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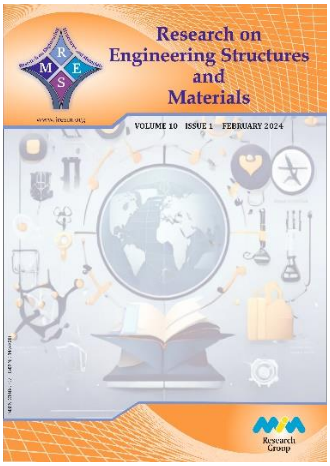

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Research Article

Improvements of mechanical and physical features of cement mortar by nano AL_2O_3 and $CaCO_3$ as additives

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Abstract

The impact of Nanoparticles of ($AL_2O_3$and $CaCO_3$) particles on the features of cement mortar was explored in current research with a mean diameter of ~50nm, and 100nm in three various amounts of 1, 3, and 5% substitution by cement's weight as binary blending materials with fixed water/cement proportion 0.46. Cement mortar's mechanical and physical features (compressive strength, density) were tested after 7 and 28 days. The findings illustrated that utilizing nanoparticles of AL_2O_3 improved the mortar compressive strength at early ages at 7 curing days better than 28 curing days, and 3% of substitution was the optimal proportion. Also, utilizing nano-$CaCO_3$ as a binary blending mixture with substitution proportion (1, 3, 5%) by cement's weight improved mortar compressive strength at early ages at 7 curing days better than 28 curing days. However, there were no apparent effects when nanoparticles of (AL_2O_3 and $CaCO_3$) were replaced on the density and ultrasonic pulse velocity of cement mortar at 7 and 28 days. The interaction impact of substitution 1 and 3 percent of nanoparticles of (AL_2O_3 and $CaCO_3$) particles to cement mortar increased the CS by (28 and 74%) at 7 curing days and (30 and 42%) at 28 curing days, respectively.

1. Introduction

Ordinary Portland cement (OPC) is a type of cement that is commonly utilized in concrete and mortar. It is made by heating limestone and clay at high temperatures and grinding the resulting material into a fine powder [1–3]. OPC is the most common type of cement utilized in various applications, including foundations, driveways, sidewalks, and walls. It also creates various structures, including bridges and dams [4,5]. OPC is highly durable and has a long-life span. It is also relatively inexpensive and has a high compressive strength (CS), meaning it can withstand much pressure. OPC concrete is made by mixing OPC with water and aggregate (sand, gravel, or crushed stone). This mixture is then poured into forms and allowed to harden. OPC concrete is strong, durable, and has a long life span, making it a popular choice for construction projects [6].

Portland cement is an essential concrete component, producing significant amounts of CO2 throughout its manufacturing process [7]. The primary sources of CO2 emissions come

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from burning fossil fuels (coal and natural gas) utilized to heat the rotary kiln and from the calcination process [8,9]. Other sources of emissions include the burning of fuels to drive the grinding and mixing equipment and the movement of materials throughout the cement manufacturing process [10,11]. However, several alternatives to OPC can be utilized in place of it [10-21]. These alternatives include fly ash, slag cement, silica fume, and the Nanomaterials that have recently been utilized in a cement matrix, which involved various types, including Nanoparticles of SiO2, TiO2, AL_2O_3, carbon Nano-fibers, Fe2O3, and $CaCO_3$. It was detected that the nanomaterials utilized in cement and concrete improve their mechanical, physical, and other features [22].

Ali Nazari et al. [23] explored the impact of AL_2O_3 with nanoparticles on the strength of concrete. Nano-AL_2O_3 with four various amounts of 0.5, 0.1, 1.5, and 2.0 percent by cement's weight. The mean particle size of AL_2O_3 with nanoparticles is 15nm, with a water/binder proportion of 0.40. Cubes with a 100mm edge were cast and compacted in two layers on a vibrating table. The CS of concrete made without add had (27.3, 36.8, 42.3) MPa at (7, 28, and 90) days. However, by increasing AL_2O_3 nanoparticles to 2.0, the CS had (27.5, 37.7, 42.6) MPa at (7, 28, and 90) days, respectively. It indicates a reduction in CS with no discernible cause. According to the researcher, "it might be since the AL_2O_3 nanoparticles greater than the required amount to incorporate with liberated lime throughout the process of hydration, resulting in excess silica leaching out and causing a deficiency in strength as it substitutes some of the cementitious material but does not contribute to strength. Additionally, the weak areas might result from faults created throughout the dispersion of nanoparticles.

Arefi et al. [24] investigated the impact of adding AL_2O_3 nanoparticles on cement mortar features. AL_2O_3 nanoparticles with a mean particle size of 20nm were utilized with three amounts of 1, 3, and 5 percent by cement's weight—water/binder proportion of 0.42. For compressive tests, cubes of size 50× 50 ×50 mm in three layers were cast and compressed by 10 impacts of a steel rod. This study illustrated that CS without add had 11.96MPa at 7 curing days, while concrete made with 1 percent of AL_2O_3 with nanoparticles had (17.25 MPa), with 3 percent had (19.54MPa). However, by increasing AL_2O_3 nanoparticles to 5 percent, the CS had (10.9 MPa). That means the mechanical features are reduced severely by increasing AL_2O_3 nanoparticles to 5 percent. The researcher thinks it may be due to reduced nanoparticle distance and Ca (OH)2 crystals since limited space cannot grow to the appropriate size. This factor, along with the agglomerated nanoparticles, causes a reduction in CS.

Liu et al. [25] investigate the impact of nanoparticles of $CaCO_3$ on cement paste. Nanoparticles of $CaCO_3$ were added to three various substitutions (1, 2, 3 percent) of cement weight and the mean particle size (15-50) nm. The water/cement proportion was 0.45. The CS test was done at 7 and 28 curing days. Samples were cubic bars with the size (20*20*80) mm. The result illustrated that the CS in the two ages increased with $CaCO_3$ until it reached 20 percent and then reduced when $CaCO_3$ was 2 percent; the CS had (111.2 percent and 108.6 percent) at age (7 and 28) curing days, respectively. "Since the consuming and refinement of $Ca(OH)_2$ grain, which occurred throughout the hydration of cement, especially at early ages".

Barbhuiya et al. [26] Conducted a study to find the impact of AL_2O_3 with nanoparticles on the CS of cement paste at an early age. AL_2O_3 with nanoparticles with a mean particle size of 27-43nm were utilized, two various replaced with 2 percent and 4 percent by cement's weight, the water-to-binder proportion of 0.4. Cubes of 50mm size were cast and vibrated on the vibration table. The CS of hydrated cubes was calculated at 1, 3, and 7 curing days. This research illustrated that the CS of cement paste having 2 percent and 4 percent nano-AL_2O_3 increased slightly at 1 and 7 curing days. It was noticed that adding nano-AL_2O_3 in cement paste does not directly impact CS because the changes in CS at 1, 3, and 7 curing days are minimal.

AL Ghabban et al. [27] explored the impact of nanoparticles of $CaCO_3$ in concrete. Nanomaterials were added in four various substitutions (1, 2, 3, and 4 percent) of cement weight in the concrete mixture, with a water/binder proportion of 0.32. The test samples utilized were cubic with dimensions (150 *150*150) mm for the CS test. The result that concretes made with (0, 1, 2, 3, and 4 percent) had (52, 54, 58, 60, and 63) MPa at 28 curing days. It has been detected that an increase in CS (4 percent) at 28 curing days, and the optimal dosages for nanoparticles of $CaCO_3$ were 4 and 3 percent, respectively, for improving the mechanical features of concrete.

Cosentino et al. [28] conducted to find the impact of nanoparticles of $CaCO_3$ in cement mortar. $CaCO_3$ nano partials with a mean diameter of 60nm were utilized with four different substitutions (1, 2, 3, and 7 percent) of cement weight. Cement mortar made without add had 40.16 MPa at 7 and 53.28 MPa at 28 curing days. Substitution of nanoparticles of $CaCO_3$ with (1, 2, 3, 7 percent) had (40.16, 43, 38, 44.16) MPa respectively at seven days, and (53.28, 55, 51.78, 50.81) MPa respectively at 28 curing days. The CS increased by 7 percent for seven days, but at 28 curing days, the CS reduced. Since poor dispersion and the agglomeration phenomena of the nanoparticles in the slurry and the cement matrix."

Jawad et al. [29] determined the impact of various nanomaterials on the CS of cement mortar. Four amounts of AL_2O_3 with nanoparticles were utilized as a partial substitution of 1, 1.5, 3, and 5 percent by cement's weight. W/C proportion of 0.45. Cubic samples with dimensions 50× 50 ×50mm of cement mortar were produced for CS after 7 and 28 curing days in water. The CS without add had (22, 26) MPa respectively at (7, 28) days. Nevertheless, with (1, 1.50, 3, and 5 percent), the CS recorded (23, 27.7, 32, 33) MPa at seven days and (26.5, 30, 36, 38) MPa, respectively, at 28 curing days. It has been detected that the CS of mortar can be increased gradually by increasing the amount of AL_2O_3 with nanoparticles up to 5 percent by the weight of cement. The increase in CS of cement mortar since the fast consumption of $Ca(OH)_2$ developed throughout the Portland cement hydration, especially early, is related to the high reactivity of AL_2O_3 with nanoparticles.

Iskra-Kozak and Konkol [30] illustrated the impact of AL_2O_3 with nanoparticles on cement mortar's physical and mechanical features at early and later ages. Four amounts of 1, 2, 3, and 4 percent of AL_2O_3 with nanoparticles, respectively utilized by cement's weight. The water/binder proportion was 0.5, and the binder to the sand proportion was 1:3. Three samples of each additive were made, and the CS of the mortars was tested after 7, 28, and 90 days of curing. The CS without add had (28.2, 36.9, 42) MPa respectively at (7, 28, 90) days. Nevertheless, with (1, 2, 3, and 4 percent) the CS recorded (34.1, 32.4, 31.6, 29.9) MPa, respectively, at seven days, had (39.5, 40.0, 39.6, 36.8) MPa, respectively at 28 curing days and had (47.3, 46.3, 44.6, 44.1) MPa respectively at 90 days. The highest CS of mortars is observed by adding 1 percent AL_2O_3 with nanoparticles. However, with the increase of the addition of nano alumina oxide, the CS of the mortar reduced since the nanoparticles of AL_2O_3 lead to the formation of agglomerates in the structure of the mortar, and this phenomenon findings from the high specific surface area of the AL_2O_3 with nanoparticles.

Muhsin and Fawzi [31] explored the impact of nanoparticles of $CaCO_3$ on concrete. Nanomaterial was added in three various substitutions (0.75,1,1.5 percent) of cement weight. The mean particle diameter is 100 nm. By utilizing standard cubic samples (50*50*50) mm, the findings illustrated that the CS increased (11.4, 39.3, 23.7 percent) at seven days, (5.8, 28.2, and 4.6 percent) at 28 curing days. Also, the result demonstrates that 1 percent of nanoparticles of $CaCO_3$ give the highest CS at all ages. "Since there is high surface energy throughout the hydration process, they grow and form a clump with nanoparticles as a nucleus that work on increasing and accelerating the hydration process.

Many studies have been directed toward improving the mechanical features of cement mortar by utilizing nanoparticles, including nanoparticles of (AL_2O_3 and $CaCO_3$) particles. Most researchers noticed that substituting AL_2O_3 with nanoparticles up to 4 percent and 5 percent by cement weight reduces the CS of cement mortar. At the same time, some authors observed that substituting 5 percent of AL_2O_3 with nanoparticles increases the CS, and others observed that substituting AL_2O_3 with nanoparticles did not impact CS. Most researchers noticed that with substitution nano-$CaCO_3$ up to (3,4, and 7 percent) by cement's weight, the CS increased at 7 and 28 curing days, while some observed the CS reduce at 7 and 28 curing days. Previous research found findings inconsistent when utilizing various proportions of nanoparticles of (AL_2O_3 and $CaCO_3$). Therefore, this research aims to study the impact of adding nanomaterials, including [nanoparticles of (AL_2O_3 and $CaCO_3$)], to cement mortar and find the best percentage of adding nanoparticles to improve cement mortar's physical and mechanical features.

2. Material and Methodology

2.1. Materials

2.1.1. Cement

Ordinary Portland cement was utilized; the physical and chemical features are illustrated in Table 1. This work utilized locally available natural sand with a fineness modulus of 2.17 as fine aggregate. The grading of this aggregate was zone 3 as limits of Iraq requirements, No.45/1984.

Table 1. The chemical and physical features of cement.

Chemical composition	Amounts (by weight %)	Limits of Iraqi Requirements NO.5/2019 (42.5 R)
Cao	60.60	---
SiO_2	19.80	---
AL_2O_3	4.80	---
Fe_2O_3	3.00	---
MgO	3.50	≤ 5.0 percent
SO_3	2.22	≤ 2.8 percent if C3A > 3.5 percent
Loss on Ignition (L.O.I.)	3.10	≤ 4.0 percent
The insoluble residue (I.R.)	0.70	≤ 1.5 percent
OPC main compounds (Bogue's Eq.)		
Tricalcium silicate (C_3S)	59.63	
Dicalcium silicate (C_2S)	11.78	
Tricalcium aluminate (C_3A)	7.64	
Tetra calcium alumina-ferrite (C4AF)	9.12	
Test name	Findings	Limits of Iraqi Requirements NO.5/2019 (42.5 R)
Fineness (Blaine method), (m^2/kg)	320	≥ 280
Setting time (Vicat's method),	90	≥ 45

Initial setting time (min.)	5	≤ 10
Final setting time (hr.)		
Compressive strength (MPa),		
Early strength (2 days)	24	≥ 20
Standard strength (28 curing days)	43	≥ 42.5

2.1.2. Supplementary Materials

Nano-AL_2O_3 with a mean particle size of ~50 nm. The physical and chemical features of AL_2O_3 with nanoparticles are given in Table 2; also, Nano-$CaCO_3$ has a mean particle size of less than 100nm. The features of $CaCO_3$ with nanoparticles are illustrated in Table 3. Finally, tap water was utilized throughout this work for mixing and curing.

Table 2. Physical and chemical features of nano-AL_2O_3.

Features	Purity	Mean particle size	Density	Ca	K	Cu	Mg	Fe	Mn	Zn	Si
Magnitudes	99.9+ percent (trace metal basis)	50 nm	3.1	<100	<100	<10	<50	<100	<50	<50	<100

Table 3. The physical and chemical features of nano-$CaCO_3$.

Features	Appearance	Density	Size	Specific area	MgO	Moisture amount	Loss on ignition	Residue on Sieve	$CaCO_3$ amount
Magnitudes	White powder	2.5	>100	≥ 20	≤0.8	≤0.9	44±1	≤0.02	≥96
Features	Alumina + Iron oxide		PH	The insoluble matter with acid		Activation rate		DOP absorbed does	
Magnitudes	≤0.3		8.5-9.7	≤0.3		≥95		35-55	

2.1.3. Sand

Locally available natural sand is applied as a fine aggregate conforming to the requirements of [32]. The fine modulus of 2.42 sulfate content is 0.1% with a density of fine aggregate of 1600 kg/m 3. The fine aggregate was utilized in the surface's saturated and dry state and has been utilized in the current study. The grading of fine aggregate is demonstrated in Table 4.

Table 4. Fine aggregate grading

Sieve size (mm)	Percent Passing %
10	100
7.75	93.5
2.36	84
1.18	75.5
0.6	50
0.3	20
0.15	4

2.2. Mixing Procedure and Samples Preparing

In this study, nine types of mixes were produced to find the impact of nanoparticles of (AL_2O_3 and $CaCO_3$) on the CS of cement mortar. These mixes were [A, B_1, B_2, B_3, C_1, C_2, C_3, B_1+C_1 and B_2+C_2]. Type-A mixture was produced of fine natural aggregate, cement, and water. Types-(B_1, B_2, B_3, C_1, C_2, C_3) were produced with various contest of nanoparticles of (AL_2O_3 and $CaCO_3$) particles. The mixes have been produced with cement substitution (1, 3, 5 percent) by weight. Types- (B_1+C_1 and B_2+C_2) mixtures were produced with nanoparticles of (AL_2O_3 and $CaCO_3$) particles and the cement substitution (1, 3 percent) by weight. In the initial step of mixing the nanomaterials, the binder to the sand of 1:2 and the w\c of 0.46 (water =300 ml and cement =) was mixed in a dry condition for one minute and another two minutes after adding the water. Cubes with size 50 ×50 ×50 mm for the CS tests were cast and compacted in two layers on a vibrating table, where each layer was vibrated for 15 s. The mold was covered for 24 hours. Then, the samples were de-molded and cured in water for the test day. The concrete samples' compressive strength (CS) tests were determined at 7 and 28 curing days (three samples for each mix and the average value). The mixtures with nanoparticles of (AL_2O_3 and $CaCO_3$) are presented in Fig. (1) and Table (5).

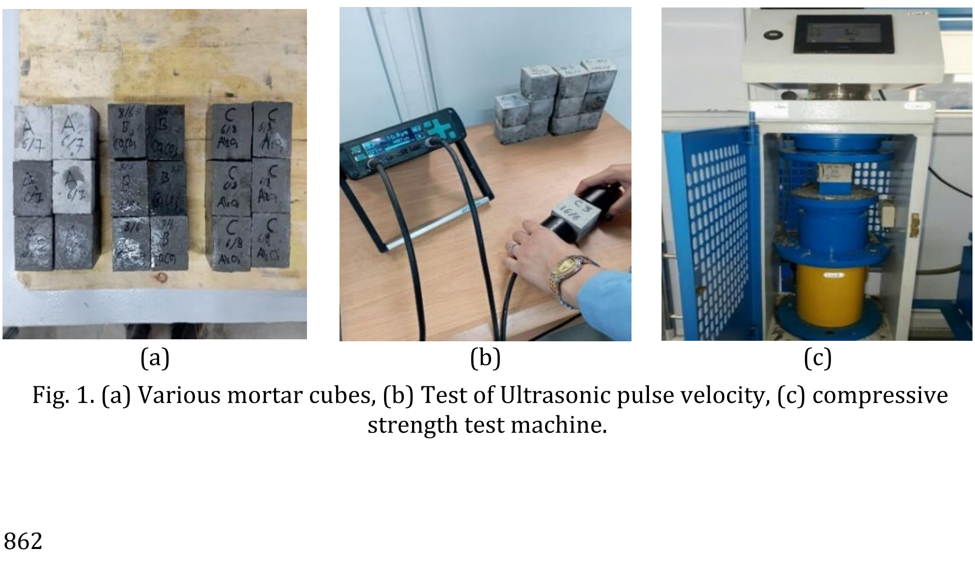
The ultrasonic pulse velocity of the high-strength concrete was measured using Pundit Lab+ according to BS:12504 [33] requirements. It had a bandwidth between 24-500HZ. The Ultrasonic pulse velocity (Pundit Lab+) is demonstrated in Fig. 1(b).

The density of the concrete was measured with 150x150x150 mm cubes by the ASTM C 642-13 standard [34]. The dry density of concrete cubes can be determined through a series of steps. Firstly, the specimens are subjected to drying in an oven at a temperature of 110 degrees Celsius for one day. After this, the specimens are submerged in water for another day. Their wet weights are recorded once the specimens have reached a stable state. Finally, the samples are weighed again while submerged in water to obtain the weights. The investigation was conducted at the respective time intervals of 7 and 28 days. The density of cubic concrete samples can be determined by employing the formula outlined in the reference [35].

$$Dry\ density = \frac{W_1}{W_{2-}W_3} * P_w \tag{1}$$

Where:

W_1: The dry weight of the sample (g), W_2: The wet weight of the sample (g), W_3: The immersed Specimen weights in water (g), P_w: The water density equals (1 g/cm^3).



(a) (b) (c)

Fig. 1. (a) Various mortar cubes, (b) Test of Ultrasonic pulse velocity, (c) compressive strength test machine.

Table 5. The mixtures of nanoparticles of (AL_2O_3 and $CaCO_3$).

Sample	Cement (gm)	Sand (gm)	Water (gm)	Nano-AL_2O_3 (gm), %	Nano-$CaCO_3$ (gm), %	W\C
A (control)	650	1300	300	-	-	0.46
B1	643	1300	300	7, (1 percent)		0.46
B2	630	1300	300	20, (3 percent)		0.46
B3	620	1300	300	30, (5 percent)		0.46
C1	643	1300	300		7, (1 percent)	0.46
C2	630	1300	300		20, (3 percent)	0.46
C3	620	1300	300		30, (5 percent)	0.46
B1+C1	643	1300	300	3.5, (1 percent)	3.5, (1 percent)	0.46
B2+C2	630	1300	300	10, (3 percent)	10, (3 percent)	0.46

where;

A is the cement mortar mix without nanoparticles, B refers to the mixes with $CaCO_3$ with nanoparticles with various substitution proportions, C refers to the mixes with AL_2O_3 with nanoparticles with various substitution proportions.

(B+C) refers to the mixes of cement mortar and a combination of both nanoparticles with various substitution proportions.

3. Result and Discussion

3.1. Mechanical and Physical Features

The CS, density, and ultrasonic pulse velocity (UPV) test of cement mortar with partial substitution of nanoparticles of (AL_2O_3 and $CaCO_3$) by cement's weight are illustrated in Table (6).

Table 6. Result of CS, density, and UPV for cement mortar with nanoparticles of (AL_2O_3 and $CaCO_3$) particles.

Samples	Nano $CaCO_3$ (%)	Nano AL_2O_3 (%)	CS (MPa)		Density (kg\m3)		UPV (m\s)
			7 days	28 days	7 days	28 days	28 days
A (control)	0	0	20.5	27	2312	2320	4587
B1		1	31	33	2288	2278	4356
B2		3	38.5	38	2288	2294	4520
B3		5	21	37.5	2282	2309	4383
C1	1		31.6	31	2352	2336	4533
C2	3		37.5	33	2253	2296	4587
C3	5		33	27.5	2285	2329	4385
B1+C1	1	1	26.3	35	2285	2296	4533
B2+C2	3	3	35.7	38.3	2270	2299	4587

Fig. 2 and 3 demonstrate the CS findings of the selected mixtures before and after replacing OPC with different nanoparticles of (AL_2O_3 and $CaCO_3$) proportions, utilizing nano (AL_2O_3, $CaCO_3$, and AL_2O_3+$CaCO_3$) increase the CS at early ages when utilizing 1 and 3 percent, but increase the replacement to 5 percent lead to decrease the early ages significantly since creating ettringite at early ages [36], and utilizing $CaCO_3$ with 3 percent considered best ratio for replacement.

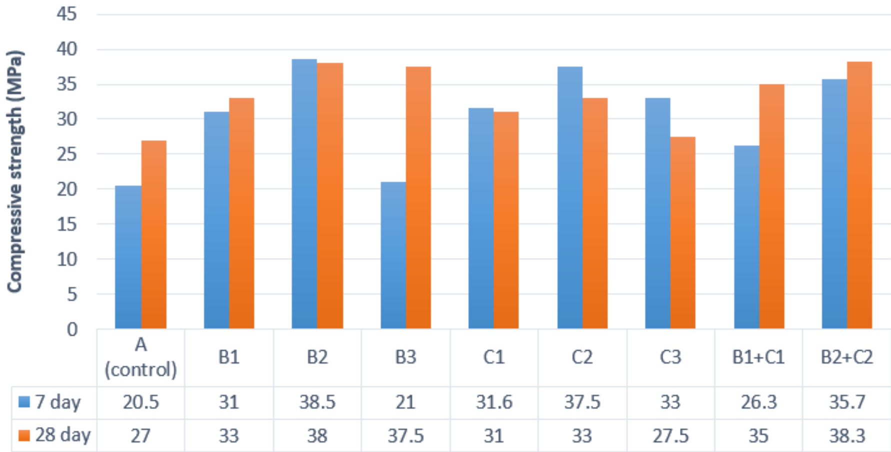


Fig. 2. CS finding various samples at 7 and 28 curing days

Fig. 3 demonstrates the CS findings of the selected mixtures before and after replacing OPC with different nanoparticles of (AL_2O_3 and $CaCO_3$) proportions, utilizing nano-AL_2O_3, $CaCO_3$, and nano-AL_2O_3+$CaCO_3$ increase the CS at 28 ages when utilizing 1 and 3 percent, but increase the replacement to 5 percent lead to decrease the final ages significantly since converting ettringite to cement's get (C-H, C-S-H) at final ages and [36–38], and utilizing nano-AL_2O_3+$CaCO_3$ with 3 percent considered best ratio for replacement at final ages.

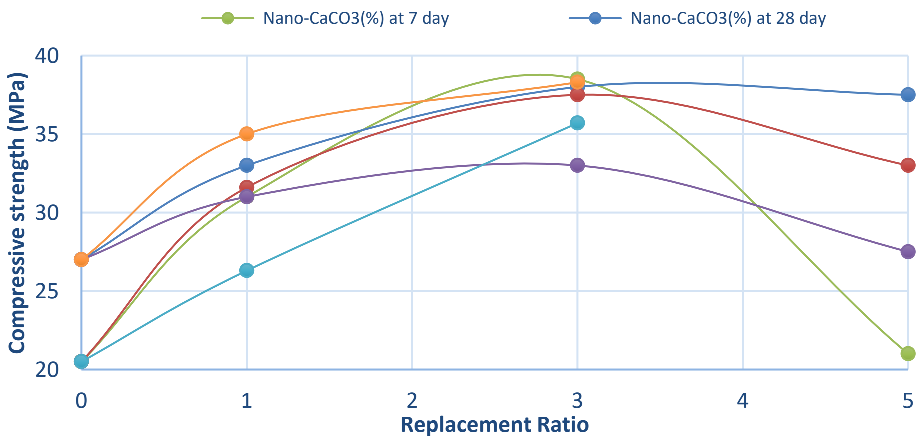


Fig. 3. Influence of replacing OPC with Nano ($CaCO_3$, AL_2O_3, and $CaCO_3$ + AL_2O_3) on CS at 7 and 28 curing days

Figs. 4 and 5 demonstrate the density findings of the selected mixtures before and after replacing OPC with different nanoparticles of (AL_2O_3 and $CaCO_3$) proportions; utilizing nano-AL_2O_3, increasing the density at 7 and 28 ages when utilizing 1, but increasing the replacement to 3 percent led to a decrease the density of the early ages significantly, utilizing nano-$CaCO_3$, decrease the density at 7 and 28 ages when utilizing 1, but increase the replacement to 3 percent lead to increase the density of the early ages little and notable for final ages. While combining nano-AL_2O_3+$CaCO_3$ with 1 and 3 percent reduces the density for both 7 and 28 curing ages, final ages give better findings than early ones.

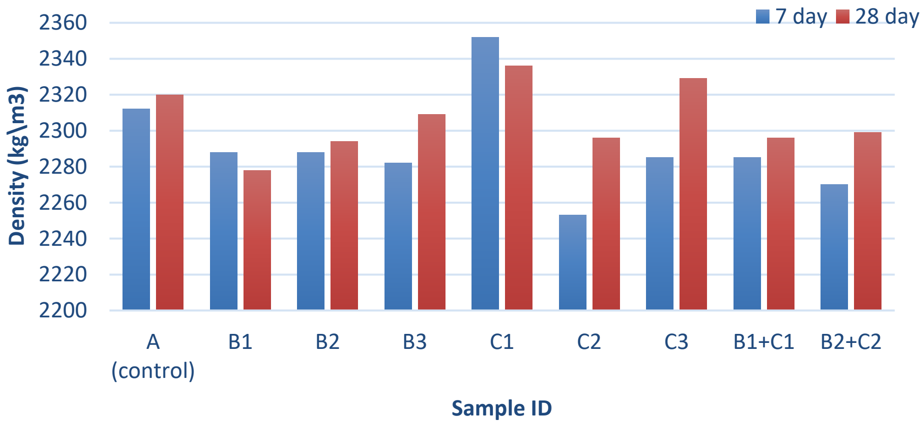


Fig. 4. Density finding for various samples at 7 and 28 curing days

It has been detected that the CS of cement mortar with $AL_2O_3$with nanoparticles (1, 3, and 5 percent) (C1, C2, C3) substitution by cement's weight, the CS increase (54, 82, 61 percent) at 7 curing days and (14, 22, 1 percent) at 28 curing days respectively. It was noticed that utilizing 5 percent AL_2O_3 with nanoparticles reduces the CS to a magnitude near the standard sample (A). It might be because there are more AL_2O_3 nanoparticles present than what is necessary to react with the freed lime throughout the hydration process, resulting in excess silica leaking out and weakening the concrete since it only replaces a portion of the cementitious material. Additionally, the weak areas might result from flaws created throughout the dispersion of nanoparticles [23]. The best CS for all cement mortar mixtures was noticed with substitution of 1 percent and 3 percent of AL_2O_3 with nanoparticles Because the AL_2O_3 had high activity. The presence of nanoparticles in the cementing system leads to the consumption of portlandite Ca(OH)2 caused by a pozzolanic reaction, filling the capillaries, reducing the pores, and increasing the strength.

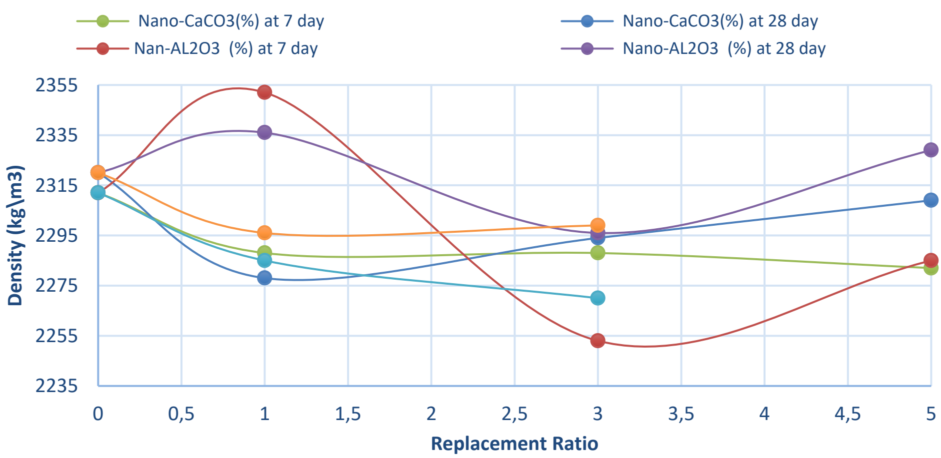


Fig. 5. Influence of replacing OPC by Nano ($CaCO_3$, AL_2O_3, and $CaCO_3$ + AL_2O_3) at 7 and 28 curing days on density.

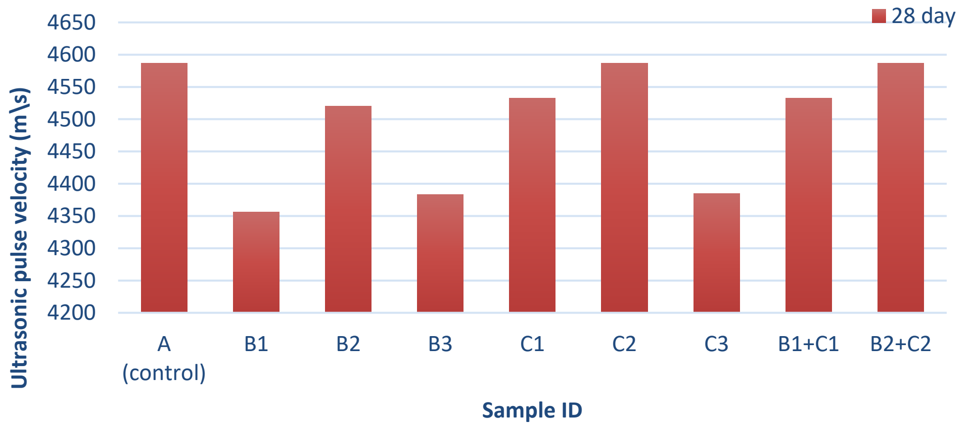


Fig. 6. Ultrasonic pulse velocity finding for various samples at 7 and 28 curing days.

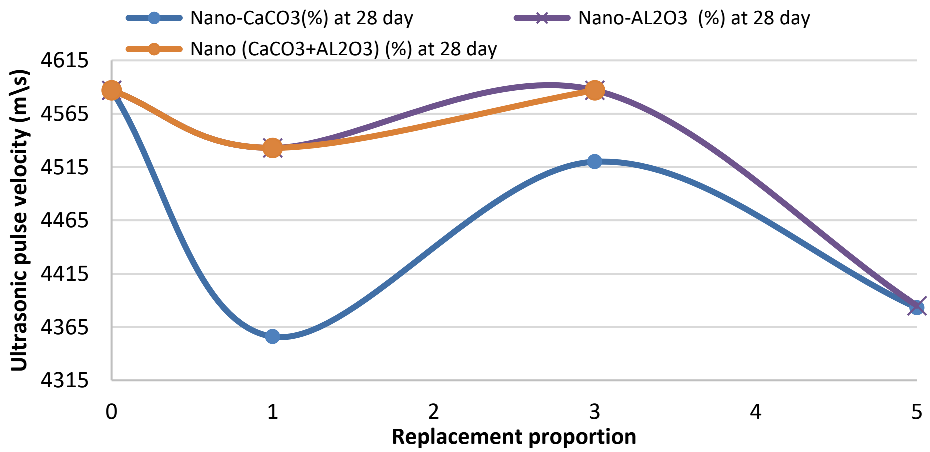


Fig. 7. Influence of replacing OPC by Nano ($CaCO_3$, AL_2O_3, and $CaCO_3 + AL_2O_3$) at 28 curing days on UPV.

Furthermore, no apparent effects were when replaced nanoparticles of (AL_2O_3 and $CaCO_3$) with (1, 3, and 5 percent) by cement's weight in density and ultrasonic pulse velocity of cement mortar at 7 and 28 curing days, respectively; this probably attributed to the size of cubes were small with dimensions (50× 50× 50) mm as illustrated in Fig. 6 and 7.

For $CaCO_3$ with nanoparticles replaced by (1, 3, and 5 percent) (B1, B2, B3) by cement's weight, the findings illustrated that the CS increase (51, 87, 2.4 percent) and (22,40,38 percent) at 7 and 28 curing days respectively. It was noted that the increase in CS at (1 percent and 3 percent) because the $CaCO_3$ with nanoparticles are chemically stable and filled the pores and increased the surface activity.

In the case of a combination of substitution of nanoparticles in cement mortar cubes having combined 1 percent and 3 percent (B1+C1) and (B2+C2) nanoparticles of (AL_2O_3 and $CaCO_3$). The substitution of 1 percent and 3 percent of nanoparticles of (AL_2O_3 and $CaCO_3$) to cement mortar increased the CS (28 and 74 percent) at 7 curing days and (30 percent and 42 percent) at 28 curing days, respectively. Because the AL_2O_3 nanoparticles had high activity, the present nanoparticles in the cementing system led to the consumption of portlandite $Ca(OH)_2$ caused by a pozzolanic reaction that fills the capillaries, reducing the pores and increasing the strength. The $CaCO_3$ with nanoparticles filled the pores and increased the surface activity.

3.2. Statistical Analysis of Results

Determining which substitution proportion of nanoparticles significantly affects the explored parameters is possible by utilizing a completely randomized design and implementing two-factor ANOVA without replication. Hence, tests of samples' mechanical and physical parameters (i.e., CS and density) on one sample of each of the nine cement mortar mixes. Table (7) presents the CS and density based on the substitution proportion (treatment) per curing age.

Table 7. Data for two-factor ANOVA without replication analysis.

Treatment Curing time	Control	B1 (1 %)	B2 (3 %)	B3 (5 %)	C1 (1 %)	C2 (3 %)	C3 (5 %)	B1+C1 (1 %)	B2+C2 (3 %)
					CS (MPa)				
7days	20.5	31	38.5	21	31.6	37.5	33	26.3	35.7
28 curing days	27	33	38	37.5	31	33	27.5	35	38.3
					Density (kg/m³)				
7days	2312	2288	2288	2282	2352	2253	2285	2285	2270
28 curing days	2320	2278	2294	2309	2336	2296	2329	2296	2299

Tables (8 and 9) demonstrate the main part of the findings of the two-factor ANOVA analysis. The rows relate to the determined factors, and the columns relate to the substitution proportion.

Table 8. Output for two-factor ANOVA analysis for CS (MPa) at a significant level of 0.05.

Source	SS	df	MS	F	p-magnitude
Rows	35.28	1	35.28	1.4796	0.2585
Columns	311.23	8	38.9037	1.6316	0.2521
Error	190.75	8	23.8437		
Total	537.26	17	31.6035		

Table 9. Output for two-factor ANOVA analysis for Density (kg/m³) at a significant level of 0.05

Source	SS	df	MS	F	p-magnitude
Rows	1122.25	1	1122.25	4.3360	0.07582
Columns	6487	7	926.7142	3.5805	0.0571
Error	1811.75	7	258.8214		
Total	9421	15	628.0666		

df: the freedom degrees in the source; SS: the sum of squares because of the source; MS: the sum of squares means because of source; F: the *F*-statistic; P: the *P*-magnitude.

As the focus was on the columns factor (substitution proportion) for both explored factors, there was a slight variance between the substitution proportions for the CS (p-magnitude = 0.2521). On the other hand, there was a significant variance between the substitution proportions for the density (p-magnitude = 0.0571), which was inferred to agree with the analysis of the previous findings [39,40].

4. Conclusion

The mechanical features of cement mortar are affected by substituting nanoparticles of (AL_2O_3 and $CaCO_3$) with cement. It has been detected from replacing nanoparticles of (AL_2O_3 and $CaCO_3$) in cement mortar that:

- The compressive strength was improved by (54 82)% and (15 and 22)% when using nanoparticles of AL_2O_3 by (1 and 3)% by cement weight at 7 and 28 curing ages, respectively.
- Increasing the utilized ratio of AL_2O_3 to 5wt% of cement led to a decreased compressive strength improvement rate for the produced mortar at the advanced ages from 61% to 2% only compared with the control sample without additives material. The best compressive value was obtained when using 3wt% of AL_2O_3.
- The compressive strength was improved by (51, 88, 2)% and (22, 41and 39)% when using nanoparticles of $CaCO_3$ by (1, 3, and 5)% by cement weight at 7 and 28 curing ages, respectively.
- Increasing the utilized ratio of $CaCO_3$ to 5wt% of cement decreased the compressive strength of the produced mortar at the advanced ages. The best compressive value was obtained when using 3wt% of AL_2O_3.
- Substituting 1 percent and 3 percent of binary combination nanoparticles of (AL_2O_3 and $CaCO_3$) to cement mortar increased the CS to (28 percent and 74 percent) MPa at 7 curing days and (30 percent and 42 percent) MPa at 28 curing days, respectively.
- The effects of replacing nanoparticles of (AL_2O_3 and $CaCO_3$) with (1, 3, 5 percent) by cement's weight on density and ultrasonic pulse velocity of cement mortar at 7 and 28 curing days were insignificant.

References

[1] Ali YA, Falah MW, Ali AH, Al-Mulali MZ, AL-Khafaji ZS, Hashim TM, et al. Studying the effect of shear stud distribution on the behavior of steel–reactive powder concrete composite beams using ABAQUS software. Journal of the Mechanical Behavior of Materials 2022;31:416–25. https://doi.org/10.1515/jmbm-2022-0046

[2] Hamad MA, Nasr M, Shubbar A, Al-Khafaji Z, Al Masoodi Z, Al-Hashimi O, et al. Production of Ultra-High-Performance Concrete with Low Energy Consumption and Carbon Footprint Using Supplementary Cementitious Materials Instead of Silica Fume: A Review. Energies 2021;14:8291. https://doi.org/10.3390/en14248291

[3] Al-Masoodi ZO., Al-Khafaji; Z, Jafer; HM, Dulaimi; A, Atherton W. The effect of a high alumina silica waste material on the engineering properties of a cement-stabilised soft soil. The 3rd BUiD Doctoral Research Conference, Dubai, AUE: 2017.

[4] Al-Husseinawi FN, Atherton W, Al-Khafaji Z, Sadique M, Yaseen ZM. The Impact of Molar Proportion of Sodium Hydroxide and Water Amount on the Compressive Strength of Slag/Metakaolin (Waste Materials) Geopolymer Mortar. Advances in Civil Engineering 2022;2022. https://doi.org/10.1155/2022/591070 1

[5] SHUBBAR ALI, Al-khafaji Z, Nasr M, Falah M. Using non-destructive tests for evaluating flyover footbridge: case study. Knowledge-Based Engineering and Sciences 2020;1:23–39. https://doi.org/10.51526/kbes.2020.1.01.23-39

[6] Zhang G, Ali ZH, Aldlemy MS, Mussa MH, Salih SQ, Hameed MM, et al. Reinforced concrete deep beam shear strength capacity modelling using an integrative bio-inspired algorithm with an artificial intelligence model. Engineering with Computers 2020:1–14. https://doi.org/10.1007/s00366-020-01137-1

[7] Al-Khafaji ZS, Al-Naely HK, Al-Najar AE. A review applying industrial waste materials in stabilisation of soft soil. Electronic Journal of Structural Engineering 2018;18:16–23. https://doi.org/10.56748/ejse.182602

[8] Hussain AJ, Al-Khafaji ZS. Reduction of environmental pollution and improving the (Mechanical, physical and chemical characteristics) of contaminated clay soil by using of recycled oil. Journal of Advanced Research in Dynamical and Control Systems 2020;12:1276–86. https://doi.org/10.5373/JARDCS/V12SP4/20201604

[9] Al-Masoodi Z, Dulaimi A, Jafer H, Al-Khafaji Z, Atherton W, Safa H. Soft Soil Treated with Waste Fluid Catalytic Cracking as a Sustainable Stabilizer Material. Iraqi Geological Journal 2022;54:84–98. https://doi.org/10.46717/igj.55.1C.4Ms-2022-03-23

[10] Hussain AJ, Al-Khafaji ZS. The fields of applying the recycled and used oils by the internal combustion engines for purposes of protecting the environment against pollutions. Journal of Advanced Research in Dynamical and Control Systems 2020;12. https://doi.org/10.5373/JARDCS/V12SP1/20201119

[11] Al-Khafaji ZS, Majdi A, Shubbar AA, Nasr MS, Al-Mamoori SF, Alkhulaifi A, et al. Impact of high volume GGBS replacement and steel bar length on flexural behaviour of reinforced concrete beams. IOP Conference Series: Materials Science and Engineering, vol. 1090, IOP Publishing; 2021, p. 12015. https://doi.org/10.1088/1757-899X/1090/1/012015

[12] Shanbara HK, Shubbar A, Ruddock F, Atherton W. Characterizing the Rutting Behaviour of Reinforced Cold Mix Asphalt with Natural and Synthetic Fibres Using Finite Element Analysis. Advances in Structural Engineering and Rehabilitation, Springer; 2020, p. 221–7. https://doi.org/10.1007/978-981-13-7615-3_20

[13] Majdi HS, Shubbar AA, Nasr MS, Al-Khafaji ZS, Jafer H, Abdulredha M, et al. Experimental data on compressive strength and ultrasonic pulse velocity properties of sustainable mortar made with high content of GGBFS and CKD combinations. Data in Brief 2020;31:105961. https://doi.org/10.1016/j.dib.2020.105961

[14] Al-Khafaji ZS, Falah MW, Shubbar AA, Nasr MS, Al-Mamoori SF, Alkhayyat A, et al. The Impact of Using Different Ratios of Latex Rubber on the Characteristics of Mortars Made with GGBS and Portland Cement. IOP Conference Series: Materials Science and Engineering 2021;1090:012043. https://doi.org/10.1088/1757-899x/1090/1/012043

[15] Al-Baghdadi HM, Shubbar AAF, Al-Khafaji ZS. The Impact of Rice Husks Ash on Some Mechanical Features of Reactive Powder Concrete with High Sulfate Content in Fine Aggregate. International Review of Civil Engineering (IRECE) 2021;12:248–54. https://doi.org/10.15866/irece.v12i4.19834

[16] Tuama WK, Kadhum MM, Alwash NA, Al-Khafaji ZS, Abdulraheem MS. RPC Effect of Crude Oil Products on the Mechanical Characteristics of Reactive-Powder and Normal-Strength Concrete. Periodica Polytechnica Civil Engineering 2020. https://doi.org/10.3311/ppci.15580

[17] Falah MW, Hafedh AA, Hussein SA, Al-Khafaji ZS, Shubbar AA, Nasr MS. The Combined Effect of CKD and Silica Fume on the Mechanical and Durability Performance of Cement Mortar. Key Engineering Materials, vol. 895, Trans Tech Publ; 2021, p. 59–67. https://doi.org/10.4028/www.scientific.net/KEM.895.59

[18] Shubbar AA, Jafer H, Abdulredha M, Al-Khafaji ZS, Nasr MS, Al Masoodi Z, et al. Properties of cement mortar incorporated high volume fraction of GGBFS and CKD from 1 day to 550 days. Journal of Building Engineering 2020;30:101327. https://doi.org/10.1016/j.jobe.2020.101327

[19] Hanoon DS, Sallal AK, Shubbar AA, Al-Khafaji ZS, Nasr MS, Al-Mamoori SF, et al. Early age assessment of cement mortar incorporated high volume fly ash. IOP Conference Series: Materials Science and Engineering 2021;1090:012019. https://doi.org/10.1088/1757-899x/1090/1/012019

[20] Shubbar AA, Sadique M, Nasr MS, Al-Khafaji ZS, Hashim KS. The impact of grinding time on properties of cement mortar incorporated high volume waste paper sludge ash. Karbala International Journal of Modern Science 2020;6. https://doi.org/10.33640/2405-609X.2149

[21] Shubbar AA, Nasr MS, Islam GM, Al-Khafaji ZS, Sadique M, Hashim K, et al. Early Age and Long-term Mechanical Performance of Mortars Incorporating High-volume GGBS. Advances in Civil Engineering, Springer; 2022, p. 267–74. https://doi.org/10.1007/978-981-16-5547-0_26

[22] Mukhopadhyay AK. Next-generation nano-based concrete construction products: a review. Nanotechnology in Civil Infrastructure 2011:207–23. https://doi.org/10.1007/978-3-642-16657-0_7

[23] Nazari A, Riahi S, Riahi S, Shamekhi SF, Khademno A. Influence of Al2O3 nanoparticles on the compressive strength and workability of blended concrete. Journal of American Science 2010;6:6–9.

[24] Arefi MR, Javeri MR, Mollaahmadi E. To study the effect of adding Al2O3 nanoparticles on the mechanical properties and microstructure of cement mortar. Life Science Journal 2011;8:613–7

[25] Liu X, Chen L, Liu A, Wang X. Effect of nano-CaCO3 on properties of cement paste. Energy Procedia 2012;16:991–6. https://doi.org/10.1016/j.egypro.2012.01.158

[26] Barbhuiya S, Mukherjee S, Nikraz H. Effects of nano-Al2O3 on early-age microstructural properties of cement paste. Construction and Building Materials 2014;52:189–93. https://doi.org/10.1016/j.conbuildmat.2013.11.010

[27] Al Ghabban A, Al Zubaidi AB, Jafar M, Fakhri Z. Effect of nano SiO2 and nano CaCO3 on the mechanical properties, durability and flowability of concrete. IOP conference series: materials science and engineering, vol. 454, IOP Publishing; 2018, p. 12016. https://doi.org/10.1088/1757-899X/454/1/012016

[28] Cosentino I, Liendo F, Arduino M, Restuccia L, Bensaid S, Deorsola F, et al. Nano CaCO3 particles in cement mortars towards developing a circular economy in the cement industry. Procedia Structural Integrity 2020;26:155–65. https://doi.org/10.1016/j.prostr.2020.06.019

[29] Jawad ZF, Salman AJ, Ghayyib RJ, Hawas MN. Investigation the effect of different nano materials on the compressive strength of cement mortar. AIP Conference Proceedings, vol. 2213, AIP Publishing LLC; 2020, p. 20190. https://doi.org/10.1063/5.0000164

[30] Iskra-Kozak W, Konkol J. The Impact of Nano-Al 2 O 3 on the Physical and Strength Properties as Well as on the Morphology of Cement Composite Crack Surfaces in the Early and Later Maturation Age. Materials 2021;14:4441. https://doi.org/10.3390/ma14164441

[31] Muhsin ZF, Fawzi NM. Effect of Nano Calcium Carbonate on Some Properties of Reactive Powder Concrete. IOP Conference Series: Earth and Environmental Science, IOP Publishing; 2021: 856; 12026. https://doi.org/10.1088/1755-1315/856/1/012026

[32] No A. Specification for aggregates from natural sources for concrete. Bs 1992;882:1–14.

[33] EN TS. 12504-4. Testing concrete–Part 4: determination of ultrasonic pulse velocity. British Standards Institution 2004:18.

[34] ASTM C. Standard test method for density, absorption, and voids in hardened concrete. C642-13 2013.

[35] Al-Khafaji ZS, Falah MW. Applications of high density concrete in preventing the impact of radiation on human health. Journal of Advanced Research in Dynamical and Control Systems 2020;12. https://doi.org/10.5373/JARDCS/V12SP1/20201115

[36] Zainab SAK, Zainab AM, Jafer H, Dulaimi AF, Atherton W. The effect of using fluid catalytic cracking catalyst residue (FC3R) as a cement replacement in soft soil stabilisation". International Journal of Civil Engineering and Technology 2018;9:522–33.

[37] Hussain AJ, Al-Khafaji ZS. Experimental investigation on applying waste iron filings in the engineering fields for protection the environment from contamination. Materials Today: Proceedings 2021. https://doi.org/10.1016/j.matpr.2021.09.039

[38] Ali AM, Falah MW, Hafedh AA, Al-Khafaji ZS. Evaluation the influence of steel- fiber on the concrete Characteristics. Periodicals of Engineering and Natural Sciences 2022;10. http://dx.doi.org/10.21533/pen.v10i3.3111
[39] Fediuk R, Makarova N, Qader DN, Kozin A, Amran M, Petropavlovskaya V, et al. Combined effect on properties and durability performance of nanomodified basalt fiber blended with bottom ash-based cement concrete: ANOVA evaluation. Journal of Materials Research and Technology 2023;23:2642–57. https://doi.org/10.1016/j.jmrt.2023.01.179
[40] Cibilakshmi G, Jegan J. A DOE approach to optimize the strength properties of concrete incorporated with different ratios of PVA fibre and nano-Fe2O3. Advanced Composites Letters 2020;29. https://doi.org/10.1177/2633366X20913882