

Effect of Overheating Degree on Activation Efficiency of Water-glass Containing Sandmix Hardened by Traditional Drying

M. Stachowicz

Wroclaw University of Technology, Department of Foundry Engineering, Plastics and Automation,
Smoluchowskiego 25, 50-372 Wrocław, Poland

Corresponding author. E-mail address: mateusz.stachowicz@pwr.edu.pl

Received 29.04.2015; accepted in revised form 01.06.2015

Abstract

Presented are results of a preliminary research on the possibility to use innovative operations of activating inorganic binders during a reclamation process of used sandmixes containing water-glass, hardened by traditional drying. The moulding sand to be examined was prepared of high-silica sand and the selected water-glass grade 145. Next, it was subject to mixing components, compacting, hardening by traditional drying at 100°C, thermal loading of the mould up to 800°C, cooling-down to ambient temperature, knocking-out, various kinds of mechanical dry and wet reclamation to restore bonding properties to the sandmix. For examinations, two ranges of overheating the mould were selected, determined on the grounds of final strength (R_c^{tk}) of the sandmixes. It was found, among others, that overheating and dedusting affect activation of a used sandmix. There is a possibility of partial restoring binding properties of the binder by its rehydration in used-up and properly processed moulding sand, provided that hardening was performed by a physical method.

Keywords: Foundry engineering, Water-glass containing moulding sands, Overheating degree, Reclaimed binder, Recycling

1. Introduction

The group of intensively utilized natural resources includes aggregates applied for manufacture of moulding and core sands. Because of generally easy availability and low purchase cost, beds of high-silica sands are exploited in masses, which causes irreversible changes in the environment. Therefore, a very topical and important question is reducing exploitation of natural deposits of the resources, from which fresh moulding sands for foundry engineering are acquired. At present, intensive works are continued on improving the methods of reclaiming sands from used sandmixes in order to reuse them as full-value bases. These methods are jointly named the reclamation process that consists in separating the bonding material (binder), chemically and

thermally reacted to a different degree, from base grains of used moulding sand.

As previous researches showed, high-silica based sandmixes containing water-glass can be successfully activated in order to restore their bonding properties provided that their hardening was performed by physical methods [1]. The physical hardening methods that enable later reclamation of the binder in used sandmixes include traditional drying [2] or heating with electromagnetic waves of frequency 2.45 GHz [3-5]. Drying in order to harden loose self-hardening sandmixes containing various binders can be an alternative solution for numerous known and applied chemical hardening methods, like the CO₂ process, i.e. blowing-through with carbon dioxide at a controlled temperature [6], or hardening with liquid esters [7]. Drying equipment is often available in foundries, so the traditional

method of drying sandmixes containing water-glass is much easier for practical use than the faster microwave heating.

However, in order that this eco-friendly and economically justified activation technology can find wide application in practice, more detailed recognition of the reclamation process of used binder is necessary, as well as complete knowledge of factors and phenomena deciding mechanical and technological parameters of the sandmix, obtained by hardening.

To this end, the sandmixes chosen for preliminary examinations on possibilities of activation should differ from each other in overheating degree of the hardened binder. Therefore, an attempt was made to determine final strength R_c^{tk} in wide temperature range. The sandmixes for these examinations were formed in cylindrical specimens according to the standard PN-83/H-11073 and subjected to physical hardening methods. After cooling-down to ambient temperature, the specimens were placed in the chamber of a silit furnace and held for 30 minutes at a determined temperature, every 100°C within 100 to 1000°C. After the heating process, the specimens were taken out and cooled-down to ambient temperature in fresh air. After reaching this temperature, the specimens were subject to destructive testing on a device LRuE-2e for mechanical testing of moulding sands. Figure 1 shows a comparison of R_c^{tk} values for the sandmix containing 1.5 wt% of binder, hardened by two physical methods: traditional drying in an oven at 100°C and heating with electromagnetic microwaves of frequency 2.45 GHz [8].

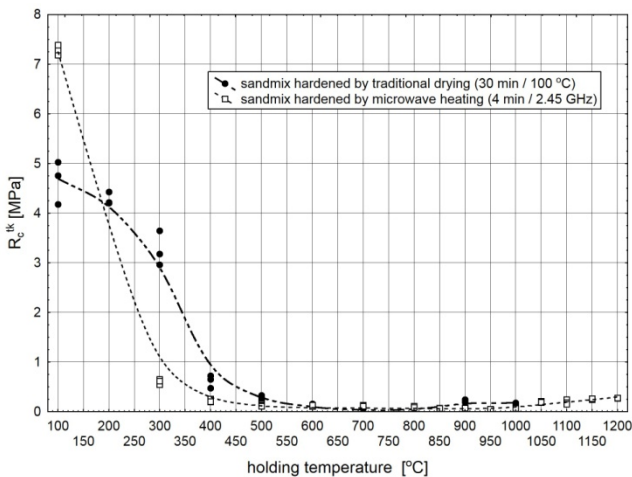


Fig. 1. Effect of holding temperature on final strength R_c^{tk} of sandmixes containing grade 145 binder (1.5 wt%) hardened by traditional drying and microwave heating [8] within 100 to 1200°C

It was found on the grounds of own results and those in [8] that both physical hardening methods give similar results, as demonstrated by course of the R_c^{tk} curves. The most important difference was observed in the initial heating period from 100 to 300°C, where at 100°C the sandmix heated with microwaves showed much higher strength. These results are confirmed by those published in [4]. It was also found that both sandmixes are characterised by low final strength R_c^{tk} within 400 to 1000°C, which can show a significant restriction of influence of active compounds present in the air [8]. The sandmixes held in this

temperature range (Fig. 2) and then cooled-down to ambient temperature can be easier for knocking-out, but this phenomenon also can be important in the researches on effective activation of these sandmixes.

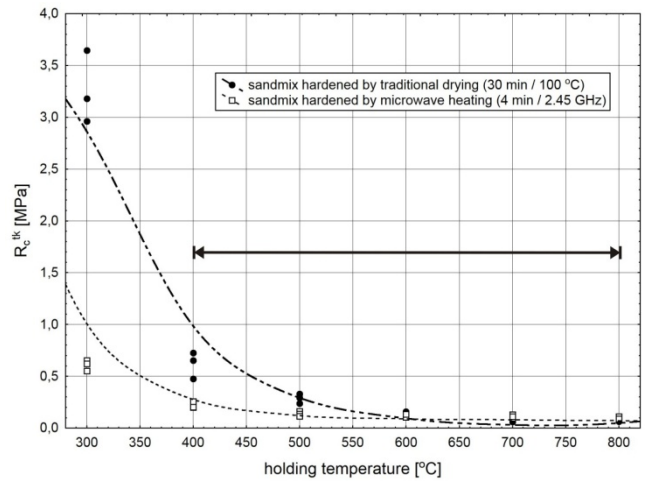


Fig. 2. Effect of holding temperature on final strength R_c^{tk} of sandmixes containing grade 145 binder (1.5 wt%) hardened by traditional drying and microwave heating within 300 to 800°C

On the grounds of SEM observations of traditionally dried sandmixes, no visible destruction of linking bridges under elevated temperature within 100 to 300°C was found. Under action of a temperature within 300 to 800°C, more and more fractures of linking bridges appeared, however nature of their destruction was various depending on the holding temperature. After holding at the temperatures coming closer to 800°C, nature of the cracks is hardly definable, see Fig. 3.

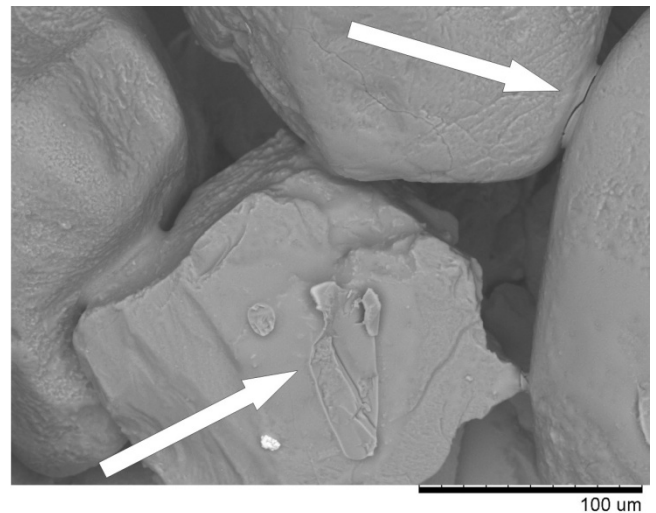


Fig. 3. Linking bridges after holding traditionally dried sandmix at 800°C

It was found on the grounds of microscopic observations and mechanical testing of R_c^{tk} that activation process of base grain

surfaces aimed at reclaiming the thermally reacted binder can be affected by its ability for secondary hydration, related to the overheating degree.

2. Purpose of the research

Within the research, an attempt was made to explain whether the reaction reverse to dehydration in the hardening process will be of practical importance for determining activation possibilities of used, thermally reacted inorganic binders in traditionally dried moulding sands. It was assumed that, depending on temperature distribution in the mould, the sandmix can show various ability for activation because of diverse thermal conversion degree of the binder. Moreover, it was assumed in the research that, by selecting proper devices for processing used sandmixes, it will be possible to activate the thermally reacted binder present on grain surfaces of high-silica base. Proper sequence, as well as parameters of dry and wet mechanical reclamation, should ensure, to possibly highest extent, restoring bonding properties of the binder by its rehydration.

A result of the research can be restricted demand for fresh high-silica sand and the binder. This is of particular importance at the time of restrictive law protecting the environment of human life and work, as well as natural resources of the Earth.

3. Methodology of the research

The examined moulding sands were prepared with use of standard high-silica sand, medium 1K with its main fraction 0.20/0.16/0.315 from the mine Grudzeń Las, and unmodified water-glass grade 145 made by Chemical Plant "Rudniki" S.A. 6 kg of the sandmix were prepared in a laboratory ribbon mixer, by adding to the sand 0.5 wt% of water and 1.5 wt% of binder. The components were stirred for 4 minutes. Introduction of water at the beginning of stirring reduced dusting and facilitated uniform distribution of small amounts of the dosed binder. Next, formed sandmixes were dried in a laboratory drier SL 53 TOP+ with capacity of 56 l, equipped with a fan forcing circulation of air heated to $100 \pm 0.1^\circ\text{C}$. During moulding, the sandmixes were vibration-compacted on a device LUZ-2e.

After moulding, traditional drying at 100°C and cooling-down, the moulds were subjected to thermal load at $800 \pm 5^\circ\text{C}$. Thanks to properly selected mass of the prepared moulds, obtained were two ranges of gradient overheating in their entire volumes: first one (ways A and B) between $350 \pm 50^\circ\text{C}$ and $800 \pm 5^\circ\text{C}$ and second one (ways A1 and B1) between $100 \pm 50^\circ\text{C}$ and $800 \pm 5^\circ\text{C}$. After cooling-down and breaking the moulds, attempts were made to reclaim the binder using the "type K" activating device. This device performs mechanical operations: crushing-grinding-stirring with a possibility to apply intensive dedusting during operation. Table 1 shows the ways of using the activating device, chosen for preliminary examinations, and times of the carried-out operations.

Table 1. Operation ways applied in preliminary examinations on activation of inorganic binders in used-up sandmixes traditionally dried

Activation way	Preliminary mechanical dry activation without dedusting in the "type K" device (4 minutes)	Preliminary mechanical dry activation with dedusting in the "type K" device (4 minutes)	Mechanical wet activation in the "type K" device (8 minutes)
A	yes	-	yes
A1	yes	-	yes
B	-	yes	yes
B1	-	yes	yes

The task of the „type K” device was preliminary disintegration of moulding sand, knocked-out, agglomerated and cooled-down to ambient temperature. The following operations were applied to activate grain surfaces of high-silica base: abrading and grinding the film of glassy sodium silicate. Figures 4 and 5 show SEM images of high-silica base grains after mechanical activation in the "type K" device without dedusting (ways A and A1) or with intensive dedusting (ways B and B1).

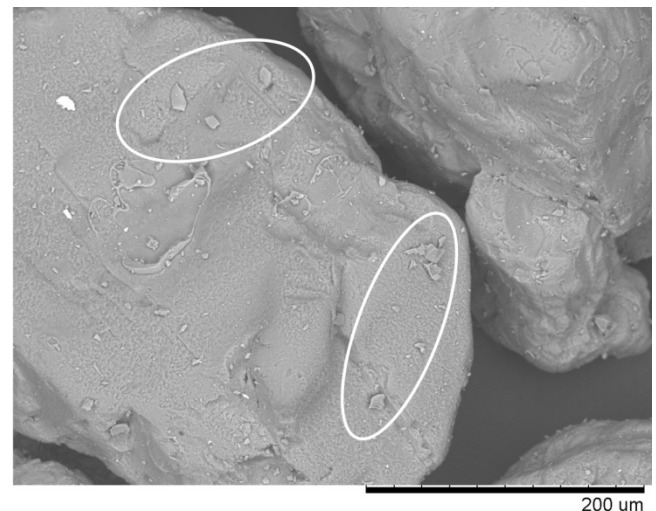


Fig. 4. View of high-silica base grains after overheating and mechanical activation without dedusting (in the ways: A and A1) of the used sandmix hardened by traditional drying with observed large number of small particles

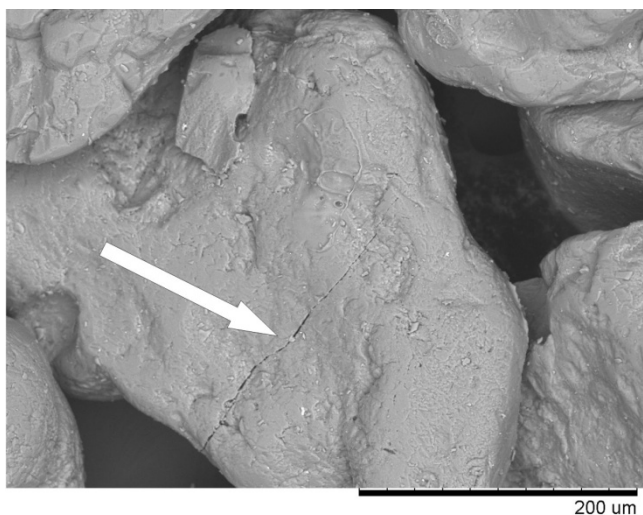


Fig. 5. View of high-silica base grains after overheating and mechanical activation with dedusting (in the ways: B and B1) of the used sandmix hardened by traditional drying with observed fragile cracking

Analysis of SEM observations of grain surfaces of high-silica base after preliminary mechanical reclamation revealed an effect of intensive dedusting on presence of fragments of linking bridges on grain surfaces of the processed sandmix. On base grain surfaces of the sandmix not subject to dedusting (ways A and A1), a larger amount of loose particles from 5 to 20 μm (Fig. 5) was found in comparison to the ways B and B1, where intensive removing of loose particles was applied.

Reduction of quantity of the particles released during mechanical reclamation can influence further activation process of thermally reacted binder, thus restricting its effectiveness. In order to explain the effect of intensive dedusting on activation effectiveness of base grain surfaces, applied was the subsequent stage of the research with use of the elements accompanying the wet reclamation. To this end, the „type K” device was used again (see Table 1), to that chamber a small, constant amount of water was dosed during operation. Thank to that operation, it was possible to restore bonding bridges to the used-up binder, left on grain surfaces of high-silica base. After preparing the sandmix with activated binder, an attempt was made to determine effectiveness of the applied ways of its reclamation. To this end, the activated sandmix was subject again to forming in cylindrical specimens and hardening by two physical methods. Then, after cooling-down the specimens to ambient temperature, mechanical testing was carried-out.

4. Results

Effectiveness of the activation ways was measured by means of compression strength R_c^U reached by hardened sandmixes. Cylindrical specimens of the sandmixes containing reclaimed binder were dried in two ways: traditionally at $100 \pm 0.1^\circ\text{C}$ for 30 minutes or in the chamber of a 1000-W microwave oven for 4 minutes. Thanks to using these two physical hardening methods,

it was possible to determine, among others, influences of overheating degree, dedusting operation and the environment on creating linking bridges of the reclaimed binder. With regard to velocity of the drying process in the entire specimen volume, the microwave heating method enables, during hardening the binder, significant restriction of influence of the factors like carbon dioxide and slow heat transmission. Results of comparative examinations for both physical hardening methods are shown in Fig. 6. The compression strength values are average values of three measurements. The obtained R_c^U values were related to those measured for the sandmix prepared of exclusively fresh components.

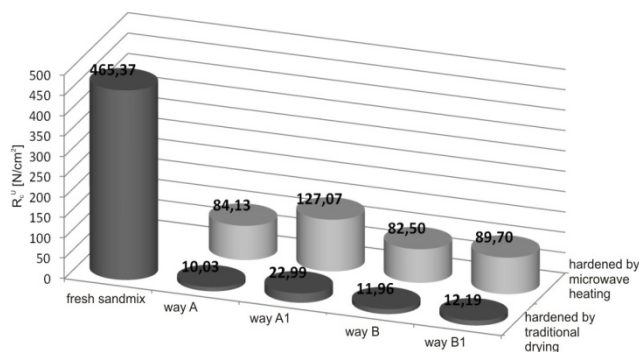


Fig. 6. Compression strength of sandmixes hardened by physical methods: fresh sandmix and the sandmixes after activation in the ways A and A1 or B and B1

As results from the examinations, the specimens traditionally dried were unable to bear compression loads, regardless of the activation way and overheating degree. Moreover, they were characterised by high grindability and difficulties during transport, see Fig. 7a. In addition, it was difficult to install the specimens on the measuring device correctly.

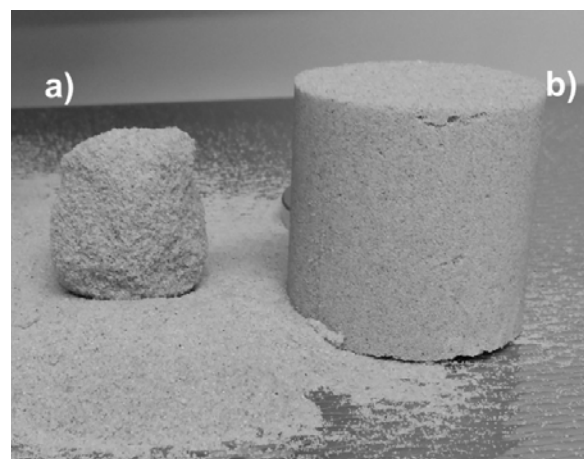


Fig. 7. Cylindrical specimens of reclaimed sandmix: one characterised by high grindability of the outer layer subjected to action of hot air during traditional drying (a) and one after rapid microwave heating (b)

Of the same activated sandmixes, cylindrical specimens were formed and subject to microwave heating, see Fig. 7b. Thanks to rapid hardening by electromagnetic waves of frequency 2.45 GHz, obtained was several times higher strength R_c^U . The effect of higher strength, in comparison to the specimens dried traditionally, probably resulted from the action of active compounds (e.g. CO_2) present in hot air in the drier chamber.

Application of rapid microwave heating made it possible to emphasize effectiveness of the applied activation ways in the "type K" device. From among the four suggested ways (A, B, A1 and B1), the best results were obtained by the method A1 without dedusting, where the sandmix was overheated within $100 \pm 50^\circ C$ to $800 \pm 5^\circ C$. In comparison to the way A, strength of the specimens activated in the way A1 was 34% higher. Similarly, a better result of activation for the sandmix overheated in this range was obtained for the way B1 than for the way B. The sandmix activated in the way A (overheated to a higher degree) without dedusting showed susceptibility to activation similar to that of the sandmix overheated to the same degree in the way B, where dedusting was applied. So, in the subsequent research, the necessity should be considered to apply dedusting during the planned cyclical performing activation processes of used-up sandmixes. This could be important for technological parameters of the sandmixes, like permeability and refractoriness.

Results of mechanical testing were confronted with microscopic observations carried-out on aggregated fragments of reclaimed sandmixes dried in traditional way and hardened with microwaves. With use of a scanning microscope, observations were performed of the places where new linking bridges could be created of the reclaimed binder present on surfaces of base grains, as shown in Figs. 8, 9 and 10.

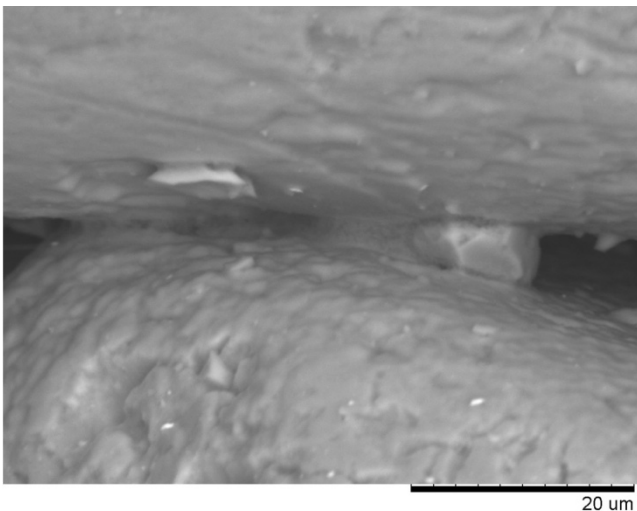


Fig. 8. A linking bridge created during traditional drying from the binder reclaimed in the way A1

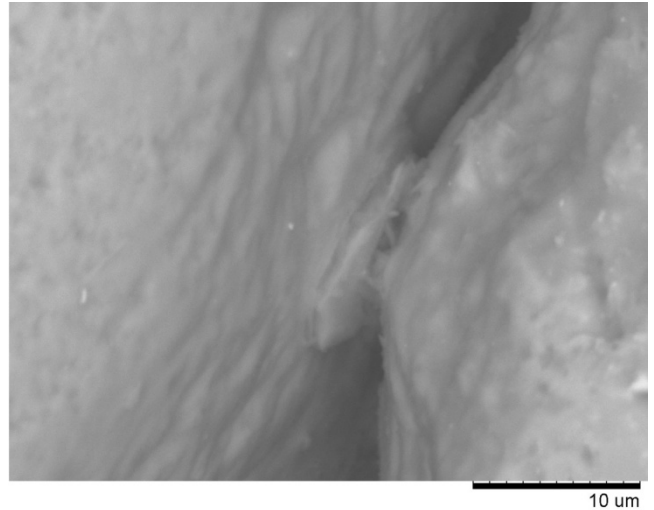


Fig. 9. View of small linking bridge created during traditional drying from the binder reclaimed in the way B1

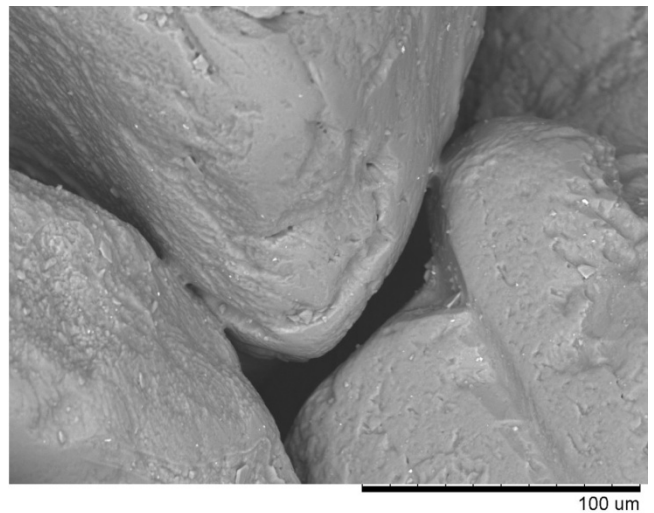


Fig. 10. View of few linking bridges created during microwave hardening from the binder reclaimed in the way A1

The performed observations confirmed the previously measured R_c^U values, see Fig. 6. For both drying methods, the linking bridges of partially reclaimed binder were characterised by irregular shape, other than the observed characteristic, smooth links specific for the sandmix prepared of exclusively fresh components [9].

5. Conclusions

In the research on the possibility to reclaim used-up inorganic binders, confirmed was occurrence of the phenomenon of secondary hydration (rehydration) under the influence of specific ways of mechanical dry and wet activation of sandmixes containing water-glass, hardened by traditional drying. The

obtained results of mechanical testing after activation and repeated hardening of sandmixes were confirmed in microscopic observations in form of the presence of linking bridges created from the reclaimed binder. The linking bridges created after activation of grain surfaces of high-silica base were different than those created of fresh binder. Their irregular shapes and smaller foundation areas indicate the reason of five- or even sixfold lower strength of a sandmix reclaimed and hardened again.

In the research, indicated are two possible ways of activating base grain surfaces in the "type K" device. It was found on this ground that the activation ways with intensive dedusting influence mechanical properties of sandmixes. Removing particles of the thermally reacted binder reduces effectiveness of the binder reclamation processes. During preliminary mechanical reclamation in the "type K" device, observed was fragile cracking of high-silica grains, especially in the sandmixes with smaller overheating degree (from 100 ± 50 to $800 \pm 5^\circ\text{C}$).

Moreover, it was found that overheating degree of a sandmix influences effectiveness of the activation processes. The sandmixes overheated from 350 ± 50 to $800 \pm 5^\circ\text{C}$ were characterised by smaller susceptibility to reclamation (rehydration) of the binder than those overheated from 100 ± 50 to $800 \pm 5^\circ\text{C}$. Therefore, effectiveness of activation operations is affected by the degree of thermal conversion (dehydration) of the binder present on surfaces of base grains.

Application, for comparative purposes, of two physical methods of hardening, i.e. traditional drying and microwave heating, revealed influence of convective and volumetric ways of hardening the film of reclaimed binder. In particular, attention was drawn to the possibility of adverse influence of carbon dioxide present in the air. Accelerating the traditional drying process together with limiting the influence of active chemical compounds during hardening a reclaimed binder will contribute to further increase of activation effectiveness, and thus to higher strength of the sandmix.

The performed examinations make a basis to continue searching a method that would give possibilities to carry-out cyclical activation of used-up moulding sands dried in traditional way, so that they could play the role of eco-friendly circulating sandmixes.

Acknowledgements

The research was financially supported from the grant for statutory activity No. B40099/K1012.

References

- [1] Stachowicz, M. & Granat, K. (2014). Possibilities of reclamation microwave-hardened molding sands with water glass. *Archives of Metallurgy and Materials*. 59(2), 757-760.
- [2] Stachowicz, M. (2015). Possibility of activating used-up inorganic binders on the example of sandmixes containing water-glass hardened by traditional drying. Conference „Foundry engineering. Technology – Practice – Ecology” Karpacz. 25-27.03.2015. (in Polish).
- [3] Grabowska, B., Kaczmarska, K. & Bobrowski, A. (2012). Research on recondition of polymeric foundry bonders. *Archives of Foundry Engineering*. 12(spec. 1), 47-52. (in Polish).
- [4] Stachowicz, M., Granat, K. & Nowak, D. (2010). Studies on the possibility of more effective use of water glass thanks to application of selected methods of hardening. *Archives of Foundry Engineering*. 10(spec. 2), 135-140.
- [5] Wang, J., Fan, Z. & Zan, X. (2009). Properties of sodium silicate sand hardened by microwave heating. *China Foundry*. 6(03), 191-196.
- [6] Samsonowicz, Z. (1974). Reasonable hardening of water-glass containing sandmixes blown-through with carbon dioxide. *Foundry Review*. 24(10), 309-311. (in Polish).
- [7] Zych, J. (2005). Optimisation of mould technology based on water-glass containing sandmixes hardened with esters. *Foundry Review*. 12. (in Polish).
- [8] Stachowicz, M., Granat, K. & Nowak, D. (2011). Influence of water-glass grade and quantity on residual strength of microwave-hardened moulding sands. *Archives of Foundry Engineering*. 11(1), 93-98.
- [9] Stachowicz, M., Nowak, D., Granat, K., Haimann, K. (2009). Effect of hardening methods on structure of linking bridges in water-glass containing sandmixes. Proceedings of XXXVII School of Materials Engineering, Kraków-Krynica, 23 IX-2 X 2009 [monograph ed. by Jerzy Pacyna]. Kraków: Polygraphic Services Shop. 342-346. (in Polish).