ARCHIVES
of
FOUNDRY ENGINEERING

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

ISSN (1897-3310)
Volume 15
Issue 2/2015

65 – 70

14/2

Evaluation of Microwave Heating of Protective Coatings Used in the Lost Foam Technology

B. Opyd *, K. Granat
Wroclaw University of Technology, Department of Foundry Engineering, Plastics and Automation,
Smoluchowskiego 25, 50-372 Wrocław, Poland
*Corresponding author. E-mail address: beata.opyd@pwr.edu.pl

Received 23.02.2015; accepted in revised form 31.03.2015

Abstract

Presented are results of a preliminary research on determining a possibility to use microwave radiation for drying casting protective coatings applied on patterns used in the lost foam technology. Taken were measurements of permittivity ε_r and loss factor tgδ at 2.45 GHz, as well as attempts were made of microwave drying of a protective coating based on aluminium silicates, applied on shapes of foamed polystyrene and rigid polymeric foam. Time and results of microwave drying were compared with the results obtained by drying at 50 °C by the traditional method commonly used for removing water from protective coatings. Analysis of the obtained drying kinetics curves demonstrated that selection of proper operation parameters of microwave equipment permits the drying time to be significantly shortened. Depending on kind of the pattern material, drying process of a protective coating runs in a different way, resulting in obtaining different quality of the dried coating.

Keywords: Innovative foundry technologies, Microwaves, Protective coatings, Lost foam

1. Introduction

Protective coatings, considered from the viewpoint of their influence on a casting alloy as passive ones, are applied on casting moulds and cores and on disposable patterns in order to obtain smooth, defect-free surfaces of castings [1-7]. This is possible when the protective coating meets specific requirements, among others: contains a base with fire resistance higher than temperature of the liquid casting alloy, shows the required surface strength and adherence to the pattern material and does not break during drying or hardening [1].

Protective coatings used in foundry processes can have variable consistence: solid (powder, granulate), doughy (paste) or liquid. However, the most commonly applied are water-based protective coatings for that the drying process, as opposed to the sintered anhydrous (alcohol-based) coatings, is slower but free from emission of harmful and flammable volatile products [1, 3, 4].

In foundry practice, the commonly applied way of removing solvents from protective coatings applied on disposable moulds and cores as well as on foamed polystyrene patterns is the technology of convection drying [1-2]. With regard to necessity of permanently improving the foundry manufacturing processes by reducing production costs, energy saving, shortening of drying time, improving quality of castings and adapting to the requirements of currently valid standards concerning environmental protection, more and more often searched are new methods of drying and/or hardening protection coatings. Nowadays, drying by means of microwave energy becomes more and more popular, since it permits the above-mentioned requirements to be met [8]. However, it should be emphasised that all the favourable effects of microwave drying and/or hardening of liquid materials depend on properly selected process parameters, in particular microwave power and exposure time [8-9]. This results directly from specificity of microwave radiation that heats-up a material in its entire volume. Consequently, various systems built from at least two components, like e.g. patterns of foamed materials covered with protective coatings, can be subject to destruction or deformation resulting from the difference between heating rates of individual materials.

This paper presents the results of preliminary examinations on using microwave radiation for drying protective coatings applied on lost disposable patterns. The preliminary works were aimed at determining parameters and effectiveness evaluation criteria of microwave heating, which will be useful at developing a mathematical model of microwave drying and/or hardening of the materials commonly used in foundry practice, like protective coatings and moulding and core sands. Depending on parameters of a microwave field and properties of the applied materials, it will be possible to select – on the grounds of the developed pattern – the most favourable process conditions guaranteeing high quality of the manufactured products.

2. Idea and methodology of the research

2.1. Materials used in the research

Aqueous protective coatings can be effectively dried and/or hardened in a microwave field. The possibility of drying alcohol-based protective coatings is currently limited with respect to emission of inflammable volatile by products that should be withdrawn from the working chamber of a microwave oven and neutralised. Therefore, for the preliminary examinations selected was the aqueous protective coating based on aluminium silicates, offered by one of the manufacturers, containing 70% of solid component with viscosity determined acc. to DIN by the outflow time of 22 s using a 4-mm Ford cup.

The protective coating was applied on two materials with similar physico-chemical properties determining the possibility to use them in manufacture of castings in the lost foam process.

The following polymeric materials were chosen for the examinations:

- foamed casting polystyrene with density 0.017 g/cm^3, commonly used in building patterns for the lost foam technology;
- rigid polymeric foam (polymethacrylimide) with density 0.032 g/cm^3 and closed porosity from the group of the materials with high transparency for microwave radiation.

2.2. Scope and methodology of the research

The protective coating with density ρ = 1.63 g/cm^3 was prepared and applied by immersion according to the manufacturer's recommendation.

Cylindrical shapes dia. 50 x 50 mm, used in the examinations, were coated by twofold immersion, maintaining a 120 s break between applying subsequent layers. The coated specimens (Fig. 1) were kept for 5 minutes on a drip grate to enable flowing-down of excess material and to guarantee constant thickness of the coating. The shapes set up on their faces were dried in traditional way and by microwaves using constant process parameters.

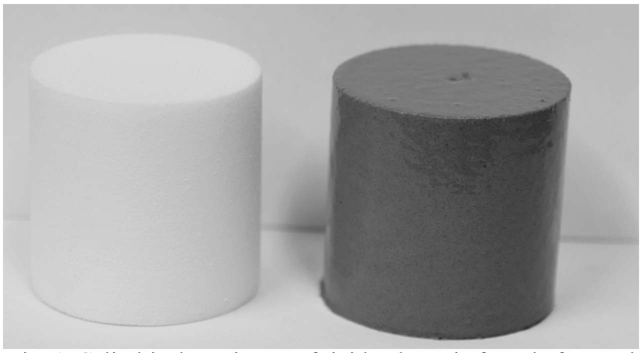

Fig. 1. Cylindrical specimens of rigid polymeric foam before and after dip application of protective coating based on aluminium silicates

Efficiency and effectiveness of microwave drying of protective coatings applied on the selected materials were determined in two phases. At the first stage determined were electrical characteristics of the protective coating: permittivity ε_r and loss factor tgδ. To this end, the stand of the waveguide resonance cavity described in [9] was used, that facilitates measuring electrical properties by the perturbation method for the frequency 2.45 GHz.

At the second stage, tests of technological drying of the coated cylindrical specimens were carried-out traditionally by convection in a laboratory drier and by the microwave method in a microwave oven with stepwise adjustment of radiation power. Drying in the laboratory drier was performed at 50 °C, as chosen from the temperature range of drying coatings on patterns of foamed polystyrene, recommended in literature [1-2]. For preliminary determining effectiveness of microwave heating of protective coatings on polymeric patterns, three levels of microwave power were selected: 100, 250 and 600 W.

The performed examinations were aimed at determining kinetics of the drying process being a basis for determining humidity content in the protective coating as a function of time. The data for preparing the drying curves were obtained by reading-out weight of the coated patterns every 30 seconds. The drying process, both by convection and with microwaves, was deemed finished when mass of the dried specimens did not change in three subsequent readings. Then, the time determined for the first identical readings was accepted as the time of complete drying the coating.

3. Results

3.1. Measurements of electrical properties

Electrical properties of the examined materials, determined by the perturbation method, are given in Table 1. The measurements were taken at ambient temperature 20 °C and air humidity of 40%. The results in Table 1 are average values of three measurements for each of the materials. Determined were permittivity ε_r and loss factor tgδ for individual polymeric materials and the protective coating based on aluminium silicates.

Table 1.
Permittivity ε_r and loss factor tgδ values obtained by perturbation method at 2.45 GHz for polymeric materials and protective coating

	Rigid polymeric foam pattern	**Casting foamed polystyrene pattern**	**Protective coating based on aluminium silicates**
Density ρ [g/cm^3]	0.032	0.017	1.63
Permittivity ε_r	1.05	1.06	4. 70
Loss tangent tgδ	0.0002	0.0011	0.0380

In order to characterise susceptibility to microwave heating of the patterns with protective coating, measurements were taken of their properties in analogous conditions as during separate examinations of the selected materials.

Table 2.
Permittivity ε_r and loss factor tgδ values obtained by perturbation method at 2.45 GHz for patterns with protective coating based on aluminium silicates

	Rigid polymeric foam pattern with protective coating	**Casting foamed polystyrene pattern with protective coating**
Permittivity ε_r	2.28	1.99
Loss tangent tgδ	0.0317	0.0441

From among the polymeric materials, the lowest loss factor (tgδ = 0.0002) is shown by rigid polymeric foam, which confirms rightness of selecting this material for examinations. Applying a coating on the material that can not be heated in electromagnetic field makes it possible to evaluate susceptibility to microwave action of the coating itself. The casting foamed polystyrene, with density half as large as that of rigid polymeric foam, shows also lower loss factor value (tgδ = 0.0011). However, in comparison to all the engineering materials, it can be determined as a material with very low looseness.

Measurements of electrical properties of the protective coating material based on aluminium silicates indicate its relatively high looseness and susceptibility to polarisation (ε_r = 4.54) under action of microwave field, which directly results from content of a solvent (water) that is a very good absorber of microwave radiation.

Observed were diverse loss factor values for combinations of the coating applied on both foamed polystyrene and rigid polymeric foam. Looseness of a system with foamed polystyrene is ca. 40% higher than that of a system with rigid polymeric foam.

The loss tangent value of the examined system with rigid polymeric foam is ca. 15% smaller and that of a system with casting foamed polystyrene is ca. 15% larger than the value recorded for the protective coating alone (see Tables 1 and 2). Observed was a significant relation between loss factor values of the coating alone and the systems created with its part.

The permittivity values of the examined systems indicate that the system more effectively subject to polarisation is rigid polymeric foam with applied protective coating. It was observed in this case that the permittivity value for the system connecting the coating and pattern materials is not proportional to the values measured separately for both materials.

3.2. Determination of drying curves

Curves of drying kinetics for the protective coating based on aluminium silicates are shown in Figs. 2 and 3, where the following marking of the specimens was introduced:

- **K** – convection drying,
- **M –** microwave drying.

Analysis of the drying curves indicates that, for all the examined specimens, use of microwave radiation made it possible to reduce the drying time in comparison to the convection method.

The 600 W microwave heating used for removing water from the protective coating permits even sevenfold reduction of drying time in comparison to traditional convection drying at 50 °C, see Fig. 3. The process runs in a similar way with use of 250 W microwave radiation. In the latter case the drying time can be shortened by 40% for both polymeric materials. Under 100 W microwave radiation, the protective coating on both substrates is dried ca. three times faster than by traditional drying at 50 °C.

Microwave drying the coating applied on a foamed polystyrene substrate runs more intensively, see Figs. 2 and 3. This results from higher looseness of the coated system. Analysis of the results in Table 2 indicates that the protective coating applied on foamed polystyrene with higher looseness (tgδ = 0.0441) is dried less effectively than the coating applied on polymeric foam with lower looseness (tgδ = 0.0317).

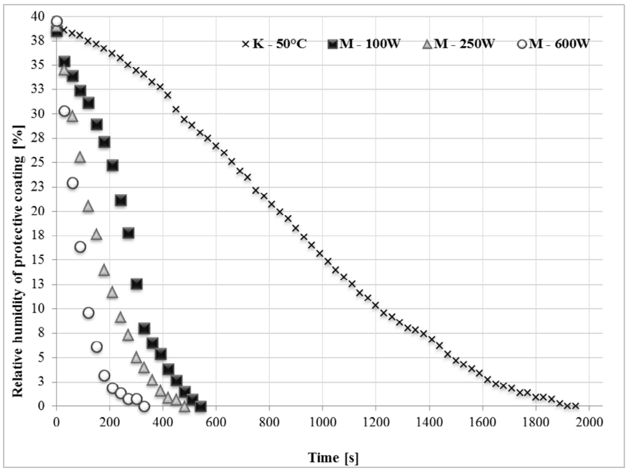

Fig. 2. Drying curves of protective coating based on aluminium silicates, applied on casting foamed polystyrene, at various heating parameters

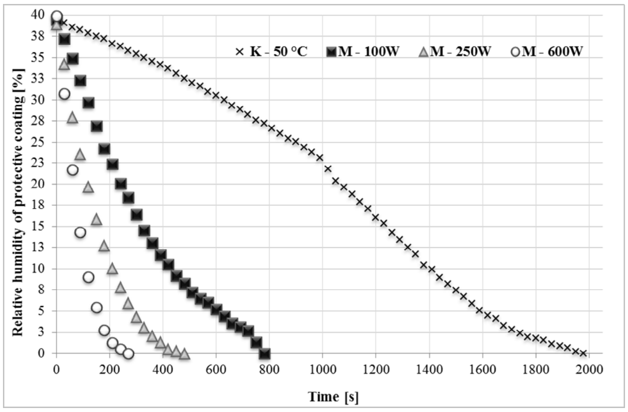

Fig. 3. Drying curves of protective coating based on aluminium silicates, applied on rigid polymeric foam, at various heating parameters

Direct observations of the microwave drying process of the protective coating indicate that it runs more effectively on cylindrical side surfaces of the specimens and this condition occurred as soon as after about half of the recorded drying time. The upper face dried unevenly and for a much longer time.

After the drying process, macroscopic and microscopic visual evaluations of the dried coating were carried-out, see Figs. 4, 5 and 6.

Surface condition of the coating after drying at various microwave power values shows that more and more pores appear with increasing heating power. Results of drying are visible on the exemplary coating applied on foamed casting polystyrene, see Fig. 3. These observations indicate accumulation of water steam inside the dried coating. A large accumulation of pores was observed each time on the surface of the coating applied on foamed polystyrene after microwave heating at 600 W. In order to determine causes and mechanisms of creating pores on the coating surface during microwave heating, it is necessary to perform a structural analysis of the pores, see Fig. 4b.

Microscopic observations of the protective coating carried-out with a scanning electron microscope (Fig. 5) confirm micro-porosity on the surface dried by microwaves. The pores probably result from too intensive evaporation of water and/or too low permeability of the coating. Observations of cross-sections of each coating (see Fig. 6) indicate that the coatings applied on both selected materials are continuous on their entire surface and the created pores do not cause their damages or breaks. In all the examined cases, the pattern of foamed polystyrene did not undergo deformation as a result of microwave heating. It results from this observation that a thorough analysis is necessary of the nature of creating pores on the microwave dried surface and perhaps developing a suitable set of components of the coating that would guarantee its adequate permeability to enable application of the innovative, economical and eco-friendly drying process.

It would be also necessary to determine influence of the created porosity on disturbances of the casting process (changed permeability of the coating) and, especially, on quality of the castings surface.

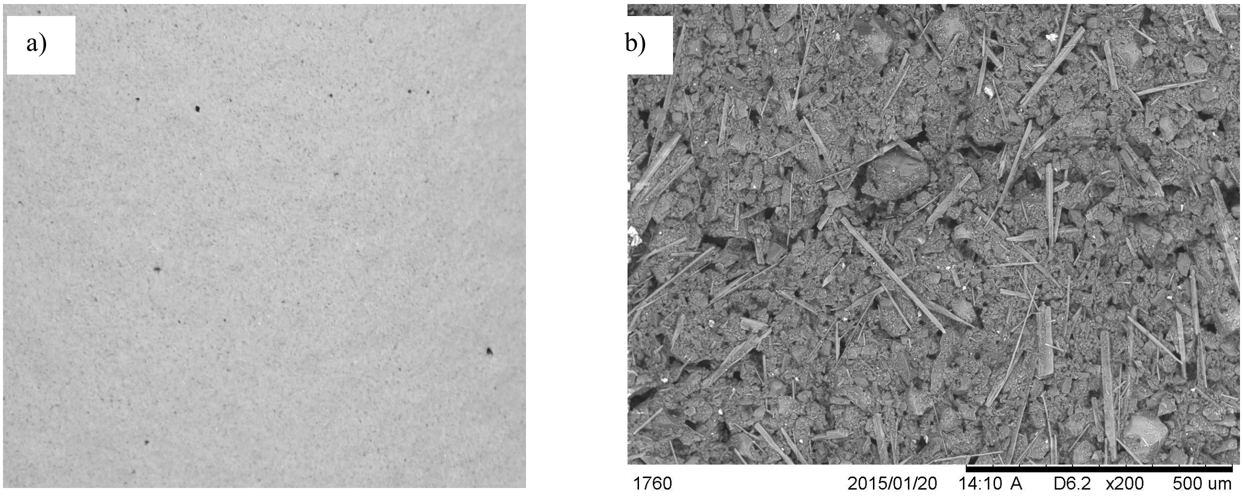

Fig. 4. Protective coating on foamed polystyrene after traditional drying at 50 °C: a) side surface (50x); b) SEM image of dried surface

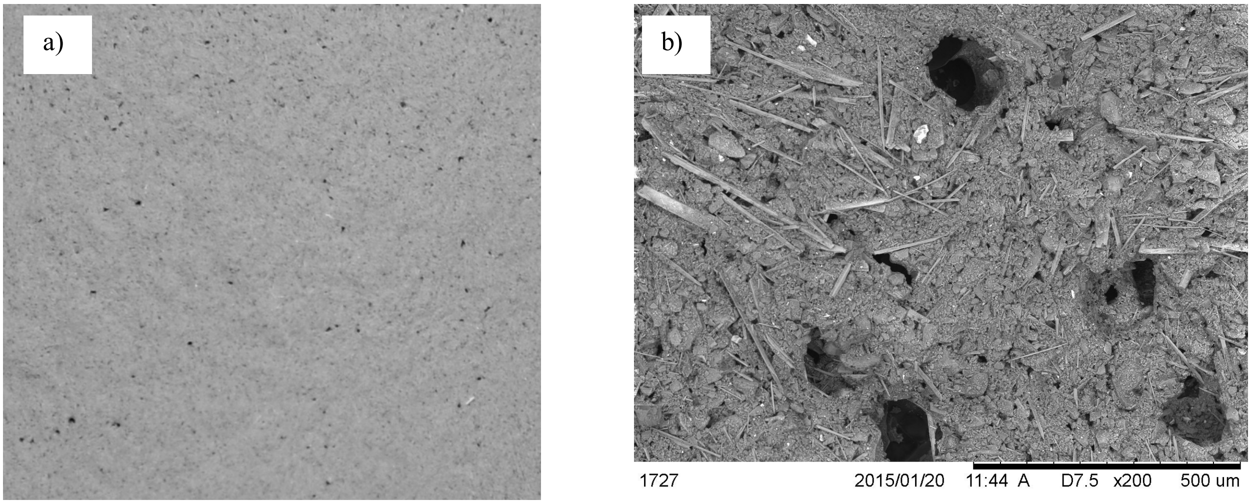

Fig. 5. Protective coating on rigid polymeric foam after microwave drying at 250 W: a) side surface (50x); b) SEM image of dried surface

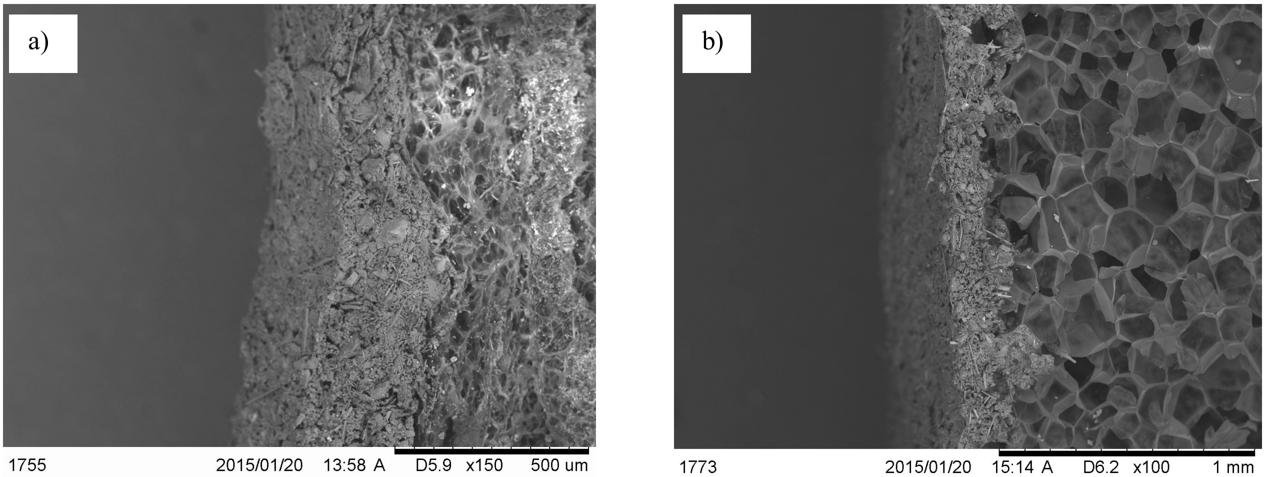

Fig. 6. SEM images of protective coating on foamed polystyrene after microwave drying at 250 W (a) and on rigid polymeric foam after traditional drying at 50 °C (b)

4. Conclusions

Results of the preliminary research on using microwave heating for drying protective coatings applied on disposable patterns permit the following conclusions to be drawn:

- Possibility and effectiveness of using microwave heating for drying protective coatings and polymeric materials designed for disposable patterns can be evaluated by measurements of permittivity ε_r and loss factor tgδ of these materials.
- Quality of dried surface (number and size of pores) of the protective coating used in the research is affected by power of microwave radiation.
- The time required for removing solvent from aqueous protective coating, based on aluminium silicates with specific qualitative and quantitative composition, depends on power of microwave heating. Its effective value should consider the possible excess temperature rise of the coating and/or the pattern material leading to its damage.
- Permittivity and loss factor of the protective coating are decisive for effectiveness of microwave heating of such a system.
- Evaluation of usability of microwave heating requires that selection of the process parameters is based on microscopic analysis of the structure created on surfaces of the dried protective coatings.
- Microwave radiation of 250 W seems to be a reasonable ground for further detailed research works.

Acknowledgements

The paper is co-financed by the European Union as a part of the European Social Fund.

HUMAN CAPITAL
NATIONAL COHESION STRATEGY

EUROPEAN UNION
EUROPEAN
SOCIAL FUND

References

[1] Lewandowski, L. (1997). *Materials for molds*. Kraków: Akapit. (in Polish)

[2] Pacyniak, T. (2013). *Loss foam method. Selected problems*. Łódź: Editorial Office of Lodz University of Technology. (in Polish)

[3] Seeger, K. (2012). Application of aqueous coatings at manual moulding. *Foundry Review*. *62* (7-8), 322-326. ISSN 0033-2275. (in Polish)

[4] Nwaogu, U.C. & Tiedje, N.S. (2011). Foundry coating technology: a review. *Material Sciences and Application*. *2*, 1143-1160. DOI:10.4236/msa.2011.28155.

[5] Jamrozowicz, Ł. Zych, J. & Kolczyk, J. (2015). The drying kinetics of protective coatings used on sand molds. *Metalurgija*. 54(1), 23-25. ISSN 0543-5846.

[6] Pacyniak, T. (2008). The effect of refractory coating permeability on the lost foam process. *Archives of Foundry Engineering*. 8(3), 199-204. ISSN (1897-3310).

[7] Holtzer, M. Bobrowski, A. Drożyński, D. & Mocek, J. (2013). Selection of protective coatings of moulds for castings of high-manganese cast steel in dependence of the applied moulding sand kind. *Archives of Metallurgy and Materials*. 58(3), s. 853–857. DOI: 10.2478/amm-2013-0101.

[8] Kowalski, S.J. Rajewska, K. Rybicki, A. (2005). *Physical basics of microwave drying*. Poznań: Editorial Office of Poznan University of Technology. (in Polish)

[9] Mujumdar, S.A. (Ed.) (1995). *Handbook of Industrial Drying* . New York: Marcel Decker.

[10] Granat, K. Opyd, B. Stachowicz, M. Nowak, D. & Jaworski, G. (2013). Usefulness of foundry tooling materials in microwave heating process. *Archives of Metallurgy and Materials*. 58(3), 919-922. DOI: 10.2478/amm-2013-0101.