



ARCHIVES
of
FOUNDRY ENGINEERING

DOI: 10.1515/afe-2017-0098

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

ISSN (2299-2944)
Volume 17
Issue 3/2017

97 – 102

Effect of Microwave Heating on Moulding Sand Properties with Gypsum Binder

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Received 29.03.2017; accepted in revised form 07.06.2017

Abstract

The paper presents results of initial research on the possibility of applying microwave radiation in an innovative process of making casting moulds from silica sand, where gypsum $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ was acting as a binding material. In the research were compared strengths and technological properties of moulding mixture subjected to: natural bonding process at ambient temperature or natural curing with additional microwave drying or heating with the use of microwaves immediately after samples were formed. Used in the research moulding sands, in which dry constituents i.e. sand matrix and gypsum were mixed in the ratio: 89/11. On the basis of the results of strength tests which were obtained by various curing methods, beneficial effect of using microwaves at 2.45 GHz for drying up was observed after 1, 2 and 5 hours since moisture sandmix was formed. Applying the microwaves for hardening just after forming the samples guarantees satisfactory results in the obtained mechanical parameters. In addition, it has been noted that, from a technological and economic point of view, drying the silica sand with gypsum binder in microwave field can be an alternative to traditional molding sand technologies.

Keywords: Foundry industry, Materials and Foundry Technology, Microwave heating, Gypsum, Binding material

1. Introduction

Gypsum hydrate is a bonding material with the chemical formula $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ (calcium sulfate dihydrate), mainly used in construction. It theoretically consists with (in % sand): CaO - 32.57%, SO_3 - 46.50%, H_2O - 20.93%. It often contains minor admixtures of CO_2 , SiO_2 , Fe_2O_3 , Al_2O_3 , MgO, NaCl. This mineral can be colorless or white. It also occurs in yellowish, pinkish, brownish or grayish color [1-4].

Gypsum is also a well-known, pro-ecological material used in foundry processes. Thanks to dynamically developing Rapid

prototyping technologies (based on 3D printing) recently the area of application of this material has increased [5-8].

In foundry technical gypsum is often used, which is found in two variants as calcium sulfate hemihydrate $\text{CaSO}_4 \cdot 0,5\text{H}_2\text{O}$:

➤ Hemihydrate α , which is characterized by greater strength resulting from better binding capacity. This is obtained by adding calcium sulphate dihydrate in saturated vapor environment or in water at temperatures above 97°C . In the dehydration process α -anhydrite III is obtained. Heating at 220°C sulphate CaSO_4II leads to formation of insoluble anhydrite II. As a result of further heating at temperatures above 1180°C , the material is transformed into anhydrite I.

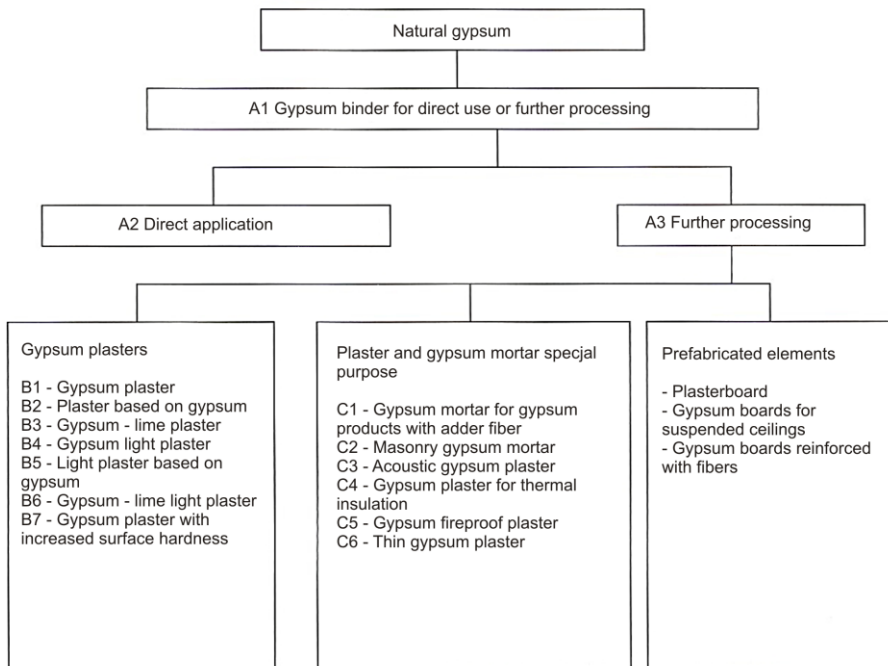


Fig. 1. Classification of gypsum binders and gypsum plasters [9]

Hemihydrate β , which is characterized by greater surface energy reacts more actively with water. β -anhydrite III is obtained from calcium sulfate dihydrate by partially dehydrating it in vacuum at a temperature not exceeding 100°C or in relatively dry air. By further heating at 350°C , insoluble anhydrite II is obtained, which turns into anhydrite I at a temperature of 1180°C [10].

Construction gypsum Dolina Nidy marked with A1 in accordance with EN 13279-1: 2009 was acting as a binding material in the following tests. The classification of gypsum materials is shown in Figure 1.

Gypsum occurs in the form of a hemihydrate ($\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$). The content of calcium sulphate is min. 50%.

It should be noted at the same time that the excess of sulfur in the moulding sand can penetrate to the solidifying surface of a casting. As a consequence, on the example of spheroidal cast iron, the performance of the modifier may decrease, which in turn leads to degradation of spheroidal graphite and its transition to a flake form. Flake graphite, especially in cast irons, dynamically loaded initiates cracks formation by changing its position.

Emission of sulfur to the casting surface can be reduced by using, for example, special hardeners [11] with reduced sulfuric acid content.

The process of gypsum binding takes place in three stages. The first is the dissolution of hemihydrate in water (Fig. 2), resulting in a saturated solution from which a gypsum dihydrate begins to precipitate. Then, in the second stage, the hemihydrate is hydrated to more difficult soluble dihydrate, which crystallises in the final stage [10].

Figure 2 shows that ambient conditions, including: humidity and temperature has an effect on the gypsum binding process. It is therefore reasonable to study the effect of each of these factors on the future use of gypsum in mixtures such as moulding and core sands. One way to influence the binding process is to provide additional thermal energy, thus affecting the binding process. Therefore, the process of microwave heating has been proposed which was checked and advantageous for other moulding sands [12, 13].

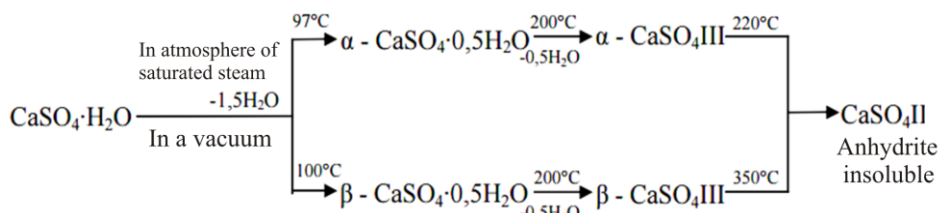


Fig. 2. Diagram of transformations of calcium sulphate dihydrate $\text{CaSO}_4 \cdot \text{H}_2\text{O}$ in insoluble anhydrite CaSO_4II [10]

The use of microwave radiation at 2.45 GHz for hardening sand with gypsum as a material binding matrix grains is justified not only due to the possibility of obtaining good quality of castings, but also the economic benefits and fulfilling more and more strict environmental requirements [14-16]. The expected effect of the study was not only the significant time reduction of gypsum -sand binding, but also the possibility of obtaining cracks-free casting forms and cores made from cheap and easily available pro-ecological materials.

Microwave drying has an increasing spectrum of uses in industrial processes. The most important advantages of this method are its economic aspects such as: time, energy and materials savings and often better products' quality [17]. Analyzing presented in literature results of current research, there are growing prospects of its introduction also in foundry industry [14, 15, 18].

The condition for obtaining positive heating effects is using suitable microwave power to fill the chamber and drying time for moulding sand composition. Inadequate selection of parameters can cause significant damage to the material. Products dried in this way are much more prone to cracks and deformations than conventionally dried ones [19].

2. Aim of research

The aim of the research was to determine the possibility of applying 2.45 GHz microwave radiation in the process of producing foundry moulds and cores from a sand mixture consisting of silica matrix, gypsum and water. It was determined on standard samples (PN-83/H-11070) [20, 21] the basic strengths and technological properties of the moulding mixture, in which the binding process took place in three technological variants, namely: 1st method – natural (after 1, 2 and 5 hours), 2nd method – combined (drying in microwave field samples hardened naturally after 1, 2 and 5 hours) and 3rd method - only in the microwave field immediately after the test samples were formed. The use of microwave heating (3rd method) is shown in the graphs (Fig. 4 - 8) as a "0.1" point. The analysis of the results of the tests allowed to evaluate the influence of selected three drying methods and parameters on the gypsum sand properties. Mechanical properties were also related to bonding bridges' construction created during hardening the samples. Gypsum bonding bridges were observed by the use of a scanning electron microscope (SEM) Hitachi TM3000.

3. Research description

Based on the analysis of the research results [22, 23], it has been found that electrical properties of moulding sand components has a significant effect on the efficiency and ability of their microwave heating. The highest loss coefficient $\text{tg}\delta$, which determines the efficiency of microwave heating, is characterized by silica sand of medium grain size. This means that the use of this raw material as a moulding matrix should favorably affect the time and effectiveness of sand' heating.

Thus, medium silica of 1K 0.20/0.315/0.16 from Grudzeń Las mine, as defined by PN-H-11001:1985, was used in the test.

The material binding matrix grains was the commercial construction gypsum Dolina Nida, marked as A1, according to EN 13279-1:2009 (Fig. 3). As a result of conducted in accordance with standard PN-EN 13279-2:2009 sieve analysis, grain size of the raw material was determined. On a sieve with mesh size of 1.0 mm, the grain residue does not exceed 0.5%, while on the sieve of 0.2 mm - 15% [9, 24, 25].

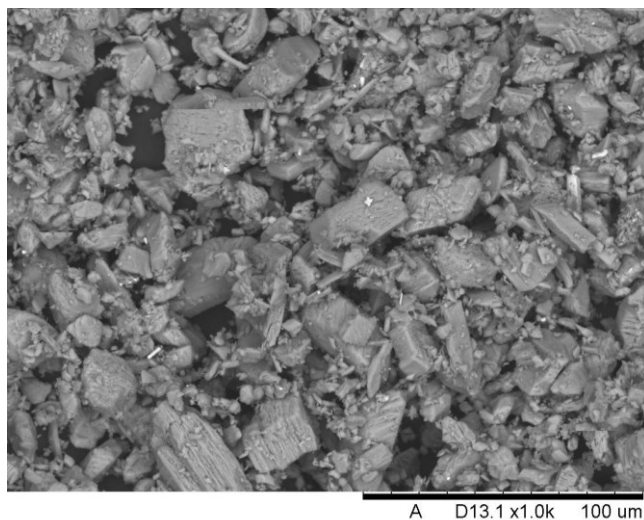


Fig 3. Picture of gypsum construction material Dolina Nidy; SEM, area: 1000: 1

After the selection of materials it was determined, based on the analysis of literature data [26, 27], information from a manufacturer, attestations and preliminary own research [22] the number of individual components and method of sand mixture preparation, which contained 89% matrix' weight particles and 11% of gypsum weight particles. For 100% of dry sand ingredients (matrix and gypsum) 11% by weight of water was dosed. Weighed amounts of dry silica sand and gypsum were mixed for 2 min, than the water was dosed and mixed for another 2 min.

Out of such a gypsum sand with the use of LU-1 laboratory beater, three times compacted standard laboratory samples were prepared: cylindrical, elongated and eight-shaped (dog bone).

According to the accepted test program, the initial sample was subjected to a natural curing at ambient temperature of 22°C. First, reliable and reproducible measurements of cured moulding sand properties were carried out 1, 2 and 5 hours after forming samples (in a 1st method). Because of their low endurance, earlier there was no possibility for manipulation and fitting them in the measuring apparatus..

In the next stage of the test, the samples, in natural way, were microwave dried (2nd method) after 1, 2 and 5 hours from the moment they were compacted. During microwave drying, a 32 liter furnace was used in which the samples were heated for 300 s with 1000W microwave power.

For comparative purposes, the microwave drying process of samples (3rd method) was carried out immediately after their

performance. The results of the tests carried out on these moldings are shown in graphs at 0.1 h.

4. Results

According to the adopted program it was determined for the tested sand:

- compressive strength R_c^u [MPa],
- bending strength R_g^u [MPa],
- tensile strength R_m^u [MPa],
- permeability P [$m^2/MPa \cdot s$],
- abrasion resistance S^u [%],

Density of the compacted moulding sand after molding was in the range of 1.72-1.78 g/cm^3 .

Samples strength measurements were carried out in accordance with PN-83 / H-11073 on LRuE-2e stand made by Multiserw-Morek, with mean values of 3 measurements, as shown in Figures 4, 5 and 6.

Permeability tests were carried out in accordance with PN-H-11072:1980, on LPiR-3e [27, 28] and the results are shown in Figure 7.

Cured moulding sand abrasion resistance was determined on LS-1 apparatus according to BN-77/4024-02 standard. Measurement time was constant 300 s for both: natural and microwave-dried samples, while during the first ones there was a lamp switched on to heat the upper surface of the sample to about $95 \pm 3^\circ C$ [26, 29, 30]. The mean measurement results are shown in Figure 8.

Analysis of the results of tensile strength R_m^u of moulding sand (Fig. 4) confirms the known relationship between natural drying time of sand at ambient temperature (1st method) and its mechanical properties [24]. Microwave drying (2nd method) results in a significant increase in the strength of the octahedral samples by up to 86%.

As can be seen from Figure 4, drying up sand using microwaves (2nd method) has many advantages such as: shortening process time while increasing compressive strength. A sample was dried for 5 min in the microwave chamber with the use of 1000 W has mechanical properties comparable to that naturally cured at ambient temperature after 1 hour.

The highest value of bending strength (Fig. 5) is obtained after 5 h of curing at ambient temperature (1st method), but its change is not only increasing over time, since after 2h of binding process its maximum can be observed for samples cured only at ambient temperature (1st method) and its minimum for sand dried up with microwaves (2nd method). The greatest difference between conventional drying and microwave drying is observed after 1h of binding and it is 74% in favor of 2nd method.

A similar, positive effect of using microwave heating (methods: 2nd and 3rd) was noted for the achieved results of bending strength tests (Fig. 6).

Permeability (P) of the tested sand cured in a natural 1st method is 110-200 $m^2/MPa \cdot s$ (see Fig. 7).

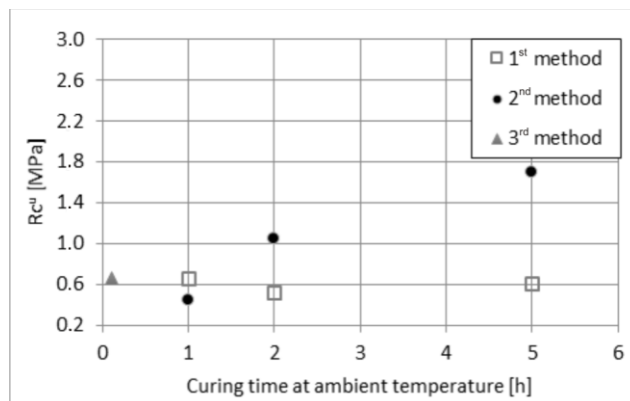


Fig. 4. Effect of curing time and methods of hardening on compressive strength R_c^u of the tested moulding sand

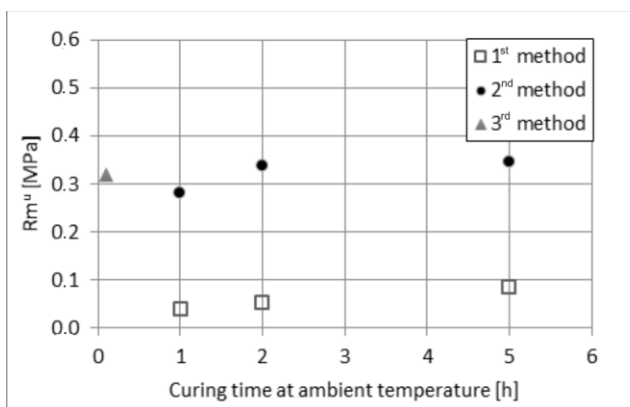


Fig. 5. Effect of curing time and methods of hardening on tensile strength R_m^u of the tested moulding sand

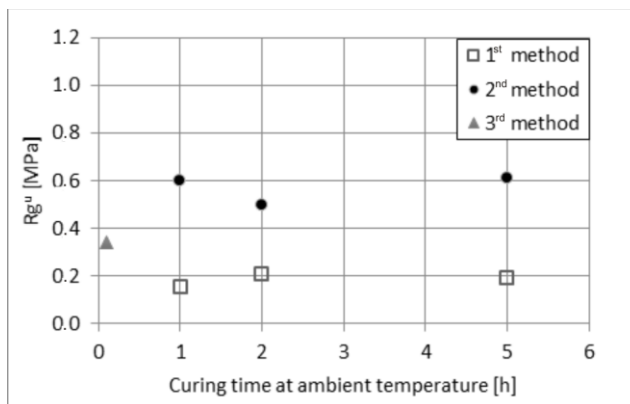


Fig. 6. Effect of curing time and methods of hardening on bending strength R_g^u of the tested moulding sand

Sand dried only by microwaves (3rd method) reach mean permeability value of approximately 120 $m^2/MPa \cdot s$. Moulding mixture formed and cured at ambient temperature and dried up with the use of microwaves (2nd method) achieved permeability from 110 to 140 $m^2/MPa \cdot s$. In the case of unsatisfactory sand permeability after drying, its improvement is possible, by using, for example more coarse-grained matrix.

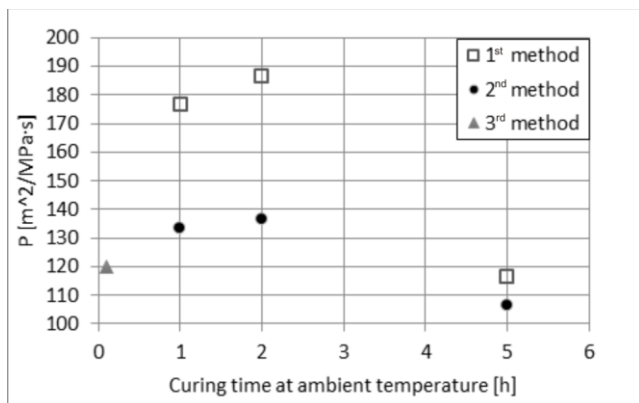


Fig. 7. Effect of curing time and methods of hardening on permeability P of the tested moulding sand

Analyzing the results of the sand abrasion resistance measurements (see Fig. 8) after microwave curing (2nd method), allows to observe that prolonging the natural drying time (in a 1st method) of sand at ambient temperature decreases. Microwave drying (in a 3rd method) provides a relatively small degree of weight loss (S^u) which is 1.51%.

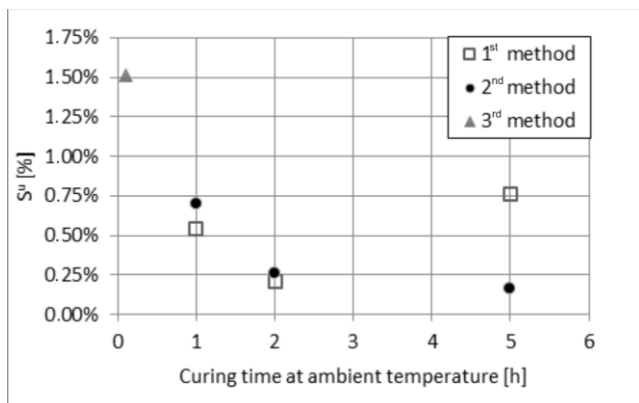
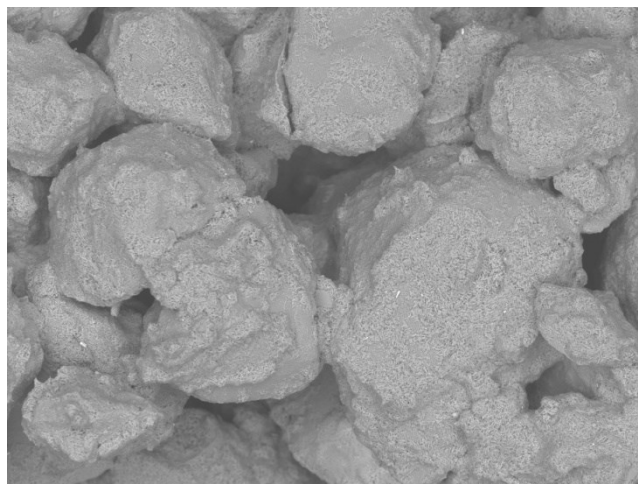


Fig. 8. Effect of curing time and methods of hardening on abrasion resistance S^u of the tested moulding sand

5. Observation results of bonding structures

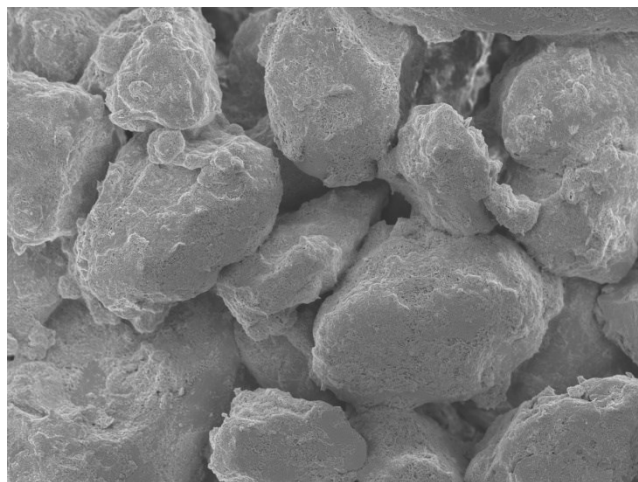
Based on SEM analysis of gypsum bridges bonding matrix grains in the naturally cured and microwave dried up moulding sand (Fig. 9 and 10), it can be observed that the course of the binding process has no significant effect on their structure. In both cases (methods: 1st and 3rd), there was a film [23] character of the binding material on the surface of the silica matrix with separable bonding bridge structures.

Bonding bridges create complex spatial structures with coniferous structures permanently binding with matrix grains. In the naturally cured sample, it was observed that the coniferous specimens were finer and less well-formed than those in microwave dried ones.



A D9.8 x250 300 μm

Fig. 9. Picture of in self-hardening sand (1st method) at ambient temperature; SEM, area: 250:1



A D8.3 x250 300 μm

Fig. 10. Picture of bonding bridges in the cured sand for 30 sec. by microwaves (3rd method); SEM, area: 250:1

6. Conclusions

Based on the analysis of the research results, it was found that:

- all strength and technological parameters of gypsum sand cured with microwaves by the 2nd method are sufficiently satisfactory so the method can be successfully applied in foundry, guaranteeing good cast quality and significantly reducing the time of production and also reducing production costs,
- microwave dried gypsum sand are characterized by very good strength parameters. Bridges bonding matrix grains in the cured moulding mixture are continuous and devoid of

- any defects typical for fast microwave-dried ceramic materials;
- the use of microwaves to dry gypsum molding sand significantly shortens their curing time, which, in economic and technological terms, has many benefits;
 - materials used for making gypsum sand are commercially available, inexpensive and ecological, and the casting process with their use is exceptionally favorable and environmentally friendly;
 - next stage of this study will examine another drying techniques with changing ambient conditions and their impact on the strength properties of molding sand.

Acknowledgement

The research was financially supported from the grant for statutory activity No. 0401/0084/16.

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