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STRENGTH AND POROSITY PROPERTIES OF NANOSILICA BASED SELF-COMPACTING CONCRETE MIXES

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ABSTRACT This paper investigates the Strength and porosity properties of nanosilica based self-compacting concrete mixes of M30 and M50 grades. The optimum dosage of nanosilica used in M30 and M50 grade self-compacting concrete is determined to be 1% and 0.5% respectively by weight of the total powder. Due to the enhanced pore refinement of the nanosilica, the compressive strength of the concrete is increased by 28.46% for M30 and 29.84% by addition of nanosilica of 0.5% and 1% for M50 by weight of powder respectively. The addition of nanosilica a improves the hydrated structure of the concrete by modifying the concrete pore structure by plugging the voids or the nanopores within cement – sand mix matrix by nanosilica particles. Addition of nanosilica into the self-compacting concrete causes the reduction in the water absorption and the porosity by 53.26% and 70% for M30 grade and 58.53% and 78% for M50 grade respectively which could in turn increases the durability of the cementitious structures significantly. So, it is concluded that with the addition of nanosilica there is significant increase in compressive strength, and decrease in the water absorption capacity and porosity due to pore refinement by nanosilica particles plugging the concrete.

KEYWORDS : nano-silica, self-compacting concrete, water absorption studies, porosity, nano-technology

1. INTRODUCTION

A dense microstructure in concrete enhances its strength properties. The reduced porosity and improved interfacial bonding between the cementitious materials result in higher compressive, tensile, and flexural strengths[1]. This is crucial for structural applications where concrete needs to withstand heavy loads and forces. A denser microstructure improves the durability of concrete by reducing the ingress of harmful substances such as wat er, chloride ions, sulfates, and aggressive chemicals[2]. With fewer interconnected pores, the movement of these substances through the concrete is restricted, mitigating the potential for corrosion of reinforcement, alkali-silica reaction, sulfate attack, and other forms of deterioration[3]. Concrete with a dense microstructure exhibits lower permeability to `water and other liquids [4]. This is beneficial in environments where moisture intrusion can cause damage, such as in coastal areas, structures exposed to freeze-thaw cycles, or structures in contact with aggressive chemicals [5]. Reduced permeability minimizes the risk of moisture-related issues, including cracking, spalling, and internal damage[6]. A denser microstructure provides better resistance to chemical attacks. It restricts the movement of aggressive substances and reduces the availability of reactants, such as calcium hydroxide, that can initiate chemical reactions within the concrete [7]. This is particularly relevant in environments with high chemical exposure, such as wastewater treatment plants, industrial facilities, and infrastructure subjected to chemical spills[8]. The combination of increased strength, improved durability, and reduced permeability due to a dense microstructure contributes to the extended lifespan of concrete structures[9]. With less susceptibility to degradation mechanisms, the need for maintenance, repair, and replacement is minimized, resulting in cost savings and sustainable infrastructure. Concrete with a dense microstructure is more resistant to freeze-thaw cycles[10]. When water enters concrete and subsequently freezes, it expands, exerting pressure on the surrounding matrix[11]. A denser microstructure with reduced pore volume limits the amount of water that can enter and decreases the potential for internal damage caused by ice formation and expansion[12]. Overall, a dense microstructure is crucial for ensuring the long-term performance and structural integrity of concrete[13]. It enhances strength, durability, chemical resistance, and resistance to various forms of deterioration, leading to safer and longer-lasting concrete structures[14]. In the current study nanosilica (nS) and microsilica (mS) are adopted to enhance the strength and durability properties of the self-compacting concrete (SCC).

2. Nanosilica (nS)

In the present research nanosilica is bought from 'Bee Chems' located at Kanpur. The main properties of Nano Silica, are Specific Surface area (180m^2/g), Nano particle size (40nm), specific gravity (1.30), dispersant form, white liquid, colloidal form.

3. Optimum Percentage of Nanosilica in SCC mixes

For the conventional OPC 53 grade the compressive strength was found to be 54.3 MPa. On addition of 0.5% of nanosilica by weight of powder the compressive strength of the specimens are found to be 59.24 MPa and on addition of 1% of nanosilica the compressive strength was found to be 63.4 MPa. Optimum percentage replacement of nanosilica was found to be 1% for which the pore refinement in the micro structure of concrete is enhanced. This improvement of compressive strength is attributed to the deposition of nanosilica particles in the pores of the concrete which modifies the cement mortar pore structure by plugging the voids or the pores within the cement-sand matrix. In this study, M30 grade SCC is admixed with optimum 1% of nanosilica by weight of powder and in M50 grade SCC the optimum of nanosilica is 0.5% by weight of powder.

4. Quantities of materials

Based on the Nan Su mix design criteria and EFNARC guidelines, the quantity of materials that are obtained for M30 and M50 grades are listed below in figures 1-4.

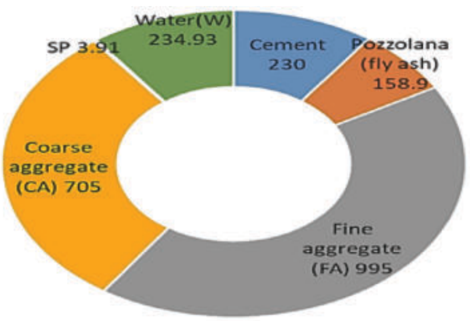

Fig 1. Quantities of materials in kg/m^3 for M30 SCC without nanosilica

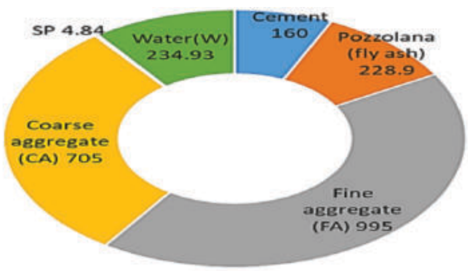

Fig 2. Quantities of materials in kg/m3 for M30 SCC with nanosilica (1% bwp)

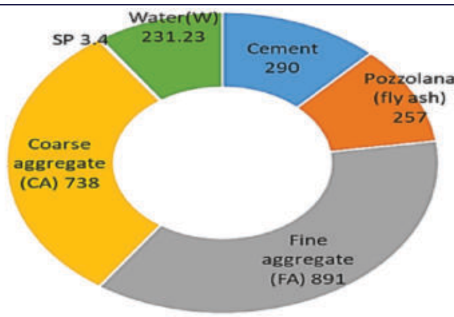

Fig 3. Quantities of materials in kg/m3 for M50 SCC without nanosilica (5% mS bwp)

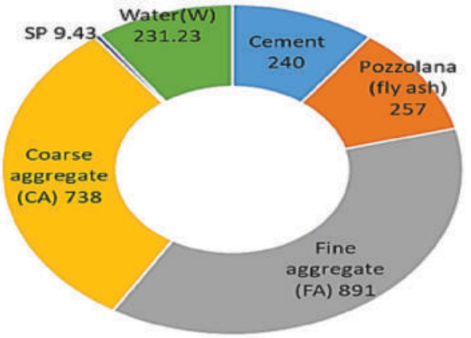

Fig 4. QuM50 SCC with nanosilica (0.5% bwp)antities of materials in kg/m3 for

5. Setting times of nanosilica based cement

The initial and final setting times of cement incorporated with nanosilica (nS) and without nanosilica are tabulated below in table 1.

Table 1-Setting times of cement mortar incorporated with and without NS

Tests	Conventional Cement 53 grade	OPC 53 Grade admixed with	
		0.5% nS	1% nS
Initial setting time(min)	35	20	12
Final setting time(hrs)	9.23	6.33	4.51

The initial setting time of SCC after adding the nanosilica is rapidly decreased due to the nature of the water absorption capability of nanosilica. The initial and final setting times of conventional concrete was found to be 35 minutes and 9.23hours. The value for initial setting time is decreased from 35minutes to 20minutes on addition of 0.5% of nS by weight of powder and decreased from 35minutes to 12minutes on addition of 1% of nS by weight of powder. The value for final setting time is decreased from 9.23 hours to 6.33 hours on addition of 0.5% nS by weight of powder and 9.23 to 4.51 hours on addition of 1% of nS by weigh of powder.

6. Fresh properties

The fresh properties of nanosilica based self-compacting concrete mixes based on EFNARC guidelines are tabulated in table 2.

Table 2- Fresh properties as per EFNARC guidelines

Tests Conducted	SCC		
	Conventional	M30 Grade with 1% nS added	M50 Grade with 0.5% nS added
Slump flow (mm)	721	653	657
J ring (mm)	1.2	2.9	5.2
V funnel (sec)	12	8	11
L box (ratio)	0.9	0.8	0.82

Slump flow tests was carried out on each SCC mix to measure fresh spread diameter of concrete which determines about filling ability of concrete. The diameter was observed to decrease with increase in amount of nanosilica in different mixes. The values were obtained for M30 and M50 mixes are above 550 mm and below 850 mm as per EFNARC specifications. The lowest slump flow diameter was found for M30 and M50 (having optimum nanosilica replacement) was 653mm. Incorporation of nanosilica in concrete, results in increase of water demand for the given workability. Increase in workability is due to smaller particle size of nanosilica as compared to that of cement. Since specific surface area of nanosilica is more than that of cement, a great amount of water is required to carry out hydration reactions. V-funnel was conducted to measure the flowability of SCC. The result from each mix indicates increase in workability by decrease in time with increased nanosilica and minimum time is taken by M30 and M50 (optimum nanosilica replacement with cement) is 8 sec and 9sec which are within the limits as per EFNARC specifications. L-box test measures passing ability of SCC mix. L-box determine the blocking ratio (BR) by dividing the height of SCC mix at the end point of horizontal section (H2) and height(H1) at starting point of horizontal section of L-box. The higher values of blocking ratio show minimum blockage of aggregates. Results show that addition of nanosilica cause decline in blockage ratio, minimum blockage ratio was found 0.8 and 0.85 for M30 and M50 (optimum nanosilica replacement). J-ring test was performed to measure the passing ability of Self-Compacting Concrete. J- Ring placed around Abram's cone provides obstruction to concrete which causes difference in inside and outside height of concrete of J-ring. Results show increased amount of nanosilica decrease the workability of concrete gradually. The maximum step height is found as 2.9 and 5.3 for M30 and M50 (optimum nanosilica replacement with cement).

7. Compressive Strength

For the M30 and M50 grade SCC mixes, the compressive strengths are tested for 3, 7, 28, 60 and 90days which are listed below in table 3 and 5 and the percentage increase in the compressive strengths for 3, 28 and 90 days are also evaluated for the M30 and M50 grade mixes and presented in table 4 and 6. Figure 5 and 6 presents the gain of compressive strengths of nanosilica based SCC for M30 and M50 grade mixes.

Table 3 -Compressive strengths of Nano-silica based SCC for M30 grade

Type of concrete	Compressive strength in MPa				
	3days	7days	28days	60days	90days
M30 grade SCC	19.12	26.04	38.22	41.96	43.19
M30 grade SCC with NS(0.5% bwp)	24.87	34.11	46.25	48.11	53.93
M30 grade SCC with NS (1% bwp)	27.24	35.82	49.10	51.89	57.78

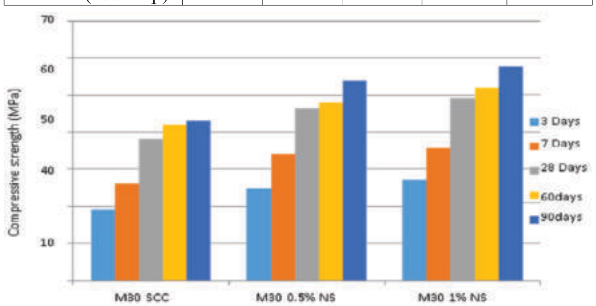

Fig 5. Gain of Compressive strengths of Nano-silica based SCC for M30 grade

Table 4- Percentage increase in compressive strength for Nano Silica based M30grade

Type of mix	Percentage increase in compressive strength		
	3 days	28 days	90 days
M30 plain SCC	-	-	-
M30 SCC with 0.5%NS	23.12	17.36	19.9
M30 SCC with 1% NS	29.08	22.15	25.25

Table 5 -Compressive strengths of Nano-silica based SCC for M50 grade

Type of concrete	Compressive strength in MPa				
	3days	7days	28days	60days	90days
M50 grade SCC (5%MS)	26.12	37.04	62.61	69.26	73.59
M50 grade SCC with NS (0.5% bwp)	34.87	44.11	63.25	73.25	79.13
M50 grade SCC with NS (1% bwp)	37.24	49.82	69.10	82.90	86.6

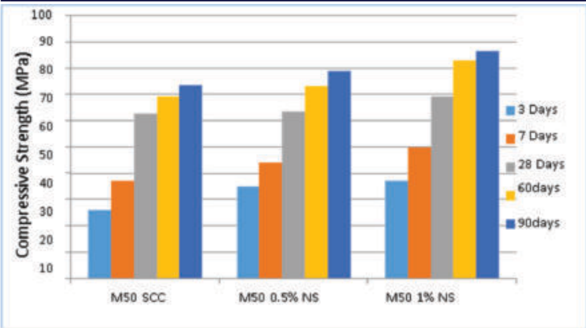

Fig 6. Gain of Compressive strengths of Nano-silica based SCC for M50 grade

Table 6- Percentage increase in compressive strength for Nano Silica based M30grade

Type of mix	Percentage increase in compressive strength		
	3 days	28 days	90 days
M50 plain SCC	-	-	-
M50 SCC with 0.5%NS	25.09	1.011	7.00
M50 SCC with 1% NS	29.86	9.39	15.02

The compressive strength of the concrete is increased by 21.09% and 28.46% for M30 and 18.85% and 29.84% by addition of nanosilica of 0.5% and 1% for M50 by weight of powder respectively. The mix design is revised, by decreasing the cement content and increasing fly ash content which is a cost-effective process of making concrete. Reduction in pores due to nanosilica will eventually increase the concrete compressive strength. Use of nanosilica in concrete reduces the interconnectivity of the pore structure by decreasing the pore size (pores refinement), which is directly related to durability. This decrease in compressive strength beyond 1% addition of nanosilica by weight of powder was because of the reduction in homogeneity of the cement matrix at higher content of nanosilica. At 1% replacement of nanosilica, there is an increased homogeneity and densification of the matrix.

The increase in compressive strength can be attributed to the filling of voids in the microstructure by the Nano SiO_2 particles which prevents the growth of $Ca(OH)_2$ crystals. In addition to it the nanosilica reacts with calcium hydroxide crystals converting them into C-S-H gel. The reduction in the $Ca(OH)_2$ content is the reason for increase in compressive strength of concrete. $Ca(OH)_2$ crystals are present in the Interfacial Transition Zone (ITZ) which is between the aggregates and the hardened cement paste. Nano SiO_2 reacts with these crystals and decreases their concentration, hence, strengthen the ITZ. Due to lesser concentration Nano SiO_2 are consumed in the reaction and hence the increase in strength is inhibited with time.

8. Water absorption

To determine the water absorption capacity the rate of water absorbed by the concrete specimens are evaluated at regular time intervals and the percentage increase in the weights of the specimens are tabulated below in table 8 and 9 respectively for M30 and M50 grade mixes. Figures 7 and 8 also presents rate of water absorption for M30 and M50 SCC mixes graphically.

Table 8 - Rate of Water absorption for M30 SCC mixes

Time in minutes	Conventional SCC		0.5% ofNS		1% of NS	
	Mo=8.0kg		Mo = 8.01kg		M0=8.03kg	
	Mi(kg)	((Mi-Mo)/ Mo) X100	Mi(kg)	Mi(%) = ((Mi Mo)/Mo) X100	Mi(kg)	Mi(%) = ((Mi Mo)/Mo)X100
0	8.0	0	8.01	0	8.03	0
15	8.05	0.62	8.01	0	8.03	0
30	8.07	0.867	8.03	0.37	8.03	0
60	8.07	0.867	8.05	0.621	8.04	0.12
90	8.09	1.112	8.06	0.744	8.04	0.14
180	8.10	1.234	8.07	0.867	8.05	0.24
480	8.11	1.356	8.07	0.867	8.06	0.37
1440	8.13	1.59	8.10	1.23	8.06	0.37
2880	8.15	1.84	8.10	1.23	8.08	0.86

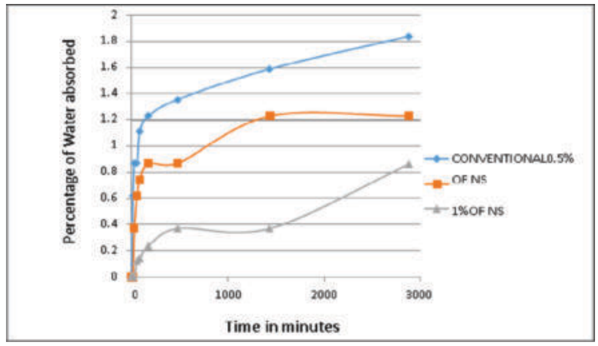

Fig. 7 - Rate of water absorption for M30 SCC mixes

Table 9 - Rate Water absorption for M50 SCC mix

Time in minutes	Conventional SCC		0.5% of NS		1% of NS	
	Mo=8.0kg		Mo = 8.01kg		M0 = 8.02kg	
	Mi(kg)	Mi(%) = ((Mi-Mo)/ Mo) X100	Mi(kg)	Mi(%) = ((Mi-Mo)/Mo) X100	Mi(kg)	Mi(%) = ((Mi-Mo)/Mo) X100
0	8.0	0	8.01	0	8.02	0
15	8.04	0.497	8.01	0	8.02	0
30	8.05	0.621	8.02	0.124	8.02	0
60	8.06	0.744	8.03	0.249	8.03	0.101
90	8.06	0.744	8.03	0.249	8.04	0.124
180	8.07	0.867	8.05	0.46	8.04	0.248
480	8.08	0.99	8.06	0.620	8.05	0.372
1440	8.08	0.99	8.07	0.743	8.06	0.510
2880	8.10	1.23	8.08	0.866	8.06	0.510

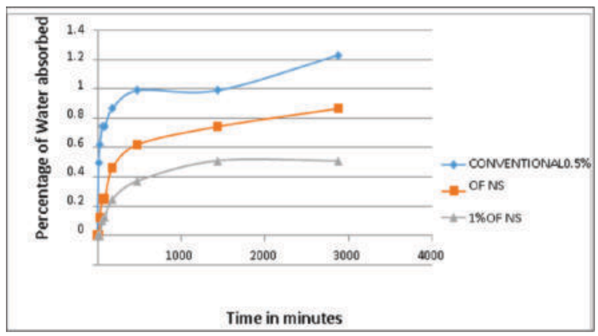

Fig. 8 -Rate of water absorbed for M50 SCC mixes

Water absorption capacity test has been carried out, the initial weight for M30 conventional concrete specimen is about 8.00kg and the rate of water absorption had been carried out in regular time intervals and it is observed that the rate of water absorption has been increased from 0 to 1.84% within 48 hours. On addition of 0.5% of nanosilica the initial weight of the cube is found to be 8.01kg and the increase in the rate of water absorption is 0 to 1.23% and on addition of 1% of nanosilica the initial weight of the cube specimen is 8.03kd and the percentage increase in the rate of water absorption was 0 to 0.86%. For M50 grade conventional Concrete the initial weight of the specimens is 8.0kg and the rate of water absorption for 48hours was from 0 to 1.23%. On addition of 0.5% of nanosilica the initial weight was 8.01kg and the rate of water absorption was found to be increase from 0 to 0.866% and for 1%additon of nanosilica the weight was found to be 8.02kg and the rate of water absorption was from 0 to 0.510% for 48 hours. The total quantity of water absorbed is related to the total open porosity, while the kinetics of the process depends principally on the distribution of the pore sizes. The smaller the diameter of the pores, the greater will be the capillary absorption. Absorption is the capacity of a sample to hold water while capillary is the rate at which the water fills the sample.

9. Porosity

Porosity of concrete is usually determined by dividing the volume of voids of the sample by its bulk volume. Bulk volume of each sample is determined using the measured lengths and diameters of the samples. Volume of voids for each sample is determined by subtracting its grain volume (the volume of the solid portion of concrete excluding the volume of pores) from its bulk volume. Total porosity therefore considers both permeable and impermeable voids whereas apparent porosity considers only impermeable voids.

Table 10- Porosity for M30 grade SCC mix

Parameters	Conventional SCC M30	M30 grade	
		0.5% nS	1% nS
Ma(kg)	8.00	8.01	8.03
Mb(kg)	8.13	8.10	8.08
Mc(kg)	8.10	8.06	8.05
Md(kg)	6.0	5.8	5.6
g1(kg/m3)	3809.5	3544.24	3277.5
g2(kg/m3)	4000	3624.43	3304.52
Water absorption capacity (%)	1.625	1.12	0.622
Volume of permeable voids (%)	5.00	2.212	0.81
Apparent porosity (%)	6.9	3.91	2.01

Table 11- Porosity for M50 grade SCC mix

Parameters	Conventional SCC M50	M50 grade	
		0.5% nS	1% nS
Ma(kg)	8.00	8.01	8.02
Mb(kg)	8.08	8.07	8.06
Mc(kg)	8.06	8.05	8.03
Md(kg)	5.8	5.5	5.0
g1(kg/m3)	3539.8	3141.17	2646.86
g2(kg/m3)	3636.36	3191.23	2655.62
Water absorption capacity (%)	1.00	0.749	0.498
Volume of permeable voids (%)	2.655	1.55	0.32
Apparent porosity (%)	4.347	2.713	0.98

Based on the test results presented in table 10 and 11, the apparent porosity percentage for M30 conventional grade is about 6.9% and on additional of 0.5% and 1% of nanosilica by weight of the powder the apparent porosity percentage was found to be 3.9% and 2.01%. M50 grade conventional concrete the apparent porosity percentage was 4.34% and on incorporating of 0.5% and 1% of nanosilica by weight of powder the apparent porosity is evaluated as 2.7% and 0.98%. Addition of nanosilica will enhance compressive strength in early days. For optimum percentage of nanosilica the decrease in the percentage of water absorption capacity for M30 and M50grade is 53.26% and 58.53% this is due to plugging of the pores present in the concrete with nanosilica particles ensuing minimum interconnecting voids. Concrete specimens incorporated with nanosilica showed significantly less water absorption capacity compared to controlled specimens.

The absorption characteristics indirectly represent the volume of pores and their connectivity. Porosity of concrete specimens for M30 and M50 is reduced by nearly 70% and 78% with induction of Nano-silica into SCC specimens. The possible reason for this is nanosilica particles in the pores reduced the average pore radius of concrete. The rate of water absorbed into concrete through the pores gives important information about the microstructure and permeability characteristics of Cement mortar specimens.

A study of relevant papers show that concrete blended with nanoSiO_2 sets quicker compared to normal concrete. Since, the mix design is carried out without the aid of supper-plasticizers, the mix dried up fast which affected the compaction of the mix using mechanical vibration. Lumps of the mix could be seen during the mixing of concrete. With increase in percentage of nanoSiO_2 the compaction gets tougher. This is the reason for degradation in its quality. It is advisable to use super-plasticizers with nanosilica.

The current work has many limitations which are mentioned below:

I. The percentage of nanosilica is restricted to 1% due to workability issues which does not give a complete idea about the maximum amount of nanosilica that can be added to get an increase in strength.
ii. Without the use of super plasticizers a proper compaction of the concrete was hindered. Partial substitution of cement by comparatively smaller sized nanosilica particles enhance the packing of the particles by occupation of the voids in the matrix and reduce the flow due to their stabilizing effect. The voids left unoccupied even by microsilica particles are occupied by nanosilica particles because of their ultrafine size and filler effect.

10. CONCLUSIONS

Based on the discussions on the test results reported in this project work and the key findings during the experimental investigations, the following conclusions are drawn:

1. The optimum dosage of nanosilica to be used in M30 and M50 grade self-compacting concrete is determined to be 1% and 0.5% respectively by weight of the total powder.
2. Due to the addition of nanosilica, the initial setting and the final setting time of nanosilica based cementitious materials are observed to be reduced.
3. Due to the enhanced pore refinement of the nanosilica, The compressive strength of the concrete is increased by 28.46% for M30 and 29.84% by addition of nanosilica of 0.5% and 1% for M50 by weight of powder respectively. The addition of nanosilica a improves the hydrated structure of the concrete by modifying the concrete pore structure by plugging the voids or the nanopores within cement – sand mix matrix by nanosilica particles.
4. Addition of nanosilica into the self-compacting concrete causes the reduction in the water absorption and the porosity by 53.26% and 70% for M30 grade and 58.53% and 78% for M50 grade respectively which could in turn increases the durability of the cementitious structures significantly.
5. So, it can be concluded that with the addition of nanosilica there is significant increase in compressive strength, and decrease in the water absorption capacity and porosity due to pore refinement by nanosilica particles plugging the concrete.

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