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ENHANCEMENT OF STRENGTH PROPERTIES OF HIGH PERFORMANCE CONCRETE MIXES USING NANO SILICA

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Abstract- The effect of nano silica and silica fume in combination as partial replacement for cement on the properties of concrete has been investigated by performing strength tests on various samples. In the study, Ultratech Ordinary Portland cement was partially replaced by nano silica with percentage of 2%, 3% & 4% and replacement level of silica fume was kept constant at 8%. The W/C of concrete was kept at 0.42 and the workability was maintained in the medium range i.e. 0.85 to 0.95 compaction factor. The experimental results show that the strength properties of the concrete having nano silica and silica fume in combination were better than that of a plain concrete.
Keywords: Nano silica, Silica fume, Strength, Durability, High performance concrete.

1. INTRODUCTION:

In the recent times, nano technology has taken attention of world due to the new potential uses of particles in nanometer (10^{-9} m) scale. The nano particles can improve properties of conventional grain-size materials of the same chemical composition. Thus, industries may be able to re-develop many existing products and to design a new and novel material that works wonder at some levels [1].

The most commonly used material for construction is concrete in current scenario and its design consumes more than 90 % the total cement production in the world. The use of large quantities of cement produces increasing CO_2 emissions, and as a consequence the greenhouse effect. A method to reduce the cement content in concrete mixes is through use of supplementary cementitious materials having significant amounts of silica fines. One of the silica fines with a very high potential as cement replacement and as concrete additive is NS (Nano silica).

The compressive strengths of mortars with NS particles were all higher than those of mortars containing silica fume at 7 and 28 days. In addition, the continuous hydration progress was monitored by scanning electron micrograph (SEM) observation, by examining the residual quantity of CH and the rate of heat evolution, which again indicates that nanoscale Silica not only improves the microstructure, but also as an activates the pozzolanic reaction [1]. The new NS can be produced in high quantities and for low prices that allows for a mass application in concrete. It may replace cement in the mix, which is the most costly and environmentally unfriendly component in concrete. The use of NS makes concrete financially more attractive and reduces the CO_2 footprint of the produced concrete products. The NS will, additionally, also increase the product properties of fresh concrete like workability and the properties in hardened state too, thus enabling the development of high performance concretes for extreme constructions. That means that a concrete with better performance, lower costs and an improved ecological foot print can be designed [2]. The experimental results show that the mechanical properties measured, and the durability of the concrete mixed with the nano particles was better than that of a plain concrete. The SEM study of the microstructures showed that the nano particles filled the cement paste pores and, by reacting with calcium hydroxide crystals from calcium silicate hydration, decreased the size and amount of these crystals. This indicates that nano scale silica behaves not only as a filler to improve microstructure, but also as an activator to promote pozzolanic reaction was found [3]. NS can absorb the CH crystals, and reduce the size and amount of the CH crystals, thus making the interfacial transition zone (ITZ) of aggregates and binding paste matrix denser. The NS particles can fill the voids of the CSH gel structure and act as nucleus to tightly bond with CSH gel particles [4]. With 3% addition, NS digested CH crystals, decreased the orientation of CH crystals, reduced the crystal size of CH gathered at the interface and improved the interface more effectively than SF. The results suggest that with a small amount of added NS, the CH crystals at the interface between hcp and aggregate at early ages may be effectively absorbed in high performance concrete (HPC) [5]. The microsilica contents of 6% and 1.5% colloidal nano silica as partial replacement of cement in the concrete mixture, with 0.45 water-cement ratio, improved the compressive strength and electrical resistance and also diminished capillary absorption of the concrete specimens seriously. The current state of the field of nanotechnology in concrete and recent key advances highlighted the potential of nanotechnology to improve the performance of concrete. They also pointed out that its use would lead to development of novel, sustainable, advanced cement based composites with unique mechanical, thermal, and electrical properties [6]. The advances in instrumentation and computational science are enabling scientists and engineers to obtain unprecedented information about

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concrete, from the atomic through the continuum scale, and the role of nanoscale structures on performance and durability. This information is crucial for predicting the service life of concrete and for providing new insights on how it can be improved [7]. The enhancement of strength was not only because of pore filling effect, but also by the accelerated cement hydration due to their higher reactivity of NS. Moreover, the water and capillary absorption results revealed significant decrease by the addition of blended NS and SF for the binder content. According to SEM microstructure studies, more refined microstructure and smaller pores were achieved by the addition of NS and SF, which can led to enhancement of mechanical, durability and micro structural properties of HPSCC [8]. Nano Silica has been found to increase the strength, flexibility, workability and durability of concrete. The nano silica particles increase the viscosity of the fluid phase of concrete and fill the voids between cement grains. It reacts with CH and results in more CSH. Almost all the mechanical and transport properties of concrete are controlled by CSH which is a nonporous, nano-structured material [9]. The management of wastes and nanotechnology in combination can lead to accessing both performance of structural components reduction of the harmfulness of hazardous by-products. The application of nanotechnology in the civil engineering related industry can play an important role in the quality of building materials (strength, durability and lightness) [10].

Now a day’s lots of work is going on nano materials in concrete construction individually and in combination with silica fume but its application and effect has not been fully understood yet. In the present work, cement in concrete has been replaced with both nano silica & silica fume and compared with normal concrete. The silica’s (Silica fume and Nano silica) are normally used for the preparation of high strength concrete (HSC) but by using silica’s for the preparation of normal strength concrete (W/C ratio 0.42), we can get the same amount of strength with lesser amount of cement. At the same time we can save the natural resources and also control the carbon dioxide emission during the manufacturing of cement. Due to the fineness of nano-materials, it reacts more actively and refines the pores of the concrete in a better ways. The only problem for using such materials is that, due to its large specific surface area, it increases the water demand and reduces the workability. This problem can be solved by using superplasticizer. Again to minimise dose superplasticizer, we add a constant dose of silica fume. Silica fume being coarser than nano silica has lesser spherical surface area and hence has less water demand than nano silica. Secondly, the nano silica is not easily available in the Indian market and is more costly than silica fume. Also, even a little amount of nano particles can react very well with calcium hydroxide (CH) to produce the stable Calcium Silicate Hydrate (CSH) which ultimately increases the strength and durability of the concrete. Therefore, this experimental study is aimed to investigate the strength and durability characteristics, specifically compressive and split tensile strength, rapid chloride penetration and abrasion test of concrete by incorporating different dosages of nano silica along with silica fume as partial replacements of cement. Superplasticizer was used as water reducing agent to maintain workability in medium range i.e. 0.85-0.95.

2. MATERIALS AND METHODS

2.1 Properties of Materials

The ordinary Portland cement of 43 grade (Ultra tech) conforming to BIS: 8112[11] was used in this experimental work. The cement used had a specific gravity of 3.10, with a Blaine specific surface of 3050 cm^2/gm. The compressive strength of OPC used after 7 days & 28 days was 33.78N/mm² & 47.36N/mm², respectively. Crushed stone aggregates of 20 mm & 12.5mm sizes, in equal proportions, having specific gravity of 2.64 and 2.62, respectively, were used as coarse aggregates. The crushed stone sand, conforming to zone-II as per BIS: 383[12], having specific gravity 2.64 was used as fine aggregate in the concrete mix. Nano silica (NS) with high specific surface and high proportion of very fine particles consisting of nearly clean SiO_2 (99%) presents the next step of modification of properties of mastic cement and concrete and making concrete with higher end-use properties. Properties of this material are similar to silica fumes; however, they are amplified by higher specific surface, hence higher reactiveness. Nano-SiO_2 has been found to increase the strength of bond between aggregate and mastic cement and considerably decrease the size of pores resultant concrete. The nano silica used was amorphous in liquid state. NS and SF used in this study were commercially available and were supplied by Bee Chems & Orkla India (Pvt) Ltd (Brand Name: Elkem Micro-silica 920-D), respectively. The physical and chemical properties of silica fume and nano-silica are given as silica contents 93.80 and 99.90 respectively. The specific gravity of silica fume and nano silica was 2.26 and 1.21 respectively and having specific surface 18 and 275-300 m^2/gm. Superplasticizer, by the brand name Master Glenium Sky 8777, was obtained from BASF construction chemicals (India). The superplasticiser used is a second generation polycarboxylic etherpolymer has a relative density 1.10 at 25°C. Normal tap water was used through-out the experimental work.

2.2 Experimental Program

2.2.1. Mix Design

Concrete mixes, as per BIS: 10262[13] guidelines, were designed for water-to-binder (the sum of the cement, nano silica & silica fume) ratios of 0.42, in the experimental work undertaken. The workability of the concrete mixes was maintained in medium range with the compaction factor lying in the range 0.85 to 0.95. The proportions of the constituent materials so obtained for control concrete mixtures corresponding to the water-cement ratios are given in Table 1. Herein, N_0 denote plain concrete mixes. The mixes N_2, N_3 and N_4 denotes concrete mixes containing nano silica at the replacement level of 2%, 3% & 4%, respectively, for given water-to-binder ratios with silica fume percentage kept constant at replacement level of 8%.

The details of the percentage various binder materials used in the mixes along with the strength (Compressive and Split tensile) values achieved are provided in Table 2.

Table 1 Mixture proportions for concrete mix without & with NS & SF

Mix Designation	Water-cement ratio	Water (kg/m^3)	Cement (kg/m^3)	Nano silica (NS) (kg/m^3)	Silica fume (SF) (kg/m^3)	Fine aggregates (kg/m^3)	Coarse Aggregate – I (20mm) (kg/m^3)	Coarse aggregate – II (12.5mm) (kg/m^3)	Superplasticizer (kg/m^3)
N_0	0.42	158.27	450	-	-	613.06	617.57	617.57	4.275
N_2			405	9	36	613.06	617.57	617.57	4.50
N_3			400.5	13.5	36	613.06	617.57	617.57	4.95
N_4			396	18	36	613.06	617.57	617.57	5.175

Table 2 Mix proportion, Compressive and Split tensile strength of high performance concrete without & with NS & SF.

Sample	Mix Proportion in mass					Compressive strength (MPa)			Split Tensile Strength (MPa)		
	C	NS	SF	W	SM	7 days	28 days	56 days	7 days	28 days	56 days
N_0	100	0	0	42	0.95	26.58	37.70	40.71	2.89	3.62	3.76
N_2	90	2	8	42	1.0	36.58	43.43	47.94	3.26	3.95	4.17
N_3	89	3	8	42	1.10	32.74	43.15	48.05	3.29	4.20	4.39
N_4	88	4	8	42	1.15	31.21	40.44	42.76	3.43	4.31	4.64

2.2.2 Preparation of Specimen for strength test

Firstly, the coarse aggregates, which were saturated surface dry, were placed in the mixer. The binder (cement only in case of control mixes and cement & silica fume for other mixes already thoroughly manually mixed) and fine aggregates were added and mixed for about a minute. Subsequently 70% of total water is mixed for nearly 3 minutes. After the initial mixing is complete remaining 30% of water, which was premixed with the pre-calculated superplasticizer dosage (from requirements of workability) and nano silica in two equal parts, was added and mixing was done for another one and a half to two minutes. The compaction factor test was conducted to check the workability, and then finally, the fresh concrete was poured into the well-oiled specimens. After pouring the concrete, an external vibrator was used to facilitate the compaction and decrease the amount of air bubbles.

2.2.3 Curing conditions for specimens

All the specimens were demoulded after 24 h and then put in water tank for curing at a temperature of 27±2°C.

2.2.4 Test of Strength

The compressive and split tensile strength tests were performed in accordance with BIS: 516[14] and BIS: 5816[15]. The cube moulds having size 150 ×150×150 mm were used for both compressive and split tensile strength. For the designated mix and for each of the testing ages, 10 samples were cast and the average value of results is given in Table 2.

3 RESULT AND DISCUSSIONS

3.1 Compressive strength

The Figure 1 shows the variation of compressive strength for different mixes with NS and SF added. The results indicate that an increase in the nano silica content from 2%, 3, 4 % and keeping 8% of silica fume constant by weight, leads to an increases in the compressive strength of concrete at all stages with reference to normal concrete (without NS and SF). This could also be attributed to high pozzolanic activity & better bond strength which is due to filling effect of nano silica. It is also observed that the nano silica and silica fume react with the Ca (OH_2) crystals existing within the concrete and produce the C-S-H material which ultimately increases the compressive strength as was reported by several other researchers [2, 4, and 16].

However, there is a decrease in the percentage increase in the compressive strength with the addition of nano silica, which is due to the agglomerate effect. For example, For N-series the increase was 37%, 15% and 18 % for 7, 28 and 56 days, respectively. The strength increase of N_3 and N_4 is less by 14% and 20 % for 7 days, by 1% and 8 % for 28 days and by 0% and 13 % for 56 days, respectively, in comparison to N_2. The results show that the optimum level of replacement for most of the W/C ratio is 2% of NS & 8% of SF as the percentage increase in strength is maximum for this combination.

This fact, that large amount of nano silica decreases the compressive strength of the composite instead of improving it, was also reported by Sadrmomtazi et al [17], because when the content of nano silica is large, nano particles are difficult to disperse uniformly. Therefore, they create a weak zone in the form of voids, consequently the homogeneous hydrated microstructure cannot be formed and a lower strength will be probable.

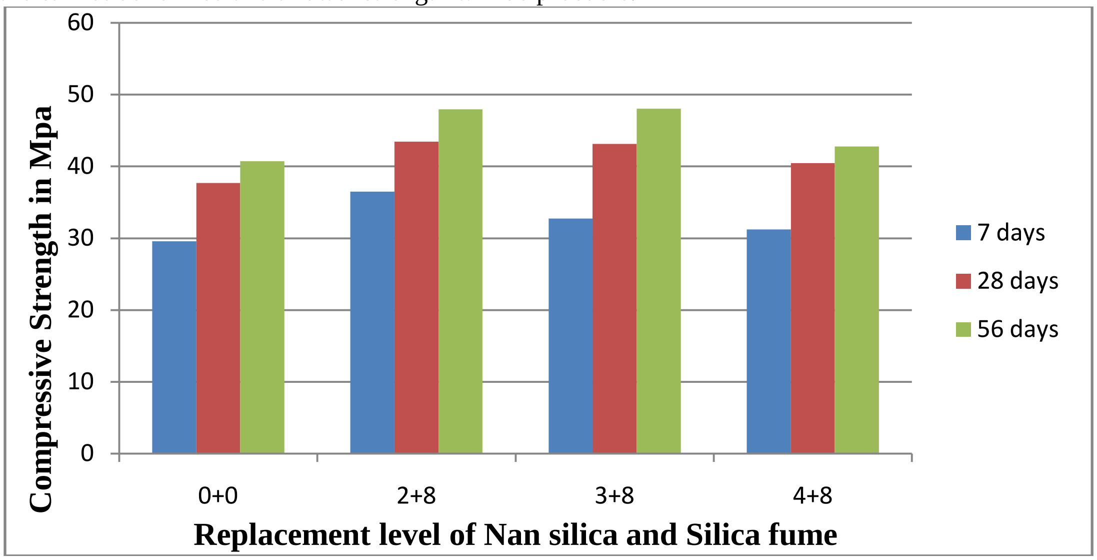

Figure 1 Effect of Nano silica and Silica fume on Compressive strength of Concrete

3.2 Split Tensile Strength

The Figure 2 shows the variation of compressive strength for different mixes with NS and SF added. The results indicate that an increase in the nano silica content from 2, 3, 4 % and keeping 8% of silica fume constant by weight, leads to an increases in the Tensile strength of concrete at all stages with reference to normal concrete (without NS and SF). This could also be attributed due to increase in bound strength between cement paste & aggregate as it has very fine particle size which fills the pores of aggregates in a better way. The high reactivity of Nano silica, which is due to its high spherical surface and fineness also contributed to increase split tensile strength of concrete. Nano silica improved the quality of the interfacial zone (ITZ) due to the precipitation of smaller and stronger CSH gel and accelerated the rate of hydration. It is also observed that the nano silica and silica fume react with the CH crystals existing within the concrete and produce the CSH material which ultimately increases the tensile strength as was reported by several other researchers [Quercia et al [18], Jalal et al [8], Khanzadi et al [2]].

For N-series, the increase was 19%, 19% and 23 % for 7, 28 and 56 days, respectively. The percentage increase in strength, with the increase in nano silica contents, for $N_{2,}$ N_3 and N_4 is 13, 14 and 19 % for 7 days, 09, 16 and 19 % for 28 days and 11, 17 and 23 % for 56 days respectively, when compared to $N_{0.}$ The results show that the optimum level of replacement for most of the W/C ratio is 4% of NS & 8% of SF as the percentage increase in strength is maximum for this combination. There was a change in optimum level of replacement, which is due to W/C ratio [19] also reported that the optimum replacement percentage is not constant but depends on the water-cementitious material ratio of mix.

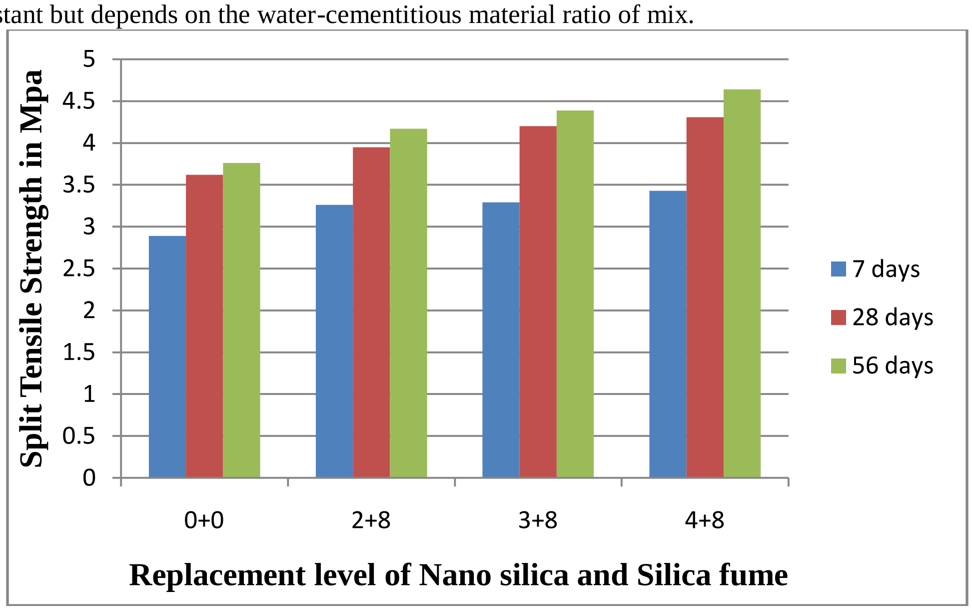

Figure 2 Effect of Nano silica and Silica fume on Split tensile strength of Concrete

4. CONCLUSION

- According to the test results, the combined application of Nano silica and Silica fume would lead to a higher compressive and split tensile strength of concrete at all level of replacement of cement and curing in comparison with that of plain concrete.
- The combined application of nano silica and silica fume lead to a higher compressive strength of concrete at the early as well as at later stage.
- The nano silica consumes CH to produce CSH (due to acceleration of hydration of tricalcium and diacalcium) which made concrete more dense and homogeneous as compared to plain concrete, which ultimately increased the strength properties of concrete.
- As the water to binder ratio decreased, the compressive strength of concrete mixes with 2, 3 and 4 % of nano silica and with 8 % of silica fume increased. This could be attributed to the fact that the bond strength between cement paste & aggregate was more than the controlled concrete, as nano silica has very fine particle size, which fills the pores of aggregates in a better way.

Conflict of interest

The authors declare that they do not have any conflict of interest.

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