INVESTIGATING THE EFFECTS OF USING SILICA NANOPARTICLES ON THE COMPRESSIVE STRENGTH OF CONCRETE AGAINST THE CORROSION OF REBARS BURIED IN REINFORCED CONCRETE

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Abstract

Silica nanoparticles have recently been used to reduce concrete permeability and seepage, and have attracted the attention of many researchers. This study aimed to investigate the effects of using each silica nanoparticle in concrete alone. It was found that the combination of nano-silica and rebars in concrete, and the combination of nano-silica, concrete, and rebars buried in reinforced concrete could affect the compressive strength, permeability, and seepage of concrete. Also, the percentage of any possible mixture to yield an optimal mixture percentage was discussed. Experiments have demonstrated that concrete with silica nanoparticles, used alone and in combination with different percentages of cement content and different water-to-cement ratios in cubic specimens (the British method), had a greater strength compared to conventional concrete (Type I) under compressive strength, permeability, and seepage tests. The findings of this study indicated that concrete with nano-silica increased its compressive strength and showed lower permeability. Although concrete with nano-silica outperformed conventional concrete and concrete with silica fume and the combination of nano-silica and silica fume of an optimal percentage in concrete performed better than when they were used alone. Considering the greasy and hydrophobic properties of silica, the uniform and compressed micro-structure of nano-silica, and the cohesive and microscopic particles of silica fume, if silica was added to this composition, the sizes, the pores inside the concrete, and the capillary force could be decreased, and thus concrete of higher compressive strength and low seepage and permeability could be produced, which would decrease cracks and the corrosion of rebars buried in concrete.

Keywords: reinforced concrete, silica nanoparticles, compressive strength, rebar corrosion

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Introduction

Using silica nanoparticles (micro-silica gel and propylene fibers) as alternatives to parts of materials constituting concrete has now received growing attention. Because using silica powder, instead of a part of cement, decreases the compressive strength, especially the tensile strength of concrete, it is used to compensate for the decreased strength. Thus, the addition of silica nanoparticles decreases calcium hydroxide amounts in concrete and forms silicate gel to reduce capillary pores in concrete, which increases compaction and strength in concrete (Aybo et al., 2022). The objective of this study was to determine an optimal level of using higher silica nanoparticle-to-cement ratios. Despite higher silica-to-cement ratios, it was demonstrated that using nano-silica as an additive could achieve a relatively acceptable strength. It is noteworthy that the total of silica and cement was constant during the entire study and amounted to 450 kg/cubic meters (Scientific-Research Journal of Civil Engineering).

Although the combined use of several incompatible additives (here, silica nanoparticles) may help improve the quality of concrete properties, they may produce reverse results (Sadovnikova et al., 2022; Samir, D., et al., 2022; Gaikwad, S. S., & Choudhari, V. P, 2022). For this, the mixture of various additives should be avoided to the extent possible, unless the manufacturing factory has foreseen their mixture. If the simultaneous use of two or several additives is under consideration, assurance of their proper function should be made through experiments to be used in workshops (Van Nguyen, T, et al,. 2022). Furthermore, if no previous background is available, the views of manufacturing factories should be asked. Additives are mainly substances ionized in water and may help blend different ions if they are mixed, as the presence of some ions may intensify and inhibit or even cease the activities of some other ions. In addition, heating degrees may intensify or undermine the activities of ions; thus, a total of these substances could change the function of the mixed additives (Rezaei-Motlagh, 2016).

Silica nanoparticles in concrete help improve compressive strength. Types of propylene fibers used in concrete are polypropylene fibers, steel fibers, etc. Meanwhile, using steel fibers (e.g., buried rebars) in concrete makes cracks smaller and aligned. As well, steel fibers cause compressive strength by bridging between the micro-silica gels of cracks in concrete (Zamani & Moghaddam, 2019).

Studies by Ramazanian et al. (1997) on concrete with silica nanoparticles of different lengths (5, 10, and 15 mm) and different weights (0.4, 1.1, 2, and 1.5 kg/cubic m) indicated that the strength and thermal strengths of concrete specimens increased when silica was used. They removed cubic specimens of 250*250*250 mm after 8 and 28 days from a pool and placed the silica nanoparticles in a furnace of 450°C for eight hours to conduct thermal tests on them. After this, compressive strength tests were carried out.

Tzeng et al. (2010) used silica nanoparticles with 4.0 mm (40%), 6% to 1 mm (35%), and 1-5 mm (25%) gradation at 5.2 to 20% amounts in concrete. At various water-to-cement ratios, the reinforced concrete abrasion was lower and similar to that of the control concrete, while increasing the amount of silica increased the abrasive strength of the concrete.

Zhang et al. (2009) reported that the abrasive strength of concrete containing 15% of silica nanoparticles of less than 75.2 mm in size rose by 20%.

Hasani et al. used silica steel (rod-wire with a diameter of 1 mm and a 5.0% v/v) in concrete containing 50 and 100% of aggregates recycled from construction waste. They found that the addition of these fibers in control concrete and those containing 50 and 100% of recycled aggregates helped improve their compressive strength by 2.3, 3.10, and 9.3% (Scientific-Research Journal of Civil Engineering).

Changes to the mechanical parameters of silica nanoparticle concrete include strength against flakiness, abrasion, and surface weathering, higher strength against fatigue stresses, greater strength against percussion, high strain capacity, high bearing capacity after the first cracking, high tensile, flexural, and shear strength, and much toughness. Reinforced concrete is capable of tolerating significant stresses and tensile strains at tensile loads, and can be used to design structures. Reinforced concrete with silica increases its tensile strength; however, the disadvantages of reinforced concrete include its porosity, which leaves negative impacts on its compressive strength of concrete.

This study discusses the mixture of silica nanoparticles, micro-silica, and propylene fibers that enhance the strength of rebars buried in reinforced concrete against corrosion. This study also replaces parts of cement with silica nanoparticles. Since higher amounts of silica nanoparticles in concrete structures compared to amounts of cement help projects to be more economically viable, this study used higher silica-to-cement ratios with amounts of 80, 1, and 12%, water-to-cementitious materials ratios with amounts of 350, 400, and 450%, and nano-silica-to-cementitious materials with amounts of 51 and 3%. This study also simultaneously used silica nanoparticles and rebars buried in reinforced concrete and tested the compressive strength of concrete against the corrosion of rebars buried in reinforced concrete. It also used a mix of silica nanoparticle powder and gravel at 8, 5.13, 5.22, and 27% v/v with the addition of sufficient rebars.

Material and Procedure

Cement Type 5 (conventional I), polypropylene fibers, steel rebars, and superplasticizers were used in six mix designs (compressive strength) to produce concrete. After being made, concrete specimens were held in pools and their compressive strengths were measured at 7 and 28 days. Findings revealed that the highest compressive strengths occurred at 1 and 2% of polypropylene fibers (propylene fiber micro-silica gel), respectively, while steel rebars helped increase the compressive strengths of the concrete specimens, as the highest compressive strength in reinforced concrete specimens was noted in steel rebars with 3 and 2% of silica and micro-silica, respectively.

Experiments and Procedure Stages

This study used the sieve analysis (gradation) test based on the ASTMC Standards to determine the distribution of aggregate size. The gravel used was made of mixed 3.8 and 3.4 crushed gravel, which was transferred to the laboratory where it was fully washed and dried up; then, certain weights of the gravel and its gradation were determined. The gravel used was made of crushed gravel. To prepare the concrete, attempts were made to avoid using needle-shaped or flaky aggregates.

The molds used in the tests were made of cast iron. Cubic molds were usually made in 15*15 cm dimensions.

After 24 h, the specimens were removed from the molds and placed in a pool for 7 and 28 days, respectively. After being removed and dried, the specimens were subjected to special compressive strength devices. The specimens were tabulated and subsequent analyses were carried out. The specimens were kept in a pool and their compressive strengths were tested at 7 and 28 days. Findings revealed that the highest compressive strengths were noted at 1 and 2% of polypropylene fibers (propylene fiber micro-silica gel), respectively, while steel rebars helped increase the compressive strengths of the concrete specimens, as the highest compressive strengths in reinforced concrete specimens were noted in steel rebars with 3 and 2% of silica and micro-silica, respectively. This study used a mixed concrete design consistent with the ACI-211 Standards.

Experimental Models

This study used the cubic (the British) method to make concrete. Designing and making compacted concrete with conventional concrete of Type 1 and 5 containing silica gel (propylene fibers) were performed like reinforced concrete. The mixed method of reinforced concrete was like that of simple concrete. The requirements of flocculation and dispersion in concrete compaction were met. First, materials to make concrete, i.e., cement, sand, gravel, water, and propylene silica gel were prepared, and then in the next stage, software was designed for the concrete mixture. Concrete mixture amounts in one cubic meter were computed by converting them into weight values for a cubic mold of 8.5 kg.

Figure 1: Tested specimens

Experiments and Concrete Compressive Strength

This study used conventional Type I concrete, which was similar to simple and compacted concrete. Designing a simple (conventional) concrete mixture is very easy. However, to make concrete with propylene fibers, some considerations should be met to prevent flocculated concrete, and to produce an effective and compacted mixture. In the process of making concrete with silica, the phenomenon of flocculation should be avoided. This problem is mainly due to using low amounts of silica fibers. For example, the gravel used was made of crushed gravel. To make concrete, needle-shaped and flaky aggregates were avoided. Although the gravel used was free of soil or extra substances, the gravel was fully washed before the experiment and necessary measures were taken to reach the gravel to equal moisture for the tests. The sand used was river sand, which was also washed at the laboratory like the gravel. Also, the cement used was conventional Type I Portland cement, and the water consumed was household water.

Materials in the Mix Design of the Concrete Used in the Laboratory

1. Type 1 and 5 cement for as much as 450 kg/cubic m
2. A water-to-cement ratio of 0.47, with water being 170 l.
3. The volume ratio of coarse-grained material to the total materials used is 48%.
4. The gravel used in the design was a mixture of 3.4 gravel (400 kg) and 3.8 gravel (550 kg). In the meantime, the natural sand and gravel in the design were crushed.
5. The concrete mix design was provided for two weight states; one for saturated materials of dry surfaces and also dry materials, and a volumetric state for dry materials.
6. The slump and consistency of the concrete were measured to be 5 cm.
7. The compressive strength of the concrete was as follows: (cubic molds of 15*15*15 cm, and 22.5 kg of gel).

Findings

1. **Concrete Experiment Results**

Results indicated that the compressive strengths of concrete with silica nanoparticles (micro-silica gel, propylene fibers) were more effective than conventional concrete. Silica nanoparticles in concrete are widely used materials (fiber). Today, propylene fibers are widely used fibers and have positive effects on concrete functions. Using propylene fibers and micro-silica gel is expected to have a positive impact on concrete functions. Concrete containing silica nanoparticles is more capable of energy absorption and enjoys more compressive strengths. Propylene fibers can cover rebars buried in reinforced concrete and prevent rebar corrosion caused by climatic factors.

2. Experimental Results of Concrete Containing Micro-Silica Gel (Silica Nanoparticles)

a) The cement used was Type 1 and 5 Cement for as much as 450 kg/cubic meter

b) The water-to-cement ratio was around 0.47, with 170 l of water

c) The volumetric ratio of coarse-grained materials to the total materials used was 48%.

d) The gravel used in the design is a mixture of 3.4 gravel (400 kg) and 3.8 gravel (550 kg), while the natural sand and the design gravel are of the crushed type.

e) The concrete mix design was produced in two weight states: one was for saturated materials of dry surfaces and also dry materials, and the other was a volumetric state for dry materials.

f) The slump and consistency of the concrete were measured to be 3 cm.

g) 22.5 kg of gel, zero-percent nanoparticles 2.37 times the total weight of the concrete, and propylene fibers 80.59 times the total weight of the concrete were applied.

h) The compressive strength of the concrete was as follows: (cubic molds of 15*15*15 cm)

Compressive strength of concrete (kg/cm^2)	**7-day specimen's age**
232	80.59 G

a) The cement used was Type 1 and 5 Cement for as much as 450 kg/cubic meter

b) The water-to-cement ratio was around 0.47, with 170 l of water

c) The volumetric ratio of coarse-grained materials to the total materials used was 48%.

d) The gravel used in the design is a mixture of 3.4 gravel (400 kg) and 3.8 gravel (550 kg), while the natural sand and the design gravel are of the crushed type.

e) The concrete mix design was produced in two weight states: one was for saturated materials of dry surfaces and also dry materials, and the other was a volumetric state for dry materials.

f) The slump and consistency of the concrete were measured to be 4 cm.

g) 22.5 kg of gel, silica nanoparticles 2.37 times the total weight of the concrete, and propylene fibers 82.22 times the total weight of the concrete were applied.

h) The compressive strength of the concrete was as follows: (cubic molds of 15*15*15 cm)

Compressive strength of concrete (kg/cm^2)	**7-day specimen's age**
240	82.22

a) The cement used was Type 1 and 5 Cement for as much as 450 kg/cubic meter
b) The water-to-cement ratio was around 0.47, with 170 l of water
c) The volumetric ratio of coarse-grained materials to the total materials used was 48%.
d) The gravel used in the design is a mixture of 3.4 gravel (400 kg) and 3.8 gravel (550 kg), while the natural sand and the design gravel are of the crushed type.
e) The concrete mix design was produced in two weight states: one was for saturated materials of dry surfaces and also dry materials, and the other was a volumetric state for dry materials.
f) The slump and consistency of the concrete were measured to be 4 cm.
g) 22.5 kg of gel, silica nanoparticles 2.37 times the total weight of the concrete, and propylene fibers 80.65 times the total weight of the concrete were applied.
h) The compressive strength of the concrete was as follows: (cubic molds of 15*15*15 cm)

Compressive strength of concrete (kg/cm^2)	**28-day specimen age**
260	80.65

a) The cement used was Type 1 and 5 Cement for as much as 450 kg/cubic meter
b) The water-to-cement ratio was around 0.47, with 170 l of water
c) The volumetric ratio of coarse-grained materials to the total materials used was 48%.
d) The gravel used in the design is a mixture of 3.4 gravel (400 kg) and 3.8 gravel (550 kg), while the natural sand and the design gravel are of the crushed type.
e) The concrete mix design was produced in two weight states: one was for saturated materials of dry surfaces and also dry materials, and the other was a volumetric state for dry materials.
f) The slump and consistency of the concrete were measured to be 5 cm.
g) 22.5 kg of gel, silica nanoparticles 2.37 times the total weight of the concrete, and propylene fibers 80.67 times the total weight of the concrete were applied.
h) The compressive strength of the concrete was as follows: (cubic molds of 15*15*15 cm)

Compressive strength of concrete (kg/cm^2)	**28-day specimen age**
266	80.67

a) The cement used was Type 1 and 5 Cement for as much as 450 kg/cubic meter

b) The water-to-cement ratio was around 0.47, with 170 l of water

c) The volumetric ratio of coarse-grained materials to the total materials used was 48%.

d) The gravel used in the design is a mixture of 3.4 gravel (400 kg) and 3.8 gravel (550 kg), while the natural sand and the design gravel are of the crushed type.

e) The concrete mix design was produced in two weight states: one was for saturated materials of dry surfaces and also dry materials, and the other was a volumetric state for dry materials.

f) The slump and consistency of the concrete were measured to be 5 cm.

g) 22.5 kg of gel, silica nanoparticles 2.37 times the total weight of the concrete, and propylene fibers 82.40 times the total weight of the concrete were applied.

h) The compressive strength of the concrete was as follows: (cubic molds of 15*15*15 cm)

Compressive strength of concrete (kg/cm^2)	**28-day specimen age**
270	82.40

a) The cement used was Type 1 and 5 Cement for as much as 450 kg/cubic meter

b) The water-to-cement ratio was around 0.47, with 170 l of water

c) The volumetric ratio of coarse-grained materials to the total materials used was 48%.

d) The gravel used in the design is a mixture of 3.4 gravel (400 kg) and 3.8 gravel (550 kg), while the natural sand and the design gravel are of the crushed type.

e) The concrete mix design was produced in two weight states: one was for saturated materials of dry surfaces and also dry materials, and the other was a volumetric state for dry materials.

f) The slump and consistency of the concrete were measured to be 5 cm.

g) 22.5 kg of gel, silica nanoparticles 2.37 times the total weight of the concrete, and propylene fibers 81.68 times the total weight of the concrete were applied.

h) The compressive strength of the concrete was as follows: (cubic molds of 15*15*15 cm)

Compressive strength of concrete (kg/cm^2)	**90-day specimen age**
296	81.68

The key properties of concrete containing silica nanoparticles (micro-silica gel and propylene fibers) indicate that the micro-silica gel enjoyed the best mixture and strength against cracking, while it was easy to use. Also, there are polypropylene fibers inside the micro-silica gel. For this, propylene fibers have a great role in concrete, and they can be used in constructing dams and impact-resistant buildings such as shelters and warehouses.

Experimental Results and Compressive Strengths of Concrete Containing Propylene Fibers

The cement used was conventional cement, which Types 2 to 5 can be sometimes used based on different situations. The gravel used was a mix of crushed gravel of two types: 3.8 (550 kg) and 3.4 (400 kg), which were transferred to the laboratory where they were washed and dried. Also, following determining weights and gradation, all laboratory measures were met. Also, the sand used was river (washed) sand for as much as 1000 kg and was prepared for the concrete mix design. The water consumed was also drinking water of 170 l, which was calculated based on the C/E ratio. In concrete made, water could change by the initial weight amount.

1. Cement (300-450 kg)
2. Washed (natural) sand (1000 kg)
3. Mixed crushed gravel of 3.8 (550 kg) and 3.4 (400 kg)
4. Drinking water of 170 l
5. Micro-silica gel of 22.5 kg.

Designing and making compacted concrete with conventional concrete of Type 1 and 5 containing silica gel (propylene fibers) were performed like reinforced concrete. The mixing method of reinforced concrete was like that of simple concrete. The requirements of flocculation and dispersion in concrete compaction were met. First, materials to make concrete, i.e., cement, sand, gravel, water, and propylene silica gel were prepared. Then in the next stage, software was designed for the concrete mixture. Concrete mixture amounts in one cubic meter were computed by converting them into weight values for cubic molds of 22 kg in total with each cube measuring 8.5 kg. The specimens were tabulated and subsequent analyses were carried out.

Six Stages of Experiments Based on Compressive Strengths of Silica Nanoparticles, Micro-silica Gel, and Propylene Fibers

Cubic molds of 15*15*15 for compressive strength

In sum, in the six stages, cubic molds were examined to see how propylene fibers could affect the compressive strengths of concrete containing silica nanoparticles.

Table 1: Experiment of concrete mix design and compressive strength of concrete (the British method)

No.	Design strength	Compressive strength (cubic)	Specific gravity	Sample volume	Specimen age
A/206	185.333	2,37	8059	3398	7
B/206	191.724	2,42	8222	3398	7
C206	207.701	2,37	8065	3398	28
D/206	212.494	2,37	8067	3398	28
F206	215.689	2,42	8240	3398	28
E/206	236.459	2,40	81.67	3398	90
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Table 2: Experiments of concrete mix design

No.		Design strength	Compressive strength of cylindrical specimen	Compressive strength of cubic specimen	Specimen's specific gravity	Sample volume	Loading value	Specimen dimensions (cm)			Specimen's age	Concrete's temperature	Concrete consistency (cm)
			)2 cm/ kg(	) gr/cm2 (	)gr(	)cm 2 (	) cm2 (	Hight	Width	Length	Day	°C	

A/206	0	185.333	232	2.37	8059	3398	226.5	15	15	15	7	21	13
B/206	0	191.724	240	2.42	8222	3398	226.5	15	15	15	7	21	13
C/206	0	207.701	260	2.37	8065	3398	226.5	15	15	15	28	21	13
D/206	0	212.494	266	2.37	8067	3398	226.5	15	15	15	28	21	13
E/206	0	215.689	270	2.42	8240	3398	226.5	15	15	15	28	21	13
F/206	0	236.459	290	2.40	8163	3398	226.5	15	15	15	29	21	13

Conclusion

Propylene fibers and micro-silica gel help concrete strength against the corrosion of rebars buried in reinforced concrete. Also, with the increased ratio of propylene fibers, the compressive strength increased. The speed and the increased compressive strength of concrete against the corrosion of rebars buried in reinforced concrete saw a rise in the first 7 days. Concrete without nanoparticles (micro-silica gel) has a brittle behavior, while concrete reinforced with propylene significantly reduces its brittleness by preventing the extension and widening of cracks. The performance of concrete with silica nanoparticles (micro-silica gel and propylene fibers) indicated that micro-silica gel enjoyed the best mix and strength against cracking as it was also easy to be implemented. Also, there are polypropylene fibers inside the micro-silica gel. For this, propylene fibers have a great role in concrete, and they can be used in constructing saloons and impact-resistant buildings such as shelters and warehouses.

It is suggested to use propylene fibers in concrete to increase its compressive strength, durability, and efficacy. Using concrete containing nanoparticles and propylene fibers significantly increases the compressive strength of concrete. This suggests that fibers (micro-silica gel and propylene fibers) and nanoparticles have a positive role in concrete. This helps prevent cracks in concrete and increases its strength (i.e., it increases concrete's strength against the cracks of rebars buried after being dried). This study used crushed gravel and sand of 3.4 and 3.8 ratios, which had a major role in increasing the strength of concrete. This mixture ratio can also be used in constructing dams, road pavement, parking floors, etc.

References

Aybo, M. E. H. M. E. T., Erol, M., & Yildiz, G. (2022). The necessity of transition from industry 4.0 to industry 5.0: Swot analysis of Turkey? S SCM strategy. *Journal of organizational behavior research*, *7*(2)1-17.

Gaikwad, S. S., & Choudhari, V. P. (2022). Efficacy and Safety of Combination Therapy of Zinc and Silver Oxide Nanoparticles in Streptozotocin-Induced Diabetic Rats. International Journal of Pharmaceutical Research and Allied Sciences, 11(3), 1-10

Rezaei-Motlaq, Hasan, Functional analysis of concrete modified with steel fibers - by recycling car tires (Construction and Project Management Conferences), Ala-Uddouleh Institute, Semnan, Garmsar.

Ramzanianpour, Ali-Akbar & Shah Nazari, Mohammad Reza (1997). Concrete Technology, Tehran, Science and Technology Publications, Sadovnikova, N., Lebedinskaya, O., Bezrukov, A., & Davletshina, L. (2022). The correlation between residential property prices and urban quality indicators. *Journal of Advanced Pharmacy Education & Research*, *12*(2), 98-103.

Samir, D., Ouissam, B., & Anfal, D. (2022). Antioxidant and Antidiabetic Effect of Biosynthesis Zinc Nanoparticles by Using Polyherbal Aqueous Extract in Wistar Rats. Journal of Biochemical Technology, 13(1), 72-80.

Tzeng Y, Lee C. Analysis of Rail Potential and Stray Currents in a Direct-Current Transit System. IEEE T Power Deliver 2010;25(3):1516–25.

Van Nguyen, T., Le, H. T. T., & Nguyen, H. T. (2022). Evaluating the curriculum of vocational schools in Vietnam. *Journal of Advanced Pharmacy Education & Research*, *12*(2) 57-62.

Zamani, Alireza & Moghadam, Behdad (2019). Investigating concrete reinforced with steel fibers, 11th Conference of Nationwide Civil Engineering Students, Tehran.

Zhang XL, Jiang ZH, Yao ZP, Song Y, Wu ZD. Effects of scan rate on the potentiodynamic polarization curve obtained to determine the Tafel slopes and corrosion current density. Corros Sci 2009;51(3):581–7.