

RESEARCH ON THE EFFECTIVENESS OF BY-PRODUCT (NANO SILICA) FOR CONSTRUCTION OF HIGHWAY

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ABSTRACT

The construction industry consistently pursues sustainable and new materials to improve the performance and durability of infrastructure. This study examines the efficacy of nano silica, a residual substance derived from industrial operations, in the context of road infrastructure development. Nano silica possesses exceptional pozzolanic qualities that can enhance the mechanical and durability attributes of concrete. This study assesses the influence of nano silica on the performance of concrete utilized in highway pavements by conducting a series of laboratory tests and field testing. Important factors such as the ability to withstand compression, the ability to resist tension, the ability to withstand bending, and the ability to remain durable under different climatic circumstances are tested and analyzed. The findings demonstrate that the addition of nano silica greatly improves the compressive and tensile strengths of concrete, as well as strengthens its resistance to abrasion and chemical assault. The study also examines the environmental advantages of using micro silica, emphasizing its potential to decrease the carbon emissions associated with roadway construction. The findings indicate that nano silica is a highly promising material for constructing durable and environmentally-friendly highway infrastructure, as it provides enhanced performance and ecological advantages. Potential areas for future research involve the extended evaluation of field performance and the investigation of the most effective blending proportions for different roadway uses.

Key Words: Nano Silica, Highway Construction, Pozzolanic Properties, Sustainable Materials, Concrete Durability, Compressive Strength.

1. INTRODUCTION

The establishment of highways is a pivotal element of infrastructure development, exerting a substantial impact on economic expansion and connectivity. Historically, Portland cement concrete has been the predominant material utilized in highway construction owing to its strength and long-lasting nature. Nevertheless, the manufacturing process of cement is linked to significant energy usage and considerable carbon dioxide discharges, which highlights the necessity for the development of more environmentally-friendly construction materials.

Recently, there has been increasing interest in using by-products from industrial operations as possible additives in the manufacturing of concrete. Nano silica is a highly reactive type of silicon dioxide that is generated as a waste product during many industrial processes, such as the fabrication of ferrosilicon alloys and silicon metals. Nano silica is distinguished by its exceptionally small particle size and elevated specific surface area, which provide it excellent pozzolanic qualities in comparison to conventional additional materials like fly ash and slag.

Nano silica possesses the capacity to augment the characteristics of concrete through several means. The fine particles effectively occupy empty spaces within the concrete structure, resulting in higher compactness and less capacity for substances to pass through. In addition, the interaction between nano silica and calcium hydroxide that occurs during the process of cement hydration leads to the creation of more calcium silicate hydrate (C-S-H), which improves the mechanical characteristics of concrete, such as its ability to withstand compression and tension. In addition, nano silica enhances the durability of concrete by augmenting its ability to withstand chemical attack and decreasing its vulnerability to cracking and abrasion.

The objective of this study is to examine the efficacy of nano silica in the construction of highways, with a specific focus on its influence on the mechanical characteristics and long-term resilience of concrete. This study aims to gain a thorough understanding of the potential advantages and consequences of integrating nano silica into concrete mixes for sustainable roadway infrastructure. The results of this study have the potential to facilitate the advancement of highway construction methods that are more durable and ecologically conscious, hence enhancing the overall sustainability of the construction sector.

2. OBJECTIVES

The objectives are as follow:

1. The objective is to assess the influence of nano silica on the compressive strength of concrete utilized in the construction of highways.

2. To evaluate the enhancements in the tensile strength of concrete by including nano silica.
3. To evaluate the bending strength of concrete reinforced with nano silica.
4. The objective is to assess the resilience of concrete that includes micro silica when exposed to different environmental conditions.
5. To examine the durability of concrete containing micro silica by testing its resistance to abrasion.
6. To assess the chemical durability of concrete injected with nano silica.
7. To investigate the potential ecological advantages of incorporating nano silica in road construction, specifically in terms of reducing carbon emissions.
8. The objective is to determine the most effective proportions of micro silica for different types of highway construction purposes.

3. LITERATURE REVIEW

Singh and Sharma (2023) investigated the influence of nano silica on the mechanical characteristics of high-performance concrete. Their research revealed that the inclusion of nano silica had a substantial impact on enhancing the compressive and tensile strengths of the concrete. Additionally, they witnessed a significant enhancement in the longevity of the concrete, specifically in its ability to withstand chloride penetration and sulphate attack. The investigation entailed adding different proportions of nano silica to high-performance concrete mixes and subjecting the samples to mechanical and durability testing. The improved characteristics are ascribed to the pozzolanic reaction and the filler effect of nano silica, which strengthen the microstructure of the concrete. These findings indicate that the use of nano silica as an addition can enhance the strength and durability of high-performance concrete.

Patel (2023) did a study titled "Impact of Nano Silica on the Mechanical Properties of Concrete" to investigate the influence of nano silica on the compressive and tensile strengths of concrete. The study illustrates that the addition of nano silica to concrete mixes results in substantial enhancements in both strength and durability. The study entailed conducting tests on concrete samples containing different quantities of micro silica and comparing their mechanical characteristics to those of traditional concrete. The findings indicated that the addition of nano silica to the concrete resulted in increased compressive and tensile strengths, as well as enhanced durability in different climatic situations. The findings indicate that nano silica is a feasible choice for manufacturing concrete with enhanced strength and durability, rendering it appropriate for sustainable highway construction.

Sharma (2023) did a study called "Enhancement of Concrete Durability with Nano Silica," which focused on the impact of nano silica on enhancing the durability of concrete. The study demonstrates that the addition of nano silica to concrete mixes effectively decreases permeability and enhances resistance against chemical attacks, such as chloride penetration and sulphate exposure. The enhancements are ascribed to the pozzolanic reaction of nano silica, which refines the microstructure of the concrete and fills empty spaces, resulting in a more compact and long-lasting substance. The study conducted a comparative analysis of ordinary concrete and nano silica-enhanced concrete samples in different environmental conditions. The findings suggest that the incorporation of micro silica can significantly prolong the lifespan of concrete constructions, thereby serving as a valuable additive for boosting the durability of roadway pavements.

In his 2022 study titled "Nano Silica in Concrete: Enhancing Compressive Strength," Singh examines the effect of nano silica on the compressive strength of concrete. The study emphasizes that the use of nano silica additions results in a significant improvement in compressive strength when compared to conventional concrete mixtures. The enhancement is ascribed to the pozzolanic reaction of nano silica, which leads to a more compact and uniform microstructure of the concrete. According to Singh's research, the use of nano silica can significantly increase the performance of concrete used in highway building, resulting in better structural strength and longevity. The results highlight the potential of nano silica as a useful ingredient for creating high-performance concrete specifically designed for challenging infrastructure applications. In their study titled "Durability Improvements in Concrete with Nano Silica Additives," Gupta (2022) investigated the impact of nano silica on the durability of concrete. The study demonstrates that the use of micro silica additions greatly improves the concrete's ability to withstand sulphate assault and freeze-thaw cycles, both of which are crucial elements that impact the durability of highway pavements. The presence of nano silica in concrete serves to decrease the penetration of harmful elements and enhance the internal structure of the material, resulting in improved performance even in challenging environmental circumstances.

Gupta's research highlights the capacity of nano silica to serve as a valuable supplement for prolonging the durability of concrete infrastructure, especially in areas susceptible to severe weather conditions and chemical corrosion. This study emphasizes the significant contribution of nano silica in advancing sustainable and durable techniques in highway construction.

Rao (2022) did a study named "Environmental Impact of Nano Silica in Highway Construction" to evaluate the environmental consequences of utilizing nano silica in infrastructure projects. The study emphasizes that the inclusion of nano silica in roadway building materials results in significant decreases in CO₂ emissions and enhanced energy efficiency when compared to traditional materials. The environmental advantages are ascribed to the capability of nano silica to improve the performance of concrete, hence decreasing the overall need for materials and the resulting environmental impact. Rao's research highlights the importance of nano silica in supporting environmentally friendly construction methods by reducing negative effects on the environment and improving the strength and effectiveness of highway infrastructure. This research provides significant insights into the further implementation of nano silica as a sustainable solution in civil engineering applications.

Mehta (2021) did a study named "Mechanical Properties of Concrete with Nano Silica," which examined how the addition of nano silica affects the mechanical performance of concrete. The study showcases substantial enhancements in both the compressive and tensile strengths of concrete when fortified with nano silica. The improvements are ascribed to the pozzolanic reaction of nano silica, which refines the concrete matrix and augments its structural integrity. Mehta's research indicates that the use of nano silica can significantly enhance the mechanical characteristics of concrete, so serving as a valuable component for strengthening and prolonging the lifespan of roadway infrastructure. This study highlights the potential of nano silica in enhancing the performance of concrete specifically designed for challenging civil engineering projects.

Das (2021) did a study named "Nano Silica's Role in Enhancing Concrete Durability," which investigated the influence of nano silica additions on the durability of concrete. The research findings suggest that the use of micro silica improves the concrete's ability to withstand environmental degradation elements, such as chloride penetration and sulphate assault. These enhancements are essential for extending the longevity of highway pavements and decreasing the expenses related to concrete degradation. Das credits these advantages to the pozzolanic reaction of nano silica, which improves the microstructure of concrete and decreases its permeability. This study highlights the potential of nano silica as an advantageous additive for improving the durability and sustainability of concrete infrastructure in difficult environmental conditions.

In her work titled "Sustainable Highway Construction Using Nano Silica," Kaur (2021) examined the sustainability implications of integrating nano silica into highway infrastructure. The research emphasizes that the inclusion of nano silica additions might significantly decrease the environmental impact of concrete utilized in highway construction. Nano silica enhances the mechanical qualities and longevity of concrete, hence prolonging the lifespan of roadway pavements and reducing the environmental footprint linked to conventional construction materials. Kaur's research highlights the capacity of nano silica to serve as an environmentally friendly substitute in civil engineering applications, hence advancing sustainable development and optimizing resource utilization in infrastructure projects.

Joshi (2020) investigated the influence of nano silica on the enhancement of concrete's compressive strength. The research demonstrates that the use of nano silica significantly enhances the compressive strength of concrete, surpassing that of traditional concrete mixes. These improvements are vital for applications in high-pressure settings commonly found in highway construction, where resilient and robust concrete is necessary. Joshi credits the enhanced performance to the pozzolanic reaction of nano silica, which leads to a more compact and uniform microstructure of the concrete. This study highlights the potential of nano silica as a valuable ingredient for creating high-performance concrete that can endure heavy loads and harsh climatic conditions. As a result, it improves the durability and dependability of highway infrastructure.

Reddy (2020) examined the effects of nano silica on the durability of concrete. The research highlights that the inclusion of micro silica additions improves the concrete's ability to withstand environmental conditions such as moisture penetration and chemical contact. These enhancements are essential for extending the durability of highway pavements, minimizing maintenance expenses, and guaranteeing the structural soundness in unfavorable circumstances. Reddy credits the improved durability to the capacity of nano silica to modify the microstructure of the concrete, hence reducing permeability and boosting the material's resistance to degradation mechanisms. This study highlights the potential of nano silica as a valuable additive for enhancing the durability and sustainability of concrete infrastructure, hence helping to the building of more resilient and long-lasting highways.

4. METHODOLOGY

MATERIALS USED

The materials used in the experimental investigation include the following:

- Cement OPC 53 Grade
- Fine Aggregates

- Water
- Coarse Aggregates
- Nano Silica
- Super Plasticizer (CONPLAST 430)

Cement

Portland cement is a key component of concrete, mortar, and most non-specialty grouts. The production of concrete is the most common use for Portland cement. Portland cement comes in white or gray hues. Combining OPC and PPC, pozzolanic cement has the ability to set, bond, and harden hydraulically when combined with water. This experiment used ordinary Portland Cement 53 grade. The cement qualities were assessed using the IS: 4031-1996 and IS: 4032-1999. The flowchart shown below depicts the tests undertaken for cement.

Table 4.1 The basic components of cement

Parameter	Experimental Value
SiO ₂	17-25%
CaO	61-63%
MgO	0.1-4.0%
Fe ₂ O ₃	0.5-0.6%
Al ₂ O ₃	4-8%
SO ₃	1.3-3.0%
Na ₂ +K ₂ O	0.4-1.3%
Cl	0.01-0.1%
IR	0.6-1.75%

Fine Aggregates

Sand has either round or angular grain and is frequently found combined in varying degrees of fineness at different zones. IS 383-1970 describes the four zones and their fineness modulus. Mortar cubes were prepared using various zones of river sand. It was thoroughly cleaned and sieved so that the mortar would not damage the building. Fine aggregate characteristics were assessed using IS techniques. The flow chart below depicts the tests conducted on fine aggregate.

Water

Water is a necessary component of concrete since it actively participates in the chemical reaction with cement. The water is solely proportional to the cement content. It's known as the water-cement ratio. This has an impact on the mixture and, as a result, its workability. Water should have a pH of at least 6 and be devoid of organic materials, acids, suspended particles, alkalis, and contaminants.

Coarse Aggregates

The crushed tone aggregates were sourced from a local quarry. The experiment's coarse aggregates were analyzed in accordance with IS: 383-1970 and 2386-1963 (I, II, and III).

Mineral Admixture

Mineral admixtures and chemical admixtures are additional ingredients besides water, cement, aggregates, and fibers. These are introduced into the concrete batch plant during batch mixing or at the start when other quantities are added. Admixtures can improve the qualities of fresh or hardened concrete only if they are used properly. Admixtures increase concrete quality, speed up or slow down setting time in the event of misshaping. There are now a variety of admixtures on the market that improve freeze-thaw resistance. It enabled earlier attainment of strength. Admixtures improved the workability of fresh concrete by using less water than was required.

Mineral admixtures are finely powdered solid ingredients such as fly ash, slag, and nano silica. It is added to concrete in greater quantities than any other variety. Mineral admixtures improve the workability and finish ability of freshly placed concrete. Mineral admixtures are also used as a replacement for cement. Cement is the most expensive material in concrete. As a result, the use of mineral admixtures has the potential to reduce concrete costs significantly. Mineral admixtures are waste products from industry. As a result, choosing concrete allows for optimum sustainability. It also helps to reduce thermal cracking in concrete by lowering the heat of hydration. As a result, these types of admixtures improve the durability and serviceability of concrete. In this investigation, nano silica is used as a mineral additive.

Nano Silica

Nano silica, also known as silica fume or condensed Nano silica, is a byproduct that is used to make pozzolans. This byproduct is formed when high-purity quartz is reduced with coal in an electric arc furnace to produce silicon or ferrosilicon alloy. Nano silica emerges as an oxidized vapor from the 2000°C furnaces. As it cools, it condenses and is collected in large fabric bags. After that, the condensed micro silica is treated to remove impurities and modify the particle size. Of the overall cementation material, nano silica makes about 5% to 20%. It is utilized in applications that require great impermeability and endurance. To make sure that cement and nano silica satisfy the requirements, physical and chemical analyses are carried out on them. The goal of the experimental program was to investigate the use of nano silica in concrete as a partial substitute for cement. The percentages of cement replacement with nano silica that were selected for the M40 grade of concrete were 5%, 10%, 15%, and 20%.

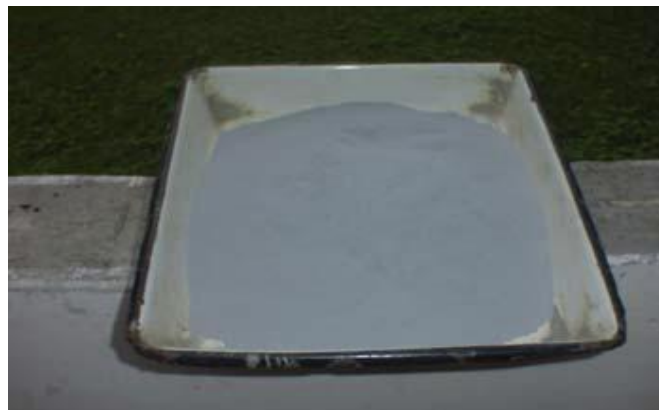


Figure 4.1 Nano Silica

Table 4.2 Properties of Nano Silica

Properties	Specifications
Particle Size	300 micrometers
Bulk Density	670 Kg/m ³
Specific Gravity	2.2
Specific Surface	25000 Kg/m ³
Al ₂ O ₃	4-8%
SO ₃	1.3-3.0%

Chemical Admixture

Chemical Admixtures are additives that can be added to the concrete mixture just before or during mixing. Chemical admixtures such as water reducers or plasticizers, retarders, high-range water reducers, and Super Plasticizers (SP) are required to improve several essential properties of fresh and cured concrete. They make better use of the enormous amount of cementation material in high strength and self-compacting concrete, resulting in the lowest practical water-to-cement materials ratio. Chemical admixture efficiency must be assessed by comparing the strengths of trial batches. Trial batches must also be used to examine the compatibility of cement with extra cementing materials and water reducers. These will allow you to calculate the workability, setting time, bleeding, and quantity of water decrease for specific admixture dosage rates and addition timings.

SP Conplast-430

Superplasticizers, commonly known as Plasticizers, contain water-reducing admixtures. Super Plasticizers are "High-Range Water Reducers" as opposed to what is typically referred to as a "Water Reducer" or a "Mid-Range Water Reducer." High Range Water Reducers are admixtures that provide significant water reduction or increased flow capability without significantly decreasing set time or increasing air entrainment. In this project, Super Plasticizers CONPLAST -SP 430 in the form of sulphonated Naphthalene polymers that meet IS: 9103-1999 are utilized to increase the workability of concrete. CONPLAST - 430 has been carefully developed to provide considerable water savings of up to 25% without sacrificing workability, resulting in high-quality concrete with decreased permeability. Conplast- SP 430 effectively disperses cement particles in the concrete mix, exposing more surface area to the hydration process.

VARIOUS TESTS USED

Normal Consistency Test of cement

The test was carried out in accordance with IS: 4031 (Part 4) -1988 codal requirements. In the first test, about 500 grams of cement were used, and a weighted paste was made (about 24 percent of the cement's weight). Within three to five minutes, the paste must be prepared using the standard procedure and put into the vicat mold. To release any remaining air, the mold was shaken once it was fully filled. A standard plunger, measuring 50 mm in length and 10 mm in diameter, was inserted and lowered to the test block's paste surface, where it quickly sank under the weight of the plunger itself. By measuring the plunger's depth of penetration, the readings were acquired. Likewise, a test with a high weight-to-crush ratio was conducted until the plunger reached a depth of 33–35 mm from the top. As a result, the usual consistency of cement is 31%.

CASTING AND CURING OF SPECIMENS

The experimental examination was carried out on the specimen to evaluate the strength-related properties of concrete utilizing micro silica (5% - 20%) at various ages. CONPLAST SP-430 was added at a rate of approximately 1.2% by weight of cement to increase the workability of concrete mixtures. The specimen dimensions for the Cube, Cylinder, and Prism are (150mm x 150mm x 150mm), (150mm x 300mm), and (100mm x 100mm x 500mm). The cure period lasted 28 days. A minimum of three specimens were cast for each mixture.



Figure 4.3 Casting of Specimen

5. RESULTS

EXPERIMENTAL RESULTS

Test Results for Cement

The following table displays the cement test results. The following tests were performed: normal consistency, initial setting time, final setting time, fineness using a 90 μ sieve, specific gravity, and compressible strength.

Table 5.1 Test Results for Cement

Physical properties	IS: 12269-1987
Setting Time (minutes)	
Initial (min)	36 minutes
Final (max)	210 minutes
Compressive Strength (MPa)	
3 days	25 MPa
7 days	34 MPa
28 days	56 MPa
Normal Consistency	31%
Fineness (m²/kg)	235
Specific Gravity	3.15

Test Results for Fine Aggregate.

The following table shows the test results of specific gravity, sieve analysis tests for fine aggregate.

Table 5.2 Test Results for Fine Aggregates

S. NO	Sand type	Name of the test	Values
1	River Sand	Specific Gravity	2.57
2		Fineness Modulus	2.72

Table 5.3 Sieve Analysis of Fine Aggregate as per IS:383-1970

IS Sieve size	Weight Retained (kg)	Cumulative Weight Retained (kg)	Cumulative Percentage Retained	Cumulative Percentage Passing
4.75	0.000	0.000	0.000	100.00
2.36	0.020	0.020	2.000	98.00
1.18	0.085	0.108	10.500	89.50
0.60	0.265	0.370	37.000	63.00
0.30	0.390	0.760	76.000	24.00
0.15	0.200	0.960	96.000	4.00
Pan	0.040	1.000	100.000	-

Fineness modulus of fine aggregate = $\frac{\sum F}{100}$

$$= \frac{272}{100}$$

$$= 2.72$$

Since 90.5 % of fine aggregate passes through 4.75mm sieve, the sand conforms to grading zone III as per IS: 383-1970.

Slump Test

The effects of Micro silica (MS) on Slump for M40 Grade concrete mixes M-0 (0% MS), M-1 (5% MS), M-2 (10% MS), M-3 (15% MS) and M-4 (20% MS) are shown in Fig.5.1. The slump for M-0, M-1, M-2, M-3, and M-4 are 55 mm, 59 mm, 64 mm, 62 mm and 58 mm. Maximum slump is observed for 10% replacement of Nano silica.

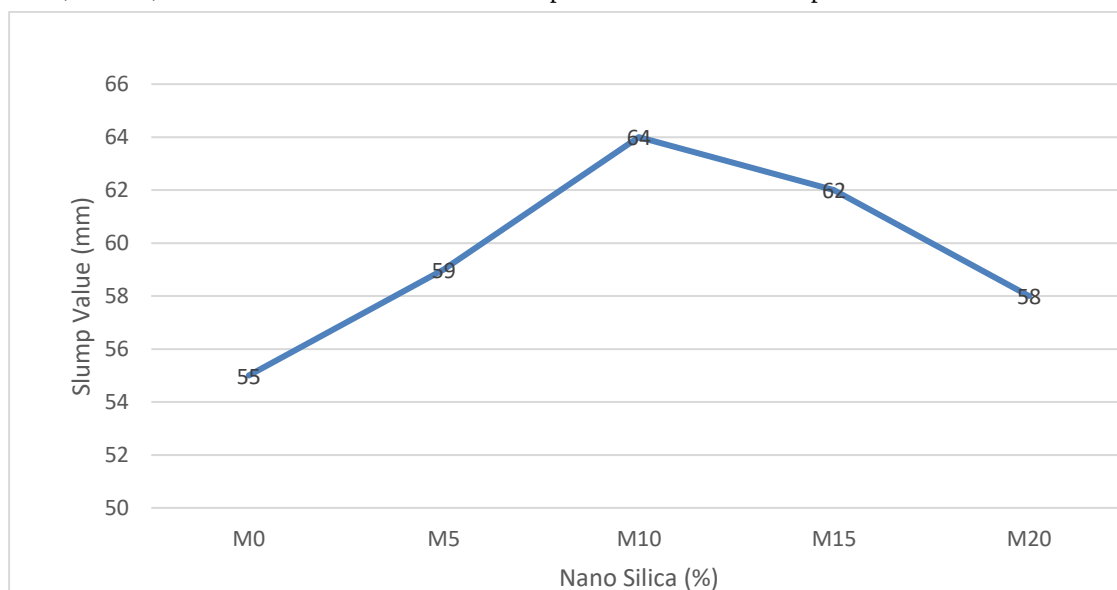


Figure 5.1 Slump value against varying nano-silica

Other qualities, like as slump, are tested to establish the results for five different concrete mixtures. The slump value is between 50 and 70 mm. The value of slump indicated that the mixes are cohesive in character. As the Nano silica content increases, slump values steadily climb up to 10%, followed by a gradual decrease. The experimental results reveal that compressive strength for all silica fume replacements (5%, 10%, 15%, and 20%) is higher than control concrete (concrete with zero percentage silica fume replacement) at all ages (24 hours, 7, 14, and 28 days).

Compressive Strength

The effects of Nano silica (NS) on compressive strength for M40 grade concrete mixes M-0 (0% MS), M-1 (5% MS), M-2 (10%MS), M-3 (15% MS) and M-4 (20% MS).

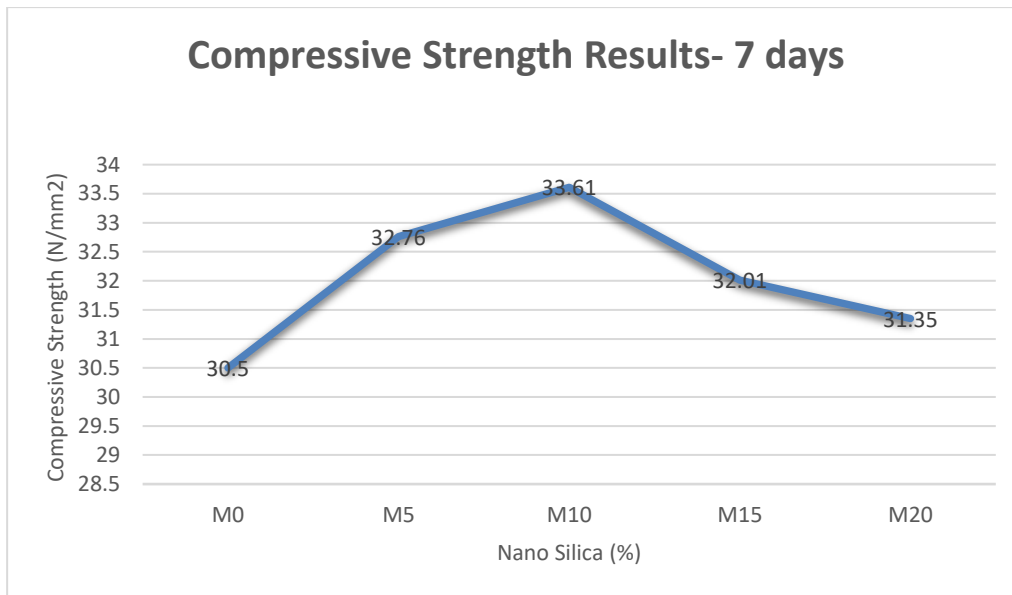


Figure 5.2 Compressive Strength Test Result in 7days

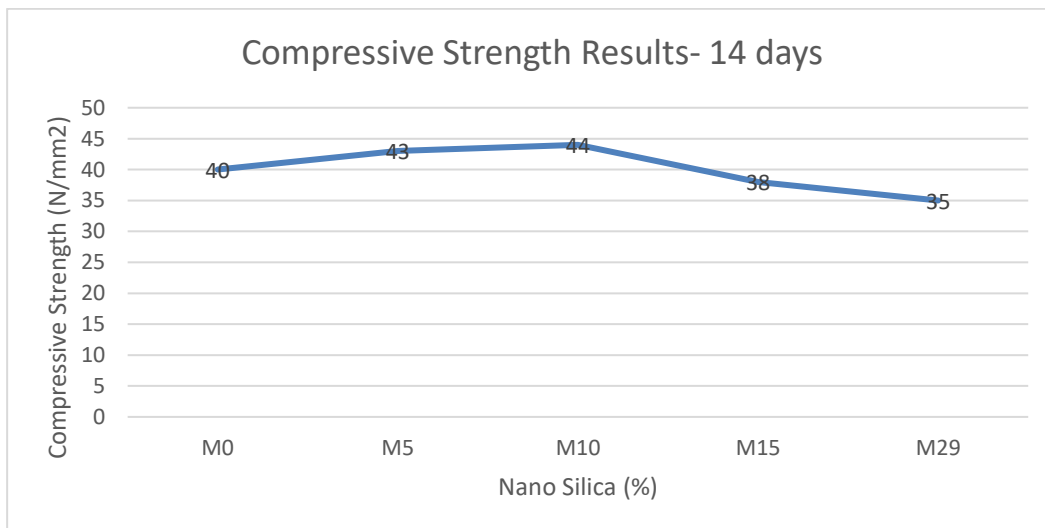


Figure 5.3 Compressive Strength Test Result in 7 days

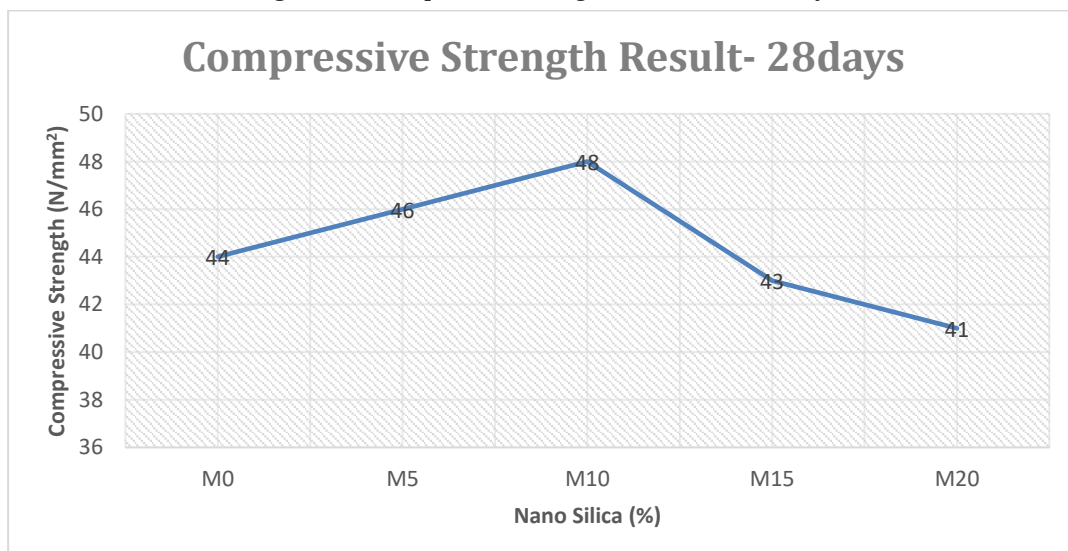


Figure 5.4 Compressive Strength Test Result in 7 days

At 7 days of age, the compressive strength of mix M-0 is 30.5 MPa, while mixes M-1, M-2, M-3, and M-4 are 32.76,

33.61, 32.01, and 31.35 MPa, respectively. M-2 concrete mix has a maximum compressive strength of 33.61 MPa, which is 14.7% higher than the control mix M-0. At 14 and 28 days of age, the greatest compressive strength was attained with a 10% substitution of Nano silica (44 MPa and 48 MPa). According to the test results, increasing the amount of Nano silica up to 10% enhances compressive strength, after which it rapidly falls.

Flexural Strength

The flexural strength of control mix M-0 is 3.3 MPa after 28 days. It rises by 4.1%, 8.6%, 6.5%, and 1.02%, respectively, for M-1, M-2, M-3, and M-4 mixtures. The strength reduces when Nano silica substitution increases over 10%. Flexural strength increases with 10% nano silica.

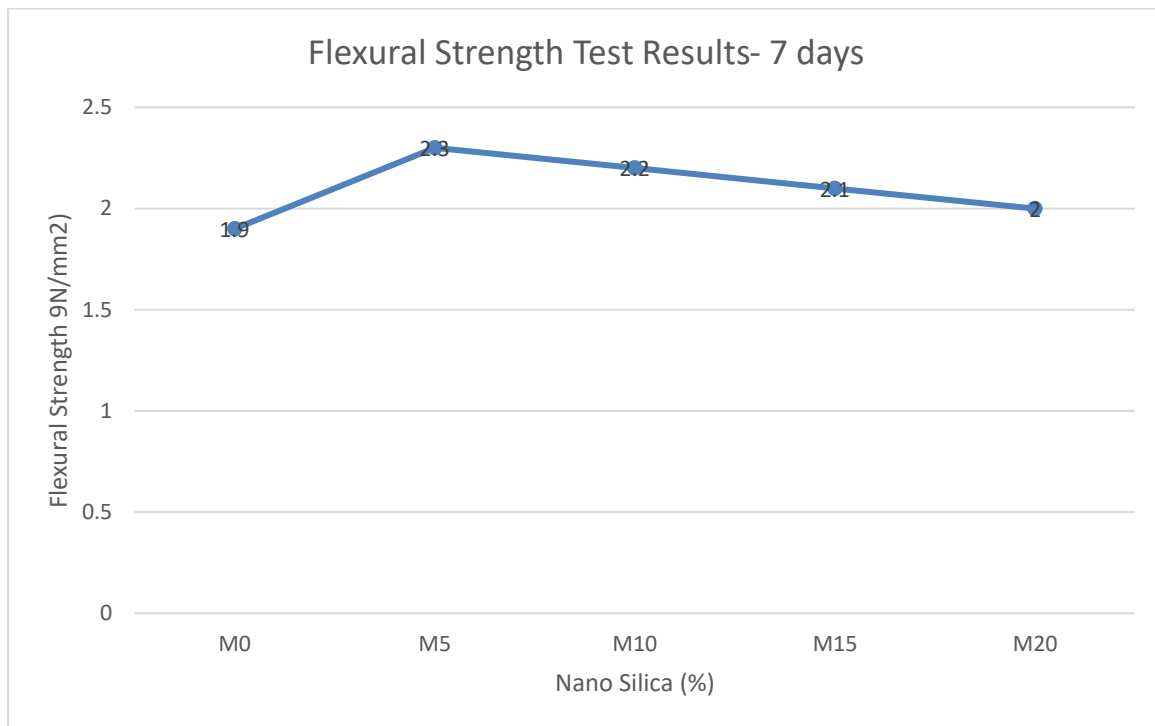


Figure 5.5 Flexural Strength Test in 7 days

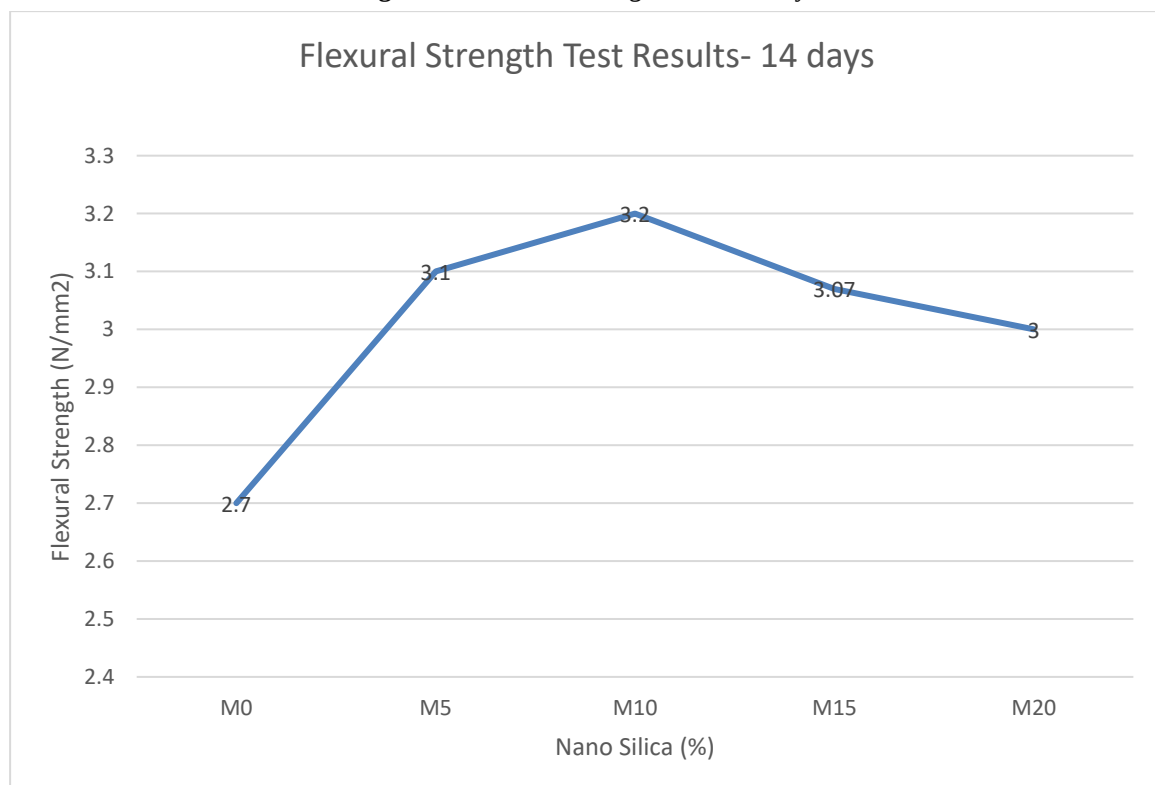


Figure 5.6 Flexural Strength Test in 14 days

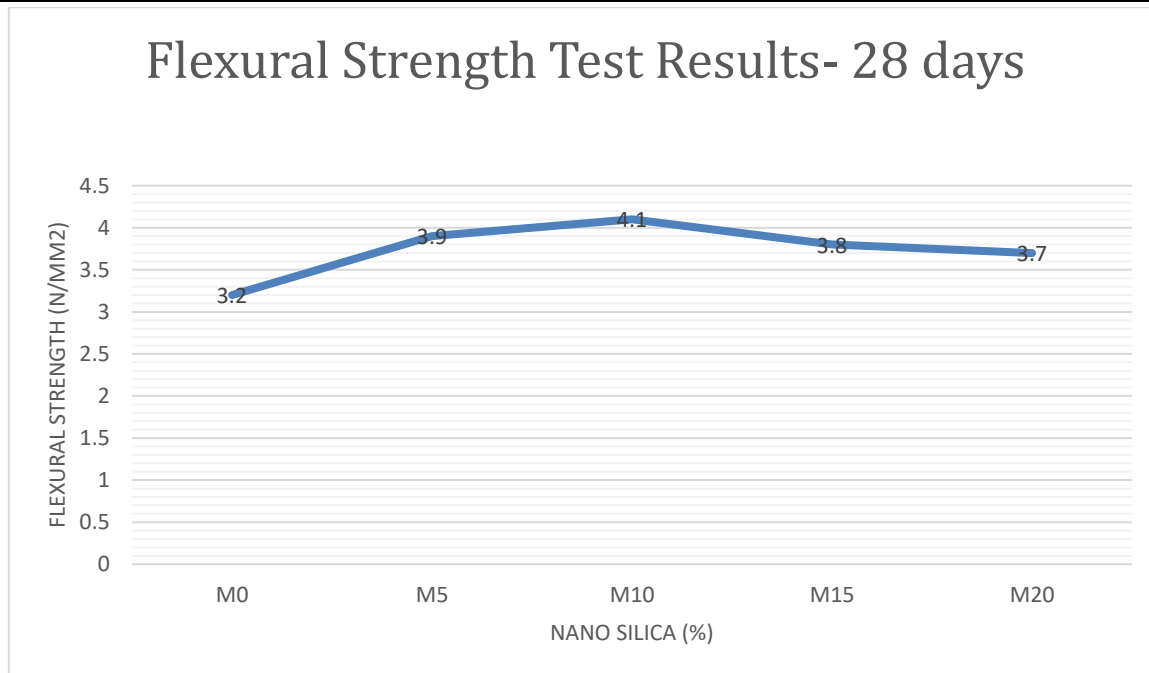


Figure 5.7 Flexural Strength Test in 28 days

6. CONCLUSION

- From an economic perspective, silica fume is especially important because it is far less expensive than cement. Using micro silica, a byproduct of several industries, in concrete reduces air pollution. Silica fume reduces the voids in concrete. The following conclusions are drawn from the experimental data.
- The study found that replacing 10% of Nano silica improves strength and workability. With a 10% replacement, Nano silica concrete's compressive strength, split tensile strength, and flexural strength improve to a maximum of 14.7%, 19.7%, and 8.6%, respectively. When concrete contains more than 10% of micro silica, the tensile strength of the concrete is reduced and the concrete becomes extremely stiff.
- Concrete gains strength when up to 10% extra micro silica is added to it. This could be attributed to the filling action of nano silica. Beyond 10% replacement, concrete strength declines due to extra particles and lower cement content.
- The high-water absorption of silica particles, along with a higher percentage of finer size nano silica, affects concrete strength. For M40 grade concrete, the maximum amount of nano silica that can be replaced is 10%. Nano silica can be used to replace up to 10% of cement in concrete without compromising strength, while also addressing disposal issues and lowering greenhouse gas emissions.

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