Theoretical and Applied Fracture Mechanics 104 (2019) 102391

Contents lists available at ScienceDirect

Theoretical and Applied Fracture Mechanics

journal homepage: www.elsevier.com/locate/tafmec

Experimental study of the simultaneous effect of nano-silica and nano-carbon black on permeability and mechanical properties of the concrete

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A R T I C L E I N F O

Keywords:
Cutoff wall
Nano-carbon black
Nano-silica
Earth dam
Permeability

A B S T R A C T

The permeability level and resistance of the concrete cutoff wall of earth dam on the penetration of fluids are crucial factors and have an essential effect on the stability of the concrete core. In this research, the simultaneous incorporation of nano-carbon black and nano-silica in the concrete with nine different mixing patterns is considered to investigate the permeability and mechanical properties of the concrete. Experimental results revealed that the addition of nanoparticles to the concrete considerably decreases permeability; while reducing the compressive strength in some mixtures and increasing the bending strength of the modified concrete in most of the studied cases.

1. Introduction

A concrete structure should be capable of service under ambient conditions and during the considered useful lifetime and have a suitable performance. Such concrete is called durable or stable concrete. The lack of durability may be due to internal or ambient factors that are imposed on the concrete [1]. Permeability in a concrete which is wholly dried, is more than its corresponding value in concrete under normal conditions. The permeability factor of the air generally increases with the increase of the water to cement ratio. However, abnormal behaviors can be expected in concrete mixtures [2,3]. Adding air to concrete nearly has no effect on the water absorption by concrete but decreases the strength slightly, which enhances the permeability, however, a less permeable concrete can be achieved compared to the regular weight concrete by substituting more compact materials in light concretes [4,5].

All the permeability experiments performed on the concrete specimens with various nano-materials and different types of fly ash demonstrate that these materials reduce the permeability. In the specimens fabricated by ash at different percentages, the abrasion and compressive resistance increased with the increase of the curing time, but the best result is obtained at the 15% ash, and the permeability generally drops by the addition of ash at every percentages [6–8]. In the specimens manufactured by nano-silica, a more compact and dense area is formed because the nano-silica can absorb $Ca(OH)_2$ crystals and decrease its amount, which leads to an improvement in the mechanical strength of the concrete and its durability. This also decreases the permeability of concrete [9,10]. Permeability plays a significant role in the stability of concrete since this characteristic shows the concrete strength against the entry of fluids such as water and carbon dioxide and oxygen gases [11,12].

Dealing with the under-load concretes, the permeability decreases at the beginning of loading due to some initial density, but this trend is changed with the increase of load and reveals a remarkable increase at the loading of more than 80% of the maximum capacity. Furthermore, the permeability of concrete increases with the increase in temperature between 105 and 150 degrees Celsius [13]. The level of the imposed damage in wet ambient on the concrete, which is subjected to a load equal to 60 to 90 percent of the concrete's final strength increases according to the changes of the permeability factor and these changes can interpret the presence of micro-cracks [12,14]. When the width of the crack is less than 50 μm, it has a little effect on permeability. As a result of the self-healing property of the cracks, the water flow through the cracks decreases slowly over time, but when the width of the cracks becomes between 50 and 100 μm, the permeability will increase [15]. During the carbonization process, the calcium phase in the cement is converted to CaCO3 as a result of the CO2 attack, which leads to a change in the permeability level of concrete as the pore space of the concrete will also change. Regardless of the water to cement ratio, the permeability rises as it is subjected for a longer time to the flow [16]. The passage of destructive materials such as chloride ions through the continuous cavities of concrete can be the reason for corrosion

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https://doi.org/10.1016/j.tafmec.2019.102391
Received 18 January 2019; Received in revised form 15 October 2019; Accepted 16 October 2019
Available online 17 October 2019

Table1
Various ratios of the materials used in the specimens.

w/c	Cement [kg/m^3]	Fine grains [kg/m^3]	Coarse grains [kg/m^3]	Water [kg/m^3]	Super lubricant [kg/m^3]	Nano-carbon black [kg/m^3]	Nano-silica [kg/m^3]
0.4	158.15	1014.44	699.7	493.75	4.93	0.4% = 1.975 0.8% = 3.950 1.2% = 5.925	0.2% = 0.987 0.4% = 1.975 0.6% = 2.962
0.45	155.74	1014.44	748.82	438.88	4.38	0.4% = 1.775 0.8% = 3.511 1.2% = 5.266	0.2% = 0.887 0.4% = 1.775 0.6% = 2.662
0.5	153.81	1014.44	788.11	395	3.95	0.4% = 1.580 0.8% = 3.160 1.2% = 4.740	0.2% = 0.790 0.4% = 1.580 0.6% = 2.370

initiation of the embedded armature in the concrete. Besides, after corrosion initiation of the armature, the penetration speed of the oxygen gas or other materials into the concrete for the execution of corrosion reactions is among the effective parameters on the corrosion intensity of the armature. Thus, permeability is known as an essential property of the concrete and a parameter for controlling the speed of the corrosion reactions in many cases [17,18].

Since the dams are rarely constructed on completely impermeable grounds, thus there is underground water flow underneath the dam in most cases. One of the most significant dangers of the dams after impoundment is the leakage from the bottom of the dam foundation and the increase of the hydraulic gradient, which leads to the occurrence of some dangers such as the erosion of the foundation. In order to control the drainage under the dams, several methods including cutting of the drainage flow network and/or reducing it by using a complete cutoff wall and or decreasing its amount by a vertical semi-permeable cutoff wall are employed. According to the fact that earth dams have a higher volume than the concrete dams, thus the selection of the required foundation for the construction of the dam can be accomplished by a less sensitivity compared to the concrete dam and this causes that the use of cutoff walls and clay core with various permeabilities to be common in the structure of the dam. Therefore, the determination of the permeability factor as a parameter by which the easiness of the fluid passage through the concrete can be obtained is of high importance [19].

Various materials such as micro-silica, natural or industrial pozzolans, ash, nano-silica, carbon nanotubes, and other diverse materials are utilized as an alternative of a part of the consumed cement for the reduction of the concrete permeability and or the increase of the concrete strength already [20–25] but nano-carbon black and nano-silica have not been used simultaneously for this purpose yet and the investigation of the effects of these two nano-materials is the main objective of this paper.

2. Mixing pattern

In this research, for each mixing pattern with water to cement ratios, w/c of 0.4, 0.45, 0.5, three proof specimens (i.e. without additive), three nano-carbon black reinforced concrete specimens for each replacement percent of cement weight (0.4%, 0.8% and 1.2%), three nano-silica reinforced concrete specimens for each replacement percent of cement weight (0.2%, 0.4% and 0.6%) and three hybrid concrete specimens (containing both nano additives) were prepared, which resulted in total number of 432 specimens. Table 1 presents the details of each mixture for different studied cases. Each of the test specimens has an abbreviated name based on their different constituent components, and the combination of these names are given in Table 2.

Carbon black is a specific kind of the basic carbon which is obtained as colloid particles from incomplete combustion or thermal decomposition of the liquid or gaseous hydrocarbons under controlled conditions. This material can be observed as a fine black powder similar to the materials obtained from the combustion of the hydrocarbons, coal or exhaust soot. Carbon black contains more than 95% of amorphous and opaque carbon and a small amount of oxygen, hydrogen, nitrogen, and others, which concentrate on the surface of the particles [5,6]. The physical properties of the nano-carbon black are given in Table 3. The consumed amount of this material in the produced specimens is 0.4% – 1.2% of cement weight for each mixing pattern (1.58–5.925 kg/m^3).

Nano-silica constitutes of particles which have a spherical shape and

Table 2
Sample name properties.

Sample name	w/c	Nano-carbon black		Nano-silica	
		wt%	Density [kg/m^3]	wt%	Density [kg/m^3]
C0S0	0.4	0	0	0	0
	0.45	0	0	0	0
	0.5	0	0	0	0
C0S1	0.4	0	0	0.2%	0.987
	0.45	0	0	0.2%	0.887
	0.5	0	0	0.2%	0.790
C0S2	0.4	0	0	0.4%	1.975
	0.45	0	0	0.4%	1.775
	0.5	0	0	0.4%	1.580
C0S3	0.4	0	0	0.6%	2.962
	0.45	0	0	0.6%	2.662
	0.5	0	0	0.6%	2.370
C1S0	0.4	0.4%	1.975	0	0
	0.45	0.4%	1.775	0	0
	0.5	0.4%	1.580	0	0
C1S1	0.4	0.4%	1.975	0.2%	0.987
	0.45	0.4%	1.775	0.2%	0.887
	0.5	0.4%	1.580	0.2%	0.790
C1S2	0.4	0.4%	1.975	0.4%	1.975
	0.45	0.4%	1.775	0.4%	1.775
	0.5	0.4%	1.580	0.4%	1.580
C1S3	0.4	0.4%	1.975	0.6%	2.962
	0.45	0.4%	1.775	0.6%	2.662
	0.5	0.4%	1.580	0.6%	2.370
C2S0	0.4	0.8%	3.950	0	0
	0.45	0.8%	3.511	0	0
	0.5	0.8%	3.160	0	0
C2S1	0.4	0.8%	3.950	0.2%	0.987
	0.45	0.8%	3.511	0.2%	0.887
	0.5	0.8%	3.160	0.2%	0.790
C2S2	0.4	0.8%	3.950	0.4%	1.975
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	0.5	0.8%	3.160	0.6%	2.370
C3S0	0.4	1.2%	5.925	0	0
	0.45	1.2%	5.266	0	0
	0.5	1.2%	4.740	0	0
C3S1	0.4	1.2%	5.925	0.2%	0.987
	0.45	1.2%	5.266	0.2%	0.887
	0.5	1.2%	4.740	0.2%	0.790
C3S2	0.4	1.2%	5.925	0.4%	1.975
	0.45	1.2%	5.266	0.4%	1.775
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C3S3	0.4	1.2%	5.925	0.6%	2.962
	0.45	1.2%	5.266	0.6%	2.662
	0.5	1.2%	4.740	0.6%	2.370

Table 3
Properties of the nano-carbon black.

Structure	Color	Particle size (nm)	Density (kg/m^3)	Blain (g/m^2)	Purity (%)
Amorphous	Black	150	380	700	98

Table 4
Properties of the nano-silica.

Color	Particle size (nm)	Density (kg/m^3)	Blain (g/m^2)	Purity (%)
White	15–20	240	180	99.8

Table 5
Properties of the utilized coarse grains.

Type	size (mm)	Weight (kg/m^3)
A	5–7	253.61
B	12–15	253.61
C	20–25	507.22

can be spread with a diameter less than 100 nm as dry powder particles or suspended form in the solution liquid, and its liquid is the most common type of nano-silica solution [7]. The physical properties of nano-silica powders can be seen in Table 4. The consumed amount of this material in the fabricated specimens is 0.2% – 0.6% of the cement weight for each mixing pattern (0.79 – 2.962 kg/m^3).

The used cement in this research is ordinary Portland (type I), the dry apparent specific weight of the fine grains is 1600 kg/m^3 and the coarse grains at three different sizes with a ratio of 1:1:2 of three types of A, B and C are combined respectively. The properties of the utilized coarse grains are represented in Table 5.

To mix the components of the considered concrete, the coarse grain, fine grain, cement, and nano-material are thoroughly mixed before adding water. Then, the components are mixed for five minutes by a mixer after the addition of water and plasticizer to obtain the desired product. The produced concrete is poured in oiled shuttering molds and thoroughly vibrated, so that pore and air free concrete settle inside the shuttering in order to implement the compressive strength and permeability tests for the 15 × 15 × 15 cm specimens and the bending strength test for the 10 × 10 × 50 cm specimens. The specimens are pulled out of the shuttering molds after 24 h and maintained into a pool with a temperature of 23 ± 2 °C until the implementation of the tests.

3. Results and discussions

3.1. Slump test

In order to assess the effect of replacing a percentage of cement by nano-materials on the concrete rheology, slump results, and the percentages of slump reduction, which were achieved in the experiments performed according to ASTM C143-78 [26] (see Fig. 1) are indicated in Table 6. In addition, Fig. 2 is plotted based on this table, in which the slump amount and the amount of the slump reduction are represented. As it can be observed from the results, the slump amount is reduced by replacing the used cement by the nano-particles, and this occurs because the specific surface of the nano-particles is more than the replaced cement and this enhances the absorption of the free water available in the mixing of the desired concrete. Moreover, it can be observed that if the two nano-particles are used simultaneously, then the amount of the slump reduction will be higher compared to the case in which only one nano-particle is used. Due to the difference in their dimensions, nano-particles act as lock and fasteners, and nano-silica particles, which have smaller sizes, are located among the nano-carbon black particles and leave less space. Due to this fact, the amount of slump decrease for hybrid concrete is higher than the case when only one of the nano-particles is replaced.

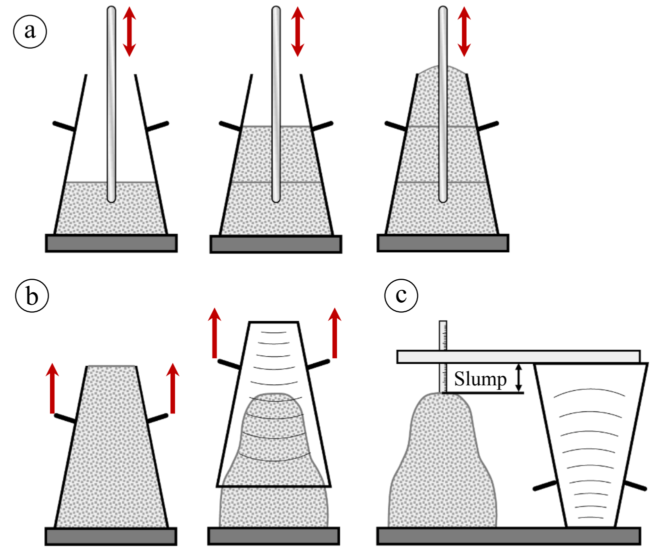

Fig. 1. Schematic view of slump testing of the concrete mixture.

3.2. Compressive strength test

BS 1881 standard [27] test procedure was employed to measure the compressive strength in this research. According to this research, the mixtures are poured into cubic steel or cast-iron shuttering molds with dimensions of 15 × 15 × 15 cm. Table 7 shows the average 28-day strength of the cubic specimens made by different compositions for the compressive strength test. The compressive strength of different modified concrete specimens and also the variation of compressive strength compared to the control specimens is illustrated in Fig. 3.

According to the plotted graphs, it can be concluded that the strength increases by adding the nano-silica because nano-silica absorbs and reduces $Ca(OH)_2$ crystals and then forms denser area, resulting in increased mechanical strength of the concrete. Nano-silica has effective and high-level pozzolanic reaction, suggesting a significant decrease in size and the total amount of Calcium Hydroxide crystals, which would cause an improvement in hard cement paste primary strength. Furthermore, the addition of nano-silica increases heating in cement hardening stages. Small particles, such as nano-silica in aqueous environments, have a high tendency in ionic particle adsorption and agglomeration. This phenomenon has a short-term effect on the properties of fresh paste and the final hard concrete. Some results show a decrease in strength, which can be attributed to the agglomeration of nano-silica particles resulting in brittle behavior of the concrete.

The strength improvement in samples containing nano-silica is due to their lower content of residual Ca(OH)2 compared to the samples without nano-silica, which represents an increase in the occurrence of pozzolanic reactions and formation of hydrated calcium silicate, which consequently fills the pores of cement. Generally speaking, the nano-silica activates the pozzolanic reaction. Noncrystalic silica (or glass silica) as a major component of pozzolanic reaction reacts with calcium

Table 6
The amount of slump based on the various percentages of nano-particles.

w/c = 0.4	Nano-carbon black	wt%	0	0.4%	0.8%	1.2%
		Slump (mm)	97	93	83	64
		Slump reduction (%)	0	4	14	34
	Nano-silica	wt%	0	0.2%	0.4%	0.6%
		Slump (mm)	97	89	65	48
		Slump reduction (%)	0	8	32	50
	Hybrid (nano-carbon black & nano-silica)	wt% (C, S)*	0	0.4%, 0.2%	0.8%, 0.4%	1.2%, 0.6%
		Slump (mm)	97	71	43	23
		Slump reduction (%)	0	26	55	76
w/c = 0.45	Nano-carbon black	wt%	0	0.4%	0.8%	1.2%
		Slump (mm)	117	109	87	61
		Slump reduction (%)	0	6	25	47
	Nano-silica	wt%	0	0.2%	0.4%	0.6%
		Slump (mm)	117	101	79	52
		Slump reduction (%)	0	13	32	55
	Hybrid (nano-carbon black & nano-silica)	wt% (C, S)	0	0.4%, 0.2%	0.8%, 0.4%	1.2%, 0.6%
		Slump (mm)	117	93	51	29
		Slump reduction (%)	0	20	56	75
w/c = 0.5	Nano-carbon black	wt%	0	0.4%	0.8%	1.2%
		Slump (mm)	129	121	115	109
		Slump reduction (%)	0	6	10	15
	Nano-silica	wt%	0	0.2%	0.4%	0.6%
		Slump (mm)	129	114	102	81
		Slump reduction (%)	0	11	20	37
	Hybrid (nano-carbon black & nano-silica)	wt% (C, S)	0	0.4%, 0.2%	0.8%, 0.4%	1.2%, 0.6%
		Slump (mm)	129	96	71	44
		Slump reduction (%)	0	25	44	65

* C: nano-carbon black, S: nano-silica.

hydroxide, which has formed in a hydration reaction. The intensity of the pozzolanic reaction is proportional to the available surface area for the reaction.

According to the experimental results, the addition of nano-carbon black initially decreases the compressive strength of the concrete, and in a higher density of the nano-particles, the strength reduction trend changes, and higher compressive strengths are obtained. Although the addition of nano-carbon black increases the brittleness of the concrete and reduces the bending and tension strength of the concrete, it can have a positive effect on compressive strength by filling concrete pores. This phenomenon is more probable to occur in higher concentrations of the nano-particles (i.e., C3 specimens).

According to Fig. 3, when both nano-particles are used simultaneously, carbon black behavior is dominant, and the resulting concrete behaves closely to the behavior of the modified concrete with nano-carbon black so that the strength decreases to a certain percentage of nano-carbon black (i.e., C2) and then increases. It is worth mentioning that by increasing the water to cement content, the compressive strength of the resultant samples is decreased.

The highest compressive strength obtained in all of the three water-to-cement ratios is related to the C0S3 composition, which has increased 17%, 14%, and 13% for the water-to-cement ratio of 0.4, 0.45 and 0.50, respectively comparing to the control sample. The lowest compressive strength obtained in all the water-to-cement ratios is related to the C2S1 composition that is containing 0.2% nano-silica and 0.8% nano-carbon black. In this case, the compressive strength of the concrete samples was 24, 20, and 21% reduced for water-to-cement ratios of 0.4, 0.45 and 0.50, respectively. Adding nano-carbon black up to 0.8% decreases the compressive strength and dealing with the samples containing 1.2% of nano-carbon black in all compositions, there was a rising trend compared to the lower weight percentages of the additive. Increasing the amount of nano-silica in all compositions would increase compressive strength.

3.3. Bending strength test

ASTM-C78 [28] standard was employed in this research to measure the bending strength. According to this standard, beams with dimensions of 15 × 15 × 50 cm are used in this research. The schematic view of the testing configuration is illustrated in Fig. 4. The average 28-day strength of the fabricated cubic specimens for the test of the bending strength is given in Table 8. Fig. 5 shows the bending strengths and variation of bending strengths of different nano-modified concrete specimens compared to the control specimens. As described earlier, the addition of nano-carbon black increases the brittleness of the concrete and reduces the bending and tension strength of the concrete. On the other hand, by the addition of the nano-silica to the concrete, the bending strength of concrete increases. This can be sue to the fact that nano-silica absorbs and reduces $Ca(OH)_2$ crystals and then forms a more compact area, resulting in increased mechanical strength of the concrete.

According to the diagrams, the addition of nano-silica to the concrete composition, increases the flexural strength between 27 to 34%, 42 to 51%, and 50 to 58% for water to cement ratios of 0.4, 0.45, and 0.50, respectively. Similar to the results from compressive tests, the addition of nano-carbon black decreases the flexural strength of the concrete with a reduction slope by adding the nano-particles up to the weight percentage of 0.8%. However, the modified concrete samples with 1.2% nano-carbon black experienced an increasing trend of flexural strength for all water to cement ratios and compositions of modified concrete samples. Generally, the flexural strength decreases with increasing ratio of water to cement, but the highest flexural strength enhancement equal to 58% was obtained from the sample C0S3 with the water to cement ratio of 0.50 and 0.6% nano-silica. Besides, the highest flexural strength reduction equal to 24% was obtained from the sample C2S0 with the water to cement ratio of 0.50 and 0.8% of nano-carbon black.

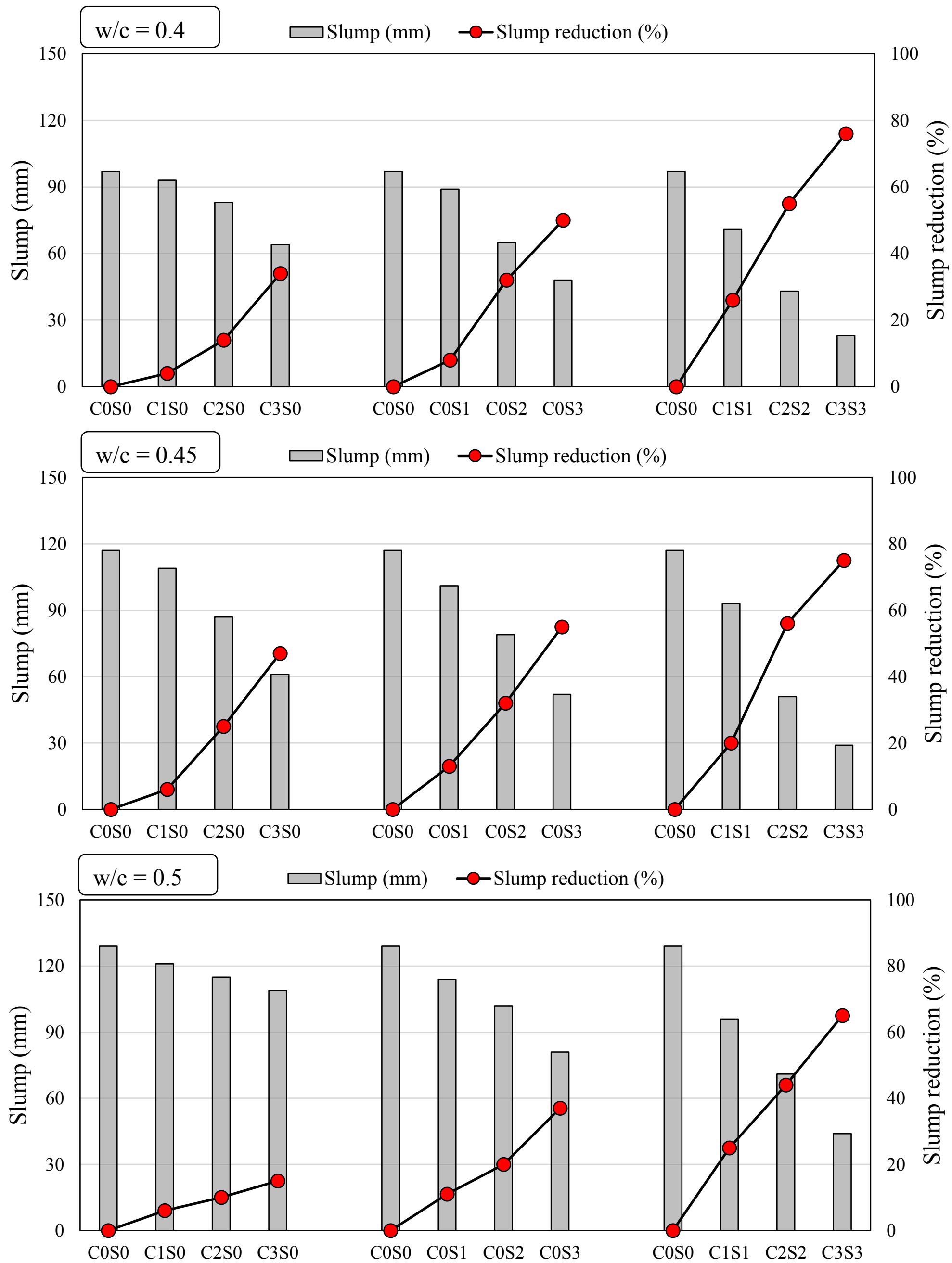

Fig. 2. The amount of slump and the amount of slump reduction based on the percentage of nano-particles for different w/c values.

3.4. Permeability test

The property which shows the ability of fluid to pass through the available pores in a material due to the existence of a pressure difference is called hydraulic conductivity. The coefficient of permeability is a characteristic of concrete by which useful information about the substructure and quality of the concrete can be achieved. In this test, the objective is to determine the penetration depth of water under constant pressure in concrete specimens, which is accomplished according to DIN 1048 standard [29]. The permeability testing procedure is schematically shown in Fig. 6. Based on this experiment, the penetration depth of the pressurized water is measured in the specimens. The considered concrete is poured into oiled 15 × 15 × 15 cm shuttering molds and compacted in three layers and conserved and prepared for 28 days. The curing and conservation temperature of these specimens is between 20 and 25 degrees. After the end of the 28 days period, the specimens are pulled out of the water and maintained at room temperature for 24 h. Then the cubic specimens are put into the equipment, and the pressure at a specified value of 5 bars is exerted on the top of the specimen such that the only feasible penetrating way of the water is from the surface into the specimens. According to the standard, the specimens are under inspection for three days. For each mixing pattern of the concrete specimens, three cubes with the mentioned dimensions are required for the test of the water penetration depth. After the application of the pressure exerted at a specified time, the concrete specimen is broken in order to obtain the level of

Table 7
Average compressive strength.

w/c	sample	Strength (MPa)	w/c	sample	Strength (MPa)	w/c	sample	Strength (MPa)
0.4	C0S0	28.04	0.45	C0S0	26.07	0.5	C0S0	25.83
	C1S0	25.85		C1S0	25.57		C1S0	22.85
	C2S0	24.76		C2S0	24.10		C2S0	20.33
	C3S0	28.32		C3S0	26.24		C3S0	22.39
	C0S1	30.62		C0S1	27.83		C0S1	26.75
	C1S1	25.71		C1S1	24.55		C1S1	23.89
	C2S1	21.26		C2S1	20.89		C2S1	20.26
	C3S1	22.51		C3S1	24.66		C3S1	27.40
	C0S2	31.74		C0S2	28.44		C0S2	27.02
	C1S2	24.42		C1S2	26.05		C1S2	25.83
	C2S2	22.52		C2S2	22.20		C2S2	21.39
	C3S2	29.06		C3S2	25.14		C3S2	24.08
	C0S3	32.97		C0S3	30.40		C0S3	29.24
	C1S3	29.09		C1S3	28.46		C1S3	27.89
	C2S3	26.29		C2S3	25.26		C2S3	23.85
	C3S3	28.00		C3S3	27.21		C3S3	24.12

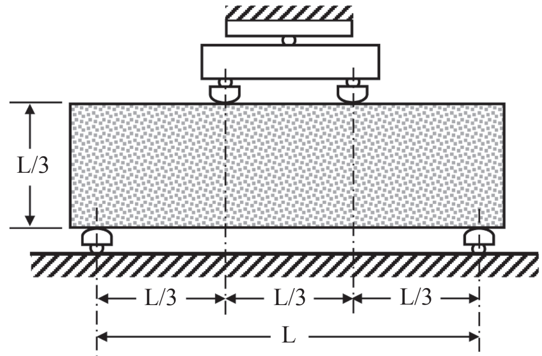

Fig. 4. Schematic view of bending test configuration (L = 15 mm).

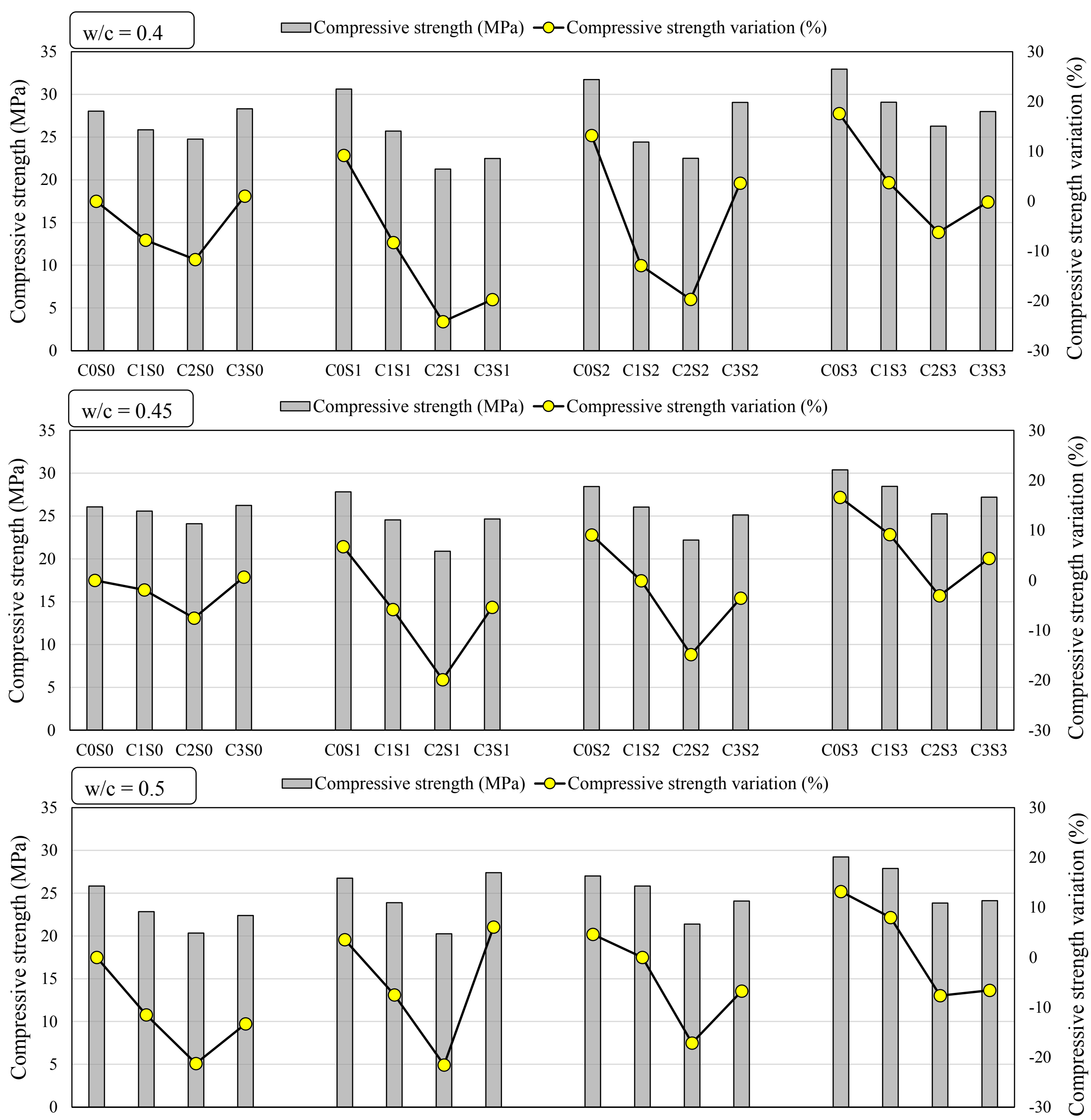

Fig. 3. Compressive strength values obtained for the modified concrete specimens with different amounts of nano additives and using different water to cement ratios.

Table 8
Average 28-day bending strength.

w/c	sample	Strength [MPa]	w/c	sample	Strength [MPa]	w/c	sample	Strength [MPa]
0.4	C0S0	5.23	0.45	C0S0	4.39	0.5	C0S0	4.05
	C1S0	5.10		C1S0	3.97		C1S0	3.29
	C2S0	4.76		C2S0	3.84		C2S0	3.08
	C3S0	4.96		C3S0	4.18		C3S0	3.19
	C0S1	6.62		C0S1	6.25		C0S1	6.06
	C1S1	5.75		C1S1	5.57		C1S1	5.38
	C2S1	5.60		C2S1	5.60		C2S1	5.34
	C3S1	6.15		C3S1	5.84		C3S1	5.85
	C0S2	6.92		C0S2	6.43		C0S2	6.17
	C1S2	6.01		C1S2	5.37		C1S2	5.26
	C2S2	5.52		C2S2	5.25		C2S2	5.15
	C3S2	6.43		C3S2	6.16		C3S2	5.47
	C0S3	7.02		C0S3	6.65		C0S3	6.39
	C1S3	5.28		C1S3	5.68		C1S3	5.38
	C2S3	5.31		C2S3	5.18		C2S3	5.05
	C3S3	5.53		C3S3	5.40		C3S3	5.22

penetration of the pressurized water in the concrete cubic specimen [5]. The results of these experiments are presented in Table 9 and Fig. 7.

Permeability is reduced by replacing the used cement by the nano-particles, and this occurs because the specific surface of the nano-particles is more than the replaced cement, and this enhances the absorption of the free water available in the mixing of the desired concrete. Moreover, it can be observed that if two nano-particles be used simultaneously, then the amount of the slump reduction will be higher compared to the case in which only one nano-particle is used. Regarding the test results, the permeability has increased by increasing the ratio of water to cement.

Adding nano-silica to the cement-based materials helps to control the chemical decomposition of HCS-calcium silicate hydrate in calcium penetration in water. This improvement can be due to the high pozzolanic activity of nanosilica, production of C–S–H gel, filling the concrete porosity, and removal of small pores in the silicate gel structure, which results in less water penetration and more concrete durability.

In the compositions containing nano-carbon black, a dramatic

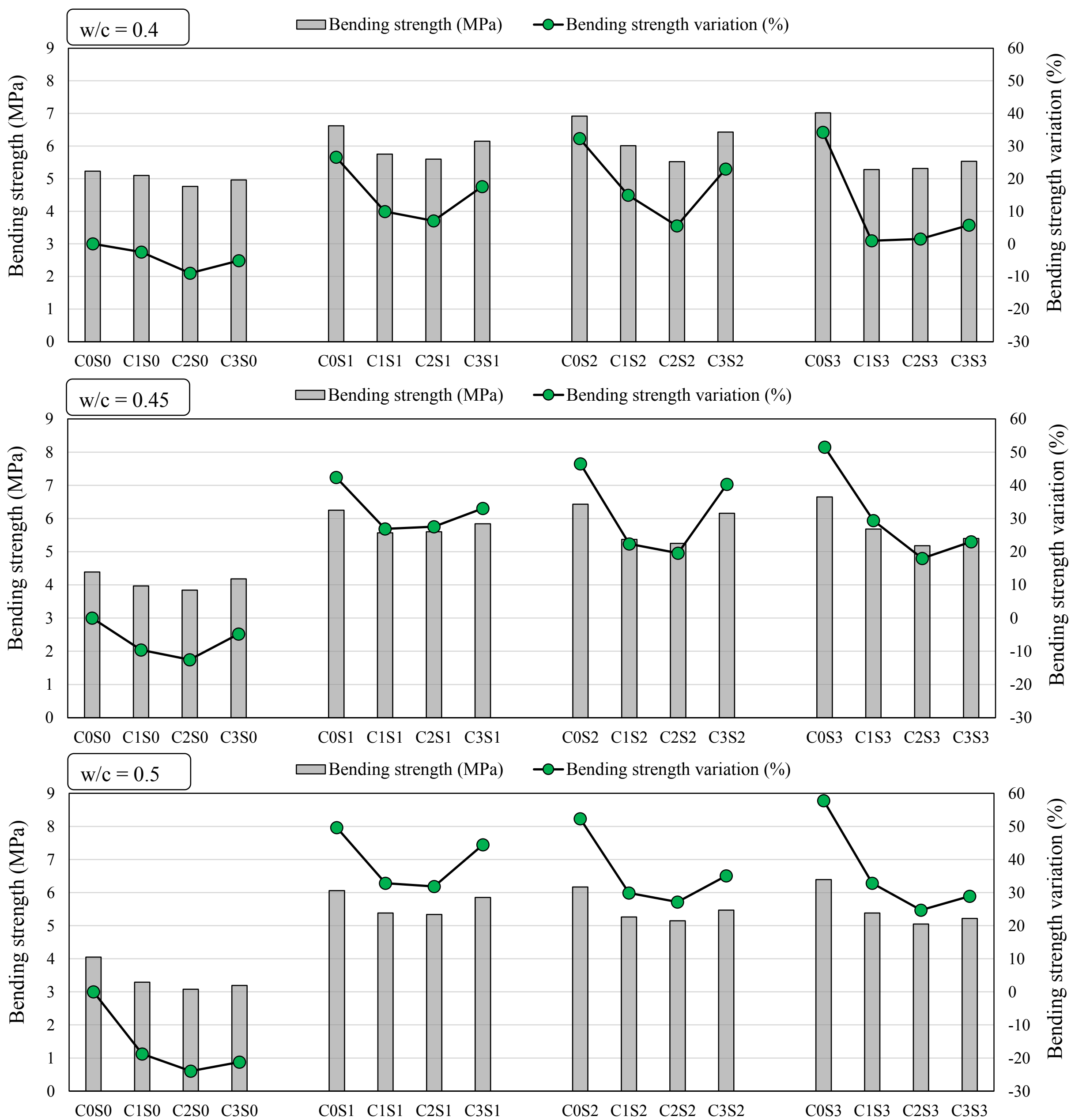

Fig. 5. Bending strength values obtained for the modified concrete specimens with different amounts of nano additives and using different water to cement ratios.

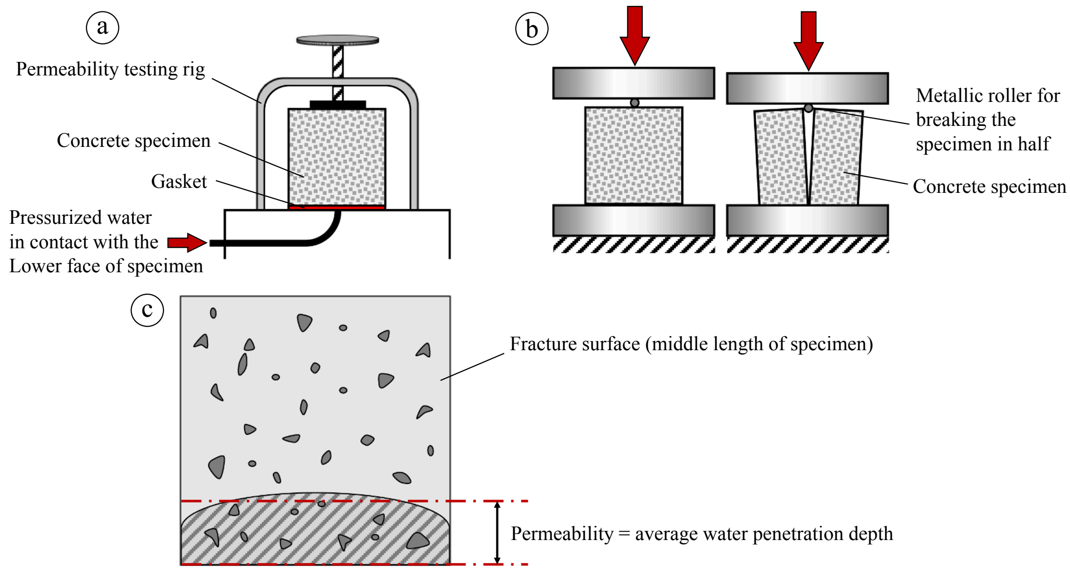

Fig. 6. Schematic view of permeability test; (a) concrete specimen in contact with pressurized water in a testing rig, (b) Breaking the test specimen into half in order to check the permeability, (c) obtaining the average length of the moist concrete from the fracture surface.

Table 9
Details of permeability test results.

w/c	sample	Permeability [mm]	w/c	sample	Permeability [mm]	w/c	sample	Permeability [mm]
0.4	C0S0	69	0.45	C0S0	96	0.5	C0S0	121
	C1S0	27		C1S0	33		C1S0	29
	C2S0	16		C2S0	16		C2S0	16
	C3S0	9		C3S0	12		C3S0	12
	C0S1	65		C0S1	94		C0S1	112
	C1S1	26		C1S1	29		C1S1	25
	C2S1	14		C2S1	16		C2S1	16
	C3S1	8		C3S1	10		C3S1	12
	C0S2	60		C0S2	87		C0S2	103
	C1S2	25		C1S2	27		C1S2	24
	C2S2	14		C2S2	15		C2S2	16
	C3S2	7		C3S2	9		C3S2	11
	C0S3	55		C0S3	80		C0S3	95
	C1S3	23		C1S3	25		C1S3	22
	C2S3	13		C2S3	14		C2S3	15
	C3S3	7		C3S3	9		C3S3	11

decrease has been achieved. However, in the samples containing nano-silica, due to the amount and weight of nano-particles, a slight reduction of up to 20% compared to the control sample was achieved. The lowest permeability was related to C3S3 and C3S2 samples, which is approximately ten times lower than the control sample. This can be attributed to the different sizes of the nano-particles making them act as locks and fasteners. Nano-silica particles that have smaller dimensions are located among the nano-carbon black and leave less space. Hence, the amount of slump decreases is more than the case when only one of the nano-particles is used in the concrete mixture.

The use of nano-silica in the concrete structure results in a smart material having a lower number of microcracks and higher density compared to the regular concrete. With the reduction of microcracks, the concrete will be water-resistant. It is important to mention that additive nano-silica powder in the modified concrete absorbs a large amount of water in concrete which can lead to inadequate hydration of concrete. In this case, adding Nano-carbon black to the concrete, which has Nano-silica, causes the reduction of water absorption in Nano-silica, and therefore, the hydration process will be completed. This ultimate mixture can be used in concrete structures that are in contact with water, assuring the low infusion of the fluid within the concrete. As presented in this paper, the overall choice of the modified concrete content highly depends on the flowability, mechanical properties, and permeability of the product. Having an allowable range for these parameters makes it possible to decide the nano-additive content of the modified concrete. This modified concrete would be used in practical applications guaranteeing the mechanical endurance of the structure and its resistance to moisture penetration. On the other hand, Nano-carbon black results in the conductivity of concrete, making it possible to diagnosis damage within the concrete structure [30,31].

As a quasi-brittle material, concretes have rapid failure evaluation under fatigue loadings. Different additives have been used by researchers in the past to improve the fatigue properties of concrete [32,33]. It has reported that the addition of nano particles in concrete can improve fatigue behavior by promoting the cement hydration, which makes the cement matrix more homogeneous and compact. Additionally, reduced porosity of reinforced concretes due to the addition of Nano-particles improves the flexural fatigue performance and strength of nano reinforced concrete [33].

Although the standard test geometries are designed in a way to provide the mechanical properties of concrete in a scale close to real-life structures, different mechanical properties can be obtained when the size of concrete parts is smaller than that of the standard specimens. In this case, both heterogeneity of the concrete due to the presence of grains and also the thickness effect play a more significant role in the failure of the part. In two separate works, Rossi et al. [34] and

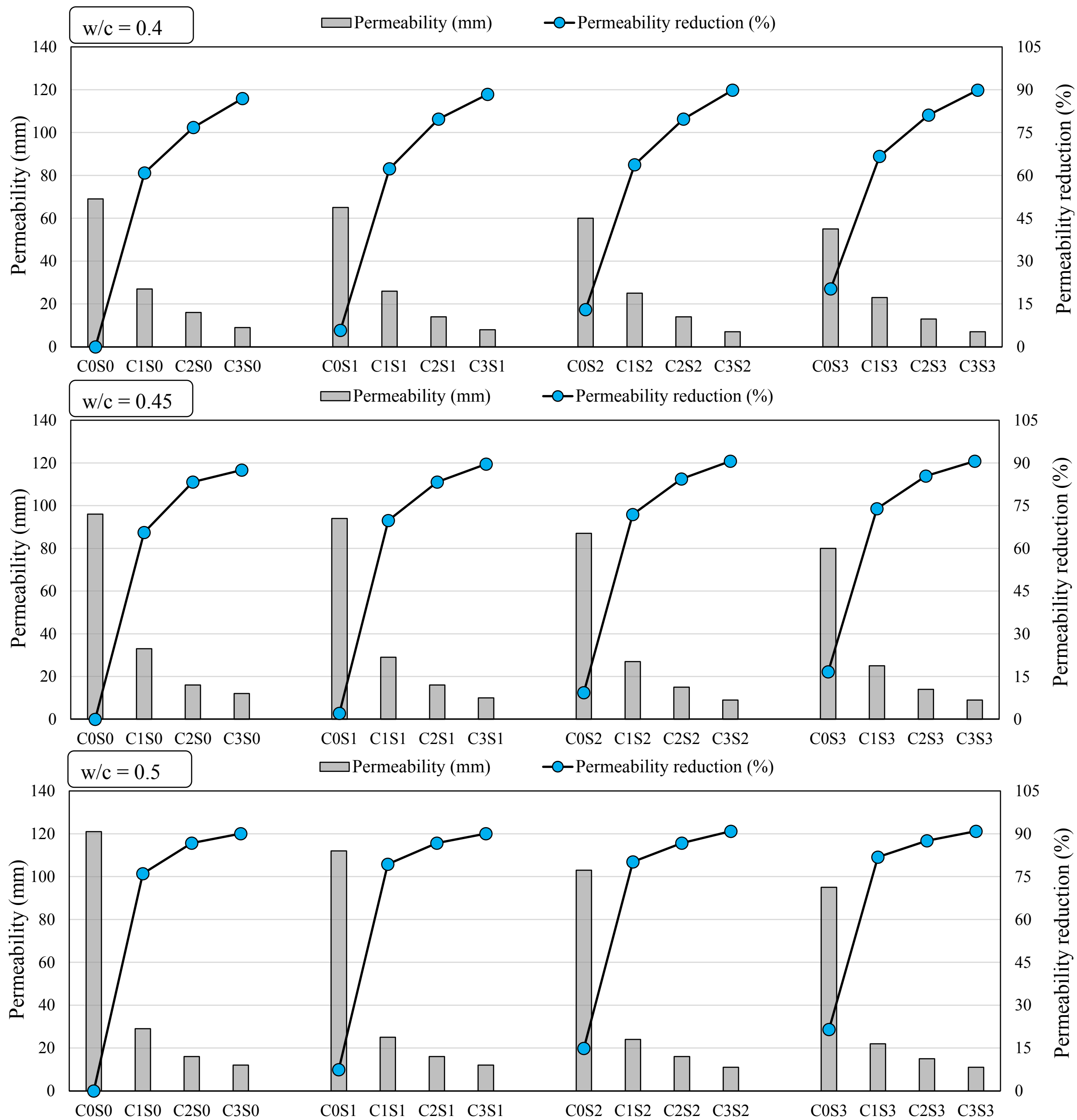

Fig. 7. Permeability values obtained for the modified concrete specimens with different amounts of nano additives and using different water to cement ratios.

Carpinteri et al. [35] reported a stronger scale effect for the concretes with lower compressive and bending strengths. This should be considered as an important factor in design since the addition of a nano additive may result in lower compressive and bending strengths and, consequently, a higher scale effect on the failure of the parts. Additionally, in the case of concrete structures with geometrical discontinuities, Pook and Bazant [36–40] demonstrated a coupled mode of fracture, being dependent on the thickness of the part and Poisson's ratio of the material. In this content, the parts with higher thicknesses and materials with high Poisson's ratios, stronger corner point singularities, and consequently stronger coupled fracture modes exist.

4. Conclusions

The impact of incorporating two nano-particles, namely nano-carbon black and nano-silica in the concrete cutoff wall of earth dams on the mechanical behavior and permeability was evaluated in this research. In this study, these two materials have been studied simultaneously by conducting slump tests, compressive tests, bending tests and permeability tests. It was concluded that

1. By adding these nano-particles to concrete, the concrete slump is reduced because the special surface of nano-particles is higher than the replacement cement, which results in more free water absorption in the mixing of the concrete.
2. The addition of nano-silica improves compressive and flexural strengths. Also, dealing with the modified concretes including nano-carbon black, by increasing the nano-carbon black content, the resistance first decreases and then increases. If both materials are used simultaneously, nano-carbon black particles result in lower compressive and flexural strength compared to the case where only nano-silica has been incorporated in the concrete mixture. Considering the modified concretes with nano-carbon black, the best obtained mechanical properties were almost equal to the control

concrete. It is also observed that as the water content increases to the cement, the resistance of the samples is decreased.

3. By replacing nano-particles instead of the consumption cement, the amount of permeability is reduced. Due to the difference in the dimensions of the nano-carbon black and nano-silica particles, the simultaneous application of both of these two nano-particles in concrete mixture results in coverage of nano-silica particles which are smaller by nano-carbon black making them act as locks and fasteners and leave less space in the paste. This reduces the amount of porosity in the resultant concrete and subsequently decreases the permeability of the modified concrete. Generally, due to the difficulty of Nano-particles dispersion in concrete for large contents, the permeability reduction experienced a decreasing trend by increasing the nano-additive content.
4. Although a wide range of experimental data has been provided in this study, designers need to choose the right combination of the two studied additives based on some key factors such as flowability, permeability, and the required mechanical properties.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest

The author declare that there is no conflict of interest.

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