Modification of mechanical properties of cement mortar by adding zinc oxide nanoparticles

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Abstract: In this paper, the flexural and compressive strength of mortar by partial replacement of cement with Nano-ZnO particles has been studied. ZnO nanoparticles with average diameter of 20 nm were used with four different contents of 0.25%, 0.75%, 1.25% and 1.75% by weight. The flexural and compressive strength tests were done after curing at the ages of 7-days as early age, 28-days as standard age. The Nano-cement mortar was prepared using cement-sand ratio of 1:3 by weight with water-binder ratio (w/b ratio) as 0.5. The results showed that the flexural and compressive strength of the cement mortars with ZnO were higher than pure cement mortar. The ultimate strength of Nano-cement mortar was gained at 1.25% of cement replacement. The enhancement in flexural and compressive strength were 19.6 % and 28.67% respectively at 28 days.

1. Introduction & Literature Survey:

Concrete is by far the most widely used construction material worldwide. Lately, various efforts were exerted to improve the environmental friendliness of concrete to make it suitable as a Green Building material. Foremost and most successful in this regard is the use of suitable substitutes for Portland cement [1].

To reduce the environmental pollution created by cement industries, the usage of cement must be limited that automatically controls the manufacture of cement. Supplementary cementitious materials are those which are added to concrete as a part of the total cementitious system to reduce the total quantity of cement to be used and most significantly to increase the strength of concrete from its normal to high strength [2].

Finer particles are being used in construction industry in recent years. Several works were performed on use of nanoparticles in concrete specimens as mineral admixtures to improve physical and mechanical properties [3]. Hui et al. (2003) [4] explored the characteristics of cement mortars mixed with nanoparticles to discover their super mechanical and smart (temperature and strain sensing) potentials. Nevertheless, until now, research prepared over the years has been mostly targeted at reaching high mechanical performance with cement replacement materials in micro level. Porro et al. (2005) [5] refers to the use of nano-silica particles as increasing the compression strength of cement pastes. Sobolev et al. (2008) [6] reported that the addition of nano-silica produced an increase in strength of 15–20%. Konsta-Gdoutos et al. (2010) [7] studied the effect of carbon nano-fibers on cement pastes (0.08% by binder mass) and observed an increase in strength.

Nazari and Riahi (2011) [8] used ZrO_2 nanoparticles with an average particle size of 15 nm and reported an improvement in the flexural strength of self-compacting concrete up to 4%. Increasing the nanoparticle content caused a reduction in flexural strength because of the inadequate dispersion of nanoparticles within the concrete matrix. According to Zhang and Li (2011) [9], the pore structure of concrete containing nano-TiO_2 is finer than that of concrete containing the same amount of nano-SiO_2.

The most significant issue in the use of nanoparticles is that of effective dispersion. Nochaiya and Chaipanich (2011) [10] also found that homogeneous dispersion can be obtained if nanoparticles are mixed with water and then subjected to ultrasound for one hour. Metaxa et al. (2012) [11] developed an ultracentrifugation concentration process for the production of highly concentrated suspensions of carbon nanotubes.

In this study, the effects of ZnO nanoparticles on compressive and flexural strength of mortar has been studies. The Nano-materials interact with calcium hydroxide generated from the hydration of calcium silicates. The rate of the pozzolanic reaction is proportional to the amount of surface area available for reaction. So, it is conceivable to add ZnO nanoparticles of a high purity (99.9%) and a high Blaine fineness value (60 m2/g) so as to enhance the properties of cement mortars [12].

In this work an attempt has been made to prove that using new materials, it is possible to obtain high performance concrete (HPC) or high strength concrete (HSC) with slight increase in cost. Because of its ability to reduce the cross-sectional area of the structural fundamentals, HPC and HSC are widely used in constructions and multistory buildings.

2. Materials and mixture:

2.1. Materials:

2.1.1. Nano-ZnO particles

Nano—ZnO with average particle size of 20 nm obtained from (NANOSHEL-INTELLIGEN MATERIALS PVT. LTD) company/USA, was used as received. Table 1 shown the properties of nano-ZnO particles.

Name	Zinc Oxide Nano powder
Chemical composition	ZnO
Particle size	22-35nm
pH	6.8
Appearance	White powder
Specific surface area(m^2/g)	21-30
Purity	>99.9%
Stability	Completely stable
Reactivity	Non-reactive

Table (1): The properties of nano-ZnO

2.1.2. Cement

The cement used in this study is Ordinary Portland Cement (OPC) type I commercially known (MASS) manufactured in Al-Sulaimaniya, Iraq. Chemical and physical analysis where conducted by National Center for Laboratories and Construction Research, test results indicate that the MASS OPC complying with the Iraqi standard specification (L.O.I.S.) No. 5 / 1984 . The chemical composition and physical properties of MASS OPC are shown in Table 2.

Table (2): Chemical Composition and physical properties of MASS OPC.

Item	**% by weight**	**Spec. Limit according to (L.O.I.S) No.5:1984**
SiO_2	19.5	-
Fe_2O_3	3.8	-
CaO	61.34	-
MgO	2.25	<5.00
Al_2O_3	4.79	-
SO_3	1.33	<2.80
Loss on ignition(L.O.I.)	1.41	<4.00
Time saturation factor(T.S.F.)	0.86	0.66 — 1.02
Insoluble residue(I.R.)	0.98	<1.50
Physical Properties	Test result	
Fineness (cm^2/g) by Blaine method	2731	>2300
Compressive strength for cement mortar cube (70.7)mm at, MPa 3 days 7 days	17.15 24.54	>15 >23
Setting time (Vicat´s method) Initial setting(min) Final setting(min)	148 275	>45 min <10 hrs.
Soundness using Auto clave%	0.25	<0.8

2.1.3. Aggregate

Locally available AL—Ukhaidher, Karbalaa, Iraq, natural sand with dimeter less than 4.75 mm is used in this study which has fineness modulus (F.M.) of (2.60), bulk specific gravity (S.G.) of (2.58) and sulfate content, (SO_3%) of (0.09%) by sand weight , which is conform the limit of Iraqi standard specification No. 45 / 1984.

2.2. Mixture:

Two main kinds of mixtures were prepared in the laboratory trials. First kind CM mixtures were prepared as control specimens. The control mixtures (CM0) were made of sand, cement and water (without Nano materials). Second kind NM mixtures were prepared with different contents of nano-ZnO particles with average particle size of 20 nm. The mixtures were prepared with the cement replacement of 0.25%, 0.75%, 1.25% and 1.75% by weight. For all mixtures the ratio of sand to cement was set at (3:1), and the water to binder ratio was set at (0.5). The proportions of the mixtures are presented in Table 3.

Table (3): shows the details of mixtures

Name of group	**Cement%**	**Nano** ZnO**%**	**(water/cement) ratio**	**(sand/cement) ratio**
CM0	100	0	0.5	3:1
NM1	99.75	0.25	0.5	3:1
NM2	99.25	0.75	0.5	3:1
NM3	98.75	1.25	0.5	3:1

NM4	98.25	1.75	0.5	3:1

3. Preparation of test specimens:

3.1. Procedure of work:

Preparation of mixtures was performed in way comparable to ASTM C 305-12 [13] with some variants:

1. Weighing components, by used sensitive digital balance of 0.01gm and for nano-ZnO other one of 0.0001gm digits.

2. If the mixture did not contained Nano-particles, cement and sand mixed manually until they reached a homogeneous appearance and then accommodated within the electrical mixer together with water and finally mechanical mixing for 3 min.

3. If the mixture contained Nano-particles, ZnO added to 95% of the total water of the mixture and mixed by hand for 5 minutes. Then this whole was submitted to the sonication for 20 minutes to obtain a dispersion of nano-ZnO and a better homogenization of the mixture [14]. For this purpose, was used the ultrasonic wave bath machine (Power Sonic 410) model (LUC) (220 V, 50 Hz, 400 W).

4. The cement and sand (previously mixed) accommodated within the mixer together with the mixture of the water and nano-ZnO.

5. After mixing for 60 sec. 5% of water slowly added and continue mixing for another 30 sec.

6. After stopping the mixer, it remained in rest for 90 sec, and then mixed for 90 sec.

7. The mortar was removed from the mixer and poured into clean oiled molds. The densification of the samples was made in two layers on a vibrating table, where each layer was vibrated for 10sec [15]. The surface finish of the samples was performed with the aid of a spatula.

8. After molding, the molds were covered with plastic sheets to preserve their moisture and the specimens were kept for 24 hours in laboratory, the temperature was about (23±1 C^{O}).

9. Then the specimens were demolded and cured in water where they were kept until the testing ages.

3.2. Compressive strength specimens:

The compressive strength test was performed according to ASTM C109-02 [16]. The compressive strength for each mixture was determined from an average of three cubic specimens (50 × 50 × 50) mm tested at the age of 28 days of curing.

3.3. Flexural strength specimens:

The flexural strength test was performed according to ASTM C 293-03 [17]. The flexural strength for each mixture was determined from an average of three prism specimens (160 × 40 × 40) mm tested at the age of 28 days of curing.

Compressive test and flexural test was performed by using Universal Mechanical test machine, TINIUS OISEN H50KT for Tensile, Compression and Flexural (Bending) strength tests in Material Testing Laboratory at Materials Engineering Department / Mustansirya University.

4. Results and Discussion:

4.1. Mechanical properties:

All the values are the average of the three trails in each case in the testing program of this study. The results are discussed as follows.

4.1.1. Compressive strength

The compressive strength results of all mixtures are shown in Table 4. Comparison of the results for 28 days specimens shows that the increase in compressive strength with nano-ZnO particles reach to top at 1.25% replacement (NM3) and then it drop, although the compressive strength of 1.75% replacement (NM4) is still higher than those of the ordinary cement mortar (CM0).The reduction of compressive strength with increase in amount of nano-ZnO particles at NM4, maybe because of bad distribution of nano-ZnO particles that causes weak regions. Also, perhaps due to the fact that the amount of nano-ZnO particles existent in the blend is more than the quantity required to combine with the liberated lime during the hydration process thus resulting to two things one is spare silica leaching out and the other is causing a lack in strength as it replaces part of the cementitious material but does not contribute to strength.

The fast consuming of $Ca(OH)_2$ which was formed during hydration of Portland cement is the main reason to occurring high increase in compressive strength of the NM mixtures particularly at early ages related to the high reactivity of nano-ZnO particles. As a result, the hydration of cement is quicker and greater volumes of reaction products are made. Also nano-ZnO particles recover the particle packing density of the blended cement, directing to a reduced volume of larger pores in the cement paste.

Table (4): Results of the compressive strength

Name	ZnO **%**	**28 days (MPa)**	**Enhanced extent (%)**
CM0	0	28.14	-
NM1	0.25	32.45	15.3
NM2	0.75	33.29	18.3
NM3	1.25	34.03	20.9
NM4	1.75	31.41	11.6

4.1.2. Flexural strength

The flexural strength results of series CM0 and NM mixtures are shown in Table 5. Similar to the compressive strength, the flexural strength of the specimens increases with nano-ZnO particles up to 1.25% replacement (NM3) and then it decreases, although the results of 1.75% replacement (NM4) is still higher than those of the ordinary cement mortar (CM0). Again, the increasing in the flexural strength is due to the rapid consuming of $Ca(OH)_2$ which was formed during hydration of Portland cement specially at early ages related to the high reactivity of nano-ZnO particles.

Table (5): Results of the flexural strength

Name	ZnO **%**	**28 days (MPa)**	**Enhanced extent (%)**
CM0	0	5.2	-
NM1	0.25	5.8	11.5
NM2	0.75	6.1	17.3
NM3	1.25	6.3	21.1
NM4	1.75	5.6	7.6

5. Conclusion:

With respect to the experimental results of compressive and flexural strength it is funded that:

1. Adding of ZnO nanoparticles up to 1.25% by weight of cement can act as a filler for strengthening

the micro structure of cement.

2. With the increase of nanoparticles quantity up to 1.75% then decrease the mechanical properties over all because decrease in nanoparticles distance and $Ca(OH)_2$ crystal due to limited space cannot grow to appropriate size.

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