Research Article

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The effect of dosage nanosilica and the particle size of porcelanite aggregate concrete on mechanical and microstructure properties

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Abstract: Several research studies have been conducted on the usage of nanoscale silica particles in concrete, based on the success of employing silica fume as an active pozzolan in concrete. The impact of several doses of nanosilicas (NpSs) in powder having a certain surface area of 160 m^2/g and two particle sizes of porcelanite rock on the mechanical characteristics of lightweight porcelanite aggregate concrete was investigated. The addition of NpS particles significantly improved the workability of mixes, according to the results. The compressive strength of samples was influenced by NpS, with higher doses of NpS resulting in greater improvement. Porcelanite aggregate concrete's compressive strength was unaffected by a modest percentage of different NpSs. NpS had an effect on the samples. Flexural strength also improved at all NpS dosages. The flexural strength of porcelanite aggregate concrete increased by a low percentage of various NpS.

Keywords: porcelanite aggregate, nanosilica, compressive strength, flexural strength, FESEM

1 Introduction

Nanotechnology, introduced about half a century ago, is one of the most active study areas in the last two decades, with both novel science and applications in various fields [1]. Nanoscale particles have considerably improved features as compared to traditional grain-size materials with the same chemical composition. As a result industries may be able to re-engineer themselves with many existing items and to develop new and innovative products that achieve high levels of performance [2]. Research in the field has been expanded to include the use of nanomaterial in concrete to enhance the structure's performance. It has been discovered that adding a small quantity of nanomaterial to the concrete can change the properties of cement at the nanoscale, making the concrete more suitable. Nanosilica (NpS), among the different nanomaterials, has recently received interest because it provides high specific surface area and greater pozzolanic reactivity than other traditional mineral admixtures [3].

Natural sands, gravels, and crushed rocks make up concrete aggregates. They are called as natural mineral aggregates [4]. The most significant kind of aggregates for the Portland cement concrete is natural mineral aggregates. About two-third of the crushed aggregate is made up of a carbonate rock; the remaining is made up of sandstones, granites, diorites, gabbro, and basalts [5]. The latter, lightweight concrete (LWC), is a lightweight material that is used in construction to reduce the amount of weight that is placed on a structure [6]. Lightweight aggregate concrete is not a new term in the world of concrete; in fact, it has existed since ancient times. The truth that these kinds of constructions are still standing demonstrates the durability of the concrete [6]. Due to its low weight and high strength, LWC has recently been the focus of many studies [7]. Most construction materials, especially concrete (density of 2,400 kg/m^3), are hindered by their weight. Fortunately, lightweight aggregates can be used to make concrete with a lower density than normal-weight aggregates because they include vesicles or air voids that give them their large size. When these low-density materials are used and when aggregates are added to a concrete mix, structural grade concrete with a density of 1,850 kg/m^3 can be produced [8]. Many research studies have lately been conducted

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to provide low-density concrete with the best possible mechanical properties [9].

To enhance the durability, strength, as well as permeation of material that has cement as a base, NpS was shown to be far more effective compared to microsilica. Various research studies have indicated widely disparate outcomes, ranging from significant strength gain to significant strength decline. Many investigations looked into the impact of NpS on the compression strength for cementitious mixtures, mortar, as well as concrete [1,10,11]. NpS has a larger surface area due to the small size of its particles, which improves cement hydration and pozzolanic processes, according to recent research [12]. The need to improve early strength is important as this helps to demould formworks/moulds as soon as possible and also makes the composite suitable for applications where higher early strength is desired. It is desirable to have strength [13]. Recent technological advances have created lots of new challenges in the production of environmental-friendly, high-performance concrete. It has been discovered that using nanotechnology to modify the properties of cementitious materials by using NpS as a mineral additive has considerably enhanced the performance of concrete [14].

The aim of this study is to add nanoparticles like NpS to porcelanite aggregate concrete and then investigate their effects on some concrete qualities, for instance, compressive strength, flexural strength, and analysis of microstructure by field emission scanning electron microscope (FESEM). In this study, coarse porcelanite aggregates in two grain sizes (4 and 5 mm) at different percentages of 1, 1.5, and 2% by weight NpS to cement content as aggregates' substitute in concrete with a mixing ratio of 1:1:1 (cement:sand:porcelanite).

2 Experimental work

2.1 Materials and methods

2.1.1 Materials

Porcelanite is a significant industrial sedimentary rock. Porcelanite was initially restricted to rocks largely constituted of opal-CT by Kastner *et al.* (cristobalite–tridymite). The State Company of Geological Survey and Mining discovered porcelanite rocks in Iraq's Western Desert, near Rutba, in 1986 [15].

Porcelanite rocks have a mineral and chemical composition that represent their particular features that make them useful for industry. Many authors have heard of porcelanite [15] (Figure 1). The X-ray fluorescence (XRF) of the porcelanite compound is represented in Table 1.

Ordinary cement throughout the experiment, the Portland cement type I, made by Krista cement factory, was employed in all combinations. According to the testing outcomes, the chosen cement meets Iraqi specifications (IQS No. 5/1984) [16].

The sand used in this research work is known as Al-Ekhaider, with the ultimate size of 4.75 mm and a grading

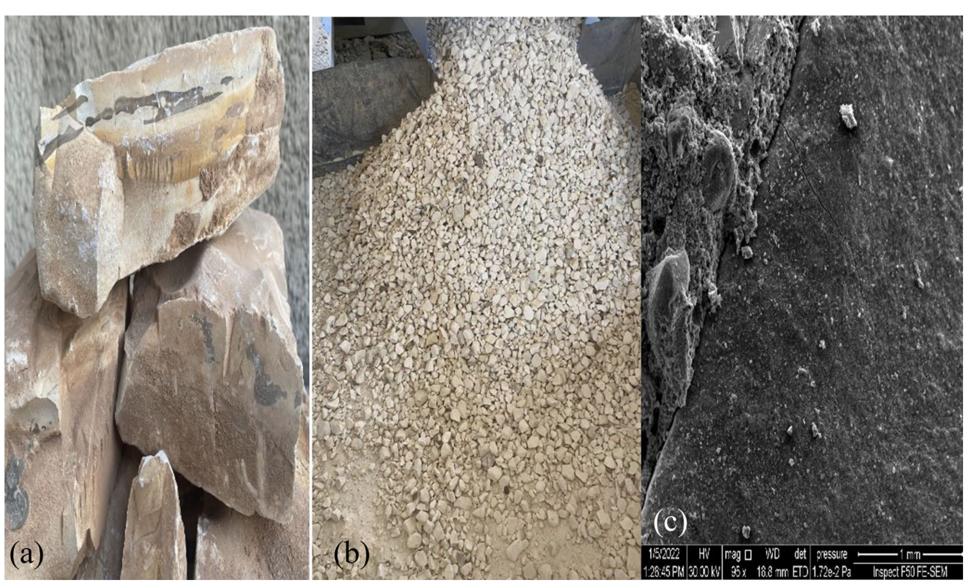

Figure 1: (a) Iraqi porcelanite rock, (b) porcelanite after mechanical crushing, and (c) porcelanite in concrete at FESEM.

Table 1: XRF of porcelanite compound

Chemical composition	SiO_2	CaO	MgO	Al_2O_3	Fe_2O_3	TiO_2	K_2O	SO_3	Na_2O	Sum
Present test results (%)	85	3	0.5	0.080	0.75	0.070	0.202	0.01	1.62	91.232

limited zone II. The results demonstrate that fine aggregate grading and sulfate content were within requirements of IQS No. 45/1984 [17].

Silicon dioxide (SiO_2) nanopowder was also utilized in the current experimentation work. Table 2 shows the properties of the nanomaterials.

EUCOBET SUPER VZ is a superplasticizer with a stunting influence that is made from synthetic materials. This complies with BS 5075 1/1974 ASTM-C494Typos G DIN and SIA standards. Table 3 depicts its proprieties.

2.1.2 Methods

As shown in Table 4, eight mixtures were cast with different mix designs. Mix types A1 Ref., A2, A3, and A4 represented concrete porcelanite aggregate at particle size of 4 mm with different ratios of NpS; and A5 Ref., A6, A7, and A8 concrete porcelanite aggregate at particle size of 5 mm with different ratios of NpS.

A rotary mixer was used for mixing. First, nanoparticles were added and then stirred for 2 min at high speed. After that, the rocks of the porcelain were crushed in a mechanical crusher and the granular size was isolated by mechanical sieves. Next, the crushed rocks were soaked for 24 h, and then they were mixed with sand and cement in equal weight ratios, they were dried to ensure homogeneity before adding NpS, plasticizer, and water.

The properly blended concrete is poured into molds to make cubes of size 10 cm × 10 cm × 10 cm. In Table 5 the entire blending proportions regarding to compressive testing prepared for each mixture produced two cubic specimens tested on the 28th day for sample numbers A1, A2, A3, A4, A5, A6, A7, and A8 and casting prisms of size 7.5 cm × 7.5 cm × 28 cm for mixtures produced two prisms for each mixture A1, B1, A2, B2, A3, B3, A4, and B4

Table 2: Properties of silica nanoparticles according data sheet

Product name	Color	Particle size	Surface area	Al_2O_3	Fe_2O_3	CaO	MgO
Silica powder nanograde	White	20 nm	160 m^2/g	0.002%	0.001%	0.002%	0.001%

Table 3: Properties of superplasticizer (EUCOBET SUPER VZ) according data sheet

Product name	Color	Specific gravity	Chloride content	Air entraining	Compatibility with cement	Shelf life
EUCOBET SUPER VZ	Brown	1.1	Nil	Does not entrain air	All types of Portland cement	Up to 2 years

Table 4: The mix proportion of specimen

Mix type	Cement (kg/m^3)	Sand (kg/m^3)	Porcelanite (kg/m^3)	Water/cement ratio	NpS (g)	Superplasticizer (mL)
A1 Ref.	550	550	550	0.35	0	18
A2	505	550	550	0.38	45	18
A3	482.5	550	550	0.38	67.5	18
A4	460	550	550	0.38	90	18
A5 Ref.	590	590	590	0.35	0	18
A6	545	590	590	0.38	45	18
A7	522.5	590	590	0.38	67.5	18
A8	500	590	590	0.38	90	18

Table 5: Mechanical properties

No. of series	Specimen cubic and prism	Compressive strength (MPa)	Enhanced range (%)	Flexural strength (MPa)	Enhanced range (%)
A1. Porcelanite aggregate at	A1	12.5	0	0.5866	0
size 4 mm (0% NpS)	B1	12.8	0	0.6257	0
A2. Porcelanite aggregate at	A2	13.9	11.2	1.9164	226.6
size 4 mm (1% NpS)	B2	13.2	5.6	2.2215	278.7
A3. Porcelanite aggregate at	A3	13.1	4.8	2.4248	313.3
size 4 mm (1.5% NpS)	B3	13.5	8	2.6360	349.3
A4. Porcelanite aggregate at	A4	13.1	4.8	3.6060	514.7
size 4 mm (2% NpS)	B4	13.9	11.2	2.8081	378.7
A5. Porcelanite aggregate at	A5	10.5	0	0.5866	0
size 5 mm (0% NpS)	B5	10.2	0	0.5475	0
A6. Porcelanite aggregate at	A6	16.9	60.9	2.5813	340
size 5 mm (1% NpS)	B6	16.1	53.3	2.5735	338.7
A7. Porcelanite aggregate at	A7	10	—	2.4796	322.7
size 5 mm (1.5% NpS)	B7	10.1	—	2.6752	356
A8. Porcelanite aggregate at	A8	19.3	83.8	2.6908	358.7
size 5 mm (2% NpS)	B8	20.1	91.4	2.816	380

for flexural testing with the particle size of porcelanite (4 mm) and compressive testing of sample numbers A5, B5, A6, B6, A7, B7, A8, and B8 and prisms of size 7.5 cm × 7.5 cm × 28 cm for mixtures A5, B5, A6, B6, A7, B7, A8, and B8 for flexural testing with the particle size of porcelanite (5 mm). To aid compacting and reduce the number of air bubbles, an exterior vibrator was employed. After being demolded for 24 h, water was utilized to cure the specimens for 28 days and then at room temperature, the specimens were air cured for 21 days.

By employing a hydraulic mechanic test system with loading control, the strength of the structure was compressively tested on the 28th day. Also on the same day, flexural strength testing was performed using a bend tester under loading control on the long surface of prism samples. The crushed samples were chosen for FESEM testing after the mechanical testing.

3 Results and discussions

3.1 Compressive strength

Table 5 displays the compressive strength of the eight porcelanite concrete mixes. This is done according to BS 1881-116: 1983 [18]. One could see that all compressive strengths of the samples with mixes of A2, B2 A3, B3, A4, and B4 on the 28th day were greater than that of reference A1 and B1 with the same particle size of porcelanite (4 mm). Similarly, one could see that all compressive strengths of the samples with mixes of A6, B6 A7, B7, A8, and B8 on the 28th day were higher than that of reference A5 and B5 with the same particle size of porcelanite (5 mm). The efficiency of the nano-SiO_2 increases with the strength.

For the particle size of porcelanite 4 mm, almost no increase in the compressive strength was observed. Furthermore, there was no enhancement in the compressive strength for sample A6 and A8 on the 28th day. According to such findings, under the current dispersing situation, the optimum content of nano-SiO_2 for reinforcing concrete applications must be 1 and 2% (by a weight of cement), respectively.

Table 5 presents a comparison of the strength of porcelain concrete without nanosilicate. The table shows that the nanoparticles have better values compared to porcelain concrete without NpS for supplying reinforcement and the importance of the particle size of the porcelain (5 mm) results in high strength.

3.2 Flexural strength

The flexural strength on the 28th day is shown in Table 5. It is carried out in accordance with BS 1881-101: 1983 [19]. The inclusion of nano-SiO_2 boosts it to new heights. The nanoparticles' efficiency in enhancing flexural strength increases in the following order: A2, A3, A4, A6, A7, and A8.

The strength of concrete without NpS is low compared to that of concrete with different nanoratios.

3.3 Microstructure and discussion

The microstructure of porcelanite concrete with and without nano-SiO_2 is depicted in Figures 2–5, FESEM test was performed on the fractured faces of the control mix and on maximum compressive strength mixes. As shown in Figure 2, the microstructure image of plain concrete at 4 mm particle size of porcelanite without nanoSiO_2, C–S–H gel was observed as “stand-alone” clusters, lapping and joined together by many needle hydrates and cracks.

As shown in Figure 3, the microstructure image of the plain concrete at 4 mm particle size of porcelanite having 2% NpS, the microstructures were uniform, compact, and the cracks disappeared.

According to Figure 4 the microstructure image of plain concrete at 5 mm particle size of porcelanite, numerous needle hydrates are seen lapped and joined together.

The microstructures of the mixture A8, which has a greater strength, are shown in Figure 5. They are not the same as the ordinary porcelanite concrete. The microstructures of these combinations are consistent as well as compact, despite slight variances in the porcelanite concrete kinds of patterns.

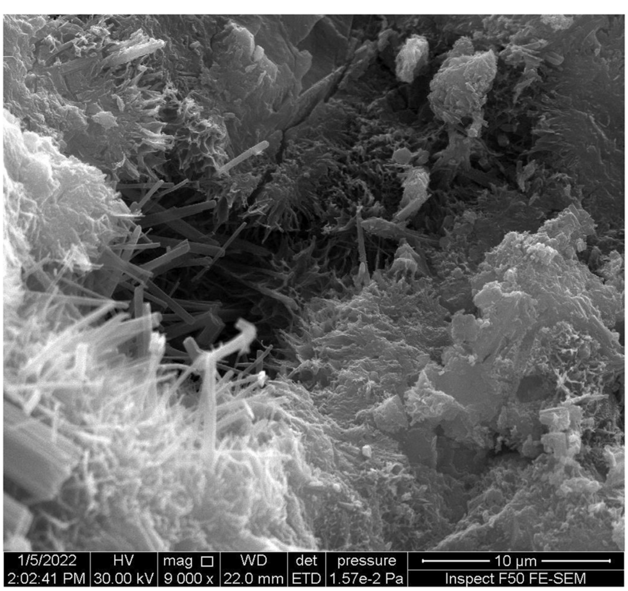

Figure 2: FESEM of reference sample A1 porcelanite concrete magnified 9,000×.

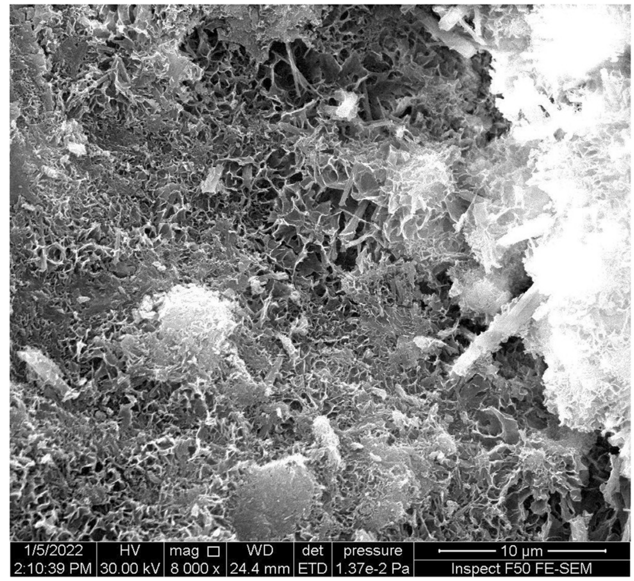

Figure 3: FESEM of sample A4 porcelanite concrete magnified 8,000×.

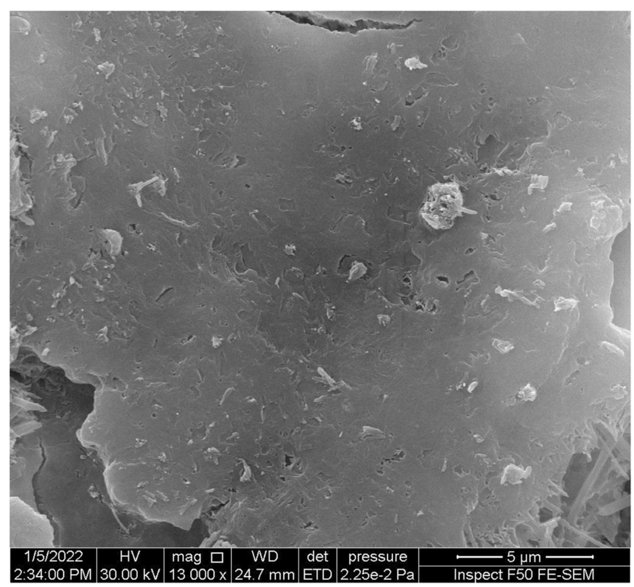

Figure 4: FESEM of sample A5 porcelanite concrete magnified 13,000×.

However, the case is similar to that of lightweight concrete, in that many hydrate productions coexist in various shapes. This microstructure was in line with the related justification. Strength increased by 91.4% as shown in Table 5. The mechanism by which nanoparticles may be able to improve the microstructure and strength of porcelanite concrete can be investigated. The following is the summary of the event. Due to their high surface energy, the cement’s hydrate productions

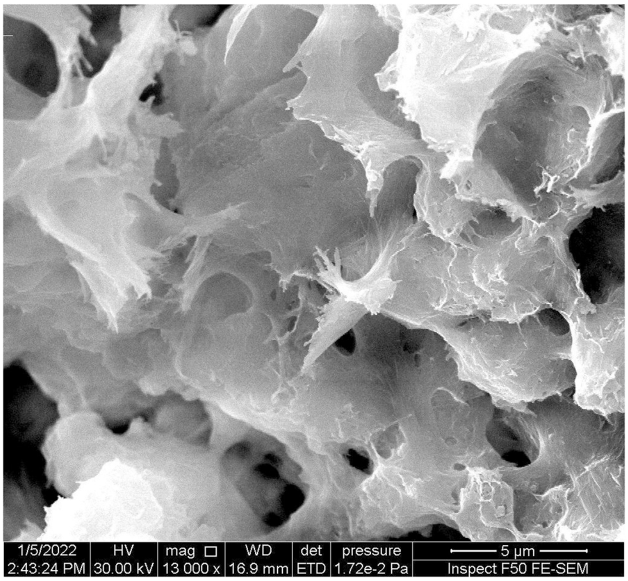

Figure 5: FESEM of sample A8 porcelanite concrete magnified 13,000×.

would settle on the nanoparticles throughout the cure procedure since they were spread evenly in the cementitious material. Hydration has grown into a conglomerate that contains the nanoparticles as "nucleus."

Because of their great activity, the nanoparticles that act as a nucleus in cement will stimulate and accelerate cement hydration even more. In the case of nanoparticles that are uniformly pressed, a good microstructure could be generated in this situation, it is an aggregation with uniform distribution. While, as stated by Wu's "centroplasm" suggestion, aggregate, sand, as well as different particles represent centroplasm, which serve both as a structure and as a transmitter. The concrete's strength is influenced by the binding force amid centroplasm with the transmitter material [20]. Several nanoparticles dispersed as "sub-centroplasm" in concrete can form a tight bond with hydrated products near the transition zone between nanoparticles and hydrate products. On the other hand, nanoparticles in the hydrate products, such as $CaOH_2$ and atomic force microscopy, inhibit the crystal from expanding, and such tiny crystals are good for concrete strength [21].

Because nano-SiO_2 could engage in the hydration procedure to generate C–S–H by interacting with $CaOH_2$, even if nano-SiO_2 is not widely disseminated, a little quantity of aggregating nano-SiO_2 would not be a feeble region, and the strength will grow when the content of nano-SiO_2 increases. This study revealed that the strength of porcelanite concrete containing nanoparticles improves significantly.

4 Conclusion

Porcelanite aggregate concrete containing nano-SiO_2 has greater compressive and flexural strength than porcelanite aggregate concrete reference. The FESEM examinations demonstrated that the nanoparticles were not only employed to avoid microcracks in the structure, but also can be an activator to speed hydration and enhance the microstructure of the concrete when the nanoparticles were evenly disseminated. The optimum concrete mix of sample A8, with 2% nanoparticles SiO_2 resulted in compressive strength of 92% and ultra-high flexural strength of 380%.

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