Experimental study of the effect of water-cement ratio on compressive strength, abrasion resistance, porosity and permeability of Nano silica concrete

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ABSTRACT. The effect of water-cement ratio on abrasion resistance, porosity and hydraulic conductivity coefficient of Nano silica concrete has been studied in this research (paper). The compressive strength of concrete in a particular temperature is related to two factors: water-cement ratio and density. Decreasing the water-cement ratio from 0.46 to 0.30 improves the abrasion resistance of Nano silica concrete by 42%, the hydraulic conductivity coefficient of concrete decreases from 28.5×10^{-15} to 1.7×10^{-15} m/s and the porosity of concrete decreases to 13.1%. The abrasion depth increases gradually by increasing the water-cement ratio from 0.30 to 0.46.

KEYWORDS. Abrasion resistance; Compressive strength; Concrete; Permeability; Water-Cement Ratio.

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INTRODUCTION

Concrete dams are strategic structures due to their fundamental role at economical system of a country. Therefore, the concrete used for these important structures should have a suitable durability and performance (Neville [1]; Yoon et al., [2]). The effect of Nano silica elements as fillers in pozzolanic concrete has been evaluated in current decade (Shih et al., [3]; Senff et al., [4]). Nano silica cement mixture has provided an attractive research field for the creation of high strength hydraulic structures (Nazari and Riahi [5]; Rahmani and Ramzanianpour [6]). Using Nano structure materials like Nano silica and an optimal water-cement ratio improved the physical characteristics of new cement mixtures (Li [7]; Wen et al., [8]). The effect of water-cement ratio on abrasion resistance, porosity and permeability of Nano silica used in making durable concrete, were considered as an effective factor on strength and performance of these concrete structures (Felekoğlu et al., [9]; Bilodeau & Malhotra [10]).
Considering the high and rather modern concrete technology, advanced researches and serious studies on special concrete specimens of hydraulic structures (such as concrete dams) seem to be necessary (Givi et al., [11]; Tavakoli & Soroushian, [12]). The water-cement ratio of concrete has been considered constant in traditional concrete (mixtures) to gain high strength and durability (Shih et al., [3]; Li [7]; Collepardi et al., [13]; Nazari et al., [14]; Aiu & Huang [15]; Nazari & Riahi

[16]; Gaitero et al., [17]). However, the water-cement ratio should be considered according to microcrystalline structure of cement used in concrete specimens (Behnood and Ziari [18]; Wittmann et al., [19]; Willer Eda et al., [20]). The amount of water and cement in the mixture are related to the size of aggregates (sands) and Nano silica structure (Shih et al., [3]; Senff et al., [4]; Popovics [21]; Li [7]; Willer Eda et al., [20]).
In this research, different amounts of water-cement ratio were considered to investigate the compressive strength and abrasion resistance of concrete specimens. High abrasion resistance and low permeability and porosity are the main advantages of using Nano silica in concrete.

EXPERIMENTAL TESTS

The concrete specimens contained 5% Nano silica. The water-cement ratio was considered 0.30, 0.34, 0.38, 0.42 and 0.46. Other characteristics of the mixture were considered constant in all concrete specimens. The following investigations were done on concrete specimens. Wet Sand Blast technique was used to detect the concrete strength. The abrasion resistance of 28 days 15×15×15 cm cubic specimens was determined. Penetration method was used to define the hydraulic conductivity coefficient of 28 days 10×10 cm cylindrical specimens. In addition, the compressive strength and hydraulic conductivity coefficient were conducted by concrete breaker jack machine and penetration depth method respectively. The designation and composition of each batch have been presented in Tab. 1.

Sample Number	water-cement ratio	Nano silica (%)	Age (Days)
1	0.30	5	7
2	0.34	5	7
3	0.38	5	7
4	0.42	5	7
5	0.46	5	7
6	0.30	5	28
7	0.34	5	28
8	0.38	5	28
9	0.42	5	28
10	0.46	5	28
11	0.30	5	90
12	0.34	5	90
13	0.38	5	90
14	0.42	5	90
15	0.46	5	90

Table 1: The properties of the studied samples in the present research.

NANO SILICA CONCRETE MIXTURE

The following items were considered in preparation of Nano silica concrete specimens:

- The slump of specimens was 60 to 100 mm.
- The aggregates were non-ballast materials.
- The distinguishable size of aggregates was mostly 10 mm.
- The cement was Portland Type I.
- The constant amount of Nano silica (added to the mixture of cement and aggregates) was 5% in all specimens.
- 28 days compressive strength of specimens was determined 40 MPa.
- The water-cement ratio was variable from 0.30 to 0.46.

– In order to access the desired workability and high performance of concrete specimens, the GELENIUM-110P was used as a superplasticizer.

RESULTS AND DISCUSSION

Abrasion Resistance Test

Abrasion strength test on cube samples 150 × 150 × 150 mm at 28 days of age was performed using Water Sand Blast method based on ASTM-C778 standard (Fig. 1).

The extracted results of abrasion resistance tests are summarized in Tab. 2. Fig. 2 shows the abrasion depth in terms of water-cement ratio. Increasing the water-cement ratio leads to increase the abrasion depth. By increasing the water-cement ratio from 0.3 to 0.46, the abrasion depth increases gradually. The more the water-cement ratio is, the less abrasion resistance of mortar phase occurred. However, the abrasion resistance of concrete inclines to the abrasion resistance of aggregates. By gradual increase of water-cement ratio to 0.46, the abrasion depth may reach to the maximum value. It seems that the maximum value of abrasion resistance is related to 0.46 water-cement ratio.

Figure 1: Abrasion strength test machine

W/C	0.3	0.34	0.38	0.42	0.46
Abrasion resistance (mm)	0.814	0.954	1.105	1.198	1.227

Table 2: Abrasion depth tests for specimens with variable water-cement ratio.

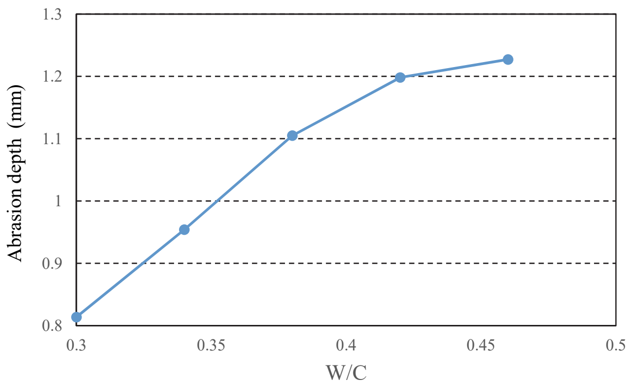

Figure 2: Abrasion depth in terms of water-cement ratio

Fig. 3 shows that the abrasion depth reverse has a reversed relationship with the water-cement ratio. Considering the reverse relationship of abrasion resistance and abrasion depth, data showed that increasing the water-cement ratio decreases the abrasion resistance reverse. The abrasion resistance and average permeability depth data for different values of water-cement ratio are shown in Tab. 3.

To enhance the abrasion resistance of concrete, it is necessary to enhance the mortar phase and the aggregate phase with one another. Mortar phase can be enhanced by reduction of water-cement ratio, using Nano silica and suitable curing. Aggregate phase can also be enhanced by abrasion-resistant aggregates like granite. The condition of performing abrasion test can be more approximated to the real condition of concrete abrasion against water. To do this the silica sand should be shot under water and in less than 90 degree angle.

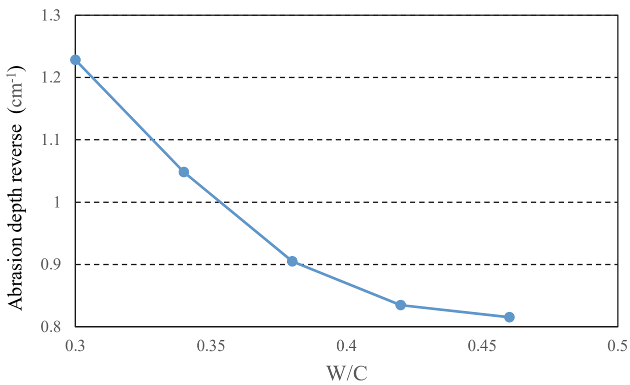

Figure 3: Abrasion depth reverse in terms of water-cement ratio

W/C	Abrasive resistance improvement	Average Permeability Depth (mm)
0.3	38.24%	0.905
0.34	26.17%	1.305
0.38	12.94%	1.845
0.42	4.56%	2.215
0.46	3.17%	3.225

Table 3: Abrasion resistance improvement and average permeability depth for various values of water-cement ratio.

HYDRAULIC CONDUCTIVITY COEFFICIENT

The hydraulic conductivity of the concrete was tested using by Penetration Method according to ASTM-C1920-5 (Eq. 1).

$$\textit{Concrete hydraulic conductivity coefficient} = H_p^2 V / (2Th) \quad (1)$$

where H_p: Water penetration depth [m], T: Influence time [s], h: Pressure height [m], V: Concrete porosity.
Fig. 4 illustrates the machine used for performing the hydraulic conductivity of the concrete tests. Fig. 5 shows the water permeability depth in terms of various amounts of water-cement ratio. The mentioned data showed that increasing the water-cement ratio, increases water permeability depth.

Figure 4: Hydraulic conductivity of the concrete test machine

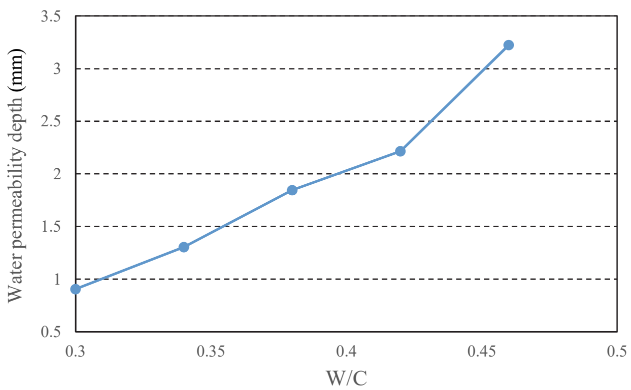

Figure 5: Water permeability depth in terms of different values of water-cement ratio

It is noteworthy that the following formula is used for calculating the permeability coefficient of concrete.

$$K_p = h_p^2 v / (2 \times t \times h) \quad (2)$$

where:
K_p is permeability coefficient of concrete [m/s]; h_p is water permeability depth [m]; t is water permeability time [s]; h is height arising from pressure [m] and v is porosity of concrete.
The following equation is used for porosity calculation:

$$v = (w/c) \times (100 - 36.15 \times \alpha) / (w + 100 / g) \quad (3)$$

where:
w/c is water-cement ratio; α is degree of cement hydration; w is gravity of water of concrete [kg/m^3] and g is specific weight of cement [g/cm^3].
Wet Sand Blast can significantly simulate the erosion in concrete, so it is a suitable technique to evaluate the water resistance of concrete. Penetration resistance test on concrete is a tool for defining comparative strengths of concrete in similar or dissimilar structures. Due to the nature of equipment, absolute values of strength cannot be obtained. Penetration Method is a suitable approach for evaluating the permeability of concrete, because this method is desired for the ratio of water depth in concrete. For the concrete cylinder height, this fact is achieved in Nano silica concretes.
Fig. 6 shows the hydraulic conductivity coefficient of concrete in terms of different values of water-cement ratio. The data indicated that increasing the water-cement ratio, increases hydraulic conductivity coefficient of concrete.

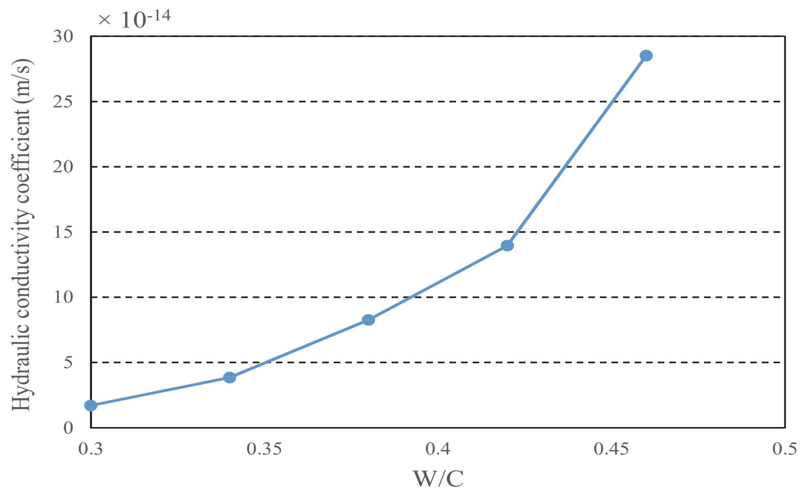

Figure 6: Hydraulic conductivity coefficient of concrete in terms of water-cement ratio

Fig. 7 shows the variation curve of porosity in terms of different amounts of water-cement ratio. The porosity of concrete increases by increasing of water-cement ratio.

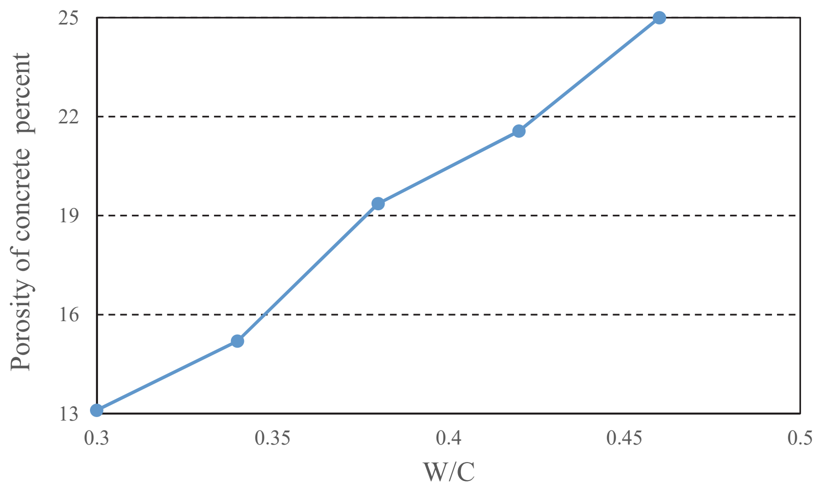

Figure 7: Variation of porosity in terms of different amounts of water-cement ratio

Tab. 4 shows the values of hydraulic conductivity coefficient and porosity of concrete in terms of water-cement ratio. The values of Tab. 5 are required for obtaining the hydraulic conductivity coefficient and porosity of Nano silica concrete.

W/C	Hydraulic Conductivity Coefficient of Cement (m/s)	Porosity of Concrete
0.3	1.7×10^{-15}	13.1%
0.34	3.84×10^{-15}	15.2%
0.38	8.25×10^{-15}	19.37%
0.42	13.95×10^{-15}	21.56%
0.46	28.5×10^{-15}	25%

Table 4: Hydraulic conductivity coefficient and porosity of concrete in terms of water-cement ratio.

Permeability time (s)	Height Arising from Water Pressure (m)	Cement Specific Weight (g/cm)	Cement Degree of Hydration (%)
259200	82	3.15	80

Table 5: Required values for calculating hydraulic conductivity coefficient and porosity of concrete.

Compressive Strength

Compressive strength tests on cube samples of 150 × 150 × 150 mm at the age of 7, 28 and 91 days have been done with a pressure test device with a capacity of 2000 kN (TEKNO test-Italy) at a speed of 2.5 kN/s accordance to ACI-C330 standard. The value of Compressive strength of samples can be evaluated using Eq. 5 as following as:

$$\textit{Compressive Strength} = (P / A)\times 1000 \tag{4}$$

Fig. 8 is the illustration of compressive strength test machine.

Figure 8: Compressive strength test machine

Fig. 9 shows the compressive strength improvements due to water-cement ratio reduction in Nano silica concrete with error bars. The compressive strength and abrasion resistance of concrete will increase by means of water-cement ratio reduction. As it can be seen in Fig. 9, by reducing the ratio of water to cement from 0.46 to 0.3, the compressive strength of samples at the age of 7, 28 and 90 days of concrete is improved by 27.92, 33.04 and 31.88% respectively.

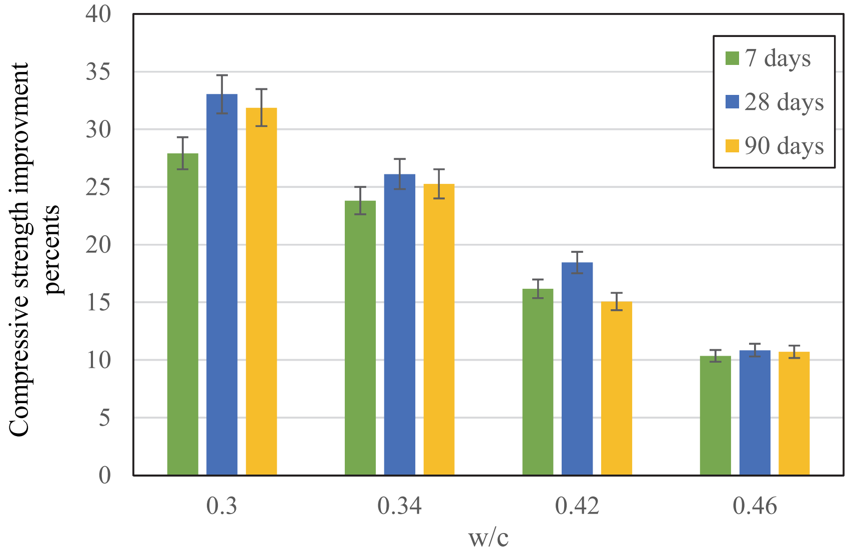

Figure 9: Compressive strength improvement after 7, 28 and 90 days

Conclusion

Due to the rapid growth of scientific and practical researches, the science and technology of nanotechnology of all industries, very little attention has been paid to the applications of this phenomenon in the building industry and construction. Recently, however, with regard to nano reinforcement in construction materials, a new wave has taken place with the ever-accelerating in the construction industry. Properties, behavior and performance of concrete depend on the nano structure of the underlying concrete, which provides adhesion, cohesion and integrity. Therefore, the construction of concrete and cement paste structures at the nanoscale is very important for the development of new building materials and their applications. The main obtained results in the present article showed that the abrasion resistance of Nano silica concrete increased by decreasing of water-cement ratio. By reducing the water-cement ratio from 0.46 to 0.30 at Nano silica concrete specimens, the abrasion resistance of concrete improved by 42%. The abrasion resistance of mortar phase decreased by increasing of water-cement ratio and the abrasion resistance of concrete approaches the abrasion resistance of aggregates. In addition, the hydraulic conductivity coefficient and the porosity of Nano silica concrete decreased by decreasing of water-cement ratio from 0.46 to 0.30. Therefore, the hydraulic conductivity coefficient of concrete decreased from 28.5×10^{-15} to 1.7×10^{-15}, the porosity of concrete decreased to 13.1% and the abrasion depth reduced gradually. This can be related to the biphasic (mortar and aggregates) nature of concrete in abrasion.

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