ENGINEERING RESEARCH JOURNAL (ERJ)

Vol. 1, No. 45 July. 2020, pp. 94 101

Journal Homepage: http://erj.bu.edu.eg

Shrinkage Behavior of Concrete Incorporating Nano Silica

Hasan Alesnawi[1], Osama Hodhod[2], Ihab A. Adam[3], Eman A. AbdElazeem[4]

[1]Assciate Professor, Civil Engineering Department, Faculty of Engineering, Al – Azhar University, Egypt
[2]Professor, Civil Engineering Department, Faculty of Engineering, Cairo University, Egypt
[3]Professor, Construction Research Institute, National Water Research Centre, Delta Barrage, Egypt
[4]Assistant lecturer, Institute of Aviation Engineering and Technology, Cairo, Egypt.

Abstract. : Concrete is the most versatile material. Due to the continuous and increasing demands made on concrete to fulfill various and difficult requirements, intensive and extensive research is being carried out in concrete technology area. The long-term behavior of reinforced concrete structures is influenced by many factors that generally depend upon one or more of the following: material properties, geometry of the structure, load history and distribution, and the environmental conditions. Engineers are continuously pushing the limits to enhance concrete performance with the aid of advanced chemical admixtures and supplementary cementitious materials like Nano Silica (NS), Fly Ash (FA), Silica Fume (SF), slag etc. NS is the subject of one of research areas in nano technology. In this study, shrinkage behavior of NS concrete was investigated. Mechanical properties were determined in terms of compressive strength tests which were performed at different ages up to 28 days on cubes of 150x150x150 mm according to the Egyptian Code of Practice. It was found that the compressive strength increased about 40% by addition of 4% NS compared to the control mix. The dimensions of concrete specimens used for measuring shrinkage strains were 100x100x500 mm. It was found that all specimens containing NS have larger values of shrinkage than the control concrete. The specimens which contain 4% NS had the lowest values of shrinkage and that contain 2% NS had the largest values of shrinkage if they compared to other NS specimens.

Keywords: Nano Silica; Shrinkage; Compressive Strength; Cement Content; w/c.

1. INTRODUCTION

Nano materials have been widely used to enhance the concrete performance since they act as an excellent modified admixture because of the influence of surface and interface, quantum size, pozzolanic reaction, and macroscopic quantum tunnel. Researchers have presented more efforts to improve the concrete performance using nano materials. They observed that nano materials can improve mechanical properties with significant benefits in terms of long-term life time [1–3].

Many researches mentioned that the incorporation of Nano Silica (NS) could improve the mechanical properties, durability, and wear resistance of concrete [4–8]. Besides, the addition of NS and nano titanium could observably enhance the flexural fatigue of concrete [9]. It was concluded that the NS can make thicker of cement paste and accelerate cement hydration. In addition, the increase of NS can increase bond strength more than compressive strength [10]. Some works also concluded that mechanical properties of ultra-high performance concrete incorporating nano materials were increased by increasing the amount of nano materials [11, 12].

It is well known that concrete drying shrinkage depends on several factors including aggregate content and particle size. The addition of supplementary cementing materials such as fly ash and slag may modify shrinkage behavior of concrete. For example, fly ash could reduce shrinkage at different ages, while shrinkage increases with increasing the amount of slag [13–18]. The inclusion of steel fiber in concrete increases porosity and, consequently, increases the rate of early drying shrinkage [19]. NS causes an enhancement in both pore structure of cement paste and the hydration products and reduces free water. Hence, NS is preferred to control concrete shrinkage [20].

Since most of researches focused on studying the effect of NS on compressive strength, the main objective of this work is to increase and improve our knowledge of the time-dependent behavior of concrete mixes incorporating NS. Many factors, which affects the time-dependent behavior of NS concrete, were investigated. Experimental setup was prepared for concrete specimens to practically explore the influence of adding NS on the concrete compressive strength and shrinkage.

2. Experimental Work

The experimental program, which was carried out at Construction Research Institute, (CRI) of National Water Research Center (NWRC) has been designed to intensively investigate mechanical properties and time-dependent deformations. Mechanical properties were expressed in terms of compressive strength and time-dependent deformations were presented in terms of shrinkage strains. Investigated specimens were divided into three groups A, B, and C as shown in Tables (1-3), respectively.

Nano silica was added to the concrete mixes as percentage of the cement content by mass. Specimens within each group were classified according to the percentage of NS added since each one of three groups contain four mixes incorporating 0%, 2%, 3%, and 4% NS specimens. The cement content of group (A) is 400 kg/m^3 with w/c ratio of 0.4 , while the cement content of group (B) is 550 kg/m^3 with the same w/c ratio. The cement content of group (C) is 550 kg/m^3 with w/c ratio of 0.3.

TABLE 1. Mix proportions of group (A) mixtures.

Code	NS%	W/C	Weight per unit volume (kg/m^3)					
			NS	SP	Cement	Dolomite	Sand	Water
A-N0	0	0.4	0	8	400	1200	600	160
A-N2	2		8	10				
A-N3	3		12	12				
A-N4	4		16	12				

TABLE 2. Mix proportions of concrete group (B) mixtures.

Code	NS %	W/C	Weight per unit volume (kg/m^3)					
			NS	SP	Cement	Dolomite	Sand	Water
B-N0	0	0.4	0	8	550	1200	600	220
B-N2	2		8	10				
B-N3	3		12	12				
B-N4	4		16	12				

TABLE 3. Mix proportions of concrete group (C) mixtures.

Code	NS %	W/C	Weight per unit volume (kg/m^3)					
			NS	SP	Cement	Dolomite	Sand	Water
C-N0	0	0.3	0	8	550	1200	600	165
C-N2	2		8	10				
C-N3	3		12	12				
C-N4	4		16	12				

2.1 Materials

Ordinary Portland cement (CEM I 42.5 N) with surface area of 3500 cm2/g and specific gravity of 3.15 from Suez Cement Company was used. It was produced according to Egyptian Standard Specification. NS with particle size ranging from 10 to 75 nm, average surface area of 400 to 600 m2/g, and purity of 99.9% was used.

The morphologies of NS were determined through Transmission Electron Microscopy (TEM) at central metallurgical research institute as shown in Fig. 1. It was shown that NS particles are characterized by highly agglomerated clusters with the size of 10 to 75nm.

XRD pattern of the NS sample as displayed in Fig.2 showed that silica is observed at a peak centered at 2 Theta (Θ) = 23 ° that indicates the amorphous nature of the nano silica particles.

The fine aggregate, which used in specimens, was natural siliceous sand with a specific gravity of 2.64 and fineness modulus of 2.34. The coarse aggregate was dolomite with a nominal maximum size of 12 mm.

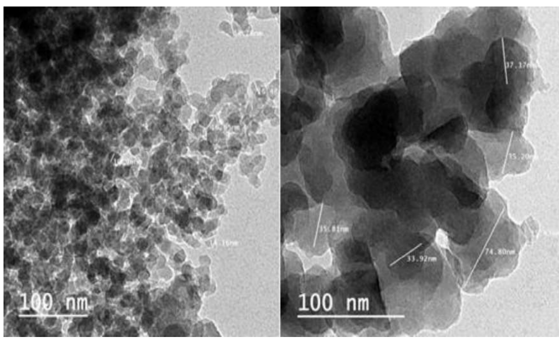

Fig 1. TEM photographs of NS.

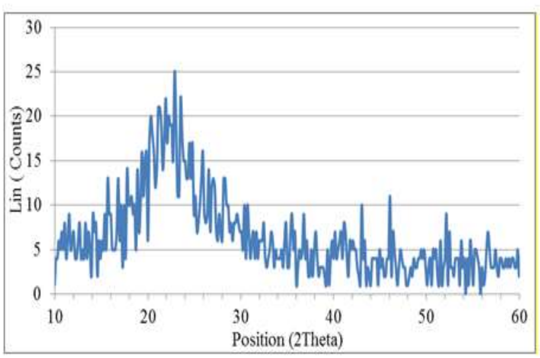

Fig 2. XRD of NS.

Super plasticizer admixture with a density of 1.10 g/cm^3 was used. The recommended dosage is 1% to 3% of cement mass and the content was adjusted to prevent segregation.

2.2 Mixing Procedures

Firstly, super plasticizer was mixed with a small part of mixing water, and then nano particles were added to the mixer and stirred at high speed for 5 minutes. The concrete mixtures were produced using a rotating drum mixer of 100 liters capacity. Oiling of the mixer was carried out prior to preparing the first mix. The oiling operation controlled the effect of the mixer dryness/wetness condition on the first intended mix. Also, it eliminated any doubts regarding the use of a damp drum mixer on the results of the first mix. Secondly, coarse aggregates, sand, and cement were mixed for 2 minutes in the mixer, then the mixture of water, super plasticizer and nano particles were slowly poured in and stirred for another 2 minutes to achieve proper consistency and workability.

Workability of concrete was measured by concrete slump test which was performed for each batch of fresh concrete. Super plasticizer affects concrete workability in a unique way, and it was important to maintain the intended workability.

2.3 Testing

2.3.1 Compressive Strength Test

Compressive strength test was performed on cubes of 150x150x150 mm in dimensions at 7 and 28 days after casting. Specimens and testing machine are shown in Fig. 3. All specimens were continuously water cured until the time of testing.

2.3.2 Shrinkage Test

Shrinkage strains measurements were done on prisms of 100x100 mm cross section and 500 mm in length. The prismatic specimen is recommended by the standard test method ASTM C 157. It is expected that if the length is much greater than the dimensions of the cross section, then shrinkage will occur only in the long direction. Measurement of time-dependent length change can provide the one dimensional shrinkage for concrete.

The time-dependent strain measurements of shrinkage were performed according to the recommendations of Acker [21]. At the day of test beginning, specimens were taken out from water. Then its outer surface was dried and cleaned from moisture. For each shrinkage specimen, one pair of gauge points, with an effective gauge length of 300 mm, was fixed on each surface of two opposite sides as shown in Fig. 4.

3.Results and Discussion

3.1 Effect of Nano Silica on Compressive Strength

The results of compressive strength at the ages of 7 and 28 days are given in Table 4, Table 5, and Table 6. These tables depict that compressive strength values increased obviously by increasing the ratio of NS for all groups.

Fig 3. Compressive strength test**.**

Fig 4. Shrinkage specimen**.**

As for the 28 days results, adding NS obviously increases the compressive strength. The compressive strength increases by 40%, 29% and 23% by the addition of 4 % NS compared to the control mix of group (A), (B), and (C), respectively. This can be recognized by the role of NS as nuclei for cement paste to promote the hydration of cement because of its pozzolanic reaction with CH. This reaction produces increased quantity of CSH gel, which has a positive effect on both cohesion between aggregates and mechanical properties of concrete. It was stated that nano particles can fill a significant part of voids existing in the matrix of cement paste and results in refinement in microstructure, regarding their ultra-fine dimension [22, 23]. Although at early stages agglomerates can significantly affect the strength gain, agglomerated particles in the mixture that had not completely dissolved will reduce the porosity and capillaries of CSH. The density of the CSH will somewhat increase in the plastic form and transform into a denser compression resisting structure after the completion of hydration process at the age of 28 days.

TABLE 4. Compressive strength values of group (A) specimens.

Code	7 days (kg/cm^2)	28 days (kg/cm^2)
A-N0	225	325
A-N2	272	392
A-N3	262	402
A-N4	357	455

TABLE 5. Compressive strength values of group (B) specimens.

Code	7 days (kg/cm^2)	28 days (kg/cm^2)
B-N0	325	433
B-N2	361	481
B-N3	383	503
B-N4	427	557

TABLE 6. Compressive strength values of group (C) specimens.

Code	7 days (kg/cm^2)	28 days (kg/cm^2)
C-N0	368	472
C-N2	382	501
C-N3	398	527
C-N4	441	581

3.2 Effect of Nano Silica on Shrinkage Behavior

The development of shrinkage strain with time for tested specimens is shown in Figs. (5-7). These figures display that the existence of NS concrete increased shrinkage strain of concrete, mainly after the period of 10 days after drying. At the early drying period (up to 10 days), the shrinkage strain changes slightly in specimens that contain NS. For later drying periods, the shrinkage strain of group (A) specimens increased by about 52%, 44%, and 21% for 2%, 3%, and 4% NS respectively after 98 days under drying. This means that the specimen contains 2% NS has the largest value of shrinkage strain rather than 3 and 4% NS specimens. Cement generally shrinks during hydration reaction. The existence of concrete drying shrinkage can be attributed to the presence of high amounts of finer CSH holding higher amounts of gel water which was released during drying [24]. In addition, all figures displayed that the shrinkage strain increased largely up to about 50 days after which the shrinkage strain development becomes slower.

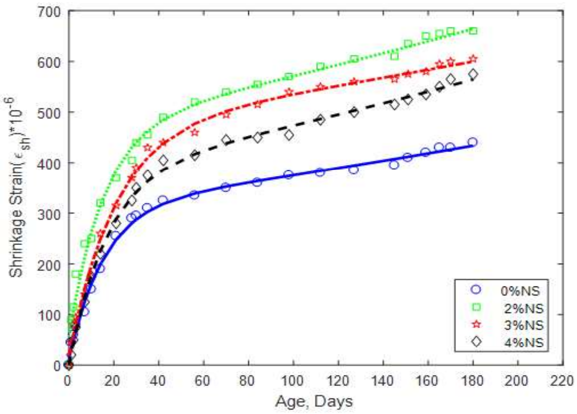

Fig 5. Effect of NS on shrinkage strain of group (A).

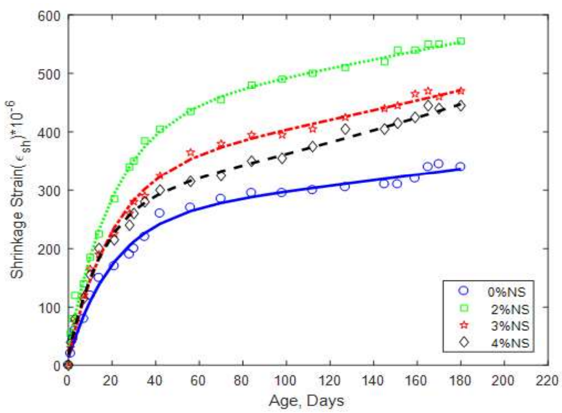

Fig 6. Effect of NS on shrinkage strain of group (B).

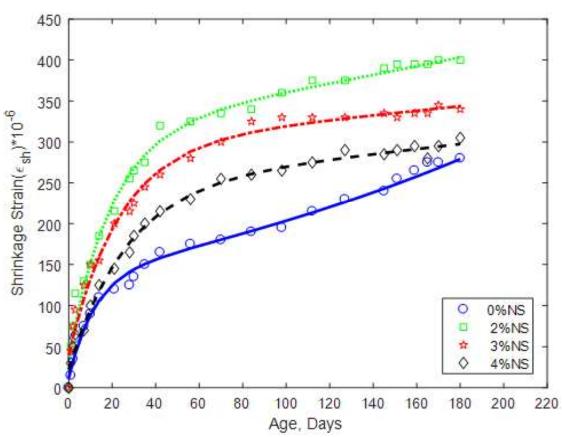

Fig7. Effect of NS on shrinkage strain of group (C).

3.3 Effect of Cement Content on Shrinkage Behavior

Figure 8 to Figure 11 display the effect of increasing the cement content from 400 Kg/m^3 (group A) to 550 Kg/m^3 (group B) on the shrinkage for 0%, 2%, 3%, and 4% NS specimens, respectively. It was observed that there is an inverse relationship between the cement content and the shrinkage strain since increasing the cement content led to a noticeable decrease in shrinkage strain. The shrinkage strain of group (B) containing 550 Kg/m^3 cement decreased by about 23%, 16%, 22%, and 24% of shrinkage strain of the corresponding specimens of group (A) containing 400 Kg/m^3 for 0%, 2%, 3%, and 4% NS specimens, respectively after 180 days under drying. This can be recognized by the higher compressive strength values of group (B) compared to that of group (A). This agrees with the well-known conclusion that the more hardened the concrete, the lower its deformation potential.

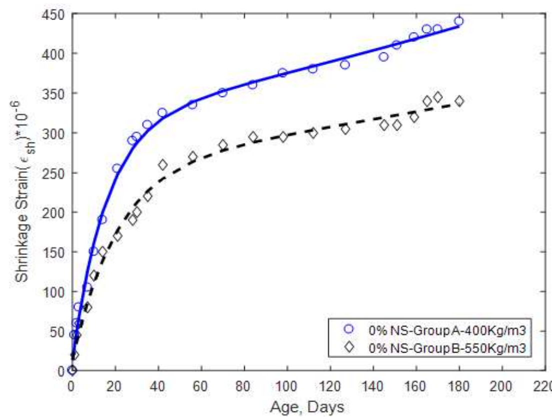

Fig 8. Effect of cement content on shrinkage strain of 0% NS specimens.

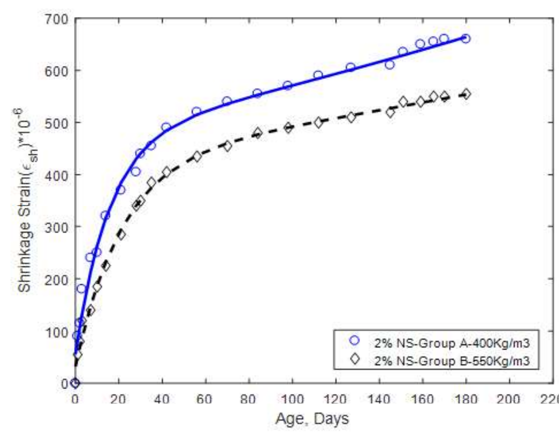

Fig 9. Effect of cement content on shrinkage strain of 2% NS specimens.

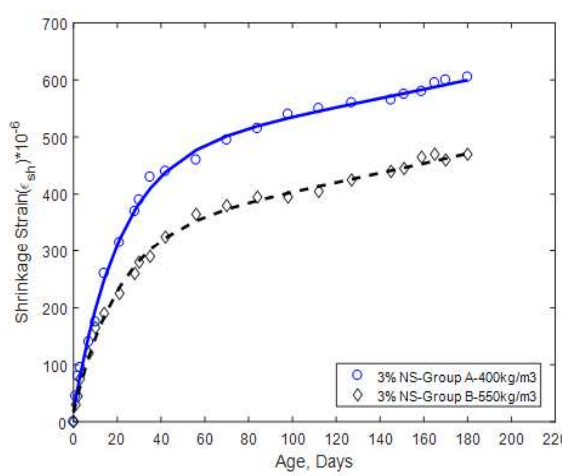

Fig 10. Effect of cement content on shrinkage strain of 3% NS specimens.

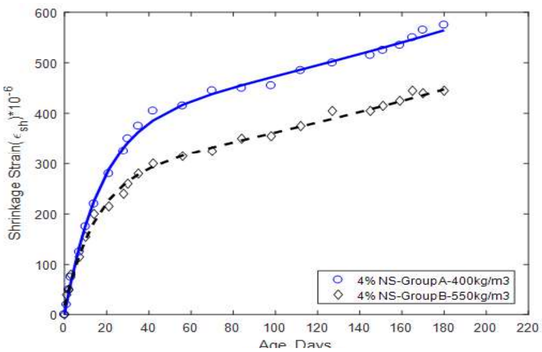

Fig 11. Effect of cement content on shrinkage strain of 4% NS specimens.

3.4 Effect of Water to Cement Ratio on Shrinkage Behavior

One of the most important factors influencing shrinkage is the w/c ratio. Figure 12 to Figure 15 display the effect of w/c ratio on shrinkage behavior of 0%, 2%, 3%, and 4% NS specimens, respectively. It was observed that the shrinkage strain has nearly the same value up to 10 days for specimens made with w/c ratio of 0.4 and 0.3. This is valid for 0%, 2%, 3%, and 4% NS specimens. After 10 days, the effect of decreasing the w/c ratio from 0.4 in group (B) to 0.3 in group (C) appears obviously in decreasing the shrinkage strain which means that the lower the w/c ratio, the lower the shrinkage experienced by the concrete specimen. At high w/c ratios, drying shrinkage increases but autogenous shrinkage decreases with an overall increase in shrinkage. On the other hand, low w/c ratios lead to decrease in drying portion and an increase in autogenous one. As the strength of concrete increases too, the global influence of decreasing w/c ratio is a decrease in total shrinkage. It is well established that effects of cement content and water content on drying shrinkage are indirect [25]. These effects are largely related to the fact that they change the paste volume, and consequently, change the amount of aggregates and its restraining effect [25, 26].

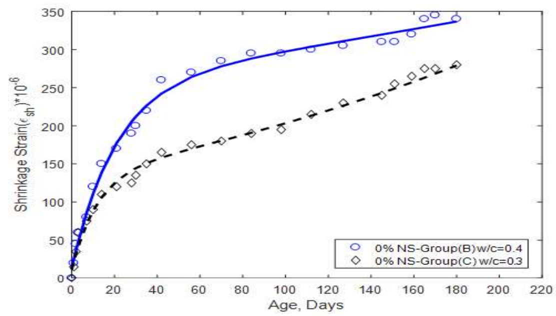

Fig 12. Effect of water to cement ratio on shrinkage strain of 0% NS specimens

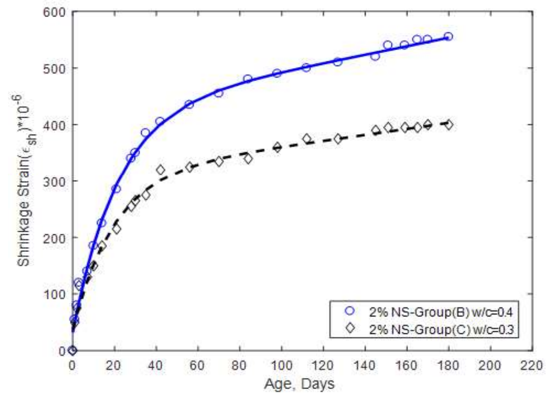

Fig 13. Effect of water to cement ratio on shrinkage strain of 2% NS specimens.

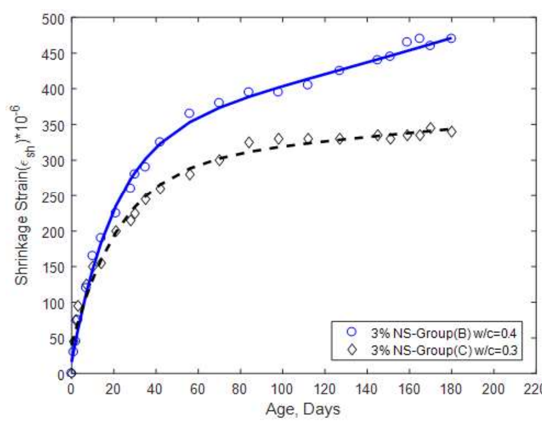

Fig 14. Effect of water to cement ratio on shrinkage strain of 3% NS specimens.

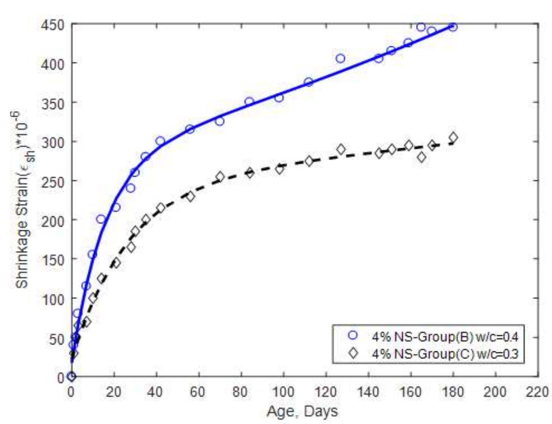

Fig 15. Effect of water to cement ratio on shrinkage strain of 4% NS specimens.

4.CONCLUSIONS

The main objective of the current research work was to improve our knowledge of the time-dependent behavior of NS concrete. Time-dependent behavior of NS concrete was investigated in terms of its mechanical properties and time-dependent deformations. Mechanical properties were expressed in terms of compressive strength tests which were carried out at different ages. Time-dependent deformations were expressed in terms of shrinkage strains. From compressive strength tests, it was found that compressive strength changes slightly in specimens that contain NS at the early ages (up to 7 days). As for the 28 days results, inclusion of NS obviously increases the compressive strength. The compressive strength increases by 40%, 29% and 23% by the addition of 4 % NS compared to the control mix of group (A), (B), and (C), respectively.

Shrinkage tests indicated that all specimens containing NS had larger values of shrinkage strain than the control concrete. The specimens which contain 4% NS had the lowest values of shrinkage and that contain 2% NS had the largest values of shrinkage in comparison with other NS specimens. The effect of other factors such as w/c ratio and cement content was also investigated in this research. It was observed that the lower the w/c ratio; the lower the shrinkage experienced by the concrete specimen. It was observed that there is an inverse relationship; between the cement content and the shrinkage strain since increasing the cement content led to a noticeable decrease in shrinkage strain.

REFERENCES

[1] R., Zhang, X., Cheng, P., Hou, Z., Ye. Influences of Nano-TiO_2 on the Properties of Cement-Based Materials: Hydration and Drying Shrinkage, Constr. Build. Mater., 81, 2015, pp. 35–41.

[2] A., Nazari, S., Riahi. The Effects of TiO_2 Nanoparticles on Physical, Thermal and Mechanical Properties of Concrete Using Ground Granulated Blast Furnace Slag As Binder, Mater. Sci. Eng. A 528, 2011, 2085–2092.

[3] A., Nazari, S., Riahi, S., Riahi, S.F., Shamekhi, A., Khademno. Influence of Al2O3 Nanoparticles on The compressive Strength and Workability of Blended Concrete, J. Am. Sci. 6 (5), 2010, pp. 6–9.

[4] A., Nazari, S., Riahi. The Effects of SiO_2 Nanoparticles on Physical and Mechanical Properties of High Strength Compacting Concrete, Composites Part B 42, 2011 , pp.570–578.

[5] A.N., Givi, S., Abdul Rashid, N.A., Farah, M.A., Aziz, M., Salleh, H., Song-Song. The Effects of Lime Solution on the Properties of SiO_2 Nano-Particles Binary Blended Concrete, Composites Part B 42, 2011, pp. 562– 569.

[6] H., Li, M., Zhang, O., Jin-ping. Abrasion Resistance of Concrete Containing Nano-Particles for Pavement Wear, 260, 2006, pp.1262–1266.

[7] Mao-hua Zhang, Hui Li, Pore Structure and Chloride Permeability of Concrete Containing Nano-Particles for Pavement, Constr. Build. Mater., 25, 2011, pp. 608– 616.

[8] H., Li, M.,-hua Zhang, O., Jin-ping. Flexural Fatigue Performance of Concrete Containing Nano-Particles for Pavement, Int. J. Fatigue, 29, 2007, pp. 1292–1301.

[9] Y., Qing, Z., Zenan, K., Deyu, C., Rongshen. Influence of Nano-SiO_2 Addition on Properties of Hardened Cement Paste as Compared with Silica Fume, Constr. Build. Mater., 21, 2007, pp. 539–545.

[10] M., Zhang, J., Islam. Use of Nano-Silica to Reduce Setting Time and Increase Early Strength of Concretes with High Volumes of Fly Ash or Slag, Constr. Build. Mater., 29, 2012, pp. 573–580.

[11] S., Yu, J., Li, C., Wu, P., Wu, Z.X., Li. Influences of Nano-Particles on Dynamic Strength of Ultra-High Performance Concrete, Composites Part B 91, 2016, pp. 595–609.

[12] Z., Rong, W., Sun, H., Xiao, G., Jiang. Effects of Nano-SiO_2 Particles on the Mechanical and Microstructural Properties of Ultra-High Performance Cementations Composites, Cem. Concr. Compos., 56, 2015, pp. 25–31.

[13] Y.J., Li, Y.L., Gong, J., Yin. Strength and Durability of High Performance Road Concrete Containing Ultra-Fine Fly Ash, Appl. Mech. Mater., 99–100, 2011, pp.1264–1268.

[14] P.C., Itcin. Non-Shrinking Concrete, in: CANMET/ACI/JCI 4th International Concrete on Recent Advances in Concrete Technology, 1998, 6, pp. 3–63.

[15] S.H., Alsayed. Influence of Superlasticizer, Plasticizer, and Silica Fume on the Drying Shrinkage of High-Strength Concrete Subjected to Hot-Dry Field Conditions, Cem. Concr. Res., 28 (10),1998, pp. 1405–1415.

[16] B., Persson. Eight-Year Exploration of Shrinkage in High-Performance Concrete, Cem. Concr. Res,. 32, 2002, pp. 1229–1237.

[17] R.D., Hooton, K., S., Pursinski. The Effect of Granulated Blast Furnace Slag (Slag Cement) on the Drying Shrinkage of Concrete: A critical Review of the literature, in: Eighth CANMENT/ACI International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, 2004.

[18] M., Valcuende, F., Benito, et al. Shrinkage of Self-compacting Concrete Made with Blast Furnace Slag as Fine Aggregate, Constr. Build. Mater., 76, 2015, pp. 1–9.

[19] J., Naeimeh, P., Kypros, et al., Moisture Transport and Drying Shrinkage properties of Steel-Fibre-Reinforced-Concrete, Constr. Build. Mater., 73, 2014, pp. 41–50.

[20] F., Nima, N., Hossein, et al., The Effect of Nano Silica on Short Term Drying Shrinkage of POFA Cement Mortars, Constr. Build. Mater., 95, 2015, pp.636–646.

[21] P., Acker. Recommendation for Measurement of Time-Dependent Strains of Concrete Loaded in Compression. In RILEM Proceedings, 1993, pp. 849-849.

[22] M.I., Serag, A.M., Yasien, M.S., El-Feky, H., Elkady. Effect of Nano Silica on Concrete Bond Strength Modes of Failure, International Journal, 12(29), 2017, pp. 2892-2899.

[23] L., Varghese, V.V.L.K., Rao, L., Parameswaran. Nanosilica-Added Concrete: Strength and its Correlation with Time-Dependent Properties, Proceedings of the Institution of Civil Engineers Construction Materials, 2018, pp. 1-10.

[24] M.A., Mosaberpanaha, O., Erenb, A.R., Tarassolyb. The Effect of Nano-Silica and Waste Glass Powder on Mechanical, Rheological, and Shrinkage Properties of UHPC Using Response Surface Methodology, Journal of Materials Research and Technology. JMRTEC, 2018, pp. 425.

[25] P.K., Mehta and P.J.M., Monteiro. Concrete: Microstructure, Properties, and Materials. 2nd ed: McGraw-Hill, 1993.

[26] A.M., Neville. Properties of Concrete. 4th and final ed: J. Wiley, 1996.