



journal homepage: <http://civiljournal.semnan.ac.ir/>

Effect of Seawater on Micro-Nano Air Bubbles Concrete for Repair of Coastal Structures

F. Taherpour Komishani¹, S F. Saghravani² and M. Jalali^{3*}

1. Research Assistant, Faculty of Civil Engineering, Shahrood University of Technology, Shahrood, Iran

2. Associate Professor, Faculty of Civil Engineering, Shahrood University of Technology, Shahrood, Iran

3. Assistant Professor, Faculty of Civil Engineering, Shahrood University of Technology, Shahrood, Iran

*Corresponding author: mjalali@shahroodut.ac.ir

ARTICLE INFO

Article history:

Received: 18 September 2019

Accepted: 06 February 2020

Keywords:

Micro-Nano Air Bubble (MNAB),
Concrete,
Seawater,
Mechanical Properties,
Experimental Study.

ABSTRACT

This paper investigated the effects of seawater curing of concrete made by Micro-Nano Air Bubbles (MNAB) on compressive, flexural and tensile strengths of the concrete. This product will be applicable for rehabilitation or repair of coastal RC structures. In this research, the effect of different combinations of concrete ingredients including 0-100, 25-75, 50-50, 75-25, and 100-0 percent seawater and MNAB, respectively, on compressive strength of concrete was investigated. A total of 93 specimens were experimentally examined to study the compressive, flexural and tensile strength of MNBA concrete (MNABC) through ASTM Standard for cube, cylinder, and beam samples. The samples were cured for 1, 7, 28 and 90 days. Results revealed that MNABC cured in seawater had about 30 % higher compressive strength at ages 7 and 28 days, but it decreased in longer periods. The flexural strength of MNABC slightly increased, about 6%, after 28 days of curing in seawater. In general, the mechanical properties of MNABC at an early age revealed a considerable increase, whereas, in the longer period of time, they were decreased gradually.

1. Introduction

Marine concrete structures are directly or indirectly exposed to seawater. Despite excellent structural features, concrete suffers early deterioration in marine environment [1]. While many researchers have investigated concrete performance in saline water for decades and have obtained

significant results, it is still a dynamic issue for further investigations.

Lamond and Pielert analyzed sea water for its main ions and reported that chloride, sulfate, sodium, magnesium, calcium and potassium are the main chemical elements of sea water and sodium chloride (NaCl) is the main salt in sea water containing up to 35000 ppm of dissolved salts [2]. Islam et al. found that

though using sea water for mixing of the concrete increases the early strength of concrete, it decreases its long-term strength [3]. Miri et al. [4] revealed that the use of nano wollastonite as a partial replacement of cement can increase the service life of reinforced concrete structures. Alaejos et al. evaluated concrete specimens cast with sulfate-resistant cement cured in seawater and observed that curing by seawater did not affect on porosity or compressive strength of the specimens [5]. Nano particles of SiO₂ [6], [7], [8], TiO₂ [9], [10], Al₂O₃ [11], [12], and Fe₂O₃ [13], [14] have improved the compressive strength of the concrete while ZnO [15] and ordinary bubbles, made by plasticizers [16] affect reversely on concrete compressive strength. TiO₂ was used as concrete coating to remove Nitrogen oxides [17].

Micro-nano bubble (MNB) is new technology that found a wide variety of scientific and industrial purposes in the recent years. Tsuge presented a detailed description for production and technical issues of MNAB [18]. It is known that MNAB increases Dissolved Oxygen (DO), Electrical Conductivity (EC), pH, turbidity, and nitrogen content in water [19]. However, use of MNB in concrete was not investigated fully, probably due to costly equipment for MNB production. MNAB can adequately enhance the mechanical properties of the concrete while reduces its workability. It was reported that tensile and compressive strength increased by 19 and 16 percent respectively, while the setting temperature dropped considerably. The initial and final setting times were also decreased, meaning that MNABC requires to be cast faster than usual concrete [20]. In other studies it was revealed that using chloride ion treatment for concrete containing zeolite as a mineral

admixture and micro-nano-bubble water could improve the durability and mechanical properties of concrete of 28 days old but the process of improvement was decreased by increasing age of the concrete [20].

Rehabilitation of coastal concrete structures is of economical and industrial importance. Because of lacking known attempts to use MNABC in coastal environments, in this research, MNABC exposed to sea water was investigated in order to study the influences of sea water on compressive, flexural and tensile strengths of MNABC. This research also examined the effect of using different arrangement of sea water and MNAB in concrete mixture on concrete compressive strength.

2. Experimental Study

In this research, total of ninety-three specimens were examined. Sixty-six cub of 150×150×150 mm for uniaxial compressive strength, eighteen standard cylinders of 150 mm diameter and 300 mm height for tensile splitting strength and nine beams of 100×100×300 mm for flexural strength. Concrete mix designed based on weight of components [21].

Three experimental sets of specimens for compressive strength were conducted. In first set, eighteen specimens were made with MNAB; half of them were cured in sea water and others in fresh water. The second set consisted of eighteen specimens made with fresh water that half of them cured in sea water and the other half cured in fresh water. In third set, thirty specimens made with different combinations of MNAB and sea water and then cured in fresh water.

In order to evaluate tensile splitting strength, eighteen standard cylindrical specimens

(300×150 mm) were made with MNAB water as mixing water and cured in sea water and fresh water. In this research, the four-point bending set-up was used to examine the flexural strength of eighteen standard beam samples (100×100 ×330 mm).

2.1. Materials

Type II of Portland cement (product of Shahrood Cement Factory in Shahrood, Iran) was employed for tests. Table 1 shows the chemical properties of cement analyzed by laboratory of Sahrood cement factory. Sea water or fresh water was used for mixing and curing water of concrete samples, in this research. The fresh water was prepared from the drinkable water supply network at the concrete technology laboratory, Shahrood University of Technology (SUT), Shahrood, Iran, and it was used to produce micro-nano bubbles water in nano fluids laboratory of SUT. Micro-nano bubbles production have a limitation which was restricted the volume of concrete in each set of casting. So in each set of casting only three specimens were tested. The MNAB was produced by a hydro-dynamical procedure. An invented device by Arefi et al (Iranian Patent #83998) was employed. It increased the pH up to 9 and results a smooth uniform bubble size distribution (Arefi et al., 2016 [20]). The presence of MNB in concrete made by some additives were investigated in other studies that showed a considerable improvements in its properties [22], [23]. Another study showed the influence of Cl ion on concrete is mainly dependent of the surface and porosity of the concrete samples [24].

The sea water was taken from Caspian Sea on Neka city beach, Mazandaran province, Iran. The sea water was sampled and analyzed to determine the main ions of it.

The analyzing was done in the laboratory of Semnan Science and Technology Park (SSTP) and the nano fluid laboratory of SUT. The results of the analysis are shown in Table 2. River gravel was employed for aggregates with the maximum aggregate size of 19 mm.

Table 1. Chemical properties of the used cement.

Chemical features	Average (%)	Limits*
SiO ₂	21.11	At least 20.5
Al ₂ O ₃	4.41	At most 5
Fe ₂ O ₃	3.95	At most 5
CaO	63.55	----
MgO	1.52	At most 2.5
SO ₃	2.74	At most 2.9
K ₂ O	0.55	----
Na ₂ O ₃	0.41	----
LOI	2.22	At most 2.9

*The limits are according to the manufacture data sheet

Table 2. Chemical components of the used sea water.

Ion	Unit	Value
Cl ⁻	ppm	1900
NO ₃ ⁻	ppm	1.1
SO ₄ ²⁻	ppm	1800
K ⁺	ppm	86.97
Ca ²⁺	ppm	190
Na ⁺	ppm	3900.8
Mg ²⁺	ppm	394.8

2.2. Concrete Mix Design

The concrete combination was designed based on the test in the concrete laboratory according to the ASTM C192M [25]. The assumptions were considered for concrete mix design features are summarized in Table 3.

Table 3. Concrete Mix Proportions.

Property	Value
Slump (mm)	35
Maximum aggregate size (mm)	19
Water-cement ratio	0.61
Moisture content of aggregates (%)	0
Cement weight (Kg/m ³)	311
Water weight (Kg/m ³)	190
Aggregate weight (Kg/m ³)	922

2.3. Preparation of Specimens

The compressive strength of concrete was evaluated by standard cubes of 150×150×150 mm. Stainless steel cylinders of 150×300 mm were used to determine the tensile strength, and steel beams for measuring flexural strength were 330×100×100 mm. As discussed before, encountering the limitations of micro-nano bubbles production, to ensure the accuracy of results, three specimens were prepared for each set of concrete casting, the average value of these three specimens were reported as a specimen final data. The inside of the molds was smear with special mold oil for easy removal of the set concrete. Concrete was mixed and made in laboratory at room temperature of 23 °C. After casting fresh concrete into molds, they were vibrated to ensure good compaction. All specimens were remolded after 24 hours. Thereafter, they were cured in standard water tanks in room temperature until testing at due days. A sealant layer was used for covering curing tanks.

3. Results and Discussion

3.1 Compressive Strength Test

The compressive strength test was performed using the 3000 kN uniaxial compressive testing machine based on ASTM C918M [26]. For each curing period, three samples were made and tested. The reported results are average of three samples for each data.

3.1.1 First Set of Specimens

In first set, specimens were made with MNAB water as mixing water and cured in sea water as well as fresh water for 7, 28 and 90 days. The results are presented in Figs. 1-3. The results presented in Fig. 1 show a significant increase of about 24% in average

strength at 7 days for specimens cured in sea water (the average strength of 30.66 MPa) compared to specimens cured in fresh water (the average strength was 24.73 MPa). Also as it is shown in Fig. 2, at 28 days, specimens cured in sea water recorded an important increase of 28% in average strength compared specimens cured in fresh water that were 36.58 MPa and 28.45 MPa respectively. At the age of 90 days, the increase rate of average strength of specimens cured in sea water was fallen significantly. At this age of curing, the average strength of samples cured in sea water was 32.25 MPa, about 6% higher than average strength of samples cured in fresh water that was 30.43 MPa, as it is depicted in Fig. 3.

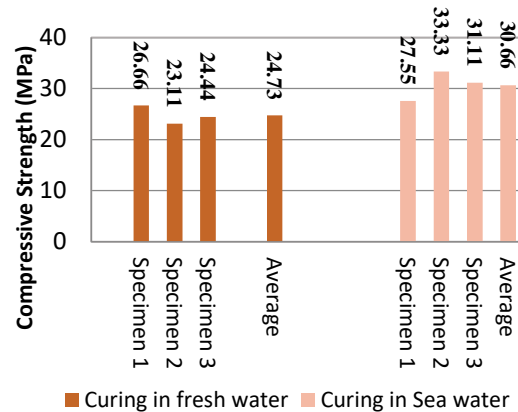


Fig. 1. The 7-days compressive strength of specimens (First set).

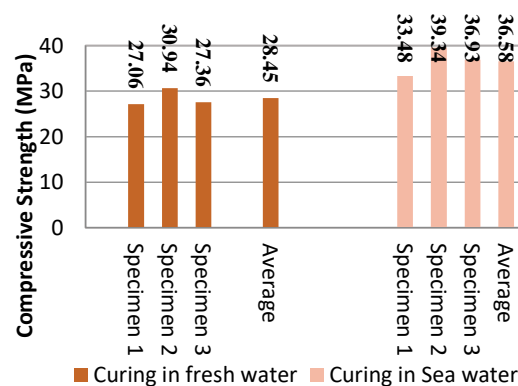


Fig. 2. The 28-days compressive strength of specimens (First set).

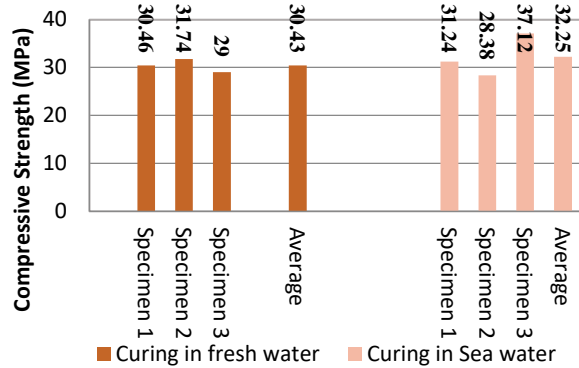


Fig. 3. The 90-days-compressive strength of specimens (First set).

3.1.2. Second Set of Specimens

For second set, eighteen specimens were made with fresh water as mixing water and cured in sea water at 7, 28 and 90 days. The results are shown in Figs. 4-6. As it is observed from Fig. 4, the average strength of samples cured in sea water was 17.18 MPa that was about 6% higher than average strength of samples cured in fresh water i.e. 15.85 MPa. The strength of specimens cured in sea water reduced by age so that after 28 days curing, specimens cured in sea water and fresh water had almost same strength, 30.59 MPa and 30.35 MPa respectively.

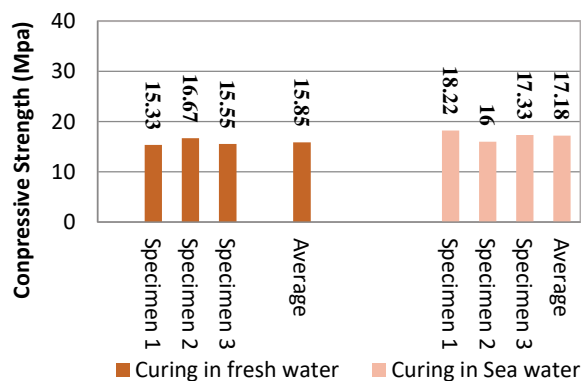


Fig. 4. The 7-days-compressive strength of specimens (Second set).

Strength of specimens cured in sea water continue to decrease in long days, as it is shown in Fig. 6, the average strength of specimens cured in sea water and fresh water

were 32.88 MPa and 34.92 MPa respectively that is shown about 6 % decrease.

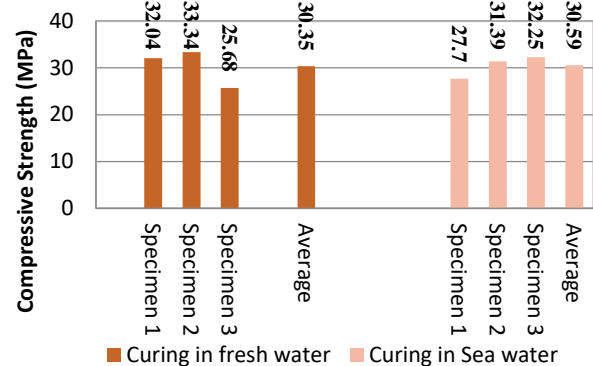


Fig. 5. The 28-days-compressive strength of specimens (Second set).

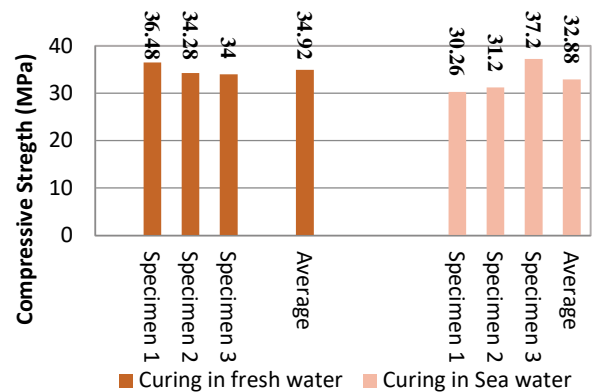


Fig. 6. The 90-days-compressive strength of specimens (Second set).

3.1.3 Third Set of Specimens

In order to investigate the influence of using combination of sea water and MNAB water as mixing water in concrete, on the compressive strength of concrete, thirty specimens with five different combinations were made i.e. six cubes with 100% sea water, six cubes with 25% sea water and 75% MNAB water, six cubes with 50% sea water and 50% MNAB water, six cubes with 75% sea water and 25% MNAB water and six cubes with MNAB water and all of them were cured in fresh water for 7 and 28 days. The results are shown in Figs. 7 and 8. As it can be seen in Fig. 7, after 7 days curing the compression strength of all specimens were

in range of 25.57 MPa – 28.85 MPa which are not so different with 7-days- compressive strength of specimens made with MNAB-water. The strength of specimens increased by increasing curing days, so that the 28-days-compressive strength of specimens were in range of 31.63 MPa – 33.14 MPa as shown in Fig. 8.

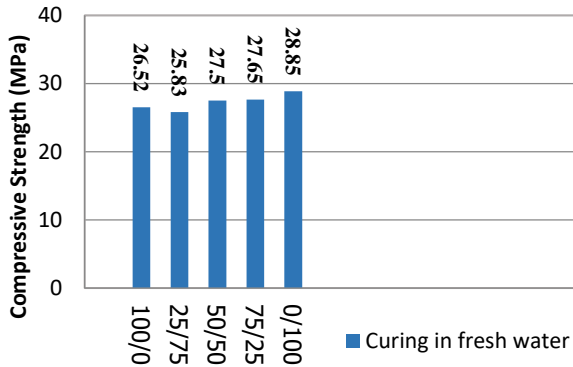


Fig. 7. The 7-days- compressive strength of specimens (Third set).

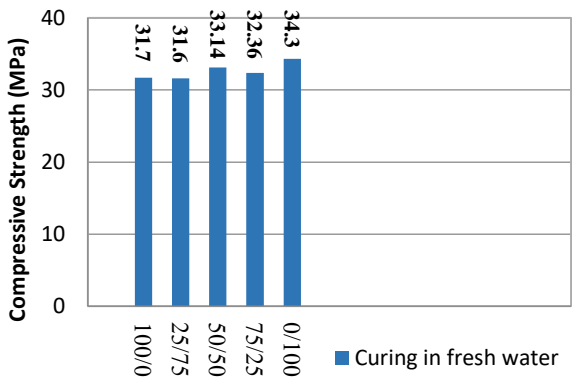


Fig. 8. The 28-days- compression strength of specimens (Third set).

3.2 Tensile Splitting Strength Test

Tensile strength is an important specification of concrete since concrete inherently is very weak in tension. In this study, the Split-Cylinder Test based on ASTM C496M [27] was performed to determine the tensile strength of concrete.

Eighteen standard cylindrical concrete specimen were considered with MNAB water

as mixing water and cured in sea water and fresh water. After one-day curing, tensile splitting strength of specimens were measured. In such tests, the compressive stress lead to a transverse tensile stress, which was uniform along the vertical diameter. Split tensile strength of concrete cylinder was measured in MPa.

The tensile splitting strength was calculated according to ASTM C496M [20] formula:

$$\text{Split Tensile Strength} = \frac{2P}{\pi LD} \quad (1)$$

Where, P, L and D are load at failure (in N), length of the sample (300 mm) and diameter of the sample (150 mm), respectively.

As depicted in Fig. 9, the average tensile strength of samples cured in sea water was 1.82 MPa that was more than 60 % higher than average tensile strength of samples cured in fresh water that was 1.08 MPa.

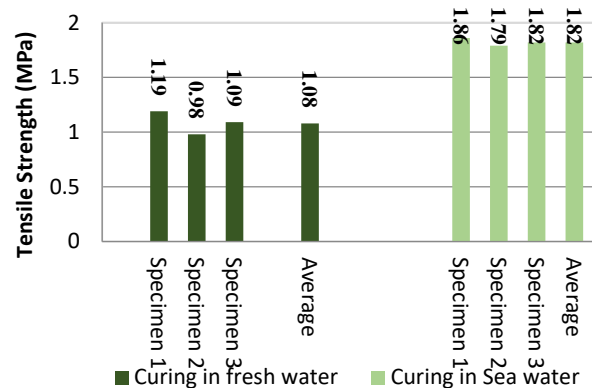


Fig. 9. The one-day-tensile splitting strength of specimens.

3.3 Flexural Strength Test

The four-point bending test according to ASTM C78M [25] was conducted to examine the flexural strength of standard beam samples (100×100×330 mm). Test setup of flexural specimens is depicted in Fig. 10. The specimens were cured in sea water and fresh water for 28-days. As the

crack occurred in the mid span, so following formula was employed to calculate the section modulus:

$$R = \frac{PL}{bd^2} \quad (2)$$

Where P is load at failure (in N), L, b and d are length, width and depth of specimen (in mm) respectively. The average flexural strength of specimens cured in sea water was 12.7 MPa. Compared to specimens cured in fresh water an increase of 6% was observed as illustrated in Fig. 11.

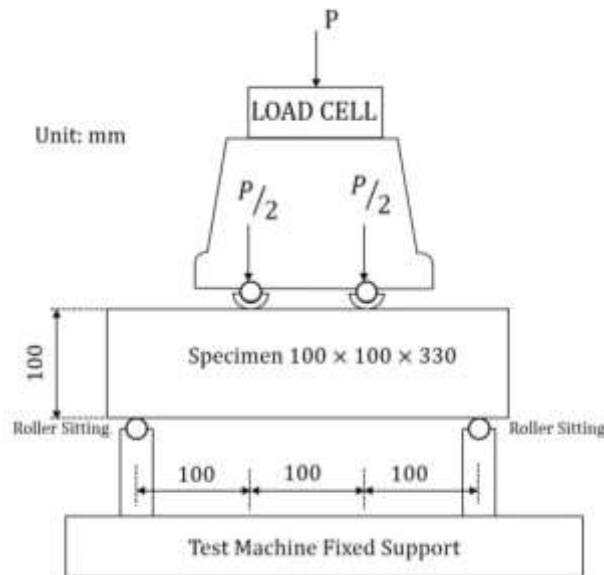


Fig. 10. Test setup of flexural specimens.

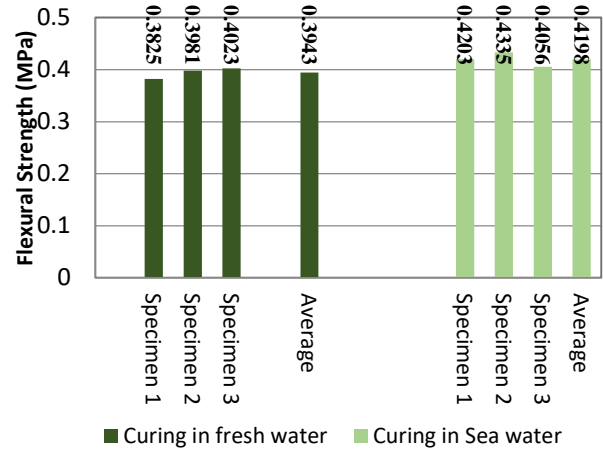


Fig.11. The 28-day-flexural strength of specimens.

4. Conclusion

The present research was designed to study the effect of sea water on MNABC. The study investigated the compressive, tensile and flexural strength of MNABC cured in sea water. The compressive strength of specimens with various combinations of MNAB and seawater in cement paste was also measured. The significant finding drawn from this study was that incorporation of Micro-Nano Air Bubbles in concrete improved concrete's strength and durability. As a result, using Micro-Nano Air Bubbles as a replacement of fresh water in concrete can increase the service life of concrete structures in coastal environment. The major conclusions driven from this study are summarized as follows:

- (1) The compressive strength of MNABC cured in seawater for 7 days was 30.66 MPa that was 24% higher than specimens cured in freshwater.
- (2) The compressive strengths of MNABC cured in seawater for 28 days of curing was 36.58 MPa. It was 28% higher than specimens cured in freshwater.

(3) Compressive strength of MNABC specimens cured in seawater decreased in long periods of curing so that the compressive strength of specimens cured in seawater for 90 days was about 6% higher than MNABC specimens cured in freshwater.

(4) The compressive strength of specimens with different combinations of MNAB and seawater as mixing water (0-100, 25-75, 50-50, 75-27, and 100-0) and curing in freshwater did not show a remarkable difference with compressive strength of MNABC cured in seawater. The 7-days-compressive strength of these specimens located in range of 25.57 – 28.85 MPa and their 28-day compressive strength was in range of 31.63 – 33.14 MPa.

(5) The tensile strength of MNABC specimens increased significantly more than 60% after one-day curing in seawater.

(6) The increase of flexural strength of specimens after 28 days of curing was around 6%.

REFERENCES

- [1] Neville, A. M., Brooks, J. J. (2010). "Concrete technology." second edition, Prentice Hall, USA.
- [2] Lamond, J. F., Pielert J. H. (2006). "Significance of tests and properties of concrete and concrete-making materials." ASTM international, American Society for Testing and Materials. USA.
- [3] Islam, M. M., Saiful Islam, M., Al-Amin, M., Mydul Islam, M. (2012). "Suitability of sea water on curing and compressive strength of structural concrete." Journal of Civil Engineering (IEB), Vol. 40, Issue 1, pp. 37-45.
- [4] Miri, M., Ghasemi, M.R., Beheshti Nehzad, H. (2019). "Experimental Investigation of Corrosion Cracking in Reinforced Concrete Beams Containing Nano Wollastonite." Journal of Rehabilitation in Civil Engineering, Vol. 7, Issues 3, pp. 117-138.
- [5] Alaejos, P., Bermudez, M. A. (2011). "Influence of Seawater Curing in Standard and High-Strength Submerged Concrete." Materials in Civil Engineering Vol. 23, Issue 6, pp. 915-920.
- [6] Boshehrian, A., Hosseini, P. (2011). "Effect of nano-SiO₂ particles on properties of cement mortar applicable for ferro cement elements." Concrete Research Letters, Vol. 2, Issue 1, pp. 167-180.
- [7] Balapour, M., Joshaghani, A., Althoey, F. (2018). "Nano-SiO₂ contribution to mechanical, durability, fresh and microstructural characteristics of concrete: A review." Construction and Building Materials, Vol. 181, pp. 27-41.
- [8] Rezania, M., Panahandeh, M., Razavi, S.M.J., Berto, F. (2019). "Experimental study of the simultaneous effect of nano-silica and nano-carbon black on permeability and mechanical properties of the concrete." Theoretical and Applied Fracture Mechanics, Vol. 104, Article 102391.
- [9] Salemi, N., Behfarnia, K., Zaree, S.A. (2014). "Effect of nanoparticles on frost durability of concrete." Asian Journal of Civil Engineering, Vol. 15, Issue 1, pp. 411-420.
- [10] Nazari, A., Riahi, Sh., Shamekhi, S.F., Khademno, A. (2010). "Assessment of the effects of the cement paste composite in presence TiO₂ Nanoparticles." Journal of American Science, Vol. 6, Issue 4, pp. 43-46.
- [11] Nazari, A., Riahi, Sh., Shamekhi, S.F., Khademno, A. (2009). "Mechanical properties of cement mortar with Al₂O₃ nano particles." Journal of American Science, Vol. 6, Issue 4, pp. 94-97.
- [12] Nazari, A., Riahi, Sh., Shamekhi, S.F., Khademno, A. (2010). "Influence of Al₂O₃ nano particles on the compressive strength and workability of blended concrete." Journal of American Science, Vol. 6, Issue 5, pp. 6-9.
- [13] Abdoli Yazdi, N., Arefi, M. R., Mollaahmadi, E., Abdollahi Nejad, B.

- (2011). "To study the effect of adding Fe₂O₃ nano particles on the morphology properties and microstructure of cement mortar." *Life Science Journal*, Vol. 8, Issue 4, pp. 550-554.
- [14] Nazari, A., Riahi, Sh., Shamekhi, S. F., Khademno, A. (2010). "The effects of incorporation Fe₂O₃ nano particles on tensile and flexural strength of concrete." *Journal of American Science*, Vol. 6, Issue 4, pp. 90-93.
- [15] Behfarnia, K., Keivan, A. (2013). "The effects of TiO₂ and ZnO nano particles on physical and mechanical properties of normal concrete." *Asian Journal of Civil Engineering*, Vol. 14, Issue 4, pp. 517-531.
- [16] Kosmatka, S.H., Wilson, M. L. (2011). "Design and control of concrete mixtures." 15th Edition, Portland Cement Association (PCA), USA.
- [17] Guo, M.Z., Ling, T.C., Poon, C.S. (2013). "Nano-TiO₂-based architectural mortar for NO removal and bacteria inactivation: Influence of coating and weathering conditions", *Cement and Concrete Composites*, Vol. 36, Issue 1, pp. 101-108.
- [18] Tsuge, H. (2015). "Micro and nano bubbles, fundamentals and applications." Pan Stanford Publishing, USA.
- [19] Mozaffari Naeeni, R. (2014). "Investigation on the hydrodynamics standard pattern using micro-nano air bubbles." M.Sc. Thesis, Shahrood University of Technology, Iran.
- [20] Arefi, A., Saghravani, S.F., Mozaffari Naeeni, R. (2016). "Mechanical Behavior of Concrete, Made with Micro-Nano Air Bubbles." *Civil Engineering Infrastructures Journal*, Vol. 49, Issue 1, pp. 141 – 149.
- [21] ASTM C192M (2014). "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory." American Society for Testing and Materials, USA.
- [22] Khoshroo, M., Shirzadi Javid, A. A., Katebi, A. (2018). "Effects of micro-nano bubble water and binary mineral admixtures on the mechanical and durability properties of concrete." *Construction and Building Materials*, Vol. 164, pp. 371-385.
- [23] Khoshroo, M., Shirzadi Javid, A. A., Katebi, A. (2018). "Effect of chloride treatment curing condition on the mechanical properties and durability of concrete containing zeolite and micro-nano-bubble water." *Construction and Building Materials*, Vol 177, pp. 417-427.
- [24] Sheikh Hassani, M., Asadollahfardi, G., Saghravani, S. F., Jafari, S., Peighambarzadeh F. S., (2020). "The difference in chloride ion diffusion coefficient of concrete made with drinking water and wastewater." *Construction and Building Materials*, Vol 231, 2020, Article 117182.
- [25] ASTM C918M (2013). "Measuring early-age compressive strength and projecting later-age strength- Test method." American Society for Testing and Materials, USA.
- [26] ASTM C496M (2011). "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens." American Society for Testing and Materials, USA.
- [27] ASTM C78M (2010). "Standard Test Method for Flexural Strength of Concrete (Using Simple –Beam with Third – Point Loading)." American Society for Testing and Materials, USA.