

Effect of $\text{Na}_2\text{O}\cdot n\text{SiO}_2$ Nanodispersion on the Strength and Durability of Portland Cement Matrix

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The aim of the research is to investigate the effect of sodium silicate as nano-modifiers on the strength and durability of Portland cement binder matrix. Three-component binding system consisting of colloidal sodium silicate solution (NSS), superplasticizer suspension and Portland cement was used to determine properties of binder matrix. The effect of sodium silicate was determined on the setting time, consistency, density, compressive strength and frost resistance of binder matrix. The formation of nano-structure in cementitious composites under the influence of nano-modifiers (sodium silicate solution, superplasticizer) was investigated. The compressive strength of hardened cement paste after 28 days remains unchanged. The NSS has no effect on logarithmic law of strength increase with time. The compressive strength accelerates the hardening process in later hardening period. In hardened cement paste with NSS ettringite crystals are covered with amorphous phase, therefore increasing the closed porosity and frost resistance factor K_f .

Keywords: Portland cement, sodium silicate solution (NSS), cement paste, hardened cement paste, durability, porosity, compressive strength, the frost resistance factor K_f .

1. INTRODUCTION

The main products of Portland cement hydration are calcium silicate hydrates (C–S–H), calcium hydroxide (CH), ettringite (AF_t), and monosulfate (AF_m). Mineral additives and aggregates also have significant influence on Portland cement hydration. With longer hardening time (higher degree of cement hydration) the capillary pores are filled with new hydration products formed during the hydration process (C–S–H, CH, AF_t , AF_m) [1–3]. The structure of newly formed products changes from mono-scale to macro-scale, which is equal to the size of cement particles and even to millimeter scale, equal to the size of concrete aggregate particles. The possibility to examine hydration processes at nano-level is important as it provides the opportunity to analyse cement hydration values form a new perspective.

Thermodynamic instability makes it difficult to keep substances in a natural nano-dispersed state while the production capacity of artificial nanodispersed substances is very low. The exception is nano-dispersed substances produced as by-products, such as SiO_2 . SiO_2 is unique for its high free surface energy. Free surface energy is generated by high chemical activity of this substance [4].

The investigation of nanotechnologies can be carried out in three ways: examination of nano-substance characteristics; exploration of known processes at nano-level; preparation of nano-substances and providing them with nano-substance-specific properties. Nano-sized particles may be also obtained artificially: by mixing the substance in high-performance grinders to disperse the solid phase; by evaporation and condensation of substances in plasmo-chemical synthesis [5, 6].

One of the key goals of cementitious substances is a purposeful correction of the formation of nano-phases

(C–S–H) achieved through modification of the substance at nano-level [7]. Nano particles induce additional atomic bonding and increase viscosity of the liquid phase, which helps to bind cement and aggregate grains and improves resistance to segregation as well as increases the workability of fresh concrete [8]. To obtain better properties of construction materials at the macro-level the formation of phases has to be purposefully corrected and properties of these materials have to be investigated at micro-level because nano-additives in cementitious materials act as additional catalysts that change the direction and rate of physical and chemical processes [9].

Sodium silicate solution (NSS), as well as superplasticizer (PCE) contains nano-structures, and the size of SiO_2 nano-particles in sodium silicate solution is 1 nm–2 nm. Even small amount sodium silicate solution (0.03 %–1 %) significantly influences cement hydration [10–12].

Due to high activity SiO_2 may be used to bind free $\text{Ca}(\text{OH})_2$ (portlandite) in hardened cement paste; the subsequent formation of stable and less water soluble calcium silicate hydrate increases durability and strength of concrete. The same result should be obtained by adding sodium silicate solution (0.25 %–0.5 % of the total cement weight) to concrete mixes. When NSS is added to concrete in the initial stage, the hydrating $\text{Ca}(\text{OH})_2$ acts with calcium silicate and forms calcium silicate hydrates, which later cause more intensive binding under natural conditions. According to V. A. Lotov [4] we may assume that the initial binding of cement is conditioned by the formation of nano-dispersed particles, which bind the majority of water. This leads to increased strength as a result of higher volume concentration of the solid phase in the system cement-water. Hydrogen ions (protons), which are released during the reaction of cement with water, have high penetration rate ($3.26\cdot 10^{-5}$ m/s) because they are much smaller in size compared to clinker minerals (H^+ ions size are $1.2\cdot 10^{-6}$ nm while C_2S particles range from 0.5 nm to 0.7 nm).

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The nano-dispersed system is formed in the initial hydration stage of the binding substance (Portland cement, high alumina cement) [12]. Therefore possibilities of hindering the formation of large crystal hydrates in the initial stage of structure formation have to be investigated and thus formation of amorphous hydration structures of nano-particle size that accumulate higher energy should be promoted in addition. A binding system consisting of colloidal sodium silicate solution and polycarboxyl ether based superplasticizer suspension may be used for this purpose. H. Hommer, K. Wutz and H. Li claim that new generation superplasticizers not only disperse the material, take active part in concrete hydration process but also contain nano-dispersed particles, which improve the nanostructure of cementitious materials [13, 14].

C. Macinni and J. Beaudoin [15] in their research of the relation of concrete freeze-thaw durability and the degree of conglomerate saturation with water have determined that pressure is one of the major factors causing destruction of concrete in the initial hardening stage under freeze-thaw conditions; this pressure rises in capillary pores during water freezing. T. Powers [16, 17] and his colleagues [18–20] analyzed the processes in concrete microstructure under repeated freezing and thawing conditions.

The destruction of repeatedly frozen and thawed conglomerate is caused not only by the expansion of freezing water in open and closed pores of the concrete. When binder matrix is in a saturated state and the freezing process in internal structure of concrete occurs in accordance with the theory of hydrostatic pressure, with the freezing of water in the binder matrix the water in pores and capillaries is pushed into bigger water-filled pores and the sample's ambient environment [21, 22].

The goal of the research is to examine the influence of sodium silicate nano-modifiers on the strength and durability of the binder matrix and the principles of nanostructures formation in the cementitious materials consisting of several binding components. Three-component binding system consisting of colloidal sodium silicate solution, superplasticizer suspension and Portland cement was used to determine the influence of nanostructures with active nano-modifiers (sodium silicate solution, superplasticizer) on cement paste flow diameter, cement paste setting time, strength of hardened cement paste as well as on porosity parameters. The different contents of NSS, namely 0 %, 0.2 %, 0.5 % and 0.8 %, were used.

2. MATERIALS AND METHODOLOGY

Portland cement CEM I 42.5R by Lithuanian Akmenės Cementas, according to European standard EN 197-1 was used in this research. Two types of superplasticizers were used in the research: pure superplasticizer in concentration of 18.7 %; pH index 6.4; electrical conductivity 4.390 mS/cm, based on polycarboxylic polymers, modified by naphthalene formaldehyde resin (marked superplasticizer R, produced by Remei GmbH and Co, Germany) and PCE superplasticizer in concentration of 36.1 %; pH index 4.4; electrical conductivity 1.480 mS/cm, based on polycarboxyl ether (marked superplasticizer F, produced by MC-Bauchemie Miuler GmbH and Co, Germany).

Electrical conductivity and pH of the superplasticizers were determined by using a Mettler-Toledo device MPC 227 (pH electrode InLab 410, measuring accuracy 0.01 pH; electrical electrode InLab 730, measuring interval (0–1000) $\mu\text{S}/\text{cm}$). The measuring was performed at ambient air temperature $21\text{ }^\circ\text{C} \pm 0.5\text{ }^\circ\text{C}$.

Another additive used was water solutions of sodium silicate (made by Lithuanian company “Remesta”) with silicate module of 3.3, dry $\text{Na}_2\text{O} \cdot n\text{SiO}_2$ and water ratio 60:40 and average density value of $1.382\text{ Mg}/\text{m}^3$. The hydrolysis reaction in sodium silicate solution is characterized by the following equation:



Cement pastes were produced from dry materials in a forced-action mixer Automix. Four group mixes of cement pastes were made by changing the NSS content in the cement paste. The proportions of cement paste mixtures are presented in Table 1.

Table 1. Proportions of the tested cement paste mixtures

Cement paste mixture	w/c ratio	NSS content, %	Superplasticizer content, %	
			R	F
Group I				
I-1	0.35	0	–	–
I-2	0.35	0.2	–	–
I-3	0.35	0.5	–	–
I-4	0.35	0.8	–	–
Group II				
II-1	0.35	0	0.5	–
II-2	0.35	0.2	0.5	–
II-3	0.35	0.5	0.5	–
II-4	0.35	0.8	0.5	–
Group III				
III-1	0.27	0	–	0.5
III-2	0.27	0.2	–	0.5
III-3	0.27	0.5	–	0.5
III-4	0.27	0.8	–	0.5
Group IV				
IV-1	0.27	0	0.5	–
IV-2	0.27	0.2	0.5	–
IV-3	0.27	0.5	0.5	–
IV-4	0.27	0.8	0.5	–

The initial and final setting time of the cement paste was recorded according to the requirements of EN 196-3 using Vicat tester. Cement pastes were tested for flow diameter using Southard viscometer. Cement pastes with the two plasticizers and different NSS content, namely 0 %, 0.2 %, 0.5 % and 0.8 % were tested. Cement paste specimens were produced in prism shape moulds (40×40×160 mm). Cement paste samples were cured in the moulds for 20 hours, at the ambient temperature of $20\text{ }^\circ\text{C} \pm 2\text{ }^\circ\text{C}$. Thereafter, the test specimens were stored in the water at a temperature of $20\text{ }^\circ\text{C} \pm 2\text{ }^\circ\text{C}$.

The compressive strength of the samples was determined after 7 and 28 days of curing. The frost

resistance factor K_f qualified concrete resistance to damage caused by repeated cycles of freezing followed by thawing was used to forecast frost resistance of the hardened cement paste. This methodology enables to forecast frost resistance of hardened cement paste by examining specimens according to porosity parameters obtained from the kinetics of water absorption. The porosity parameters of hardened cement paste were determined after 7 and 28 days of curing. For investigation of porosity parameters the hardened cement paste specimens were dried to constant weight. Later the water absorption of hardened cement paste was determined after 15 min., 1 hour, 24 hours and 120 hours. Hardened cement paste open, close and total porosity were calculated by methods presented in general requirements to methods of determination of density, porosity, moisture content, water absorptions and water tightness [23–25].

For investigation of hardened cement paste microstructure microscopic test was performed using a scanning electron microscope JSM-5600 (firm JEOL).

3. RESULTS AND DISCUSSIONS

3.1. Cement paste setting time and flow diameter test

The initial setting time of cement pastes without plasticizing admixture (group I) remain unchanged or become insignificantly shorter (Fig. 1, a). The initial setting time of the cement paste shortens from 260 min. to 220 min. Therefore we may conclude that NSS slightly improves cement hydration.

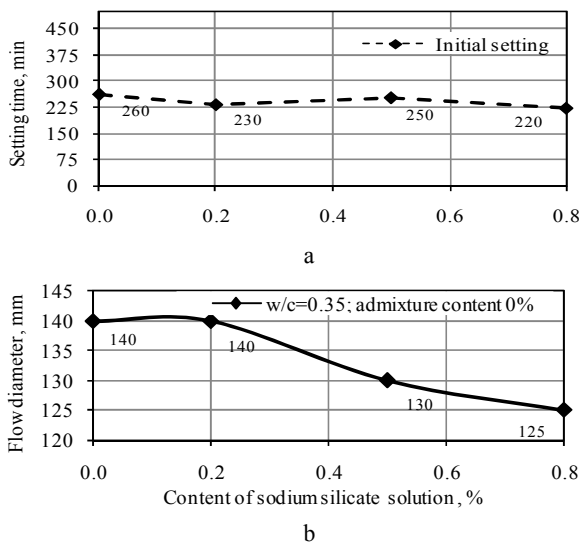


Fig. 1. Dependence of cement paste ($w/c = 0.35$) setting time (a) and flow diameter (b) on NSS (sodium silicate solution) content for group I cement paste's

The consistency of cement pastes without plasticizing admixtures (cement paste flow diameter) remains unchanged with the addition of 0.2 % of NSS, however higher content of NSS reduces the flow diameter, which diminishes from 140 mm to 125 mm (Fig. 1, b). This indicates changes in rheological properties of the mix. Figure 1 illustrates the dependence of group I cement paste setting time and flow diameter on NSS (sodium silicate solution) content when $w/c = 0.35$.

The setting time (initial setting and final setting) of the cement paste with modified polycarboxylate polymer plasticizing admixture R (0.5 % of the cement weight) (group II) is in linear proportion with NSS content in the cement paste, i. e. the setting time shortens with higher NSS content in the cement paste (Fig. 2, a). The initial setting time of such a paste shortens from 269 min. down to 200 min., while the final setting time shortens from 364 min. to 285 min. Therefore we may state that sodium silicate solution when used together with the plasticizer makes Portland cement hydration faster. When NSS is added to 0.8 % of the cement weight, the initial setting time of the cement paste shortens by 21.7 % and the final setting time shortens by 25.7 %.

The consistency (flow diameter) of the cement paste with plasticizing admixture R (0.5 % of cement weight) (group II) changes from 240 mm to 180 mm, when NSS is added up to 0.5 %, whereas with higher content of NSS the flow of the paste increases up to 200 mm (Fig. 2, b).

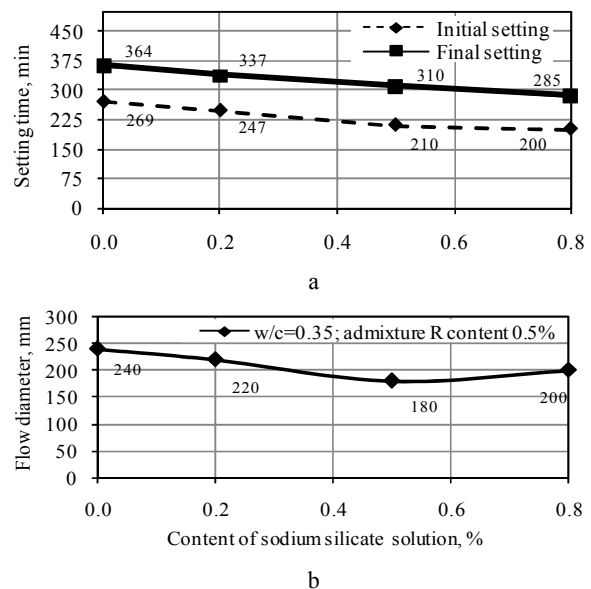


Fig. 2. Dependence of cement paste ($w/c = 0.35$) with plasticizing admixture R (0.5 % of cement weight) setting time (a) and flow diameter (b) on NSS content for group II cement paste's

The results have shown that NSS content below 0.5 % lessens the flow diameter of the cement paste, while the higher NSS content does not lessen but even slightly increases the cement paste's flow diameter. When up to 0.5 % NSS is added the flow diameter of the cement paste diminishes about 25 %.

The setting time (initial setting and final setting) of the cement paste with PCE plasticizing admixture F (0.5 % of the cement weight) (group III) made from polycarboxylate ethers decreases almost in linear proportion with NSS content in the cement paste (Fig. 3, a). Sodium silicate solution when used together with polycarboxylate ether plasticizer (PCE) makes Portland cement hydration faster. When NSS is added to 0.8 % of the cement weight, the initial setting time of the cement paste shortens by 29.8 % and the final setting time shortens by 32.0 %.

The consistency (flow diameter) of the cement paste with plasticizing admixture F (0.5 % of the cement weight)

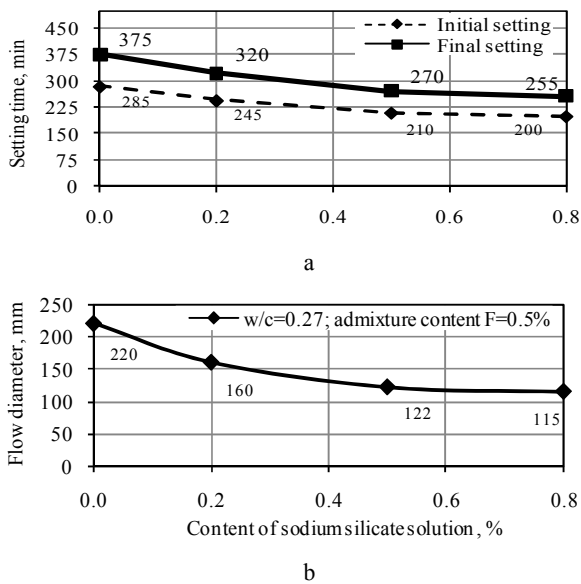


Fig. 3. Dependence of cement paste (w/c = 0.27) with plasticizing admixture F (0.5 % of cement weight) setting time (a) and flow diameter (b) on NSS content for group III cement paste's

(group III) changes more intensively from 220 mm to 122 mm when NSS content is up to 0.5 %; if more NSS is added, the flow diameter of the cement paste diminishes only slightly, down to 115 mm (Fig. 3, b). The test results have demonstrated that NSS admixture, when added up to 0.5 % of the cement weight, diminishes the flow of the cement paste, while higher content of this admixture has a small effect on the paste flow diameter. When 0.8 % NSS is added by weight the flow diameter of the cement paste diminishes about 48 %.

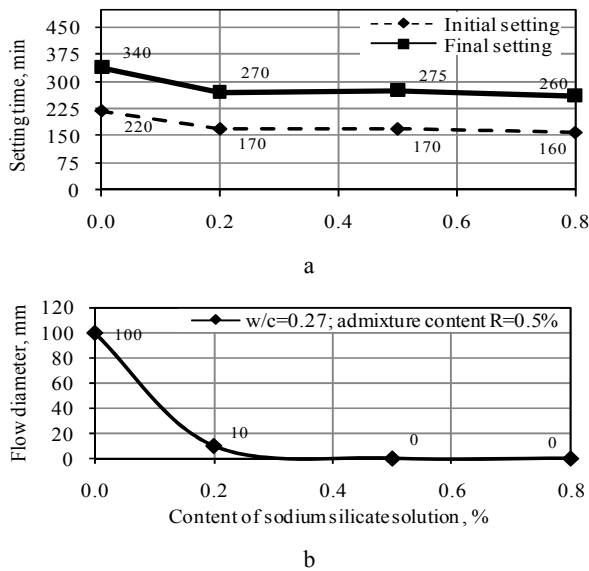


Fig. 4. Dependence of cement paste (w/c = 0.27) with plasticizing admixture R (0.5 % of cement weight) setting time (a) and flow diameter (b) on NSS content for group IV cement paste's

The setting time with modified polycarboxylic polymers plasticizing admixture R (0.5 % of the cement weight and w/c ratio 0.27) (group IV) decreases in proportion with NSS content in the cement paste (up to 0.2 %); higher

content of this admixture has little effect on the setting time. Sodium silicate solution, when used together with polycarboxylic polymers plasticizer, accelerates Portland cement hydration. When NSS is added to 0.8 % of the cement weight, the initial setting time of the cement paste shortens by 27.3 % and the final setting time shortens by 23.5 % (Fig. 4, a).

The consistency (flow diameter) of the cement paste with plasticizing admixture R (0.5 % of the cement weight and w/c ratio 0.27) (group IV) changes intensively from 100 mm to 60 mm, when NSS content in the mix is up to 0.2 %. With higher NSS content the flow diameter of the cement paste becomes so small that it is impossible to determine (Fig. 4, b). The test results have demonstrated that sodium silicate solution, when added up to 0.2 % of the cement weight, significantly diminishes the slump flow of the cement paste.

3.2. Microstructure of hardened cement

The microstructure of the hardened cement paste with NSS admixture and without it is presented in the Figure 5.

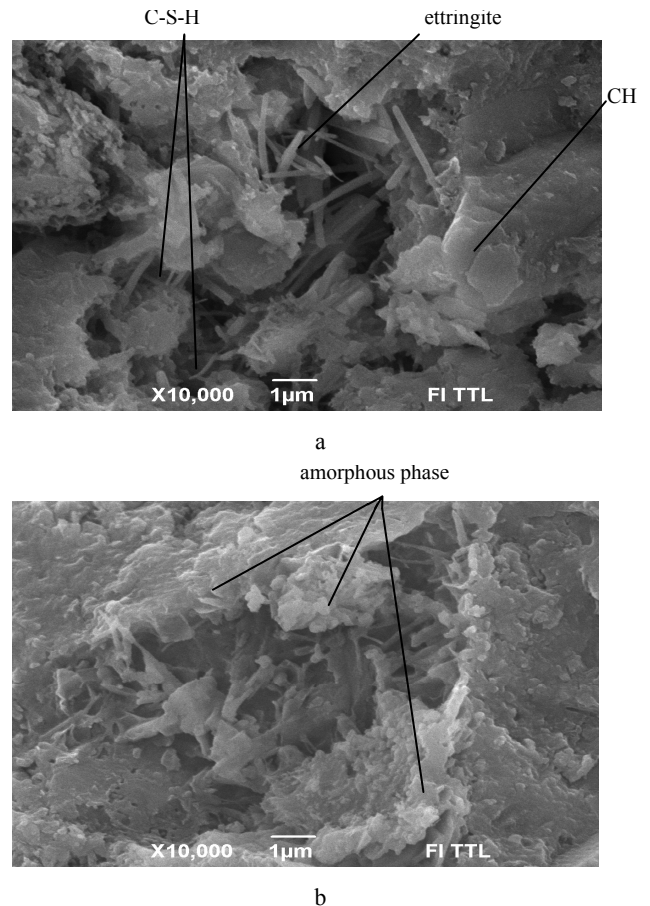


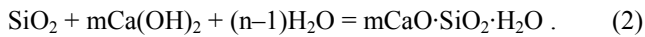
Fig. 5. SEM micrographs of hardened cement paste with 0 % (a) and 0.5 % (b) of NSS after 180 days curing (group III)

In Figure 5 the capillary pore zone of hardened cement paste is presented.

From Fig. 5, a, we can see high amount of ettringite (needle shape long crystals) and amalgamated to coarse agglomerates crystals of splinting forms calcium silicate hydrates crystals (C-S-H) and large plate forms crystals of calcium hydroxide (CH).

In Figure 5, b, microstructure of hardened cement paste with 0.5 % of NSS is presented. It can be seen that in cement paste with NSS we can't identify. From this picture it is clearly seen that hardened cement with NSS admixture has high amount of amorphous (irregular shape) phases, which are coating the C-S-H and CH crystals. This factor has high influence for the porosity parameters of hardened cement by the increasing of hardened cement close porosity, the capillary pores are closed with amorphous masses in the hardened cement paste.

SEM micrographs confirm the proposition by V. A. Lotov [4] presented in the Introduction about reaction between SiO_2 , formed in the hydrolysis reaction of sodium silicate solution, and Ca(OH)_2 with formation calcium silicate hydrates (C-S-H):



Sodium hydroxide aroused in sodium silicate hydrolysis reaction (eq. 1) forms amorphous phase, which covers the surfaces of cement hydration products. This amorphous phase clearly observed in Fig. 5, b. Therefore can be stated, that NSS acts as active hydraulic additive and forms in additional some amount of Na(OH) amorphous phase in hardened cement paste. The sodium hydroxide has fastening effect on Portland cement hydration process (Figs. 1, a-4, a). About fastening influence of NSS on cement hydration is pointed in the I. Pundienė, B. Sandberg and the other scientists research works [10–13].

3.3. Hardened cement paste strength

After 28 days of curing the density of hardened cement paste with w/c ratio of 0.35 and added NSS reduces less, only about 1.5 % or does not reduce at all at w/c ratio 0.27 (Fig. 6).

After 28 days of curing the hardened cement paste compressive strength as well as density depends more on the plasticizing admixture than on water and cement ratio. At w/c ratio of 0.35 the compressive strength of the hardened cement paste after 28 days of curing reduces very slightly (about 5 MPa), and increases slightly at w/c ratio 0.27 (Fig. 7).

The diagrams illustrate that after 28 days of curing the density of the hardened cement paste with w/c ratio of 0.35 where NSS was added reduces less, only about 1.5 % or does not reduce at all when w/c ratio is 0.27 (Fig. 6). After 28 days of curing the compressive strength of hardened cement paste with w/c ratio of 0.35 reduces slightly (about 5 MPa) and increases slightly when w/c ratio is 0.27 (Fig. 7). In general, irrespective of the composition of the mix, with the increase of NSS the hardened cement paste strength remains unchanged after 28 days of curing or reduces slightly. The compressive strength of cement pastes group III and IV is one-fourth higher compared to cement paste of other groups. The process may be explained by the effect of plasticizing admixture and lower w/c ratio in hardened cement paste of compositions group III and IV.

Curves in Figures 8–9 illustrate the kinetics of increased compressive strength of hardened cement paste specimens with different NSS content.

The comparison of hardened cement paste compressive strength kinetics (Figs. 8–9) leads to the statement that sodium silicate admixture does not change the logarithmic law of growing strength with time.

With higher content of sodium silicate in hardened cement paste stone the compressive strength of mixes with plasticizing admixtures rapidly increases in the later period of curing, namely from 7 to 28 days.

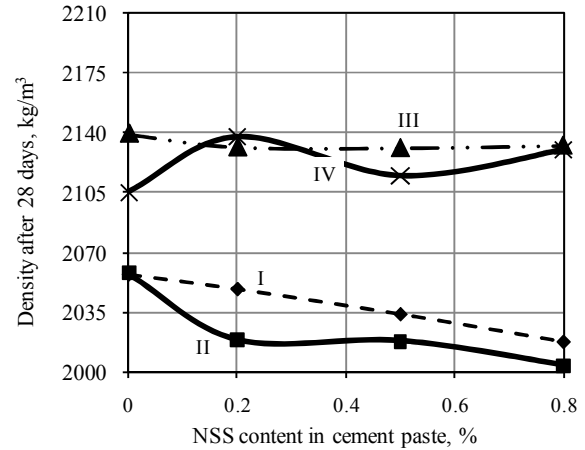


Fig. 6. Dependence of various groups cement specimen density on sodium silicate solution (NSS) after 28 days

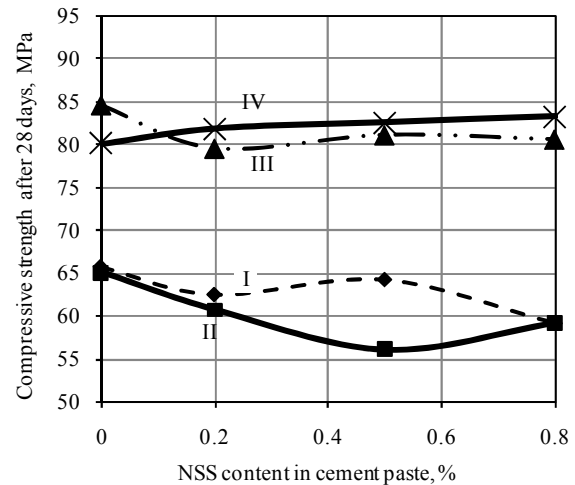


Fig. 7. Dependence of various groups cement specimen compressive strength on sodium silicate solution (NSS) after 28 days

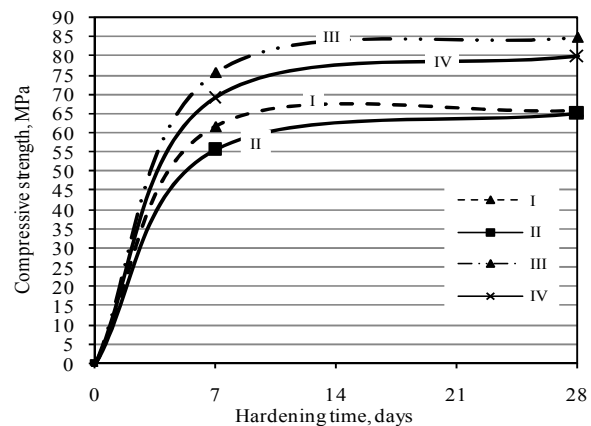


Fig. 8. Kinetics of compressive strength of cement specimens with 0 % NSS after 28 days of curing

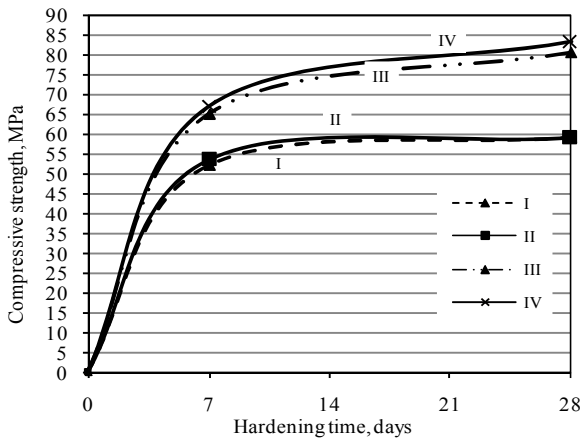


Fig. 9. Kinetics of compressive strength of cement specimens with 0.8 % NSS after 28 days of curing

3.4. Porosity parameters and durability of hardened cement paste

With increased content of NSS in the cement paste with modified polycarboxylic polymers plasticizing admixture R after 28 days of curing the frost resistance criterion increases due to the slight increase of the closed porosity of hardened cements pasta (Fig. 11).

The frost resistance of hardened cement paste in this case is influenced only by the closed porosity, which is presented in Figs. 10–13.

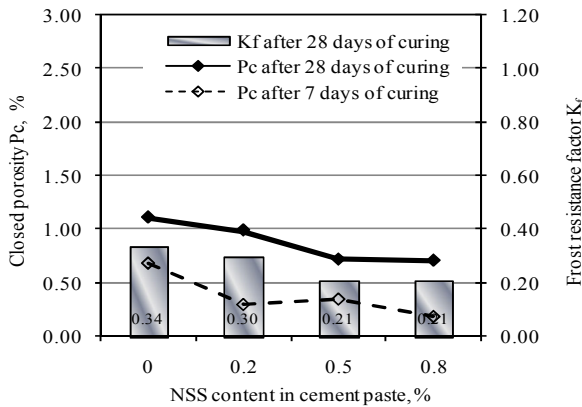


Fig. 10. Dependence of frost resistance factor K_f and closed porosity P_c on the content of sodium silicate solution (NSS) in cement specimens (group I)

According to theory hydrostatic pressure the frost resistance of concrete generally is determined by the open (capillary) porosity and closed porosity of hardened cement paste. Because the w/c ratio of hardened cement paste in this taste was constant capillary porosity of hardened cement paste has no changed.

When only sodium silicate solution is used as admixture in the hardened cement pasta (Fig. 10) an inverse process is observed: with higher content of NSS in the mix its closed porosity diminishes and frost resistance also goes down; therefore the hardened cement pasta durability is lower compared to the cement paste where sodium silicate solution is used together with the superplasticizer. Figures 10–11 illustrate the dependence of frost resistance factor K_f and closed porosity P_c on the

content of sodium silicate solution (NSS) in hardened cement specimens group I and II.

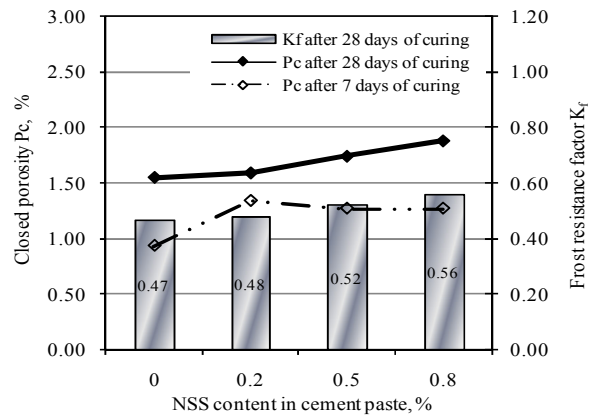


Fig. 11. Dependence of frost resistance factor K_f and closed porosity P_c on the content of sodium silicate solution (NSS) in cement specimens (group II)

Figures 12–13 illustrate the dependence of frost resistance factor K_f and closed porosity P_c on the content of sodium silicate solution (NSS) in cement specimens group III and IV.

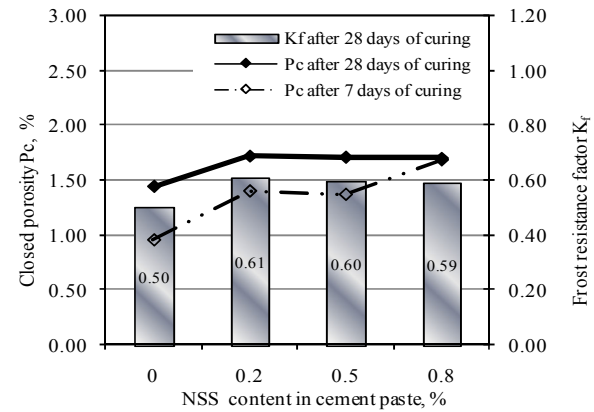


Fig. 12. Dependence of frost resistance factor K_f and closed porosity P_c on the content of sodium silicate solution (NSS) in cement specimens (group III)

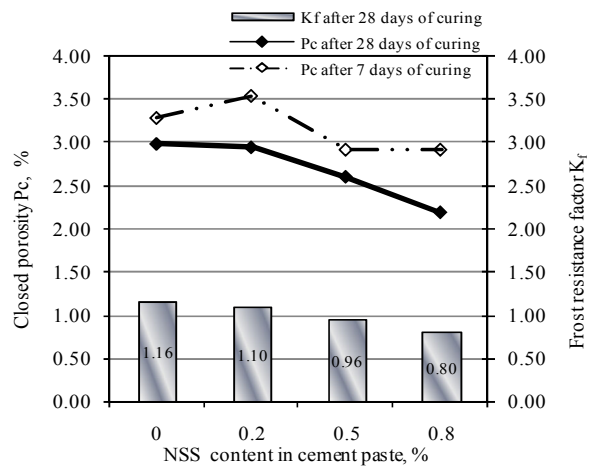


Fig. 13. Dependence of frost resistance factor K_f and closed porosity P_c on the content of sodium silicate solution (NSS) in cement specimens (group IV)

The graphically presented results show that concrete closed porosity, which contributes to the solid density, increases frost resistance of the hardened cement paste and in cement specimens with different NSS content at $w/c = 0.27$ with added PCE plasticizing admixture (admixture marking F) (group III) with dry particle content of 36.1% by weight it may be as high as 0.96%–1.72%.

The closed porosity also increases with higher content of NSS and lower w/c ratio in the cement paste. The increase ranges from 0.96%, when sodium silicate solution content in the hardened cement paste is 0%, up to 1.70%, when sodium silicate solution content in the cement paste is 0.8%. As hardened cement paste porosity is tightly related with air content in the mix, its value is usually slightly lower than that of air content in the mix, we may assume that with higher content of sodium silicate solution (NSS) in the cement paste and with PCE superplasticizer added the cement stone has better freezing-thawing resistance.

The analysis of curves presented in Figures 12–13 reveal that with the same cement paste composition and different superplasticizers the increase of NSS content in the hardened cement paste produces inverse change of results (compared to compositions group III), i.e. with higher content of sodium silicate solution in the hardened cement paste the values of closed porosity and frost resistance factor K_f in the hardened cement go down, although the change of cement matrix density is the same as in compositions group III mix. i.e. densities in both mixes remains more or less unchanged (Fig. 6). The change in resulting values can be explained by the use of PCE superplasticizer with dry particle content at 36.1% (admixture marking F) in the first case; it ensured good technological properties of the cement paste (Fig. 3) and good durability of the hardened cement paste because the frost resistance factor K_f increases with higher sodium silicate solution content in the hardened cement paste (Fig. 12, group III).

Statements about positive influence of PCE superplasticizers both for the dispersion and plastification of fresh cement paste, nanostructure and durability of hardened cement paste are presented in Li, H., Xiao, G. H., Ou, J. P. scientific works too [14].

In the second case (Fig. 13, group IV) with the same mix composition and by only replacing plasticizer F with plasticizer R (modified polycarboxylic polymers plasticizing admixture, with dry particle content being only at 18.7%) we obtain poor properties of the cement paste: with increased NSS content the cement paste flow diameter value measured with Southard viscometer becomes zero, the cement paste becomes unspreadable and to some extent non-homogeneous (Fig. 4). The change of the results could be interpreted in different pH and electrical conductivity values of the plasticizing admixtures, compared to compositions group III. Ion concentration and electrical conductivity of the plasticizing admixtures solutions increase, when the plasticizer R pH value is 45.5% higher than plasticizer F. Process of the cement hydration is accelerated and formed less closed pore amount in the cement paste.

The decrease of frost resistance factor K_f value in compositions group IV cement paste (Fig. 13) shows that

with the use of sodium silicate solution with superplasticizer at the cement paste flow diameter value equal to zero the durability of the cement stone will decrease due to decreased closed porosity of the cement matrix (Fig. 13), therefore the freezing-thawing resistance of the hardened cement paste will also decrease.

4. CONCLUSIONS

1. The setting time (initial setting and final setting) of the cement paste with Portland cement without plasticizing admixtures remain unchanged or shorten slightly while the setting time of the cement paste with plasticizing admixture become shorter 22%–32% in linear proportion to NSS content in the cement paste.
2. The sodium silicate solution admixture reduces the flow diameter of the cement paste (yield stress increases). The sodium silicate solution admixture added up to 0.5% has bigger effect on diminished cement paste flow diameter while the higher content of the admixture does not have significant effect of the paste flow diameter.
3. High amorphous mass content was obtained when hardened cement paste with sodium silicate solution was used. These amorphous compounds coats calcium silicate hydrates and calcium hydroxide crystals and partially close capillary pores.
4. The compressive strength after 28 days of curing of the hardened cement paste remains unchanged.
5. The sodium silicate solution admixture has no effect on logarithmic law of strength increase with time; however the compressive strength of pastes with plasticizing admixtures increases more rapidly in later setting period, namely from 7 to 28 days.
6. Very small amount of sodium silicate solution in complex with polycarboxyl ether superplasticizer in the cement paste increases frost resistance factor of hardened cement paste.

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