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EXPERIMENTAL INVESTIGATION AND COMPARATIVE ANALYSIS OF NANO-SILICA INCORPORATION ON STRENGTH PROPERTIES OF CONCRETE

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Abstract

Environmental pollution is increasing due to many reasons such as vehicles, industrialization and urbanization. Because of this the concrete loses its strength. Present study examines the strength performance of M70 grade concrete with the use of Silica Fume, Fly Ash and Nano Silica as partial replacement of cement. Because nano-silica looks so tiny, it may be used to make concrete, it denser also improved performance of concrete. The former researchers already studies on Silica Fume, Fly Ash and Nano Silica as partial replacement of cement for 10%,15% and 3% respectively in the context of M50 concrete only in that strength properties increase 10%, but decrease in workability 5%. In this present work research on workability, the mechanical qualities for M70 Grade concrete. The cement is partially replaced with fly ash, silica fume and Nano-silica ranging from 11%,10% and 0-4% at an interval of 1% respectively, are prepared and tested. Based on findings of tests, it was determined that combination of 11% fly ash, 10% silica fume and 3% nano silica in addition to cement.

Keywords: High strength concrete, silica fume and fly ash, Nano silica.

1. Introduction

The problem that is then, and the problem yet to address, is concrete. Concrete has been used from the earliest times, so it is one of the oldest but still used materials today, especially in building construction as in factories, bridges, airports, buildings, etc. Concrete must be stronger and more durable, given the demands of a growing world population. Technology could help us toward that end. Cement is one of the many ingredients that go into making concrete, and it's an essential binding ingredient. To produce high strength and durable concretes, the mechanism of cement hydration has to be thoroughly investigated, and better alternatives need to be proposed.

There are various supplementary cementitious materials (SCMs) like fly ash, GGBS, silica fume and Nano silica are added to concrete to improve its properties. not only enhance concrete's qualities but also reduction in size of elements that is minimize of size of structural elements. As we noticed that day to day the environmental pollutions are increased due to so many reasons to improve resistance against today’s environmental condition various technologies are used in that situation nano-technology, this is a promising method for utilizing nanomaterials to increase the strength and durability of concrete.

NANO MATERIALS: Materials that have at least one dimension on the nanometre scale in the length, width, and thickness directions—typically between 1 and 100 nm—are referred to as nano materials or nano-materials. Because such material has such a small size and a large surface area in relation to bulk-type material, it has very different, unique physical, chemical and mechanical characteristics. Nanomaterials have been impacting most industries, and the construction industry has not been an exception, given the use of nanomaterials within concrete that has been providing tremendous strides. While there are several kinds of nanomaterials in concrete, most reports often show that nano-silica possesses superior traits above and beyond other materials. The main topics that will be covered in great length are nano-silica, nano alumina, nano-iron oxide, nano-clay, and nano-zinc oxide, along with the reasons that nano-silica is frequently recommended as being better.

Nano Silica ($nSiO_2$) Definition and Properties: Nano silica refers to silicon dioxide particles in the nanometre size, which are usually between 1–100 nanometres in diameter. Its exceptional reactivity and extremely high specific surface area are the primary causes of its special qualities. High Surface Area: The surface area of nano-silica can be as high as ranging from 100 to 600 m^2/g - quite high compared to conventional silica. More availability for the interaction with the cement pastes and aggregates is expected. Poaszolanic Reactivity: More C-S-H gel forms with nano-silica when it comes into touch with calcium hydroxide, or $Ca(OH)_2$. It is anticipated that the gel will adhere more firmly and strengthen the concrete. Particle Size and Dispersion: High surface area of nano-silica and its relatively uniformed particle size further enhance its dispersion in a concrete matrix where it fills up voids and thus it is able to further improve concrete.

2. Literature Survey

By the authors previously of the particular study associated with cementitious materials such as nano silica and their impact on the properties of concrete discussed in detail as follows [1]. the values. Concrete demands a huge amount of water or admixtures to sustain the slump value of concrete, Van Minh Nguyen et al. (2023) adding 2% of nano silica to concrete can improve to assess the use of CSM in concrete for sustainable development, studies on mechanical qualities, durability, and environmental impact were carried out. The results proved to show that CSM was made more environmentally favourable with the incorporation of fly ash and nano-silica into concrete, 3. The CSM was found to be improved environmentally by procuring fly ash and nano-silica at the various portions used. Mayank Nigam and Manvendra Verma (2023) adding 0%–3% of cement at intervals of 0.5% would raise the compressive strength of the concrete by 12% at 2% of nano silica added. As the amount of nano-silica in the concrete increases, the workability of the concrete also diminishes, 4. V.V. Praveen Kumar and Subhashish Dey (2023) 2% of nano silica can replace cement in concrete. By using these materials to partially replace cement, the compressive strengths of blended concrete mix increased significantly as compared to concrete that contained 0% Nano silica. The blended concrete mix with 1% Nano silica had a compressive strength of 29.58 MPa, 36.91%, 51.40 MPa with 2% Nano silica, 27.82%, at 72.33 MPa with 3% Nano silica, 19.35%. The mechanical qualities have been improved, demonstrating improved resistance to acid environments and chloride ion penetration.5. Vikram Singh Kashyap et al. (2023) Concrete mixtures containing 1%, 2%, and 3% Nano silica were made with a constant water to binder ratio of 0.4. By lowering the number of pores in the matrix, nano silica (2%) in cement increased the bulk density and general durability properties of the concrete mixture. According to the durability tests, adding 2% of Nano silica mixed in reduced permeability by up to 57% and water absorption by up to 26%. Similarly, concrete mixtures with 2% Nano silica experienced a reduction in carbonation depth of 20%.

3. Materials

3.1 Portland Cement: A type of ordinary Portland cement (OPC) with a grade 53 was used in this study limited to IS: 12269-2013 [16]. The cement was tested according to IS:4031-2019[17] to obtain its properties with specific gravity as 3.14, fineness modulus as 5%, consistency as 33%, initial and final setting time as 30 and 360 mins, re spectively.

3.2 Fly Ash: Fly Burning coal in thermal power plants produces fly ash, which is often used as an admixture in concrete for greater strength and durability. According to IS:1382(part1):2013[18]; this standard specifies requirements for fly ash when used as an admixture in cement mortar and concrete.

3.3 Silica Fume: Silica fume (or micro silica) is a waste material produced during the process of creating silicon metal or ferrosilicon alloys in electric arc furnaces. It is classified as a pozzolanic material and is added to concrete for improving performance. Fine material in size spherical conforming to IS: 15388-2003[19], and amorphous, having an average particle size of 0.0000145mm, available in powder form, as shown in fig1

Fig 1 Silica fume

3.4 Nano Silica: Nano silica refers to silicon dioxide particles in the nanometer size, which are usually between 1.1–101 nanometers in diameter. Its exceptional reactivity and extremely high specific surface area are the primary causes of its special qualities. The surface area of nano-silica can be as high as ranging from 101 to 599 m^2/g - quite high compared to conventional silica. Available in powder form as depicted in fig 2.

Fig 2 Nano silica

3.5 Fine and coarse aggregate: According to IS: 383-2016 [20], natural sand has parameters such as a specific gravity of 2.74 and a fineness modulus of 7.3, which were evaluated by IS 2386 1963 [21].Impact and crushing value tests have been conducted for 20 mm coarse aggregate 17.23% and 27.37%, respectively, were the outcomes. It comes from a nearby quarry and has a specific gravity of 2.63 and a fineness modulus of 2.95.

3.6 Super Plasticizer: A naphtha-based chemical that complies with IS: 9103-1999 [22] was utilized for the experimental study, which is in liquid form and has an iron content of less than one percent. These chemical aids fresh concrete in maintaining its workability, while also minimizing permeability and bleeding.

3.7 Water: Water having a pH value greater than 6.5 was utilized for mixing and curing concrete, ensuring it is devoid of other chemicals and organic impurities in accordance with IS: 456- 2000 [23].

4.Experimental Investigation

This mainly focuses on the mix design done for the M70 grade of concrete with the help of IS:10262-2019[24] and the methodology adopted to ascertain the properties of the concrete. For determine the mechanical properties of M70 grade high strength concrete mix cube, cylinders and beams are casted. The cubes of 150mmX150mmX150mm, cylinders of 150mm Dia and 300mm length and beams of 100mmX100mmX500mm are utilized. All the specimens are permitted to curing for 7days, 28 days at ambient temperature. Different mechanical properties of M70 high strength concrete are determined. The compressive strength and split tensile strength of concrete were determined using a compression testing machine (CTM). 3. The flexural strength was determined using two-point load test.

4.1 Mix Trails Details

Table 1 Nomenclature of concrete mixes:

Types of Mixes	OPC	Fly Ash	Silica Fume	Nano Silica
M1	79%	11%	10%	-
M2	78%	11%	10%	1%
M3	77%	11%	10%	2%
M4	76%	11%	10%	3%
M5	75%	11%	10%	4%

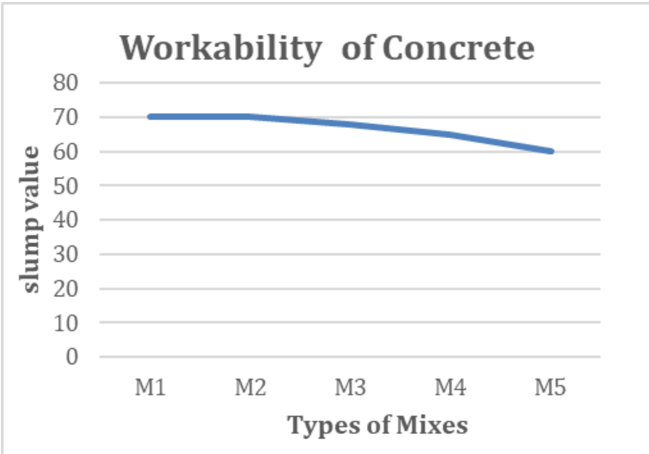
5. Results And Discussions

5.1 Workability test on fresh concrete

The test was done to measure the workability property of the concrete, the test indicates the homogeneity and uniformness of the concrete mix, the segregation and bleeding phenomena is observed by this trail investigation. By doing this experiment we can say that workability decreases due to high surface area of nano silica.

Table 2 workability of concrete test results

Types of Mixes	Slump(mm)
M1	70
M2	70
M3	68
M4	65
M5	60



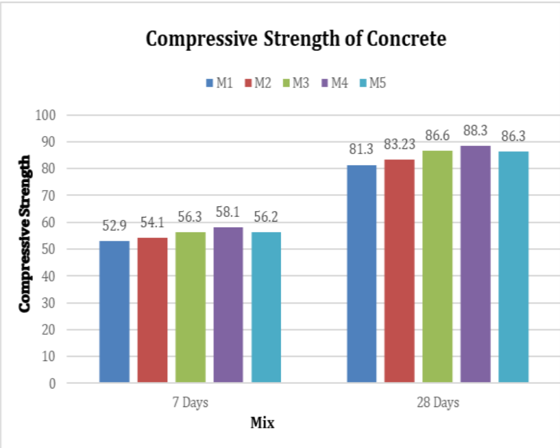
Graph 1: Comparison of workability of concrete

5.2 Compressive Strength of Concrete Test

The values for the compressive strength of proportions 7 days and 28 days are calculated and represented in following graph below as per code IS: 516-1959 [25]. From results obtained by this test we can say that compressive strength increases by 10 % with reference to standard concrete.

Table 3 compressive strength of concrete test results

Mix	Compressive strength	(N/mm^2)
	7 Days	28 days
M1	52.9 N/mm^2	81.3 N/mm^2
M2	54.1N/mm^2	83.23 N/mm^2
M3	56.3N/mm^2	86.6 N/mm^2
M4	58.1N/mm^2	88.3 N/mm^2
M5	56.2N/mm^2	86.3 N/mm^2



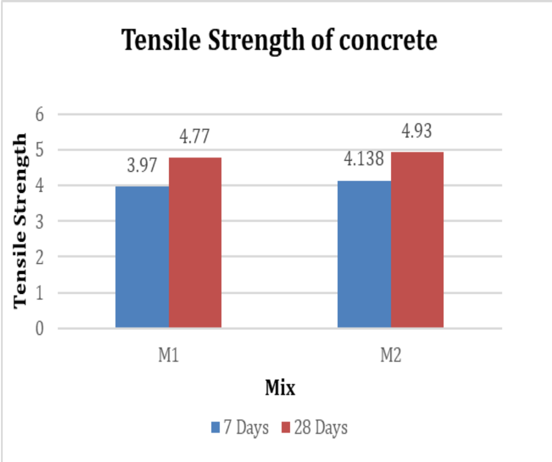
Graph 2: Comparison of compressive strength of concrete

5.3 Split Tensile Strength Test

The values for the split tensile strength of proportions 7 days and 28 days are calculated and represented in following graph below as per code IS:5816-1999[26]. From results we can say that split tensile strength increase by 4% when compare with standard mix.

Table4 split tensile strength of concrete test results

Mix	Split Tensile Strength	(N/mm^2)
	7 Days	28 Days
M1	3.97	4.77
M4	4.138	4.93



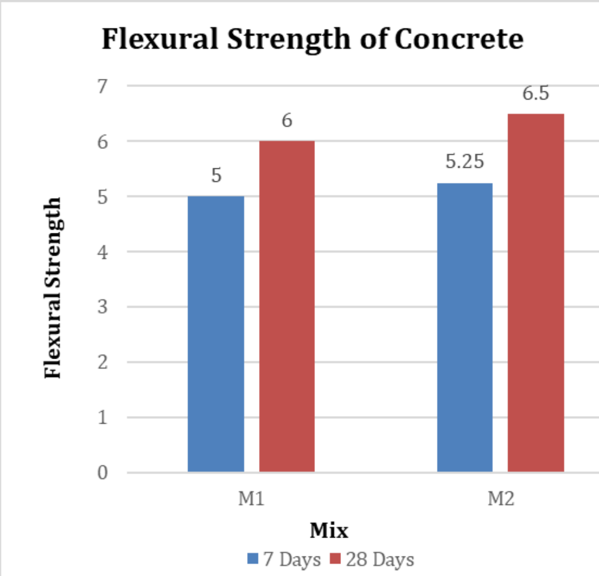
Graph 3: Comparison of split tensile strength of concrete

5.4 Flexural Strength of Concrete Test

The values for the flexural strength of proportions 7 days and 28 days are calculated and represented in following graph below as per code IS:516-1959[25]. From results we say that flexural strength increases by 5% when compare to standard mix.

Table 5 flexural strength of concrete test results

Mix	Flexural strength	(N/mm^2)
	7Days	28 Days
M1	5	6
M4	5.25	6.5



Graph 4: Comparison of flexural strength of concrete

6. Conclusions

- Compressive strength for a grade of M70 was evaluated for different composition of mixes such as M1(standard concrete), finally, the strength is maximum at a composition of 79% Cement, 11% fly ash, and 10% silica fume; hence this composition is considered as an optimum.
- The workability (slump) is about 70 mm for reference mix M1 (79% cement, fly ash 11% & silica fume 10%), then as the dosage of nano silica content was was 5% less when it achieved a peak compressive strength, which congruently, we can say that was similar peak workability/compressive and peak workability/split tensile strength respectively.
- The compressive strength of M4(optimum concrete) mix at 7 days and 28 days is increased by 10% as compared to the reference mix M1, it may be due to silica (SiO_2) content which is more in nano silica.
- The split tensile strength of M4 mix at 7 days and 28 days is increased by 4% as compared to the reference mix M1.
- The flexural strength of M4 mix at 7 days and 28 Days is increased by 5% as compared to the reference M1 mix.

7. Future Work

The compressive, split tensile, and flexural strengths have also been notably enhanced with the incorporation of nano-silica as a supplementary cementitious material. To identify a universal optimum for different grades of high-strength concrete, future work can focus on the optimization of the dosage of nano-silica in excess of 3–5%.

There is also wider scope to evaluate long-term performance such as shrinkage, creep, carbonation resistance, and penetration of chloride under actual environmental conditions since the present work mainly considered mechanical and durability properties (acid resistance, water absorption, and sorptivity).

Future research can focus on hybrid combinations of nano-silica with other nanomaterials such as carbon nanotubes, nano-alumina, or nano-titania to enhance sustainability. These combinations could provide multifunctional characteristics such as self-cleaning, improved thermal resistance, or self-sensing properties..

8. References

1. Fadi Alothey, Osama Zaid, Rebeca Martinez-Garcia, Fahad Alsharari & Mohamed M.Arbili. 2023. "Impact of nano-silica on the hydration, strength, durability and microstructural properties of concrete: a state -of-the art review". *Case Studies in Construction materials, 18, e01997*. https://doi.org/10.1016/j.cscm.2023.e0199
2. Van Minh Nguyen, Thang Ba Phung, Duc Thang Pham, Lanh Si Ho. 2023. "Mechanical properties and durability of concrete containing coal mine waste rock, f-class fly ash, and nano-silica for sustainable development". *Journal of Engineering Research, 11, 75-86*. https://doi.org/10.1016/j.jer.2023.100097.
3. Mayank Nigam, Manvendra Verma. 2023. "Effect of nano-silica on the fresh and mechanical properties of conventional concrete". *Forces in Mechanics, 10, 100165.* https://doi.org/10.1016/j.finmec.2022.100165
4. V.V. Praveen Kumar, Subhashish Dey. 2023. "Study on strength and durability characteristics of nano-silica based blended concrete". *Hybrid Advances, 2, 100011.* https://doi.org/10.1016/j.hybadv.2022.100011
5. Vikram Singh Kashyap, Gaurav Sancheti, Jitendra Singh Yadav. 2023. "Durability and microstructural behavior of Nano silica-marble dust concrete". *Cleaner Materials, 7, 100165*. https://doi.org/10.1016/j.clema.2022.100165
6. Saber Fallah-Valukolaee, Renza Mousavi, Arash Arjomandi, Mahdi Nematzadeh, Mostafa Kazemi. 2022. "A comparative study of mechanical properties and life cycle assessment of high-strength concrete containing silica fume and nano silica as a partial replacement". *Structures, 46, 838-851*. https://doi.org/10.1016/j.istryc.2022.10.024
7. M Thanmanaselvi, V Ramasamy. 2021. "A study on durability characteristics of nano-concrete". *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2021.06.349
8. Taher A. Tawfik, Khaled Aly Metwally, S.A. EL-Beshlawy, Doha M.Al Saffar, Bassam A. Tayeh, Hassan Soltan Hassan. 2021. "Exploitation of the nanowaste ceramic incorporated with nano silica to improve concrete properties". Journal of King Saud University – *Engineering Sciences, 33, 581-588*.https://doi.org/10.1016/j.jksues.2020.06.007
9. Sujay H.M., Nishant A. Nair, H. Sudarsana Rao, V.Sairam. 2020. "Experimental study on durability characteristics of composite fiber reinforced high-performance concrete incorporating nano silica and ultra-fine fly ash". *Construction and Building Materials, 262, 120738*. https://doi.org/10.1016/j.conbuildmat.2020.120738
10. A.O. Adetukasi, O.G. Fadugba, I.H. Adebakin, O.Omokungbe. 2020. "Strength characteristics of fiber-reinforced concrete containing nano-silica". *Materials Today: proceedings, 2214-7853*. https://doi.org/10.1016/j.matpr.2020.03.123
11. Anas Alkhatib, Mohammed Maslehuddin, Salah Uthman Al-Dulaijan. 2020. "Development of high-performance concrete using industrial waste materials and nano-silica". *Journal of Materials Research and Technology, 9(3):6696-6711* https://doi.org/10.1016/j.jmrt.2020.04.067
12. M. Rezania, M.Panahandeh, N.Razavi, F.Berto. 2019. "Experimental study of the simultaneous effect of nano-silica and

nano-carbon black on permeability and mechanical properties of the concrete". *Theoretical and Applied Fracture Mechanics, 104,102391*.https://doi.org/10.1016/j.tafmec.2019.102391

13. Mahdi Mahdikhani, Omid Bamshad, Mohammad Fallah Shirvani. 2018. "Mechanical properties and durability of concrete specimens containing nano silica in sulfuric acid rain condition". *Construction and Building Materials,167,929-935*.https://doi.org/10.1016/j.conbuildmat.2018.01.137
14. Abdulkadir Cevik, Radhwan Alzeebaree, Ghassan Humur, Anil Nis, Mehmet Eren Gulsan. 2018. "Effect of nano-silica on the chemical durability and mechanical performance of fly ash based geopolymer concrete". *Ceramics International, 44, 12253-12264*. https://doi.org/10.1016/j.ceramint.2018.04.009
15. Bashar S.Mohammed, Mohd Shahir Liew, Wesam S. Alaloul, Veerendrakumar C.Khed, Cheah Yit Hoong, Musa Adamu. 2018. "Properties of nano-silica modified previous concrete". *Case Studies in Construction Materials, 8, 409-422*.https://doi.org/10.1016/j.cscm.2018.03.009
16. IS: 12269- 2013. Ordinary Portland Cement 53 Grade- Specifications, Bureau of Indian Standards. New Delhi.
17. IS: 4031-2019. Methods of physical tests for hydraulic cement, Bureau of Indian Standards. New Delhi.
18. IS: 15388-2003. Silica Fume-Specification. Bureau of Indian Standards. New Delhi.
19. IS:383-2016. Coarse and Fine aggregate for concrete specification, Bureau of Indian Standards. New Delhi.
20. IS:2386-1963. Methods of Test for Aggregates for Concrete, Bureau of Indian Standards. New Delhi.
21. IS: 9103- 1999. Concrete admixtures-Specification, Bureau of Indian Standards. New Delhi.
22. IS: 456- 2000. Plain and Reinforced concrete code of practice, Bureau of Indian Standards. New Delhi.
23. IS: 10262-2019. Concrete Mix Proportioning- Guidelines, Bureau of Indian Standards. New Delhi.
24. IS:516- 1959. Methods of tests for strength of concrete, Bureau of Indian Standards. New Delhi.
25. IS: IS:5816-1999 the methods for testing the strength of concrete