Metallurgy and Foundry Engineering – Vol. 41, 2015, No. 3, pp. 133–141
http://dx.doi.org/10.7494/mafe.2015.41.3.133

**Karolina Kaczmarska, Beata Grabowska, Dariusz Drożyński,
Żaneta Kurleto, Łukasz Szymański**

An assessment of the effectiveness of physical curing methods of molding sand bonded by binders based on starch and aluminosilicates

Ocena efektywności metod fizycznego utwardzania masy formierskiej wiązanej spoiwem skrobiowo-glinokrzemianowym

Abstract

In this study, the effectiveness of curing methods by conventional heating and innovative microwave curing were compared, based on the results of determining molding sand selected properties such as permeability, tensile strength, and wear resistance. The tested molding sand used for our research was a composition of silica sand with a commercial binder in the form of Albertine F/1 (Hüttenes Albertus). This binder is a mixture of water-swellable starch derivatives and aluminosilicates. Binding in the molding sand occurred via solvent evaporation from the samples (water). The obtained results showed a dependence of molding sand properties and selected methods of physical cure, especially after one and four hours of cured-sample storage. However, after 24 hours of sample storage (as apparent from the analysis of the obtained results), both curing methods used were almost equally effective, and marked differences in the molding sand properties were located in the range of measurement uncertainty. Using electromagnetic waves in the microwave range made it possible to significantly reduce the time of curing as well as the energy consumption of the drying process.

Keywords: molding sands, physical methods of curing, drying, microwaves, starch binder

Streszczenie

W niniejszej pracy na podstawie wybranych właściwości (przepuszczalności, ścieralności i wytrzymałości na rozciąganie w stanie utwardzonym) porównano efektywność metod utwardzania przez konwencjonalne nagrzewanie oraz innowacyjnej metody utwardzania mikrofalowego mas

---

Karolina Kaczmarska M.Sc., Beata Grabowska Ph.D., D.Sc. Eng., Dariusz Ph.D., Żaneta Kurleto Eng., Łukasz Szymański Eng.: AGH University of Science and Technology, Faculty of Foundry Engineering, Krakow, Poland; karolina.kaczmarska@agh.edu.pl

formierskich z komercyjnym spoiwem skrobiowym w postaci produktu Albertine F/1 (Hüttenes Albertus). Spoiwo to stanowi mieszaninę pochodnych skrobi z glinokrzemianami pęczniejącą w kontakcie z wodą. Wiązanie w masie zachodzi w wyniku odparowania wody rozpuszczalnikowej. Na podstawie uzyskanych wyników stwierdzono wyraźną zależność właściwości mas formierskich od doboru metody fizycznego utwardzania, szczególnie po jednej i czterech godzinach składowania kształtek. Natomiast po 24 h składowania kształtek, jak wynikało z analizy uzyskanych wyników, obie zastosowane metody utwardzania są niemal tak samo skuteczne, a różnice wartości oznaczonych właściwości mas mieściły się w granicy niepewności pomiaru. Dzięki zastosowaniu fal elektromagnetycznych w zakresie mikrofal możliwe było wyraźne skrócenie czasu utwardzania i zredukowanie zapotrzebowania na energię procesu suszenia form.

Słowa kluczowe: masy formierskie, utwardzanie fizyczne, suszenie, mikrofale, spoiwo skrobiowe

1. Introduction

In the technology of molding sands, the selection of materials and choice of curing methods are two important aspects of the production of proper molds and cores. However, in order to meet the demands of industry, the quality of materials are not the sole criterion. Economic and environmental aspects of the technology should also be taken into account when preparing forms [1, 2].

Therefore, research is being conducted around the world in an effort to develop new, relatively cheap, and clean technologies of molding sands with binders that consist of (e.g.) natural renewable materials, including biopolymers. The advantage of biopolymers is the easy availability of raw materials, the low cost of production, the possibility of using nontoxic solvents (usually water), and a minimal impact on the environment [2–15].

For example, the most known and frequently used binder (an alternative to synthetic resin) is a thermosetting protein-based binder GMBOND made by General Motors. It is a mixture of natural polypeptides [3]. In addition to this eco-friendly binder, a great interest in natural starch has been observed. Starch (in its native form, or derivatives after appropriate chemical or physical modification) is an effective binder material in the molding sands cured at high temperature [4–13]. Starch products used in the technology are present in sand molds such as native starches from yam and cassava [4, 5], a binding mixture of cassava starch and clay [6], water-soluble starch binder type WSMB [7], a component of polymeric binder type BioCo [8–13], and the self-contained binder based on etherified starch with different degrees of substitution [14, 15].

In all of the above-mentioned technologies of preparing molding sands with the application of starch products, molds can be partially or totally dispensed with the chemical curing agents to composition, but it is necessary to use curing molds or cores produced at a suitable temperature range of 70–200°C. The purpose of heating is to primarily evaporate the solvent or dehydrate the binder. Moreover, molding sand with a biopolymeric binder at a predetermined temperature during curing does not emit toxic gases [3, 8, 14, 15].

In the case of water-soluble biopolymeric binders, conventional heating is the most commonly used method of curing and drying. However, this method requires high-energy consumption and relatively long holding the molds or cores at raised temperature [16]. The time and energy consumption of the process of preparing forms can be significantly reduced by using an innovative method of microwave curing of the molding sands with binders binding via dehydration [17]. Literature data shows that a good efficacy of microwaves was observed for molds with both selected organic [9–12] or inorganic binders [16, 17]. The effectiveness of the process depends not only on the binding material properties and microwave power, but also the mold's time of exposure in an electromagnetic radiation field.

2. Purpose

In this work, the effectiveness of physical methods of curing and molding with a binder in the form of a mixture of organic (starch) and inorganic ingredients (aluminosilicates) in the form of commercial products was evaluated.

The aims were also to investigate the possibility of applying an innovative microwave curing method of molding sand bonded by an organic-inorganic binder as well as to assess the effectiveness of this method as compared to the conventional method of curing by heating. The material was cured by the physical evaporation of water solvent from the molding sands in both of the applied methods.

The analysis of the effectiveness of the two methods used was based on the results of studies of selected properties (i.e., permeability, wear resistance, and tensile strength in the cured state) of molds prepared with the participation of a starch-aluminosilicate binder in the form of a commercial product by Hüttenes Albertus.

3. Materials

The matrix of molding sand was silica sand SIBELCO EUROPE (BK D 0.16–0.32 MM). The binder applied to preparing molding sand was product Albertine F/1 (Hüttenes Albertus) (Tab. 1).

Table 1. Characteristic of Albertine F/1

Form	Composition	Content [%]	pH
extra-fine powder; white and yellow color	water content	10–12	4,5
	content of starch products with different swelling capacities	75–79	
	ash content	<1,0	
	heat-resistant materials; aluminosilicates	8–14	

4. Methodology

4.1. Molding sand preparation

The molding sand was prepared as follows: portions of quartz sand (5 kg) were poured into a laboratory roller mixer type LM-1 and then added in 2.5 parts by the weight of binder Albertine F/1 (in powdered form). After mixing the dry ingredients for one minute, 5 parts by weight of water were added into the mixer pan to partially dissolve the adhesive and plasticize the composition. Pre-mixing sand and loose binder were preferred due to the starch derivatives and aluminosilicates comprising Albertine F/1, which were improperly distributed in the sand grains (which could cause an adverse formation of agglomerate accumulations when in contact with water. All of the ingredients (with solvent) were mixed together for 3 minutes.

Such a prepared mixture was used for the formation of standard samples for the determination of characteristic molding sand properties.

4.2. Preparing and curing samples

In the study of selected properties, two kinds of shapes of standard laboratory samples of molding sand were prepared; i.e., cylindrical-shaped samples to measure permeability and wear resistance, and figure 8-shaped samples to determine tensile strength [9]. All of the samples were compacted by hitting of standard laboratory rammer (LU type) three times.

One series of molding samples was cured by the conventional heating of samples at a temperature of approx. 100°C for 1 h in laboratory drier Model SU-P-2 with the function of drying and heating the dry weight of the hot air.

The second series of samples was cured physically by electromagnetic radiation in the microwave range. Samples were exposed to microwaves at a power of 800 W and frequency of 2.45 GHz (device MD INOTEC 10940-type). The temperature of samples heated in the microwave apparatus was about 100°C. The time of samples exposure to radiation was 120 seconds for the figure 8-shaped samples and 240 s for the cylindrical-shaped samples.

After curing (but before strength testing), the samples were cooled in the open air and stored in the laboratory at a humidity level of 35–48% and an ambient temperature within the range of 23–26°C.

4.3. Methods of examination

4.3.1. Permeability determination

Permeability (P) was performed by the fast method on electrical apparatus type LPiR1. The permeability values were expressed in the SI unit $10^{-8}\,\frac{m^2}{Pa \cdot s}$. Permeability was determined for the uncured cylindrical samples as well as the cured samples after 1 hour and 24 hours of storage [2].

4.3.2. The wear resistance determination

Wear resistance was determined by means of a special apparatus (Huta Stalowa Wola production) on cylindrical specimens after curing according to method described in [2]. Due to the expected high abrasion of the tested molding sands, only half of the recommended weight of steel shots (i.e., 875 g) was used in measurements. Wear resistance (S) in % was calculated based on formula (1):

$$S = 2 \cdot \frac{Q_1 - Q_2}{Q_1} \cdot 100\% \tag{1}$$

where:

Q_1 – mass of the sample before the test/g,

Q_2 – mass of the sample after the test/g.

S was examined after 1, 4, and 24 h of storage.

4.3.3. Tensile strength determination

The specimens for tensile strength were tested using the universal strength testing machine LRU type (MULTISERW Morek) according to PN-83/H-11073/EN. The result was registered on the scale of the machine [2]. The tensile strength was examined after 1, 4, and 24 h of sample storage.

5. Results and discussion

The results of determining molding sand properties after curing by both conventional and microwave methods are shown in Figures 1–3.

The permeability of uncured molding sand as compared to molding sand cured by physical agents is shown in Figure 1; this indicates that the best value of the P parameter was achieved by microwave curing after one hour of sample storage. In comparison to the uncured molding sand that was characterized by P at 145 units, the conventionally cured molding sand obtained P at 175 units, and the molding sand cured in the microwave had P at 208 units. The relatively high level of permeability of the microwave-treated molding sand indicates intense evaporation of water solvent from the inside of samples due to even a short exposure to electromagnetic radiation. However, after 24 hours from the time of curing, the figure 8-shaped samples clearly showed that prolonged storage time had contributed to the increased P of the conventionally cured ones obtained by heating the molding sand. This probably resulted from the ongoing process of evaporating water from the samples for several hours after the curing agent's action had ceased. After 24 h, stabilization of the permeability value at a constant level was observed.

No similar impact of the prolongation of storage time has been recorded for the microwave-cured molding sand. On the contrary, a reduction of permeability was noted (lower by approx. 10 units), which could have been caused by the absorption of water in ambient conditions by the dry molding sand, which was associated with the natural ability of starch derivatives contained in Albertine F/1. Finally, after 24 hours of storage, permeability in the molding sand was maintained at a level of approx. 195 (±2) units, regardless of the curing method.

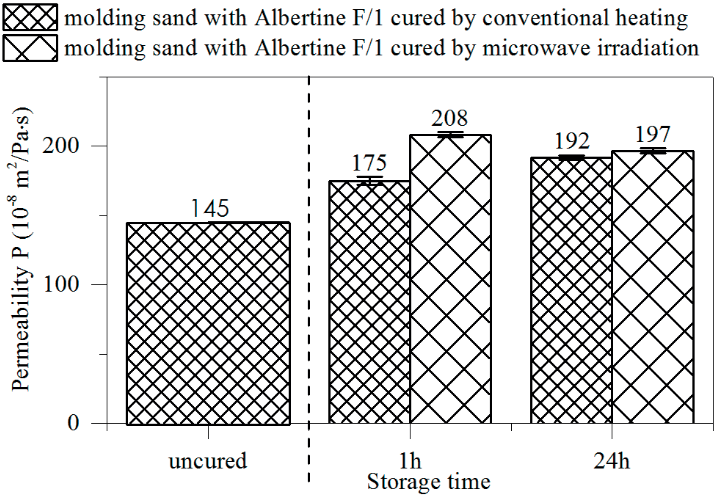

Fig. 1. Permeability of molding sand with Albertine F/1 cured by various physical agents

Analysis of the value of the tensile strength of molding sand after curing indicated that the use of microwave radiation did not cause a fully satisfactory result as with the 1- and 4-hour storage fittings. The remained at a low level of 0.10–0.12 (±0.01) MPa.

Conventionally cured molding sand has a higher tensile strength as compared to microwave-cured molding sand. In the results of curing samples in a dryer, an approximately five-fold-higher value could be obtained; i.e., 0.45 (±0.09) and 0.57 (±0.01) MPa after 1- and 4-hour sample storage, respectively. The dispersion of the obtained values of tensile strength after 1 hour of storage (±0.09) could result from uneven heat distribution in the dryer chamber and an incomplete curing of all samples.

The measurement conducted after 24 hours of storage showed that the microwave-cured and conventionally cured molding sand achieved strength at a similar level. Thevalue of conventionally cured molding sand was 1.27 (±0.02) MPa, and the microwave-cured was 1.18 (±0.01) MPa. These values differed slightly, which indicated the almost identical impact of the two methods of physical curing on this property of the molding sand with binder Albertine F/1.

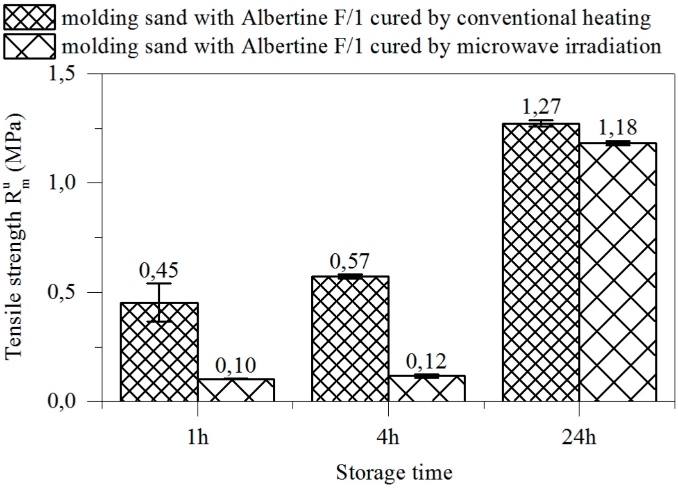

Fig. 2. Tensile strength of molding sand with Albertine F/1 cured by various physical methods

Another property determined in order to assess the effectiveness of the curing agent was the wear resistance (*S*). The obtained results are summarized in Figure 3.

The molding sand cured by conventional heating obtained an *S* value of approx. 0.92% (±0.10), 0.89% (±0.10), and 1.04% (±0.15) after 1, 4, and 24 hours of storage, respectively. With a regard to the measurement uncertainty of the results, it was noted that the wear resistance values of molding sand cured conventionally by heating were maintained at a similar level throughout the measurement duration.

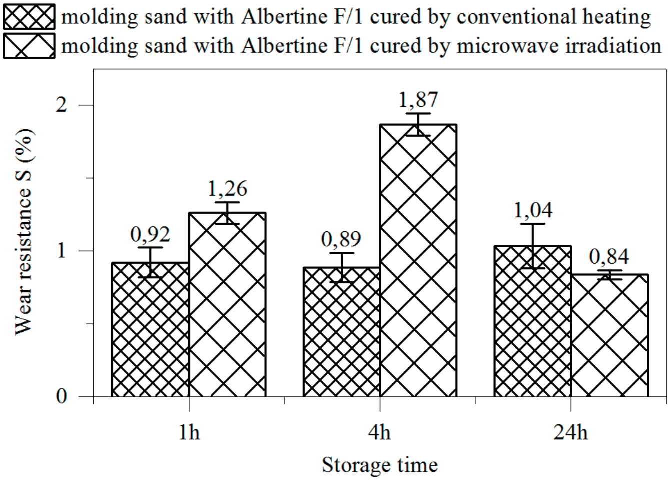

Fig. 3. Wear resistance of molding sand with Albertine F/1 cured by various physical methods

Microwave-cured molding sand initially showed an increase wear resistance from 1.26% (±0.07) after 1 h to 1.87% (±0.08) after 4 h of sample storage; but after 24 hours, the *S* value had visibly decreased to 0.84 MPa (±0.03). These changes can be caused by the dehydration of molding sand during intensive heating samples in microwave irradiation, and then in the cooling process, the evaporation of water from the samples was still observed. The *S* value decreased to 0.84% after 24 h, presumably due to the natural ability to adsorb moisture from the ambient by starch products and aluminosilicates. This allowed a more-permanent bonding of the matrix grains of quartz on the surface of the cured molding sand samples.

6. Summary

The results of this work demonstrated that:

- first of all, it was possible to conduct microwave-curing molding sand with binder in the form of a mixture of starch derivatives and aluminosilicates,
- through the use of innovative methods of curing, it was possible to significantly shorten the duration and reduce the energy consumption of the drying process of molding sand involving binder Albertine F/1,
- molding sand cured by conventional heating after a short storage time (1 and 4 h) was characterized by better strength properties and better wear resistance as compared to molding sand cured by microwave,
- both microwave-cured molding sand and molding sand that was conventionally cured by heating achieved favorable properties after long-time storage under ambient conditions,
- after 24 hours of sample storage, the values of permeability, tensile strength, and wear resistance of the molding sands subjected to curing by conventional heating or cured by exposure to microwave irradiation were similar. This evidenced an almost identical effectiveness of both methods of physical curing of molding sand with binder Albertine F/1.

References

[1] Burian A.: Nové ekologické pojivové systemy. Slévárenstvi 57, 1–2 (2009), 6

[2] Lewandowski J.L.: Tworzywa na formy odlewnicze. Wydawnictwo Naukowe AKAPIT, Kraków, 1997

[3] Eastman J., Herreid R.: TEKSID and FATA put GMBOND® to the Test. Foundry Management & Technology,130, 9 (2002), 36–40

[4] Zhou X., Yang J., Guohiu Q.: Study on synthesis and properties of modified starch binder for foundry. Journal of Materials Processing Technology, 183, 2–3 (2007), 407–411

[5] Shehu T., Bhatti R.S.: The use of Yam flour (starch) as binder for sand mould production in Nigeria. World Applied Sciences Journal, 16 (2012), 858–862

[6] Opaluwa A., Oyetunji A.: Evaluating the Baked Compressive Strength of Produced Sand Cores Using Cassava Starch as Binder for the Casting of Aluminium Alloy T-Joint Pipe. Journal of Emerging Trends Engineering and Applied Sciences, 3, 1 (2012), 25–32

[7] Atanda P.O., Olorunniwo O.E., Alonge K., Oluwole O.O.: Comparison of Bentonite and Cassava Starch on the Moulding Properties of Silica Sand. International Journal of Materials and Chemistry, 2 (2012), 132–136, doi: 10.5923/j.ijmc.20120204.03

[8] Yu W., He H., Cheng N., Gan B., Li X.: Preparation and experiments for a novel kind foundry core binder made from modified potato starch. Materials & Design, 30 (2009), 210–213, doi:10.1016/j.matdes.2008.03.017

[9] Grabowska B., Holtzer M., Dańko R., Górny M., Bobrowski A., Olejnik E.: New BioCo binders containing biopolymers for foundry industry. Metalurgija, 52 (2013), 47–50

[10] Grabowska B., Sitarz M., Olejnik E., Kaczmarska K.: FT-IR and FT-Raman studies of cross-linking processes with Ca^{2+} ions, glutaraldehyde and microwave radiation for polymer composition of poly(acrylic acid)/sodium salt of carboxymethyl starch – Part I. Spectrochimica Acta, Part A, 135 (2015), 529–535, doi:10.1016/j.saa.2014.07.031

[11] Grabowska B.: Microwave crosslinking of polyacrylic compositions containing dextrin and their applications as molding sands binders. Polimery, 54, 7–8 (2009), 507–513

[12] Grabowska B., Kaczmarska K.: FT-IR studies of the polymeric binder BioCo1 with modified biopolymer – Part I. Metallurgy and Foundry Engineering, 40, 2 (2014), 63–68

[13] Kaczmarska K., Grabowska B.: Biodegradation of a new polymer binder based on modified starch in a water environment. Metallurgy and Foundry Engineering, 40, 1 (2014), 7–14

[14] Zhou X., Yang J., Sua D., Qu G.: The high-temperature resistant mechanism of starch composite binder for foundry. Journal of Materials Processing Technology, 209 (2009), 5394–5398, doi:10.1016/j.jmatprotec.2009.04.010

[15] Zhou X., Yang J., Qian F., Qu G.: Synthesis and application of modified starch as a shell-core main adhesive in a foundry. Journal of Applied Polymer Science, 116 (2010), 2893–2900, doi: 10.1002/app.31781

[16] Stachowicz M., Granat K., Nowak D.: Application of microwaves for innovative hardening of environment-friendly water-glass moulding sands used in manufacture of cast-steel castings. Archives of Civil and Mechanical Engineering, 11 (2011), 209–219

[17] Granat K., Nowak D., Pigiel M., Stachowicz M., Wikiera R.: Microwaves energy in curing process of water glass molding sands. Archives of Foundry Engineering, 7, 1 (2007), 183–188