Measurement of standing wave ratio for evaluation of microwave absorption efficiency by molding materials

K. Granat*, D. Nowak*, M. Pigiel*, M. Stachowiec*, R. Wikiera

*Zakład Odlewictwa i Automatyzacji, Politechnika Wrocławska, ul. Łukasiewicza 5, 50-371 Wrocław, Polska
*Corresponding author. E-mail address: kazimierz.granat@pwr.wroc.pl

Received 08.07.2008; accepted in revised form 29.07.2008

Abstract

The presented work includes results of standing wave measurement for evaluation of microwave absorption efficiency by molding materials. Initial research has been conducted using microwave gap line. It has been demonstrated that foundry quartz sands have minimal microwave absorption capability. The following binders used for research: bentonite "Geco" and bentonite "Specjal", demonstrated the highest absorption of $P_{abs}$ microwave power output of over 60% $P_{in}$. It has also been demonstrated that water content, constituting component of synthetic molding sands, significantly influences change of microwave absorption. We have established that application of this kind of measuring device may allow for precise determination of characteristic features, such as microwave absorption factor $k$, of various foundry materials as well as determination of their suitability in foundry processes, e.g. microwave formation of foundry molds and cores. Microwave gap line may also serve as a device for precise determination of water content as well as other molding sand components and for their identification with the use of characteristic parameters, e.g. reflection factor $|\Gamma|$.

Keywords: Innovative foundry materials and technologies, Standing wave ratio, Microwaves, Molding materials

1. Introduction

Microwaves are broadly applied in such fields as telecommunications, farming, motor industry and construction, meteorology or chemistry. Microwave energy might also be used, among others, in foundry engineering and curing process of molding sands, including water glass molding sands [1-5]. In this work, we applied microwaves, through measurement of standing wave ratio, for evaluation of microwave absorption efficiency by molding materials, for example, in microwave processes of foundry molds and cores' formation. [6-8]

2. Measurement of standing wave ratio and reflection factor

Gap measurement line with a mobile probe slipped through a gap into a waveguide (figure 1) is used for standing wave ratio measurement.

The carriage with probe should be moved slowly along the waveguide, points of the highest as well as the lowest signal determined and the signals measured. The ratio of the highest signal value to the lowest signal value (considering detector characteristics) allows for determination of standing wave ratio.
Module measurement is conducted through measurement of standing wave ratio $swr$, whose value is substituted into the following formula:

$$\left| \Gamma \right| = \frac{swr - 1}{swr + 1}$$  \hspace{1cm} (2)

where:

$$\left| \Gamma \right|^2 = \frac{P_{\text{ref}}}{P_{\text{in}}}$$  \hspace{1cm} (3)

$P_{\text{ref}}$ - reflected power

$P_{\text{in}}$ - incident power

and absorbed power equals difference between incident power and reflected power:

$$P_{\text{abs}} = P_{\text{in}} - P_{\text{ref}}$$  \hspace{1cm} (4)

Thus, it is possible – through measurement of maximal and minimal signals in the gap line - to determine what part of generator power is supplied to load and what part is reflected.

### 3. Measuring position

Microwave gap lines are used in microwave metrology for measurement of final impedance $Z_k$ as well as reflection factor $\Gamma_k$ [9]. Figure 2 presents station for measurement of the above mentioned parameters. Waveguide length is $L \gg 0.5 \lambda$. The waveguide of rectangular cross-section has a gap at one side. This allows for sliding of a probe with detector into the waveguide. The probe serves for dependence measurement of complex voltage values of incident wave $U_{\text{pad}}$ and reflected wave $U_{\text{odb}}$ from load impedance. Movement of this measuring element along the...
waveguide and precise positioning are ensured by special guide with a rule.

Microwave generator with smoothly regulated output power, within 0W up to 1500W range, has been used for measurements. Microwave generator has been additionally equipped with fluid cooling system. Such solution was used in order to ensure the device operation safety at high programmed powers. Also, an additional module, suppressing the reflected wave returning to load, has been installed between the gap line and microwave generator. This is a very important element of the measuring position, since it protects magnetron against damage from reflected wave and allows, thanks to additional detector, for measurement of power $P_{\text{ref}}$, reflected from load.

Load measuring chamber with exchangeable holders, used for placement of the tested mold materials, is located at the end of gap line. Research station also includes two meters connected with detectors and module ensuring smooth control of generator output power.

4. Research results

The microwave device has been calibrated before beginning of measurements of complex voltage values. Calibration of the microwave gap line consisted in determination of minimal and maximal voltages at programmed output power of microwaves of 430W and frequency of 2.45 GHz. Calibration has been conducted at full short circuit of the lines. Total reflection has been achieved in this way, where: $P_{\text{ref}} \approx P_{\text{in}}$. A graph of the conducted calibration has been presented in figure 3. Accuracy of the conducted measurements depends mostly on the quality of measuring devices (detectors), waveguide structure and measuring chamber material as well as on correct readings of $U_{\text{max}}$ and $U_{\text{min}}$. The method of determination of measuring probe location in the waveguide gap also significantly influences accuracy of measurements [10]. Because of certain imperfections of measuring devices, related, among others, to power input of the probe, $U = f(x)$ graph differs from theoretical – sinusoidal course of this function.

Two kinds of quartz sand have been used for research: 0,20/0,16/0,10 fine sand and coarse sand of 0,40/0,32/0,20 main fraction, bentonite „Geco” and bentonite „Specjal”.

Portions of 200 g of the tested substrates have been placed in the measuring chamber. Reading of indications has been conducted immediately after magnetron switching on.

Changes of wave shape inside the waveguide, observed after placing of the tested substrates in the measuring chamber, have been compared with full short circuit state of the microwave gap line (table 1).

It has been observed in case of fine and coarse sand samples that practically entire $P_{\text{in}}$ power of microwaves has been reflected and returned to wave attenuator. The absorbed $P_{\text{abs}}$ power of these materials, for the programmed output of 430W, has been close with regard to value to losses measured in case of full short circuit of the lines.

It has also been found that in case of bentonite „Geco” and bentonite „Specjal”, heating of both binders gave the best results. Power $P_{\text{abs}}$ values were highest among the measured ones for low reflection factors of these molding sands, ranging from $0 < |\Gamma_k| < 1$. This obviously proves very good absorption of microwaves by these substances.

The experiment also determined the influence of water addition – indispensable component of synthetic molding sands. For this reason, 5% by weight of water have been added to fine sand. As we expected, reflection factor $|\Gamma_k|$, in comparison to the one measured for dry substrate, has improved. Thus, it has been revealed that addition of water might be of decisive influence on the properties of material subject to microwave effects.

We observed location changes of complex voltage values of $U_{\text{min}}$ and $U_{\text{max}}$ during all the conducted experiments, also in case of fine and coarse sand, reflecting microwaves very well when dry.

| Measurement | $P_{\text{in}}$ [W] | $P_{\text{ref}}$ [W] | Probe location for the parameter of $U_{\text{min}}$ [cm] | $P_{\text{abs}}$ [W] | $|\Gamma_k|$ | swr |
|-------------|---------------------|---------------------|---------------------------------------------------|---------------------|-----------|-----|
| full short circuit | 430 | $\approx$430 | 32 | 34 | 0.96 | 48.57 |
| fine sand | 430 | 395 | 25.6 | 35.5 | 0.96 | 46.43 |
| coarse sand | 430 | 393 | 25.6 | 37 | 0.96 | 44.46 |
| bentonite „Geco” | 430 | 162 | 23.7 | 268 | 0.61 | 4.18 |
| bentonite „Specjal” | 430 | 167 | 24.1 | 263.5 | 0.62 | 4.29 |
| fine sand with 5% water | 430 | 347 | 26.8 | 83.5 | 0.90 | 18.54 |
5. Final conclusions

It might be said while analyzing the results of microwave absorption by basic components of synthetic molding sands, that:

- quartz molding sands used for experiments, demonstrated minimal ability of microwave absorption,
- bentonite „Geco” and bentonite „Specjal”, binders used for experiments demonstrated the highest absorption of output power $P_{abs}$, amounting to over 60%,
- water content, constituting component of synthetic molding sands, significantly influences change of microwave absorption,
- a change of $P_{abs}$ value in the function of substrate temperature change as well as location change of $U_{min}$ and $U_{max}$ parameters have been observed,
- application of this kind of measuring device may allow for precise determination of characteristic features, such as microwave absorption factor $k$ of various foundry materials and their suitability for microwave formation of foundry molds and cores,
- the microwave gap line may serve as a device for precise determination of water content as well as other components of the sands, and for their identification using characteristic parameters, for example $|\Gamma|$.

References


