

The Effect of Nano Ceramic Powders On Mechanical and Physical Properties of Normal Concrete

Zainab Jawad Kadhim¹, Ahmed Raad Al-Adhadh², Dhay Ali sabur³

¹Department of Civil Engineering, Al-Mustaqbal University College, Babylon, Iraq

²Department of Civil Engineering, Engineering College, Al-Muthanna University, Al-Muthanna, Iraq

³Department of Physics Science, Al-Mustaqbal University College, Babylon, Iraq

ahmad_al_iraqi2000@yahoo.com

Abstract. Concrete is one of the most important materials used in construction. Properties of concrete can be improved using additives like nano-ceramics which acts as reinforced phase to raise the mechanical properties of concrete. Effect of nano-powder on some properties of concrete has been determined. In this study, two concrete mixes have been prepared, first one, by adding different contents of nano-ZrO₂, second using nano – Al₂O₃ powder. Properties of concrete have been studied through the compressive strength, Splitting tensile strength, workability and water absorption. Results showed that the slump reduced from 103 mm to 62 mm when 1.1% nano-zirconia added, the same behavior observed in mix that contain nano alumina powder. The compressive strength increases when nano-zirconia added, the maximum value of compressive strength obtained when 0.7% nano-zirconia added (45.3 MPa at 28 days, 48.3 MPa at 60 days and 52.3 MPa at 90 days). Moreover, splitting tensile strength was improved with increasing nano-zirconia content and the maximum values were at 0.7% of nano-zirconia, (5.2 MPa at 28 days ,6.6 MPa at 60 days and 8.2 MPa at 90 days), water absorption decreased when nano-zirconia percentage increased (0.12 % at 28 days and 0.1 % at 60 and 90 days). In this research, it is also observable that nano alumina powder has more influence for enhancing concrete properties than zirconia powder. Compressive strength and splitting tensile strength of concrete mix with nano alumina increased highly with increasing content of Al₂O₃ and reach its optimum value at 1.1 % of Al₂O₃ in NA6. Alumina powder has a high ability to diminish pores size and to increase density of concrete mixture; so, low permeability, low water absorption concrete produced.

1. Introduction

Concrete is the most important ingredient used in construction. Mechanical properties and durability of concrete is an essential issue nowadays. Properties of this concrete can improve by adding additives like nano-ceramic powders, which acts as reinforced phase to improve the properties of concrete.

Nano particles are the simple building block in nanotechnology science and are consist of up to thousands of atoms of 1 – 100 nm. Nano-technologies are developing with high rate, due to unique applications and using of nano-technology; there is interest in studying the effect of nano-ceramic powders on characterizations of hardened cement paste, cement mortar and concrete. There are few researches focused on utilization of nano powders with concrete and other construction materials. Shekariand and Razzaghi [1] investigated the effect of nano particles on performance and properties of high strength concrete. The nano materials he used to be nano ZrO₂, nano Fe₃O₄, nano TiO₂, nano Al₂O₃. Results reveal that Nano powders can be very successful in improvement of mechanical



properties and durability of concrete. Moreover, the Nano- Al_2O_3 contribution on enhancements the properties were more than other nano particles. Ali Nazari [2] studied the effect of nano alumina particles on mechanical properties of blended concrete, it has been concluded that the partial replacement of cement with nano alumina powder improved mechanical properties of concrete but decreased its workability. Konstantin Sobolev [3] reviewed the beneficial effects of the nano-particles for the enhancement of concrete properties and performance. Ali Nazari [4] has studied the compressive strength and workability of concrete by partial replacement of cement with nano Fe_2O_3 particles, the results showed that strength of concrete has been improved with incorporation of nano Fe_2O_3 particles up to maximum substitution percent of 2%. The workability of fresh concrete decreased with increasing nano particles content. Hui Li [5] studied the characterizations of mortar mixed with nano particles. Results of this study showed that the compressive and flexural strength of mortar mixed with nano particles at curing age of 7 days and 28 days were higher than that of plain cement mortar.

In this research, the influence of Nano – ZrO_2 and Nano – Al_2O_3 powders on properties of concrete through the compressive strength, splitting tensile strength, workability and water absorption experimentally investigated. For this purpose, different concentration of nano- ZrO_2 and Al_2O_3 such as 0.1, 0.3, 0.5, 0.7, 0.9 and 1% (wt. %) as partial replacement of cement has been added to concrete mix.

2. Materials and primary test methods

The physical and chemical properties of the materials used in this study are specified in this section. The materials used in this include ordinary Portland cement, coarse aggregate, fine aggregate, Nano – Powders and water. *A subsection*
Some text.

2.1. Cement

Ordinary Portland cement has is used in this study. Tables (1 and 2) show the physical and chemical properties of cement used in this study according to Iraqi Specification No.5 / 1984.

Table 1. Physical properties of O.P.C (according to IQS No. 5/1984).

Physical Properties	Test Results	IQS No. 5/1984
Setting Time (Vicat's Method)	103	≥ 45 min
	235	≤ 600 min
Fineness (Blaine Method), m^2/kg	310	≥ 230 m^2/Kg
Compressive Strength, MPa		
	3 days	≥ 15 MPa
7 days	26.9	≥ 23 MPa

Table 2. Chemical composition of O.P.C (according to IQS No. 5/1984).

Compound	Chemical Name	Test Results %	IQS No. 5/1984
Lime	CaO %	60.14	-
Silica	SiO_2 %	19.77	-
Alumina	Al_2O_3 %	4.38	-
Iron Oxide	Fe_2O_3 %	5.20	-
Sulphate	SO_3 %	2.15	≤ 2.8
Magnesia	MgO %	1.71	≤ 5
Free Lime	Free CaO %	1.12	-
Loss On Ignition	L.O.I. %	3.19	≤ 4
Insoluble Residue	I.R. %	1.23	1.5
Lime Saturation	L.S.F.	0.95	0.66 – 1.02
Main Compounds	Percent by weight of cement		

Tricalcium Silicate	C ₃ S	57.47	-
Dicalcium Silicate	C ₂ S	12.55	-
Tricalcium Aluminates	C ₃ A	6.06	-
TetracalciumAlumino Ferrite	C ₄ AF	10.83	-

2.2. Coarse aggregate (Gravel)

Aggregate of 20 mm maximum size and 2.65 specific gravity were used in this study. It was brought from AL- Nibai quarry. Grading of aggregate has been determined regarding the Iraqi Standard No. 45/1984. Physical and chemical Properties of coarse aggregate are shown in table 3. Figure 1 shows the Grain size distribution curve of the coarse aggregate.

2.3. Fine aggregate (Sand)

Natural sand used with maximum size of 5 mm. It was brought from Al-Ukhaider quarry. Table 4 shows the chemical and physical properties of sand which conforms to Iraqi Specification No.45/1984. Figure 2 demonstrates. Grain-size distribution curve of sand.

Table 3. Physical and Chemical Properties of Coarse Aggregate (according to IQS No.45/1984).

Physical Properties	Test Results	IQS No. 45/1984 for Zone II
Specific Gravity	2.65	-
Sulfate Content	0.10 %	≤ 0.1 %
Absorption	0.5 %	-
Clay Content	0.14 %	≤ 3 %

Table 4. Chemical and Physical Properties of the sand (according IQS No. 45/1984).

Properties	Test Results	IQS No. 45/1984 for Zone II
Specific Gravity	2.60	-
(SO₃) %	0.28	≤ 0.5 %
Absorption %	0.75	-
Clay Content %	3.67	≤ 5 %

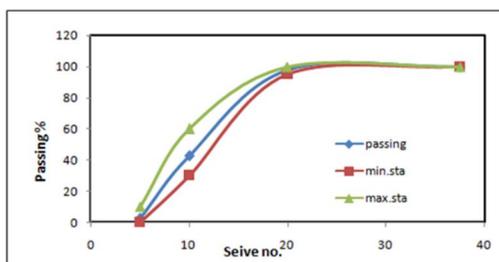


Figure 1. Grain-size distribution curve of Coarse Aggregate.

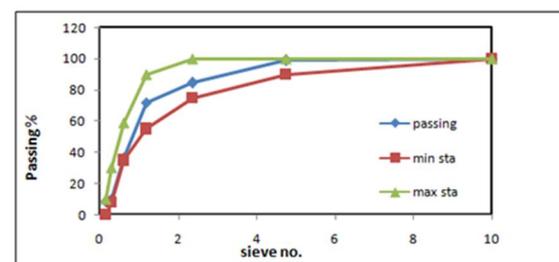


Figure 2. Grain-size distribution curve of Fine Aggregate.

2.4. Nano-Powders

Two types of nano-materials are used in this study, Nano-Zirconia and Nano-Alumina. These materials are used as a form of nano powder.

2.4.1. Nano-Zirconia powder. Nano Zirconia powder manufactured by (SIGMA Company) has been used in this study. Table 5 illustrates the purity of this powder.

2.4.2. Nano-Alumina powder. In this study, fine, very pure alumina (> 99 %) was used. Manufacturing company tested the properties of powder and the results of tests are shown in table 6.

Table 5. Chemical composition of zirconia nano-powder.

ZrO ₂	Al	Pb	Fe
> 99.9%	< 0.07%	< 0.02%	< 0.01%

Table 6. Characters of alumina nano-powder.

Phase	Purity %	Average Size (nm)	Surface area (cm ² /g)	Density Cm ³ /g
γ	99.95	< 170	13.5	0.4 – 0.5

2.5. Mixing water

In this study, portable water was used for mixing and curing.

3. Concrete Mixture

Series of NZ and NA mixtures were prepared using various percentages of nano powders. Content of Nano ceramic powders within each sample was (0, 0.1%, 0.3%, 0.5%, 0.7%, 0.9% and 1.1% by weight of cement) for both alumina and zirconia powder as shown in table 7.

Table 7. Mix proportions of concrete specimens.

Zirconia Samples				Alumina Samples			
Samples	Nano Zirconia %	W/C	Cement Kg/m ³	Samples	Nano Alumina %	W/C	Cement Kg/m ³
C0	0	0.5	580	C0	0	0.5	580
NZ1	0.1	0.5	579.42	NA1	0.1	0.5	579.42
NZ2	0.3	0.5	578.26	NA2	0.3	0.5	578.26
NZ3	0.5	0.5	577.1	NA3	0.5	0.5	577.1
NZ4	0.7	0.5	575.94	NA4	0.7	0.5	575.94
NZ5	0.9	0.5	574.78	NA5	0.9	0.5	574.78
NZ6	1.1	0.5	573.62	NA6	1.1	0.5	573.62

4. Methodology

To study the effect of nano-ceramic powders on properties of concrete, concrete samples were prepared with selective mix proportions of 1:1.5:2.5 by weight and water / cement ratio of 0.5. Fresh concrete Specimens with dimensions of (150*150*150 mm) cubes were prepared in order to evaluate the compressive strength. Moreover, samples with dimensions of (300*150 mm cylinder) are prepared for testing the splitting tensile strength. All specimens were cured for 28, 60 and 90 days using portable water at room temperatures.

4.1. Compressive strength test

Compressive strength tests were carried out according to B.S 1881 part 116: 1983 [6]. All cubes were tested using a hydraulic compressive machine of 2000kN (ELE digital testing machine). All specimens were cured in water until testing age is up. The compressive strength value was taken to be an average value of three tests.

4.2. Splitting Tensile Strength

The splitting tensile strength was resolute according to the procedure outlined in BS 1881 part 117:1983 [7]. Cylinders were cast, molded and cured in a similar way as the cubes. Each value was average of three specimens for each age.

4.3. Water absorption

This test was performing on three samples of each mixture according to BS 1881 part 122:1983 [8].

4.4. Workability

Slump, compacting factor and V-B test were performed on fresh concrete according to BS 1881 part 2:1970 [9].

5. Results and Discussion

All the tests results are presented in this section. The results contain the effect of nano ceramic powder on the workability of concrete mix, compressive and tensile strength, and finally water absorption results.

5.1. Workability Results

Workability of control fresh concrete (without additives) and of these samples containing different percentages of Nano Zirconia and Nano Alumina powders are shown in table 8. Workability of Control concrete (C0), NZ and NA series concrete are shown in figure. 3. Results demonstrate that control concrete samples have high slump value (110mm). It can be clearly noticed that workability decreases as the nano ceramic powder, Nano Zirconia and Nano Alumina, increases. This might be relevant to the concept that explains how fine materials increase bonding between cement paste and aggregate to provide adequate workability without segregation [4]. On the other hand, increasing of nano powders concentration leads to high surface area mixture and consequently increased water requirements which necessary for wetting the surface of cement particles [2, 3], for this reason, slump values decreased with increasing nano powders content as water-cement ratio is constant which is 0.5.

Compacting factor and V-B value are within acceptable range, indicating that fresh concrete was flow easily and at the same time liberated from segregation as indicated in table 10.

Table 8. Workability of concrete specimens.

Zirconia Samples				Alumina Samples			
Samples	Slump (mm)	Compacting Factor %	V – B test (second)	Samples	Slump (mm)	Compacting Factor %	V – B test (second)
C0	110	0.78	10.2	C0	110	0.78	10.2
NZ1	101	0.84	8.5	NA1	106	0.84	9.5
NZ2	100	0.86	8.1	NA2	102	0.87	8.8
NZ3	95	0.89	7.5	NA3	98	0.92	8.4
NZ4	93	0.94	7.3	NA4	95	0.95	8.1
NZ5	89	0.90	7.1	NA5	90	0.96	7.7
NZ6	62	0.85	7.0	NA6	65	0.96	7.3

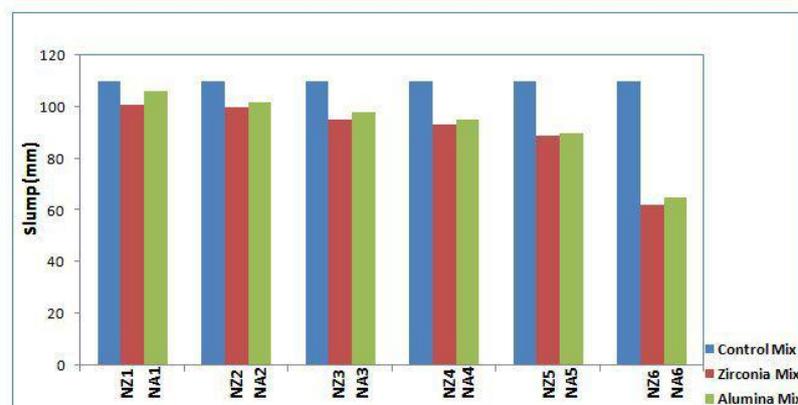


Figure 3. Slump of investigated specimens.

5.2. Strength Results

5.2.1. Compressive strength. Compressive strength of control concrete and samples that contain Nano powders after 28, 60 and 90 days are indicated in tables 9 and 10. Figure 4 illustrates that compressive strength of concrete samples that contain nano zirconia and nano alumina powders at age of 28 days. Compressive strength of NZ series increases as the percentage of Nano ZrO_2 powder increases up to 0.7% and then it starts to fall down slightly with (0.9 and 1.1 %) but still higher than that of control samples. Therefore, the optimum percentage ZrO_2 to reach maximum compressive strength of concrete is 0.7%. On the other hand, For NA series, compressive strength increases as the content of Al_2O_3 increases and there is no optimum percentage of Al_2O_3 to reach maximum compressive strength conversely to the effect of ZrO_2 .

Figure 5 and 6 reveal the compressive strength of NZ and NA series at curing age of 60 and 90 days respectively. At age of 60 and 90 days NZ and NA series follow the same behavior that at 28 days. As observed from figure 4, 5 and 6, Nano alumina powder more effective in enhancing the strength of normal concrete than nano zirconia powder.

High enhancement in compressive strength has been attributed to high activity of Nano powder which accelerate the hydration reactions of cement and lead to form large quantities of hydration products (high gel volume) and consequence, consuming of $Ca(OH)_2$ that formed at early ages of the hydration process [10]. Also, Nano powder responsible about increasing the packing density to cement paste due to its tiny particles size, which act as filler materials, and then decrease the porosity and pores volume in hydrated cement paste. Maximum strength of concrete samples is related with workability and this can only obtain when the fresh concrete has adequate degree of workability because of ability on self-compacting [11-13].

Table 9. The effect of nano Zirconia on the compressive and tensile strength of concrete.

Zirconia Samples	Compressive Strength (MPa)			Splitting Tensile Strength (MPa)		
	28 days	60days	90days	28 days	60days	90days
C0	33.3	38.5	41.3	4.1	5.5	6.2
NZ1	41.3	45.4	47.7	4.3	6.1	6.5
NZ2	42.1	45.8	48.4	5.1	6.5	7.5
NZ3	43.8	46.6	49.2	5.6	6.8	7.6
NZ4	45.3	48.3	52.3	6.5	7.3	8.2
NZ5	42.5	47.5	49.4	6.1	6.8	7.8
NZ6	42.1	47.1	48.6	5.7	6.3	7.4

Table 10. The effect of nano Alumina on the compressive and tensile strength of concrete.

Alumina Samples	Compressive Strength (MPa)			Splitting Tensile Strength (MPa)		
	28 days	60days	90days	28 days	60days	90days
C0	33.3	38.5	41.3	4.1	5.5	6.2
NA1	42.5	45.7	48.5	4.8	6.7	6.8
NA2	43.6	46.2	49.1	5.6	7.2	7.5
NA3	44.2	46.8	49.6	6.2	7.7	8.3
NA4	46.2	48.7	52.4	6.8	8.1	8.8
NA5	47.1	49.2	52.8	7.1	8.7	9.2
NA6	47.7	49.6	53.2	8.2	9.3	9.7

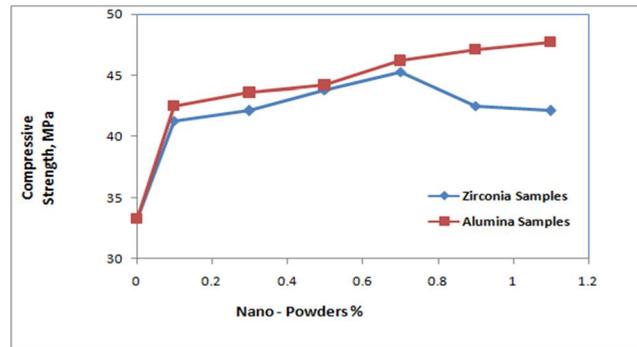


Figure 4. Compressive strength for concrete samples with Nano Al_2O_3 and ZrO_2 at 28 days.

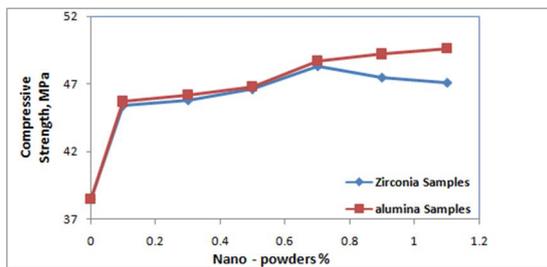


Figure 5. Compressive strength for concrete with Nano Al_2O_3 and ZrO_2 at 60 days.

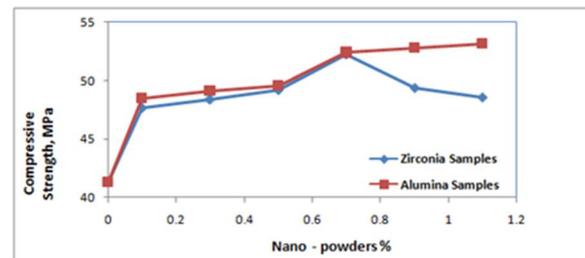


Figure 6. Compressive strength for concrete samples with Nano Al_2O_3 and ZrO_2 at 90 days.

5.2.2. Splitting tensile strength. Tensile strength of control concrete and samples that contain Nano powders after 28, 60 and 90 days are demonstrated in table 9 and 10. Figure 7 shows splitting tensile strength for concrete mixes that contain nano zirconia and nano alumina powders at age of 28 days. Tensile strength follows same behavior as compressive strength. Splitting tensile strength developed in specimens containing Nano ZrO_2 powder higher than that of control specimen and increased with increasing Nano ZrO_2 powder concentration up to 0.7% and then it falls down slightly with (0.9 and 1.1 %) at all ages but still higher than that of control samples. Figure 8 and 9 illustrate the tensile strength of NZ and NA series at curing age of 60 and 90 days respectively.

At all ages and for each case, tensile strength of NA series follow the same behavior as compressive strength. It can be seen that the effect of nano alumina powder in enhancement of splitting tensile strength of concrete is more than the effect of nano zirconia powder. High enhancement in mechanical properties achieved by nano alumina powder might be attributed to the reaction of nano alumina with hydrated lime to form hydrated calcium aluminate (one of hydration products), which consequently fills the capillary pores between hydrated cement paste and aggregate. This may lead to increase the densification of interfacial zones between concrete components [12, 13]; so, the density increases and both compressive and splitting tensile strengths increases higher than that in case of using nano zirconia powder.

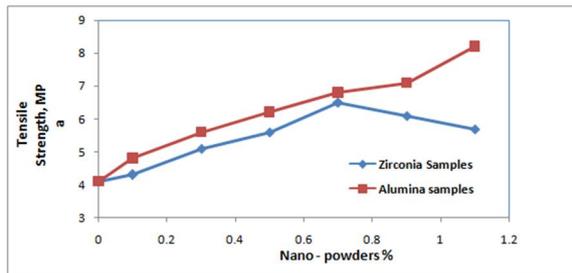


Figure 7. Splitting tensile strength for concrete Samples with Nano Al_2O_3 and ZrO_2 at 28 days.

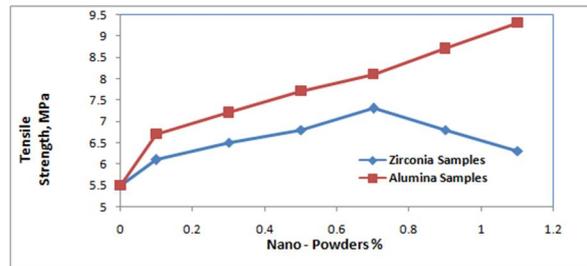


Figure 8. Splitting tensile strength for concrete with Nano Al_2O_3 and ZrO_2 at 60 days.

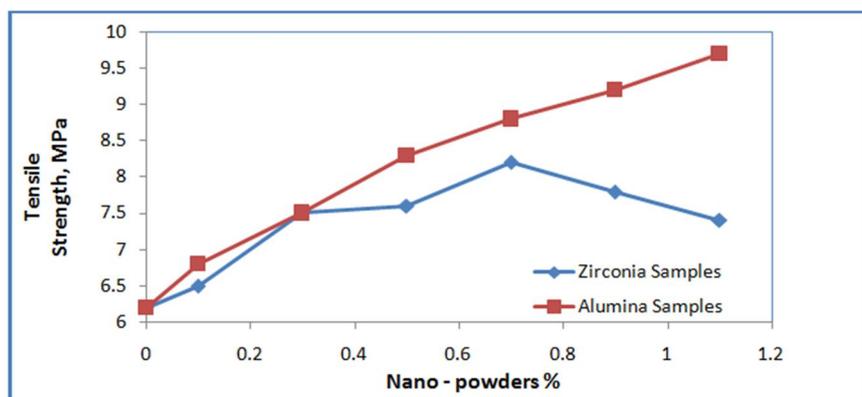


Figure 9. Splitting tensile strength for concrete samples with Nano Al_2O_3 and ZrO_2 at 90 days.

5.3. Water absorption result

Values of water absorption (in percent) for control concrete and samples that contain Nano powder at age of 28, 60 and 90 days are indicated in table 11. As illustrated in figure 10, 11 and 12, the water absorption percent decrease with increasing the concentration of nano powder at all ages and for all specimens. This behavior attributed to decreasing the volume of pores and spacing between particles in cement paste after addition of Nano powder [10, 11].

Table 11. The effect of nano powder on the concrete water absorption.

Samples	Zirconia samples			Alumina Samples			
	28 days	60days	90days	Samples	28 days	60days	90days
C0	0.48	0.42	0.38	C0	0.48	0.42	0.38
NZ1	0.42	0.35	0.29	NA1	0.39	0.34	0.28
NZ2	0.38	0.30	0.25	NA2	0.30	0.25	0.22
NZ3	0.32	0.28	0.21	NA3	0.28	0.23	0.19
NZ4	0.17	0.15	0.12	NA4	0.19	0.14	0.12
NZ5	0.14	0.13	0.09	NA5	0.13	0.11	0.08
NZ6	0.11	0.09	0.07	NA6	0.11	0.06	0.04

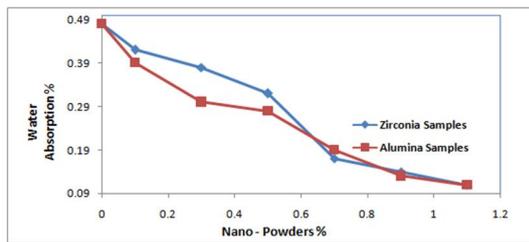


Figure 10. Water absorption for concrete with Nano Al_2O_3 and ZrO_2 at 28 days.

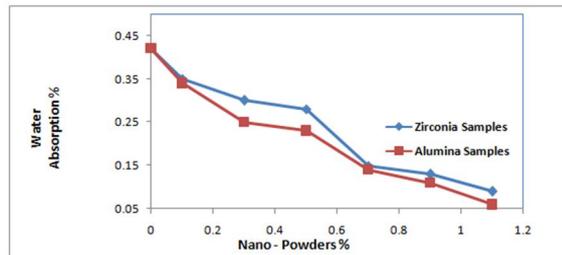


Figure 11. Water absorption for concrete samples with Nano Al_2O_3 and ZrO_2 at 60 days.

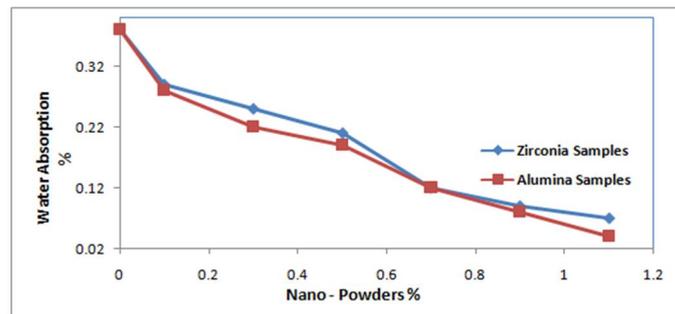


Figure 12. Water absorption for concrete samples with Nano Al_2O_3 and ZrO_2 at 90 days.

6. Conclusions

- Results show that all of concrete samples, which contain nano powder, have significantly higher splitting tensile strength and compressive strength, less workability and water absorption as compare to that of concrete without nano ceramic powder.
 - Slump of fresh concrete decreased from 110 mm to 62 mm when zirconia content increased from 0.0 % to 1.1 % in NZ series, while in NA series it is decreased from 110 mm to 65 mm, this attributed to high surface area of nano powders which cause increasing water requirements at constant W/C.
 - Compressive strength of NZ series increased with increasing Nano ZrO_2 powder percent up to 0.7% in NZ4 of 52.3 MPa, and then it is decreased with (0.9 and 1.1 %) in NZ5 and NZ6.
 - Splitting tensile strength developed in specimens containing Nano ZrO_2 powder higher than that of control specimen and increased with increasing Nano ZrO_2 powder concentration up to 0.7% in NZ4, which equal to 8.2 MPa and then it is decreased slightly with 0.9 and 1.1 % at all ages but still higher than that of control samples.
 - Optimum percentage of ZrO_2 to reach maximum compressive strength and splitting tensile strength of concrete is 0.7%.
 - For NA series that contain nano alumina powder, compressive strength and tensile strength increases linearly with increasing content of Al_2O_3 and have no optimum percentage to reach maximum value of strength.
 - Tensile strength of NA series followed the same behavior as compressive strength.
 - Low pores volume and small spacing between particles in cement paste after addition of Nano powder result in low permeability, low water absorption concrete mixes for both NZ and NA series.

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