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COMPREHENSIVE ASSESSMENT OF POLYMERIC MATERIALS FOR FOUNDRY TOOLING USED IN MICROWAVE FIELD

KOMPLEKSOWA OCENA MATERIAŁÓW POLIMEROWYCH NA OPRZYRZĄDOWANIE ODLEWNICZE STOSOWANE W POLU MIKROFALOWYM

The paper presents a research on abrasion resistance of selected construction materials designed for foundry tooling applied in the innovative microwave heating process of moulding and core sands. One of the main selection criteria of the materials for foundry tooling, in particular for models, moulding boards, moulding boxes and core boxes, is their good abrasive wear resistance. Usability of the selected polymeric materials, designed for foundry tooling used in electromagnetic field, is decided also by other evaluation criteria determined in the examinations, like thermal resistance and electrical properties. Abrasion resistance of the selected materials was determined for three grades of the moulding sand matrixes. Combined analysis of the determined abrasion resistance, considering also electrical properties and thermal resistance of the foundry tooling materials, characterising their usability for microwave heating of moulding and core sands, will make possible their systemising with respect to effectiveness and efficiency of the heating process, taking under consideration durability of such foundry tooling to be used in industrial conditions.

Keywords: innovative foundry technologies, microwaves, abrasive wear resistance, foundry tooling

W pracy zaprezentowano wyniki badań odporności na ścieranie wybranych materiałów konstrukcyjnych przeznaczonych do budowy oprzyrządowania odlewniczego przewidywanego do zastosowania w innowacyjnym procesie nagrzewania mikrofalowego mas formierskich i rdzeniowych. Jednym z głównych kryteriów doboru materiałów na elementy oprzyrządowania odlewniczego, w szczególności: modele, płyty podmodelowe, skrzynki formierskie i rdzennice, jest ich dobra odporność na zużycie ścierne. O przydatności wybranych materiałów polimerowych, przewidzianych do budowy oprzyrządowania stosowanego w polu elektromagnetycznym, decydują również, określone w badaniach, inne kryteria oceny, do których należą: odporność termiczna oraz właściwości elektryczne. Badania odporności na zużycie ścierne, wybranych materiałów oprzyrządowania, określono dla trzech różnych gatunków osnowy mas (ścierniwa). Analiza wyników oznaczenia odporności na ścieranie, powiązana z właściwościami elektrycznymi oraz odpornością termiczną materiałów oprzyrządowania, charakteryzujących ich przydatność w mikrofalowym nagrzewaniu mas formierskich i rdzeniowych, umożliwi ich usystematyzowanie pod względem skuteczności i efektywności procesu nagrzewania z jednoczesnym uwzględnieniem trwałości takiego oprzyrządowania odlewniczego dla zastosowania w warunkach przemysłowych.

1. Introduction

Complex evaluation of the materials designed for foundry tooling to be used in microwave field is defined, first of all, by their electrical properties that determine their ability for microwave heating. However, electrical properties of the materials commonly used in foundry technique that can be applied in electromagnetic field, are unknown. Heating in the innovative microwave process requires thorough evaluation of these materials, including determination and analysis of their electrical properties, as well as associating these properties with physico-chemical and usable properties.

The other research field, important for future application of the materials in industrial scale, is determining their basic usability, i.e. wear resistance that can be defined as the changes occurring on the material surface resulting from its loss caused by friction [1-3]. The constructional materials exposed to abrasion should be characterised by possibly highest resistance to this type of wear occurring during their operation. In the foundry industry, because of permanent presence of the materials acting as abrasives, wear plays an extremely important role in the processes of preparing moulds and moulding cores by traditional manual forming or by machine forming, e.g. by spraying, blowing or injecting [4].

Selection of a constructional material with optimum durability for specific wear conditions of foundry tooling components requires analysing the nature and kind of their surface wear [5]. Such an analysis, combined with choosing suitable electrical properties, is the objective of this work, resulting in a complex evaluation of usability of the materials designed for foundry tooling to be used at microwave heating of moulding and core sands.

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2. Measurements of abrasive wear resistance

An apparatus T-07 designed for testing metallic materials and coatings was used for preliminary evaluation of wear resistance of the selected plastics, see Fig. 1.

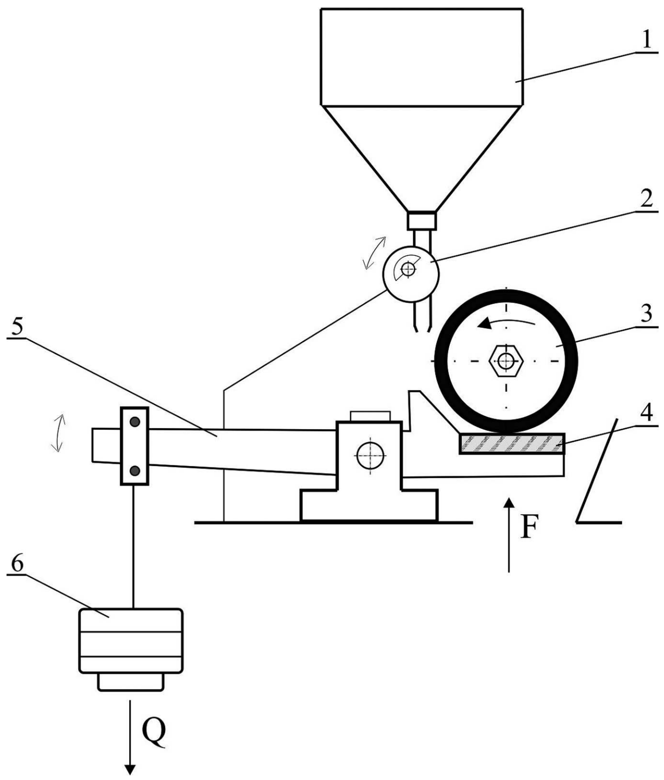

Fig. 1. Layout of the test stand T-07 for wear resistance [6]: 1) container with abrasive material; 2) feeder; 3) counterpart; 4) material sample; 5) lever; 6) weights

The measuring stand ensures indefinite kind of contact between the abrasive material and the sample, as well as sliding motion with dry friction under constant load Q [6]. The constant pressure force F (44 N) between the sample and the counterpart being a metallic disk coated with rubber (hardness of 78 to 85° ShA) was realised by means of a system of levers and weights. The counterpart rotated at 60±2 rpm. The samples of the materials to be used for foundry tooling were shaped as plates $30^{-0.05}\times30^{-0.05}\times3^{-0.025}$ mm. Measurements were taken on three samples of each examined materials.

2.1. Factors affecting friction process and wear of materials

The most common kind of tribological wear of mechanical nature is abrasion that happens when loose abrasive material is sliding over to the material surface. This abrasion process, consisting in ridging or micromachining the surface by loose grains of sand that is the main component of moulding and core sands, occurs during operation of foundry tooling materials. Abrasive wear of models, moulding boards, moulding boxes and core boxes is caused by action of the abrasive material moving over their surfaces during manual or mechanised compacting moulding sands in manufacture of moulds and cores [2,4].

The factors determining wear of the materials used in foundry processes can be divided into two basic groups: material properties and conditions of friction. The basic properties influencing abrasive wear of polymers are degree of crystallinity and type of the supermolecular structure. It is believed that increased fraction of crystalline structure of polymers results in their higher abrasion resistance [2]. Conditions of friction are determined by sliding speed and surface pressure. Moreover, abrasion effects depend on type of the abrasive material and in particular on size, shape and hardness of the abrasive particles [7].

2.2. Examined materials

Two grades of plastics: polytetrafluoroethylene (PTFE) and recycled polytetrafluoroethylene (RPTFE) were subject to the examinations being a beginning of complex evaluation of the materials designed for foundry tooling. This choice was dictated by both their suitable physico-chemical properties, as well as very good permittivity and favourable loss factor, determined in the previous research works, see Table 1 [8].

TABLE 1

Properties of PTFE and RPTFE [8-10]

Quantity	PTFE	RPTFE
Permittivity ε_r	2.043	2.054
Loss factor tgδ	0.0011	0.00095
Density [g/cm^3]	2.18	2.16 to 2,20
Degree of crystallinity [%]	50 to 85	60 to 85
Compressive strength [MPa]	5.9	7.1
Tensile strength [%]	250 to 400	75 to 150
Operation temperature range [°C]	-200 to +260	-260 to +260
Machinability	Very good	Very good

Good electrical properties of these materials justify classifying them to the group of the materials transparent for microwave radiation. Use of PTFE and RPTFE for manufacture of foundry tooling to be applied in microwave field guarantees relatively high effectiveness and efficiency of transferring the radiation deep into the heated moulding and core sands [11].

2.3. Materials used as abrasives in the tests

The materials used as abrasives were chosen on the grounds of general knowledge on the most often applied types of sandmix matrix that are high-silica and chromite sands [4]. In addition, in the examinations was used a traditional abrasive material aloxite No. 90 acc. to PN-ISO 8486-2[1)], recommended for testing materials with high abrasion resistance. The applied medium-size high-silica sand has the main fraction 0.2/0.315/0.4, medium sphericity index and rounded grains, see Fig. 2 [12].

[1)] Replaces PN-76/M-59115.

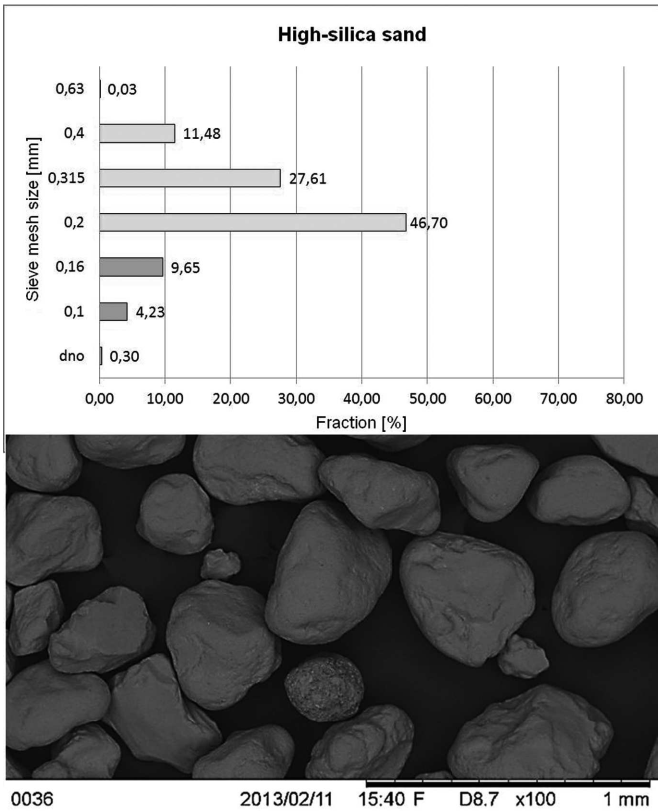

Fig. 2. Granularity and SEM image of medium high-silica sand

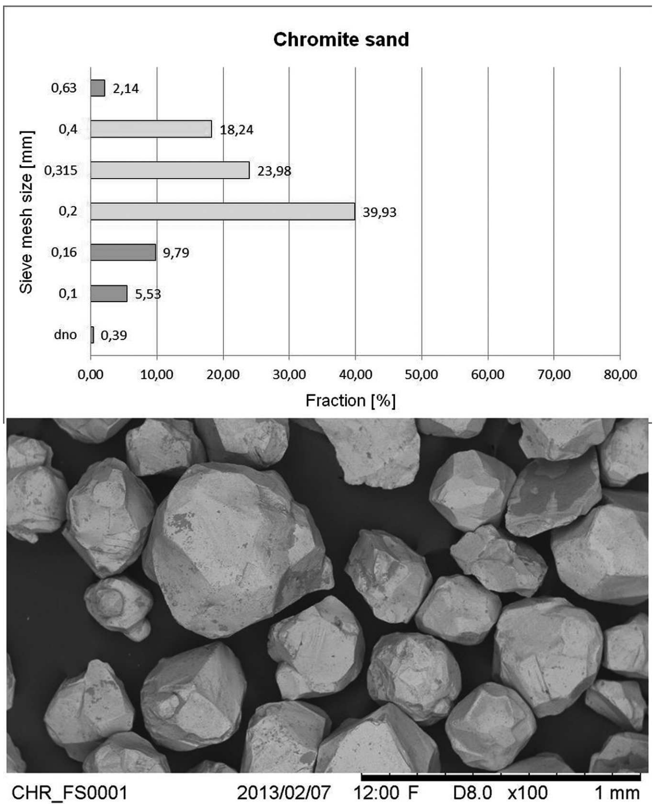

Fig. 3. Granularity and SEM image of chromite sand type FS

Figure 3 shows an image of the chromite sand type FS used in the examinations and its grain size distribution (main fraction 0.2/0.315/0.4), similar to that of the high-silica sand. It is characterised by high sphericity index and slightly irregular shapes of grains [12]. Measurements of wear resistance of the examined materials, in contact with the sands commonly used as matrixes of moulding sands, are compared with the results obtained for the traditional abrasive – aloxite with very irregular, more fine grains (0.1/0.16/pan), low sphericity index [12] and relatively high homogeneity, see Fig. 4.

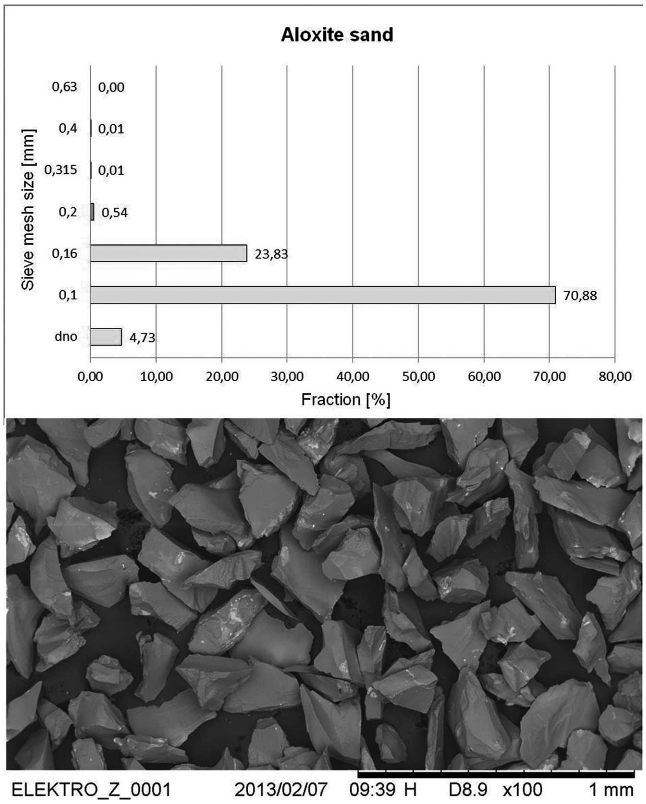

Fig. 4. Granularity and SEM image of aloxite abrasive No. 90

3. Measurements of abrasive wear resistance

Measurement results of abrasive wear resistance, carried-out with constant pressure suitable for abrasion-resisting materials, expressed by mass loss of the sample, are compared in Table 2. Quality of the obtained results is characterised by standard deviation (σ) being a measure of spread of data about the mean values given in Table 2.

TABLE 2

Abrasive wear resistance of PTFE and RPTFE

Average mass loss of the sample:	PTFE	RPTFE
Fine-grained high-silica sand: $\sum \Delta m$ [g]	0.114	0.126
Standard deviation (σ)	(0.0095)	(0.0069)
Wear: Δm / L [g/m]	0.0024	0.0027
Chromite sand type FS: $\sum \Delta m$ [g]	0.019	0.022
Standard deviation (σ)	(0.0049)	(0.0056)
Wear: Δm / L [g/m]	0.00040	0.00047
Aloxite No. 90: $\sum \Delta m$ [g]	0.111	0.116
Standard deviation (σ)	(0.0089)	(0.0047)
Wear: Δm / L [g/m]	0.0047	0.0049

During the examinations, the number of rotations of the dia. 50 mm roller (N) was experimentally reduced from 600 to 300 (5 minutes) for both high-silica and chromite sands. It turned-out that the presumed abrasibility of polymeric materials was higher than that of the metallic materials and coatings. In the case of aloxite abrasive, the number of rotations N was reduced during the test to 150 (2.5 min) because of big loss of the sample mass. In order to refer abrasive wear resistance with aloxite to that with the other abrasive materials, applied was a wear index expressed by the relation of mass loss to friction distance [g/m] calculated from the formula $L = N \cdot \pi d$.

Analysis of the obtained results delivered information on the expected intensity of abrasive wear of parts made of PTFE and RPTFE. It was found that, in the executed tests with use of three grades of abrasives (high-silica, chromite and aloxite), the recycled polytetrafluoroethylene (RPTFE) undergoes more intensive wear (lower wear resistance) in all cases. Therefore, the parts of tooling made of RPTFE will get worn during operation in a shorter time, which can result in premature errors of shapes and dimensions of the moulds and cores prepared with their use, than it would be in the case of using PTFE.

Abrasive wear resistance of PTFE determined by means of chromite sand type FS was ca. 6 times higher than that determined with use of medium high-silica sand. A similar situation (wear resistance ca. 5.7 times higher) was observed for the samples made of RPTFE.

The largest difference was observed between the results for chromite sand. In this case, abrasive wear resistance was 15.8% higher for RPTFE than that for PTFE. A similar difference was observed for high-silica sand (10.5%) and for aloxite abrasive (4.5%). So, it seems that PTFE is the material more favourable for manufacture of foundry tooling.

The subsequent stage of evaluation of abrasive wear resistance of the selected constructional polymeric materials designed for foundry tooling used in electromagnetic field was visual assessment of surface condition after a dry friction test. Observations were carried-out on a SEM microscope and the obtained images are shown in Figs. 5 and 6. For comparative reasons, all the pictures of the surfaces were taken at magnification 500x.

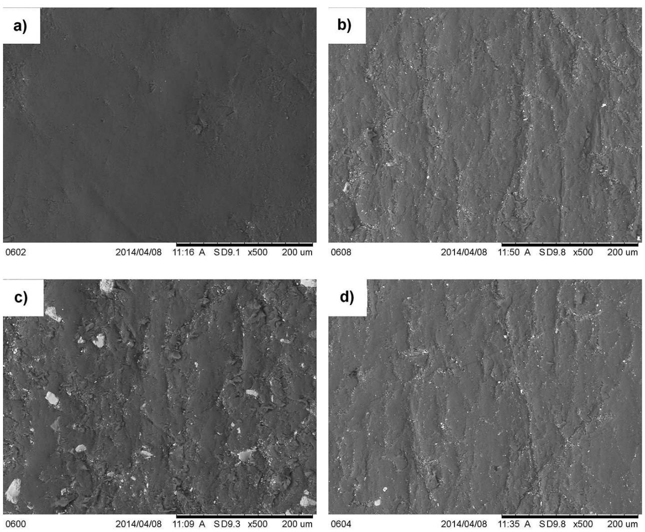

Fig. 5. Surface of PTFE samples: a) raw sample, b) after abrasing with high-silica sand, c) after abrasing with chromite type FS sand, d) after abrasing with aloxite 90

On the grounds of surface observations after the abrasion process, an attempt was made to identify the wear mechanism of the examined materials, which can have the nature of scratching, micromachining, ridging or a combination of them.

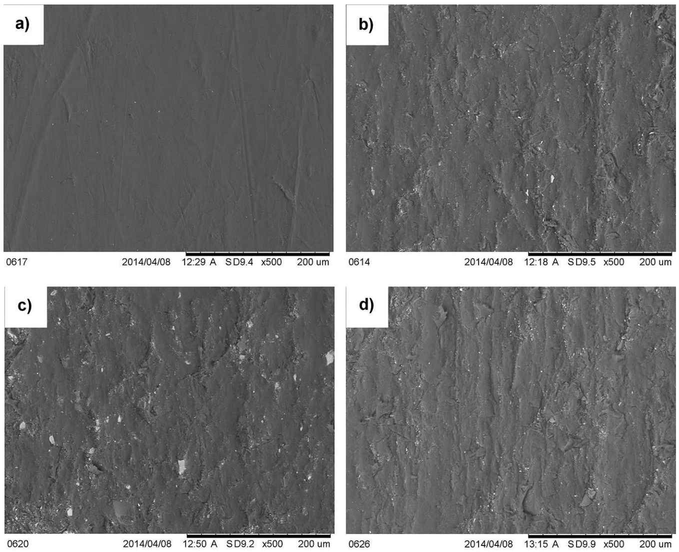

Fig. 6. Surface of RPTFE samples: a) raw sample, b) after abrasing with high-silica sand, c) after abrasing with chromite type FS sand, d) after abrasing with aloxite 90

Analysis of the surface images before and after abrasing with high-silica sand indicates that abrasion of the samples of both PTFE (Figs. 5a, 5b) and RPTFE (Figs. 6a, 6b) proceeded by concurrent micromachining and dominating ridging of the material surface. This results from the shape of high-silica sand grains that, in comparison to the other abrasives, were rounded (oval). Numerous plastic deformations on the examined surfaces were visible as flat-tipped ridges (Figs. 5b and 6b), characteristic for ridging.

In the case of chromite sand having angular, spheroidal and irregular grains (Fig. 3), the wear proceeded by abrasion and dominating micromachining. This is evidenced by deep scratches on surfaces of the PTFE and RPTFE samples (Figs. 5c and 6c), created by machining by the abrasive grains.

In the case of aloxite abrasive having fine, angular and irregular grains, the surface wear proceeded by ridging and micromachining, resulting in loss of the material as soon as after the first travel of the abrasing element, see Figs. 5d and 6d.

Comparison of the measurement results and visual assessment of the surface after abrasing with aloxite and high-silica sand shows that abrasion of both PTFE and RPTFE proceeds more intensively in the case of the second abrasive. Moreover, in both polytetrafluoroethylene samples observed was significant influence of size and shape of abrasive grains, manifesting itself by different abrasion rate at similar interaction mechanisms.

4. Conclusions

The following conclusions can be drawn from the presented research aimed at comprehensive assessment of polymeric materials designed for foundry tooling to be applied at microwave heating of moulding and core sands:

- The suggested test stand can serve evaluation of abrasive wear resistance of the materials with higher abrasibility than that of metallic materials, provided that the test parameters (number of revolutions and/or pressure value) are properly adapted.
- Interaction of properties of grains of a moulding sand making the matrix of sandmixes, like grain size and shape, results in a change of their mechanical action on the material surface (micromachining or ridging).
- The parts made of recycled polytetrafluoroethylene (RPTFE), mating moulding sands with high-silica sand matrix, will be exposed to the most intensive abrasive wear.
- The parts made of polytetrafluoroethylene (PTFE), mating moulding sands with chromite sand matrix, will be exposed to the least intensive abrasive wear.
- Abrasion with use of fine-grained high-silica sand proceeds by micromachining with slight ridging of surfaces of both PTFE and RPTFE.
- Abrasion with use of chromite sand type FS proceeds mainly by ridging of surfaces of both PTFE and RPTFE.
- Abrasion with use of aloxite abrasive proceeds by highly intensive micromachining of surfaces of both PTFE and RPTFE.
- Chromite sand making the matrix of moulding sands designed for microwave hardening is a material with the highest absorption index of microwaves with frequency 2.45 GHz from among the abrasive materials [13] and can make the most favourable solution for process engineering based on polytetrafluoroethylene tooling that is characterised by very good transparency for microwaves, high working temperature range and very good machinability.
- In the case of using the aloxite abrasive with surface morphology like in the presented research, it is not recommended that elements of foundry tooling are made of polytetrafluoroethylene.

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