

ARCHIVES
of
FOUNDRY ENGINEERING



DOI: 10.2478/v10266-012-0087-9

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

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

87 – 90

Microwave Absorption by Used Moulding and Core Sands

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Received 16.04.2012; accepted in revised form 02.07.2012

Abstract

The paper presents measurement results of standing wave ratio to be used as an efficiency indicator of microwave absorption by used moulding and core sands chosen for the microwave utilization process. The absorption measurements were made using a prototype stand of microwave slot line. Examined were five used moulding and core sands. It was demonstrated that the microwave absorption measurements can make grounds for actual microwave utilization of moulding and core sands.

Key words: Recycling, Standing wave ratio, Microwaves, Moulding materials

1. Introduction

Microwaves are widely used in such fields like telecommunications, agriculture, automotive, building and chemical industries, as well as in meteorology. Microwave energy can be also used in foundry engineering, e.g. for hardening moulding sands, including those with water-glass [1-5]. In the presented work, absorption efficiency of very low-power microwaves by used sandmixes was assessed by measuring the standing-wave ratio (SWR). The obtained results can be used for selecting proper parameters of actual microwave utilization of foundry wastes [6-8] that consists in heating them up to preset temperatures.

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] 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 a layout of the test stand. As the electromagnetic wave source was used a device made by Marconic Company, equipped with a microwave frequency synthesizer.

Power of the generated signal was 3.98 mW, maintained constant during the entire measuring cycle. Modulus of the measured standing-wave ratio was read-off on the meter. Before the measurement, calculated wavelength λ_f in the wave-guide for the measurement frequency 2.45 GHz. To this end, the equation (1) was applied, in that λ_0 is wavelength in vacuum [6-8]:

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

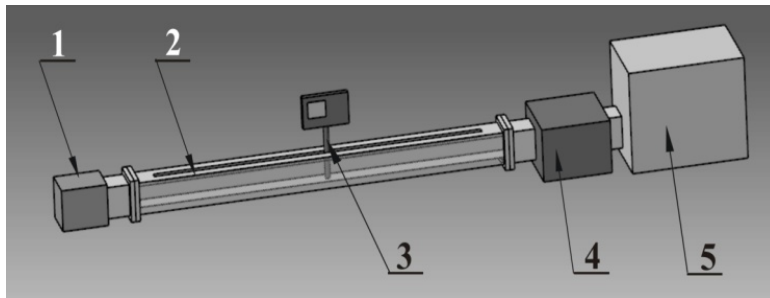


Fig. 1. Layout of the test stand: 1 - load chamber with exchangeable substrates, 2 - wave-guide measuring line, 3 - probe with detector, 4 - transition of the wave-guide to the coaxial system in the WR340 standard, 5 - microwave frequency synthesizer

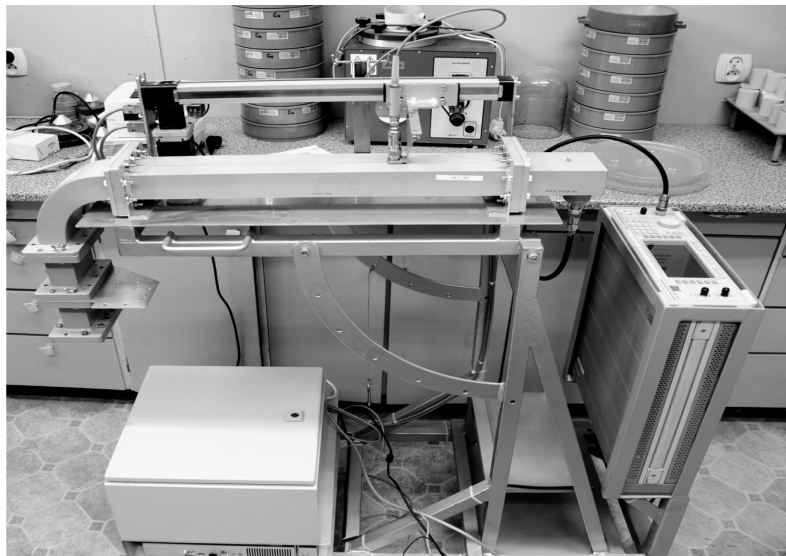


Fig. 2. View of a microwave slot line and the module responsible for power output control of the magnetron

The wavelength λ_{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 λ_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: $L \gg 0.5 \lambda_f$ [1].

3. Measurement of microwave absorption

The performed research was aimed at determining precisely the part of microwave power input P_{wej} 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 3 shows balance of microwave power affecting the examined specimen.

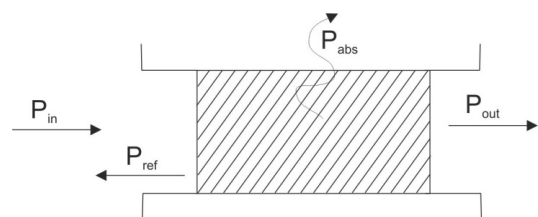


Fig. 3. Balance of microwave power affecting the specimen

The respective equation is as follows:

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

where:

$$\begin{aligned} P_{in} &= \text{power input,} \\ P_{ref} &= \text{reflected power,} \end{aligned}$$

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 A_d [6]:

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

where:

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

To determine the scattering parameters s_{11} and 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 Z_L is described by the relationship:

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

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

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

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

$$\Gamma_{in} = |\Gamma_{in}| \cdot e^{i\theta_{in}} \quad (6)$$

where:

$$\theta_{in} = \pi + \frac{4\pi}{\lambda} \cdot dL \quad (7)$$

$$\Gamma_{in} = \frac{SWR_1 - 1}{SWR_1 + 1} \quad (8)$$

and

$$SWR_1 = \frac{U_{max1}}{U_{min1}} \quad (9)$$

where: U_{max} – maximum voltage, U_{min} – standing wave minimum voltage, dL – standing wave minimum displacement, λ – wavelength.

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

For the examined specimen and the line shorted at the end $\Gamma_L = -1$, 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):

$$\Gamma_{in2} = \frac{SWR_2 - 1}{SWR_2 + 1} \quad (11)$$

$$SWR_2 = \frac{U_{min2}}{U_{max2}} \quad (12)$$

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 inserted to the constant-volume chamber installed at the end of the waveguide. The chamber was made of a material with very low microwave attenuation coefficient that ensures the wave to go freely through its walls and to penetrate deep inside the moulding sand placed in the chamber. The specimens were preliminarily compacted by a laboratory ram type LU. The following used moulding and core sands were examined:

- sandmix with phenolic resin Fenotec P439, No. 1,
- thermosetting sandmix with phenol-formaldehyde resin type nowolak, No. 2,
- core sand with phenolic resin and protective coating novanol 165, No. 3,
- sandmix with water-glass R-145 hardened with Flour, No. 4,
- sandmix with urea-furfuryl resin Kalahari U404, No. 5.

Table 1. Measurement results of moulding and core sands

	SWR_1	SWR_2	$dL_1 [mm]$	$dL_2 [mm]$	$P_{abs} [\%]$	$P_{ref} [\%]$	$P_{out} [\%]$
Sandmix No. 1	2.59	20.48	9.30	20.03	33.11	19.67	47.20
Sandmix No. 2	1.83	1.00E+07	14.36	12.94	28.47	8.57	62.95
Sandmix No. 3	3.40	1.00E+07	6.94	23.55	14.82	29.71	55.46
Sandmix No. 4	3.31	13.54	6.94	27.19	14.40	28.70	56.88
Sandmix No. 5	3.91	1.00E+07	5.59	32.14	2.76	35.15	67.60

4. Results

Measurement results of moulding and core sands are given in Table 1.

The biggest part of absorbed power of ca. 30 % was found in the case of the sandmixes No. 1 and No. 2. The smallest value of ca. 3 % was obtained for the sandmix No. 5. Therefore, it can be said that the sandmixes No. 1 and No. 2 quite well absorb electromagnetic radiation with frequency 2.45 GHz. The levels of power absorbed by the sandmixes No. 3 and No. 4 at ca. 14 % and by the sandmix No. 5 at ca. 3 % indicate that these sandmixes will require appliances with higher microwave output power to increase dynamics of the heating process. It was found that the sandmixes with the part of absorbed power below 15 % reflect microwaves more intensively, which can affect correct operation of microwave generators. So, it is necessary to furnish the utilization equipment with suitable components neutralising the reflected electromagnetic wave. In order to eliminate risk of damaging the utilization equipment, to increase absorbed power fraction and thus to improve efficiency of the heating process of sandmixes, it is recommended to use special materials intensifying absorption of microwaves.

5. Summary and conclusions

Analysis of microwave absorption by used moulding and core sands destined for utilization indicates that:

- The sandmixes containing synthetic resins: phenolic (No. 1) and phenol-formaldehyde novolak type (No. 2) absorb the biggest part of microwave power.
- The sandmix containing urea-furfural resin (No. 5) absorbs the smallest part of microwave power.
- The sandmixes with the absorbed power level below 30 % are faster heated with microwaves.
- The prototype stand with microwave slot line can be applied for preliminary assessment of suitability of moulding and core sands for microwave utilization.
- The microwave slot line can be also used to assess microwave absorption by other materials, e.g. those intended for intensifying the microwave utilization process of used moulding and core sands.

Acknowledgements

The scientific work was financed from the budgetary means for science in the years 2010 to 2012 as a research project.

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