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

B. Opyd, K. Granat, D. Nowak

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 \( f = 2.45 \text{ GHz} \), 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 \( \varepsilon_0 \), relative permittivity \( \varepsilon_r \) and dielectric loss factor \( \tan \delta \)) [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.

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 \( \text{TE}_{101} \) 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...
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 \( \varepsilon_r \), determined by the formula (1) [6]:

\[
\varepsilon_r = \varepsilon' - j\varepsilon''
\]

where: \( \varepsilon' \) – real component of complex relative permittivity, \( \varepsilon'' \) – imaginary component of complex relative permittivity.

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

\[
\varepsilon' = \frac{V_c(f_0 - f_s)}{2V_f f_s} + 1 \quad (2)
\]

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 / m³, \( V_f \) – volume of the sample / m³.

\[
\varepsilon'' = \frac{V_s}{4V_c} \left( \frac{1}{Q_c} - \frac{1}{Q_s} \right) \quad (3)
\]

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

\[
\tan \delta = \frac{\varepsilon''}{\varepsilon'} \quad (4)
\]

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])

<table>
<thead>
<tr>
<th>Properties</th>
<th>PTFE</th>
<th>PE-100</th>
<th>PP</th>
<th>PVC</th>
<th>PVDF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density / kg·m⁻³</td>
<td>2.180</td>
<td>1.940</td>
<td>1.620</td>
<td>1.780</td>
<td></td>
</tr>
<tr>
<td>Shore hardness D</td>
<td>55</td>
<td>65</td>
<td>72</td>
<td>82</td>
<td>78</td>
</tr>
<tr>
<td>Working temperature range / °C</td>
<td>-200 + 250</td>
<td>-50  + 100</td>
<td>0  + 80</td>
<td>-20 + 60</td>
<td>-60 + 150</td>
</tr>
<tr>
<td>Mechanical workability</td>
<td>Very good</td>
<td>Medium</td>
<td>Good</td>
<td>Very good</td>
<td>Good</td>
</tr>
</tbody>
</table>

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 \( \tan \delta \)).

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 \( \tan \delta = 0.0003 \) 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 1](image1)

**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)

![Figure 2](image2)

**Figure 2** Measured values of dielectric loss factor \( \tan \delta \) 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:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name/ Unit</th>
<th>SI-unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>f</td>
<td>Frequency/ GHz</td>
<td>$10^9 \cdot \text{s}^{-1}$</td>
</tr>
<tr>
<td>f₀</td>
<td>Resonance frequency of the cavity / GHz</td>
<td>$10^9 \cdot \text{s}^{-1}$</td>
</tr>
<tr>
<td>fₛ</td>
<td>Resonance frequency of the cavity with a sample / GHz</td>
<td>$10^9 \cdot \text{s}^{-1}$</td>
</tr>
<tr>
<td>ε₀</td>
<td>Permittivity of free space/ dimensionless</td>
<td></td>
</tr>
<tr>
<td>εᵣ</td>
<td>Permittivity/ dimensionless</td>
<td></td>
</tr>
<tr>
<td>ε’</td>
<td>Real component of complex relative permittivity/ dimensionless</td>
<td></td>
</tr>
<tr>
<td>ε”</td>
<td>Imaginary component of complex relative permittivity/ dimensionless</td>
<td></td>
</tr>
<tr>
<td>tgd</td>
<td>Dielectric loss factor/ dimensionless</td>
<td></td>
</tr>
<tr>
<td>Qc</td>
<td>quality of the cavity/ dimensionless</td>
<td></td>
</tr>
<tr>
<td>Qₛ</td>
<td>quality of the cavity with a sample/ dimensionless</td>
<td></td>
</tr>
<tr>
<td>Vc</td>
<td>volume of the resonance cavity/ m³</td>
<td></td>
</tr>
<tr>
<td>Vs</td>
<td>volume of the sample/ m³</td>
<td></td>
</tr>
<tr>
<td>Density/ kg·m⁻³</td>
<td>kg·m⁻³</td>
<td></td>
</tr>
<tr>
<td>Shore hardness D/ dimensionless</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature/ °C</td>
<td>K</td>
<td></td>
</tr>
</tbody>
</table>

REFERENCES


Note: The responsible translator for English language: “INTER-TK” Translation Office, Wroclaw, Poland