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Influence of Microwave Heating on the Molding Mass with Gypsum Binder Structure and Strength

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Abstract

The paper presents results of influence microwave drying on strength and technological properties of molding sand with gypsum binder researches, which, immediately after making and after the natural initial setting in air for 1, 2 or 5 hours, was heated with 250 W microwave power for 3, 6, 9 and 12 min time periods. The test was carried out on a mass containing (% -wt.): 88% Grudzeń-Las quartz sand, 12% "Dolina Nidy" plaster gypsum and 6% water. The loss of moisture content during natural drying and then microwave drying was determined, significant from the point of view of using the mass with gypsum binder in the production of products, using an environmentally friendly technology without casting incompatibilities. Additionally, the compressive strength of the mass was measured. The influence of both drying methods on the binder crystallization process and the associated mass strength was demonstrated, especially in terms of the possibility of selecting parameters and / or intensifying a specific drying method for use in the technology of manufacturing molds and foundry cores.

Keywords: Foundry, Foundry materials and technologies, Plaster gypsum, Molding and core sands, Strength of masses

1. Introduction

In casting processes and technologies, the use of gypsum is widely known, which is the main material of foundry molds, and is also used as an additive to molding and core sands [1].

Natural gypsum forms huge deposits in a series of sedimentary rocks and is one of the most abundant minerals in the earth's crust [2]. In Poland, it accompanies salt deposits and occurs in the Miocene and Cieszyn evaporative formations. Gypsum binders are obtained in Poland mainly from natural stone (gypsum and anhydrite) or are a waste product, eg from the flue gas desulphurization process [3,4].

Use of gypsum binders in the technological process often determines the setting time, which determines the possibilities and parameters for selected practical applications.

Gypsum binding process takes place in 3 stages: hydration, dissolution and crystallization. In water media it is based on the transformation of a hemihydrate ($CaSO_4 \cdot 0.5H_2O$) into a dihydrate ($CaSO_4 \cdot 2H_2O$) [5], which is released on its surface in the form of acicular crystals.

Introduction of gypsum to water is considered to be the beginning of its binding, the time of which is measured in minutes and is divided into 3 stages [5]:

1. flowability period during which the mixture is in the liquid state;
2. beginning of the bond, where the mass stops flowing, is plastic and deformable,

3. end of binding, i.e. the time after which the mass is completely solidified.

The structure changes described in the literature [5-8] in the process of binding the mixture of gypsum hemihydrate, water and fine quartz sand (4-5 min) lead to an increase in its strength to approx. 0.15 MPa. The dihydrate precipitates crystallize on the surface of the hemihydrate, and the damage to such a structure within 3-4 minutes does not affect the strength of the mixture after hardening. An increase in the amount of dihydrate gypsum forming coagulation networks leads to an increase in the strength of the mass, which after approx. 30 minutes reaches the value of 1.5 MPa.

Maintaining plasticity of the mass until the element is formed and quick crystallization after its completion is one of the requirements. If the mass starts to set before the completion of molding, the bonds between the gypsum grains may be irreversibly damaged, and, as a result, the mechanical properties of the product deteriorate [5].

Binding rate of gypsum depends mainly on the grain size, since the length of the process and the intensity of the hydration reaction are influenced by the overall wetting surface. Its increase is associated with an increase in the amount of water (for the appropriate consistency of the mass) influencing the setting time of the plaster. In addition, the fragmentation of the plaster affects the number of grain contact points and greater compressive and tearing strength. The increase in mortar water demand, related to the fragmentation of the binder (deteriorating the strength of the binder), improves the plasticity of the gypsum mortar, which is technologically advantageous [5].

The use of a gypsum binder as a binding material in modlind and core sands is associated with the need to remove moisture from them, which is dangerous both from the point of view of the formation of casting imperfections as well as environmental protection. Therefore, in the process of producing molds and cores from masses with gypsum binder, the extended time of their natural binding (drying) should be taken into account, or additional heating of the products should be introduced.

During convection drying of the molding sand, it is possible to remove approx. 80% of the water contained in it. This process is long and energy-consuming, especially in the case of low thermal conductivity of the mold or the core, and the most difficult thing is to get rid of 20% of the residual water in the central zone of the heated product [9-10]. Drying gypsum mortar with hot air can reduce its strength by up to 70% [11, 12], while initial thermal treatment of "raw gypsum" (at 170 ° C, a few hours before use), causing the dihydrate to be fully converted into a hemihydrate, shortens the time process [5].

Research on microwave drying of molding sand with bentonite [9, 13] showed that it is possible not only to shorten the process time (even 10 times), but also to improve its properties. The compressive and shear strength is higher by 20-35% and 5-10%, respectively, than that of conventionally dried masses. Extending the time of heating the sand with lower power microwaves results in a linear increase in compressive and shear strength.

The time of drying the sand with gypsum binder with microwaves is influenced by both the water content and its mineralogical composition (physicochemical properties).

Microwave drying, thanks to its specific action, removes all moisture from the mass, leaving no "residual" water. Drying takes place simultaneously in the entire volume of the substrate. Water vapor escapes from the inside towards the surface of the dried element and no wet zone is formed inside [9].

Microwave radiation, in the processes of producing ceramic products, is used in drying, sintering and synthesis of products. Its efficiency and effectiveness depends on the dielectric parameters of the substrate components [14].

Of key importance in the microwave drying process is the selection of appropriate parameters: radiation power and heating time. During too intensive microwave drying, the increasing pressure inside the material, especially when the phase it contains turns into a gas state, with limited permeability, may lead to deformation or even destruction of the product [13, 15].

Literature describes a favorable interaction of microwaves, for example, in the case of sands with a bentonite binder activated by radiation (increase in strength) [9], sands with a starch-based binder, in which they initiated the cross-linking process and the formation of permanent intra- and intermolecular hydrogen bonds [16] or in combined convection drying with air flowing through the material, which also removes the moisture generated during the simultaneous microwave heating of the substrate [14].

Combined drying techniques are used, for example, in convective heating of materials: with low thermal conductivity (temperature difference between the surface and the core), or less well-absorbing ceramic microwaves, convectionally heated to the critical temperature above which, thanks to the increase in the dielectric loss factor, they easily absorb radiation .

Combining the techniques of volumetric heating with microwaves for heating the interior of ceramics with the convective external one helps to reduce the thermal gradient between the surface and the core and is of key importance in the processing of brittle ceramics susceptible to thermal stress cracking [13, 17].

Intensive microwave drying, more than convection drying, exposes the products to cracks and deformations and requires particularly precise selection of process parameters. The selection of the correct microwave power and drying time, adjusted to the composition of the molding sand (dielectric parameters of the components) and the degree of chamber filling, is necessary to achieve the best heating effects [13, 18-22].

2. Research goal

Purpose of research was determinate possibility of using microwave heating in order to reduce time of natural drying mass with gypsum binder in production of molds and foundry cores, which will allow for acceleration of technological process, improvement of strength and technological properties of mass and ensure, by removing moisture in a short time, necessary conditions for pouring metal into molds or cores.

Using of elasticized, commercially available plaster gypsum "Dolina Nidy" [23, 24], aims to provide the molding sand, compared to the commonly used building gypsum, favorable molding properties, especially extended setting time, important from the point of view of its use in technology mold and core.

A characteristic, very important feature of selected binder is a slower crystallization process and extended flexibility, increasing the service life of the mass during molding, which meet the next goal of planned tests.

The combination of the recommended [25], reduced water content in the molding sand [23], which should ensure its loose consistency and non-sticking to the tooling and intensive microwave drying, will ultimately guarantee the achievement of the main research objective, which is to shorten the drying time, and thus improve the mold making process and cores and its easy mechanization and / or automation.

3. Description of the tests

The tests were carried out for molding mass containing (parts by weight): 88 pbw. dry quartz sand Grudzeń-Las (main fraction 0.20 / 0.16 / 0.315, class 1K), 12 pbw. Plaster Gypsum: "Dolina Nidy" [16] (moisture content 4.1%) and 6 pbw. water [25-28]. The composition of the mass is consistent with the gypsum binders used in the studies on the possibility of using various types of gypsum binders as a binding material [23].

The commercially available binder used in the research contains mainly $CaSO_4 \cdot 0.5H_2O$ β-hemihydrate and $CaCO_3$ carbonate as well as additives modifying and regulating the setting time [23, 24].

The mass was prepared in a device with a planetary agitator drive system, combining dry ingredients for 2 minutes, then adding water, continuing the process for another 2 minutes. Immediately after the mass preparation, cylindrical shapes were prepared in accordance with the recommendations of the PN-83 / H-11070 [28] standard, the average density of which was approx. 1.62 g/cm^3.

Measurements of the compressive strength Rcs, carried out in accordance with the recommendations [29], were preceded each time by the determination of the weight loss of the samples from their preparation to the measurement after the period of natural drying and those cooled to ambient temperature after heating with microwaves. For a more precise evaluation, the loss value was determined as a percentage related to the actual sample weight.

The research on the influence of the gypsum binder setting conditions on the compressive strength of the mass was carried out immediately after its preparation, for up to approx. 0.05 h and after the following combined drying process, selecting its parameters for the actual anticipated conditions of its use in the production of molds and cores, namely:

- natural, at 23°C and 48% air humidity after 1, 2, 5 hours,
- microwave for 3, 6, 9 and 12 minutes with power of 250 W.

After the compressive strength measurements, the mass samples taken from the damaged area were observed using a scanning electron microscope.

4. Research results

The averaged results of the tests carried out are presented in Table 1 and Figures 1 and 2.

The analysis of the change in the compressive strength of the mass, from the moment of its preparation and preparation of samples to 5 hours of natural drying, shows that it increases from only 0.03 to 1.40 MPa. Analyzing the use of this method in the molding process, the maneuverability of the mold or the core guarantees a strength of 0.43 MPa, achieved only after 2 hours of drying (Table 1, Fig. 1).

The introduction of additional heating with microwaves with the power of 250 W in the technology of molding masses with gypsum binder, favors, with the change of the process time from 3 to 12 minutes, the increase of Rc^s strength, the amount of which depends on the period of initial natural drying.

Microwave heating of the mass for 12 minutes, immediately after its preparation, provides a 7-fold increase in its strength (from 0.03 to 0.21 MPa), which may, in certain cases, be beneficial for the continuation of the molding process.

Heating the naturally dried mass with microwaves for 1 hour allows to achieve a strength of 0.22 MPa after only 3 minutes, which after 12 minutes of the process reaches 10 times the initial value (0.97 MPa).

Table 1.
Drying conditions and parameters, percentage weight loss of samples and compressive strength of the tested mass

Conditions and parameters drying	Loss of weight				R_c^s	
	natural[1]		after drying[2]			
	[%]	[σ]	[%]	[σ]	[MPa]	Σ
Natural 0.05 h	–	–	–	–	0.03	0.001
3 min/250 W	–	–	1.95	0.04	0.10	0.01
6 min/250 W	–	–	3.00	0.10	0.11	0.01
9 min/250 W	–	–	4.73	0.02	0.14	0.01
12 min/250 W	–	–	5.20	0.11	0.21	0.01
Natural 1 h	0.57	0.03	–	–	0.09	0.01
3 min/250 W	0.58	0.04	1.71	0.17	0.22	0.01
6 min/250 W	0.55	0.05	3.26	0.12	0.29	0.04
9 min/250 W	0.62	0.01	4.23	0.12	0.53	0.01
12 min/250 W	0.75	0.03	4.32	0.06	0.97	0.01
Natural 2 h	1.00	0.01	–	–	0.43	0.01
3 min/250 W	0.99	0.04	0.99	0.11	0.66	0.02
6 min/250 W	1.01	0.03	2.27	0.20	1.05	0.11
9 min/250 W	1.01	0.03	2.90	0.06	1.42	0.03
12 min/250 W	1.07	0.01	3.00	0.05	3.08	0.09
Natural 5 h	2.02	0.04	–	–	1.40	0.12
3 min/250 W	1.89	0.07	0.44	0.06	1.44	0.07
6 min/250 W	1.89	0.09	1.35	0.16	1.78	0.09
9 min/250 W	1.83	0.11	1.82	0.09	2.26	0.02
12 min/250 W	1.98	0.04	1.88	0.02	3.20	0.20

[1] after natural drying, [2] after microwave heating

The use of microwave heating of the mass, dried naturally for 1 hour (9 and 12 minutes) and for 2 hours, creates the basis for its application in the production of molds and cores thanks to the possibility of selecting the parameters of such a combined process.

The natural drying of the mass with gypsum binder for 5 hours gives it a sufficiently high strength, which can be increased by the use of microwave drying. The heating process also ensures that the mass is dried and, in accordance with the aim of the discussed research, the removal of moisture, which is unfavorable from the qualitative and ecological point of view of the application of this molding material in the production of castings.

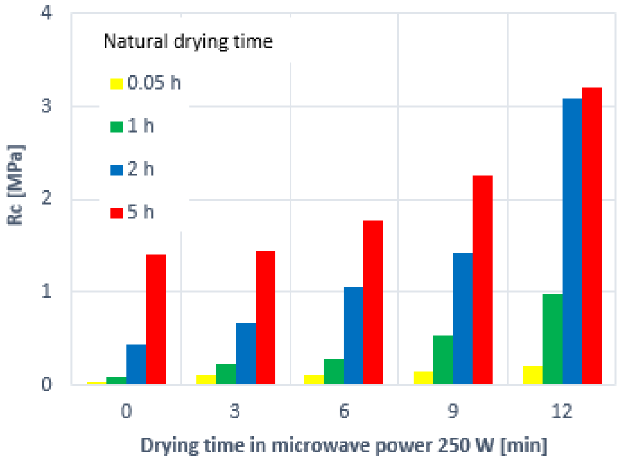

Fig. 1. Influence of the natural and microwave drying time on the compressive strength of the tested mass

In the process of natural drying of the mixture tested for 1, 2 and 5 hours, it loses, respectively, from approx. 0.6 by 1 to 2% of its initial weight (Table 1, Fig. 2).

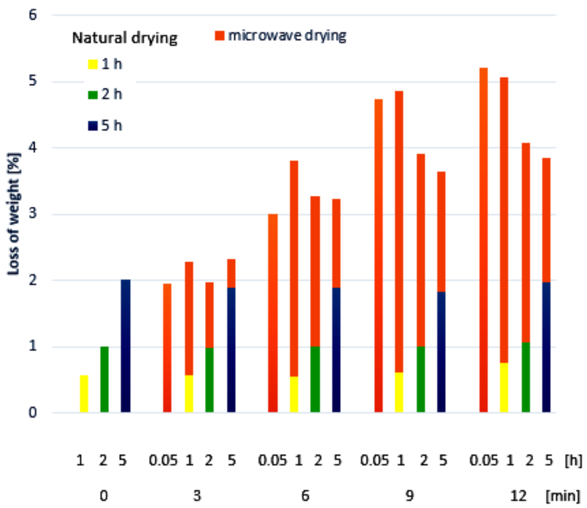

Fig. 2. Total, percentage weight loss of samples after natural drying (0.05, 1, 2, 5 h) and drying or further drying with microwaves (3, 6, 9, 12 min)

Microwave heating of the mass for 3, 6, 9 and 12 minutes immediately after its preparation causes a systematic weight loss of the samples from about 2 to over 5%.

Microwave heating of the naturally pre-dried mass also causes an increase in the weight loss of the samples with increasing heating time. When analyzing the changes presented in the summary (Fig. 2), a logical reduction in losses related to heating the material dried for 1, 2 and 5 hours with microwaves is particularly noteworthy. . The total weight loss of the samples dropped below 4%, but their strength reached values above 2.2 MPa.

The mass structure observations showed that the natural, long drying ensures the correct crystallization of the coniferous particles of the gypsum binder forming the bonding bridges (Fig. 3).

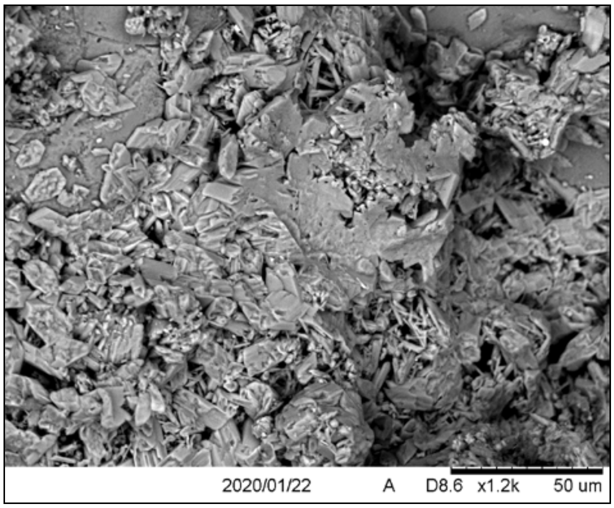

Fig. 3. SEM view of the bonding bridge in the mass naturally dried for 72 hours

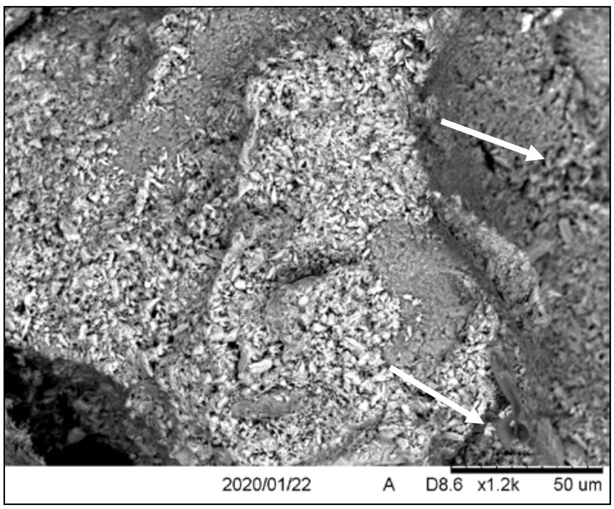

Fig. 4. SEM view of the bonding bridge in the mass naturally dried for 1 h and dried for 12 minutes in microwaves; The areas of primary, natural crystallization of the binder were indicated

Microwave drying of the naturally pre-hardened mass, through intensive drainage of water, breaks and disrupts the process of proper crystallization of the binder (Fig. 4). As a result, bonding bridges with a degraded structure are formed, and in addition, improper selection of the parameters of the heating process (power and time) leads to their cracking, which is the reason for the low strength of the mass. Figure 5 shows the view of the bridge in the mass with gypsum binder, heated with 1000 W microwave power for 12 minutes, presented in the literature [18].

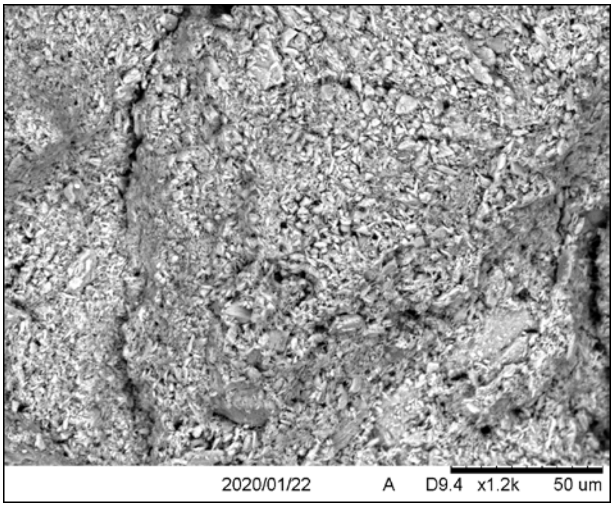

Fig. 5. SEM view of the structure of bonding bridges in the mass with gypsum binder [18]

5. Conclusions

Analyzing the results of the research on the influence of the method and parameters of natural drying and / or microwaves, on the strength and structure of bridges binding the grains of the matrix, the mass with gypsum binder, it was found that:

- natural drying only after 5 hours provides the test mass with favorable compressive strength, thanks to a good connection with the matrix of the properly crystallized binder (Fig. 3). After this drying time, however, more than 4% of the mass of moisture remains in the mass, which, when combined with the products of thermal decomposition of the binder, may cause foundry incompatibilities and the release of hydrogen sulphide during pouring;
- accelerated microwave drying of the mass, intensively removing moisture, shortens the process of natural crystallization in the water environment and leads to the formation of a degraded, fragmented binder structure (Fig. 5). This dynamic heating process additionally causes cracking of the bonding bridges and, as a result, low strength. Longer microwave drying times (> 9 min) lead to a favorable, virtually complete removal of moisture from the mass;
- combined natural and microwave drying, with an appropriate combination of the parameters of both methods, can be successfully used in the production of molds and cores, will allow the selection of appropriate mass strength, reduction of the process time and, thanks to the complete removal of moisture, prevent the formation of foundry incompatibilities and harmful gases after its contact with liquid metal;
- the use of the mass with a binder with a prolonged crystallization process ensures its good fluidity, extending the time of formability, and thanks to the reduction of water content, also a loose consistency and non-sticking to foundry equipment;

The presented research results may constitute guidelines for the development, thanks to the use of microwave heating, of ecological and economic casting technologies based on masses with gypsum binder, intended for industrial use.

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