HYDRATION PROCESS AND PHYSICAL PROPERTIES OF CEMENT SYSTEMS MODIFIED BY CALCIUM CHLORIDE AND MULTI-WALLED CARBON NANOTUBES

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The application of accelerating admixtures is required in construction work where fast-setting is required or in an environment of low temperature. This type of admixtures allows to regulate the setting and hardening time of cement composites and could influence on their strength and performance. The accelerating admixtures are exemplified by chloride, nitrate and other salts. Some investigations demonstrated the application of different types of nano- and complex additives as a method to accelerate the hydration processes of cement composites.

The present study focuses on the investigation of the combined action of multi-walled carbon nanotubes (MWCNT) dispersion and various types of accelerating admixtures such as calcium chloride, calcium nitrate and magnesium chloride. The amount of accelerating admixtures ranged from 1% to 3% by weight of cement, the amount of MWCNT for all compositions remained equal to 0.005% by weight of cement. The setting time of cement pastes modified by different types of accelerating admixtures and MWCNT dispersion was determined. The combined effects of MWCNT dispersion and accelerating admixtures on compressive and flexural strength, water absorption and porosity of cement mortar modified by calcium chloride and MWCNT were studied. Besides, the cement hydration products were evaluated by FT-IR spectroscopy and XRD analysis. The individual and combined effects of accelerating admixtures and MWCNT addition are reported in the article.

Keywords: *Cement, Accelerating admixtures, Setting time, Calcium chloride, Multi-walled carbon nanotubes*

1. Introduction

Control of setting time and hardening of cement composites can be achieved by addition of accelerating admixtures , which are commonly based on salts of chloride, nitrate, carbonate or others salts. Accelerating admixtures are widely used in construction practice and they can be multifunctional. For instance, the usage of accelerating admixtures as anti-freeze agent allows carrying out the construction work in winter conditions.

The effect of accelerating admixtures on cement composites is determined not only by the dosage but also the ambient temperature and type of binder used [1]. In addition, the authors of the study [2] noticed the influence of radius of the cation and atomic structure of accelerating admixture on the accelerating effect. Despite the relatively high effectiveness, the application of these admixtures may have a negative effect on the engineering performance. In particular, the decrease in early and long-term strength of cement composites was observed in some cases [2].

Nowadays, the complex additives are developed to prevent negative impacts. Reference [3] proposed the complex additive for concrete based on galvanic sludge, the introduction of which would reduce the setting time and enhance the strength of cement system from 29% to 32%. In another study, the usage of a complex additive based on sodium sulfate mixture and superplasticizer led to an increase in strength by 122% and 68% at ages of 1 and 28 days, respectively [4].

The usage of ground granulated blast furnace slag in combination with accelerating admixtures such as C-S-H crystal seeds, calcium nitrate and triethanolamine, allows to improve the accelerating effect, increase early strength and prevent the decline in long-term strength [5, 6].

The greater interest appears to be the development of complex additives on the basis of different types of nanostructures with the application of nanotechnology. Reference [7] established that the introduction of 2% of nano-silica by weight of cement in the composition of concrete containing slag, led to reduction in the initial and final setting time, by 95 and 105 min, respectively. Similarly, the introduction of nano-silica in the cement composites containing fly ash could lead to the acceleration of setting and solidification [8].

The modification of cement-fly ash systems, by calcium carbonate nanoparticles and nano-TiO_2 contributes to the acceleration of hydration of cement and setting [9, 10]. Conversely, the usage

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of nano-alumina gives rise to the retardation effect in cement systems [11].

Among various types of nano-particles, considerable attention of researchers is paid to the modification of cement systems by carbon nanotubes [12-16].

The study in reference [12] demonstrated that carbon nanotubes prolong the initial and final setting time of cement systems. The setting time of cement paste modified by carbon nanotubes in the amount from 0.0005 to 0.005% by weight of cement was increased from 150 to 190 min. The final setting time was increased from 200 to 290 min with the introduction of carbon nanotubes in the amount of up to 0.05% by weight of cement.

The complex additives based on carbon nanotubes have been developed [17-19]. These modifiers could exert influence on several properties of cement composites. The complex additive, based on superplasticizer, water repellent and carbon nanotubes, was developed [19] and demonstrated the reduction of setting time by 50-70 min, increase in strength of normal concrete by 1.5-2.0 times, frost resistance by 2.5 times, and water resistance from 6 to 16 bar in comparison with the control composition without additive.

The aim of this study is to investigate the influence of combined action of accelerating admixtures and multi-walled carbon nanotubes (MWCNT) in dispersion state on cement systems.

2. Experimental program

2.1. Materials

The cement CEM I 42.5 R (supplied by AB "Akmenes Cementas") conforming to European Standard EN 197-1 was used as a binder. The mineral composition of the cement is presented in Table 1. The physical and mechanical properties of the cement are listed in Table 2.

The sand with fraction of 0/4 mm conforming to the requirements of European Standard EN 12620 was applied as the fine aggregate.

Table 1

Mineral composition of cement

Component	Amount, %
Tricalcium silicate (C_3S)	57.9
Dicalcium silicate (C_2S)	15.6
Tricalcium aluminate (C_3A)	7.5
Tetracalcium aluminoferrite (C_4AF)	11.9

Table 2

Physical and mechanical properties of cement

Property	Value
2-day compressive strength, MPa	28±2
28-day compressive strength, MPa	55±3
Initial setting time, min	160
Final setting time, min	180
Volume stability, mm	1.0
Water consumption, %	26.6
Residue on the 90μm sieve, %	1.5
Specific surface, cm^2/g	4000

The calcium chloride, calcium nitrate and magnesium chloride were added in the cement composites as accelerating admixture in the amount of 1, 2 and 3% by weight of cement. These admixtures conformed to the European Standard EN 934-2. Potable water according to European Standard EN 1008 was used for preparation of cement paste and mortar.

The nanomodification was done with an aqueous dispersion "Fulvek 100" produced by the company "Novyj dom" (Izhevsk, Russia). The dispersion was prepared from the masterbatch pellets "Graphistrength CW 2-45" produced by the company "Arkema" (Colombes, France). The masterbatch pellet contains 45 wt. % of MWCNT and 55 wt. % of carboxymethylcellulose (CMC). The MWCNT was characterized by filament length equal to 0.1–10 μm and diameter equal to 15–20 nm. The concentration of "Graphistrength CW 2-45" in the dispersion was equal to 4.5%. The particle dispersion of MWCNT was performed by using high-speed bead mill mixer for a duration of 2 hours. Subsequently, the dispersion was subjected to ultrasonication for a duration of 3 min. Fresh MWCNT dispersion with ultrasonication treatment was used in the course of the experiments with cement paste and cement mortar samples. Besides, the MWCNT dispersion was tested after 1.5 months of storage to determine the preliminary storage period. The MWCNT dispersion was used in the amount of 0.25% by weight of cement, hence the solid concentration of MWCNT was equal to 0.005% by weight of cement. The concentration adopted was a based on the previous research [20] and was applied in the course of all tests of the current research.

2.2. Test methods

The influence of accelerating admixtures, MWCNT and their combined effect on the properties of cement paste and mortar were examined.

The quality of dispersion was observed by the particle size analyzer “CILAS 1090”. The operating principle is based on laser diffraction of beams. The resolution of measurement is between 0.04 and 2500 μm. Particle size analysis was conducted in liquid mode. To enhance the accuracy of measurement, the dispersion was subjected to additional ultrasonication in the particle size analyzer.

The particle size distribution graphs are generated using specialised software. The processing of obtained results was automatically performed based on Mie’s theory for small particles with diameters less than the wave-lengths of laser beam (the particle size analyzing instrument is equipped with two electric clocked lasers of wave-lengths 635 nm and 830 nm).

The cement pastes were prepared according to European Standard EN 196-3. The amount of water for standard consistence and setting time of cement pastes were determined using Vicat apparatus as described in the same standard. The water to cement ratio for standard consistence of cement paste was equal to 0.275 for standard consistence when the distance between plunger and base-plate reached 5 mm. The temperature was 20±2°C during the consistence and setting time test of cement pastes.

After testing the cement paste, the standard prisms of size 40×40×160 mm for determination of density, flexural and compressive strength, water absorption and porosity were prepared with reference to EN 480-1 and EN 196-1. The cement mortar mixtures with water to cement ratio equal to 0.5 and cement to sand ratio of 1:3 were produced.

The consistence of cement mortars was determined based on the flow table method as described in European Standard EN 1015-3.

Calcium chloride was chosen as an accelerative admixture for cement mortar samples owing to its wide application in construction industry. The dosage of calcium chloride was 2 and 3% by weight of cement.

The density, flexural and compressive strength of cement mortar were tested according to European Standard EN 1015-10 and EN 1015-11.

The water absorption test was performed according to the method described in Russian Standard GOST 12730.3-78. The samples were dried to a constant mass, weighted and then immersed in water for 5, 30, 60, 1440 and 2880 min. The water-saturated samples were weighted by hydrostatic balance. The water absorption by mass W_m was calculated according to the formula:

$$W_m = \frac{m_d - m_s}{m_d} \qquad (1)$$

where: m_d – mass of dry sample;

m_s – mass of water-saturated sample.

The total and open capillary porosity, the parameter of average size of open capillary pores λ and parameter of the size homogeneity of open capillary pores α were determined according to GOST 12730.4-78.

The total porosity P_t was calculated based on the formula:

$$P_t = \frac{\rho_m - \rho_0}{\rho_0} \qquad (2)$$

where: ρ_m – density of cement mortar in dry state;

ρ_0 – density of mortar crushed into the powder determined by pycnometer method.

The open capillary porosity P_0 was calculated according to the formula:

$$P_0 = \frac{W_m \cdot \rho_m}{\rho_w} \qquad (3)$$

where: W_m – water absorption of cement mortar by mass;

ρ_m – density of cement mortar in dry state;

ρ_w – density of water.

The parameters of porosity were determined based on kinetics of water absorption taking into account the possibility to describe the curves of water absorption by Equation (4) and the nomograms presented in GOST 12730.4-78.

$$W_t = W_m\left[1 - e^{-(\lambda t)^{\alpha}}\right] \qquad (4)$$

where: W_t – water absorption of cement mortar by mass for the time *t;*

W_m – water absorption of cement mortar by mass;

e – base of the natural logarithm approximately equal to 2.718;

t – time of water absorption;

λ – parameter of average size of open capillary pores determined by nomograms presented in GOST 12730.4-78;

α – parameter of the size homogeneity of open capillary pores determined by nomograms presented in GOST 12730.4-78.

Apart from the above, samples with size 20×20×20 mm based on cement without aggregates were produced to study the hydration products of cement compositions modified by MWCNT. The Fourier-transform infrared spectroscopy (FT-IR) and X-ray diffraction (XRD) analysis were used to study the hydration products and understand the chemical processes which took part in the nanomodified cement systems.

The FT-IR spectra were obtained by FT-IR spectrometer "Spectrum 100" in the frequency range 3900-450 cm^{-1}. The XRD analysis was performed using diffractometer DRON-7 with Co anode, Ni filter, operating at anode operating voltage of 30.0 kV, anode emission current of 8 mA, and goniometer apertures of 0.5, 1.0 and 1.5 mm.

3. Results and discussion

3.1. Particle size analysis of MWCNT dispersion

The results of particle size analysis obtained for MWCNT dispersion "Fulvek 100" with and without ultrasonication are shown in Fig. 1.

Some differences between particle size distribution for the dispersion of MWCNT with and without ultrasonication were observed. The dispersion without ultrasonication was characterized by the presence of agglomerates with diameter in the range of 0.3-3.0 μm and with the average diameter of particles equal to 0.84μm.

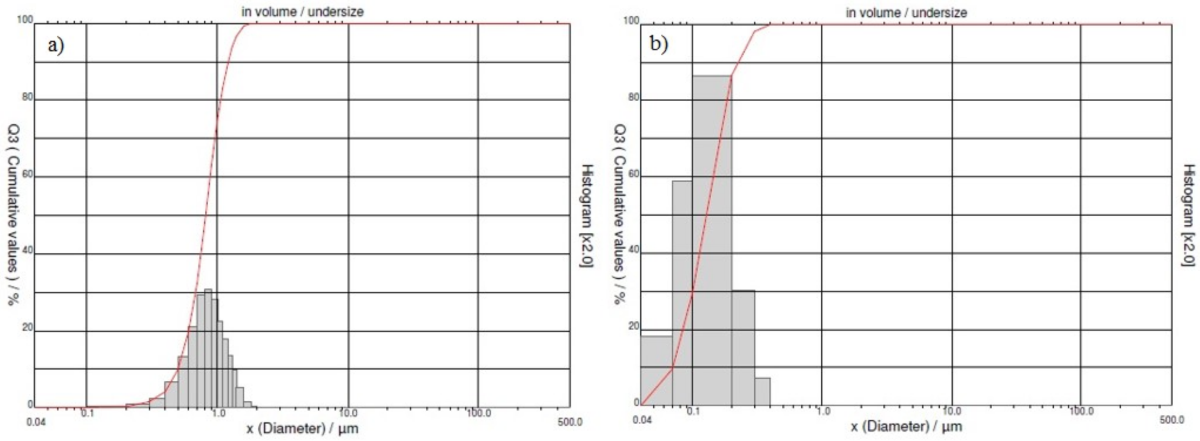

Fig. 1 - Particle size analysis of fresh MWCNT dispersion: a) without and b) with ultrasonication.

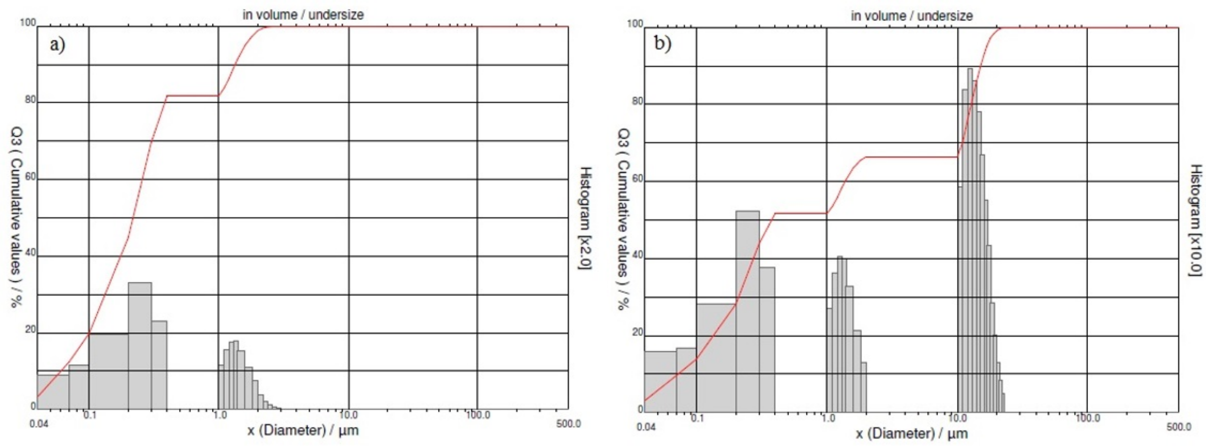

Fig. 2 - Particle size analysis of MWCNT dispersion: a) without and b) with ultrasonication after 1.5 months of storage.

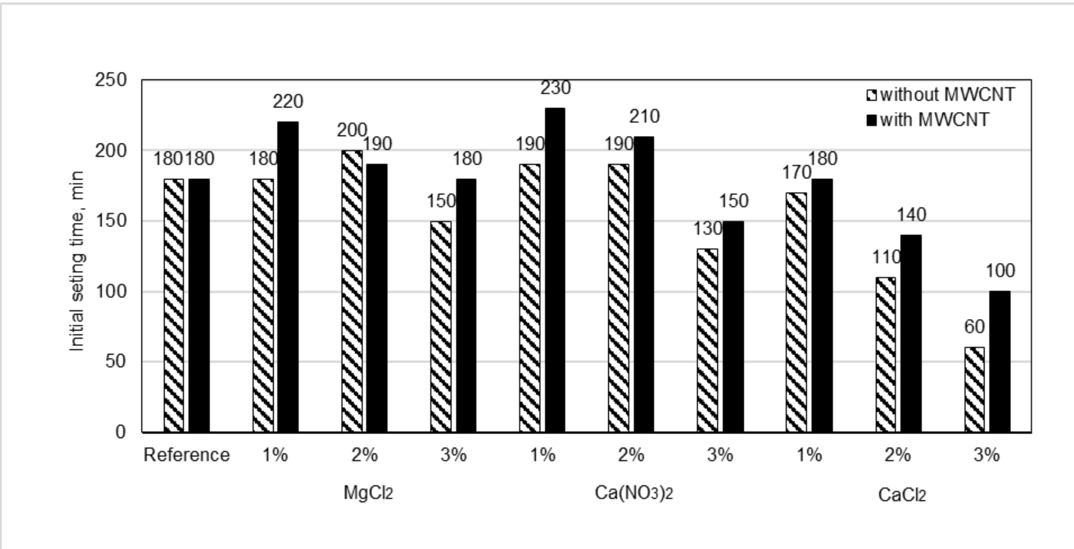

Fig.3 -Initial setting time of cement paste.

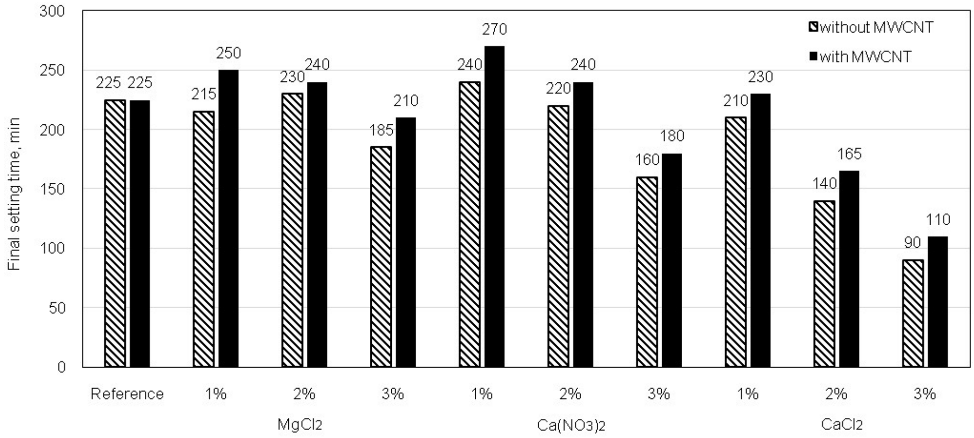

Fig.4 - Final setting time of cement paste.

The ultrasonication treatment of MWCNT dispersion reduced the range of diameter of agglomerates to 0.04-0.6 μm, and also reduced the average diameter of agglomerates to 0.14 μm. Evidently, the ultrasonication was facilitative to the MWCNT particles dispersion.

The MWCNT dispersion was changed in the course of storage due to coagulation process which is present in the dispersion. The coagulation process is explained by the strong Van der Waals forces between nanoparticles. Fig. 2 demonstrates the properties of dispersion after 1.5 months of storage.

Comparing Fig. 1 and Fig. 2, the differences in the particle size distributions are obvious. The shifting of agglomerates diameter to the ranges 1.0-4.8 μm was obtained for dispersion without ultrasonication and shifting to the ranges 1.0-3.1 and 10-36 μm was observed for dispersion with ultrasonication.

Hence, the production of MWCNT dispersion requires control of the storage time before its usage as admixture for cement composites.

3.2. Setting time of cement paste

The results of setting time test of cement pastes are presented in Fig. 3 and Fig. 4. The accelerating effect of admixtures is determined by the properties of their cation and anion, as well as their dosage in the cement paste.

The better accelerating effect was achieved for cement system modified by calcium chloride $CaCl_2$ in the amount from 1% to 3% by weight of cement. The reduction in initial setting and final setting time with $CaCl_2$ in the amount of 3% was 120 and 135 min, respectively.

It is found that the MWCNT dispersion alone added in the amount of 0.25% by weight of cement did not affect the setting time of cement paste. The initial and final setting time remained constant.

The combined modification of cement paste by accelerating admixtures and MWCNT dispersion generally led to retardation effect. This effect was observed for both initial and final setting time. The maximum retardation by 50 min for initial setting time and 45 min for final setting time was noticed in the case of modification of cement paste by MWCNT dispersion and 1% $Ca(NO_3)_2$ in comparison with the reference sample without MWCNT dispersion.

The increase in setting time was noticed for every sample modified by accelerating admixture and MWCNT dispersion in comparison with samples modified only by accelerating admixture. The maximum increase in initial setting time was 40 min as resulted from 1% $MgCl_2$, 1% $Ca(NO_3)_2$ and 3% $CaCl_2$. The corresponding increase in final setting time was 35, 30 and 25 min for 1% $MgCl_2$, 1% $Ca(NO_3)_2$ and 2% $CaCl_2$, respectively.

The results can be explained by the possible physical interactions between MWCNT and accelerating admixtures. Probably, carbon nanotubes, which possess strong electrostatic properties, influence on the cations and anions of accelerating admixtures, thereby leading to the retardation of setting time in cement paste.

3.3. Density, flexural and compressive strength of cement mortar

The influence of accelerating admixtures in combination with carbon nanotubes on the setting time of cement pastes gives the possibility to suggest the influence of complex admixture on the properties of cement mortar. The cement mortars modified by calcium chloride and carbon nanotubes separately and in their combination were prepared to evaluate the influence of admixtures on the cement systems in hardened state. Calcium chloride was chosen among the other tested accelerating admixtures due to its better results in setting time test with cement pastes.

The modification by accelerating admixtures, MWCNT dispersion and their combined application did not change the density of cement mortar, as shown from Fig. 5.

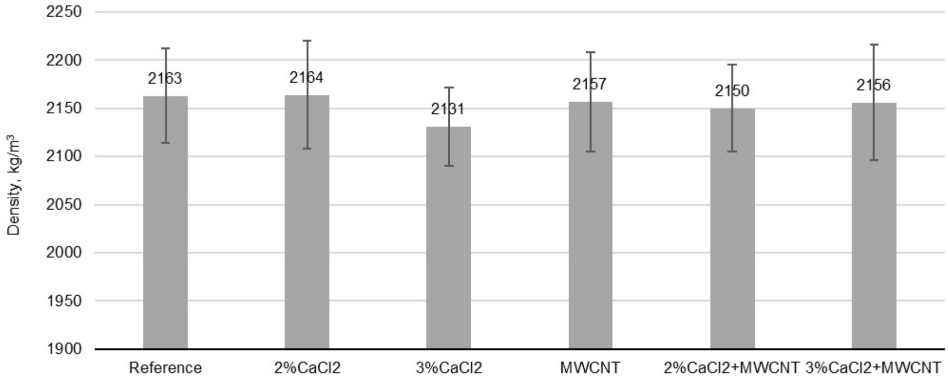

Fig. 5 - Density of cement mortar.

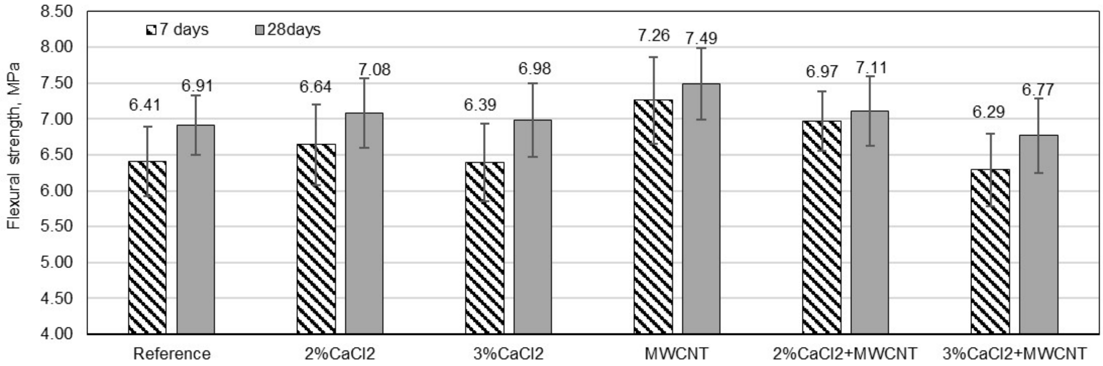

Fig. 6 - Flexural strength of cement mortar.

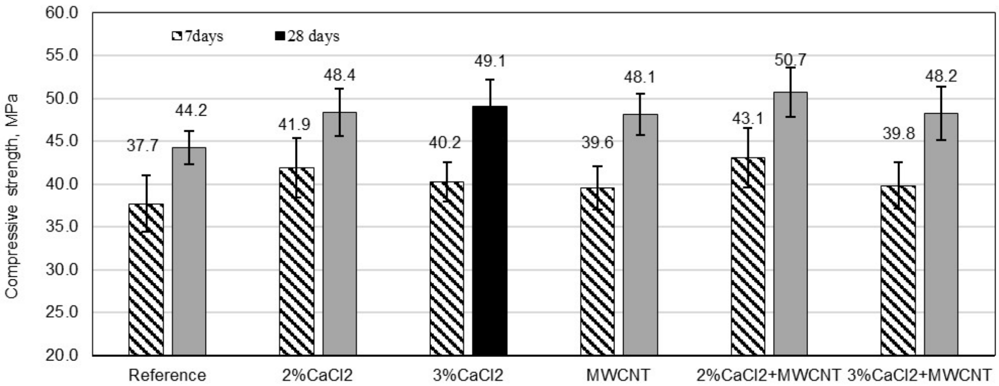

Fig. 7 - Compressive strength of cement mortar.

Apart from the determination of cement mortar density, the flexural and compressive strength of cement mortar after 7 and 28 days were tested and the results are presented in Fig. 6 and Fig. 7, respectively.

The analysis of results in Fig. 6 reveals the following aspects. The flexural strength at 7 and 28 days age of samples modified by accelerating admixtures did not change significantly. The introduction of MWCNT dispersion alone contributed to the increase in 7 and 28 days flexural strength by 13.3 and 8.4%, respectively. The flexural strength of cement mortar modified by 3% accelerating admixture and MWCNT changed marginally. It means that notable advantage was not gained from the combined addition of MWCNT and accelerating admixture in large dosage.

Fig. 7 demonstrates the results of compressive strength test of cement mortar at the age of 7 and 28 days. The compressive strength increased with modification of cement mortar by accelerating admixture and MWCNT at 7 and 28 days. Comparatively, better results were obtained for samples modified by MWCNT in the amount of 0.25% and calcium chloride in the amount 2% by weight of cement. The increase in compressive strength was 14.3% and 14.7% at 7 and 28 days, respectively. However, the difference between strength of cement mortar modified by calcium chloride with and without MWCNT is insignificant. There were only up to 4.8% differences for the samples at 28 days.

The attempt to understand the influence of carbon nanotubes on the properties of cement systems were made based on results of FT-IR spectroscopy and XRD analysis, which are presented in section 3.5.

3.4. Water absorption and porosity of cement mortar

The water absorption and porosity of samples were determined as an important characteristic of the cement mortar durability. The results of water absorption test are presented in Fig. 8. The water absorption measurements were performed at 5, 30, 60, 1440 and 2880 min. The main water absorption value was observed during first 240 min and it did not change rapidly after this time (Fig. 8). The differences between total water absorption of reference sample and sample modified by MWCNT were not significant.

The introduction of calcium chloride admixture increased the total water absorption of cement mortar by 0.3% and 0.7% for $CaCl_2$ content of 2% and 3% by weight of cement, respectively. Whereas the combined application of MWCNT dispersion and 3% calcium chloride led to an increase in total water absorption by only 0.6%. The rate of water absorption for all samples appeared to be independent on the quantity of accelerating admixture and MWCNT. The results of total water absorption of cement mortar after 2 days of immersion in water are shown in diagram form in Fig. 9.

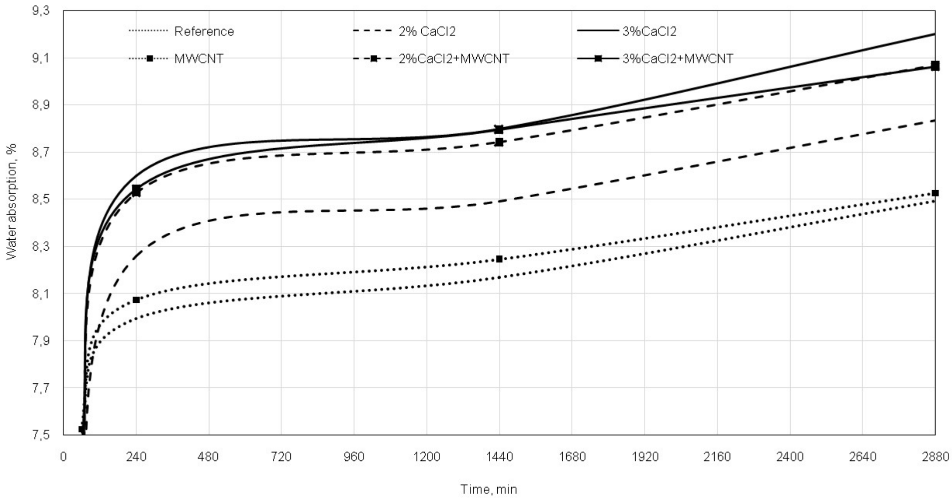

Fig. 8 - Water absorption of cement mortar after 28 days of curing.

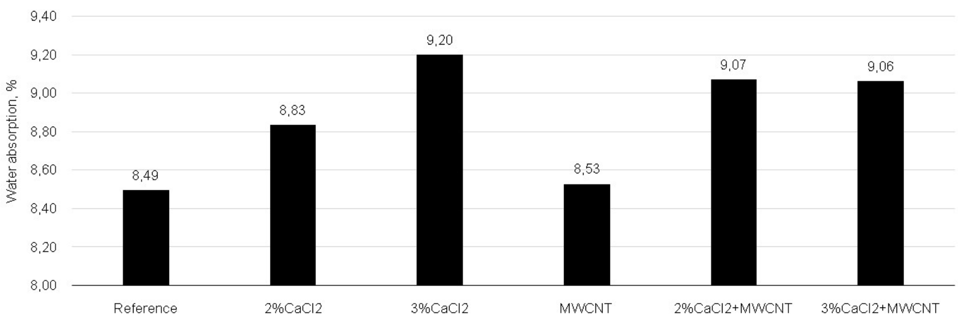

Fig. 9 - Total water absorption of cement mortar after 28 days of curing.

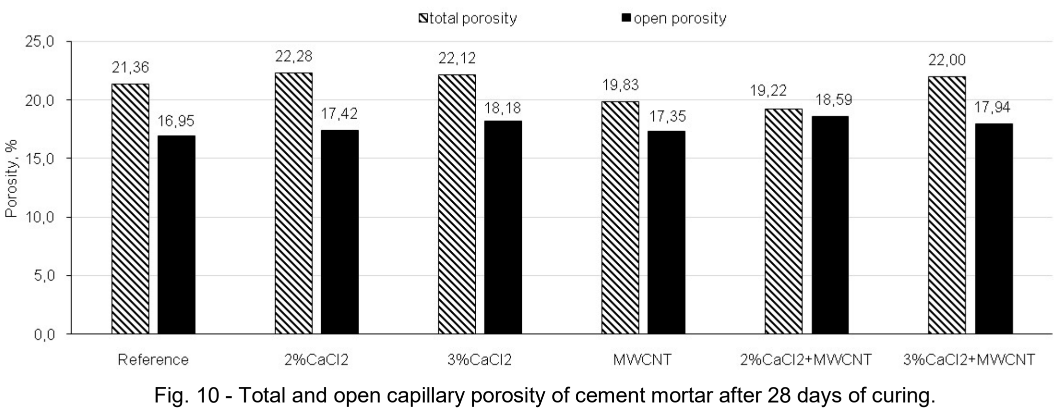

Fig. 10 - Total and open capillary porosity of cement mortar after 28 days of curing.

Fig. 10 presents the results of total and open capillary porosity of cement mortar. The total porosity was determined on the basis of density measurements of samples with irregular form through hydrostatic weighing and the true density by testing in pycnometer. The calculation of open capillary porosity was based on measurements of water absorption.

The maximum decrease of total porosity by 2.1% was obtained for samples modified by MWCNT and calcium chloride in the amount of 2% by weight of cement. The open capillary porosity of cement mortar increased in the case of modification by calcium chloride with and without MWCNT. The maximum increase by 1.6% was obtained for cement mortar modified by MWCNT and calcium chloride in the amount of 2% by weight of cement.

Table 3 presents the experimental results of porosity testing. It can be seen that the parameter of average size of open capillary pores λ decreased with modification by accelerating admixture with and without MWCNT. Besides, the homogeneity parameter of total capillary porosity α confirmed the reduction of relatively homogeneous distribution of the pores sizes with addition of acceleration admixture.

Table 3

Values of parameters of porosity, α and λ

Sample	α	λ
Reference	0.67	3.13
2%$CaCl_2$	0.60	1.86
3%$CaCl_2$	0.63	2.11
MWCNT-0.25%	0.70	2.98
2%$CaCl_2$+MWCNT	0.64	2.19
3%$CaCl_2$+MWCNT	0.63	2.32

The results of water absorption and porosity test as well as density and strength characteristics can be explained by changes in cement hydration products resulted from the cement paste modification. The analysis of cement hydration products is presented below.

3.5. Effect of MWCNT dispersion on the cement hydration products

The FT-IR and XRD analysis were performed to understand the possible processes which have taken place in nanomodified cement paste.

The FT-IR absorbance spectra of hardened cement paste at 28 days of age without and with modification by MWCNT dispersion are presented by separate curves in Fig. 11.

The spectrum illustrates O-H stretching of $Ca(OH)_2$ at 3645 cm^{-1}, symmetric and asymmetric stretching (v_1, v_3) of O-H at zone 3100…3400 cm^{-1}, C-H stretching at zone 3000…2750 cm^{-1}, H-O-H bending bond from 2265…2420 cm^{-1}, deformation (v_2) of H-O-H at 1650 cm^{-1}, peak (v_3) and peak (v_4) of CO_3^{2-} at 1480 and 875 cm^{-1}, respectively; peak (v_3) of SO_4^{2-} at 1115 cm^{-1}, stretching (v_3) of Si-O at 990 cm^{-1}, (v_4) of Si-O at 520 and (v_2) of Si-O at 450 cm^{-1}.

New bonds are not identified for the modification of hardened cement pastes by MWCNT dispersion. However, the intensity of the absorption lines 3645, 1650, 1480, 1115, 990, 875, 520, 450 cm^{-1} and the intensity of lines at the zones 3000…2750, 2265…2420 cm^{-1} became lower after modification by MWCNT dispersion.

The decrease of absorption line in the range 3500…3250 cm^{-1} and decrease of signal intensity in the range 1750…1500 cm^{-1} can be linked with changes of character of water bonding in the calcium hydrosilicates. Besides, the changes in the composition of calcium hydrosilicates can be confirmed by the decrease of signal intensity in the range 3000….2750 cm^{-1} and by absorption lines 990, 520 and 450 cm^{-1} for Si-O.

The decrease in the intensity of absorption lines for CO_3^{2-} in the ranges 1500…1250 cm^{-1} and 1000…750 cm^{-1} can be explained by the decrease in the content of free calcium hydroxide in hardened cement paste before carbonization process. Decrease in signal intensity for calcium hydroxide was observed from this spectrum in the range 3750…3500 cm^{-1} as well.

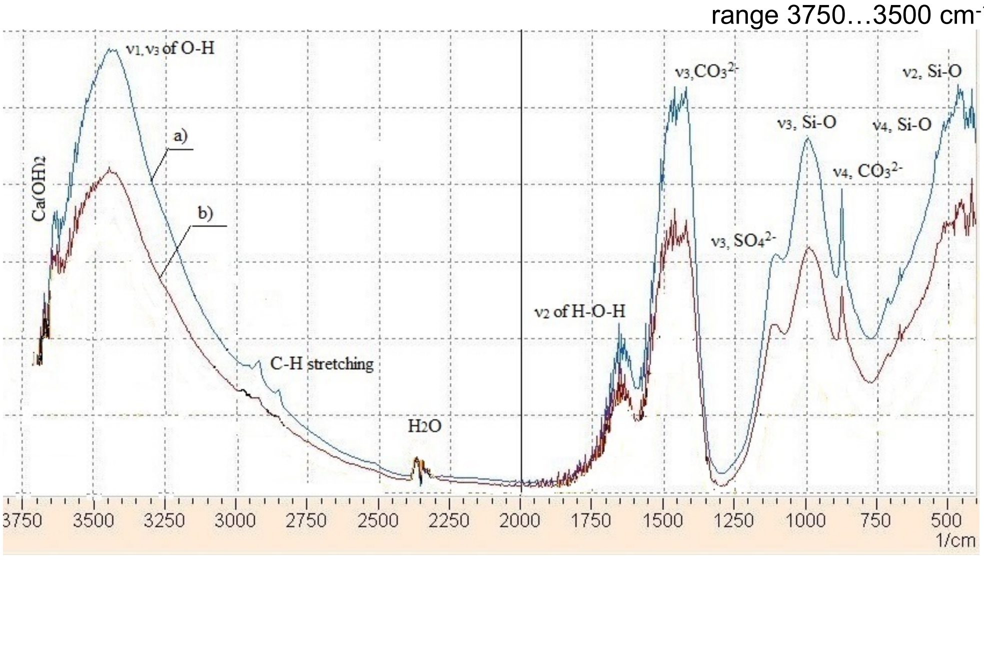

Fig. 11 - FT-IR-spectra of hardened cement paste after 28 days of hydration: a) reference; b) modified by MWCN.

The lines at 1115 cm^{-1} for peak (v_3) of SO_4^{2-} indicates the reduction of ettringite phase in cement matrix which could lead to increase in the degree of cement hydration

The results of XRD analysis are presented in Fig. 12. From the XRD analysis, the phases relevant to the $Ca(OH)_2$, unreacted C_3S, and $CaCO_3$ from carbonization of $Ca(OH)_2$ were identified. The modification of cement matrix by MWCNT dispersion did not lead to the development of new phases. Some reduction in the content of $Ca(OH)_2$ was observed after cement paste modification by MWCNT.

The results of FT-IR spectroscopy and XRD analysis are coherent with the results obtained for compressive strength, flexural strength, water absorption and porosity test in the sense that the cement systems were mainly modified physically rather than chemically by the accelerating admixtures and MWCNT dispersion. The results of FT-IR and XRD analysis of nanomodified cement paste can explain the absence of drastic changes of physical properties of cement mortar.

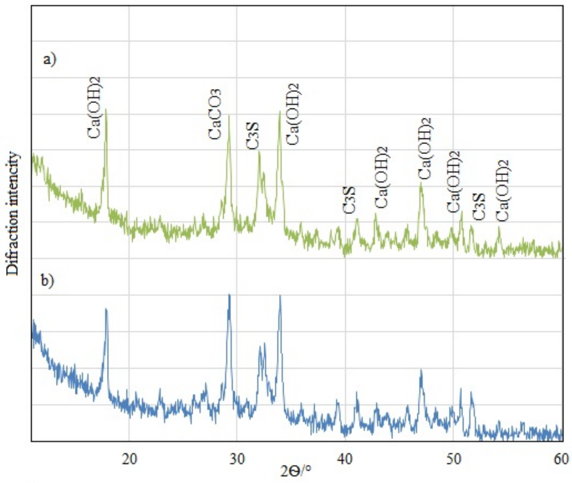

Fig. 12 - XRD analysis for hardened cement paste after 28 days of hydration: a) reference; b) modified by MWCNT.

4. Conclusions

The following conclusions are drawn in this study:

1. The control of storage period of MWCNT dispersion before its application as admixture for cement composites is required to prevent undesirable coagulation.

2. The retardation of setting time in cement pastes was observed due to the complex modification by accelerating admixtures and MWCNT dispersion. The maximum retardation effect by 50 min for initial setting time and 45 min for final setting time was noticed in the case of modification of cement paste by MWCNT dispersion and 1% $Ca(NO_3)_2$ in comparison with the reference sample. The cause of these results could be linked with possible physical interactions between the MWCNT and accelerating admixtures.

3. Despite the changes in setting time of cement pastes with carbon nanotubes and accelerating admixtures, the density, flexural and compressive strength of cement mortar modified by calcium chloride and MWCNT did not change significantly. The maximum increase in compressive strength by 14.7% was attained for cement mortar modified by MWCNT and calcium chloride in the amount of 2% by weight of cement in comparison with reference sample without admixtures.

4. The introduction of MWCNT in combination with calcium chloride did not remarkably influence the total water absorption of cement mortar. The total porosity decreased by 2.1% and the open capillary porosity increased by 1.6% for cement mortar modified by MWCNT and calcium chloride in the amount 2% by weight of cement.

5. FT-IR spectroscopy and XRD analysis did not identify new bonds and phases in the hardened cement paste modified by MWCNT. The absence of new bonds and phases in nanomodified cement pastes is related to the absence of the significant improvement in physical properties of nanomodified cement mortars.

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MANIFESTĂRI ȘTIINȚIFICE / SCIENTIFIC EVENTS

5th Historic Mortars Conference

The 5th HMC 2019 will focus on **research about aspe concerning technology and characterization of histo mortars**, significance of the mortars and conservation a restoration issues in historic masonry structures a archaeological sites, historic plasters, design and preparati of preservation products, repair materials (mortars, rende plasters and grouts) and test methods (for historic and rep mortars).

The proposed **topics** for this edition of the Conference are:

- Characterization of historic mortars and masonry structures. Sampling and test methods.
- Historic production, processing and application of mortars, renders and grouts. Lime technologies.
- Mortars in archaeological sites. Construction history. Archaeometry. Dating of historic mortars.
- Historic renders and plasters. Gypsum-based plasters and mortars. Adobe and mud morta Rammed earth constructions. Natural and Roman cement mortars. Assessment.
- Conservation issues concerning mortars, plasters, renders and grouts. Diagnosis. Decay a damage mechanisms. Case studies.
- Preservation. Consolidation materials and techniques. Development of new products. Prevent conservation.
- Repair mortars and grouts. Requirements and design. Compatibility issues. Durability a effectiveness. Adequacy of testing procedures.

https://www.unav.edu/web/historic-mortars-conferer

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