



## Effect of Starch Powder on Behavior of Silica Fume Biopolymer Concrete

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### HIGHLIGHTS

- Adding Biopolymer to concrete reduces environmental pollution.
- Improving mechanical properties for concrete containing Biopolymer substances.
- Starch as a Biopolymer substance is very available and cheap price.

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### ABSTRACT

The great economic development and the growth of modern means of construction have led to the spread of large quantities of chemical admixtures that we must be cautious of. As the world is turning towards environmentally friendly alternatives, finding locally viable solutions is becoming inevitable. The influence of using Nano starches of a biopolymer on certain properties of silica fume concrete in the fresh case (slump and fresh density) and in the hardened case (compressive strength, splitting tensile strength, and flexural strength) has been investigated. It has been added to silica fume concrete in various percentages of (0%, 0.25%, 0.5%, and 0.75%) by cement weight. The mix proportions of concrete mixtures were 1:2.3:2.3, with a fixed w/c of 0.47 and 15 % silica fume added by the weight of cement for all mixers. super plasticizer of 0.75% is also added by the weight of cement for all mixtures. According to the findings, slump increased by 19%, and fresh density increased by 3% when Nano starch was added at a concentration of 0.75%. The optimal level of Nano starch addition was 0.25%, which resulted in a 43% increase in compressive strength and a 34% and 26% increase in splitting tensile and flexural strength of concrete, respectively.

### 1. Introduction

Civil substructures around the world are being in an unfinished state, and essential determinations are needed for rendering the crumbling substructures back to working and harmless condition, hence multi-functional and clever compounds, such as nanomaterials are ideal substances to achieve such goals [1]. The nanomaterials are utilized to develop the cementations substances' durability, strength, and structural proficiency. In addition, the nanomaterial's utilization with cement can reduce the releases of (CO<sub>2</sub>) associated with concrete industry [2]. Over the last few decades, the development of environmentally friendly, high-performance, and renewable materials such as biopolymers has signaled a growing trend toward sustainable construction. In concrete blends, organic, biodegradable, and recycled biopolymers have been used to enhance their physical and mechanical features and sturdiness [3]. Nano-starch was used as one of the concrete components in this project. The main advantages of this biopolymer are the lower cost of acquisition and the fact that it has properties that make it suitable for use as additive materials. Another significant advantage of employing plants is that they are renewable natural resources that do not harm the environment. Otoko [4] looked at the possibility of employing cassava powder additives in hot environment concrete to eliminate or lessen fresh and hardened concrete difficulties. It has been determined that a tiny amount of cassava powder, equivalent to 0.05 percent of the weight of cement, has the potential to improve concrete workability and initial and long-term strength. Laboratory studies conducted by Abd *et al.* [5] have shown that the use of cassava powder as a retarder can delay setting time, improve workability and increase the long and early-term strength of concrete. Its use is an easy solution to its environmental dilemma, which is economically favored. Waleed and Hawraa [6] indicated that the starch addition of 0.5% by weight of cement showed a 50% increase in compression and splitting tensile strength and also showed 26% increase in flexural strength. Thus, it has offered a clear improvement in workability and increased the slump with an increasing percentage of starch. Akindahunsi and Uzoegbo [7] used starch (cassava and maize) as additives to investigate certain aspects of concrete, including strength, oxygen permeability, and sorptivity. These results showed a decrease in oxygen permeability

and rates of sorptivity, with concretes containing starch as admixtures giving better performance than the control concretes, compressive strength increase, and incorporation of cassava and maize starches into concrete improves the durability properties of the concrete. The mechanical characteristic of biopolymer compounds is influenced by interfacial interactions among the biopolymer and the Nano filler [8].

Silica fume is a side product of the ferrosilicon alloy smelting process and silicon processing. Physically, silica fumes are exceptionally fine, with grain sizes varying from 10 to 100 microns. Due to its fineness and small grain size, silica fume is a very efficient pozzolanic material [9]. One of the most significant common uses of silica fume as a concrete additive is its important physicochemical characteristics that create a reactive pozzolan. The addition of silica fumes to concrete progresses the resistance and characteristics. Increasing silica fume content by 30% caused a considerable increase in the compressive strength by 34% [10].

## 2. Materials and methods

### 2.1 Materials

#### 2.1.1 Cement

The chemical and physical properties of the used ordinary Portland cement (O.P.C.) produced in Iraq commercially known as (Almas) are displayed in Tables 1, and 2 respectively. The findings conform to the Iraqi specification I.Q.S. No.5/1984[11].

#### 2.1.2 Aggregate

Crushed coarse aggregate was used in concrete based on the Iraqi Standard I.Q.S. 45/1984 [12]. Table 3 below shows the physical properties of the aggregate. Tables 4 and 5 show the grading of coarse and fine aggregate, respectively.

**Table 1:** Portland cement used (chemical composition)

Oxide	% By weight	I.Q.S. 5 /1984– Type II Limits [11]
SiO <sub>2</sub>	20.54	—
CaO	61.30	—
SO <sub>3</sub>	1.87	< 2.8
MgO	1.93	< 5
Fe <sub>2</sub> O <sub>3</sub>	3.12	—
Al <sub>2</sub> O <sub>3</sub>	5.05	—
Insoluble residue (I.R)	1.32	< 1.5
L.S.F	0.88	0.66-1.02
Loss on ignition (L.O.I)	2.54	< 4
Main compounds		
C <sub>3</sub> S	43.85	—
C <sub>2</sub> S	25.88	—
C <sub>3</sub> A	10.04	—
C <sub>4</sub> AF	9.97	—

**Table 2:** Test physical properties of cement

The Physical properties	findings of test	I.Q.S. 5 / 1984-Type I
Soundness (Autoclave) %	0.05	≤ 0.8
Compressive strength (MPa)		
3days	20.0	≥ 15
7days	29.5	≥ 23
Setting time (Hrs. min.)		
Initial	2.05	≥ 45 min.
Final	4.00	≤ 10 hrs.
Specific surface area (Blaine method. (m <sup>2</sup> / kg)	367	≥ 230

**Table 3:** The physical properties of aggregate

Property	Fine aggregate	Coarse aggregate
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Fineness modulus	3.13	
Specific gravity	2.67	2.36
Bulk density (kg/m <sup>3</sup> )	1605	1685
(%) Absorption	1.6	0.62
The Content of Sulfate (%)	0.1	0.082

**Table 4:** The grading of coarse aggregate

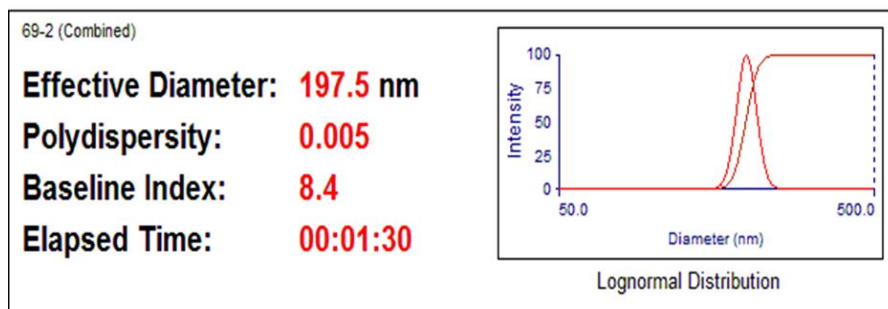
Size of Sieve (mm)	%Passing	Limits of I.Q.S. No.45 /1984 [12] No.45 /1984 [12]
20	100	100
14	100	90-100
10	83	50-85
5	5	0-10
2.36	0	0

**Table 5:** Test grading of fine aggregate

Size of Sieve (mm)	%Passing	I.Q.S. No.45 /1984 zone (2) [12]
9.5	100	100
4.75	96	90-100
2.36	85	75-90
1.18	62	55-90
0.6	41	35-55
0.3	14	8-30
1.15	7	0-10

2.1.3 Nano starch

The highest limit is typically 100 nm. However, this is a "fluid" restriction; items of larger dimensions (even 200 nm) are frequently classified as Nanomaterial's [13]. The term "Nano-sized starch" refers to organic starch nanoparticles (S.N.s) with a size of 50 to 200 nm that are made from starch using either physical or chemical processes [14]. Corn starch from the market has been manufactured as a Nano in the engineering research laboratory at the University of Technology by an effective diameter of 197.5 nm, as shown in Figure 1. Tables 6 and 7 demonstrate the chemical composition and physical properties of Nano starch, respectively.



\* The test was carried out in Nanotechnology Center / University of Technology

**Figure 1:** Effective diameter for Nano starch

**Table 6:** Chemical composition of Nano-starch

Code	Component	Condensation (ppm)
Na	Sodium	<640
Ca	Calcium	45.6
Al	Aluminum	<18
Mg	Magnesium	<100
Si	Silicon	55.5
P	Phosphor	45.3
K	Phosphor	87

**Table 7:** Physical properties of the Nano- starch

Specialty	Upshot
Effective Diameter (nm)	197.5
Look	Aqueous suspension
Tint	Transparent

#### 2.1.4 Silica fumes (S.F.)

Dandified grey-colored silica fume was used in the report. It's a pozzolanic substance composed of tiny spherical particles with a significant amount of amorphous silicon dioxide. MEGA is a substance that produces latently reactive silicon dioxide in extremely fine (0.1-0.2 m) molecules. Tables 8 and 9 represent the chemical composition and the physical characteristics of S.F. The S.F. utilized in this research meets the ASTM C1240-10 [15] specifications.

**Table 8:** Chemical composition of Silica fume

Oxide installation	Oxide content percentage	ASTM C1240 Limits
SiO <sub>2</sub>	94.58	≥ 85
Al <sub>2</sub> O <sub>3</sub>	0.1	—
Fe <sub>2</sub> O <sub>3</sub>	0.06	—
K <sub>2</sub> O	0.35	—
Na <sub>2</sub> O	0.21	—
CaO	0.58	—
MgO	0.22	—
SO <sub>3</sub>	0.11	—
L.O.I	1.98	≤ 6
Moisture content	0.57	≤ 3

MgO 0.22 -----

**Table 9:** Physical Properties of Silica fume

Physical Properties S.F	Upshot
Specific gravity	2.016
Smoothness (m <sup>2</sup> /kg)	20000
Look	powder
Tint	grey

#### 2.1.5 High range water reducing admixture (HRWRA)

High range water reducing admixture super plasticizer was made by Swiss Chemistry Company and marketed as EUCOBET SUPER VZ. This additive complies with ASTM C494 type G [16].

#### 2.1.6 Water

Water used for mixing and curing concrete was Tap water and had a pH value between 8-8.5.

## 2.2 Experimental work

### 2.2.1 Mix proportions

For all mixes, the mix proportion was (1:2.3:2.3) (371:854:854) (kg/m<sup>3</sup>) (cement: sand: gravel), w/c=0.47, depending on the concrete mix design method by the American concrete institute [17]. Table 10 below shows the details of mixes.

### 2.2.2 Preparation of Concrete

The materials for this project were prepared according to ASTM C192 [18] and weighed in a laboratory balance. Four types of concrete specimens were prepared; reference mix cast as the first set of concrete specimens, and the other three were with 0.25%, 0.5%, and 0.75% adding of Nano starch by weight of cement, respectively. In addition, all mixes have added silica fume and super plasticizer to fixed proportions of 15% and 0.75% by weight of cement, respectively.

**Table 10:** Specifications of mix designation

Mix Title	Cement kg /m <sup>3</sup>	Fine Aggregate kg /m <sup>3</sup>	Coarse Aggregate kg /m <sup>3</sup>	W/C kg /m <sup>3</sup>	Nano starch (by weightof)	Weight of Starch kg /m <sup>3</sup>	Silica fume kg/m <sup>3</sup>	Super plasticizer kg /m <sup>3</sup>
Ref	371	854	854	174.4	0.0	0.0	55.7	2.79
1	371	854	854	174.4	0.25	0.93	55.7	2.79
2	371	854	854	174.4	0.5	1.86	55.7	2.79
3	371	854	854	174.4	0.75	2.79	55.7	2.79

### 2.3 Experimental tests

- 1) Slump test; the slump test was performed, as specified in the ASTM C143 [19]. The blend proportions were 1:2.3:2.3, with a steady w/c of 0.47 for all mixes.
- 2) Fresh Density test; this test was performed according to ASTM C 138M-01[20].
- 3) Compression Strength test; the compressive strength test was performed, depending on BS 1881 Part 101[21]. For each concrete mix, the mean compressive strength of the three samples was determined.
- 4) Splitting tensile strength test; the ASTM C496-04[22] was used to perform the splitting tensile strength test. For each test, two cylinders with d = 100 mm and h = 200 mm were used.
- 5) Flexural strength test; Flexural strength test was performed in accordance with ASTM C 78-04 [23]. The force was applied on the side that was vertical to the aspect of the pour.
- 6) Scanning Electron Microscope Reviews, S.E.M.; this test necessitates the preparation of the test samples in accordance with ASTM C-856-14 [24].

## 3. Results and discussions

### 3.1 Slump

Table 11 and Figure 2 demonstrate that the addition of Nano starch biopolymer by the weight of cement in silica fume concrete can increase the slump of concrete by 19% for 0.75%, while about 6% and 10% for 0.25% and 0.5% Nano starch in comparison to reference mix, improving the workability of concrete. This performance may be due to the high surface area of Nano starch in the mixture, which acts as a lubricant that tends to decrease the interior spirant between the atoms and aggregates, and consequently, the factor of compacting and the workability increases [25]. Another reason is that the main polymers of starch are amylose and amylopectin macromolecules with one hydrophobic and one hydrophilic end. The charge on the face of cement and sand grains pulls the hydrophilic end, whereas the hydrophobic end lowers surface tension resulting in decreased viscosity [26].

### 3.2 Fresh density

According to the findings of fresh density for silica fume concrete shown in Table XI and Figure 3, adding 0.75% Nano starch by weight of cement results in a 3% increase in fresh density, while adding 0.25% and 0.5% Nano starch results in a 1.9 % and 1.4% increase in fresh density, as compared to the standard mix. It may be because nanomaterials have a substantially higher surface area for absorbing water due to their small particle size [25]. Still, the addition of Nano starch was small, therefore there was a few increases in fresh density.

**Table 11:** Results of fresh properties in 28 days

Mix Designation	Nano starch (%)	Slump(mm)	Fresh density(kg/m <sup>3</sup> )
Ref	0	80	2486
1	0.25	85	2521
2	0.5	88	2532
3	0.75	93	2560

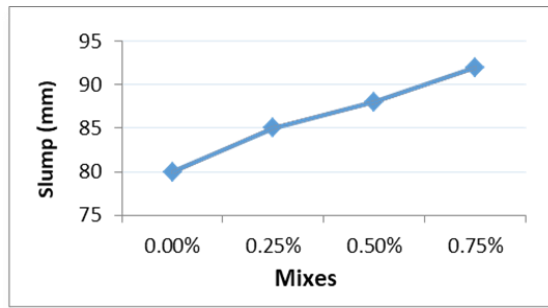


Figure 2: Slump of Silica Fume concrete

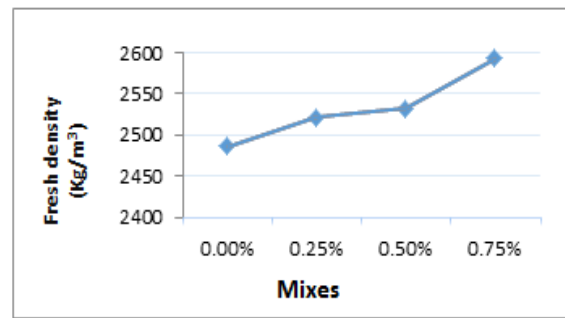


Figure 3: Fresh density of Silica Fume concrete

### 3.3 Compression strength

According to the findings of the compression strength test shown in Table XII and Figure 4, the increase in compression strength of silica fume concrete was by (43, 25.8, and 11.8) % for (0.25, 0.5, and 0.75%) addition of Nano starch, respectively, as a comparison to the control mixture. This rise could be explained by the fact that Nano starch is known to have a rising degree of polymerization, resulting in greater cohesive force; however, the degree of polymerization of a starch molecule is impacted by the raw material [27]. This improvement in compressive strength could be because incorporating polymers into concrete improves the mechanical characteristics of the ITZ, resulting in concrete with improved mechanical characteristics. Therefore, it is projected that C-S-H output will be higher in the ITZ. In theory, the higher the C-S-H content, the better the bond among the aggregate (sand and gravel) and the cement paste, and thus the more significant the compressive strength [28].

### 3.4 Splitting tensile strength

The tensile strength results of silica fume concrete shown in Table 12 and Figure 5 exhibited an apparent increase in tensile strength, with 0.25% of starch powder addition giving 34% increase in splitting tensile strength of the concrete. In comparison, 0.5% and 0.75% of starch powder addition gave 9% and 6% increase in splitting tensile strength of the concrete, respectively. The split tensile test results revealed the same pattern in strength progression. This improvement was due to the use of Nano-starch, which reduced the rate of water segregation in concrete, preventing moisture from gathering beneath the aggregate and contributing to the microstructure of the aggregate-cement paste interface transition area. At the same time, the pozzolanic reaction was used to change the structure of pores in cement paste. As a result, concrete strength was improved using silica-containing pozzolan materials [29,30], which is similar to the findings of Hossain et al. [31].

### 3.5 Flexural strength

The flexural strength findings of silica fume concrete shown in Table 12 and Figure 6 showed that 0.25 percent starch powder addition resulted in 26 percent increase in flexural strength. In comparison, 0.5 percent and 0.75 percent starch powder addition resulted in 12 percent and 5 percent increase in flexural strength of concrete, respectively, compared to the original mix of 0 percent. The decrease in adhesion between the surface of aggregate particles and the cement paste, including starch powder, could explain this phenomenon. Because of the flat surface of the starch biopolymer, the aggregate and cement paste may have a weak bonding strength, or the cause for this is the weak nature of the starch gelatin [6].

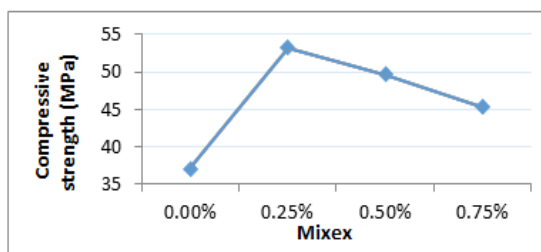


Figure 4: Compressive strength of Silica Fume concrete

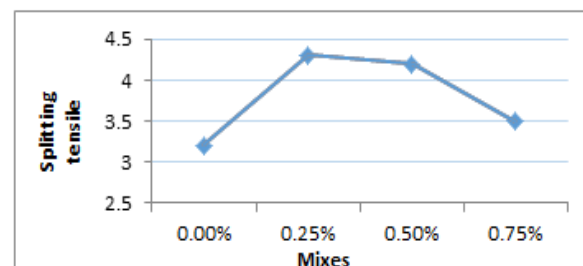
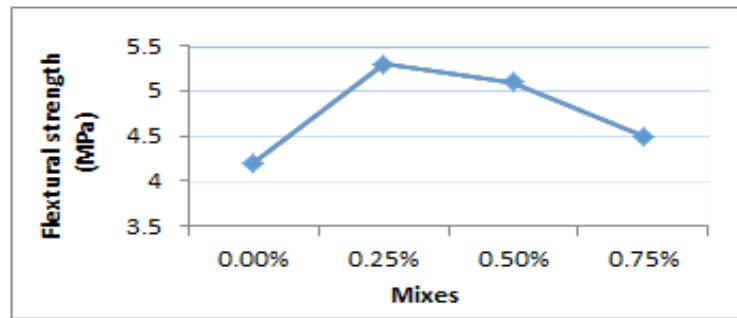


Figure 5: Splitting tensile strength of Silica Fume concrete





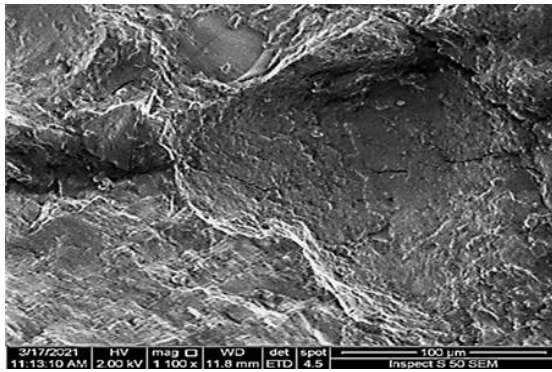
**Figure 6:** Flexural strength of Silica Fume concrete

**Table 12:** Results of hardened properties in 28 days

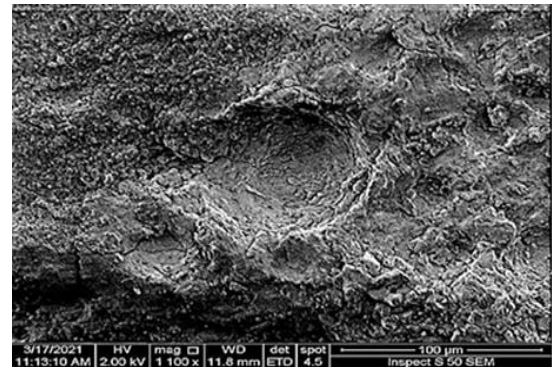
Mix Designation	Compression Strength(MPa)	Splitting Tensile Strength (MPa)	Flexural Strength (MPa)
Ref.	37.1	3.2	4.2
1	53.2	4.3	5.3
2	49.7	4.2	5.1
3	42.5	3.5	4.5

### 3.6 Scanning electron microscope reviews, s.e.m.

The variations in morphology before and after adding the Nano starch to the concrete were revealed by S.E.M. pictures. Nano starch molecules in the mix lead to a more uniform microstructure than the reference mix, as shown in Figures 7 and 8. The permeability is reduced by filling the pores in I.T.Z. with Nano starch. Because the particle size of the Nano starch is tiny, well mixing, and the nature of gelatin starch make the I.T.Z. significantly denser, where these particles could fill pores better than the reference mix [32].



**Figure 7:** S.E.M. image of the control mixture in 28-days at 1100x enlargement



**Figure 8:** S.E.M. image of the optimum mixture 0.25 % Nano starch in 28-days at 1100x enlargement

## 4. Conclusions

In light of the experimental investigation reported in this study, the following inferences are drawn:

- 1) The study indicated a great benefit from using Nano starch in concrete mixtures, as it improves the physical and mechanical properties of silica fume concrete.
- 2) The microstructure of the concrete after 28 days of curing was more homogeneous, with fewer cracks and pores, indicating an improvement in the microstructure compared to the reference mixture.
- 3) It is recommended not to use higher than 0.25% to 0.5% Nano starch by weight of cement.
- 4) From an economic and environmental point of view, using biopolymer Nano starch as an additive instead of chemical additives is less expensive and environmentally friendly.

### Author contribution

All authors contributed equally to this work.

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## Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

## Conflicts of interest

The authors declare that there is no conflict of interest.

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