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Article

Laboratory Investigation on Durability of Nano Clay Modified Concrete Pavement

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Abstract. Today, one can take a strategy to improve durability in concrete coatings by using modern materials, especially nano-materials. Nano clay is one of the nanoparticles that increases mechanical properties and strength in concrete. With respect to very rich deposits for clay sources in properties of concrete it seems necessary to conduct studies in this regard. Nano clay was utilized with percentages of 1wt%, 2wt% and 3wt% in this study. The effects of both types of water curing and plastic cover curing were examined. The results indicate that using nano clay may increase compressive strength, flexural strength and tensile strength and reduce water penetration and absorption percentage. The best mix design belongs to replacement of 1wt% nano clay. Under water curing conditions in this mix design, rates of compressive strength (35%), flexural strength (31%) and tensile strength (34%) versus control specimen increased, while penetration (35%) and absorption percent (54%) were reduced. The mechanism, nano clay, therefore increases strength and durability in concrete in such a way that the existing Al_2SiO_5 in nano clay may involve in hydration process and reduce large crystals $Ca(OH)_2$ and accelerate C–S–H gel formation. As a result, dense C–S–H gel is produced and cement mortar and paste will have a more compressed structure. Following the increase in quantity of nano clay up to 2wt% and 3wt%, it is added to the rates of compressive and flexural strengths versus control sample, but in nano clay specimen (1wt%), compressive and flexural and tensile strengths are reduced while water penetration and absorption percentage are increased. It was characterized by analysis on curing methods that showed water curing method was followed by higher strength and durability than in plastic cover curing technique.

Keywords: Compressive strength, flexural strength, nano clay, penetration, absorption percent.

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1. Introduction

The interdisciplinary nature is deemed as one of the main aspects of nanotechnology; the interaction among this science with knowledge of concrete may create a turning point in road-construction industry. Finding a new generation of materials with high performance and new and different properties compared to ordinary materials is assumed as the final goal for analysis on concrete at nano scale. One of the major dimensions of nanotechnology is the interdisciplinary nature of this knowledge. The interaction of this science with concrete science can create a turning point in the concrete pavement industry. The existing additives may not always improve all characteristics of the concrete. Nanotechnology has shown that it can improve performance of concrete comprehensively; nanoparticles fill the pores in concrete with respect to their dimensions and also enhance properties of concrete by creation of nano-crystals. Nano clay is one of the nanoparticles that improve mechanical and physical properties of concrete. Given highly rich deposits of clay sources (bentonite, montmorillonite, kaolinite, helictite and halloysite, etc.) and the considerable effect these materials exert to properties of concrete, it seems necessary to conduct the related studies in the country. Structure of clay includes crystalline layers of aluminum phyllosilicate with approximate diameter of one nanometer. Adding clay nanoparticles to cement materials controls chemical analysis caused by (C-S-H) due to deposition of calcium occurred in water and also it prevents water penetration into the concrete where these processes increase durability and strength of it [1, 2, 3, 4].

Based on the conducted studies, some nanoparticles e.g. nano-silica, nano-iron oxide and nano clay, etc. extraordinarily affect mechanical properties of cement mortar [5]. Li et al. evaluated concrete with titanium nanoparticle contents and concluded that fatigue performance of concrete has been remarkably improved by raising the content of titanium nanoparticles [6]. In another study that was carried out by Li et al. they concluded that abrasive and compressive strength of concrete was increased by increase in quantity of nano-titanium and the concrete with nano-titanium contents had better performance than concrete with nano-silica content [7].

Fan et al. constructed concrete and mortar with high mechanical properties that were resistant to invasion by penetration of chloride ion using mixture of cement with kaolinite nano clay. In this study, Ordinary Portland Cement (OPC) was mixed with some percentage of kaolinite clay soil (0-10%). It was concluded that kaolinite clay soil might improve penetration and compressive strength [8]. Hakamy et al. explored nano clay and nanocarbon in concrete with different percentages (1, 2 and 3%) where 1% nano clay with 1% nanocarbon increased density, compressive strength, flexural strength, toughness, impact strength and hardness compared to other mixture compositions [9]. By adding nano-silica and nano clay, Mohammad found that mechanical properties were improved in concrete and nano-silica might affect more mechanical properties than nano clay [10]. Fan et al. analyzed effect of nano clay on cemented concretes exposed to freeze-thaw and found nano clay improved strength in concrete against freeze-thaw [11]. Hosseini and Afshar explored properties of the self-compressed concrete with content of montmorillonite nano clay. Their findings indicated that following a rise in the percentage of nano clay in self-compressed concrete, the compressive strength was gradually increased up to approximately 0.5%, but the compressive strength of self-compressed concrete was gradually reduced for nanoparticles to 0.5-1.5% [12]. Mirgozar Langaroudi and Mohammadi analyzed effect of nano clay on mechanical durability properties of self-compressed concrete. By mixing cement including 15% silica, 30% fly ash, 15% rice husk ash, and 45% slag and adding 1, 2 and 3% of nano clay, they concluded that 3% of nano clay improved durability but that effect was limited to mechanical properties and nano clay 3% has acted better than 1 and 2% nano clay in self-compressed concrete [13]. In a survey, Xiaorun et al examined the effect of nanomaterial additives on abrasive strength of concrete with content of cement mixture of slag, nano-silica and fly ash. They concluded that the abrasive strength would increase by increasing the quantity of nano-silica [14]. Asadi et al. explored impact of nano clay on mechanical and thermal properties of geopolymeric concrete including fly ash (F-class). Adding nano clay with weight ratios (1%, 2% and 3%) demonstrated that the porosity was reduced by replacement of 2% nano clay, and water absorption percentage was noticeably increased and the highest flexural and compressive strength was obtained [15]. In a study done by Irshidat and Alsalah, effect of nano clay additive with different ratios (0.5%, 1% and 2%) was examined on mechanical properties, efficiency and water absorption. The mechanical properties of cement mortar have been remarkably improved by increasing small quantities of nano clay. Cement mortar showed the best results by mixing with 2% nano clay and compressive strength, flexural strength and tensile strength have been increased 11%, 5% and 9% respectively [16]. Wang used nano clay with percentages (0.1, 0.2, 0.3, 0.4 and 0.5). As cement was replaced with 0.3% and 0.5% nano clay, the coefficients of compressive strength and thermal conductivity of concrete were increased [17]. Morsi et al. analyzed effect of nano clay (meta-kaolin) with 0, 2, 4, 6 and 8% in mechanical properties and microstructure of cement mortar. Compressive strength (49%) and tensile strength (7%) were increased by adding 8% nano clay [18]. By replacement of 0, 1 and 2% of nano clay (montmorillonite), Irshidat and Alsalah examined mechanical properties of concrete exposed to high temperature. The maximum relative improvement was obtained in flexural and compressive strength by replacement of 2% nano clay at temperature of 400 °C [19]. In an investigation done by Rashad, nano-materials in which efficiency and water absorption percentage was reduced by using iron nano-oxide, nano clay and nanoalumina in cement matrix and compressive strength, tensile strength, flexural strength and abrasive strength and modulus of elasticity were added [20]. Heikal et al. reviewed effect of replacement of nano clay on physical, chemical and mechanical performance of concrete. The mechanical properties were improved in concrete by using 6% nano clay and then mechanical properties were reduced again by using more than 8% nano clay [21].

2. Lab Program and Materials

2.1. Cement

The cement type 1 produced by Abyek factory with specific surface area of 3069cm²/g was used in this study. Chemical, physical and mechanical properties of this cement are compliant with portland cement standard ASTM C150 [22].

2.2. Aggregate

Grading used for making specimens has been displayed in Table 1 and is according to ASTM C33 standard [23]. The broken sand with maximum particle size (19.5mm) was utilized for production of concrete in this study. The used coarse aggregate has saturated specific weight (2668kg/m³), massive density of milled dry sand (1674kg/m³) and water absorption rate (0.25%). The used natural sand has saturated specific weight (2580 kg/m³), water absorption rate (1.7%), sand value (85.29%) and modulus of softness (2.99).

Table 1. Sieve aggregates analysis (mm).

Coarse aggregates	**Aggregate size(mm)**	25	19	9.5	4.75	2.36
	Percentage of screening sieve(%)	100	96	38	8	0
Fine aggregates	**Aggregate size(mm)**	1.18	0.6	0.3	0.15	0.075
	Percentage of screening sieve(%)	82	58	26	7	2

2.3. Water

The drinkable water of city was used in this test without any type of additive.

2.4. Nano clay particles

The nano clay powder was utilized in this study and whereas powder of nano clay particles is very light-weight and it may be spread through the air upon mixing, thus it should be converted into liquid form. The method of liquefaction of powder of nanoparticles is as follows. Initially, nanoparticle powder is poured into a beaker with a designated quantity and the needed water is added to it. A magnet is then placed into the beaker and it is put on heated stirrer device and mixed with rotation speed 250-300rpm and stirred for 6 h. Due to being light weight, nanoparticle powder is floats on the water surface and after putting the beaker on heater-stirrer device, a cavity emerges in the middle of beaker on the water surface that acts similar to a wave, moving the nanoparticle powder from the upper level to the bottom surface and vice versa so that OH ion is created on water surface. This OH-ion is well reacted with water and homogenous suspension is created on the surface of water. Table 2 shows the physical properties of nano clay used in this study.

Table 2. The physical properties of nano clay.

Kind of Clay	Diameter (nm)	Surface volume ratio (m²/g)	Density (g/cm³)	colour
Montmoriolonit	1-2	500-750	5.7	yellow

2.5. Mix design

Mix design has been implemented according to ACI 211/1 standard. Nano clay particles with weight percentages (1%, 2% and 3%) were used in this survey and also a (control) sample without nano clay additive was used in this study. Table 3 shows constituent elements for design of mixtures. Water-to-cement ratio was considered 0.45 for all specimens.

Table 3. Mixing design for cement concrete (kg/m³).

Mix Design	Fine aggregates	Coarse aggregates	Cement	Nano clay
OPC	865	985	400	0
1NC	865	985	396	4
2NC	865	985	392	8
3NC	865	985	388	12

2.6. Lab Program and conditions of samples

In this study, 4 mix design were analyzed. Nano clay additive was prepared before test and then all coarse aggregate materials were poured into a mixer and stirred with 50% cement and nano clay for a few seconds. Afterward, all sand materials and the remaining cement and nano clay were added to it and mixed with each other. A mechanical mixer was used to stir the materials. Then the prepared mixture was poured into a cast with two layers, impacted 25 impacts and vibrated. Curing was done by two methods in this study; plastic cover curing and water curing in order to analyze the effect of each of the curing factors on concrete with nano clay content. Table 4 denotes lab program and conditions of specimens. Figure 1 shows curing process under plastic cover and with water.

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Table 4. Lab program and sample conditions.

Test	Sample dimensions (mm)	Age (day)	Number of samples in mix	Conditions curing
Compressive strength	100 × 300 Cylinder	28	12	Curing at laboratory temperature of 25 °C, half of the samples are in water and the other half are under the plastic cover
Flexural strength	500 × 100×100	28	12	
Tensile strength	100 × 300 Cylinder	14	12	
Water penetration	200 × 200×120	28	6	
Water absorption percentage	100 × 100×100	28	6	

Fig. 1. Plastic cover curing (right); water curing (left).

Fig. 2. Image of compressive strength test.

3. Testing Methods, Results, and Discussion

3.1. Compressive Strength

Compressive strength test is the most commonly conducted test on hardened concrete. This is due to ease of execution on the one hand, and the fact that most of the favorable characteristics of concrete qualitatively depend on the given compressive strength on the other hand. The compressive strength was tested on standard specimens with 150mm diameter and 300mm height at loading speed (1mm/min) according to ASTM C470 standard at ages of 28 and 90 days [24]. Figure 2 indicates the image of compressive strength test. The results of compressive strength test (28 and 90 days) are given in Figs. 3 and 4 under plastic cover curing and water curing conditions.

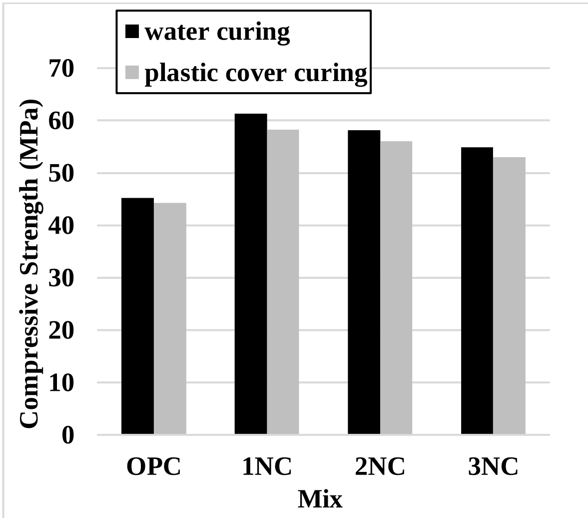

Fig. 3. Results of compressive strength test (28 days).

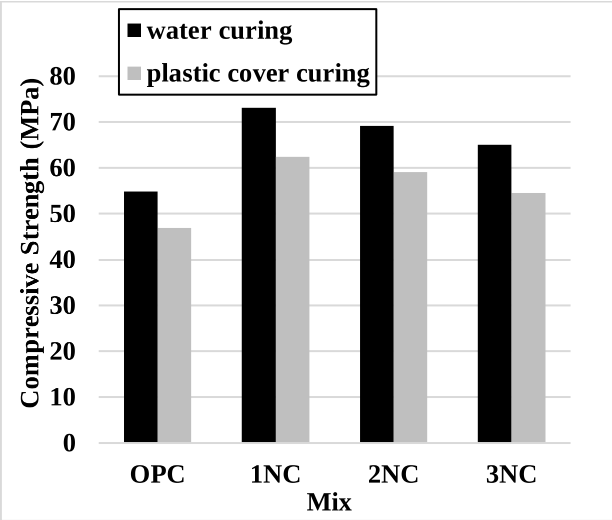

Fig. 4. Results of compressive strength test (90 days).

Based on the given results from diagrams in Figs. 3 and 4, compressive strength is added by increasing the percentage of nano clay and the highest strength belongs to 1NC sample. The compressive strength (28 days) treated by water curing has been increased 35.6%, 28.5% and 21.3% respectively in 1NC, 2NC and 3NC samples. Similarly, the results show that the specimens treated with water curing experienced higher compressive strength than samples treated under plastic cover curing in 28 and 90 days. The effect of curing technique is not significant on compressive strength in concrete (28 days). For example, compressive strength (28 days) in samples treated with water curing has been increased from 0.93 to 3.1MPa compared to specimens treated with plastic cover curing. However, curing technique has significant impact on compressive strength (90 days). For instance, the compressive strength with water curing in 1NC sample is about 10.73MPa greater than compressive strength of sample treated by plastic cover curing. To explain this phenomena, it can be said that the cement needs humidity and time to carry out the whole chemical reactions and C-S-H gel will not be formed uniformly throughout the cement matrix in lack of water. Curing under plastic cover until the 28 days provides some of the humidity required for the reaction but in longer time it will face the water shortage. By adding more than 1% nano clay, compressive strength is reduced in comparison with 1NC sample. The reason for such behavior may be justified by this fact that nano clay may act as supplement for micro-grained aggregates in the mixture and fill the blank pores and spaces and create homogenous and dense concrete. This issue may decrease pores and increase compressive strength because of better connection between sand grains with mortar as well as reliance of aggregates on each other, but with overuse of nano clay, the nanoparticles agglomerate around the cement aggregates and cause semi-perfect hydration in cement grains, creating hydrated products with weak bonds. On the other hand, the surficial interaction is reduced among cement matrix and nano clay by increasing the content of nanoparticles.

3.2. Flexural Strength

The flexural strength is used for design approach of concrete pavement to consider fatigue criterion that controls cracking of concrete under frequent loadings. Flexural emerges in concrete pavement under axial loadings from both compressive and flexural stresses. Of course, ratio of compressive stresses to compressive strength is so small that it has no effect on design of thickness of concrete slab. Ratios of flexural stresses to flexural strength may have higher values, even greater than 0.5. As a result, flexural stresses and strength are used for design of thickness of concrete pavement. Testing sample with flexural strength was built in dimensions (500×100×100mm) to conduct this experiment according to ASTM C78 standard and after curing of samples they were put under universal testing machine (UTM) to measure their flexural strength [25]. Figure 5 shows flexural strength test. The results of flexural strength test (28 and 90 days) have been indicated for water curing and plastic cover curing in Figs. 6 and 7.

Fig. 5. UTM device under flexural loading.

The results in Figs. 6 and 7 show that flexural strength is increased in concrete by adding a percentage of nano clay and 1NC sample has the highest quantity of flexural strength, these specimens can tolerate higher stress compared to OPC, 2NC and 3NC. The compressive strength is reduced versus 1NC sample by adding more than 1% nano clay. The flexural strength for water curing during 28 days has been increased 31.7%, 25.7% and 17.7% respectively in 1NC, 2NC and 3NC concrete specimens. Comparison of these results indicates that due to their filler and pozzolanic effects, nano clay particles improve properties in contact area of cement paste with nanoparticles and aggregates and thereby adhesion is increased in contact areas. As a small amount of nanoparticles is distributed homogenously in cement mortar or paste, nanoparticles act similar to atomic nucleus with respect to their high specific level and thus very high surficial energy and they create strong adhesion with hydrated cement. As a result, hydration trend is continued because of the high potential reaction of nanoparticles and mechanical strengths is increased.

Similarly, results show those samples which have been treated by water curing, have higher flexural strength than specimens under plastic cover curing in 28 and 90 days. The effect of curing method is not significant on compressive strength in concrete within 28 days. For example, rate of flexural strength of 1NC sample under water cuing conditions is about 0.3MPa greater than specimen treated under plastic cover curing. However, curing technique has a significant effect on flexural strength for 90 days. For instance, under water curing conditions, flexural strength of 1NC sample is about 1 time higher than sample under plastic cover curing.

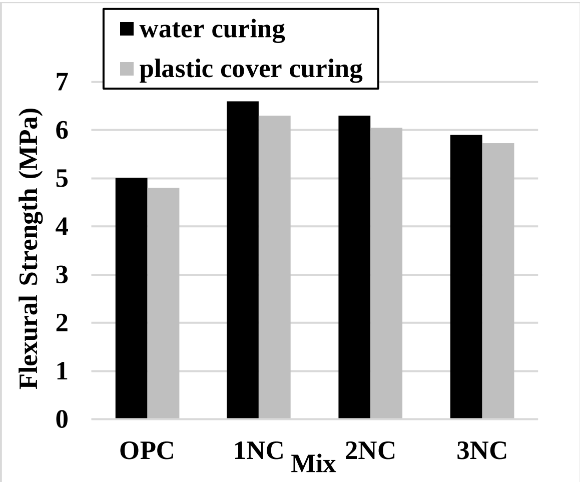

Fig. 6. Results of flexural strength for 28 days.

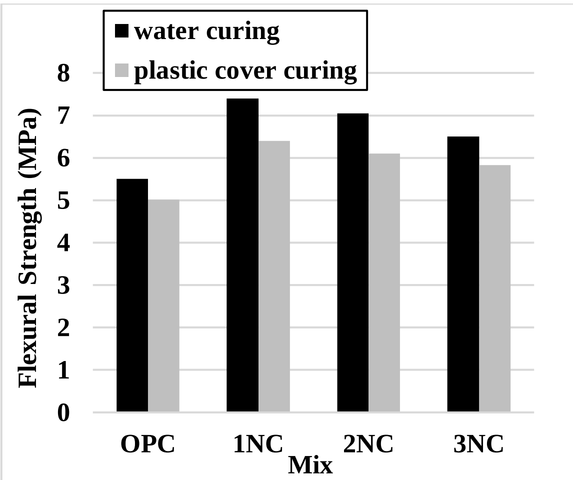

Fig. 7. Results of flexural strength for 90 days.

3.3. Tensile Strength

Tensile strength was indirectly exerted on samples treated with water curing and plastic cover curing in 28 and 90 days according to ASTM C496 standard. In this testing method, by exertion of diagonal pressure force to concrete sample with 150mm diameter and 300mm height that has been placed horizontally between two plates in testing machine, this loading is exerted constantly and homogenously and without sudden variations at constant speed (about 700-1400Pa/s) until rupture of concrete [26]. Figures 8 and 9 show the results of tensile strength for various concrete specimens.

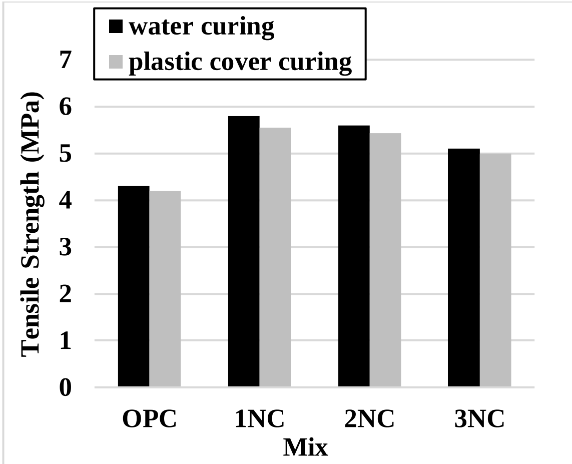

Fig. 8. Results of tensile strength for 28 days.

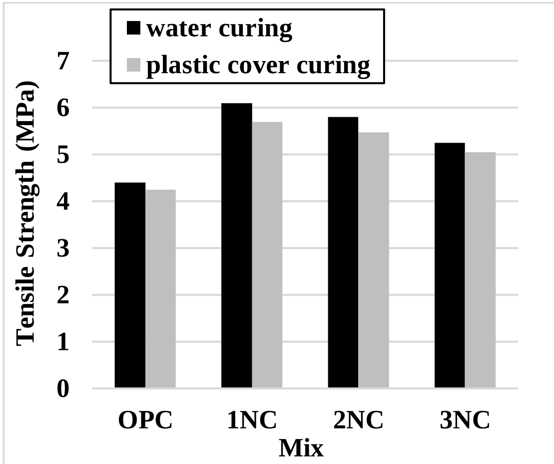

Fig. 9. Results of tensile strength for 90 days.

Based on the results derived from Figs. 8 and 9, tensile strength is increased by adding to percentage of nano clay and the highest strength belongs to 1NC. Tensile strength under water curing conditions has been increased 38.6%, 31.8% and 19.3% respectively in 1NC, 2NC and 3NC samples. Similarly, the results indicate that the samples treated under water curing conditions possessed higher tensile strength than specimens which have been treated under plastic cover curing for 28 and 90 days. The effect of curing method is not significant on tensile strength in concrete sample for 28 days. For example, 1NC concrete sample under water curing conditions includes tensile strength 0.25MP a higher than in sample under plastic cover curing conditions. However, curing technique has a more considerable effect on tensile strength for the 90-day period. For example, the rate of tensile strength is about 0.4MPa greater in 1NC concrete sample treated under water curing than the one by plastic cover curing conditions. To explain this phenomenon, it can be said that cement takes time and humidity to perform all chemical reactions, and Curing under plastic cover until the 28 days provides some of the humidity required for the reaction but in longer time it will face the water shortage.

3.4. Water Penetration

The concrete samples were built with dimensions (200×200×120mm) for conducting water penetration under pressure test according to EN 12390-8 standard and after 28-day curing period they were placed in oven under 100°C and then ambient temperature (24±2) for 24hr to achieve the same temperature with environment. Then some part of the sample that was under penetration became slightly coarse by wire brush to create space for water penetration and the other end of sample was smoothened by flint; afterwards, samples were put under penetration device and 5bar pressure was exerted to samples for 72h. Then samples were split into two halves by Brazilian Test Machine and maximum water penetration depth was measured [27]. Figure 10 indicates tested water penetration depth.

Fig. 10. Testing water penetration depth in concrete.

Figure 11 shows trend of penetration variance in terms of nano clay percentage and curing type. Based on these results, rise of nano clay percentage reduces water penetration depth. The highest depth of water penetration has occurred in OPC (31mm) under water curing conditions while the lowest water penetration belongs to 1NC sample (20mm) in depth. Penetration was decreased in OPC by increasing the percentage of nano clay, but concrete penetration was reduced by increase in nano clay from 1% to 2 and 3%. This function is due to this fact that nanoparticles have reacted with calcium hydroxide among hydration products and C-S-H dense gel is produced and therefore cement paste will have a more compressed structure. Of course, micro-filling property of nanoparticles e.g. pozzolana may be more intensified because of the micro structure of these materials; as a result, nanoparticles fill the pores of concrete and even pores with nanometer diameter and it reduces penetration. Comparison of the given results for the samples treated by water curing and plastic cover curing show that water penetration depth is higher in specimens under plastic cover curing. For example, water penetration depth in 1NC sample is 15.52 greater under plastic cover curing than when treated with water curing.

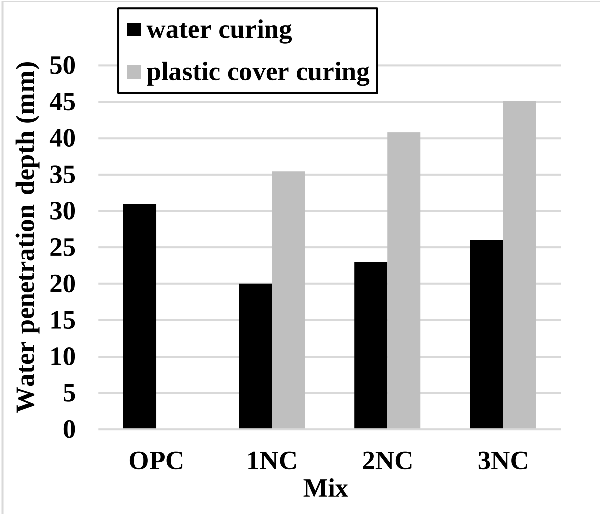

Fig. 11. Water penetration in concrete.

3.5. Water Absorption Percentage

According to ASTM C642 standard, concrete specimens with dimensions (100×100×100mm) were placed inside oven for 72±2hr after 28 days under curing and at temperature of 110±5 °C and then weight of sample (A) was precisely measured. Then, samples were placed in water for 24±2hr and the water on their surface was dried by a towel (under saturation with dry surface) and their weight (B) was determined and finally water absorption level was calculated by volumetric technique based on Eq. (1) [28]. The results of absorption percentage have been shown in diagram of Fig. 12.

$$\mathrm{AC}\ (\%) = \frac{\mathrm{B} - \mathrm{A}}{\mathrm{A}} \times 100 \quad (1)$$

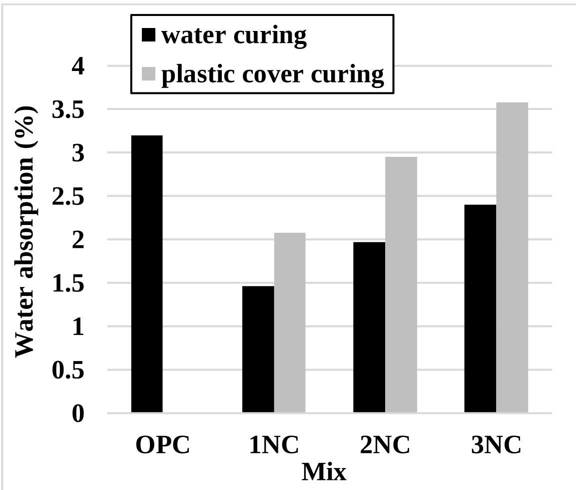

Fig. 12. Water absorption percentage.

Based on diagram in Fig. 12, water absorption is reduced by rise in nano clay percentage. The highest percentage of water absorption belongs to OPC sample (3.2%) under water curing conditions while the lowest percentage of water absorption is visible in 1NC sample (1.46%). It can be concluded from this test that water absorption rate is increased by rise of nano clay percentage but nonetheless these specimens include lower absorption rate than on OPC sample. In fact, water absorption percentage has been reduced in 1NC, 2NC and 3NC samples up to 54.3, 38.4 and 25% compared to OPC sample.

The derived results from water curing and plastic cover curing indicate that pure water has a better effect on reducing water absorption rate; for example, water absorption has been reduced 1.74% in 1NC sample treated by water curing and also water absorption has been decreased 0.87 under plastic cover curing conditions. Therefore, water absorption under plastic cover curing is almost 50% greater than under water curing. This function may be explained by this point that plastic cover curing does not allow chemical reactions to be completed. Therefore, as it is exposed to the water the specimen tries to absorb the water and to continue the reaction and this, in turn, leads to rising water absorption.

3.6. Relations

The linear relationship was written based on the results of compressive strength tests and water penetration depth and flexural strength test with water absorption percentage (Figs. 13 and 14). There is linear correlation with regression coefficient (0.98) among compressive strength and water penetration depth in Fig. 13. There is linear correlation among flexural strength and water absorption percentage with regression coefficient (0.98) in Fig. 14. This linear correlation shows that there is reverse relationship among compressive strength and water penetration depth as well as among flexural strength and water absorption percentage. Namely, water penetration depth and water absorption percentage are respectively reduced by increase in the rate of compressive strength and flexural strength. Due to having higher strengths than ordinary concrete, the concrete with nano clay content is less subject to crack caused by internal stress and this, in turn, leads to lower penetration in them. Following the rise of nano clay up to the 1% level and due to pozzolanic function, C-S-H gel is produced, thereby leading to filling pores in concrete and reducing penetration in concrete. Concrete penetration depth and water absorption are reduced by increase in nano clay percentage in concrete. It should be implied that all results of tests belong to specimen under water curing for 28 days.

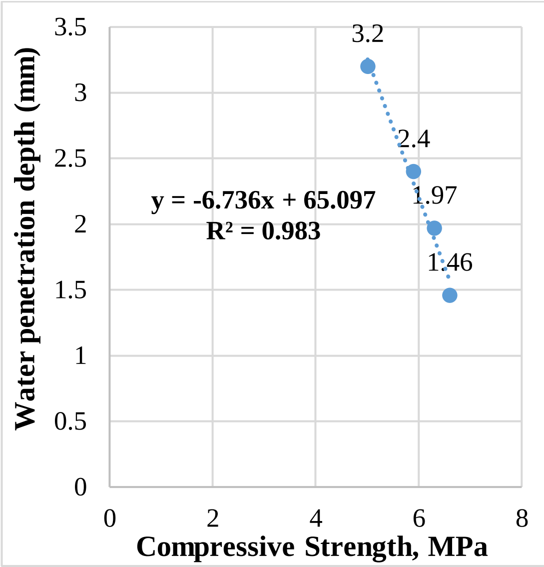

Fig. 13. Relationship between compressive strength and water penetration depth.

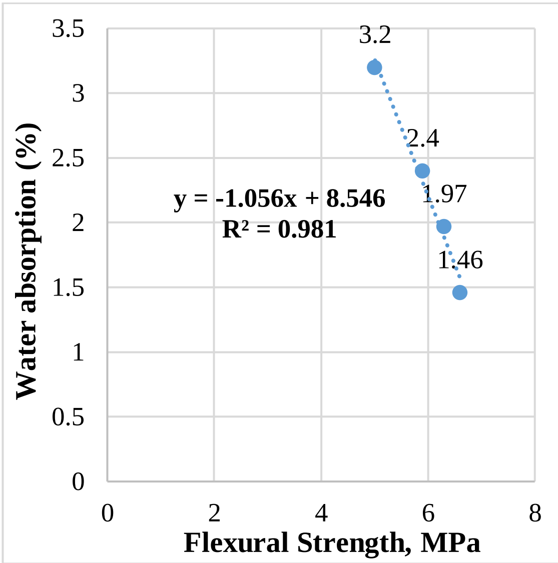

Fig. 14. Relationship between flexural strength and water absorption percentage.

4. Conclusions

The rate of increase of flexural and compressive strength is greater in samples with nanoparticle contents than in OPC specimen by adding nano clay. Two types of curing including water curing and plastic cover curing may affect compressive, flexural and tensile strengths, water penetration potential and water absorption. The foremost findings of the present research are as follows:

- The best mix design belongs to 1NC; by addition of nano clay up to 1% to specimens under water curing for 28 days, rates of compressive strength (35%), flexural strength (29%), and tensile strength (34%) were increased and penetration level (35%) and absorption percentage (54%) were reduced.

- Using nano clay increases compressive strength in the concrete and the compressive strength was increased in 1NC, 2NC and 3NC samples during 28 days respectively up to 35.6%, 28.5% and 21.3% while compressive strength was increased 33.2, 25.9 and 18.6% respectively in 90 days.
- Using nano clay has increased flexural strength in the concrete. Compressive strength was increased up to 31.7%, 25.7% and 17.7% in 1NC, 2NC and 3NC specimens for 28 days and at the same time compressive strength was increased 34.5, 28 and 18.1% respectively during 90 days.
- Use of nano clay increased tensile strength in the concrete. The compressive strength was increased in 1NC, 2NC and 3NC samples during 28 days respectively up to 34.8%, 30.2% and 18.6% and it increased respectively up to 38.6%, 31.8% and 19.3% within 90 days.
- The effect of curing is not significant on strength of concrete at age 28 days, but it significantly affects it during 90 days.
- Compressive, flexural and tensile strengths have been increased in 2NC and 3NC samples compared to OPC specimen, but reduction of compressive, flexural and tensile strengths and increase in penetration and absorption percentage have been seen in 1NC sample. The reason of this function can be justified by this point that the nanoparticles are agglomerated around cement aggregates by a rise in nano clay and this is led to partial hydration on cement aggregates and creation of hydrated products with weak bonds.
- Water penetration is reduced by increase in nano clay percentage in concrete. Compared to treating with plastic cover curing, as a specimen is under water curing, penetration rate is reduced further.
- Using nano clay may reduce water absorption percentage in concrete. The absorption percentage is decreased more as a sample is treated with water curing than under plastic cover curing.
- The penetration and water absorption percentage are lower in concrete under higher compressive and flexural strengths and as a result it obtains more durability.

References

[1] P. Balaguru, and K. Chong, "Nanotechnology and concrete: Research opportunities," in *Proceedings of the ACI Session on Nanotechnology of Concrete: Recent Developments and Future Perspectives*, 2006.

[2] N. Farzadnia, A. A. Ali, R. Ramazan, and M. P. Anvar, "Effect of halloysite nano clay on mechanical properties, thermal behavior and microstructure of cement mortars," Journal of Cement and Concrete Research, vol. 48, pp. 97-104, 2013.

[3] E. S. Bakhoum, G. L. K. Caras, M. E. Allam, and H. Ezz, "The role of nano-technology in sustainable construction: A case study of using nano granite waste particles in cement mortar," *Engineering Journal*, vol. 21, no. 4, pp. 217-227, 2017.

[4] W. C. Wang, S. Y. Wang, and C. H. Lin, "Effect of hot environment on strength and heat transfer Coefficient of Nano-Clay Concrete," *Journal of Materials Science and Chemical Engineering*, vol. 4, no. 7, pp. 749-757, 2016.

[5] J. Bernal, E. Reyes, J. Massana, N. Leon, and E. Sanchez, "Fresh and mechanical behavior of a self-compacting concrete with additions of nano-silica, silica fume and ternary mixtures," *Journal of Construction and Building Materials*, vol. 160, pp. 196-210, 2018.

[6] H. Li, M. H. Zhang, and J. P. Ou, "Flexural fatigue performance of concrete containing nano-particles for pavement," *Journal of Fatigue*, vol. 29, no. 7, pp. 1292-1301, 2007.

[7] H. Li, M. H. Zhang, and J. P. Ou, "Abrasion resistance of concrete containing nano-particles for pavement," *Journal of Wear*, vol. 260, no. 11, pp. 1262-1266, 2006.

[8] Y. Fan, S. Zhang, S. Kawashima, and S. P. Shah, "Influence of kaolinite clay on the chloride diffusion property of cement-based materials," *Journal of Cement and Concrete Composites*, vol. 45, pp. 117-124, 2014.

[9] A. Hakamy, F. Shaikh, and I. M. Low, "Characteristics of nano clay and calcined nano clay-cement nanocomposites," *Journal of Composites Part B: Engineering*, vol. 78, pp. 174-184, 2015.

[10] A. M. Mohamed, "Influence of nano materials on flexural behavior and compressive strength of concrete," *HBRC Journal*, vol. 12, no. 2, pp. 212-225, 2016.

[11] Y. F. Fan, S. Y. Zhang, and S. P. Shah, "Influence of nano clay on concrete subjected to freeze-thaw cycles and bond behavior between rebar and concrete," *Journal of Civil and Environmental Engineering*, vol. 711, no. 1, pp. 256-262, 2016.

[12] P. Hosseini, A. Afshar, B. Vafaei, A. Booshehrian, E. Molaei Raisi, and A. Esrafili, "Effects of nano-clay particles on the short-term properties of self-compacting concrete," *Journal of Environmental and Civil Engineering*, vol. 21, no. 2, pp. 127-147, 2017.

[13] A. M. Mirgozar langaroudi and Y. Mohammadi, "Effect of nano-clay on workability, mechanical, and durability properties of self-consolidating concrete containing mineral admixtures," *Journal of Construction and Building Materials*, vol. 191, pp. 619-634, 2018.

[14] Z. He, C. Xiaorun, and X. Cai, "Influence and mechanism of micro/nano-mineral admixtures on the abrasion resistance of concrete," *Journal of Construction and Building Materials*, vol. 197, no. 2, pp. 91-98, 2019.

[15] H. Assaedi, F. U. A. Shaikh, and I. M. Low, "Effect of nano-clay on mechanical and thermal properties

of geopolymer," *Journal of Construction and Building Materials*, vol. 4, no. 1, pp. 19-28, 2016.
[16] M. Irshidat and M. H. Alsalah, "Influence of nano clay on the properties and morphology of cement mortar," *Journal of KSCE Journal of Civil Engineering*, vol. 4, no. 1, pp. 1-8, 2018.
[17] W. C. Wang, "Compressive strength and thermal conductivity of concrete with nano clay under various high-temperatures," *Journal of Construction and Building Materials*, vol. 147, no. 1, pp. 305-311, 2017.
[18] M. S. Morsy, S. H. Alsayed, and M. Aqel, "Influence of nano clay on the properties and morphology of cement mortar," *Journal of Civil and Environmental Engineering*, vol. 10, no. 1, pp. 21-25, 2010.
[19] M. R. Irshidat and M. H. Al Salah, "Effect of elevated temperatures on mechanical performance of cement mortar with nano clay," *MATEC Web of Conferences, ASCMCES-17*, vol. 120, p. 02005, 2017.
[20] A. M. Rashad, "A synopsis about the effect of nano-Al_2O_3, nano-Fe_2O_3, nano-Fe_3O_4 and nano-clay on some properties of cementitious materials–A short guide for civil engineer," *Journal of Materials and Design*, vol. 52, pp. 143-157, 2013.
[21] M. Heikal and N. S. Ibrahim, "Hydration, microstructure and phase composition of composite cements containing nano-clay," *Journal of Construction and Building Materials*, vol. 112, pp. 19-27, 2016.
[22] *Standard Specification for Portland Cement, American Society for Testing and Materials*, West Conshocken, ASTM C150-04, 2016.
[23] *Standard Specification for Concrete Aggregates, American Standards for Testing and Materials*, West Conshocken, ASTM C33, 2003.
[24] *Standard Specification for Molds for Forming Concrete Test Cylinders Vertically*, 100 Barr Harbor Drive West Conshocken, ASTM C470, 2008.
[25] *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*, American Society for Testing and Materials, West Conshocken, ASTM C78, 2016.
[26] *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*, ASTM C496-96, 1996.
[27] *Standard Testing Hardened Concrete, Depth of Penetration of Water Under Pressure*, EN, DIN. 12390-3, 2009.
[28] *Standard Test Method for Density, Absorption, and Voids in Hardened Concrete*, Philadelphia, Pa: Annul Book of ASTM Standards, ASTM C642, 2009.

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