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Investigation the Effect of Different Nano Materials on the Compressive Strength of Cement Mortar

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Abstract. In the present study, the compressive strength assessments of cement mortar containing different amounts of ZrO2, SiO_2, Al_2O_3 and $CaCO_3$ nanoparticles have been investigated. Four different contents for each nanoparticles type were utilized as a partial replacement of cement 1%, 1.5%, 3% and 5% by the cement weight. The compressive strength was estimated for two ages (7) and (28) days. The end results manifested that the specimens' compressive strength enhanced via the addition of the nanoparticles of ZrO_2 and SiO_2 to the paste of cement till 3.0% and then decreased but remained greater than the reference mix. While, the compressive strength of specimens enhanced via the addition of the nanoparticles of Al_2O_3 and $CaCO_3$ ZrO2 up to 5%. Maximum compressive strength recorded was 42.5 MPa for mixes with 3% nano SiO_2 followed by 38 MPa, 37 MPa and 33.5 MPa for mixes with 4% nano Al_2O_3, 3% nano and ZrO2 and 4% nano $CaCO_3$, respectively.

INTRODUCTION

Mortars and concretes are cementitious composites whose physical and mechanical properties are affected by each material in their constitution, such as the cementing agent, the fine and/or coarse aggregates, and the water. In construction industry, mortar is the raw materials blend, the binder component, such as cement or lime, water, and sand, which form a paste that hardens during the process and hydration kinetics [1]. The characteristics of mortar constituents modify, in a different way, the structure of the mixture from workability to performance in the use phase.

Cement mortar has a low strength and durability, so it is ineffectively used for aggressive environment, such as chemical industries, offshore structures, power plants etc. To overcome the above downsides, nanoparticles are added. The construction region burdens products, such as steel, cement, paints, window glass, insulation materials, and so on. Nano materials are incorporated into those products to improve their properties or to develop new functionalities [2]. Nanotechnology is the extreme effective research area and development activity that has been growing explosively worldwide in the past few years. Nanoparticle belongs to the promising materials in the civil engineering field. The principal aim of the present study is to establish a blended mortar having higher mechanical properties.

Ali Nazari et, al 2010 investigated the influence of adding ZrO_2 nanoparticles. Results manifested that both strength and resistance to water permeability enhanced via the addition of nanoparticles of ZrO_2 to the paste of cement till 4.0 wt. (%) [3]. Mingli Cao et al. 2019 found that the Nano-calcium carbonate also possesses both chemical and physical influences upon the cementitious composites characteristics, and such influences conduct even more influentially than the ones for the micro-calcium carbonate so it makes a remarkable enhancement on the cement blended mechanical properties [4]. Ehsan Mohseni et al. 2016 examined the impact of adding nano alumina on the mortar structure and compressive strength, this investigation depicted that with the addition of nanoparticles

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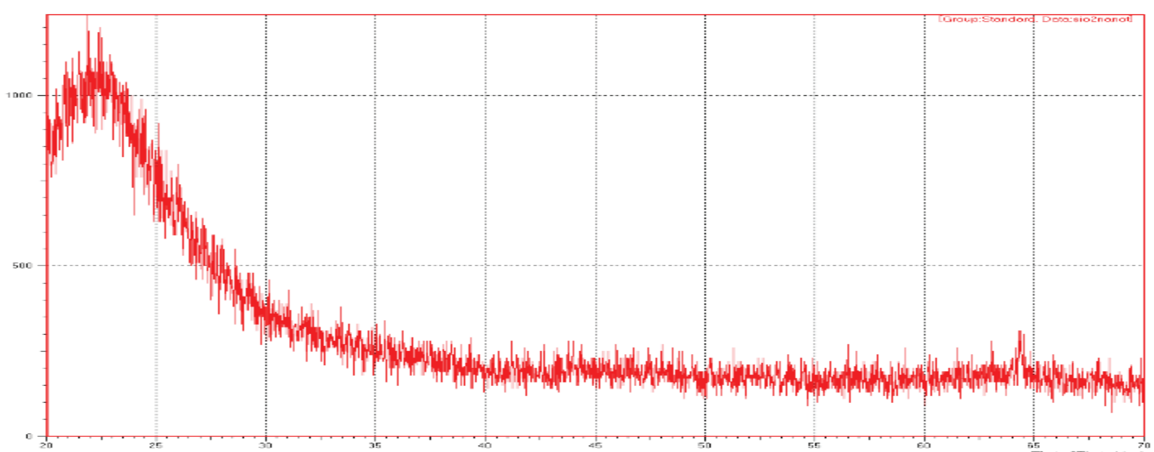
up to 3%, an enhancement in the compressive strength was visible, also the pore structure was enhanced [5]. Yu So et.al 2016 examined the effects of (nano-$CaCO_3$), (nano-SiO_2), (nano-TiO_2) and (nano-Al_2O_3) on the compressive stress, and the maximum enhancement was found in the mixes with (nano-$CaCO_3$), (nano-SiO_2), flowed by the mixes with (nano-Al_2O_3) and (nano-TiO_2), respectively [6].

Used Materials

Commercially available, the Iraqi ordinary Portland cement (Type I), called Karasta, was tilized in the current investigation. The chemical and physical properties that are listed in Table 1 indicate that this type of cement is in conformity to the Iraqi specifications (I.Q.S.) No. 5/1984 [7]. Nano SiO_2, nano Al_2O_3 nano ZrO_2 and nano $CaCO_3$ were employed as cement replacement in the present study. Figure (1) depicts the (XRD) spectra for every admixture, whereas figure (2) reveals the nanoparticles particle size analysis.

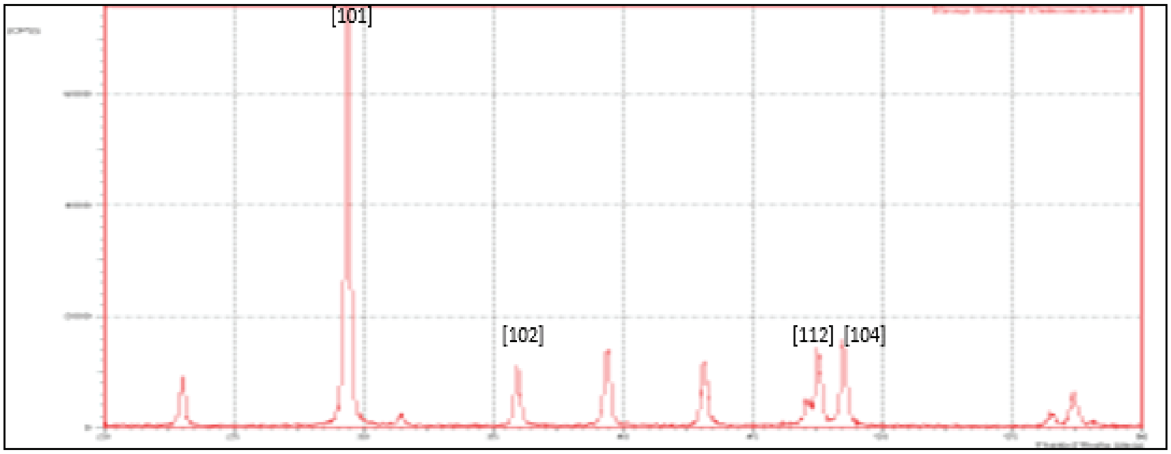
TABLE 1. The physical and chemical properties of the used cement

Oxide	**%**	**I.O.S.5: 1984 Limits**
CaO	66.11	-
SiO2	21.93	-
Al2O3	4.98	-
Fe2O3	3.10	-
MgO	2.0	<5.0
K2O	0.75	
Na2O	0.35	
SO3	2.25	<2.8
Compound	**%**	**I.O.S.5: 1984 Limits**
C3S	50	-
C2S	20.48	-
C3A	4.0	-
C4AF	13.17	-
Physical Properties	**Test Results**	**I.O.S.5: 1984 Limits**
Setting Time:		
Initial hrs: min		>45 min
Final hrs : min	2.05	< 10 hrs
	4.00	



(a)

FIGURE 1. XRD spectrum for: (a) Nano SiO2, (b) Nano CaCO3, (c) Nano ZrO2 and (d) Nano Al2O3.



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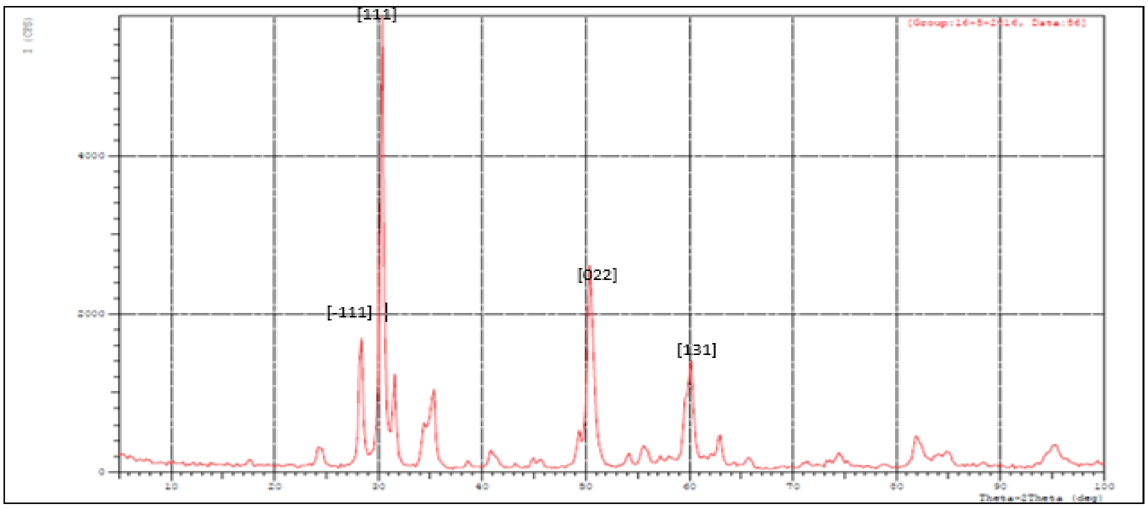

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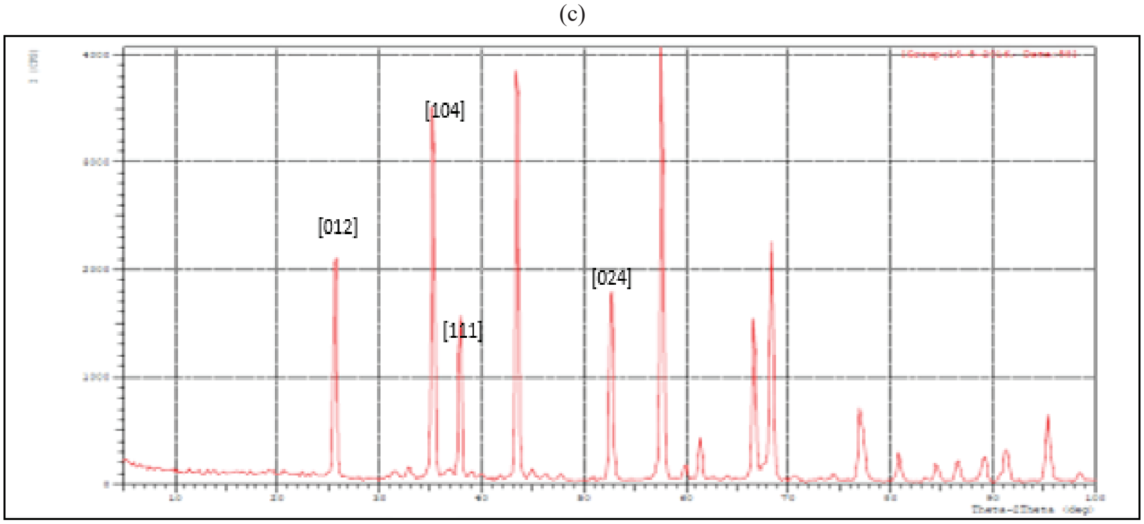
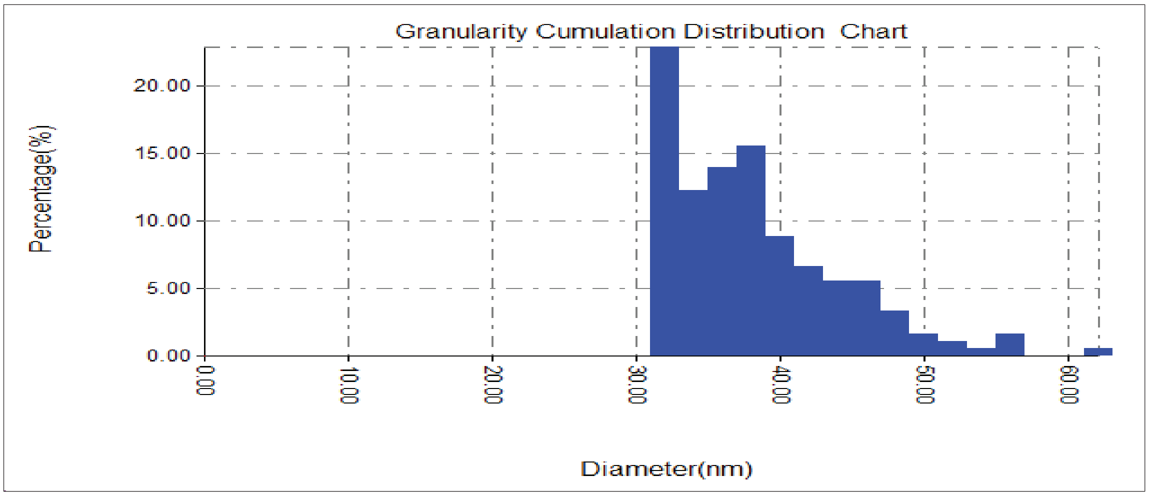
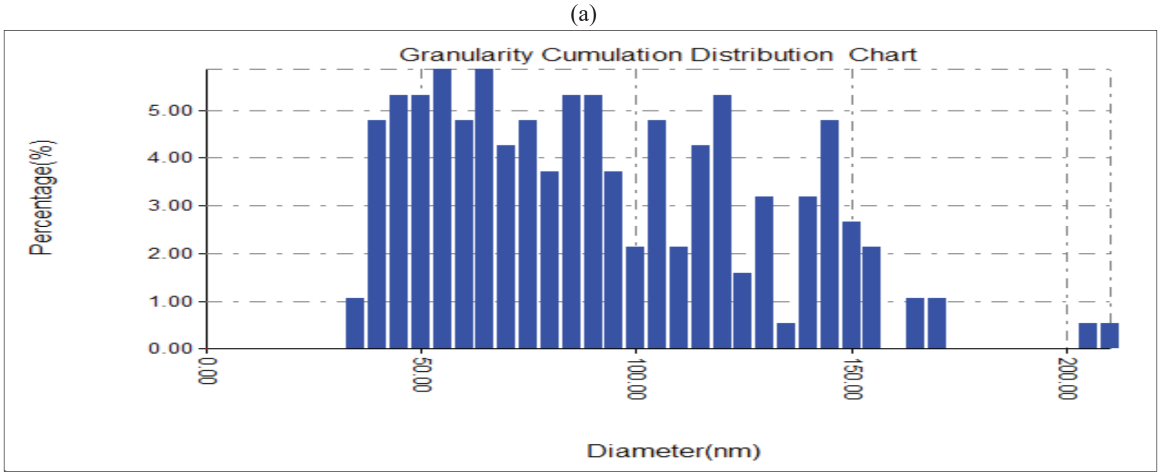


(d)

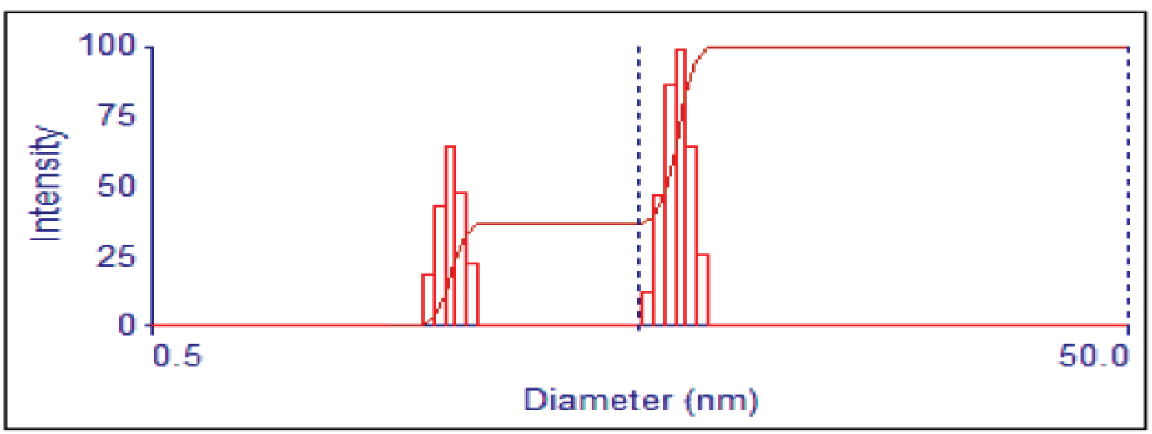
FIGURE 1.Continued. XRD spectrum for: (a) Nano SiO_2, (b) Nano $CaCO_3$, (c) Nano ZrO_2 and (d) Nano Al_2O_3.



(a)

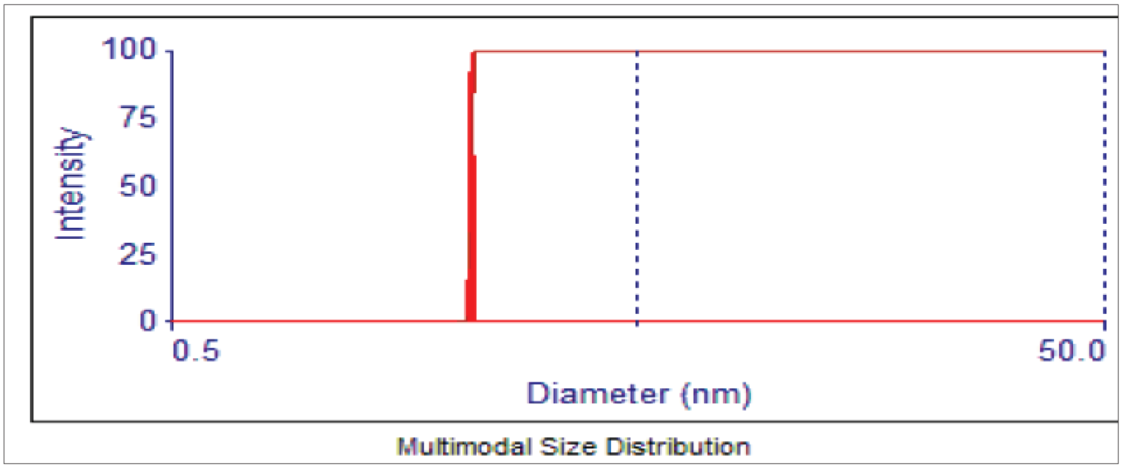


(b)



(c)

FIGURE 2. Particle size analysis of: (a) Nano SiO2, (b) Nano CaCO3, (c) Nano ZrO2 and (d) Nano Al2O3.



(d)

FIGURE 2.Continued. Particle size analysis of: (a) Nano SiO_2, (b) Nano $CaCO_3$, (c) Nano ZrO_2 and (d) Nano Al_2O_3.

Mixes Proportion

Mortar mixes details for (nano ZrO_2), (nano Al_2O_3) (nano SiO_2) and (nano $CaCO_3$), and are shown in Table 2. Constant w/c ratio 0.45 were be used for all mixes. The amount of superplastizer type G54 was added so specified to the flow range (153-161 mm) according to ASTM C1240 [8], ASTM C 1437 [9] procedure was used for measuring mortars flow. Sixteen mixes with nano particles were prepared in addition to reference mix in this work.

TABLE 2. Mortar Mixes

Mix Symbol	**Cement (g)**	**Sand (g)**	**Nano SiO2**	**Nano ZrO2**	**Nano Al2O3 (g)**	**Nano CaCO3 (g)**	**G54/ cament (%)**	**Flow (mm)**
Control	500	1375	-	-	-	-	0.5	160
1NS	495	1375	5	-	-	-	0.75	153
1.5NS	492.5	1375	7.5	-	-	-	0.5	155
3NS	485	1375	15	-	-	-	0.6	160
5NS	475	1375	25	-	-	-	0.7	157
1NZ	495	1375	-	5	-	-	0.65	-
1.5NZ	492.5	1375	-	7.5	-	-	0.65	-
3NZ	485	1375	-	15	-	-	0.7	-
5NZ	475	1375	-	25	-	-	0.7	-
1NA	495	1375	-	-	5	-	0.55	-
1.5NA	492.5	1375	-	-	7.5	-	0.57	-
3NA	485	1375	-	-	15	-	0.6	-
5NA	475	1375	-	-	25	-	0.6	-
1NC	495	1375	-	-	-	5	0.54	-
1.5NC	492.5	1375	-	-	-	7.5	0.54	-
3NC	485	1375	-	-	-	15	0.55	-
5NC	475	1375	-	-	-	25	0.57	-

Where, NA is the mixes with Nano Al_2O_3.
NC is the mixes with Nano $CaCO_3$
NS is the mixes with Nano SiO_2.
NZ is the mixes with Nano ZrO_2.

Specimens and Tests

Cubic specimens with dimension 50x50x50 mm of cement mortar in compliance with the ASTM C109/109 [10] as illustrated in the figure (3) were prepared for the compressive strength tests that were measured according to ASTM C109/109 [10] after curing for (7) and (28) day in water.

FIGURE 3. Specimens of compressive strength test

Result and Discussion of Compressive Strength Test

The test of compressive strength was performed beyond the curing for (7) and (28) day. The results indicated in the Table 3 were the average of (3) specimens for every mortar mix.

TABLE 3. Compressive strength results for the mortar mixes

Replacment Type	Compressive Strength (MPa) in 7 days					Compressive Strength (MPa) in 28 days				
	0%	1%	1.50%	3%	5%	0%	1%	1.50%	3%	5%
Nano SiO2	22	30	31	39	34	26	34	37	42.5	40
Nano ZrO2	22	25	29	31	24	26	30	34	37	28
Nano CaCO3	22	22	25	28	30	26	27	29	31	33.5
Nano Al2O3	22	23	27.7	32	33	26	26.5	30	36	38

The results of the compressive strength for the mortar mixes with nano SiO_2 elucidated a remarkable enhancement in the strength recognized with the increment of nano SiO_2 content up to 3% replacement for both ages 7 and 28 day, as evinced in figure 4. Then, the compressive strength decreased at 5% replacement but it was still greater than reference mix. The nano SiO_2 exhibited a higher pozzolanic activity since it interacts with the (CH) that made over the hydration of cement and causes a higher strength-carrying (C-S-H) into the mix. The more pozzolanic reaction that takes place in the blend, the higher strength-carrying (C-S-H) is made, and that finally results in a higher total strength. Such results are compatible with those in the works of W. Li Z. [11] and M. Rupasinghe et al. [12].

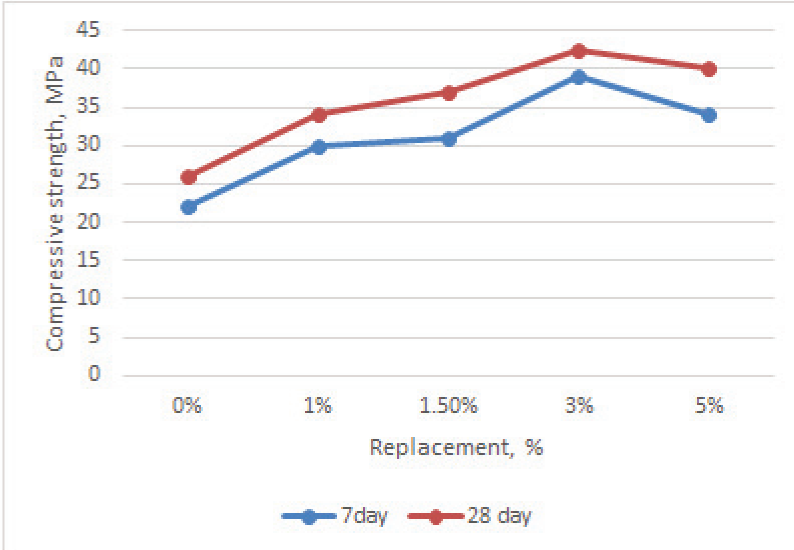


FIGURE 4. Compressive strength results for the mortar mixes with nano SiO_2

Fig. 5 showed the compressive strength results obtained for the mortar mixes with nano ZrO_2 replacement, they also show reveal that the compressive strength raises via the addition of nanoparticles of ZrO2 up to (3.0%) replacements by the weight of cement and after that it reduces despite the addition of (5%) of nanoparticles of ZrO2 made the specimens having compressive strength greater than the reference mix. The decreased compressive strength via the addition of more than 3% of nanoparticles of ZrO2 may be owing to the fact that the (ZrO_2) nanoparticles amount that exists in the mix is higher than the amount needed for combining with the released lime due to the hydration process, hence resulting in more leaching out of silica and creating a lack in the strength when it takes the place of a part of cementitious substance but doesn't share in strength [3]. And, it's perhaps owing to the produced defects from the nanoparticles agglomeration that results in feeble regions.

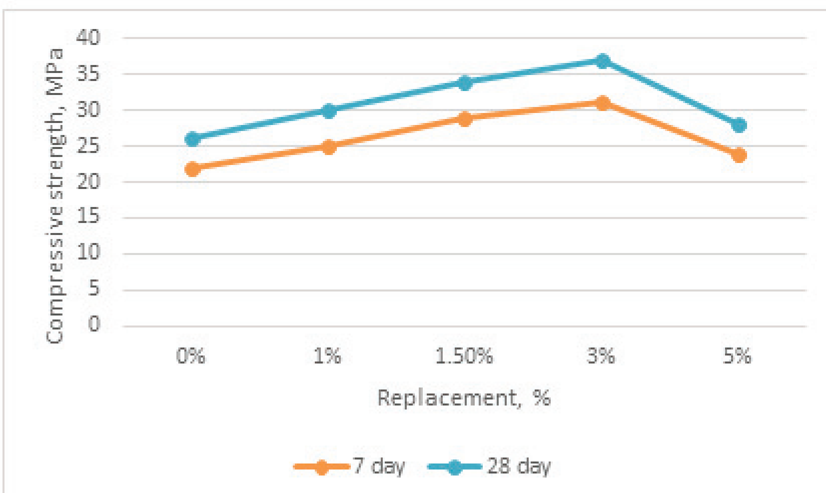


FIGURE 5. Compressive strength results for the mortar mixes with nano ZrO_2.

Fig. 6 and 7 manifest that the results of compressive strength for the different mortar mixes with nano $CaCO_3$ and nano Al_2O_3 replacements, respectively, both replacements showed a good enhancement in the compressive strength with raising the nanoparticles content. The maximum compressive strength recorded for nano $CaCO_3$ at 5% replacement was 33.5 MPa while for the mixes with 5% of nano Al_2O_3, the maximum recorded compressive strength was 38 MPa. Nano $CaCO_{3\ \text{and}}$ (C3A) are able to react with each other to make mono-carbonate that is a material with a particular structure having vigorous bonds of H_2 between the atoms of O_2 and the groups of the inter-layer waters carbonate [13], and the nanoparticles of $CaCO_3$ varied the hydration products development, thus shared in the enhancement of properties of the betimes-age compressive strength and durability of the concrete [14]. The increasing in the compressive strength for mixes with nano alumina is owing to fast consumption of $Ca(OH)_2$ that was developed during the Portland cement hydration, especially at the betimes ages that are related to the nano Al_2O_3 particles' high reactivity [15].

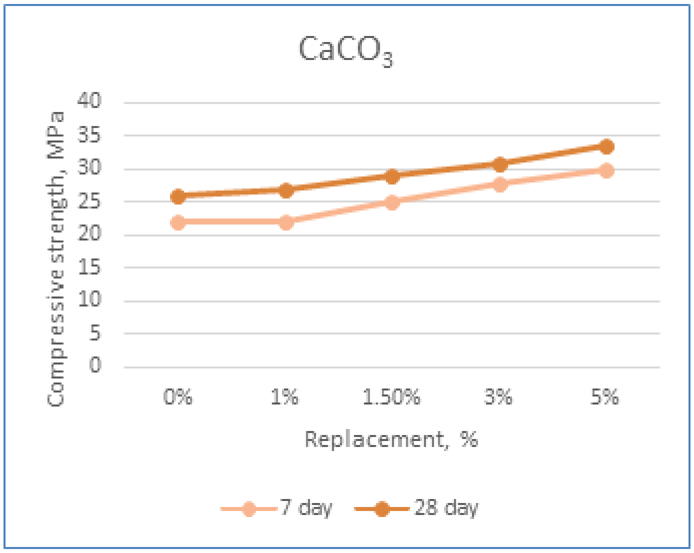


FIGURE 6. Compressive strength results for the mortar mixes with nano $CaCO_3$.

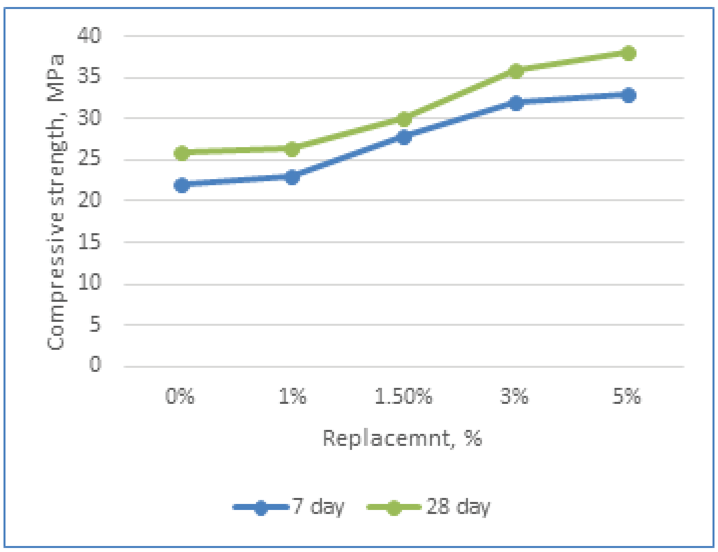


FIGURE 7. Compressive strength results for the mortar mixes with nano Al_2O_3.

CONCLUSION

The following conclusions may be drawn from the obtained experimental data:

1. Results elucidated that cement blended with nano particles had considerably a higher compressive strength in comparison to that of the cement mortar without nanoparticles.
2. It is noticed that cement could be advantageously substituted with nano SiO_2 and nano ZrO_2 particles up to a maximum limit of 3.0% which remarkably improved the compressive strength of cement mortar.

1- It is observed that compressive strength of mortar can be increased gradually by increasing the content of nano Al_2O_3 and nano $CaCO_3$ particles up to 5% by the weight of cement.

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