Effect of hardening methods of moulding sands with water glass on structure of bonding bridges

M. Stachowicz a, K. Granat a,*, D. Nowak a, K. Haimann b

a Foundry and Automation Team, Wroclaw University of Technology, ul. Łukasiewicza 5, 50-371 Wroclaw, POLAND
b Materials Science Team, Wroclaw University of Technology, ul. Smoluchowskiego 25, 50-370 Wroclaw, POLAND
* Corresponding author. E-mail adress: kazimierz.granat@pwr.wroc.pl

Received 30.04.2010; accepted in revised form 01.07.2010

Abstract

Research on influence of hardening methods on structure of bonding bridges in moulding sands with sodium water glass is presented. Moulding sands with addition of 2.5% of binder with molar module 2.0 were hardened with CO2 and dried in traditional way or hardened with microwaves. It was proved that the hardening method affects structure of bonding bridges, correlating with properties of the hardened moulding sands. It was found that strength of the moulding sands hardened with microwaves for 4 min is very close to that measured after traditional drying at 110 °C for 120 min. So, application of microwave hardening ensures significant shortening of the process time to the value comparable with CO2 hardening but guaranteeing over 10-fold increase of mechanical properties. Analysis of SEM images of hardened moulding sands permitted explaining differences in quality parameters of moulding sands by connecting them with structure of the created bonding bridges.

Keywords: innovative foundry technologies, water glass, moulding sand, microwaves, CO2 process

1. Introduction

Water glass, being a water solution of sodium silicate, has been used in foundry technique for over sixty ears for manufacture of mould and core moulding sands. Along with technical progress and widening knowledge on this inorganic binder, many hardening methods of it containing moulding sands were developed, including blowing with carbonic anhydride in the CO2 process and drying with air at higher temperature[1]. There are also many other hardening methods, but they do not make the subject of this work.

In order to find innovative solutions in foundry industry, undertaken are, among others, trials of using microwave energy for quick manufacture of moulds and cores of moulding sands containing water glass. Of particular interest is microwave radiation with frequency 2.54 GHz and wavelength 12.2 cm, known first of all from household microwave ovens. Despite popularity of their application, not all the mechanisms of influence of microwaves on various materials and their connections (mixtures, solutions) are completely recognised. Possibly exact recognition of the effects of microwave interaction can result in introducing innovative solutions in many fields of the economy, including foundry practice. As the research works indicate, the so-far used energy- and time-consuming technologies can be replaced by cheaper and shorter-time processes utilising the above-mentioned microwave radiation. It results from comparison of the traditional and microwave drying processes that energy consumption in the latter solution is even 10 to 100 times less and its duration is 10 to 200 times shorter than at traditional drying [2].

Analysis of the so-far published results [3] shows that quality of the water glass coat created on the base grains and of the
bridges between them in mould and core moulding sands depends mostly from the way of transformation of orthosilicic acid sol [1] to silica gel, and therefore depends on the applied hardening method. Figs. 1, 2 and 3 show examination results of basic parameters of moulding sands with water glass (strength values $R_{U}^{I}$, $R_{U}^{U}$ and $R_{m}^{U}$), which can be accepted as quality indices for bonds created between the base grains (bonding bridges).

Moulding sands were prepared with five grades of water glass and hardened in three ways: in the CO$_2$ process, by traditional drying and by microwave hardening [3].

![Fig. 1. Effect of water glass molar module on compression strength of moulding sands hardened by three methods [3]](image1)

Analysis of compression strength values for five grades of sodium water glass with module from 2.0 to 3.3 (Table 1) indicates that the results of traditional drying and of microwave hardening are similar and much higher than those measured for the CO$_2$ process. In the case of the parameters $R_{U}^{I}$ and $R_{m}^{U}$, however, one can see quality differences between water glass bonds after traditional drying and after microwave hardening, in favour to the innovative microwave technique.

![Fig. 2. Effect of water glass molar module on bending strength of moulding sands hardened by three methods [3]](image2)

![Fig. 3. Effect of water glass molar module on tensile strength of moulding sands hardened by three methods [3]](image3)

As can be seen in Fig. 4, application of microwave hardening for moulding sands with hydrated sodium silicate increases quality of the created bonds of base grains. For a given binder content, strength values of moulding sands after microwave hardening are higher than those obtained after traditional drying, with maintained short hardening time, characteristic for the CO$_2$ process.

![Fig. 4. Fracture surface of moulding sand hardened with microwaves, obtained in tensile test. Visible bright envelopes on grain surface are residues after bonding bridges. Light microscopy, 28.5x](image4)

The presented work was aimed at explaining, on the grounds of examining bonding bridges created during hardening moulding sands with water glass by three selected methods, differences in their creation processes and thus influence of bonds between silica base grains on mechanical and technological properties of the examined moulding sands.
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2. Examined materials and moulding sand preparation

Moulding sands were prepared of silica sand 1K from the mine Nowogród Bobrzański with the main fraction 0.32/0.2/0.16 and sodium water glass grade 150 produced by Chemical Works "Rudniki" S.A., with properties (acc. to the works certificate) given in Table 1. The above-mentioned water glass grade was selected for the research because of its highest dynamic viscosity equal to 1 and content of oxides SiO₂ and Na₂O.

Components were mixed in a laboratory muller mixer [5,6]. According to the literature recommendation, individual components were dosed in the following portions: silica sand 97 %, water glass 2.5 % and water 0.5 % with observed proper sequence of dosing. First, silica sand was mixed with water for 60 s to reduce dusting and improve wettability of grains, then binder was added and mixed for the next 180 s.

Of the so prepared moulding sands, specimens were prepared on a laboratory rammer in identical way as for mechanical tests. From the specimens, samples were taken for SEM observations. Apparent density obtained by ramming ranged from 1.55 to 1.64 g/cm³.

3. Moulding sands hardening methods

Strength of bonds between base grains is affected by both cohesion forces of bonding bridges and adhesion forces in the assembly water glass – surface of silica grains. Considering the adhesion forces it should be emphasized that of decisive importance for good distribution of water glass on the base surface is low viscosity of water solution of sodium silicate. In [6], presented are viscosity test results at 10 to 50 °C of sodium water glass with module 2.5 and identical dynamic viscosity (P) as the considered here water glass with module 2.0. It was found on the ground of those examinations that viscosity of sodium water glass does not significantly change in the considered temperature range. However, it was found in [5] that viscosity changes with further temperature increase, which can deteriorate wettability of the grains surface and, as a consequence, can pose a trouble in the case of traditional drying or microwave hardening.

The problem of proper distribution of water glass on the base grains surface and creation of bonds between them should be examined considering changes occurring at temperatures above 50 °C. Heating at both drying and microwave hardening processes can significantly affect viscosity and wettability of the silica base grains. When examining structure of bonding bridges, one should take into account hardening speed of the binder and intensity of its density changes during creation of silica gel.

At the first hardening method, moulding sand specimens were blown with CO₂ for 60 s under gas pressure 0.02 MPa. In that case, the hardening reaction proceeded according to the formula [1]:

$$\text{Na}_2\text{O}·n\text{SiO}_2·x\text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{Na}_2\text{CO}_3 + n\text{SiO}_2 + x\text{H}_2\text{O} + Q$$  (1)

The other method consisted in drying specimens in a traditional dryer at 110 °C for 120 min. The dehydration reaction proceeded according to the formula [1]:

$$\text{Na}_2\text{O}·n\text{SiO}_2·x\text{H}_2\text{O} + Q \rightarrow \text{Na}_2\text{O}·n\text{SiO}_2$$  (2)

where: n, x – stoichiometric coefficients.

To investigate influence of microwaves on creation of silica gel bonding bridges, the rammed moulding sand was hardened in a microwave chamber for 4 min. On the grounds of the former researches [4], output power of microwaves was fixed at 700 W. The heating process was carried out using the microprocessor-controlled device described in literature [3]. It is supposed that in this case the chemical reaction can proceed according to the formula (2) that describes the water glass dehydration process. Further researches connected with quantitative and qualitative analysis of the microwave hardened coats on silica grains can provide information confirming this hypothesis.
4. Specimen preparation

For further examination of the traditional drying and microwave hardening processes, suitable material portions were taken from the hardened specimens after their temperature equalized with the ambient temperature. Hardened moulding sand for SEM observations was taken in a way excluding additional stresses which could result in cracking of the water-glass film created during hardening.

Specimens for SEM observations were sprayed with graphite.

5. Examination results

View of the coat on grains and their connecting bridge created at the CO₂ hardening process is shown in Figs. 5 and 6.

The bonding bridge in Fig. 5 shows numerous cracks and exfoliated portions of hardened water glass, which reduce total strength of the moulding sand. The observed cracks are not only superficial but also penetrating (a bridge fragment indicated by an arrow) and run deeply into the bonds between sand grains.

Cracks are also visible in the areas of water glass concentration in irregularities and pits on the silica grain surfaces, see Fig. 6. Low adhesion forces (low strength) in the CO₂ process permit easier regeneration of used moulding sand, but obtaining the specified strength requires adding more binder and extending the blowing time.

Figures 7 and 8 show bonding bridges created after traditional drying. Layer of water glass creating bridges between sand grains is smooth, more regular than at the CO₂ process and with no clearly visible cracks.

As results from Figs. 7 and 8, this hardening method that can significantly affect viscosity due to the solution density changes, is not adverse to shape of the created bridges. Thanks to slow heating, the binder becomes even more fluid and, as a result of further heating and dehydration, is fixed in form of smooth and gentle transitions of the coat in a bridge connecting base grains. The silica grain surface coated with water glass is much less irregular and uneven than in the case of blowing with CO₂. However, some irregularities were found on the film surface in form of cracks (indicated with arrows in Figs. 7 and 8). The observed changes can be the cause of lower strength $R_u$ and $R_m$ with respect to the microwave hardening method.
Fig. 9. Bonding bridges between silica sand grains after microwave hardening

Fig. 10. Smooth transition between sand grains, creating small arches of binder after microwave hardening

Figs 9 and 10 show connections between base bridges after microwave heating of moulding sand with water glass grade 150. The SEM image in Fig. 9 shows influence of quick microwave hardening on creation of durable and strong bonds between the base grains. Like traditional drying, microwave hardening is advantageous for viscosity of the applied binder and surface wettability of quartz at temperatures above 50 °C, exceeding even 120 °C. Surface of the water-glass bridge shown in Fig. 10 is more smooth and free from defects than in the case of traditional drying. The binder heated-up with microwaves creates, probably as a result of surface tension changing during rapid temperature rise, a durable glassy film, gentle and fluently passing to a bonding bridge.

Subsequent stages of the research will include further observations of structures of the other water glass grades used in foundry practice. Moreover, the examinations will be complemented with chemical analysis of coats created during various hardening processes.

5. Conclusions

The obtained results indicate the following:

- Structure and quality of bonding bridges is affected by hardening method of the moulding sand with 2.5 % of sodium water glass grade 150.
- Bonding bridges and coat on the grain surface created after blowing the moulding sand with carbonic anhydrite (CO₂ process) are uneven and cracked.
- Structure of water-glass coats obtained by traditional drying and microwave hardening indicates a similar nature of the water glass dehydration process.
- Cracks visible on surfaces of bonding bridges obtained by traditional drying create some discontinuous areas.
- SEM examinations confirm the relationships between mechanical properties of moulding sand determined in previous basic researches, and structure of bonding bridges.
- Moulding sands with water glass hardened by microwaves, in which bonding bridges and binder coat are smooth and not cracked, are characterised by the highest strength.
- Moulding sands with water glass hardened in the CO₂ process, in which bonding bridges and binder coat are exfoliated and cracked, are characterised by the lowest strength.
- Intensification of heating and rapid evaporation of water during microwave hardening do not deteriorate mechanical properties of moulding sands.
- Change of a moulding sand viscosity during traditional drying and microwave hardening, becoming evident by smooth transition of coat between base grains, results in higher quality of bonds.
- In comparison to traditional drying with a similar result, the innovative microwave hardening is more effective, more efficient and less time-consuming.

References

