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Effect of Sand Wetting on Physically Hardened Moulding Sands Containing a Selected Inorganic Binder. Part 2

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Abstract

In the paper, an attempt is made to explain the previously observed increased effectiveness of utilising hydrated sodium water-glass grade 137 after hardening moulding sands with selected physical methods. In the modified process of preparing sandmixes, during stirring components, water as a wetting additive was introduced to the sand-binder system. Presented are examination results of influence of faster microwave heating and slower traditional drying of the so-prepared moulding sands on their tensile and bending strength, calculated per weight fraction of the binder. The measurement results were confronted with SEM observations of linking bridges and with chemical analyses of grain surfaces of high-silica base. On the grounds of comprehensive evaluation of hardened moulding sands, positive effects were found of the applied physical process of binder dehydration and presence of the wetting additive. It was observed that introduction of this additive during stirring, before adding the binder, improves flowing the binder to the places where durable linking bridges are created. It was also found that the applied methods of hardening by dehydration enable creation of very durable linking bridges, strongly connected with the sand base, which results in damages of high-silica grain surfaces, when the bridges are destroyed.

Keywords: Foundry engineering, Microwaves, Hardening, Moulding sand, Water-glass

1. Introduction

Numerous research methods are applied for evaluating the binder contained in moulding and core sands with respect to its ability to bond the base grains. Even the most complex evaluation method should relate mechanical and technological parameters of the moulding sand with observations of the linking bridges. The standard method of classifying binders according to their quality consists in calculating average tensile strength of the hardened sandmix per 1 wt% of the used binder [1]. According to the recommendations in [1,2], the moulding and core sands containing organic and inorganic binders can be subdivided into three groups with respect to their tensile strength R_m^U calculated per 1 wt% of the binder:

– class I with $R_m^U > 0.5$ MPa;
– class II with R_m^U between 0.3 and 0.5 MPa;
– class III with $R_m^U < 0.3$ MPa.

In the paper [3], another classification of sandmixes containing water-glass into three groups is suggested, with the criteria based on the effects of physical and chemical hardening, determined by bending strength R_g^U calculated per 1 wt% of the binder. The suggested method of evaluating hardened sandmixes is an expansion of the classification according to R_m^U values and can present an equivalent quality index of moulding and core sands.

After calculating the R_g^U values per 1 wt% of the binder, the classification is as follows:

- class I with $R_g^U > 1$ MPa;
- class II with R_g^U between 0.5 and 1 MPa;
- class III with $R_g^U < 0.5$ MPa.

As results from analysis of previous researches on sandmixes [4-5], including those containing water-glass [6-7], there is a possibility of better utilisation of bonding properties of binders thanks to application of modern hardening methods. Of particular importance become the researches on physical hardening methods, like microwave heating at 2.45 GHz and traditional drying, with regard to exceptional possibilities offered by these methods. In the sandmixes being the object of this research, containing water-glass grade 137 and hardened with the a.m. methods, dehydration of the binder takes place, which enables obtaining highest quality linking bridges belonging to the classes I and II acc. to the R_m^U criterion calculated per 1 wt% of the binder (Table 1), likewise in the classification acc. to R_g^U [3]. In the case of standard hardening methods, like e.g. purging with CO_2, water-glass grade 137 is omitted in practical applications for casting moulds and cores because of its low strength characteristic for III-class binders and short life of the sandmix.

Advantages of using water-glass as a binder in foundry industry include low purchase cost and low harmfulness for the environment and human being. Its disadvantages include, first of all, worse knock-out properties, which hampers cleaning the castings of used moulding sand and especially core sand. One of the ways of improving knock-out properties of a sandmix containing hydrated sodium silicate can be restricting its content in the sandmix. Till now, the fraction of 2.5 wt% is considered the minimum, limit concentration of this binder. A smaller content of this binder, e.g. 1.5 wt%, causes problems with maintaining high and fully repeatable quality parameters of casting moulds and cores. In order to stabilise these parameters, an addition of water wetting the sand base was introduced during preparation of the sandmix [8].

Table 1.
Classification of binders acc. to tensile strength of sandmixes [2,9]

Class acc. to Rm^U per 1 wt% of binder	Way of bonding		
	chemical	by solidification	by dehydration
I	synthetic resins, raw drying oils, alloyed oils	–	**water-glass 137**
II	raw semi-drying oils, oil mixtures, ethyl silicate, **water-glass 137**	–	dextrin, starch, **water-glass 137**
III	oil mixtures, gypsum, cement, lime, **water-glass 137**	colophony, tar products	waste sulphite liquor, molasses, starch

It was observed in the paper [8] that quality of linking bridges can be affected by various content of water wetting the high-silica base. Analysis of the examination results showed that, in the case of the sandmixes containing 1.5 wt% of water-glass grade 137, introducing small addition of water during stirring before adding the binder resulted in improved quality of the links between sand base grains, created during hardening with physical methods.

2. Purpose of the research

It results from literature data that water present on surface-active crystalline structure of high-silica base [10] can penetrate micropores of sand grains and, moreover, can create superficial adsorptive and absorptive layers, where water will be bonded with the grain material by hydroxyl groups (OH). Good wettability of sand base and low viscosity of binder increase probability of creating non-enveloped links [11] between the sand base and the bonding material, which give the sandmix higher strength in comparison to those containing enveloped links. In the paper [8] described is the effect of introducing additional water to the sand-binder system subject to physical hardening (slow traditional drying and much faster microwave heating). The expected result of wetting the sand base with an additional amount of water before adding the binder was improvement of mechanical parameters of the sandmix.

The purpose of the presented research was associating this effect with observations of the created linking bridges and explaining the differences between mechanical parameters after the processes consisting in dehydration of the binder.

3. Methodology of the research

To prepare the moulding sands used in the research, applied was dried and cooled-down standard high-silica medium sand 1K with main fraction 0.20/0.16/0.315 from the mine Grudzeń Las and unmodified sodium water-glass grade 137, made by Chemical Plant „Rudniki" S.A. (Table 1).

Table 2.
Physico-chemical properties of water-glass commonly used in foundry practice

Water -glass grade	Molar module SiO_2/Na_2O	Content of oxides (SiO_2+Na_2O) %	Density (20 °C) g/cm^3	Fe_2O_3 % max.	CaO % max.	Dynamic viscosity min. (P)
137	3.2÷3.4	35.0	1.37÷1.40	0.01	0.1	1

In a ribbon laboratory mixer, 6 kg of moulding sand was prepared according to [8], as follows:

- variant 0%: 1.5 wt% of binder was dosed to the sand base after starting the mixer and stirred for 4 minutes;
- variant 0.5%: 0.5 wt% of water was dosed to the sand base after starting the mixer, then, after stirring for 60 s, 1.5 wt% of binder was dosed and stirring was continued for 4 min;
- variant 1%: 1 wt% of water was dosed to the sand base after starting the mixer, then, after stirring for 60 s, 1.5 wt% of binder was dosed and stirring was continued for 4 min.

Next, longitudinal and octal specimens, formed by vibration compacting on a LUZ-2e stand, were hardened:

- by traditional drying – for 30 min in 56-l chamber of a laboratory drier SL 53 TOP+ equipped with a recirculation fan at 100 ±0.1 °C, with the ventilation stack unsealed to remove moisture from the drying chamber;
- by microwave heating – for 4 min in 32-l chamber of a 1000 W microwave furnace.

Mechanical tests were performed on a laboratory stand LRuE-2e for sandmix testing.

4. Results

Results of the examinations of influence of hardening method on properties of the sandmixes containing 1.5 wt% of water-glass grade 137 are shown as average values in Fig. 1.

The results aggregated in Fig 1 are as follows:

→ tensile strength R_m^U per 1 wt% of the binder for the sandmix hardened by microwave heating,

→ tensile strength R_m^U per 1 wt% of the binder for the sandmix hardened by traditional drying,

→ bending strength R_g^U per 1 wt% of the binder for the sandmix hardened by microwave heating,

→ bending strength R_m^U per 1 wt% of the binder for the sandmix hardened by traditional drying.

Observations of linking bridges were performed on fragments of test pieces after mechanical testing, using a scanning microscope equipped with an EDS analyser. Results are shown in Figs. 2 to 4.

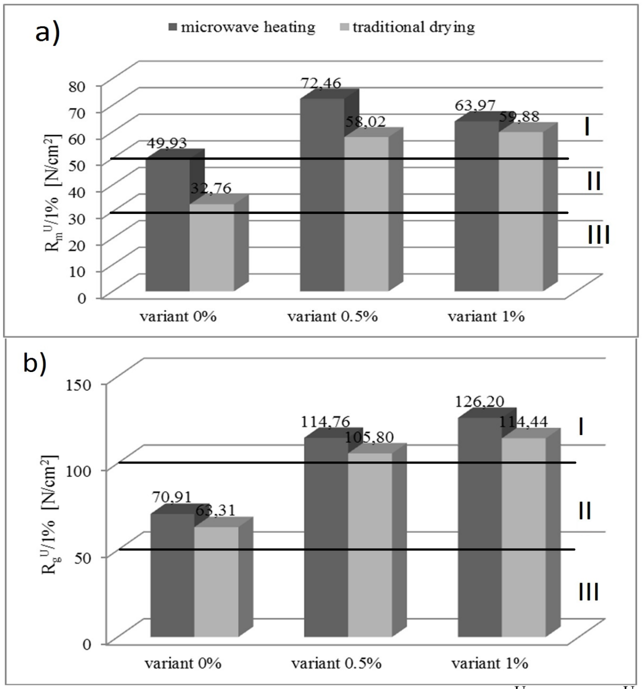

Fig. 1. Quality indices acc. to strength criteria: a) R_m^U and b) R_g^U per 1 wt% of binder 137 for sandmixes hardened by physical methods

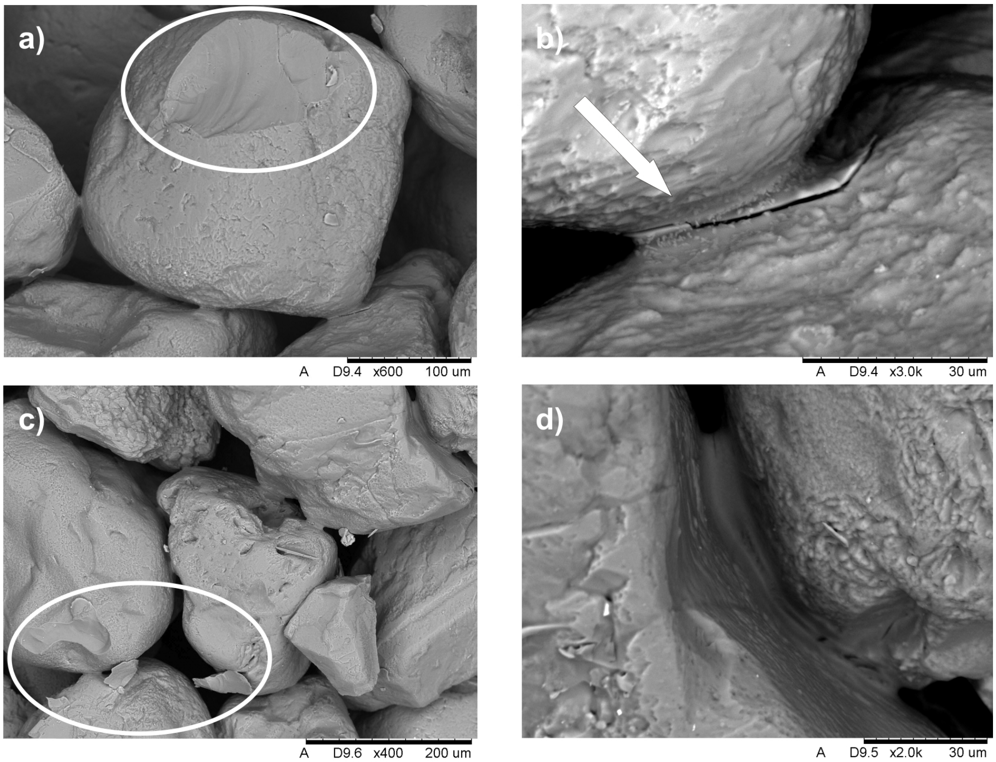

Fig. 2. Fragments of the sandmix prepared in variant 0% after mechanical testing: a) and b) – hardened by traditional drying; c) and d) – hardened by microwave heating. Visible surface defects of quartz grains in Figs. a) and c), and bright precipitates in vicinity of linking bridges in Fig. b), not observed after fast microwave heating d)

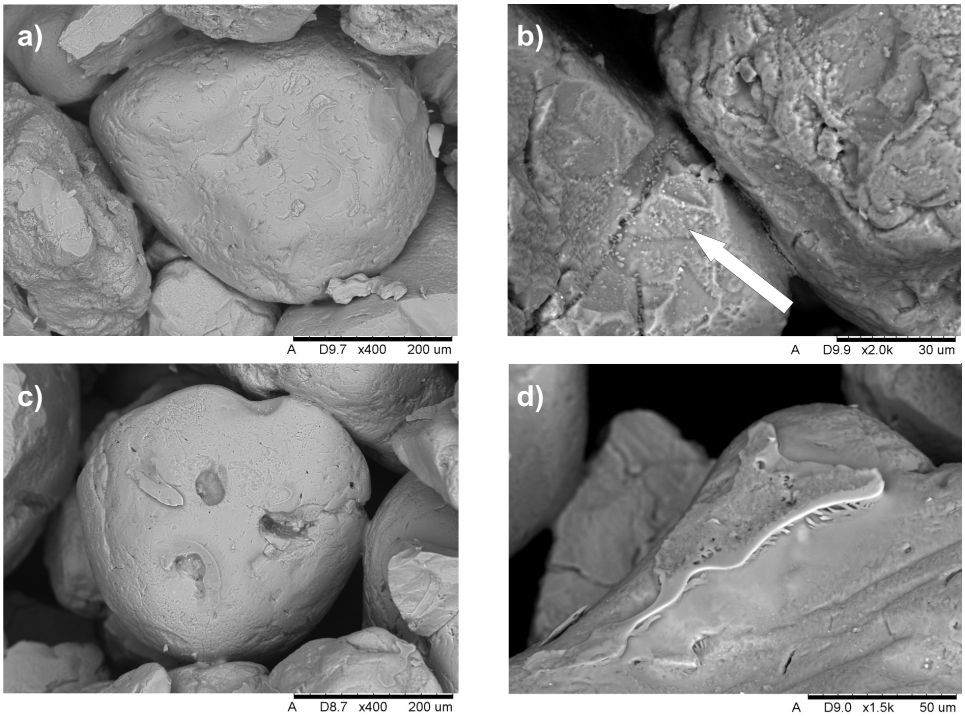

Fig. 3. Fragments of the sandmix prepared in variant 0.5% after mechanical testing: a) and b) – hardened by traditional drying; c) and d) – hardened by microwave heating. Visible fragments of linking bridges on surfaces of quartz grains in Figs. a) and c), and bright precipitates in vicinity of linking bridges in Fig. b), not observed after fast microwave heating

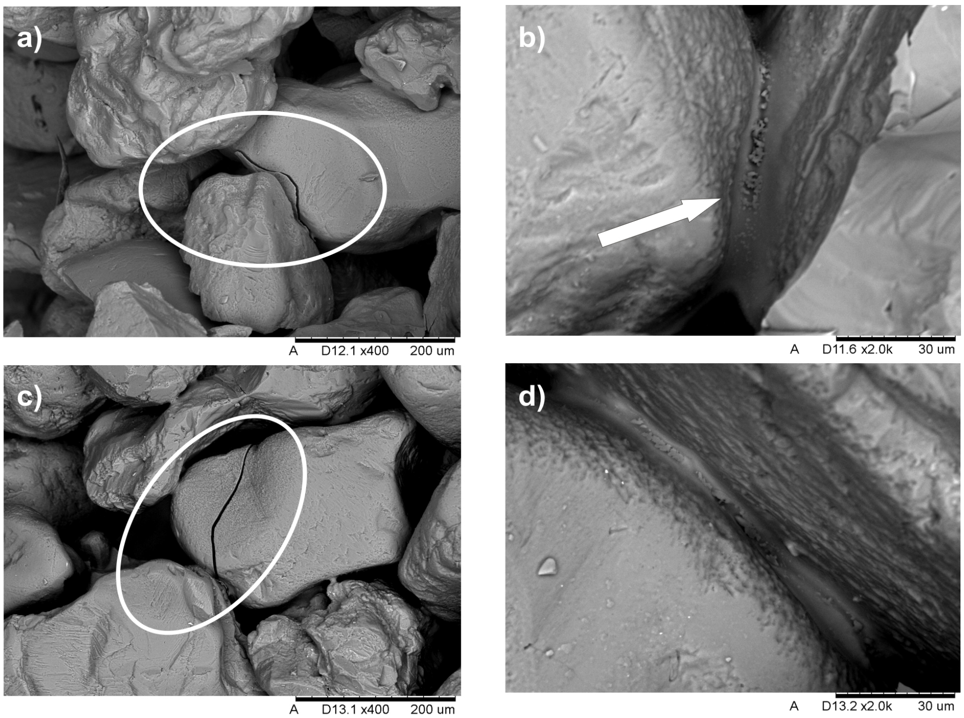

Fig. 4. Fragments of the sandmix prepared in variant 1% after mechanical testing: a) and b) – hardened by traditional drying; c) and d) – hardened by microwave heating. Visible cracks of quartz grains in Figs. a) and c), and bright precipitates in vicinity of linking bridges in Fig. b), not observed after fast microwave heating

The results in Fig. 1 show a clear positive effect of adding water to the sand-binder system in order to wet surfaces of quartz grains before dosing the binder grade 137. This action enabled creating high-quality linking bridges characteristic for the highest I class of binder in the sandmixes prepared in the variants 0.5% and 1% and hardened by two physical methods. A repeated difference between the strength values R_m^U and R_g^U per 1 wt% of the binder can be also observed between two applied hardening ways. Strength of the sandmix after fast microwave heating is higher than that after slow, traditional drying with hot air. In both hardening processes consisting in dehydration of water-glass, transition from viscoelastic state to solid state is described by the general formula [1]:

$$Na_2O{\cdot}nSiO_2{\cdot}x\,H_2O + Q \rightarrow Na_2O{\cdot}nSiO_2, \qquad (1)$$

where: n, x – stoichiometric coefficients, Q – heat.

A final result of the dehydration reaction is anhydrous layer of glassy sodium silicate ($Na_2O{\cdot}nSiO_2$) that forms linking bridges between base grains, in this case of high-silica base. It is supposed that lower effectiveness of the binder, visible in Fig. 1 after drying with hot air, may be caused by CO_2 present in the air. Lower strength of the sandmix can be caused by Na_2CO_3 created as a result of the reaction between the binder and CO_2 present in the air [12]:

$$Na_2OnSiO_2\;x\,H_2O + CO_2 \rightarrow Na_2CO_3 + nSiO_2 + x\,H_2O + Q. \qquad (2)$$

Images of linking bridges in fragments of the sandmix (Figs. 2 to 4) after mechanical testing indicate that, for both physical hardening methods, adhesion and cohesion forces of hardened binder prevail over cohesion forces of grains of high-silica base (Figs. 2a, 2c, 4a, 4c). The observed cracking can be considered undesirable and unfavourable from the viewpoint of further utilisation of high-silica base, e.g. at cyclical refreshing of moulding sands containing water-glass [13,14]. Except the precipitates visible in vicinity of linking bridges after traditional drying, no differences were observed in their structures that could explain various mechanical parameters (Fig. 1).

Therefore, performed was EDS analysis of grain surfaces of high-silica base that, because of its irregular structure, can explain the observed differences between strength of linking bridges.

Figure 5 shows EDS analyses of precipitates in vicinity of linking bridges (Figs. 2b, 3b and 4b) observed after drying with hot air. The presented analysis indicates accumulation of sodium and carbon compounds in the places where the precipitates occur. So, during traditional drying, a reaction partially proceeds between the binder to be hardened and CO_2 present in the air, which can explain slight weakening of the linking bridges in relation to those with higher strength, obtained after fast microwave heating.

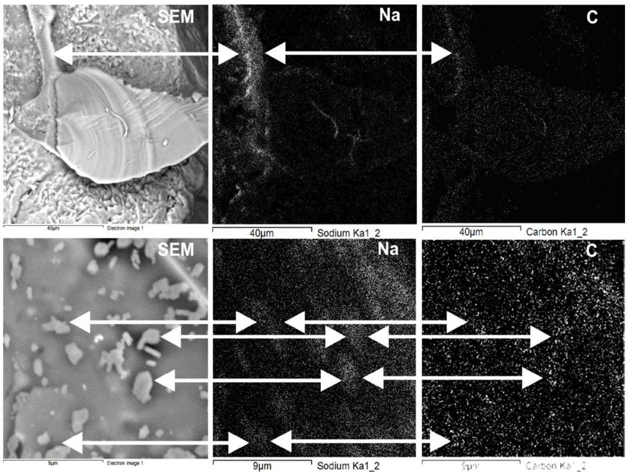

Fig. 5. Surface view and EDS analyses of quartz grains with accumulations of compounds containing Na and C, which confirms presence of Na_2CO_3 after the reaction (2)

Figure 6 shows EDS analyses of quartz base grains of the sandmix prepared in variants 0% (no water addition) and 1% (1 wt% of water).

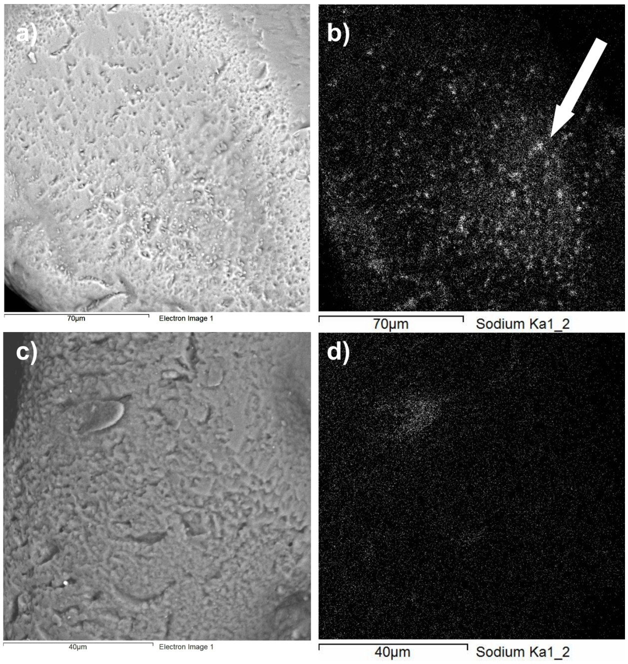

Fig. 6. Surface view and EDS analyses of quartz grains of the sandmix prepared without water addition: a), b) and with 1 wt% of water addition: c), d). Indicated with an arrow visible accumulations of compounds containing Na

It was found on the grounds of EDS analyses of the places containing agglomerates of Na-rich particles that, in the sandmixes with no water addition, the binder is kept on irregular surface of the sand base grains, see Fig. 6a and Fig. 6b.

Analysis for the variants 0.5% and 1% shows a positive effect of flowing the binder to contact places between base grains as a

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result of introducing a wetting addition to the sand-binder system, see Fig. 6c and Fig. 6d. Easier flowing of the binder and restriction of the places where it accumulates result in creation of volumetrically larger linking bridges, which is effective in quality indices of the sandmixes, see Fig. 1.

5. Conclusions

The results of the research on the effect of wetting high-silica base grains with water dosed during stirring, before introducing water-glass, and of the applied physical method of hardening lead to the following conclusions:

- The applied unmodified binder grade 137 with average molar module 3.3 can be used as a foundry binder that, after physical hardening, is characterised by quality indices for the highest I quality class at its concentration in the sandmix as low as 1.5 wt%.
- The obtained mechanical parameters are influenced by water added in order to prepare surfaces of high-silica base grains for the applied binder and to facilitate its flowing to the places where linking bridges are created, which restricts accumulation of the binder on irregular surfaces of quartz base grains.
- Hardening of the sandmix with the applied methods increases strength of linking bridges, which results in cracks of quartz grains around footings of the bridges, which is considered unfavourable.
- In comparison to traditional drying, the effect of the faster microwave heating is stronger and more favourable at all the examined sandmixes, because it restricts precipitation of sodium with carbon compounds in structures of linking bridges.
- Sandmixes with low content of the binder characterised by high molar module and viscosity not below 1, designed for physical hardening, should be prepared with an addition of water that extends life of the sandmix.
- In order to determine favourable effect of wetting high-silica base during stirring before adding the binder, the research should be extended by further grades of sodium water-glass, including those with medium and low molar module, and an attempt should be made to determine the most favourable quantity of water addition for a specific binder grade and sand base type.

Acknowledgement

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