Influence of Nanosilica on Properties of Ternary Blended Concrete

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Abstract— **Nanosilica is a nano product by its addition in concrete leads to the improvement of performance of concrete. This study investigates mechanical and durability properties of colloidal nanosilica on concrete incorporating cement and silica fume. In this study five different mixes are prepared, one is the control mix, the other four mixes are prepared by replacing cement by 10% of silica fume (kept constant) and varying the percentage of nanosilica in 0%, 1%, 2% and 3% of the total weight of cementitious materials. The properties of these mixes are found out using various laboratory test and compared with a control mix (M30) without any supplementary cementitious material. It is found that mechanical, and durability properties are getting improved by the addition of nanosilica. From the test results, it is concluded that the mix containing 2% nanosilica and 10% silica fume gives optimum values for various properties.**

Keywords - nanosilica; silica fume; ternary blended concrete; mechanical properties; durability properties.

I. INTRODUCTION

In the modern age of concrete design, concrete researchers and developers are taking advantage of secondary cementitious materials to give concrete greater strengths. One of the newest technologies to break into the concrete design area is the use of pozzolanic nanoparticles in the concrete matrix. Nanotechnology is one of the most promising research fields that may significantly improve the mixture design, as well as the performance and production of cement-based materials. The properties of concrete exist in, and the degradation mechanisms occur across, multiple length scales (nano to micro to macro) where the properties of each scale derive from those of the next smaller scale. The concrete at the nanoscale is a composite of molecular assemblages, surfaces (aggregates, fibers), and chemical bonds that interact through local chemical reactions, intermolecular forces, and intra phase diffusion. The properties and processes at the nanoscale define the interactions that occur between particles and phases at the microscale and the effects of working loads and the surrounding environment at the macro scale. Nanoparticles can act as nuclei for cement phases, further promoting cement hydration due to their high reactivity, as nano reinforcement, and as filler, densifying the microstructure, leading to a reduced porosity. The most significant issue for all nanoparticles is that of effective dispersion. **Maheswaran *et al.* (2013)** presented the influence of nanosilica in concrete and its application for the development of sustainable materials in the construction industry. They studied the pore filling effect and its pozzolanic activity with cement towards improvement of mechanical properties. **Siva Sai *et al.* (2013)** studied the mechanical properties of M60 and M70 concrete with the use of micro silica and in combination with colloidal nano-silica. Concrete composites with superior properties can be produced with the combination of micro-silica and nano-silica **Kontoleontos. F *et al.* (2012)** studied the influence of colloidal nanosilica on an ultrafine cement in terms of physicomechanical and microstructure properties. Nanosilica improves the cement microstructure and as a promoter of pozzolanic reaction by transforming portlandite into calcium silicate hydrate gel. **Said A.M *et al.* (2012)** investigated the effect of colloidal nanosilica on concrete incorporating single and binary binders.Significant improvement in terms of reactivity, strength development, refinement of pore structure and densification of interfacial transition zone. Micro-structural and thermal analyses indicated contribution of pozzolanic and filler effects to the pore structure refinement depended on the dosage of nanosilica. From literature review it is found that 10 percentage replacement of cement by silica fume in concrete shows better performance regarding to mechanical properties.

II. EXPERIMENTAL PROGRAM

A. Materials

Ordinary Portland cement (OPC) conforming to IS 12269 (53 Grade) was used for the experimental work. The main properties of the cement used are its specific gravity 3.15 and fineness 4%. The nano-silica used was in colloidal form with 30.50% SiO_2 content. The mean particle size of the nanosilica was 17 nm, specific gravity 1.214, pH 9.78 and specific surface area 160 m^2/gm. Corniche SF" brand Silica fume conforming to IS 15388 was used for the study. Locally available good quality M sand was used. Laboratory tests were conducted on fine aggregates to determine the different physical properties as per IS 383 (Part III)-1970. The fine aggregate has fineness modulus 3.076 and specific gravity 2.50. Fine aggregate used conforms to IS 383:1970 specification (Zone II). Laboratory tests were conducted on coarse aggregate to determine the different physical properties as per IS 383 (Part III)-1970. The coarse aggregate has a fineness modulus 7.119 and specific gravity 2.80. Potable water was used for casting as well as curing. The superplasticizer used was Ceraplast-300 and is Naphthalene Formaldehyde based.

B. Mix Design

The mix design for concrete having characteristic compressive strength 30 N/mm^2 (mainly used for ordinary purposes) was done using IS: 10262-2009 and mix proportion is shown in Table 1. In this study 5 different mixes were prepared. One is control mix and other four concrete mixes by replacing cement by 10% silica fume (kept constant) and varying nanosilica in 0%, 1%, 2% and 3% of the total weight of cementitious materials. The various mix designation are shown in Table 2.

TABLE 1: DETAILS OF MIX (M30)

Materials	*Proportion*	
Cement (kg)	390.00	1
Fine aggregate(kg)	656.00	1.68
Coarse aggregate(kg)	1178.60	3.022
Water (kg)	172.70	0.43
Superplasticizers(kg)	0.145	0.50
w/c ratio	0.43	

TABLE 2: MIX DESIGNATION

Mix Designation	*Cement (%)*	*Nanosilica (%)*	*Silica Fume (%)*
CM	100	0	0
NS0	90	0	10
NS1	89	1	10
NS2	88	2	10
NS3	87	3	10

C. Test Specimens

Cubes of standard size 100 mm × 100 mm × 100 mm, cylinders with 150 mm diameter × 300 mm height and prisms of size 100 mm × 100 mm × 500 mm were prepared using the standard moulds. The samples were demoulded after 24 hr of casting and kept in a water tank for 28 days curing. Specimens werere cast for testing the mechanical and durability properties. Mechanical properties such as compressive strength, split tensile strength, flexural strength, modulus of elasticity and impact resistance and durability properties such as resistance to sulphate attack, resistance to acid attack and resistance to chloride attack were studied.

III. RESULTS AND DISCUSSIONS

A. Properties Of Fresh Concrete

The workability of various mixes was assessed by determining the slump value and compacting factor as per the IS 1199:1959 specification. Fig.1 and Fig.2 show the values of slump and compacting factor for various mixes of concrete. The values show that workability decreases as percentage of nanosilica increases. Since nanosilica has large effective surface, it absorbs too much of water and thus reduces workability of concrete. It may be due to the fine size of nanosilica, it fill the complete voids in the concrete and decreases the flowability of the mix. This would also increase the concrete's shear strength against the flow of concrete. Mixes with small percentage of nanosilica has greater workability compared to the mixes with higher percentage of nanosilica. Reduction in bleeding was found in mixes with nanosilica. Hence, it can be stated that adequate quantities of superplasticizers are to be added when admixtures like nano silica, silica fume are used along with cement in concrete mixes. While using the nano silica solution in concrete the original water cement ratio of concrete mix is to be corrected by the amount of water available in nano silica solution.

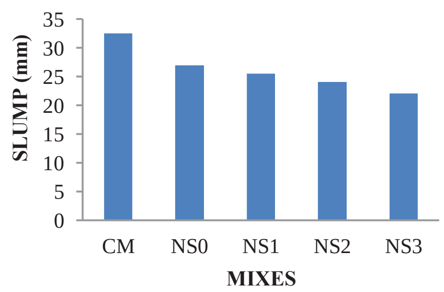


Fig.1 Slump values

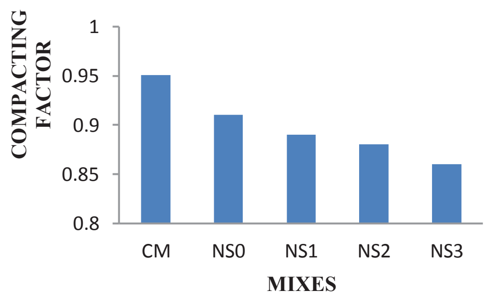


Fig. 2 Compacting factor

B. *Mechanical Properties of Hardened Concrete*

1) Compressive strength

Fig. 3 shows the variation of cube compressive strength. Fig. 4 shows the cube compressive strength for mixes at different ages. Fig. 5 shows the variation of cylinder compressive strength at 28 days. It shows that as percentage of nanosilica increases up to 2%, the compressive strength of NS mixes also increases. NS2 shows better compressive strength than other mixes. It shows an increase in compressive strength of 26.25% than the control mix. Increase in compressive strength with the addition of nanosilica is due do its high pozzolanic activity. Nanosilica, due to its high specific surface, is so reactive, and produces C-S-H condensed gel as a result of reaction with $Ca(OH)_2$. High-strength dense gel C-S-H, which is a product of pozzolanic reaction increases the density of transition region/ area by filling empty spaces and thus increases the strength. Increased dosage of nanosilica decreases compressive strength of concrete because nanosilica particles, due to their high surface energy, have a pronounced tendency towards agglomeration. The dispersion of nanoparticles within the cement paste is a significant factor governing the performance of these products. When nanoparticles are added in excess to the mixture, these are not uniformly dispersed in the cement paste, and as a consequence weak areas appear in the concrete due to agglomeration. Another reason is that the amounts of nanosilica in the mixtures can also have been exceeded the quantity required for consuming the $Ca(OH)_2$ and this excessive amount of silica did not contribute to enhance the compressive strength. In general, the improvement in the mechanical properties for the mixtures incorporating nano-silica can be ascribed to the pozzolanic and filler effects of nano-silica.

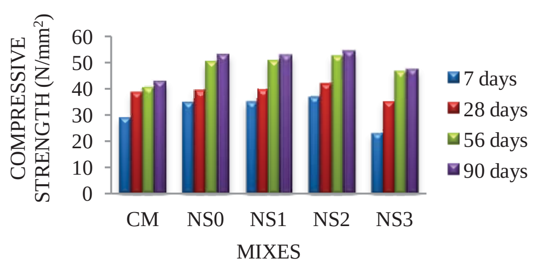


Fig. 3 Variation of cube compressive strength

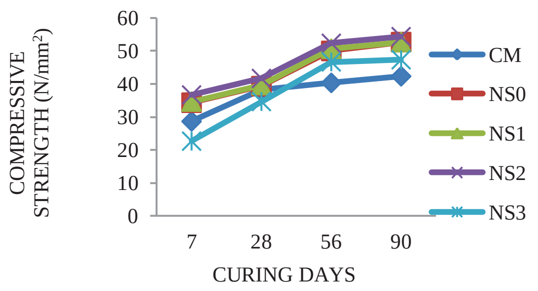


Fig.4 Variation of cube compressive strength with curing days

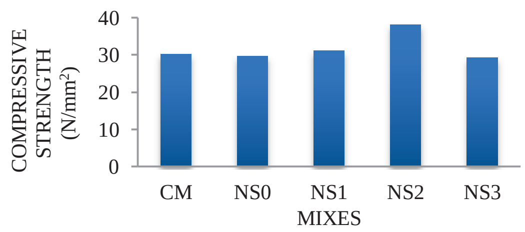


Fig. 5 Variation of cylinder compressive strength

2) Split Tensile Strength Test

For each mix, cylinder specimens of size 150mm × 300mm were tested for determining the split tensile strength. Split tensile test was done after 28 days of water curing. Fig.6 shows the variation of split tensile strength. It shows that as percentage of nanosilica increases up to 2%, the split tensile strength of mixes also increases. Further increase in percentage of nanosilica in mixes shows a reduction in the split tensile strength. NS2 mix shows 5.3% increase in split tensile strength than control mix. The higher split tensile strength for mixes with nanosilica may be due to the additional binding property of finely divided nanosilica because of high pozzolanic reaction and cement paste – aggregate interfacial refinement leading to higher bond strength. Higher dosage of nanosilica (3%) shows a reduction in split tensile strength.

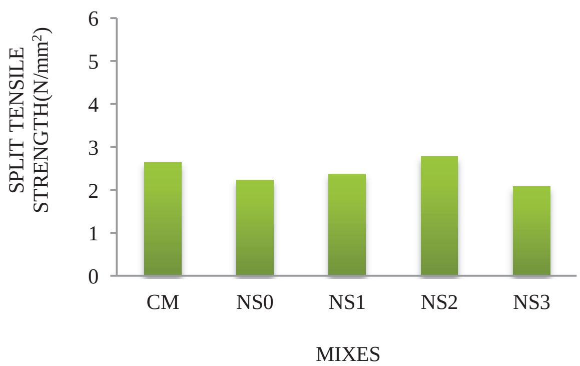


Fig.6 Variation of split tensile strength

3) Modulus of elasticity

The Young's modulus values are computed from stress-strain diagram obtained by carrying out the test on 150mm × 300mm cylinder specimens. From the load and deformation obtained in the test, stress-strain diagram was drawn and young's modulus was found out. Fig.7 shows the modulus of elasticity for the mixes. NS2 mix shows 6.02% increase in modulus of elasticity than that of control mix. Variation of Modulus of elasticity was similar to that of the 28 day compressive strength.

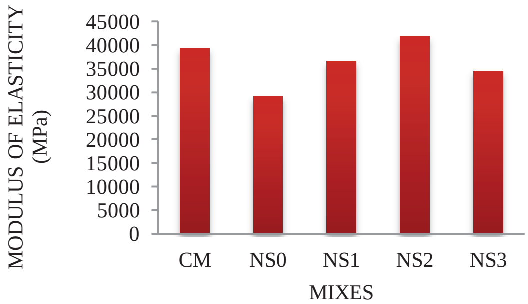


Fig.7 Modulus of elasticity for the mixes

4) Flexural Strength test

For determining flexural strength of mixes, beam specimens of size 100mm×100mm×500mm were used. Testing was done after 28 day water curing. Fig.8 shows the variation of flexural strength. It shows that as percentage of nanosilica increases up to 2%, the flexural strength of mixes increases. Further increase in percentage of nanosilica in mixes shows a reduction in the flexural strength. The mix NS2 shows 1.97% increase in flexural strength than that of control mix. Flexural strength assessments demonstrated that having filler and pozzolanic effects, nanosilica can improve the structural properties and adhesive of the cement matrix-fibres and mortar–aggregates interfaces area.

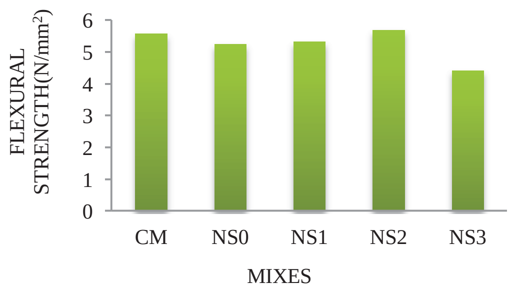


Fig. 8 Flexural strength for the mixes

5) Impact test

Dynamic energy absorption or strength is called as impact resistance and is one of the major attributes of concrete. Drop weight test was conducted in order to determine the number of blows required to produce a crack and ultimate failure on the specimen. Three specimens were tested for each mix. The resistance offered by the concrete was found out using this test. To determine the impact resistance of concrete no. of blows for the first crack and ultimate failure of specimens were determined. The resistance offered by the concrete was found out using this test. Fig.9 shows the variation of impact resistance for mixes. Higher impact resistance may be due to the higher degree of pore refinement because of finer particle size of nanosilica and additional binding property due to high pozzolanic reaction resulting in a denser concrete mix with finer pore structure there by increasing the dynamic energy absorption capacity of the mix. Decrease in impact strength with high dosage may be due to agglomeration of nano particles.

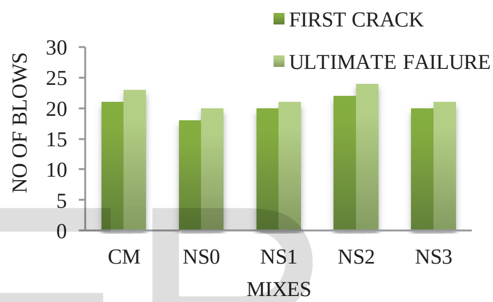


Fig.9 Variation of impact resistance

C. Durability Properties of Hardened Concrete

For a concrete to withstand in this environment without any loss in strength with ages is an important aspect. Durability study of concrete is very important for controlling the quality of any concrete structure. Based on durability aspect sulphuric acid attack test, sulphate attack test, bulk diffusion test and rapid chloride permeability test were conducted.

1. Sulphuric acid attack test

Strength Loss

Cube specimen of size 100mm×100mm×100mm was used for this test. The cube specimens were exposed to 3% sulphuric acid solution after 7 days of water curing. Compressive strength was determined after 56 and 90 day acid curing. Fig.10 shows the compressive strength variation of mixes under 90 days exposed to acid environment. Fig.11 shows the compressive strength variation for mixes under 56 days exposed to acid environment. Fig. 12(a) and Fig.12(b) shows the strength loss variation under 56 days and 90 days exposed to acid environment respectively. All mixes exposed to acid environment shows reduction in strength compared to that of strength of specimens under water curing. The reduction in strength during acid exposure may be due to the reaction of sulphuric acid with free lime $Ca(OH)_2$ in cement paste forming gypsum ($CaSO_4.2H_2O$). This reaction is associated with an increase in volume of the concrete. Another destructive action is the reaction between calcium aluminate present in cement paste and gypsum crystals producing ettringite (calcium trisulphoaluminate). These are very expansive compounds producing internal pressure in the concrete, which leads to formation of cracks. Because of this reaction surface become soft and white and concrete structure losses its mechanical strength. Reason for less strength loss in nanosilica replaced concrete is because during the hydration reaction nanosilica reduces the amount of $Ca(OH)_2$. So formation of expansive components will be less compared to that of control mix. It can be seen that strength loss is maximum in control mix. Reduction in strength loss is seen with increasing nanosilica content up to 2% in mixes. NS2 shows a strength loss of 17.20% and 30.66% under 56 days and 90 days acid exposure than control mix. By comparing the compressive strength at 56 day and 90 day acid exposure it can be seen that the rate of strength loss was less for nanosilica mixes than that of the control mix.

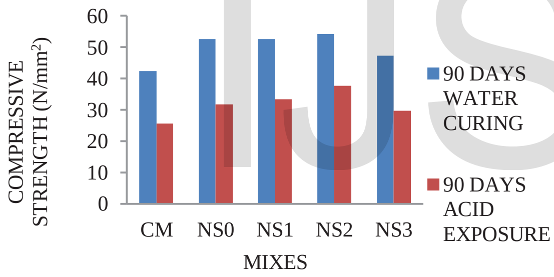


Fig. 10 Effect of acid attack (90 days acid exposure)

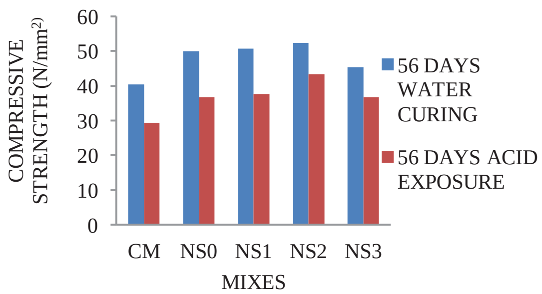
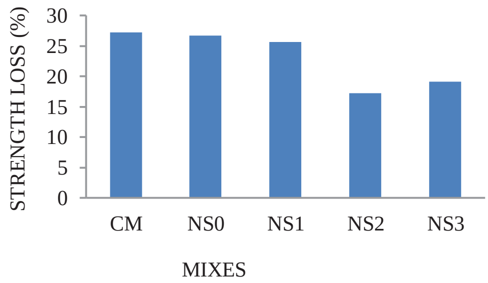
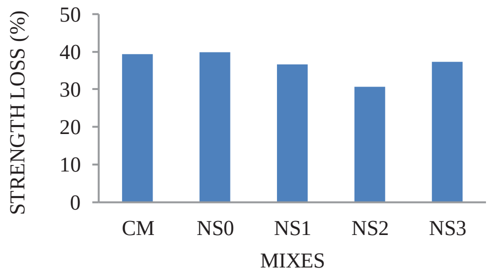


Fig. 11 Effect of acid attack (56 days acid exposure)



a) 56 days acid exposure



b) 90 days acid exposure
Fig. 12 Percentage of strength loss

Mass Loss

Percentage mass loss of concrete cubes exposed to 3% Sulphuric acid solution (after 7 day water curing) was found out at 56 and 90 days. Variation in mass loss of mixes subjected to sulphuric acid is shown in Fig.13. Mass loss variation shows that as percentage of nanosilica increases mass loss reduces. From the experimental investigation it is clear that the percentage of mass loss is maximum for the ordinary mix compared to all other mix. For all nanosilica mixes the percentage of mass loss decreases with increase in the percentage of nanosilica. It can be attributed to the high specific surface area of nanosilica which results in greater pozzolanic activity. Concrete with nanosilica shows good resistance against acid attack. NS3 shows less percentage of mass loss than all other mixes.

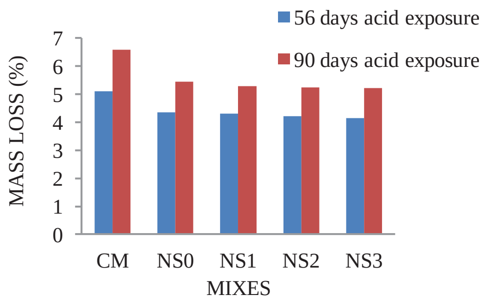


Fig.13 Percentage of mass loss

2. Sulphate attack test

Strength Loss

Cube specimen of size 100mm×100mm×100mm was used for this test. The concrete cubes were found visually intact after immersion of cubes in 20,000ppm (52gm $MgSO_4 7H_2O$ in one liter solution) sulphate solution for 56 and 90 days after 7 days of water curing. After exposure to sulphate solution, white patches were found on the surface of concrete specimens. This white precipitation layer was significant in control specimens (with cement as the only binder). Compressive strength was determined after 56 and 90 day acid curing. Fig.14 shows the compressive strength variation for mixes under 56 days exposed to acid environment. Fig.15 shows the compressive strength variation for mixes under 90 days exposed to acid environment. Fig.16 (a) and Fig.16(b) shows the strength loss variation for mixes under 56 days and 90 days exposed to acid environment. From this study it is observed that when the concrete specimen is immersed in 20000ppm solution the cube compressive strength of all the mixes get reduced slightly as the duration of sulphate exposure increases. The reduction in strength may be due to the reaction of sulphates with free lime and calcium aluminate compounds in concrete to form gypsum and ettringite that can cause internal disruption of concrete by volume increase of paste. From the figures it is clear that compared to all other mixes the strength loss is maximum for the CM mix than other mixes. Comparing the strength corresponding to 56 and 90 day sulphate exposure the percentage of strength loss was found to be minimum for NS2 mix for 7 day curing condition. By the addition of nanosilica the sulphate resistance of concrete mix was improved.

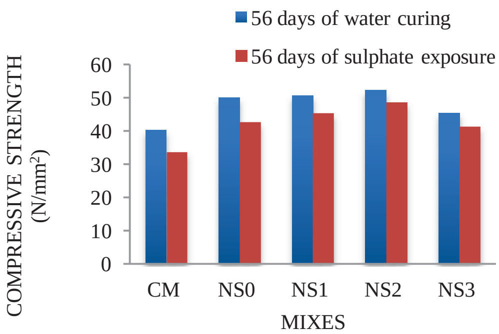


Fig. 14 Effect of sulphate attack (56 days acid exposure)

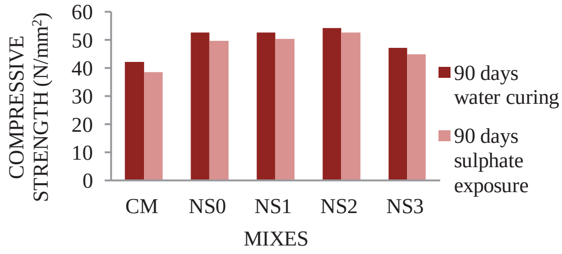
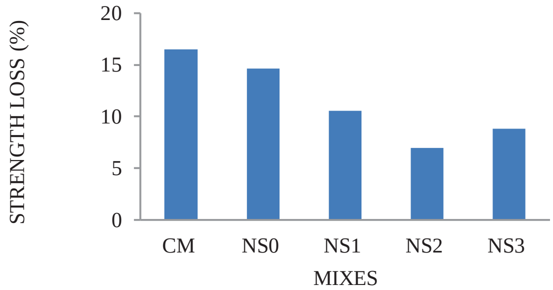
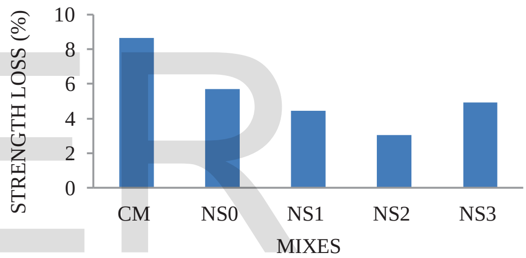


Fig.15 Effect of sulphate attack (90 days acid exposure)



a) 56 days sulphate exposure



b) 90 days sulphate exposure

Fig. 16 Percentage of strength loss

Mass Loss

Fig.17 shows percentage of mass loss for various mixes. From the figure it can be seen that percentage mass loss decreases with increase in nanosilica content. Incorporation of nano silica decreases the percentage of mass loss compared to that of control mix. From the experimental investigation it is clear that the percentage of mass loss is maximum for the control mix compared to all other mix. For all nanosilica mixes the mass loss percentage decreases with the increase in the percentage of nanosilica. It can be attributed to the high specific surface area of nanosilica which results in greater pozzolanic activity. Concrete with nanosilica shows good resistance against sulphate attack. NS3 shows minimum percentage of mass loss in all the mixes.

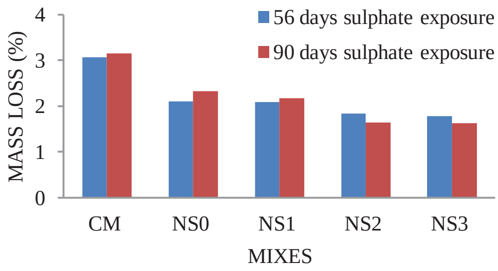


Fig.17 Percentage of mass loss

3. Bulk Diffusion Test

The test was carried out to determine the depth of penetration of chloride ions. Depth of penetration of chloride ions was found out by spraying 0.1M $AgNO_3$ solution to the split face of the cylinder exposed to 1.8 M NaCl solution. A white precipitation will form up to the penetrated depth of chloride ion. After 7 days of water curing, the concrete specimens were exposed to NaCl solution for 56 days and 90 days. The depth of penetration of chloride ions is measured in millimetre. Variation in the depth of penetration of chloride ions in mixes are shown in Fig.18. Chloride induced reinforcement corrosion is the main durability problem for concrete structures in marine environment. If the chlorides reach the reinforcement steel, it will de-passivate and start to corrode in presence of air and water. Since the corrosion products have a larger volume than the initial components, stresses are induced in concrete, leading to spalling and degradation of the concrete structures. By measuring the depth of penetration of chloride ions we can determine the resistance of concrete to chloride attack. With small dosage of nanosilica itself, the depth of penetration decreases. Finer porosity, greater tortuosity and more precipitated C-S-H gel decrease the mobility of the chloride ions into the concrete pores. By the addition of nanosilica, chloride ion penetration can be considerably reduced. The fine particles of nanosilica form a layer around the reinforcement and protect it from chloride attack. When nanosilica dosage increased considerably chloride ion penetration increases due to the agglomeration of nanoparticles. Depth of penetration is minimum in the mix NS2.

Chloride diffusion coefficient (m^2/s) was found out using depth of penetration of chloride ions by using the equation $D=X_d^2/16t$ where X_d-the chloride penetration depth in meter, t -The time of exposure in seconds, and D – Chloride diffusion coefficient in m^2/s. Fig.19 shows the variation of chloride diffusion coefficient in mixes. Chloride diffusion coefficients of all mixes with nanosilica under 56 days exposure are less than 1×10^{-12} m^2/s. It shows that all the mixes with nanosilica show low permeability (56 days exposure). As age increases up to 90 days NS2 shows low permeability and other mixes show average chloride ion permeability.

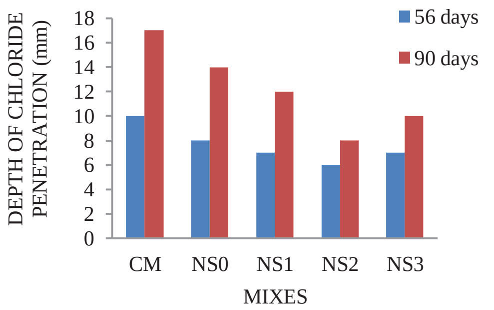


Fig.18 Penetration of chloride ions

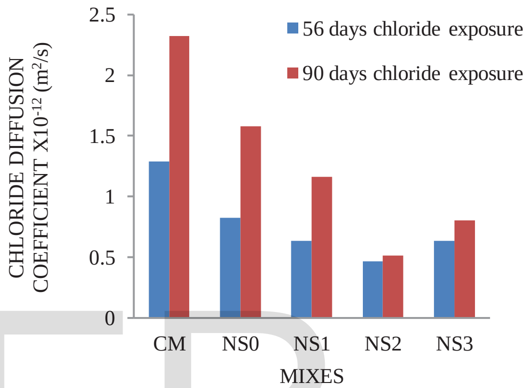


Fig.19 Chloride diffusion coefficient

4. Rapid Chloride Permeability Test

Specimen of size 150mm diameter and 50mm thickness was used for RCPT test after 90 days of water curing. Fig.20 shows the charge passed in mixes. Due to the microstructure improvement, especially the fact that the connectivity of the pore system can be blocked where the agglomerates filled, chloride penetration resistance of the concrete was also improved by adding nano-silica. It can be seen that by incorporating nanosilica, chloride ion penetration decreases. This property can be attributed to the high activity of nanosilica in reaction with calcium hydroxide (which is low-resistance to chemical attacks). Chemical reactions product is calcium silicate hydrate, which is compacted and so improves the microstructure of concrete against chloride ion penetration and reduces the associated corrosion in concrete. This property could maintain the chloride ion penetration value at the low level of 100–1000 Coulomb. Increase in charge passed after optimum dosage of nanosilica is due to agglomeration of nanoparticles.

TABLE 3 TOTAL CHARGE PASSED IN DIFFERENT MIXES

MIX	*Total charge passed (Coulomb) 90 day*	*Penetrability class (ASTM C 1202)*
CM	1059.30	Low
NS0	864.99	Very low
NS1	316.53	Very low
NS2	205.11	Very low
NS3	254.52	Very low

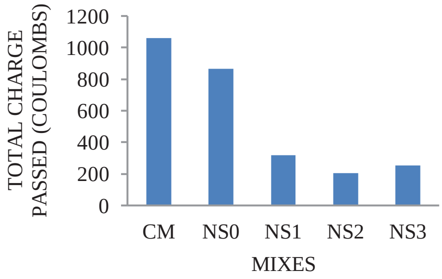


Fig.20 Total charge passed

IV. CONCLUSIONS

From the present experimental investigation the following conclusions are arrived at.

- Workability of concrete containing silica fume and nanosilica shows decrease in workability with increase in the percentage of nanosilica. But in all NS mixes slump value and compacting factor value are found to be less than that of control mix.
- The mechanical properties such as compressive strength, flexural strength, split tensile strength, and modulus of elasticity gets improved due to the addition of nanosilica up to 2% and shows reduction in properties on further increase in percentage of nanosilica.
- There is only a marginal improvement in impact resistance for NS2 mix than control mix.
- The durability properties such as resistance to sulphate attack, resistance to acid attack, and resistance to chloride attack gets improved due to the addition of nanosilica up to 2% and shows reduction in properties on further increase in percentage of nanosilica.
- The reduction in compressive strength was found to be minimum for NS2 mix compared to control mix and other NS mixes. The percentage mass loss reduces with the addition of nanosilica; but as dosage of nanosilica increases there is not much change in the percentage mass loss, when subjected to sulphuric acid and sulphate solution.
- The depth of penetration of chloride ions under 56 and 90 days exposure is less for all NS mixes than control mix. NS2 shows least value than other NS mixes.
- Chloride diffusion coefficient is very low in all NS mixes.
- The chloride penetrability rating for all NS mixes was found to be very low while control mix shows low chloride penetrability rating.

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