Zhongguo Kuangye Daxue Xuebao
Journal of China University of Mining and Technology

2024 | Vol 29 | Issue 3 | Page 409-420
Journal Homepage: https://zkdx.ch/
DOI: 10.1654/zkdx.2024.29.3-37

Enhanced Mechanical Properties of Modified Clay Soil Using a Mixture of Nano-Additive and Activator Nano White Cement

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Abstract
Egypt's national highway network expanded by an astounding 98.78% between 2013 and 2024 (from 65.7 thousand km to 130.6 thousand km). The California Bearing Ratio (CBR) test is a crucial test for both road design and maintenance procedures. Also, a tried-and-true, simple technique, CBR test uses in Egyptian highway construction to assess the strength of base course materials and soil subgrades. While adding conventional materials like fly ash, cement, and lime to improve mechanical properties is thought to be environmentally harmful, the new science of the nanotechnology revolution has positive ecological and economic feedback.

The strength of the tested soil varies in each sample depending on the percentage of nano-white cement (N-WCem) alone or combined with the nano-silica (N-Si) additive. The resulting difference in soil strength depends mainly on increasing the percentage of additions, which in turn increases the amount of water for each sample, especially with high percentages of nanomaterials. Thus, the present study tried to evaluate CBR Test in many varying degrees of soaking. Various percentages of the additives N-Si and activator N-WCem were added to the tested soil, namely (0.3, 0.6, 0.9, and 1.2%) and (0.5, 1, and 1.5%), respectively. The improvement in the CBR test values continued when the two materials were mixed, even at low percentages of N-WCem.

Keywords
Nano-white cement, Nano-silica, Kaolin soil, California bearing ratio, unconfined shear strength, Soil stabilization

1. Introduction
The Delta is a central region in the north of Egypt, and clay is the main component of its soil. Recently, it has become a priority for the Egyptian government to focus on establishing a modern and fast road network that connects all parts of Egypt for the purpose of development, encouraging industry and export, and reducing congestion on the old road networks. The highway serves as a main thoroughfare for public transportation between important locations, including big cities and towns (Elbasiouny and Elbehiry, 2019; Ibrahim et al., 2024).
Geotechnical engineering has a crucial role in the construction of highways by working on enhancement the bearing capacity and soil shear strength. The engineer must determine the ideal thickness from the bottom layer of subgrade to the surface course to build a highway that is economical. Using stabilizing agents (binder materials) to improve field soils and restore their geotechnical qualities is referred to as soil stabilization. Soil minerals, and stabilizing agents or binders (cementitious materials) are the traditional components of stabilization technology. Conventional stabilizing materials like; fly ashes, cement, and lime; were used to improve the geotechnical properties (Ur Rahman et al., 2021; Lindh and Lemenkova, 2023).

Cement is a negative eco-material. Despite all its drawbacks, it is a valuable and efficient way to stabilize the soil or make it more efficient to get the soil that is appropriate for the design (Kakavand and Dabiri, 2018). Practical experience has proven that the elevation of the percentage of cement used to improve and raise the soil efficiency, especially when constructing modern road networks that require superior bearing strength, especially in clayey soil areas. So, the new scientific studies should focus on finding alternative eco-friendly materials to reduce the percentage of cement used to improve and raise the soil efficiency.

Nanotechnology has become a major influence in geotechnical engineering in recent years, especially in soil stabilization methods (Haeri et al., 2015; Garcia et al., 2017). Because of its high specific surface area (SSA) and extremely fine particle size, this nanomaterial binds to soil particles quickly. The physical and chemical characteristics of the soil can be altered by even minute amounts of nanomaterial (Kulanthaivel et al., 2021). When nanomaterial is introduced to the soil, either alone or in combination with the activator, it narrows the X-particle spacing and strengthens the bond with the soil's cement constituents (Aguib, 2021; Kulanthaivel et al., 2021).

Previous researches compare between the behavior the additive construction materials in nano-size and particular-size to enhancement the soil properties (Thomas and Rangaswamya, 2020; Liu et al., 2021). They concluded that using nano-size material decrease the amount material used in improving the bearing capacity and soil shear strength because they have fewer pores and less porosity (Thomas and Rangaswamya, 2020; Liu et al., 2021).

Also, other studies recorded that adding above than the optimum percent of the nano-additive material decline the previous enhancement in strength. The explanation of that negative behavior is due to particle agglomeration occurring (Thomas and Rangaswamya, 2020; Nie et al., 2022). Eco-friendly building materials can be made with nanomaterials like nano-silica (N-Si) and nano-white cement (N-WCem). As a result, on-site geotechnical testing is required. The behavior of white cement in the structural elements of buildings is altered when it is reduced to nanoscale (either above or below the soil level). Construction materials treated with N-WCem, like concrete, are thought to be of higher quality because they have fewer pores and less porosity (Thomas and Rangaswamya, 2020). The calcium silicate hydrate (viscous gel) that N-WCem generates in large quantities effectively fills the pores. Another significant benefit of N-WCem is that it has a longer safe storage life than ordinary white cement. For these reasons, it is strongly advised that such important research be supported globally to create new scientific applications in contemporary construction (Thomas and Rangaswamya, 2020). The nanoparticles have positive impact on the soil physical and chemical behaviors such as water absorption and cracks when it loses moisture (Mostafa et al., 2016; Ochepo and Kanyi IM., 2020). The nanoparticles fill the small voids between the soil particles improving the liquid and plastic limits (Adnan et al., 2023).

In geotechnical engineering, especially in pavement and high-road networks design, the California Bearing Ratio (CBR) is a commonly used indirect technique that provides the pavement thickness directly and is used to assess the strength of the subgrade. Therefore, if the CBR value increases, the pavement's thickness will drop, which will lower the pavement structure's building costs (Afrin, 2017; Ayininuola and Balogun, 2018). Therefore, the current research aims to study the effectiveness of adding three different proportions of percents of nano white cement (N-WCem) only/with different percents of nano-silica (N-Si) to decrease harmful geotechnical attributes of kaolin soil and improve its California bearing ratio (CBR).

2. Materials and Method

2.1 Materials

The primary material utilized in the experimental work was the kaolin ore that was received, which came from Wadi Kalabsha in Aswan, Egypt. The used silica sample was provided by Asfour Company for Mining and Refractories in Cairo, Egypt. The white cement (WCem) used in this study was obtained from Sinai White Portland Cement Co. in Cairo, Egypt, and it met ASTM C150 requirements (ASTM C150/C150M, 2022).

2.2 Method

2.2.1 Materials Preparation

To create Nano-size of the N-WCem, the ordinary white cement powder was first thermally treated by burning it in an oven at 400°C for two hours. After that, it was crushed for another two hours using ceramic balls (Alyasiry et al., 2017). The Pulverisette 6 Canada Planetary Mono Mill was used for this grinding process. Dry grinding was carried out with balls ranging in diameter from 3 to 20 mm. Also, the silica powder heated in a Muffle Furnace at Nabertherm GmbH, Lilienthal, Germany, for four hours at 600 degrees Celsius. Then it was grounded for four hours using a Pulverisette 6 Canada Planetary Mono Mill. The final two nano-powder's particle sizes were determined with a laser Microsizer 201C analyzer (InTechSA Ltd, China).

2.2.2 Mixture Preparation

Experiments were conducted on two main groups of mixtures at varying treatment ages (7, 14, 21, and 28 days). Three samples, each with a different percentage of water and N-WCem (0.5, 1.0, and 1.5% by dry weight), make up Group (A). Group (B) is made up of three sub-complex groups (C1, C2, and C3). As shown in Table 1, each sub-group has a different water percentage and each group has a fixed percentage of N-WCem and four percentages of N-Si (0.3, 0.6, 0.9, and 1.2 dry weight %). For a minimum of fifteen minutes, the nanomaterials were combined with half as much water. To prevent the agglomeration of nanomaterial particles, use a Sonicator (FALC Instruments, Italy) Figure 1 (A, B). Next, combine the kaolin soil with the remaining half of the water volume, as shown in Figure 2. Pressure testing was used to determine the ideal water intake, yielding the maximum dry density (MDD) and optimal moisture content (OMC) (Shalaby et al., 2024). Following thorough mixing with water, the samples were stored for the various treatment ages (7, 14, 21, and 28 days) in a closed container filled with wet sawdust Figure 1(C) for CBR. The CBR test was run three times for each mixture, and the average readings were noted. To compare and examine the changes in internal structure when using only N-WCem, the prepared samples were characterized using SEM-EDX.

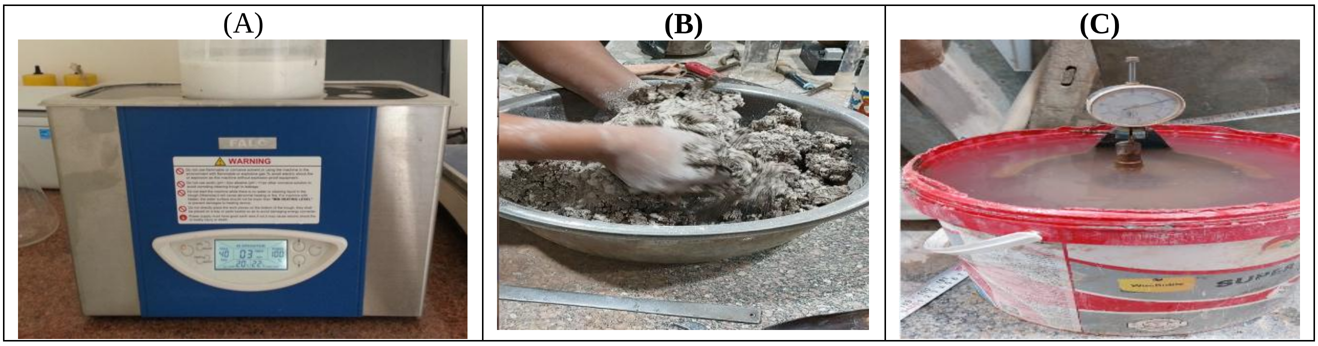


Fig. 1 A) Sonicator, B) after mixing, and C) Preparation CBR test the curring days in putting in wet sawdust

Table 1 Investigated modified soil mixes

Tested soil	Material Component		Mixture Code
	N-WCem %	N-Si %	
kaolin	0	0	M0,0

Group	NO	Material Component		Mixture Code
		N-WCem %	N-Si %	
1	1	0.5	0	M1,0
	2	1	0	M2,0
	3	1.5	0	M3,1

Group	NO	Material Component		Mixture Code
		N-WCem %	N-Si %	
2A	4	0.5	0.3	M1,1
	5	0.5	0.6	M1,2
	6	0.5	0.9	M1,3
	7	0.5	1.2	M1,4
2B	8	1	0.3	M2,1
	9	1	0.6	M2,2
	10	1	0.9	M2,3
	11	1	1.2	M2,4
2C	12	1.5	0.3	M3,1
	13	1.5	0.6	M3,2
	14	1.5	0.9	M3,3
	15	1.5	1.2	M3,4

3. Results and Discussion

3.1 Physicochemical Composition of the Raw Materials

The chemical constituent of kaolin is mainly SiO_2 (66%), AL_2O_3 (23%), Fe_2O_3 (5.45%), and other minor impurities (MnO; MgO; CaO; Na_2O; K_2O; P_2O_5; Cl; as well as SO_3). The XRD result of the kaolin sample shows the peaks of kaolinite and quartz minerals. The physical characteristics of the unmodified kaolin soil sample indicate that it is composed of 48.7% silt and 51.29% clay. Additionally, the kaolin soil sample's liquid limit [39.72%], plastic limit [21.22%], plasticity index [18.5%], MDD (Maximum dry density; 1.85 g/cc), OMC (Optimum Moisture Content [14%], UCS (Unconfined Compressive Strength [65.94 Kpa/m^2]), and CBR (California Bearing Ratio) are, (29.72, 21.22, 18.5, 1.85, 14, 65.94, and 2.1, respectively). The unified soil classification system (USCS) classified the soil as stiff kaolin soil. The kaolin ore sample's average particle size (D_{50}) is 1497.7 nm. Figure 2 (A) displays the SEM image of the kaolin ore sample, demonstrating the micro-scale presentation of kaolin ore.

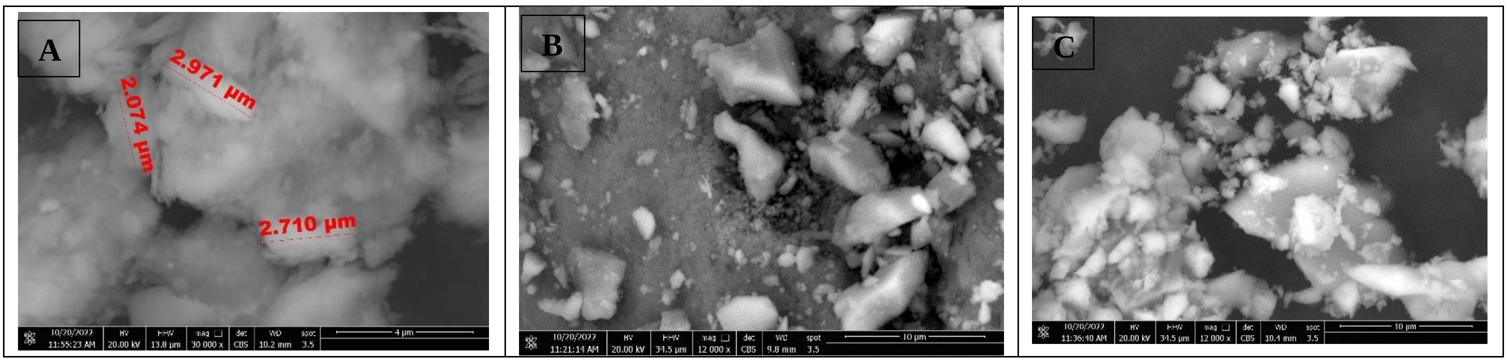


Fig. 2 SEM image of A) Kaolin, B) N-Si, and C) N-WCem particles

The chemical constituent of N-Si is mainly SiO_2 (97.63%), AL_2O_3 (0.13%), MgO (0.11%), CaO (0.14%), Na_2O (0.21%), and other minor impurities (Fe_2O_3; and P_2O_5). The prepared N-Si sample's XRD shows that quartz minerals make up most of the sample. The average N-Si particle size is 582.2 nm. Figure 2(B) displays the prepared N-Si sample's SEM image.

The XRD analysis results of the prepared N-WCem are Calcite ($CaCO_3$); dicalcium Silicate (C_2SiO_4); tricalcium Silicate (C_3SiO_5); Halite NaCl; Tricalcium aluminate ($C_3AL_2O_6$); Gypsum ($CaSo_4.2H_2O$); and Pyrite (FeS_2). The average N-WCem particle size is 794.9 nm. Figure 2 (C) shows the SEM image of the prepared N-WCem sample. Additionally, the declaration of performance of white cement (No.2092/02-Dop) [from Sinai White Portland Cement Company, Egypt] is Initial setting time, Soundness/Explanation, SO_3 content, Cl content, Portland Cement Clinker, Limestone, Minor additional constituents.

3.2 The Mechanical Properties of the Modified Soil

3.2.1 California Bearing Ratio (CBR) and Use in Pavement Design Method

The universal criterion for estimating the physical strength and weakness of natural and treated soil for subgrade construction is the California Bearing Ratio (CBR). The CBR test was conducted in compliance with ASTM D 1883-94. After four days, each soil sample was submerged in wet sawdust. Three trials were conducted for this test, and the average was calculated. Figures 3-6 display each sample's test results. The dry density and water content of the soil are two factors that have been used to calculate the CBR value. The test was conducted on three layers within 55 blows for each layer separately because the CBR measurements, also known as the basic soil strength, were primarily dependent on the degree of soil compaction.

As illustrated in Figure 3, all treated samples (0.5 %, 1.0 %, and 1.5% N-WCem) exhibit a significant strength improvement (CBR value) when compared to a control sample in varying curing days. The capillary action and attractive forces between the cement gel, clay, and the large cluster of N-WCem are responsible for this increase in CBR strength. Additionally, the N-WCem's pozzolanic action sped up the hydration process and combined with Ca $(OH)_2$ to create the C-S-H gel network (Sasanian and Newson, 2014).

$$Cao + H_2O \longrightarrow Ca(OH)_2 \text{ [Calcium hydroxide] ……. Hydration Reaction}$$

$$Ca(OH)_2 \rightarrow Ca^{2+} + OH^{-} \quad \text{……………………… Dissociation Reaction}$$

$$Ca^{2+} + SiO_2 \longrightarrow \text{CSH [Calcium Silicate Hydrate] …Pozzolanic Reaction}$$

As seen in Figure 4, adding N-Si to the binary mixtures containing N-WCem increased the CBR value in comparison to the untreated samples. The C-S-H gel and the N-Si particles formed a solid bond because the N-Si particles could function as the nucleus.

Additionally, they could generate a significant number of white cementitious hydration product nucleation sites, which would improve the microstructure of the gel and increase the soil mixture's strength and durability (García-Lodeiro et al., 2010; Wong et al., 2020). Due to the hydration process that occurred over time and produced more Ca $(OH)_2$, which reacted with the nano-added ingredients on the surface of soil particles to form additional C-S-H gels, the treated mixture strength was enhanced in long curing samples [Figure 5, Figure 6]. These pozzolanic reactions improved the soil's engineering qualities and happened gradually over time. The improvement in CBR matches the results of Wong et al. (2020), Onyelowe et al., (2021), Marik et al. (2022) concurs with this result.

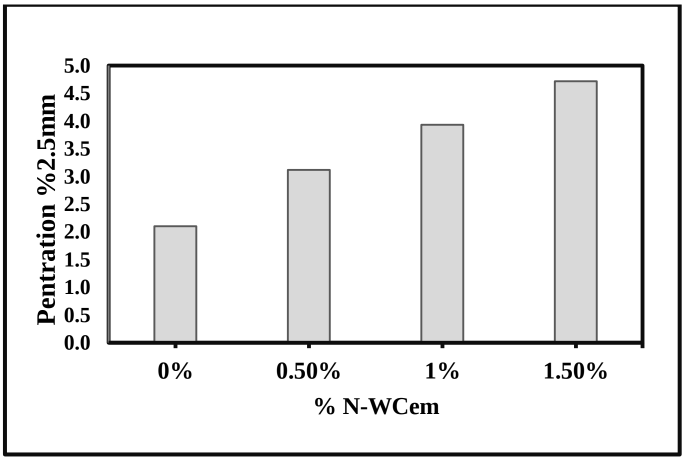


Fig. 3 Effect of N-WCem addition on the CBR of the treated soil mixtures after 4 days of curing age

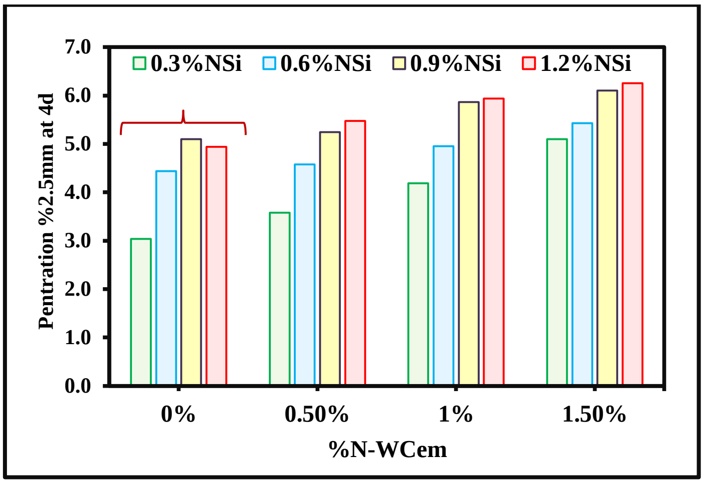


Fig. 4 Effect of N-WCem and N-Si addition on the CBR of the treated soil mixtures after 4 days of curing age

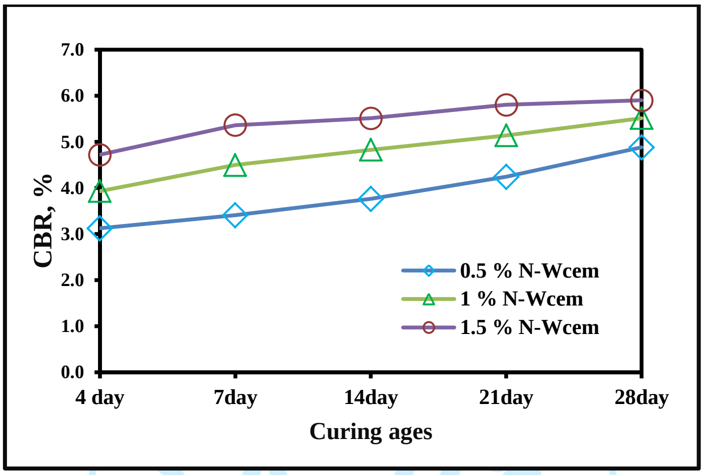


Fig. 5 Effect of curing age on the California Bearing Ratio (CBR) of the treated soil in the presence of Different percentages of N-WCem

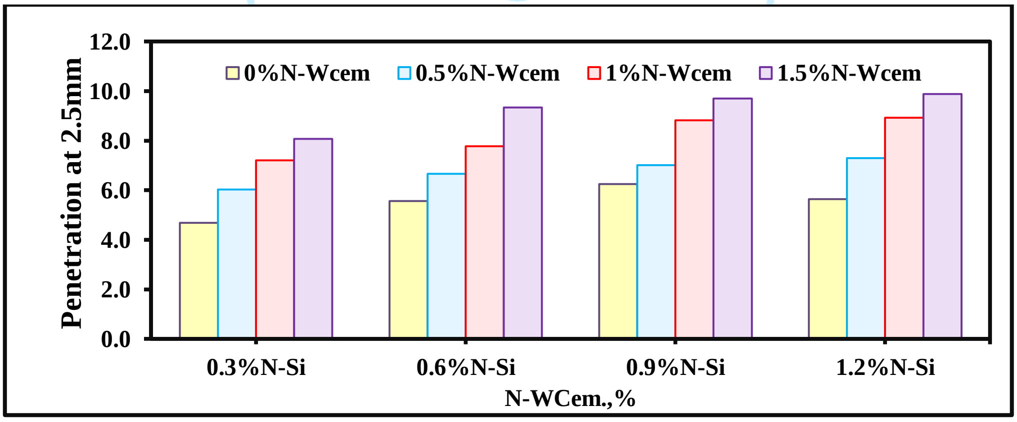


Fig. 6 Gaining the CBR value of the treated soil with the addition of a mixture of N-W Cem. & N-Si Mixture after 28 days curing age

Based on the results and discussions previously discussed and through the groups recorded in Table 1, the following conclusions were reached:

In Group 2, by comparing the CBR reading at sample No. (7) [the lowest precent of N-WCem (0.5%) and highest precent of N-Si (1.2%)] with the CBR reading at sample No. (8) [the precent of N-WCem (1%) and lowest precent of N-Si (0.3%)] gives enhancing by approximately 1.1%.

By comparing the CBR reading at sample No. (11) [N-WCem (1%) and highest percentage of N-Si (1.2%)] with the CBR reading at sample No. (12) [The highest percent of N-WCem (1.5%) and lowest percentage of N-Si (0.3%)] gives enhancement by approximately 9.6%.

So, it was observed that using the lowest percentage of N-WCem accompanied with the minimum percentage of N-Si led to reduce the amount of N-WCem which is the main objective of the current study.

3.2.2 The Effect of N-Wcem & N-Si Addition on the Microstructural Composition of Modified Clay Soil Mixtures

It was evident that both calcium hydroxide and C-S-H gel (calcium silicate hydrate) formed during the pozzolanic reaction of N-WCem in the presence of water were present in the soil samples treated with N-WCem and soil samples treated with the nanoparticle mixture (N-Si). The formation of C-S-H gel gave the N-WCem treated soil its increased strength (which was recorded before in the results) compared to the untreated soil. As a result, it could be confirmed that the presence of the two nanomaterials increased the N-WCem and N-Si particles which was the main reason for the strong bonding strength between the gel-coated ettringite needle and soil structures (tested kaolin) which leads to reduce the pore size between the tested soil particles (Gupta and Kumar, 2016; Ng et al., 2020; Al-Saffar et al., 2023).

To learn more about these ettringite needles and how they are formed and spread between soil particles, it is important to know that clinker is the main component of white cement. It is important to know that clinker is made from raw materials in a cement kiln with calcium sulfate and 5% gypsum rocks by weight and is heat-treated in stages. The first stage produces clinker, which is tetra-calcium alumino-ferrite (C_4AF) and dicalcium silicate (C_2S). The second stage produces tricalcium aluminate (C_3A), followed by the third stage tricalcium silicate (C_3S). It is necessary to know some of the basic symbols in cement chemistry, the most important of which are: C = CaO, S = SiO_2, A = Al_2O_3, and F = Fe_2O_3. Then comes the role of the clinker grinding process, which turns it into a fine powder, which in turn increases the hydration rate (to increase the surface area exposed to water when adding the specific amount for each sample). The pozzolanic reaction can be simply identified by the exchange of both cations and agglomeration at room temperature, and therefore this mechanism is the most important in the stabilization steps. The reactions can be organized in the form of equations of the following form.

$$2C_3S + 6H \rightarrow C\text{-}S\text{-}H + 3Ca\,(OH)_2 \quad \text{……………………….Equation 1}$$

$$2C_2S + 4H \rightarrow C\text{-}S\text{-}H + Ca\,(OH)_2 \quad \text{…………………………Equation 2}$$

Where, H = H_2O and C-S-H = calcium silicate hydrate ($C_3S_2H_3$).

Another possible reaction between calcium and alumina is C-A-H, which has cementing properties. The responses are as follows:

$$Ca\,(OH)_2 + SiO_2 \rightarrow C\text{-}S\text{-}H \quad \text{………………………………Equation 3}$$

$$Ca\,(OH)_2 + Al_2O_3 \rightarrow C\text{-}A\text{-}H \quad \text{……………………………Equation 4}$$

To arrive at the above equations, one must focus on the specific doses of water which are determined from the experiment of the proctor Test, which agree with Herzog and Mitchell (1963) demonstrated the necessity of dissolving basic soil elements such as silica and alumina to produce more cementitious materials (C-S-H and C-A-H). The results of the analysis of the soil to be improved were as follows: silica (51.6%), alumina (28.31%) and other trace elements in the soil. The hydration process makes the clay porous, resulting in the production of C-S-H (calcium silicate hydrate) gel, which reduces porosity and increases soil strength. Using N-Si with the lowest possible dose of N-WCem (0.5%) improved the strength of tested soils, which may have potential environmental and economic benefits. By adding N-WCem, the calcium hydroxide in the tested soil reacts with the silica and alumina, resulting in a pozzolanic reaction. N-WCem (as Nano size) is superior compared to WCem (as particle size) in its ability to generate a higher proportion of calcium silicate hydrates causing complete fill of the pores in agreement with previous research (Changizi and Haddad, 2017; Tang et al., 2021). The engineering properties of the tested soils were enhanced by these slow-moving pozzolanic reactions where it needs more curing time to arrive to the maximum strength which in agreement with previous research [Mostafa et al., 2016; Changizi and Haddad, 2017; Aguib, 2021]. By adding N-Si to the tested mixture (N-WCem and soil), the hydration process of N-Cem was increased and the soil strength was improved, because nano silica has a high capacity to absorb water, whether in the particular size or nano form, which has a higher capacity than in the particular size case.

To confirm all the results that were reached, it was necessary to use SEM to identify the Ettringite needles and calcium silicate hydrate (C-S-H) that distributed throughout the sample form on clay soil (Figure 9 [1] and Figure 10 [1]). The effect of those needles on the sample was noticeable which leads to reduced pore spaces which in turn helped to strengthened soil structures, and an increase in strength (Ural, 2021). Figure 9 [2] shows the EDX results of a kaolin soil sample treated with N-WCem. Furthermore, Figure 10[2] displays the EDX results of a kaolin soil sample treated with N-WCem and having N-Si in optimal condition. As shown in Figures (9 and 10), the Ettringite needles are spread throughout the sample mixed with cement alone, while in Figure 10 (1) there was a high-density gel covering the Ettringite needles so that the interstitial spaces between the tested soil particles were reduced. Through the bonding between the kaolin particles and the added particles, as shown in Equations (1-4), the combination of N-WCem and N-Si can give the soil mixture stiffness and strength.

The presence of the sticky gel that resulted from the presence of N-Si materials that have a high capacity to absorb water, which creates a strong cohesion and covers the Ettrengite needles and it was larger than the size of the Ettrengite needles individually, which helps to reduce the gaps between the clay particles and the additives, which in turn increases the friction force between the soil sheets and thus makes the friction force very high, so the tested sample becomes very cohesive, which explains the increase the strength in the CBR in The diagram Figure (7). The diagram illustrates the effect of the treatment of clay soil by the addition of N-WCem only and in mixed with both of N-WCem and N-Si, as confirmed by the SEM picture in Figure 7 (C) the above conclusion of tested soil with both additive & activator, showing the dense viscous gel coating Ettringite needles.

In Figures (9 and10), by focusing on specific points (A, B, C, D and E) using EDX test the results show peaks for silicon, aluminum, calcium, oxygen, and carbon. By concern on the calcium aluminate hydrate (CAH), aluminum is a cementing element that converting into aluminates. The fact that the stabilized soil contains more aluminum indicates that the stabilization has strengthened the soil, which in turn explains the clear increase in CBR values in both Figures (5 and 6). Thus, in the presence of water, the calcium available in N-WCem and kaolin reacts with the alumina and silica from kaolin clay and N-Si to produce stabilized calcium silicate hydrate and calcium aluminate hydrate, that improve the geotechnical properties of the soil and results in long-term strength gain which was in agreed with Attaha et al. (2020), ElDeeb et al. (2022), and Nnochiri et al. (2023). Therefore, it is necessary to reach a confirmed fact about the importance of the role of additives and activators with each other, as they work as fillers for spaces and cracks in the soil, which leads us to the explain of the reasons for the improvement of all the properties of the tested soil, that confirming the fact that the better the degree of dispersion and distribution within the soil, the greater the improvement of the mechanical properties.

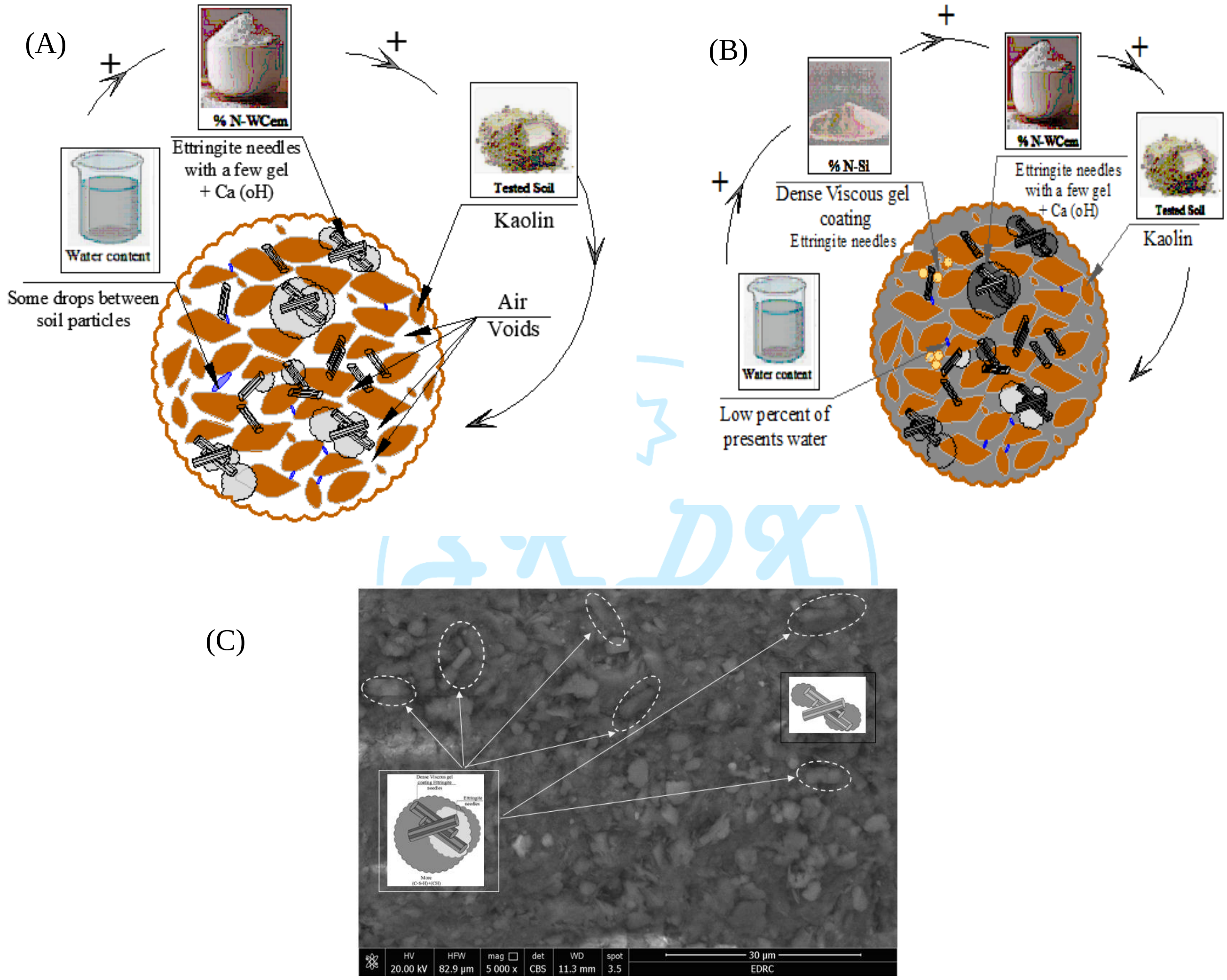
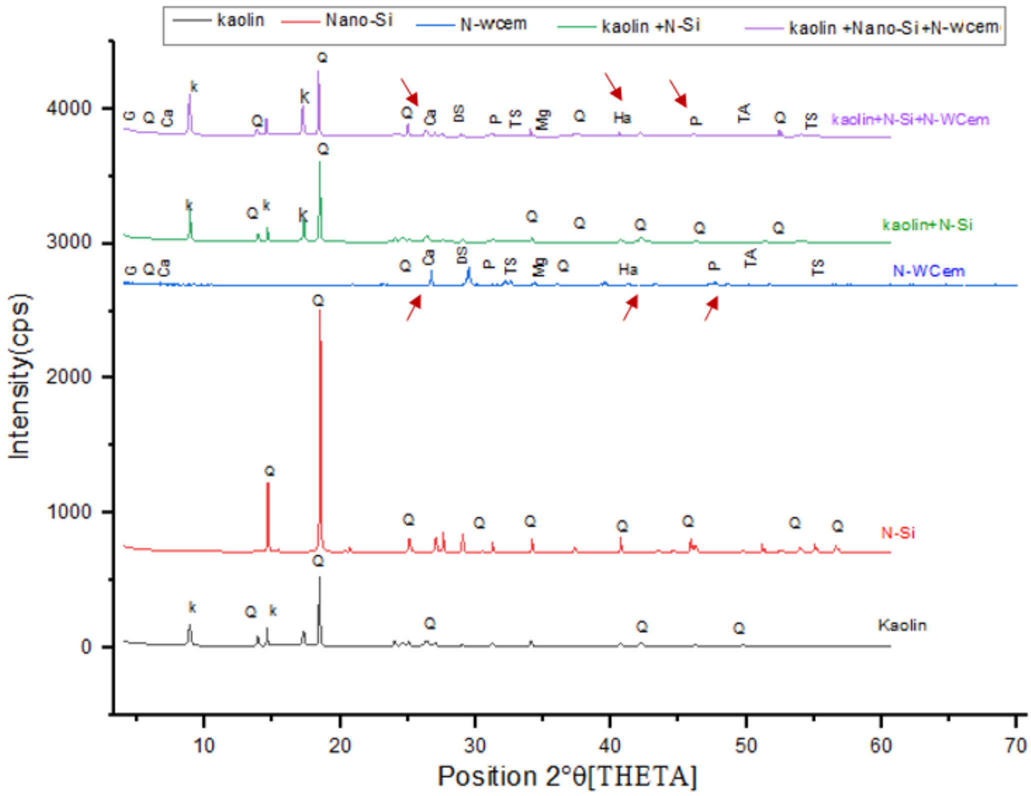


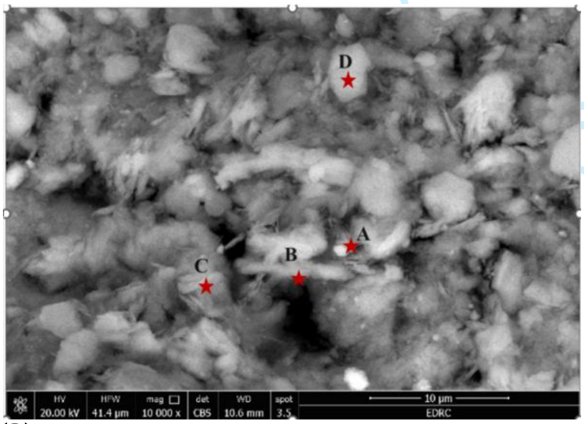
Fig. 7 The diagram illustrates the effect of the treatment of clay soil by the addition of N-WCem only and mixed with both N-WCem and N-Si. A) Tested Soil with N-WCem, B) Tested soil with both Additive (N-Si) and Activator (N-WCem), and C) SEM picture of tested soil with both Additive and Activator, showing the Dense Viscous gel coating Ettringite needles



G:Gypsum CaSO42H2O	Ha:Halite NaCL	K: Kaolinit SiO4
Q:Quartz SiO2	He:Hematite Fe2O3	
ca:Calcite CaCo3	TSi: Tri Calcium Silicate C3SiO5	
DSi:Di Calcum Silicat C2Si4	TAL:Tri Calcium Aluminate C3AL2O6	
P:Prite FeS2		

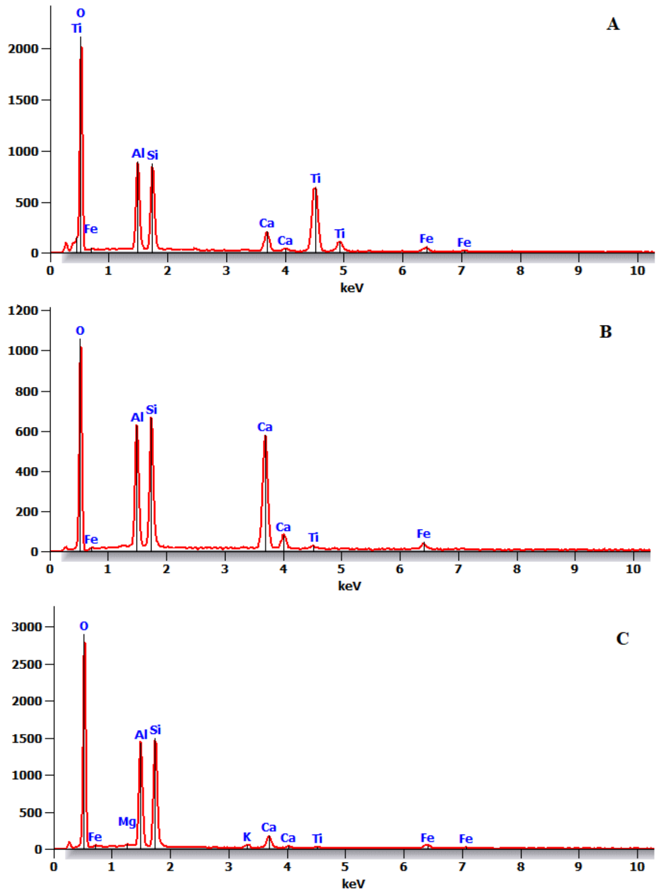
Fig. 8 XRD analysis of different tested soil samples

(1)



(2)

Weight, %	Pt-1	Pt-2	Pt-3	Pt-4	Pt-5
O	53.4	50.4	56.6	50.3	54.1
Mg	-	-	0.4	-	-
Al	8.2	10.5	15.2	17.2	13.5
Si	8.7	12.1	18.9	20.7	17.1
K	-	-	0.9	-	0.3
Ca	4.1	21.7	3.9	1.0	9.3
Ti	22.8	1.3	0.6	0.3	1.2
Fe	2.8	3.9	3.6	10.5	4.6



Atom %	*Pt-1*	*Pt-2*	*Pt-3*	*Pt-4*	*Pt-5*
O	72.9	68.3	71.0	66.4	69.9
Mg	-	-	0.3	-	-
Al	6.6	8.5	11.3	13.5	10.4
Si	6.8	9.4	13.5	15.5	12.6
K	-	-	0.5	-	0.1
Ca	2.2	11.7	1.9	0.5	4.8
Ti	10.4	0.6	0.2	0.2	0.5
Fe	1.1	1.5	1.3	4.0	1.7

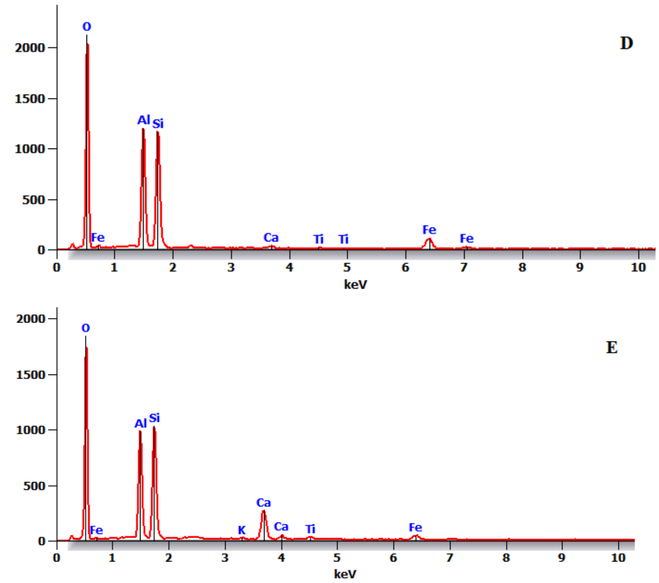
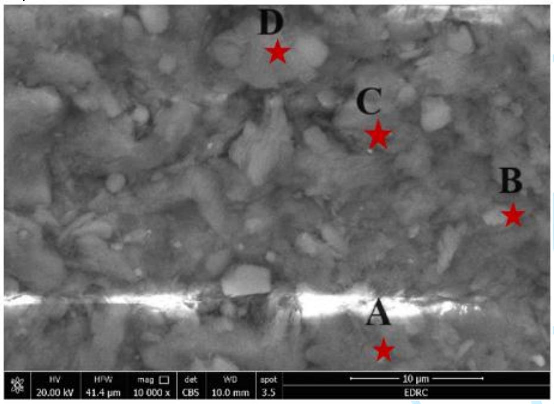


Fig. 9 (1) SEM image of soil + N-WCem (at ×10 µm) and (2) its elemental composition (Table on right) after 28 days of curing

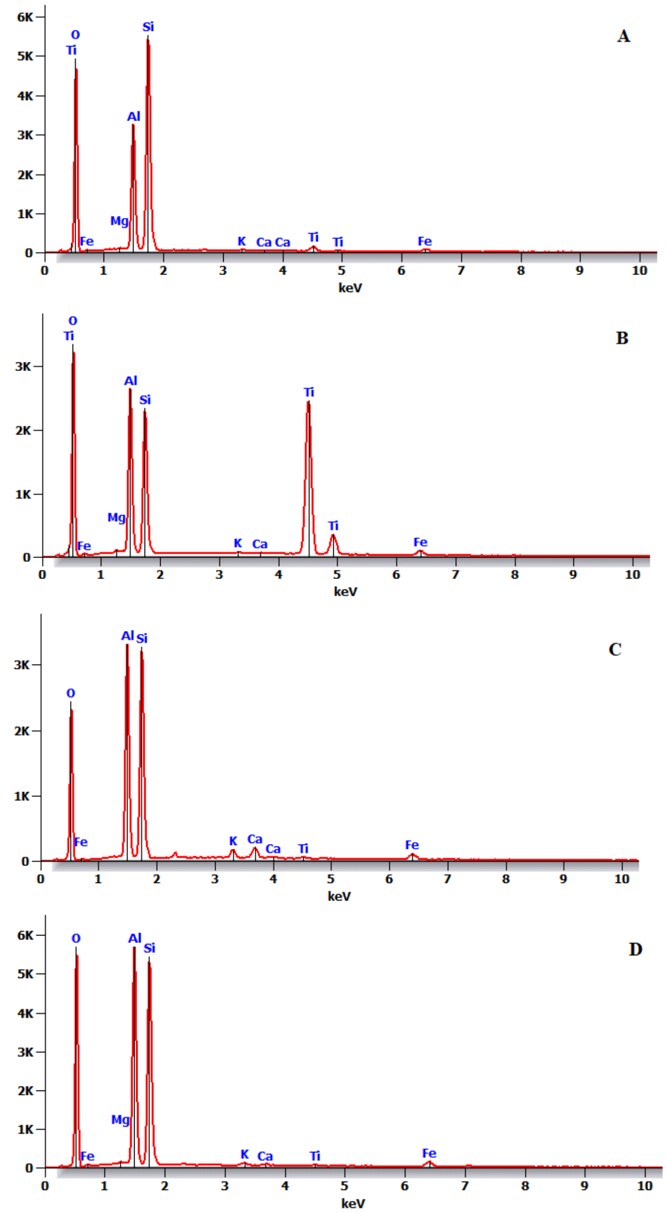
1)



2)

Weight, %	*Pt-1*	*Pt-2*	*Pt-3*	*Pt-4*	*Pt-5*
O	47.8	43.7	39.1	44.7	45.0
Mg	0.1	0.1	-	0.2	-
Al	14.7	10.2	22.0	21.9	16.2
Si	32.1	10.3	28.2	27.1	28.1
K	0.2	0.2	2.1	0.7	0.5
Ca	0.1	0.2	3.1	0.4	3.0
Ti	2.6	33.1	0.7	0.6	1.7
Fe	2.3	2.3	4.7	4.4	5.5

Atom, %	*Pt-1*	*Pt-2*	*Pt-3*	*Pt-4*	*Pt-5*
O	62.5	64.7	54.4	59.5	60.7
Mg	0.1	0.1	-	0.2	-
Al	11.4	8.9	18.2	17.3	12.9
Si	23.9	8.7	22.3	20.5	21.6
K	0.1	0.1	1.2	0.4	0.3
Ca	0.1	0.1	1.7	0.2	1.6
Ti	1.1	16.4	0.3	0.2	0.8
Fe	0.9	1.0	1.9	1.7	2.1



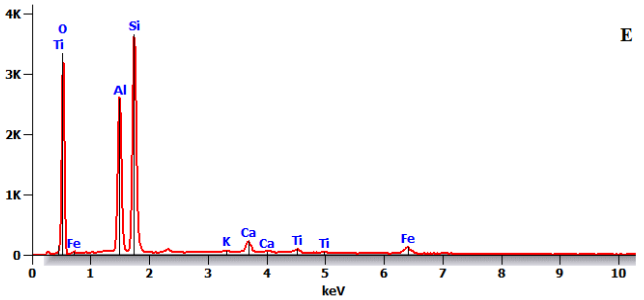


Fig. 10 (1) SEM image of soil + N-WCem + N-Si (at ×10 µm) and (2) its elemental composition (Table on right) After 28 days of curing

4. Conclusion

The goal of the study that is being presented to assess the altered kaolin clay soil that has had varying amounts of N-WCem alone and N-Si added to binary mixtures that contain N-WCem. One way to "summarize" the conclusion is as follows:

The effect of adding nanomaterials on the physical properties of the soil was measured and gave an improvement in the results compared to the tested soil without additives. The positive effect of adding the two previous nanomaterials on the CBR test of the tested soil has been recorded, which differed from using N-WCem alone, due to the presence of N-Si doubled the production of viscous gel and covered the Ettringite needles with increasing the volume of the filler material between the soil sheets and reduced the interstitial spaces. According to the results, N-Si and N-WCem improved the CBR of sample number 6 (0.9%N-Si and 0.5% N-WCem ratio of both materials) compared with the sample number 1 (0.5% N-WCem only) by 44% after 28 days of treatment. So, using the lowest percentage of N-WCem accompanied with the optimum percentage of N-Si improves soil properties and reduces the harmful environmental impacts of N-WCem. SEM and EDX analysis showed that the small particle size for the N-Si and N-WCem represents the main factor that improves the tested soil behavior, as they act as filler for the interface spaces among soil grains. The significant positive effect of N-Si addition is due to the double coating effect on the present Ettringite needle plus the chemical hydration reaction with the free Ca $(OH)_2$ having more production of C-S-H gel.

So, the use of nano materials is expected to be a sustainable and environmentally friendly solution. given the positive impact that use in nano form which decreases the amount of cement in the future infra-structure.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Author Contributions

Ola Bakr Shalaby: I am a PhD student, and all parts of the work are parts of my PhD thesis under the supervision of the rest of the authors (Prof. Ayman L. Fayed; Prof. Nabil M. Nagy; Prof. Hala M. Elkady and Dr. Mohamed Salah). Dr/ Amr B. ElDeeb supervise the XRD part and SEM.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

All authors' names that participate in the manuscript are mentioned.

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