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DETERMINATION OF ELECTRICAL PROPERTIES OF MATERIALS USED IN MICROWAVE HEATING OF FOUNDRY MOULDS AND CORES

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The environment-friendly and cost efficient microwave heating of moulding and core sands opens possibilities to use plastics and wood for structures of foundry instrumentation, where transparency to microwaves is the main requirement. Presented are results of a preliminary research on determining possibilities to use selected materials in microwave field. From the viewpoint of specificity of this process, the basic parameter is ability to absorb or transmit microwave radiation. Determined were the following electrical properties: tangent of dielectric loss angle and permittivity of selected materials. The materials were classified according to their transparency to electromagnetic radiation in order to choose the ones suitable for tooling applied in foundry processes.

Key words: electrical properties, permittivity, dielectric loss factor, microwaves, foundry tooling

INTRODUCTION

Application of microwaves for manufacture of high-quality casting moulds and cores brings difficulties related to selecting materials with proper physico-chemical properties and service life for foundry tooling. Nowadays, microwave devices equipped with large working chambers in that created is electromagnetic field with uniform density and frequency f = 2,45 GHz, are available with no problem. However, proper selection of materials for foundry tooling to be used in this process makes a significant barrier at spreading this eco-friendly and economical technology of drying or hardening moulding and core sands [1].

It can be found in the topical literature that a material subject to action of variable electric field with specific intensity and frequency reflects and transmits a part of the emitted energy, and the remaining part is absorbed and converted to heat. The energy absorbed to heat-up the material is directly proportional to the product of intensity and frequency of the field, as well as to the electrical properties (permittivity of free space ε_0, relative permittivity ε_r and dielectric loss factor $tg\delta$) [2]. Knowledge of electrical properties like permittivity and loss factor of the materials commonly used in foundry practice will enable selection and control of parameters of microwave heating of moulding and core sands, in particular in the case of laminar systems that are interfaces between moulding sand and materials of foundry tooling.

In the case of the materials designed for foundry tooling to be used in electromagnetic field, like models, moulding boards, moulding boxes and core boxes (plastics, wood, composites) [3], the main requirement is their transparency for microwaves [4] that guarantees delivering possibly largest amount of energy deep into the heated moulding and core sands, ensuring quick and effective process of their drying and/or hardening. Possible is also an inverse system in that thermal energy must be delivered by foundry tooling to the moulding sand with low radiation absorption in order to initiate crosslinking of the binder. In this case, materials for foundry tooling should be characterised by high absorbing capacity of microwaves, since in such a set the tooling becomes a heating element.

This research is aimed at determining the degree of transparency for microwave radiation on the grounds of electrical properties of plastics designed for use at microwave heating of moulding and core sands with inorganic binders. The presented results were obtained from a part of the works related to determining kinetics of microwave heating of laminar technological systems built of moulding sand containing an inorganic binder and materials of foundry tooling.

MEASUREMENT STAND AND METHODOLOGY OF THE RESEARCH

The stand for measuring electrical properties by the perturbation method, described in details in [5], is composed of a high-frequency signal source, a diode array detector, an oscilloscope and a rectangular resonator 0,086 m x 0,043 m x 0,08 m with the basic field TE_{101}, transmission-connected in the waveguide line and coupled through round holes dia. 0,015 m in the resonator walls. In the presented solution of the perturbation method, a cylindrical sample of a plastic dia. 0,02 m x

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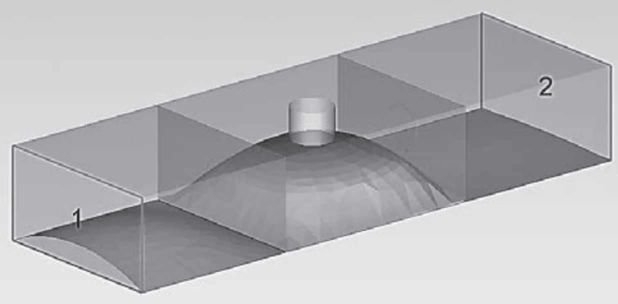

Figure 1 Schematic presentation of rectangular waveguide resonator with a sample of the examined material located in the place with maximum intensity of electrical field; marked are measurement ports (1 and 2)

0,033 m is located in the resonance cavity in the place where intensity of electrical field reaches its maximum, see Figure 1. At that time, electrical capacity of the resonator cavity changes, which results in a change of basic parameters of the waveguide resonance cavity like resonance frequency f_0 and quality of the cavity Q_c.

Parameters of the cavity will be used for determining basic electrical properties of the examined materials and, in the future, multimaterial systems as well.

Macroscopic properties of dielectric materials in variable electrical field are described by complex relative permittivity ε_r, determined by the formula (1) [6]:

$$\varepsilon_r = \varepsilon' - j\varepsilon'' \qquad (1)$$

where: ε' – real component of complex relative permittivity, ε'' – imaginary component of complex relative permittivity.

The real ε' and the imaginary ε'' components of permittivity ε_r can be determined from the relationships (2) and (3) that permit also the dielectric loss factor $tg\delta$ to be determined, see (4) [6].

$$\varepsilon' = \frac{V_c(f_0 - f_s)}{2V_s f_s} + 1 \qquad (2)$$

where: f_0 – resonance frequency of the cavity / GHz, f_s – resonance frequency of the cavity with a sample / GHz, V_c – volume of the resonance cavity / m^3, V_s – volume of the sample / m^3.

$$\varepsilon'' = \frac{V_c}{4V_s}\left(\frac{1}{Q_s} - \frac{1}{Q_c}\right) \qquad (3)$$

where: Q_c – quality of the cavity, Q_s – quality of the cavity with a sample.

$$tg\delta = \frac{\varepsilon''}{\varepsilon'} \qquad (4)$$

Measurements of electric properties of the selected sands were carried-out at 22 °C and at constant air humidity of 60 %. Preliminarily, parameters of empty resonance cavity were determined: resonance frequency f_0 = 2,26 GHz and quality of the cavity Q_c = 753.

EXAMINED MATERIALS

Examined were four grades of plastics designed for foundry tooling, with various physico-chemical properties: polyvinyl chloride PVC, polypropylene PP, polyethylene PE-100 and polyvinylidene difluoride PVDF. This choice resulted from their both physico-chemical and operational properties, see Table 1. Considered were such properties like density, hardness, operating temperature range and mechanical workability. They make criteria of selecting materials for the planned tests of hardening moulding and core sands. Examination results for the selected grades of plastics were compared with electrical properties of polytetrafluoroethylene PTFE [5] that is commonly regarded as a material transparent for microwave radiation [7].

Table 1 **Electrical properties of selected plastics (based on [7, 8])**

Properties	Plastics				
	PTFE	PE-100	PP	PVC	PVDF
Density /kg·m^{-3}	2 180	940	620	1 420	1 780
Shore hardness D	55	65	72	82	78
Working temperature range / °C	-200 ÷ 250	-50 ÷ 80	0 ÷ 100	-20 ÷ 60	-60 ÷ 150
Mechanical workability	Very good	Medium	Good	Very good	Good

EXPERIMENTAL RESULTS

Measurement results of permittivity and loss tangent for the selected materials suggested for manufacture of foundry tooling are shown in Figures 2 and 3. Three samples of each plastic were examined and arithmetic averages of the measurements were compared. The materials were arranged according to declining transparency for microwave radiation (loss factor $tg\delta$).

Analysis of the obtained values of electrical properties of the selected plastics, in particular of loss tangent values determining a part of energy converted to heat as a result of microwave action, delivered information about expected behaviour of foundry tooling in microwave field. Polytetrafluoroethylene shows the lowest loss tangent $tg\delta$ = 0,0003 that decides its transparency for microwave radiation. With regard to its electrical properties, working temperature range and very good workability, this material is suitable for models, mould-

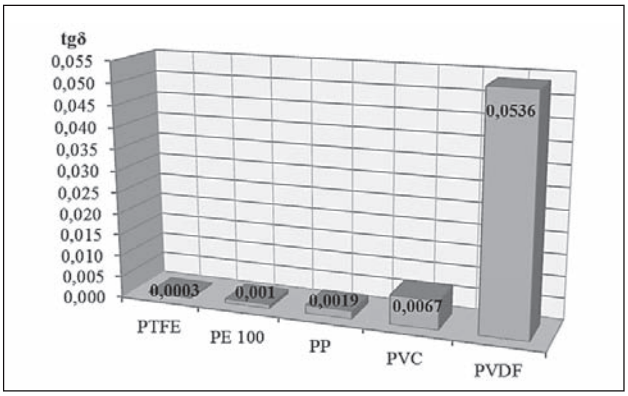

Figure 2 Measured values of dielectric loss factor $tg\delta$ of selected plastics

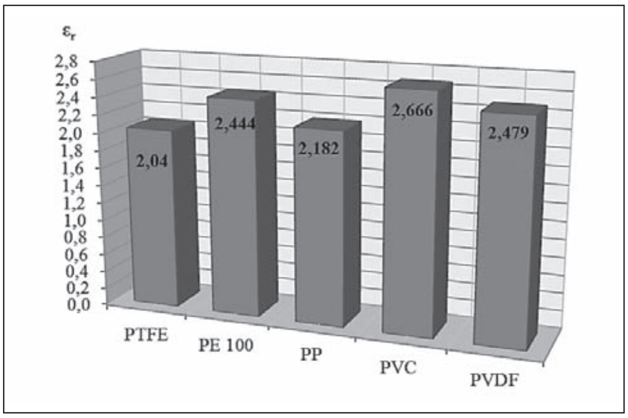

Figure 3 Measured values of permittivity ε_r of selected plastics

ing boards, moulding boxes and core boxes used in microwave field with frequency 2,45 GHz.

Values of loss tangent for polyethylene and polypropylene, respectively 0,0010 and 0,0019, permit them to be classified to the group of the materials transparent for microwave radiation with frequency 2,45 GHz.

Polyethylene shows higher permittivity than polytetrafluoroethylene and polypropylene, which can result in its higher ability to reflect radiation from surfaces of foundry tooling. Polyvinyl chloride that is characterised by permittivity value of 2,666 and loss tangent of 0,0067 applied in foundry tooling shows ability to absorb and to reflect microwave radiation.

The largest part of microwave energy is absorbed by the samples made of polyvinylidene difluoride for that loss factor is 0,0536. Considering its other usable properties, it can be said that this material, in spite of relatively low transparency for microwave with frequency 2,45 GHz, can find application for heating moulding and core sands.

CONCLUSION

The presented measurements of electrical properties of plastics designed for foundry tooling to be used at microwave heating of moulding sands permit the following conclusions to be drawn:

- Foundry tooling made of polytetrafluoroethylene used in microwave field makes possible obtaining high effectiveness of heating moulding sands.
- Foundry tooling elements made of polypropylene guarantee relatively high effectiveness and efficiency of transferring microwave energy deep inside the heated moulding and core sands.
- Using foundry tooling of polyethylene and polyvinyl chloride in microwave field results in relatively lower effectiveness of heating moulding and core sands than in the case of transparent polytetrafluoroethylene.
- Polyvinylidene difluoride can be used for building models, moulding boards, moulding boxes and core boxes in the case when moulding sand with very low water content and low lossiness requires thermal energy to initiate the process of crosslinking / hardening.
- The future research works should be extended with determining behaviour of plastics combined with moulding and core sands in the process of microwave heating.

List of physical characteristic and factors:

Symbol	Name/ Unit	SI-unit
f	Frequency/ GHz	$10^9 \cdot s^{-1}$
f_0	Resonance frequency of the cavity / GHz	$10^9 \cdot s^{-1}$
f_s	Resonance frequency of the cavity with a sample / GHz	$10^9 \cdot s^{-1}$
ε_0	Permittivity of free space/ dimensionless	
ε_r	Permittivity/ dimensionless	
ε'	Real component of complex relative permittivity/ dimensionless	
ε''	Imaginary component of complex relative permittivity/ dimensionless	
$tg\delta$	Dielectric loss factor/ dimensionless	
Q_c	quality of the cavity/ dimensionless	
Q_s	quality of the cavity with a sample/ dimensionless	
V_c	volume of the resonance cavity/ m^3	m^3
V_s	volume of the sample/ m^3	
	Density/ $kg \cdot m^{-3}$	$kg \cdot m^{-3}$
	Shore hardness D/ dimensionless	
	Temperature/ °C	K

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Note: The responsible translator for English language: "INTER-TK" Translation Office, Wrocław, Poland