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Effect of silica addition on properties of concrete: A review

Pakhare S.R.[1], S. M. Zubair [2]

[1]*PG Student ,Dept of Civil Engineering ,Deogiri Institute of Engineering and Management Studies, Aurangabad,*
[2]*Assistant professor Dept of civil Engineering ,Deogiri Institute of Engineering and Management Studies, Aurangabad.*

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ABSTRACT - *Since few decades, it was normal practice to replace some of the cement with pozollanic materials in order to improve the qualities of concrete. These compounds are referred to as supplemental cementing materials since they have the same pozzolanic and binding qualities as cement. Silica is well-known for its usage in constriction as silica fume, but as nano-particles become more prevalent in the construction sector, the impact of nano-silica on concrete characteristics is also being investigated. This review paper summarizes the research that has been done on the effects of silica fume and nano-silica colloidal form on the fresh and mechanical properties of concrete. This review work included a study of the fresh qualities of concrete, such as workability, bleeding and segregation, and setting time. This paper also evaluated the literature on the effects of silica on mechanical parameters such as compressive strength, flexural strength, and split tensile strength.*

Keywords: Nano-material, Silica, Compressive strength, Flexural strength.

1. INTRODUCTION

In recent years, high-strength and high-performance concrete has become more popular around the world, mandating a decrease in the water/binder ratio and an increase in the binder content. [3,4] However, when attempting to create high-strength and high-performance concrete, both economic and environmental considerations must be taken into account. As a result, other Supplementary Cementing Materials (SCMs) are currently employed in concrete to partially replace the Portland cement component. In modern concrete technology, active pozzolanic admixtures such as silica fume (SF) and metakaolin are used as SCMs to achieve high performance qualities. Nano-scale pozzolans aid in the creation of more dense micro structural packing and a more impervious cement matrix. [10] In recent years, there has been a growing interest in the use of nano-silica in concrete. [1]According to studies, nano-particles have an ultrafine size, which causes them to have unique physical and chemical properties that are distinct from those of regular materials. According to the number of dimensions, the author has classified nano-particles into four primary groupings that are not limited to the nanoscale range: (i) Quantum dots and fullerenes are zero-dimensional (0-D) materials. (ii) Nanotubes, nanowires, and nanorods are examples of one-dimensional (1-D) materials. (iii) Graphene and nanosheets are two-dimensional (2-D) materials. (iv) Nano-porous materials, which are three-dimensional (3-D). [7]Silica is one of the SCMs that comes in a variety of forms, including silica fume, colloidal silica, and nano-silica. Silica has a variety of effects on the strength and characteristics of concrete in its many forms. The impact of silica fume on concrete strength has yet to be properly quantified. [9]The use of active pozzolanic admixtures, dense microstructure packing of particles, and a low water/cement ratio are the most common techniques to obtain high-performance features in concrete. The most common and effective pozzolanic additive is silica fume (amorphous SiO_2). The particle sizes of silica fume (SF) range from 20 to 500 nanometers. [10]Although there is a lot of info about silica fume concrete in the literature, much of the research focuses on compressive strength, and technical data on tensile strength is few. [9]Although several studies have looked at the influence of nano-silica on cement mortars, this research has focused on nano-silica engineering in order to achieve significant outcomes. The authors used a simple and quick sol–gel approach to make silica nanoparticles. The impact of calcination and surfactant on the size and shape of nano-silica was studied. Different dosages of produced silica nanoparticles were added to cement mortars, and the effects on compressive and flexural strengths were investigated. [7]Colloidal silica (CS) is a term used to describe tiny particles made up of an amorphous SiO_2 core with a hydroxylated surface that are insoluble in water. The particles' sizes can range from 1 to 500 nm, making them tiny enough to stay suspended in a fluid medium without settling.The nanometer-sized CS particles have a large specific surface area, making them a highly reactive siliceous material. However, it is still unknown whether the faster hydration of cement in the presence of nano-silica is related to its chemical reactivity during dissolution (pozzolanic activity) or a high level of surface activity. [6]According to the study, nano-silica comes in two forms: compressed dry grains and colloidal solution. Dry nano-silica necessitates a particular preparation method prior to mixing to ensure that the nano-particles are well dispersed in the mixing water, or other liquid admixtures, and are evenly distributed throughout the concrete mixture. Colloidal nano-silica, on the other hand, is a ready-to-use version of nano-silica that is generated as a suspension stabilized by a dispersive agent. [11]When compared to typical grain-size materials with the same chemical composition, nanoscale particles can have dramatically better characteristics. As a result, industries may be able to re-engineer many existing items and build new and creative products that perform at previously unimaginable levels. [6] It should be underlined that nano-silica is a much more expensive admixture than silica fume; therefore replacing SF with nano-silica is not cost-effective. A more efficient technique to achieve some favorable secondary effects is to utilize nano-silica in small amounts. [10]The effect of different types of colloidal silica on the characteristics of concrete is briefly examined in this article.

2. MATERIALS

2.1 Cement

There are several types of cement, including OPC, PPC, rapid hardening cement, low heat cement, and so on, with OPC and PPC being the most popular. The most frequent type of cement utilized in studies is OPC, which stands for ordinary Portland cement. Irish Cement Ltd provided the ordinary Portland cement (PC) used in this investigation. The cement had a specific gravity of 3.15 g/cm^3 and was grade 42.5. [2]Low thermal conductivity characterizes lightweight concrete.As a result, slow-hydration cement should be utilized in mix designs to prevent thermal microcracking caused by heat evolution during cement hydration. As a result, CEM III/A 42.5 N slag cement was used. [5]Ordinary Portland Cement was employed, which has a 28-day compressive strength of 54 MPa. [9]This investigation employed a type I Portland cement with a Blaine fineness of 385m^2/kg. [11]

Table1. Chemical composition and physical properties of cementitious materials [6]

Constituents	Content (%)
SiO_2	16.51
Al_2O_3	3.59
Fe_2O_3	2.62
CaO	62.15
MgO	1.05
K_2O	0.50
SO_3	3.53
Na_2O	0.09
Cl	0.03
Physical properties	
Specific gravity	3.02
Specific Surface Area (m^2/g)	0.318

2.2 Aggregate

A typical concrete mixture contains 10% to 15% cement, 60% to 75% aggregate, and 15% to 20% water. As a result, aggregate is the most significant component of concrete. As a reason, the aggregate must be carefully graded. Sand with particle sizes ranging from 1.18 mm to 5 mm, a specific gravity of 2.60 g/cm^3 - 2.78 g/cm^3, and fineness modules of 2.5 to 3 were employed. Water absorption was measured in the range of 0.2 percent to 0.8 percent. [2,6,8,9,12]The coarse aggregate utilized was well-graded natural gravel with particle sizes ranging from 10 to 25 mm, a specific gravity of 2.77 g/cm^3 - 2.78 g/cm^3, and fineness modules of 6.95. Water absorption was measured in the range of 0.6 percent to 0.9 percent. [2,8,10,12] For the experiment with light-weight concrete as a lightweight aggregate, Liaver expanded glass with varied fractions (0.5–1, 1–2, and 2–4 mm) was employed. [5]

2.3 Water and admixtures

In concrete, water plays a crucial function. Water aids the hydration of cement, resulting in the cement's binding properties. The portable water had a pH range of 6 to 7.5. Different research used a wide variety of water cement ratios, ranging from 0.26 to 0.45 and higher up to 0.80. [3,6-9,11] In some research, varying dosages (0.1 to 3.5 percent) of admixture super-plasticizers are used to achieve a consistent workability level. [2,3,9,10,12]

2.4 Silica

The effect of silica on various qualities of concrete has been studied in literature. The silica utilized in this approach was either solid or liquid. Silica fume is solid silica, and colloidal silica or nano-silica is liquid silica.

Colloidal silica is a suspension in a liquid phase containing tiny amorphous, nonporous, and generally spherical silica particles. It's characterized as a concentrated stable dispersion made up of discrete and dense amorphous silica SiO_2 particles with uniform particle sizes ranging from 5 to 100 nm with a high specific area. These suspensions have a solid concentration of 30%. [6]The colloidal silica sol utilized had a solid content of 15% by weight. The particle size was 5 nm, with a specific surface area of 500m²/g. [2]

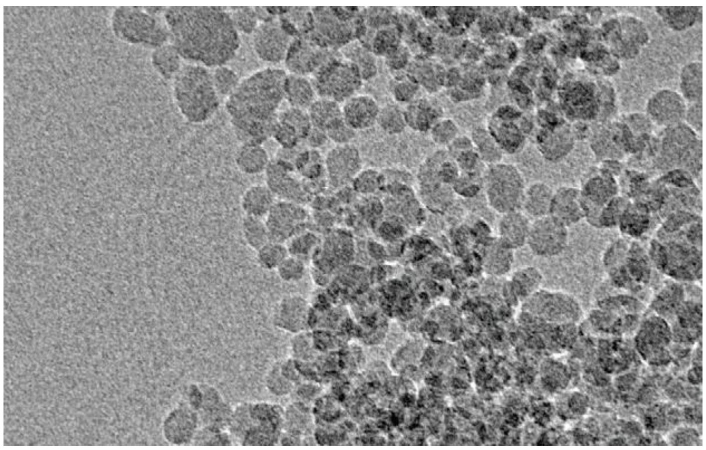

Fig. 1 Transmission electron micrograph (TEM) of nano-SiO_2. [6]

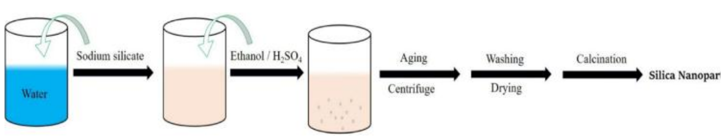

Fig. 2 Schematic procedure of silica nano-particles preparation [7]

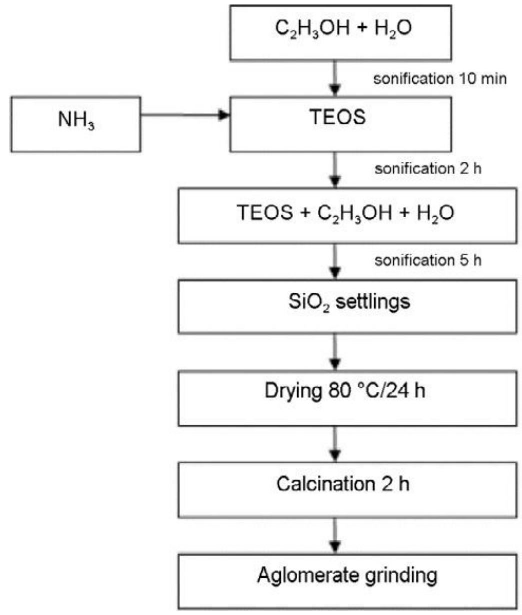

Fig. 3 Genady Shakhmenko et al. Used Sol-Gel method for synthesizing SiO_2 nano-particle [10]

P. Sikora et al. used silica fume to replace cement in light-weight concrete and compared the results to colloidal silica-replaced concrete. [5]Instead of using nanoSiO_2 powder, colloidal nanoSiO_2 (CNS) was employed to ensure a uniform dispersion of nanoSiO_2 in the cement paste. The sol–gel process was utilized to manufacture sodium stabilized CNS with an average particle size of 10 nm (CNS-10). [11]The nano-silica used was in the colloidal form of a 50 percent SiO_2 aqueous solution. The nano-silica had a mean particle size of 35 nm, a specific gravity of 1.36, and a pH of 9.5, respectively. [12]The research suggests that in the majority of cases, silica fume replacement is greater, ranging from 5% to 30%. [3,8,9]The nano-silica replacement, on the other hand, was in a smaller proportion, ranging from 1% to 15%.[2,5-7,10-12]

3. PROPERTIES OF SILICA ADDED CONCRETE

3.1 Fresh state properties

The fresh qualities of concrete, such as workability, bleeding and segregation, and setting time, are all affected by silica in any form. Because of the large increase in viscosity caused by adding Nano-Silica to the mix, a smaller amount of stabilizer (or none at all) is required to prevent bleeding and segregation.[5]After observing a decrease in workability when adding silica fume to concrete, M. Mazloom et al. discovered that mixes containing higher silica fume content required larger super-plasticizer dosages. [3]According to Mounir Ltifi et al., the setting of fresh pastes was marginally accelerated as the nano-SiO_2 content increased, but the gap between the initial and final time decreased as the NS content was increased. [6]Behnam Behnia also affirms that by adding 4% silica nanoparticles to the cement paste, the sample's curing time was reduced to 220 minutes from 250 minutes for the 0% silica sample. [7]

3.2 Mechanical properties

3.2.1 Compressive strength

The impact of silica on concrete's compressive strength is quantifiable. Several investigations have been conducted on the effect of silica on concrete compressive strength at various curing ages of 7, 14, 28, and 90 days. M. Aly discovered that when colloidal silica was substituted by waste glass, the compressive strength rose by 31 percent at a 3 percent colloidal silica replacement percentage. [2]M. Mazloom discovered that at the age of 28 days, the strength of concrete containing 15% silica fume was around 21% higher than that of control concrete, with a minimal increase after 90 days. This demonstrates that the addition of silica fume to concrete mostly impacts the concrete's short-term strength. [3]P. Sikora investigated the effect of nano-silica on light weight concrete, discovering a significant increase in flexural and compressive strengths after 28 days of curing in both LW and ULWA concretes when cement was replaced by NS. [5]The addition of nano-SiO_2 to cement mortars improves their strength properties, according to the author. As the nano-SiO2 content in the mortars increased from 3% to 10%, the strength of the mortars increased. They also stated that increasing the amount of nano-SiO_2 in the mix must be followed by changes in the water dosage to guarantee that specimens do not suffer from excessive self-desiccation and cracking. [6]

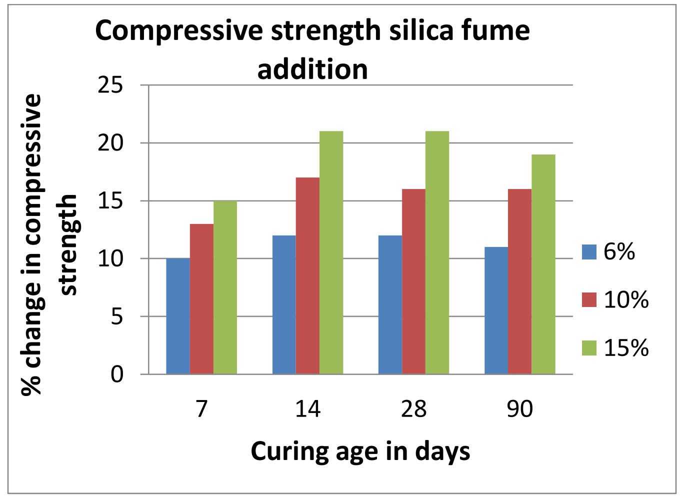

Chart-1 Percentage change in Compressive strength of concrete incorporating silica fume [3]

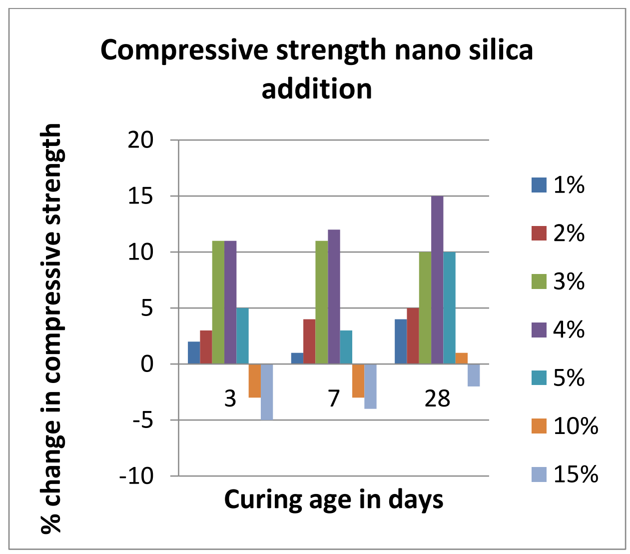

Chart-2 Percentage change in Compressive strength of concrete incorporating nano-silica [7]

Both the 6 percent and 12 percent SF concrete mixtures demonstrated an increase in compressive strengths when compared to ordinary concrete, according to J.M.R. Dotto et al. [8]S. Bhanja and B. Sengupta discovered that at 15 percent silica fume replacement, the maximum compressive strength was attained at 28 days curing age, however that increasing the silica fume percentage caused slightly reduced compressive strength. [9]According to Genady Shakhmenko et al., the sol-gel nano-silica has no noticeable effect on long-term compressive strength. [10]According to A.M. Said et al., adding nano-silica to the mix boosted the strength by up to 6% at all curing ages. The compressive strength of mixtures containing 30 percent Class F fly ash and nano-silica was significantly improved at 28 days. [12]

3.2.2 Flexural strength, tensile strength

As well as compressive strength, silica has an effect on flexural and tensile strength. According to M. Aly et al., colloidal silica can boost the flexural strength of concrete by up to 55 percent. [2]P. Sikora et al. studied the effect of silica fume and nano-silica on light and ultra-light weight concrete and observed that the silica fume dose had no effect on the flexural strength of LW and ULW concrete. Nano-silica, on the other hand, has a favorable and visible impact on both LW and ULW concrete's flexural strength. [8]Incorporating 4% silica nano-particles into the mix resulted in optimal flexural strength of 22.61 percent for 3 days, 10.12 percent for 7 days, and 17.20 percent for 28 days, according to Behnam Behnia. These findings suggest that nano-silica aids in the development of flexural strength in concrete at an early age. He also notes that increasing the silica dosage reduces the flexural strength of concrete slightly. [7]

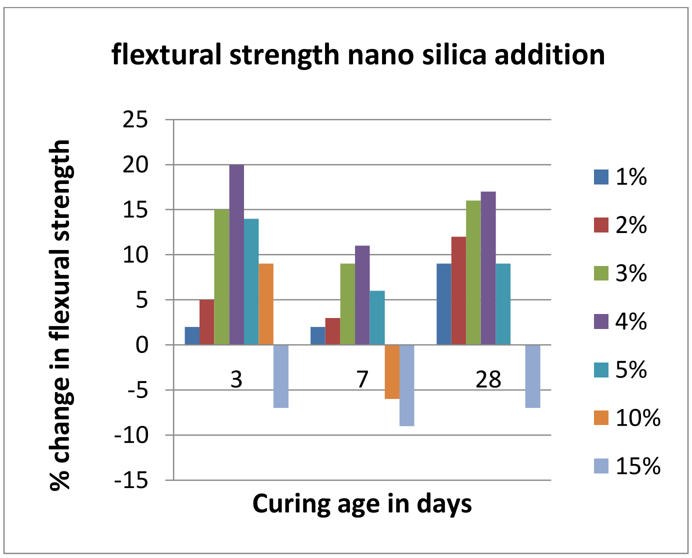

Chart-3 Percentage change in Flexural strength of concrete incorporating nano-silica [7]

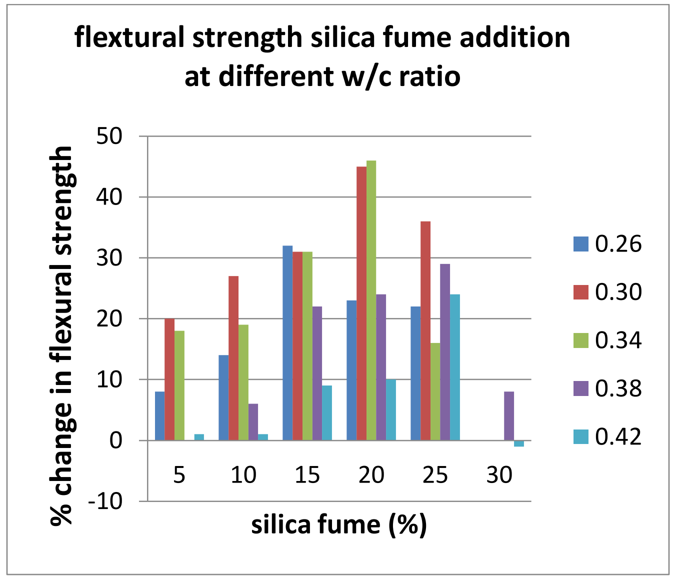

Chart-4 Percentage change in Flexural strength of concrete incorporating silica fume [9]

S. Bhanja and B. Sengupta further confirm that increasing the dosage of silica fume replacement reduces the increase in split tensile strength. In terms of percentages, 15% and 20% silica fume replacement improve split tensile strength by 25% and 25.7 %, respectively; however 25% silica fume replacement only improves split tensile strength by 19.3 percent. However, flexural strength increases significantly with larger silica fume replacement percentages. [9]

4. OUTLOOK AND CONCLUSIONS

This chapter presents an overview of studies on the impact of silica on concrete mechanical properties. The following are the findings of the literature review:

• Nano-silica improves the concrete's fresh characteristics. The use of a little amount of nano-silica reduces bleeding and segregation.

• Adding colloidal silica to concrete reduces its workability, necessitating the addition of a substantial amount of super-plasticizer to keep the concrete workable.

• The same is applicable for silica fume: as the percentage of silica fume added increases, the demand for super-plasticizer increases to keep the concrete workable.

•Due to the presence of silica, the setting time of concrete is accelerated.

•Up to a specific dosage, silica improves the compressive strength of concrete at various curing ages, but further silica replacement causes no appreciable increase in compressive strength.

• After adding silica to concrete, the split tensile and flexural strengths respond similarly to the compressive strength. The silica replacement exhibits a substantial increase in flexural and split tensile strength at a given dosage.

According to the literature, silica has a significant impact on the characteristics of concrete, indicating that it is a viable alternative for usage as a supplemental cementing element. The usage of silica fume is now common in the construction sector, but colloidal silica will be more effective in the future, both environmentally and economically.

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