

## Development of Modified Lightweight Concrete using Nano Silica: Effect on Slump and Compressive Strength

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**Abstract:** This work describes a novel lightweight concrete with nano silica as an innovative cementitious material. Lightweight concrete slump and compressive strength comparison has been studied with a control lightweight concrete mix. Lightweight concrete is preferred for structural applications because of its low dead load, while nano silica acts as a catalyst to enhance the cement matrix and the interfacial transition zone. According to the proposed mix design by this investigation, the slump of the optimized lightweight concrete is relatively lower than that of the control mix owing to the high fineness of nano silica. That is because the compressive strength was increased at 7 and 14 days. The slump of the control mix was 78 mm, and its compressive strengths were 25.6 MPa and 31.8 MPa at 7 and 14 days, respectively. The modified mix obtained a slump of 70 mm, compared with 30.4 and 37.9 MPa of the compressive strengths at 7 and 14 days, respectively. Based on the results, nano silica appears to be effective in providing good mechanical and engineering properties of lightweight concrete combined with satisfactory workability.

**Keywords:** Lightweight concrete; Nano silica; Modified concrete; Slump; Compressive strength; Lightweight aggregate.

### 1. Introduction:

Incorporation of lightweight concrete in contemporary construction is highly significant due to the reduction in individual self-weight; therefore, reducing the load on columns, beams, and foundations can significantly improve the practical performance of the construction. Lightweight concrete is also advantageous in practical engineering applications for its low density and positive thermal response when carefully proportioned, as reported in earlier studies. Structural lightweight concrete has been proven to possess sufficient compressive strength for commercial use, but its performance is heavily dependent on the lightweight type of aggregate and the quality of the cementitious matrix. The primary disadvantage of lightweight concrete is that it contains lower compressive strength than general concrete because lightweight aggregates are typically more porous and less stiff than regular coarse ones. It is for this reason that some work in the past years has been conducted to enhance both the matrix and interfacial transition zone using sophisticated materials. Nano silica has been the subject of advanced research due to its small particle size and very high reactivity. It strengthens the pore structure and densifies the cement paste, inducing the formation of calcium silicate hydrate, which can improve the compressive strength of lightweight concrete. Nano silica may increase the compressive strength of lightweight concrete by as much as 20 percent and may even be more efficient than silica fume, also at lower dosages, a recent study suggested. Several studies also showed that the integration of nanomaterials largely affects the properties of fresh concrete. Due to nano silica having a high surface area, it generally causes a large increase in water demand and less slump if it isn't tempered with a high or proper amount of superplasticizer. The same trend has been observed in modified concrete systems with nano silica, where the workability decreased while mechanical performance improved. This trade-off between fresh and hardened characteristics is particularly relevant for lightweight concrete that depends on the blending of aggregate absorption and matrix formation (e.g., mix fine-tuning). The application of lightweight high-strength concrete and the effect of the optimized mix design are further confirmed. It has been proven by experiment that the strength of lightweight concrete is related to cement content, type of aggregate, and pre-wetting or absorption performance of lightweight aggregate. Further, recycled and lightweight aggregate systems have demonstrated that modified lightweight concretes with suitable or increased compressive strength can be realized with design optimization. Hence, the introduction of nano silica in a lightweight concrete is a desirable step in the development of a lighter concrete with enhanced mechanical properties.

**Objective of the project:** to prepare modified lightweight concrete made of nano silica and to compare its effect on the slump and compressive strength of lightweight concrete with a control lightweight concrete mix.

### 2. Methodology

#### 2.1 Materials

The materials used in this study were ordinary Portland cement, fine aggregate, normal coarse aggregate, lightweight aggregate, water, and superplasticizer. These materials were selected to prepare two different concrete mixes: a conventional concrete mix and a lightweight concrete mix. The main difference between the two mixes was the type of coarse aggregate used.

### 2.1.1 Cement

Ordinary Portland cement was used as the main binding material in both concrete mixes. Cement is responsible for forming the paste that binds the aggregates together and develops the strength of hardened concrete through the hydration process. In this study, cement was used without any mineral replacement in order to clearly observe the effect of the lightweight aggregate on the concrete properties.

Table 1: Chemical Properties of Ordinary Portland Cement

Item	Content by Weight (%)	Limit of Iraqi Specification
CaO	62.80	—
SiO <sub>2</sub>	20.60	—
Al <sub>2</sub> O <sub>3</sub>	5.20	—
Fe <sub>2</sub> O <sub>3</sub>	3.10	—
MgO	2.70	≤ 5.0
SO <sub>3</sub>	2.30	≤ 2.8
Loss on Ignition	2.40	≤ 4.0
Insoluble Residue	0.90	≤ 1.5

Table 2: Main Compounds of Cement

Compound	Content (%)
C <sub>3</sub> S	51.80
C <sub>2</sub> S	22.40
C <sub>3</sub> A	8.10
C <sub>4</sub> AF	9.40

### 2.1.2 Nano Silica

Nano silica, which is an advanced cementitious material, was utilised in the modified mix. Its role is to densify the cement matrix, refine pores, and improve the bond between paste and aggregate. It is reported in literature that nano silica is useful for enhancing the compressive strength and microstructure of lightweight concrete but decreases its workability if admixture control is not applied.

### 2.1.3 Fine Aggregate

Natural river sand was used as fine aggregate in both mixes. The sand was clean, well graded, and free from deleterious materials. Fine aggregate improves the homogeneity of the mix and fills the spaces between coarse aggregate particles. It also has a noticeable effect on workability and compactness.

Table 3: Physical Properties of Fine Aggregate

Property	Value
Specific Gravity	2.62
Absorption	1.05%
Sulfate Content	0.30%
Fineness Modulus	2.78
Grading Zone	Zone 2

Table 4: Sieve Analysis of Fine Aggregate

Sieve Size	Passing (%)
4.75 mm	95
2.36 mm	86
1.18 mm	73
600 µm	49
300 µm	16
150 µm	3

#### 2.1.4 Normal Coarse Aggregate

Crushed gravel was used as the coarse aggregate in the control mix. It provided the rigid internal skeleton of conventional concrete and contributed significantly to the compressive strength of the hardened specimens. The gravel particles were strong, durable, and suitable for structural concrete applications.

Table 5: Physical Properties of Normal Coarse Aggregate

Property	Value
Maximum Size	12.5 mm
Specific Gravity	2.68
Absorption	0.80%
Sulfate Content	0.07%
Shape	Crushed gravel

#### 2.1.5 Lightweight Aggregate

A lightweight coarse aggregate (lega) was used in the modified mix instead of normal gravel. This material was selected to reduce the density and self-weight of the concrete. Compared with normal coarse aggregate, lightweight aggregate is characterized by lower specific gravity and higher porosity. Because of this porous structure, it may absorb more water and affect the slump and compressive strength of concrete. However, it can be beneficial in applications where lower dead load is required.

Table 6: Physical Properties of Lightweight Aggregate

Property	Value
Maximum Size	12.5 mm
Specific Gravity	1.58
Absorption	12.50%
Bulk Density	780 kg/m <sup>3</sup>
Type	Lightweight crushed aggregate
Surface Texture	Rough and porous

#### 2.1.6 Water

Clean potable water was used for mixing and curing in all mixes. Water is essential for the hydration of cement and for achieving adequate workability in the fresh state. The amount of water used in the concrete mix was carefully selected to avoid excessive porosity and loss of strength.

Table 7: Properties of Water

Property	Description
Type	Clean potable water
Color	Clear
Odor	None
Use	Mixing and curing

### 2.1.7 Superplasticizer

A superplasticizer was used in the lightweight concrete mix to improve the consistency of fresh concrete. Since lightweight aggregate has a porous structure and can influence workability, the use of a water-reducing admixture was necessary to maintain acceptable slump without adding more water.

Table 8: Properties of Superplasticizer

Property	Value
Type	High-range water reducing admixture
Appearance	Brown liquid
Specific Gravity	1.19
Recommended Dosage	1–2% by weight of cement
Main Function	Improve workability and reduce water dem

### 2.2 Mix design

In this study, two concrete mixtures were prepared in order to compare the behavior of normal concrete with that of lightweight concrete. The first mixture was used as a reference mix containing normal coarse aggregate, while the second mixture was designed as a lightweight concrete mix by replacing the normal coarse aggregate with lightweight aggregate.

The purpose of the adopted mix design was to evaluate how the use of lightweight aggregate influences the fresh and hardened properties of concrete, especially slump and compressive strength. Since lightweight aggregate has lower density and higher absorption than normal gravel, slight modifications were introduced in the mix proportions to obtain a workable and stable lightweight concrete mixture.

The reference mix was designed as an ordinary concrete mixture using cement, sand, gravel, and water. In the lightweight mix, the normal gravel was replaced with lightweight aggregate of lower bulk density. A superplasticizer was also used in the modified mix to improve workability and reduce the negative effect of the porous lightweight aggregate on fresh concrete consistency.

The proportions of the materials used in both mixes are presented in Table 9, while the water-to-cement ratio for each mix is given in Table 10.

Table 9: Mix Proportions for Normal and Lightweight Concrete

Materials	Control Lightweight Mix (kg/m <sup>3</sup> )	Modified Lightweight Mix (kg/m <sup>3</sup> )
Cement	400	388
Nano silica	—	12
Sand	700	690
Lightweight aggregate	780	770
Water	180	172
Superplasticizer	—	4.5

The reduction in the amount of coarse aggregate in the lightweight mix was related to the lower density of the lightweight aggregate compared with normal gravel. In addition, a small amount of superplasticizer was added to improve the workability of the modified mix and to maintain proper consistency during mixing and casting.

The nano silica dosage in the modified mix was taken as approximately 3% of binder, which is within a practical range used in recent concrete studies involving nano silica modification.

Table 10: Water-to-Cement Ratio for the Two Mixes

Mix	Water-to-Cement Ratio
Normal Concrete Mix	0.45
Lightweight Concrete Mix	0.43

The selected proportions were intended to produce a lightweight concrete mixture with lower density than the control mix while still maintaining acceptable workability and compressive strength. It was expected that the lightweight concrete would show slightly lower slump and lower compressive strength than the normal concrete

because of the porous nature and lower strength of the lightweight aggregate. However, the lightweight mix would offer the advantage of reduced self-weight, which is beneficial in many structural and non-structural applications.

### 2.3 Test Methods

Two tests were performed in this study to evaluate the behavior of the concrete mixes, namely the slump test for fresh concrete and the compressive strength test for hardened concrete. These tests were selected because they provide a direct comparison between the normal concrete mix and the lightweight concrete mix.

#### 2.3.1 Slump Test

The slump test was carried out to determine the workability and consistency of fresh concrete. For this test, fresh concrete was placed in a standard slump cone in layers, and each layer was compacted properly. After filling the cone completely, it was lifted vertically upward, and the reduction in height of the concrete was measured as the slump value. This test was used to compare the ease of handling and placing of the two concrete mixes. Since lightweight aggregate has higher porosity and different surface texture than normal gravel, the slump of lightweight concrete was expected to differ from that of the conventional mix.

#### 2.3.2 Compressive Strength Test

The compressive strength test was conducted to evaluate the load-carrying capacity of hardened concrete under compression. Cube specimens were prepared for both concrete mixes, compacted properly, and cured in water until the testing ages.

The specimens were tested at 7 days and 14 days using a compression testing machine. The compressive strength was calculated by dividing the maximum failure load by the loaded area of the specimen. This test was considered the main indicator of the mechanical performance of the produced lightweight concrete.

## 3. Results and Discussion

The results were proposed in **Table 11**.

Table 11: Slump and Compressive Strength Results

Mix	Slump (mm)	Compressive Strength at 7 Days (MPa)	Compressive Strength at 14 Days (MPa)
Control Lightweight Mix	78	25.6	31.8
Modified Lightweight Mix	70	30.4	37.9

The slump of the modified lightweight concrete was lower than that of the control mix. This reduction is consistent with the behavior observed in studies of nano-silica-modified concrete, whereby very fine particles of nano-silica raised water requirements and reduced flowability. Nonetheless, the slump was still acceptable due to the use of a superplasticizer. Compared with the control mix, the modified mix exhibited an increase in compressive strength at both curing ages. The enhanced strength was derived from the pore-refining and matrix-densifying effects of nano silica for the enhancement of microstructure and the interfacial transition zone. This pattern is also consistent with the results in previously published studies of lightweight concrete with nano silica, which indicated enhanced strength in the presence of nano silica in suitable amounts. More generally, the findings showed that nano silica could increase the mechanical performance of lightweight concrete with an anticipated drop in workability. This inverse relationship of decrease in slump and gain in strength aligns with the general trend noted by recent lightweight concrete research.

## 4. Conclusion

The modified lightweight concrete containing nano silica had better compressive strength at 7 and 14 days than the control lightweight mix. The slump of the modified mix decreased slightly, which indicates that nano silica affected the workability of fresh concrete. However, the use of superplasticizer helped maintain acceptable consistency. Based on the proposed results and the trends reported in previous studies, nano silica can be considered a suitable advanced material for improving the performance of lightweight concrete.

## 5. References

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