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Effect of nanosilica on properties of porcelanite aggregate concrete

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Abstract. Lightweight concrete has been used in buildings for centuries, due to its longevity and durability. In recent years, new studies have shed light on additives capable of reducing concrete weight while increasing strength. Nanosilica is one of these additives, which regulate the fundamental Calcium Silicate Hydrate CSH process in water. The addition of nanosilica (NS) particles to concrete improves its density and strength. In this work, we started by creating a reference mixture without additives and another mixture containing a different ratio of nanosilica. Porcelanite was used as a lightweight aggregate. First, the porcelanite aggregate was crushed into pieces of different sizes (6 and 9.5 mm). The results of testing under compression showed that mixes containing 1, 1.5, 2 wt. percent of nanosilica gave the best results when compared to a reference mix without nanosilica. Porcelanite rich in SiO_2 and nanosilica were utilized to partially substitute cement. A comparison was made with the reference mix (without nanosilica) to figure out the efficiency of using nanosilica in lightweight porcelanite concrete. The highest average compressive strength at a particle size of porcelanite (6 mm) of 18.1 MPa and 15.3 MPa can be obtained at 28 days using 1.5 and 2 wt. percent of nanosilica, with 40.3 % and 18.6 %, respectively. The addition of 1 wt. percent of NS, on the other hand, has a negative effect on the compressive strength of 6 mm grain size porcelanite by a factor of not more than 2.3 % at 28 days. Flexural strength of 3.04 MPa can be obtained at 28 days using 1.5 wt. percent of NS at a particle size of 6 mm of porcelanite, with percentages of 424.1 %. The flexural strength of porcelanite aggregate concrete increases with a low percentage of various NS. The bulk density decreases when using porcelanite aggregate concrete at 6 mm and 9.5 mm particle sizes with 2 % from nanosilica by 4.84 % and 8.86 %, respectively. field Emission Scanning Electron Microscope FESEM test was carried out to study the structure of the fractured nature of the highest compressive strength samples and reference.

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1. Introduction

Lightweight aggregate concrete (LWAC) is not a new concept in the world of concrete; however, it has been used for thousands of years. The durability and longevity of concrete are demonstrated by ancient buildings [1]. LWACs building materials included pumice, scoria, and other naturally occurring volcanic debris [2]. In construction, the weight represents a great issue. Luckily, the LWAC may be produced by utilizing LWA (lightweight aggregates) [3]. Porcelanite lightweight aggregate rocks were discovered to be a locally available material in the production of cost-effective Structural Lightweight Concret (SLWC) [4]. Due to its low weight and high strength, Lightweight Concrete LWC has recently been the focus of many studies. [5–7]. The equilibrium density of structural lightweight concrete ranges between 1120 and 1920 Kg/m^3.This type of concrete, which is suitable for structural purposes, must have a compressive strength of 17 MPa after a 28-day water cure [8]. Low Strength Concrete LSC is defined as concrete with a compressive strength of less than 17.0 MPa after 28 days; Medium Strength Concrete MSC is defined as concrete with a compressive strength of between 17 and 27 MPa; and High Strength Concrete HSC, which is defined as concrete with a compressive strength of more than 41 MPa [9]. Nanotechnology is a new approach to science that deals with the understanding and control of matter at the nanoscale, or between 1 and 100 nanometers in size [10]. Nanosilica NS is one of the nanomaterials utilized in the formation of building materials, has generated a lot of concern [11]. Adding NS to concrete mixtures has improved the materials properties [12]. NS has a larger surface area due to the small size of its particles, which improves cement hydration and pozzolanic processes, according to recent research [13]. NS has a high reacting pozzolan that can put away Calcium Hydroxide CH and generate subsidiary Calcium Silicate Hydrate (CSH) [14, 15]. A few studies show that adding nanosilica has a greater effect on primary silicate polymerizing compared to the CSH quantity produced in the end [16]. Microstructural studies indicated that NS considerably impacts the concrete pore properties, resulting in denser and stronger microstructures. [17]. Another process by which NS might affect the characteristics of cement composite is the seeding effect, where hydration products are preferentially exposed to more places for them to precipitate [18, 19].

The application of nanoconcrete is used in civil engineering projects such as highway bridges [20], dams, and structural buildings.

The objective of this study is to investigate their effects on some concrete qualities, such as compressive strength, flexural strength, bulk density, and microstructure analysis by Field Emission Scanning Electron Microscope FESEM, by adding nanosilica to porcelanite aggregate concrete and comparing all properties of porcelanite concrete without nanosilica (reference concrete) with porcelanite concrete with nanosilica. As a lightweight cement substitute, two grain sizes of 6 and 9.5 mm of crushed coarse porcelanite aggregates were used in this work. Nanosilica was added in different percentages (0, 1, 1.5, and 2 wt. percent to the cement content as an aggregate substitute in concrete with a mixing ratio of cement, sand and porcelanite 1:1:1.

2. Materials and Methods

2.1. Materials

table one and table two show the chemical and physical compositions of regular Portland cement Type1 that was utilized, manufactured by al Mass Factory, Iraq. The test results indicate that the adopted cement conformed to ASTM C150-16 [21] and Iraqi Standard Specifications (IQS No.5, 1984) [22].

Table 1. Chemical parameters of regular Portland cement.

Constituent	Lime (CaO)	Silica (SiO_2)	Alumina (Al_2O_3)	Iron Oxide (Fe_2O_3)	Magnesia (MgO)	Sulfur Trioxide (SO_3)
Weights %	61.5	20.8	3.5	3.2	1.7	2.5
ASTM C150-16	–	20 (min)	6 (max)	6 (max)	6 (max)	3 (max)
Limited of IQS No.5 %	–	–	–	–	≤ 5	≤ 2.8

Table 2. Physical parameters of regular portland cement.

Constituent	Specific surface area m^2/kg	The Primary setting time h min	Last setting period h min	Compressive strength (MPa) 3 Days	Compressive strength (MPa) 7 Days
Weights%	350	2 20	8 20	17	24
ASTM C150-16	280 min	00 45	06 25	10 min	17 min
Limited of IQS No 5	–	1 00	10 00	≥ 15	≥ 23

Silicon dioxide (SiO_2) nanopowder was also utilized in the current experimentation work, manufactured by skyspring nanomaterials, USA table three shows the properties of the nanomaterial according to data sheet.

Table 3. Nano-silica (SiO_2) Properties.

Product Name	Color	Particle Size (nm)	Surface area (m^2/g)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)
Silica Powder Nano Grade	White	20	160	0.002	0.001	0.002	0.001

In this study, porcelanite was used as a coarse aggregate, it is locally available, and exits in nature as a lightweight and white in color stone. The Ministry of Industry and Minerals State Corporation of Geological Sciences Survey and Mining received porcelanite in huge lumps. Porcelanite stones avail in Wadi Mallusa (Rutba) at a location called El-Anbar Provinces Western Desert, Iraq; it is done according to ASTM, C330-05. [23]. See table four.

Table 4. Properties of lightweight porcelanite aggregate.

Product Name	Color	Water absorption %	Saturation %	Thermal conductivities W/m. K	apparent density Kg/m^3	density Kg/m^3
Lightweight Porcelanite aggregate	Off white	39	3.5	0.2 -1.0	1600 -1900	1447

EUCOBET SUPER VZ is a superplasticizer with a stunting influence that is made from synthetic materials, manufactured by Swiss Chem., Egypt, table five depicts its proprieties according data sheet.

Table 5. Properties of Superplasticizer according to data sheet.

Product Name	Color	Specific gravity	Chloride content	Air entraining	Compatibility with cement	Shelf life
EZ	Brown	1.1	Nil	Does not entrain air	All type of Portland cement	Up to 2 years

In this work, the cementations mix included NS with a purity of 99.5 percent and a bulk density of 0.08 to 0.10 g/cm^3. A commercially available colloidal silica suspension nanosilica NS was used to make the concrete, table three shows nanosilica's characteristics.

3. Methods

3.1. Dispersing nanomaterial in water

Nanosilica must be dispersed in water before adding it into the concrete mix. The ultrasonic method was to disperse the nanomaterial in water [24]. Before starting dispersal, using gloves and face mask. That the handling of nanomaterials is a dangerous process. First, the nanomaterial required for each sample batch of the design mixture was weighed and placed into a beaker. A quantity of water was poured and mixed. Ultrasound for this purpose is placed at a frequency of 100 Hz. Note that mixing the dispersed nanomaterial into the concrete mixture was done within 5 minutes to keep it constant.

3.2. Samples' preparation

table six shows the mixture design employed in the current experimentation, it is done in the concrete laboratory in Technology university as well as the amount of utilized design material. The difference between each batchs mix compositions is the percentage of nanosilica used and the grain size of porcelanite.

Measuring all essential components was done in accordance with the mix design percentage before the concrete mixing commenced. After wetting the concrete mixer, it was added the entire dry mix components, such as porcelanite, sand, and cement. After that, in the mixer, 10 percent of the needed water was provided and thoroughly blended. The left water was then added, preceded by the nanomaterial that had been disseminated. The materials were combined until the mortar and concrete became homogeneous.

For eight of the concrete mixtures containing (48 samples), the concrete got poured and put flat into lubricated cubic molds with dimensions of 100 mm *100 mm * 100 mm . It is done according to BS 1881-116 1983 [25], and prism molds with dimensions 280 mm * 75 mm *75 mm, it is carried out in accordance with BS 1881-101 1983 [26]. Were used to cast three specimens A, B and C at each batch, out of a total 24 cubic samples and 24 prism samples.

For compaction, three layers of concrete were placed in each mold, and a vibrator was used for around 3–4 minutes to equally disperse the concrete. Finally, a trowel was used to smooth out the molds.

For each mixture, three samples are poured and the average is taken for the calculations. All cast specimens were covered for at least 24 hours to avoid any early loss of moisture via evaporation under room conditions, then they were demolded. One got demolded, the mortar specimens were promptly labeled and deposited in the curing tank for a 28-day curing phase. In lab settings, the water in the cure tank was left at room temperature.

Table 6. The Proposed mix of specimen.

Mix type	Cement (kg/m^3)	Sand (kg/m^3)	Porcelanite (kg/m^3)	Water/ cement ratio	Nanosilica (kg/m^3)	Superplastsizer (wt. %)
A1 Ref.	570	570	570	0.35	0	0.4
A2	564.3	570	570	0.38	5.7	0.4
A3	561.45	570	570	0.38	8.55	0.4
A4	558.6	570	570	0.38	11.4	0.4
A5 Ref.	650	650	650	0.35	0	0.4
A6	643.5	650	650	0.38	6.5	0.4
A7	640.25	650	650	0.38	9.75	0.4
A8	637	650	650	0.38	13	0.4

4. Results and Discussion

The property of nano porcelanite concrete is poured into molds to make three cubes and three prism for each batch.

4.1. Compressive strength test

A compressive strength test was employed in the current study, before starting with this testing, each sample was air cured for a period of 21 days to remove extra moisture. The specimen was carefully positioned in the center of the test appliance, in the opposite direction of loading. After that, the compressive strength test appliance was calibrated according to the manufacturers requirements. Until the cube was crushed, the loading ratio got set to 10 KN/s. Fig. 1 and 2 showes the compressive strength with various failure patterns.

At particle size six mm of porcelanite aggregate (PA) all compressive strengths of batch A2, A3 and A4 were greater than the reference A1, but at particle size 9.5 mm of PA the compressive strength little increases than the reference at batches A6 and A7 but at batch A8 decreases than the reference, the efficiency of the nanosilica increases with strength at particle size 6 mm of PA.

fig. 1 and fig. 2 / table six are comparisons of strength of porcelanite aggregate with different nanosilica and different particle size of porcelanite, show that batch A3 is high strength than other batch.

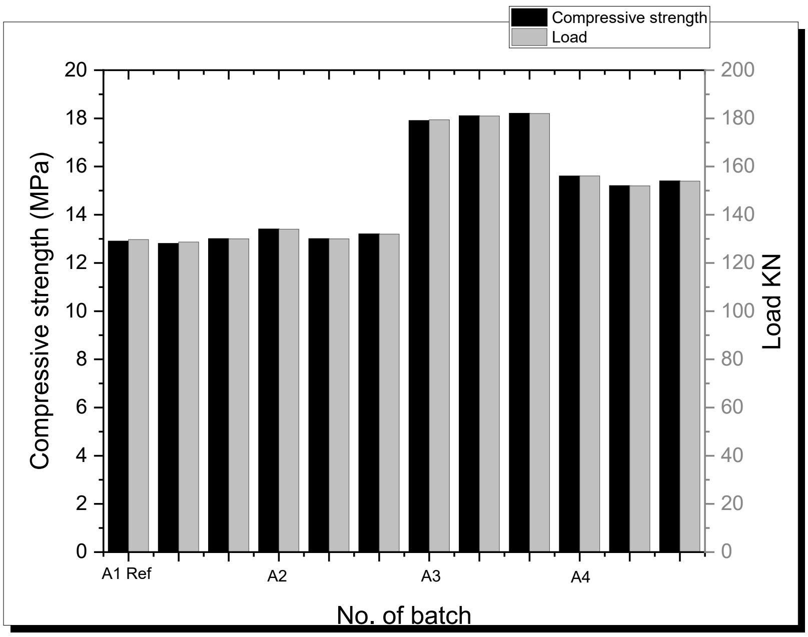

Figure 1. Compressive strength of porcelanite aggregate concrete at coarse porcelanite 6 mm with different ratio of nanosilica.

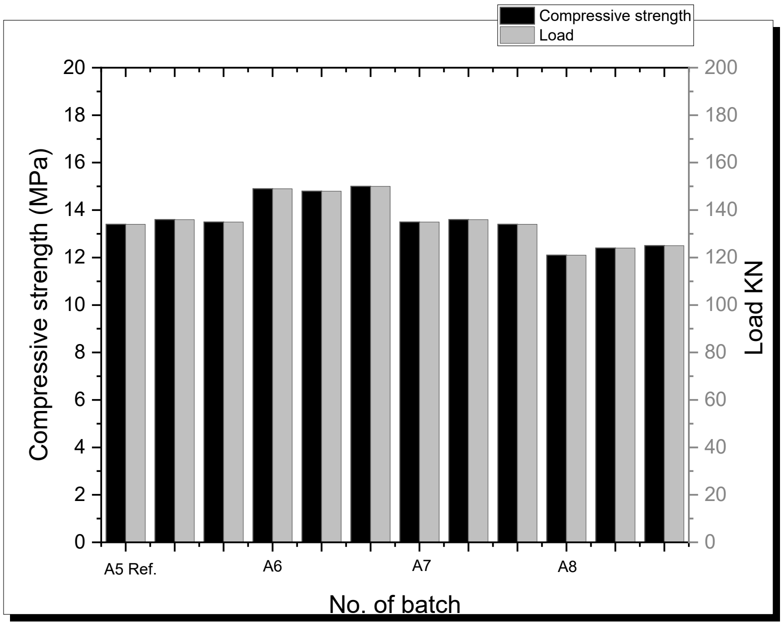

Figure 2. Compressive strength of porcelanite aggregate concrete at coarse porcelanite 9.5 mm with different ratio of nanosilica.

4.2. Flexural strength

The flexural strength at the 28th day is shown in fig. 3 and fig. 4 / table six. The inclusion of nanosilica boosts it to new heights. The nanoparticles efficiency in enhancing flexural strength increases the following order: A2, A3, A4, A6, A7, and A8, respectively.

The strength of concrete without nanosilica is lower compared to that of concrete with different nano ratios.

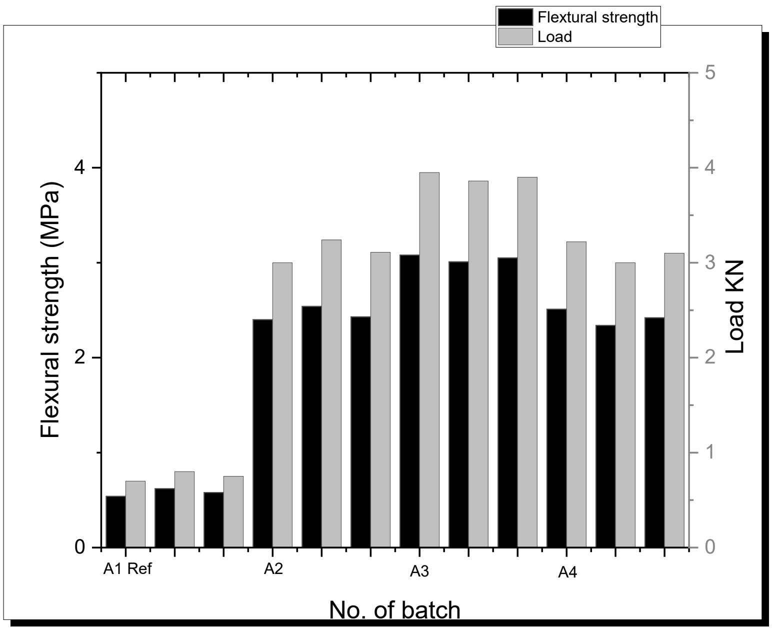

Figure 3. Flexural strength of porcelanite aggregate concrete at 6 mm coarse aggregate with different ratio of nanosilica.

Compressive strength, flexural strength, and density are the most acceptable terms to use when describing concrete strength. The concrete strength in relation to the mortar composition can be used to describe the overall picture of its quality. Adding nanosilica to lightweight aggregate can improve its compressive strength, which can help in the construction industry by casting any thinner section or longer span.

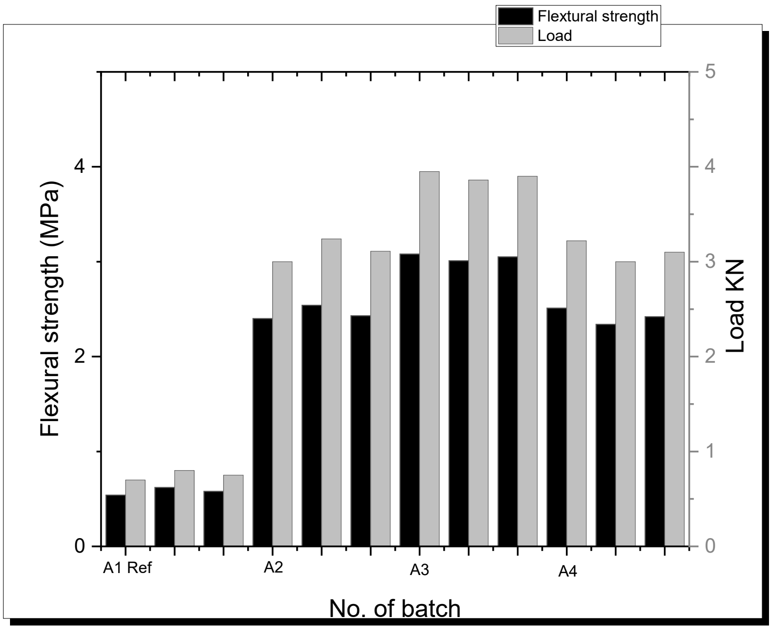

Figure 4. Flexural strength of porcelanite aggregate concrete at 9.5 mm coarse aggregate with different ratio of nanosilica.

4.3. Fresh and bulk density

Fig. 5 and fig. 6 / table six display the fresh and bulk density results batch according to ASTM C642-97 [27]. The variables' weight, density, and the compressive strength need to be considered. Loads at specimens failure and densities from the same batch show significant variation. As illustrated the dispersing techniques of nanomaterial as well as the casting procedure are identical. Because the whole batch was blended together, any weight discrepancy caused by nanoparticles or nanomaterial dispersing is not apparent. Consequently, the weight discrepancies could be explained by the fact that the amount of mortar used in the two molds differs. As a result, the total amount of content may differ. As a result, each specimen weight may differ; this can be attributed to human errors, which is unavoidable. Nonetheless, the demolded cubes showed no signs of wear.

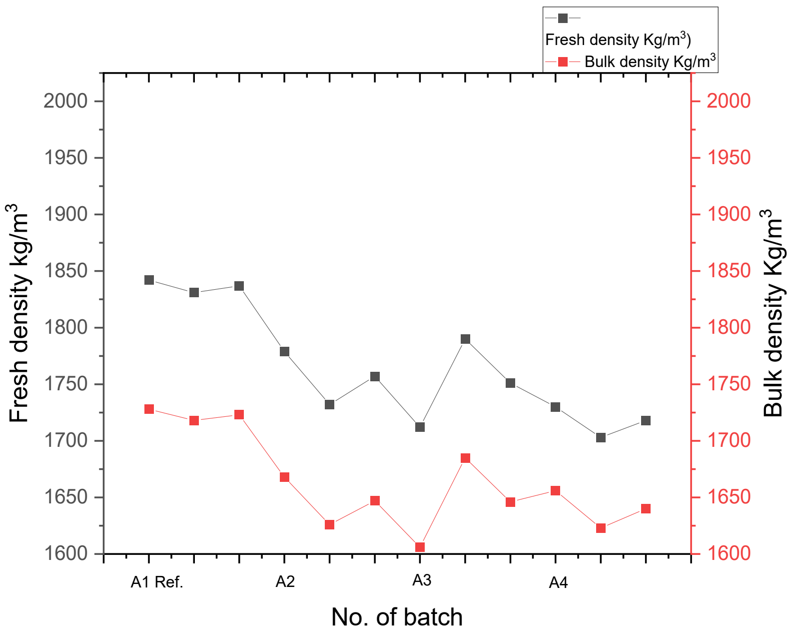

Figure 5. Fresh and bulk density of porcelanite aggregate concrete at 6 mm coarse aggregate with different ratio of nanosilica.

Considering this, there was no deformation in the demolded cubes; the distribution of the mortar was also uniform and smooth. In batches A2, A3, and A6, compacting and distributing the mortar become more difficult because of the hydrophobic qualities of NS. However, with a lot of vibrating and compacting, the distributing was even.

The nanosilica enhancing the densities are lightest than the reference in all batches A2, A3, A4, A6, A7 and A8.

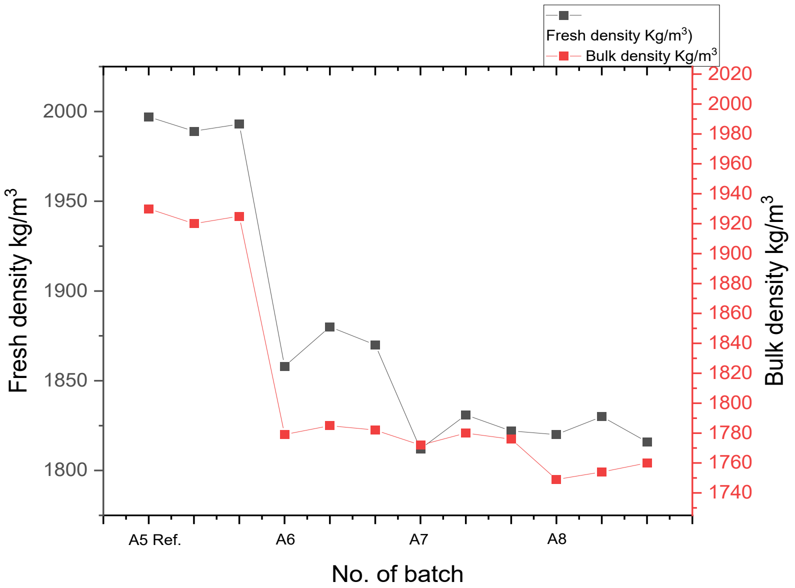

Figure 6. Fresh and bulk density of porcelanite aggregate concrete at 9.5 mm coarse aggregate with different ratio of nanosilica.

4.4. FESEM analysis

After 28 days of water curing and dry the samples, FESEM imaging was performed on the fractured faces of the reference batch and maximum compressive strength batch, as well as the minimum compressive strength batch without nanosilica.

fig. 7 show FESEM micrographs of the reference batch A1 of the material at magnifications ranging from figure 7-A equal 4000X and figure7- B to 15000X.

The three phases of concrete are cementitous paste, aggregates, and the interfacial transition zone (ITZ). Lesser anhydrate cement, lesser CSH, larger calcium hydroxide crystals, more ettringite content, and increased porosity (lower density) characterize the ITZ.

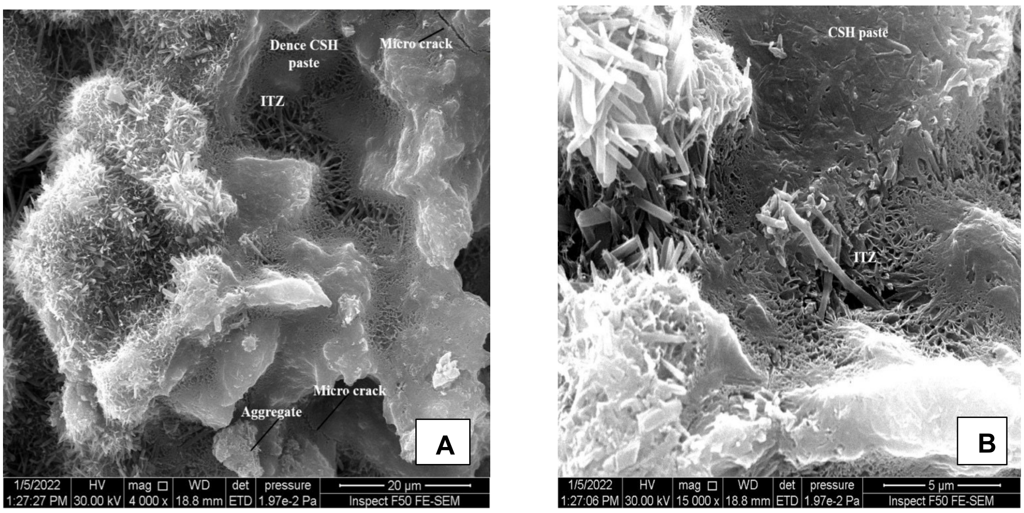

Figure 7. A, B Field emission scanning electron of reference batch at particle size of porcelanite 6mm without nanosilica at different magnification.

Because it strongly depends upon materials porosity, penetrability, and pore size distributing, the pore structure of cementitious materials is well recognized as an important feature because it impacts parameters like strength and permanency [28, 29]. The micro-structure of the reference batch that has the largest density is extremely compact. It has lesser voids as well as porosity features similar to the needle-like C-S-H crystals. The reference batch has no high compressive strength because the produced voids did not regularly exist and the porosity features did not evenly spread throughout the mix [30, 31].

Three dissimilar areas of the FESEM imaging of the mixture design are shown in fig. 8, it can be noticed that the best compressive strength was achieved at magnifications ranging between 7000 and 13000. Nanosilica fill the openings among aggregates, NS takes the shape of conglomerated clumps, as seen in the figures above. These strengthen the bond strength by filling up any void or space amid the aggregates. Accordingly, this mixture, in comparison to the reference mixture, achieves high compressive strengths while having a lower density.

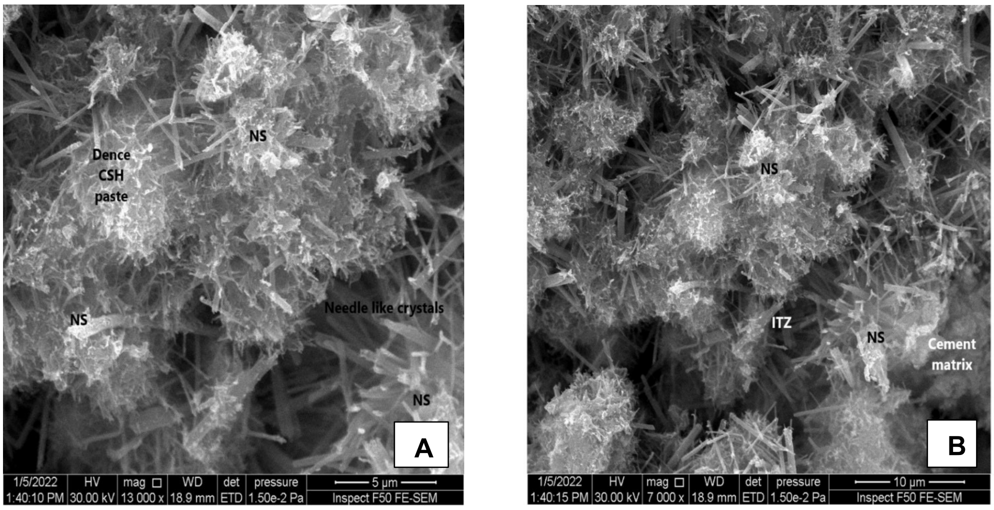

Figure 8. A, B Field emission scanning electron microscope of best batch of compressive at particle size of porcelanite 6mm with 1.5wt. % nanosilica at different magnification.

Fig. 9 depict reference specimen at grain size of porcelanite 9.5 mm intensification between 8000 and 15000 correspondingly. The specimen is without nanosilica but contains more cracks and voids.

1 wt. % of nanosilica was added to mix A6; this percentage represents the lowest quantity of nanosilica. As it can be seen in fig. 10, C-S-H paste and C-S-H crystal forming are relatively low in FESEM images. C-S-H is formed when cement reacts with water, but because to the high quantity of nanosilica in the cement, the unrestricted water content in the cement could be decreased, leading to less C-S-H creation as well as a porous matrix. This also reveals the samples microstructure, which shows a highly insecurely packed cement matrix, which reduces density and increases compressive strength. fig. 10 shows that the interacting has a crucial function of enhancing the compressive strength of lightweight concrete.

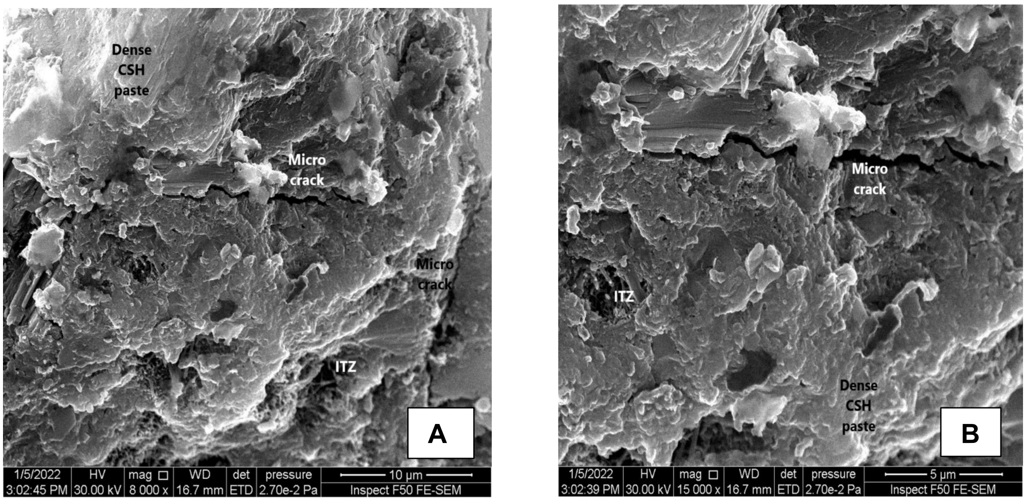

Figure 9. A, B Field emission scanning electron microscope of control batch at particle size of porcelanite 9.5 mm without nanosilica at different magnification.

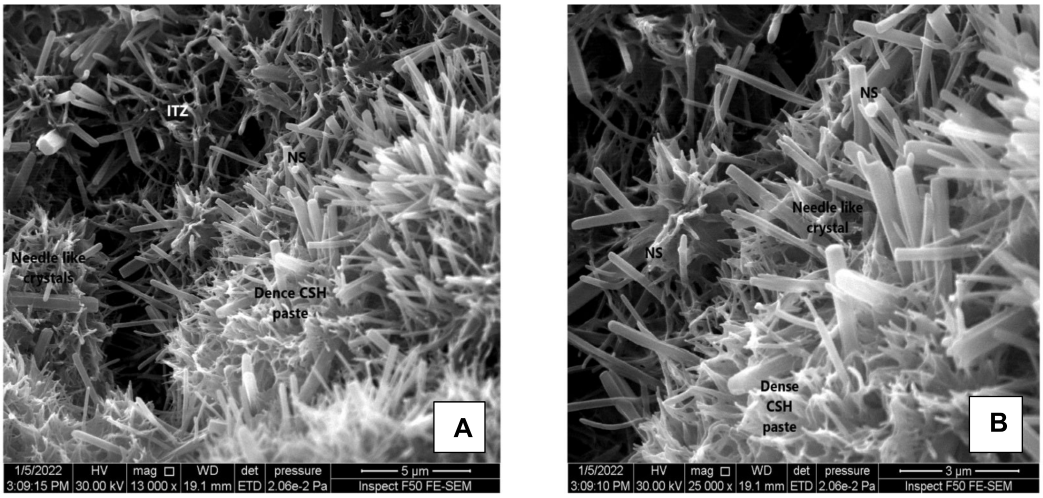

Figure 10. A, B Field emission scanning electron of best batch of compressive strength at particle size of porcelanite 9.5 mm with 1wt. % nanosilica at different magnification.

5. Conclusions

Some conclusions were established based on the investigation of the nanosilica influence upon the compressive strength of lightweight concrete as follow:

1. All specimens classified lightweight concrete LWC.
2. Most of the specimens of nanomaterial reinforced lightweight concrete show an increasing in compressive strength.
3. The density of the concrete is lightest when adding nanoparticles to the mixture. So, it can be considered as Structural Lightweight Aggregate Concrete SLWAC .
4. The costs of nanomaterial reinforced concrete could be reduced to a minimal increase when mass-produced in huge quantities, after reaching industrialized grade NS.
5. After 28 days of curing, the lightweight concrete without nanomaterial for such mixture design had an average compressive strength of 12.9 MPa.
6. Batches A3 and A6 have strong compressive strengths of 18.1 MPa and 14.9 MPa, with 40.3 percent and 10.3 percent increase over the control mixture, respectively.
7. The optimum combination consists of 1.5 wt. percent NS with a grain size of porcelanite six mm, batch, it is consider Medium Strength Concrete MSC.
8. Flexural strength high increased at all ratio of nanosilica and at any particle size, the optimum of flexural percentage increase 424.1 %.
9. FESEM micrographs provided information about pore distribution and voids of the prepared porcelanite concrete. In addition, it is uniform adhesion resulting stronger and lighter.

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