot line.

3.1 Preparation of test specimens

The examined specimens were introduced to the constant-volume chamber installed at the end of the wave-guide. The chamber was made of a material with very low microwave damping coefficient, so that the wave freely penetrated through the chamber walls and then deep into the moulding sand present inside. The specimens were preliminarily compacted with a laboratory rammer LU-type to guarantee a constant thickening degree of the sandmix.

4. Determination of absorption damping parameters and insertion losses of moulding sands

Before the main research, preliminary measurements were taken to determine correlation between bentonite content, insertion losses I_L and absorption damping A_d of microwave energy. These measurements consisted in determining the I_L and A_d values for dried moulding sand with various content of bentonites Specjal and Geco.

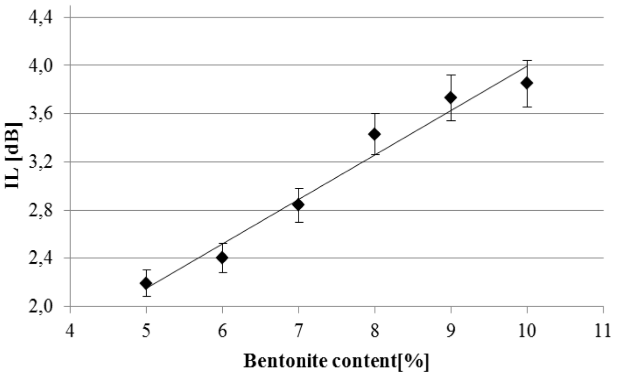

Fig. 3. Effect of bentonite Specjal content in traditional moulding sand on insertion losses I_L

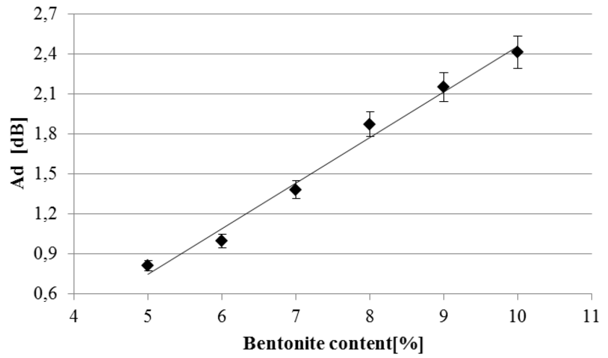

Fig. 4. Effect of bentonite Specjal content in traditional moulding sand on absorption damping A_d

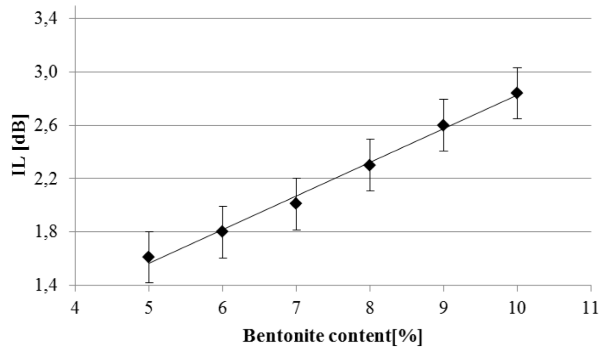

Fig. 5. Effect of bentonite Geco content in traditional moulding sand on insertion losses I_L

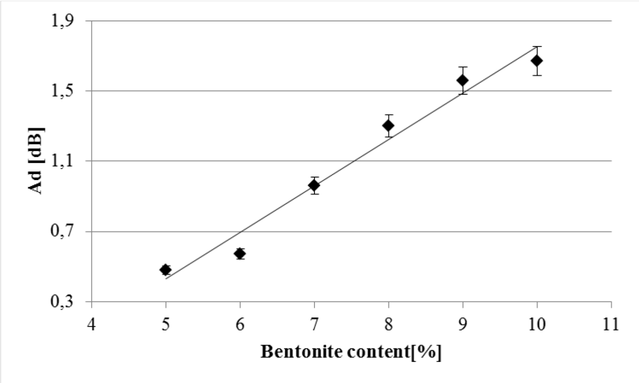

Fig. 6. Effect of bentonite Geco content in traditional moulding sand on absorption damping A_d

Figures 3 to 6 show dependences of insertion losses I_L and absorption damping A_d on contents of bentonite Specjal and bentonite Geco in a traditional moulding sand.

Analysis of the preliminary results presented in Figs. 3 to 6 indicates that the changes of insertion losses I_L and absorption damping A_d are linear. So, it can be found that it is sufficient to measure a single parameter only, namely insertion losses I_L or absorption damping A_d, to be able to determine concentration of bentonite contained in a sandmix.

5. Final conclusions

Analysis of the obtained examination results leads to the following conclusions:

- It is possible to measure binder content in a moulding sand using a new microwave-based measurement method consisting in determining, be means of a slot line, values of one of the two parameters: insertion losses I_L or absorption damping A_d.
- An advantage of the new method of measuring binder content in moulding sand is short measurement time related to specificity of microwave radiation.
- The presented results of preliminary measurements with use of a microwave slot line, consisting in measuring parameters of insertion losses I_L or absorption damping A_d, make an introduction to developing a method of measuring active binder content in circulating sandmixes, identifying binder grade and, at a further stage, determining humidity of a moulding sand.

References

[1] Lewandowski, J.L. (1997). *Materials for casting moulds*, Akapit, Cracow, 1997 (in Polish).

[2] Thomas, H.E. (1978). *Microwave technologies and microwave equipment*, Handbook, WNT, Warsaw (in Polish).

[3] Pigiel, M., Granat, K., Nowak, D. & Florczak W. (2006). Utilization of microwave energy in foundry processes, *Archives of Foundry Engineering*, No. 21, Vol. 6 (in Polish).

[4] Granat, K., Nowak, D., Pigiel, M., Stachowicz, M. & Wikiera R. (2008). Measurement of standing-wave ratio for effectiveness assessment of microwave absorption by moulding materials, *Archives of Foundry Engineering*, Vol. 8, Special Issue 3/2008 (in Polish).

[5] Granat, K., Pigiel, M., Nowak, D. & Stachowicz M. (2009). Determination of microwave energy reflection coefficient for moulding materials, *Rada Hutnická*, No. 2, Vol. LII (in Polish).

[6] Galwas, B. (1985). *Microwave metrology*, Wydawnictwa Komunikacji i Łączności, Warsaw (in Polish).

[7] Litwin, R. & Suski, M. (1972). *Microwave technology*, WNT, Warsaw (in Polish).

[8] Garczyński, W. (2003). *Basics of microwave technology*, Editorial Office of Wroclaw University of Technology, Wrocław (in Polish).