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Nanostructuring sodium silicate solutions applied as binding substance of molding sands in foundry

M V Akulova¹, T E Slizneva¹, Yu A Sokolova² and A G Sokolova²

¹Federal State Budget Educational Institution of Higher Education “Ivanovo State Polytechnic University”, 21, Sheremetevskiy Ave., Ivanovo, 153000, Russia

²National Research Moscow State University of Civil Engineering, 26, Yaroslavskoye Shosse, Moscow, 129337

Abstract. The present paper deals with the effect of sodium silicate solution dispersion on the strength of molding sand. The authors proposed the method for modifying sodium silicate solution widely used as a binding substance while producing expendable molds in foundry, provided chemical agents are not included in the molding sand composition. Nanostructurization of sodium silicate solutions is carried out under the integral action, including hydrodynamic, acoustic and magnetic impacts, in the colloidal mill. As a result of processing, there was the obtained solution of uniform gravimetric composition providing lower sodium silicate content in molding sands up to 4.5 % without loss of strength.

1. Introduction

Among silicate binding substances widely spread in building materials manufacturing as well as in foundry for molding sands production, sodium silicate solution (soluble water glass) shows ever-growing use. The advantages of sodium silicate solution include its accessibility, relatively low cost, rapid hardening, gas generation value and ecological cleanliness. The above-mentioned competitive strengths over organic binding substances, in particular, environmental aspect, induce a rising tide of interest in soluble water glass [1-3].

However, the application of sodium silicate solution for press molds production has one significant drawback such as low knocking-out ability connected with the tendency of sodium silicate to react with silicon earth presented in the molding sand as the sand. Evidently, to improve knocking-out ability, it is required to lower the amount of sodium silicate in the molding sand while ensuring the strength properties of molds [4].

Soluble water glass as an independent binding substance is characterized by the air hardening method. In order to accelerate the hardening process, heat treatment, air-drying of molding sand and carbonation process (CO₂-process) [5] are used with the purpose of excess moisture removal.

The CO₂-process facilitates the formation of silicic acid gel with the spatial structure. Introduction of carbon dust and thorough selection of process conditions of the CO₂-process of molding (the content of soluble water glass, batch mixing time, the percentage of carbon dioxide) based on the mathematical analysis of the tests' results influence mold hardness and permeability [6]. But they do not guarantee rapid strength gain. Addition of peat ash to enhance flow rate and asbestos tailings for compactability improvement [1] led to a reduction of carbon dioxide consumption by a factor of 3.2. However, the issue of strength loss has not been solved. The authors [7] added nepheline slime, chloride of sodium and soda wastes of isothermal quenching, then carried out carbonation and blowing pressurized air. However, the content of sodium silicate has reached up to 6 mass percent. The binding properties of soluble water



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glass are manifested to a lesser extent if compared with hardening without blowing. The CO₂-process requires the build-up of its content as the molding sand [8]. Thus, the new innovative methods of modification of silicate binding substance should be found.

One of the efficient methods is waiving mix blowing with carbon dioxide and introduction of organic and inorganic additives into the molding sand composition. Such additives include sugar, carbon loam and compound ether as gelatinizing agents [9], chloride of calcium and acid phosphates of chrome and aluminum forming the substances with the higher fusing temperature [10], fly ash and microsilica suspension for mixture compacting [11], ultra-disperse pyro carbon and asbestos tailings for “sandbuckle” removal [12], organic substances altering binding properties of sodium silicate [13]. The use of chemical modifiers of soluble water glass could lower its content in the mixture simultaneously increasing knocking-out ability of press mold and lead to environmental deterioration, pollution of atmosphere and water resources with harmful substances and facilitation of their accumulation in the human body [14-16].

A significant increase in the knocking-out ability of soluble water glass compositions is accompanied by the lowering weight content of soluble water glass in the mixture anywhere from 6...8 to 3 % due to augmentation of composition stability and properties of soluble water glass [4].

The nanostructure of sodium silicate sol has a significant impact on foundry sand bonding [2]. In the presence of organic substances containing groups –NH₂, =CONH, –CONH₂, –COOH, the structure of sodium silicate solution is altered as they, on the one hand, act as protective colloids inhibiting the growth of silica gel molecules during binder strengthening, and, on the other hand, they serve as supplementary “bridges” facilitating formation of internal interpenetrating networks [13, 17]. Chemical binder’s modification could lead to formation of the small particle cluster (or agglomerates) characterized by a high average diameter reaching up to 131 Nm [13]. The residual strength of molds is being lowered while the risk of environmental pollution by organic additives remains high. Moreover, inhibiting sodium silicate means the reduction of its content in the sand mix.

Transmission of sodium silicate through the magnetic field (density 0.3 T) with the rate of 140 cm/sec during 14 min [18] could be regarded as one of the methods for cutting sodium silicate content (with the module 2.7) down to 2.5 %. However, the proposed method requires application of the ether hardener. The magnetic field has an impact on the properties of soluble water glass which could be seen in the change of its surface tension [19]. Thus, under the influence of the magnetic field with the density ranging from 20000 to 200000 A/m, the surface tension of soluble water glass 2.86 is increased by 52 %.

The goal of the present research is the receipt of nanostructured solutions of sodium silicate without using chemical agents.

2. Materials and Methods

Nanostructuring sodium silicate (All-Union State Standard GOST 13078-81) was carried out in the colloidal mill [20], presented in figure 1. The mill forms a part of the laboratory facility with the scheme depicted in fig.2. In the colloidal mill, the liquid-saturated medium was exposed to the integral action including hydrodynamic, acoustic and magnetic impact. High shear stresses have arisen as the sequence of the action of radial slots on the liquid flowing through the hollow arbors 2 and 6, while spinning upper (3) and lower (7) rotors contrariwise due to cavitation. Pointed on the both edges, thin steel plate 12 radiated by powerful ultrasonic fields giving rise to cavitation leads to ultrafine size reduction of solid particles. The treated liquid was twice exposed to magnetic fields: firstly, when placed on the inner surface of side guard 4, rubber-lined 5 with magnetic properties, and secondly, when passed through annular magnets 13. The magnetic field destroyed molecules associates and altered the liquid structure.

The analysis of particles size for hydrosols of sodium silicate as well as their electro kinetic properties (zeta potential, electrophoretic migration, electrical conduction) of colloid sodium silicate solutions has been implemented by the method of Dynamic Light Scattering by means of the analyzer Zetasizer Nano ZS, produced by Malvern Instruments Ltd, England. To eliminate method interferences and to achieve the required degree of purity for the investigated nanoscale objects, the analyzed solutions were taken

by the discardable syringes; the measurements were carried out in the Rotilabo-disposable cuvettes (company Carl Roth GmbH+Co.KG, Germany). The application of expendable Rotilabo-Spritzenfilter (company Carl Roth GmbH+Co.KG, Germany) with the pore size of $0.45\ \mu\text{m}$, when dosing solution in the measuring cuvette, provides separation of fine particles with a micrometric range. The experimental data have been received by averaging of results from the series of 5 parallel measurements.

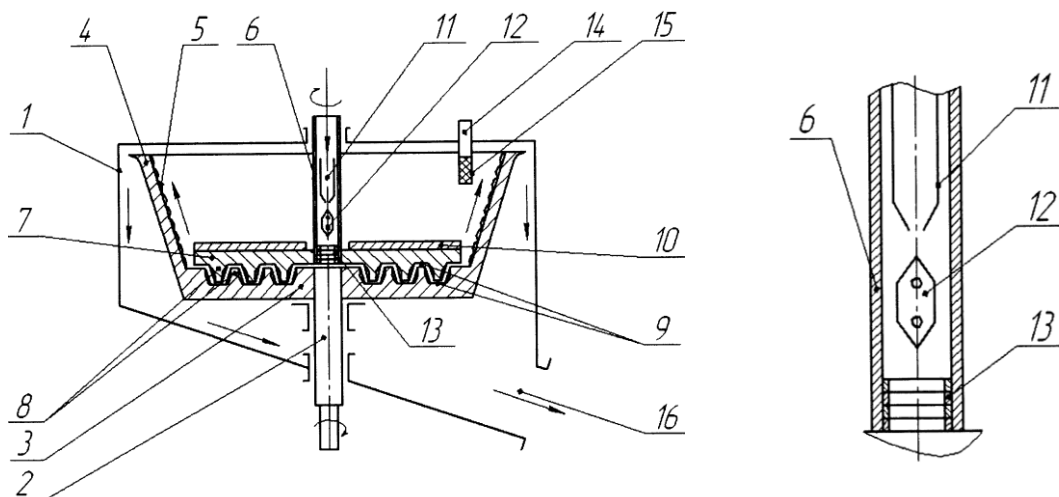


Figure 1. The colloidal mill: 1 – cover; 2 and 6 – lower and upper parts of the hollow arbor; 3 – lower disk rotor; 4 – side guard; 5 – magnetic rubber; 7 – upper rotor; 8 – annular lug; 9 – annular notches; 10 – blades; 11 – gap nozzle; 12 – steel plate; 13 – annular magnet; 14 – bellows element; 15 – filter element; 16 – outlet fitting

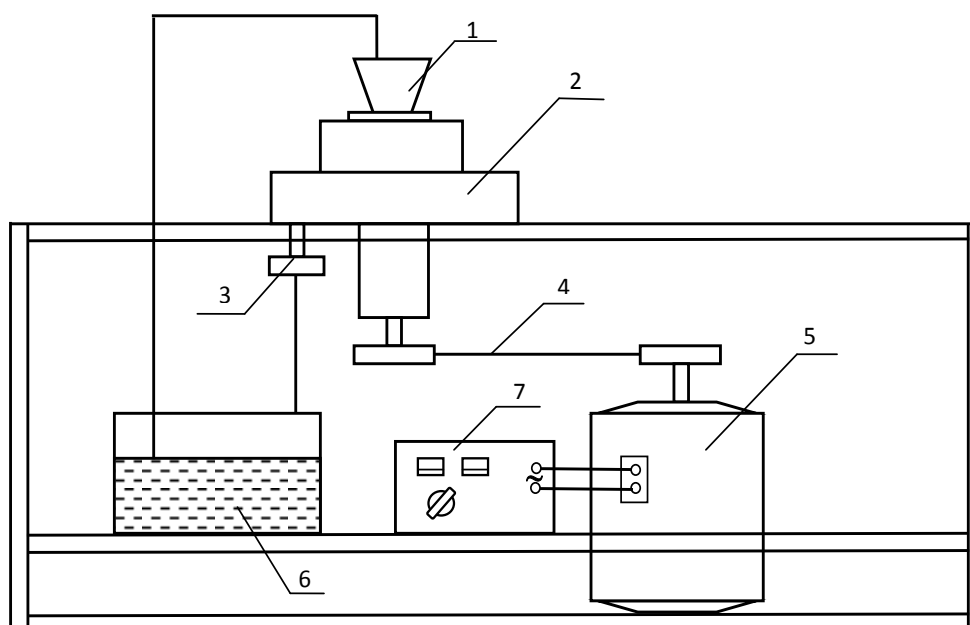


Figure 2. A schematic diagram of the laboratory facility for modification of sodium silicate solutions: 1 – inlet fitting; 2 – colloid mill; 3 – outlet fitting; 4 – vee belt transmission; 5 – electric motor; 6 – liquid container; 7 – governor unit for controlling rotor spinning velocity.

When sodium silicate solution had passed magnetic and acoustic treatments, it was mixed with sand (All-Union State Standard 29234.1-29243.5 and 29234.11-29234.13). Then the molding box was filled

with the molding sand, compacted and heated in the microwave oven at the temperature of 100°C. When hardened, it was extracted from the mold and was subjected to strength test. The specimen contained various amounts of soluble water glass.

3. Results and discussion

The principal effect of processing soluble water glass in the colloid mill is increase in the degree of dispersion of sodium silicate. In the initial solution the following factions were presented:

the particles size ranging within 5... 20 nm, amounted to 38.5 % by volume;

the particles size ranging within 30...80 nm, amounted to 39 % by volume;

the particles size ranging within 200...500 nm, made up 2 % by volume;

the particles size ranging within 600...100 nm, made up 20 % by volume.

Nanostructured solution consisted basically of one fraction (98 % – by the volume and 98.2 % – by the particle number) with the particle size ranging from 1nm to 5nm. Cavitation-magnetic treatment provided homogeneous composition of hydrosol Na_2SiO_3 .

After the treatment, hydrogen ion exponent pH and electrical conductivity of the solution as a function of the treatment time were ranging from 7 % to 3 %, respectively. Change of electro kinetic potential is more significant – from –22.3 mV to –24.92 mV. For molecules and particles characterized by a rather small size, high zeta potential means stability and resistance to aggregation. The higher electro kinetic potential (in absolute terms), the more stable colloid.

The strength test results for the specimen are shown in figure 3.

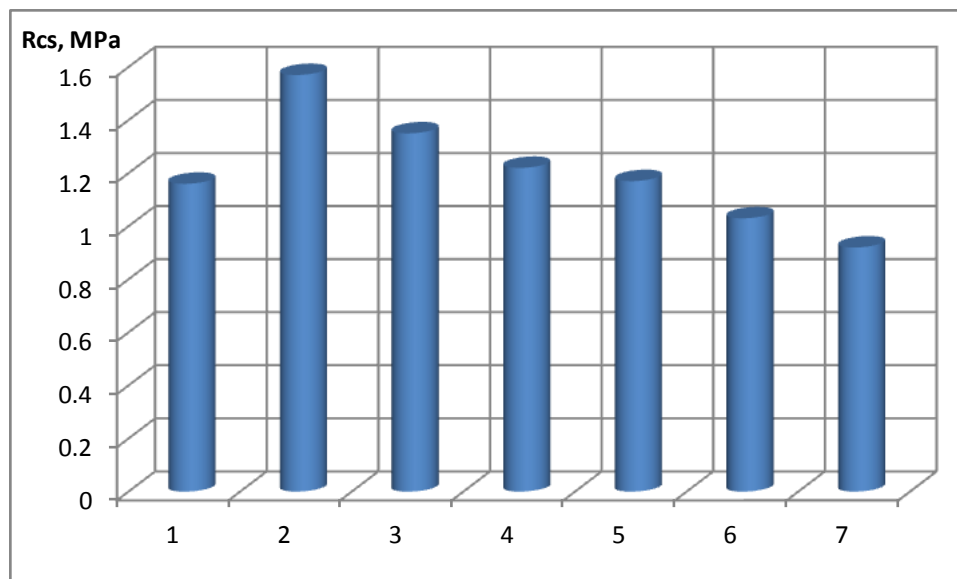


Figure 3. Dependence of compression strength R_{cs} , MPa of the specimen of hardened sand mix on the amount of soluble water glass: 1 – 6 % without cavitation-magnetic treatment; 2 – 6.0 mass. %; 3 – 5.5 mass. %; 4 – 5.0 mass. %; 6 – 4.0 mass. %; 7 – 3.5 mass. %

Investigation of specimen strength for sand mixes after hardening has shown that the amount of soluble water glass undergone magnetic-cavitation treatment could be cut down to 4.5 % without any strength loss.

4. Conclusions

Cavitation-magnetic treatment in the colloid mill contributes to:

1. obtaining nanostructured sodium silicate solutions with the particle size ranging from 1 to 5 nm that corresponds to 98 % of the total particle volume;
2. stabilizing the colloid system due to increase in the absolute value of zeta potential from -22.3 mV to -24.92 mV;
3. cutting down the amount of soluble water glass in the sand mix without any strength loss.

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