

Impact of nano silica on strength and durability properties of self-compacting concrete



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ABSTRACT

This paper reflects self-compacting concrete which is developed using modified Nan-Su mix design. Slump flow, J-Ring, V-funnel tests are conducted to justify the fresh properties of SCC and are checked. Cubes of 150x150x150mm size casted in which 15 cubes are SCC without Nano silica and 15 cubes are of each 1 %, 1.5% and 2% of Nano silica (colloidal state with 16% and 30% Nano content). In order to get relative idea about the compressive strength and durability properties of SCC, axial compression test on cubes for 7 days and 28days of curing in water were done and also cubes were immersed in 5% HCl and 5% H₂SO₄ respectively. Sorptivity test has also been conducted to assess durability of SCC. Test results indicate that use of Nano Silica in SCC has improved the performance of SCC in strength as well as in durability.

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1. Introduction

Self-Compacting Concrete (SCC) is considered as a new generation of concrete, which has generated tremendous interest in construction industry. SCC was first introduced in late 1980's by Japanese Researcher to reach durable concrete structures. According to [Okamura and Ouchi \(2003\)](#) SCC can be compacted into every corner of a formwork by means of its own weight. Okamura in 1986 started a research project on the flowing ability and workability of this special type of concrete, later called SSC. In 1989, [Ozawa et al. \(1989\)](#) succeeded in developing SCC for the first time. The year after that, an open experiment on the new type of concrete was held at the University of Tokyo, in front of more than 100 researchers and engineers. As a result, intensive research has begun in many places, especially in the research institutes of large construction companies and the University of Tokyo.

Even with difficult casting conditions SCC can be used for placing in congested reinforced concrete structures. It ensures proper filling and good structural performance of heavily reinforced structural members, for such applications, the fresh concrete must possess high fluidity and at the same

time, cohesive enough to be handled without segregation or bleeding.

SCC development is a desirable achievement in the construction industry in order to overcome problems associated with cast-in-place concrete. The other advantages of SCC are:

- Not affected by the skills of workers.
- The shape and amount of reinforcing bars or the arrangement of a structure.
- It can be pumped longer distances.
- Shorten construction period.
- Assures compaction in the structures especially in the confined zones where vibration and compaction is difficult.
- It provides high stability during transport and placement.
- It provides uniform surface quality and homogenous.
- It provides greater freedom for design.
- It is useful for casting of underwater structures.

1.1. Nano materials

The Nano materials can improve vital characteristics of construction materials such as strength, durability, and lightness, endow useful properties (e.g., heat-insulating, self-cleaning, and antifogging), and function as key sensing components to monitor construction safety and structural health.

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1.2. Nano-silica

The particle packing in concrete can be improved by using Nano-silica which leads to densifying of the micro and nanostructure resulting in improved mechanical properties. Li et al. (2004) studied the effect of nano silica addition on concrete water permeability and microstructure. Different concrete mixes were evaluated incorporating nano silica particles of 10 to 20 nm (s.s.a. of 160 m²/g), fly ash, gravel and plasticizer to obtain the same slump time as for normal concrete and nano silica concrete. The test results show that nano silica can improve the microstructure and reduce the water permeability of hardened concrete. Ji demonstrated that nano silica can react with Ca (OH)₂ crystals, and reduce the size and amount of them, thus making the interfacial transition zone (ITZ) of aggregates and binding cement paste denser. The nano silica particles fill the voids of the CSH-gel structure and act as nucleus to tightly bond with C-S-H-gel particles. This means that nano silica application reduces the calcium leaching rate of cement pastes and therefore increasing their durability.

Nano-silica addition to cement based materials can also control the degradation of the fundamental C-S-H (calcium-silicate-hydrate) reaction of concrete caused by calcium leaching in water as well as block water penetration and therefore lead to improvements in durability.

Nano-Silica (NS) is the first nano product that replaced the micro silica. It has a specific surface area near to 1,00,000 m²/kg (micro silica has only 20,000 m²/kg) and a particle size of 5 nm to 250 nm. Nano Silica (NS) can contribute to efficient 'Particle Packing' in concretes by densifying the micro and nanostructure leading to improved mechanical and durability properties.

As the strength and behaviour of SCC is a function of the aggregate characteristics and mineral as well as chemical admixture content, there is a need to reinvestigate proportion of mineral and chemical admixtures that would result in optimized performance of SCC. The combined use of cement, nano silica (NS), and superplasticiser (SP) on durability of SCC is assessed by conducting, water absorption, sorptivity and immersion in acid (5% HCl and H₂SO₄) test (EFNARC, 2005). Their research work presents the results of a comparative study of the sorptivity, accomplished in mixtures of SSC with different types of additions and a normal concrete compacted by vibration. The study of Bassuoni and Nehdi (2009), aimed at investigating the resistance of a variable range of SCC mixture designs to sulphuric acid attack.

2. Experimental investigation

2.1. Materials used

The different materials used in this investigation are:

- Cement: the cement used in present work is 53 grade cement confirming to IS: 12269. The specific gravity of cement used is 3.10. The cement produced from, the same constituent has been throughout the experimental program. The initial setting time is 30min.
- Fine aggregate: river sand and local sand confirming to IS 383, Zone 2 sand has been used in this experimental program. Specific gravity of fine aggregate is 2.62.
- Coarse aggregate: machine crushed granite confirming IS 383 and IS 2386, has been used in this experimental program. Specific gravity of coarse aggregate is 2.82.
- Water: potable water is used in this investigation.
- Chemical admixture (conplast SP430): high range water reducing admixtures known as super plasticizers are used for improving or workability for decreased water-cement ratio without decreasing the compressive strength. Conplast SP430 combines the properties of water reduction and workability retention. It allows the production of high performance concrete and/or concrete with high workability.
- Fly ash: fly ash confirming to IS 3812:1981 is used as mineral admixture. Mineral admixtures are used to improve the fresh and hardened properties of concrete and at the same time reduce the cost of concrete materials. In order to achieve the necessary viscosity to avoid segregation, additional fine materials are used.

2.2. Properties of nano-sio2

In this study, two different types of suspended nano silica gel containing different percentages of active nano silica with 99.99% pure SiO₂ is used. The nomenclature followed for different nano silica gel is given in Table 1.

Specific gravity of each material varies from 1.08 to 1.32. Particle size of nano Silica varies between 5-40 nm. The pH of the solutions is between 9.3 and 10.4. The properties of different nano silica provided by the manufacturer are given in Table 1.

3. Introduction to experimental study

The experimental study consists of arriving at suitable mix proportions that satisfied the fresh properties of SSC as per EFNARC (2002) specifications. Standard cube moulds of 150mm x 150mm x 150mm made of cast iron were used for casting standard cubes.

The standard moulds were fitted such that there are no gaps between the plates of the moulds. If there are any small gaps they were filled with plaster of paris. The moulds were then oiled and kept ready for casting. After 24 hrs of casting, specimens were demoulded and transferred to curing tank wherein they were immersed in water for the desired period of curing. The Table 2 gives the details of the specimens used for the experimental study.

3.1. Mix design proportions

The Mix design is prepared for M40 grade of concrete for the experimental program and shown in the Table 3.

3.2. Acid attack study

An experiment was conducted on SCC with and without nano silica additions. Specimens were immersed in 5% solution of H₂SO₄ and 5% solution of HCl. These specimens were placed in plastic tub such a way that the clearance around and above the specimens is more than or equal to 30 mm. After an

interval of 7 days measurements were taken and the solution has been changed. Once the specimen has been removed for testing from the plastic tub, each specimen is brushed with soft nylon brush and rinsed in tap water. The response of the specimen after immersing in the solution was evaluated through change in compressive strength, weight, appearance, thickness and solid diagonals. For determining the resistance of concrete specimens to aggressive environment such as acid attack, the durability factors are proposed by the author, as described in ASTM C 666 – 1997, as the basis. ASTM C 666 – 1997 gives the standard test method for resistance of concrete to rapid freezing and thawing and the durability factors.

Table 1: Properties of nano-sio2

Notation for Nano Silica Gel	Active nano content (%wt/wt)	pH	Specific gravity
XLP	16.0	9.3-9.6	1.08-1.11
XTX	30.0	9.0-10.0	1.20-1.22

Table 2: Details of specimens cast

SCC with NS (30% Nano content)			SCC with NS (16% Nano content)			SCC (without NS)	Type of Concrete
2%	1.50%	1%	2%	1.50%	1%		% of NS added by BWOC added
15	15	15	15	15	15	15	No. of cubes cast

Table 3: Mix proportion

Mix	Cement (kg/m3)	Fly ash (kg/m3)	F.A (kg/m3)	C.A (kg/m3)	SP 430 ((lit/m3)	Water (lit/m3)	NS(colloidal) (kg/m3)
Normal SCC	468	353.05	946.72	794.48	19.7	244.71	-
NS.XLP (1%)	468	353.05	946.72	794.48	19.7	220.14	29.25
NS.XLP (1.5%)	468	353.05	946.72	794.48	19.7	207.86	43.87
NS.XLP (2%)	468	353.05	946.72	794.48	19.7	195.60	58.50
NS.XTX (1%)	468	353.05	946.72	794.48	19.7	229.11	15.60
NS.XTX(1.5%)	468	353.05	946.72	794.48	19.7	233.79	23.40
NS.XTX (2%)	468	353.05	946.72	794.48	19.7	222.87	31.20

In the present investigation, the author derived the “Acid Durability Factors” directly in terms of relative strengths. The relative strengths are always with respect to the 28 days value (i.e. at the start of the test). The “Acid Durability Factors” (ADF) can be designed as follows:

$$Acid\ Durability\ Factor\ (ADF) = Sr\ N / M$$

Where,

Sr = relative strength at N days, (%)

N = number of days at which the durability factor is needed.

M = number of days at which the exposure is to be terminated. Acid attack test was terminated at 28 days.

So, M is 28 in this case.

The extent of deterioration at each corner of the struck face and the opposite face is measured in terms of the solid diagonals (in mm) for each of two cubes and the “Acid Attack Factor” (AAF) per face is calculated as follows:

$$AAF = (Loss\ in\ mm\ on\ eight\ corners\ of\ each\ of\ 2\ cubes) / 4$$

The percentage weight loss and strength loss at 3,7,14, 21, 28 days.

3.3. Sorptivity study

The sorptivity tests were carried out on all batches of SCC with size of 15x15 x15cm, These specimens were kept in the oven for drying at a temperature 100 °C, it was stored until there was negligible weight loss. The test specimens were weighed and recorded before placing them in the recipient. Afterwards the specimens were placed in the recipient in contact with water level capable to submerge them about 5mm .After definite interval of time the specimens were removed, weighed and measurements recorded. Again these specimens were placed in the recipient for definite intervals of time and repeated for 15min, 30 min, 1 hour, 2 hour, 4 hours, 6 hours, 24 hours, 72 hours, 7 days, 14 days and 28 days.

Because of a small initial surface tension and buoyancy effects, the relationship between cumulative water absorption (kg/m²) and square root of exposure time (t^{0.5}) shows deviation from linearity during first few minutes. Thus, for the calculation of sorptivity coefficient, only the section of the curves for exposure period from 15 min to 72

hrs, where the curves were consistently linear, was used.

The sorptivity coefficient (k) was obtained by using the following expression:

$$\frac{W}{A} = k\sqrt{t}$$

Where,

W = the amount of water adsorbed in (kg);

A = the cross-section of specimen that was in contact with water (m²);

t = time (min);

k = the sorptivity coefficient of the specimen (kg/m²/min^{0.5}).

4. Discussion of test result

The results of various strength and durability tests are described here.

4.1. Effect of nano silica on compressive strength

Fig. 1 shows the details of Compressive Strength of SCC with and without nano silica. It is very much evident from the figure that there is only a steep increase in the compressive strength of SCC with nano silica concrete than without nanosilica. It can also be said that nano silica with 1.5% addition is optimum in both the grades of nano silica. Compressive strength of NS-XLP of 1.5% bwoc added in SCC is more compared to NS-XTX of 1.5% bwoc.

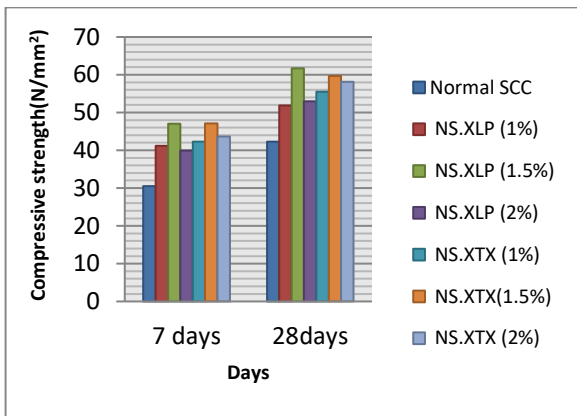


Fig. 1: Average compressive strength of SCC without and with nano silica

4.2. Acid attack

To study the resistance of with and without nano silica SCC, specimens were cured for 28 days and then immersed in 5% of H₂SO₄ and HCL respectively. This is the idea to test the influence of acids (H₂SO₄ & HCL) concrete. 12 cube specimens of 150*150*150mm were immersed in a tub. These tubs were kept covered throughout the tests to minimize the loss of evaporation. The chemical resistance was calculated by weight loss and compressive strength loss of the specimens. At the end of 7, 14, 21 and 28 days the weight loss is given by (W₂-W₁)/W₁ * 100 where, W₁ and W₂ are

weights of specimen (in grams) before and after the immersion of specimens in acid. In acid attack studies on nano silica additions in SCC, the effect of 5% H₂SO₄ and 5% HCL acid were studied. The various observations made are explained below.

4.2.1. Change in mass

The change in the mass of the specimens were observed and plotted against the number of immersion days in acids as shown in the following Figs. 2 and 3.

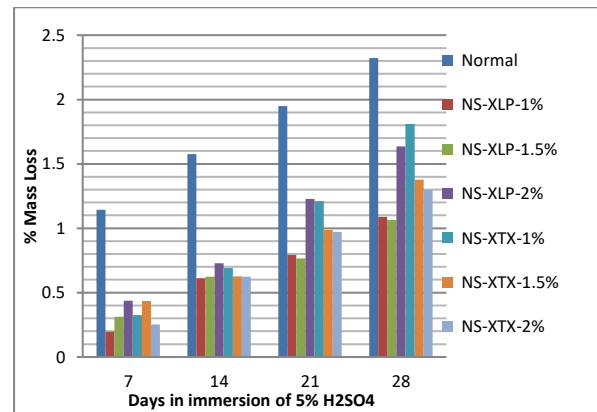


Fig. 2: % mass loss when immersed in 5% H₂SO₄

From the Fig. 2 it can be observed that specimens immersed in 5% H₂SO₄ for 28 days that the percentage of mass loss in normal SCC is more when compared to various percentages of nano silica additions.

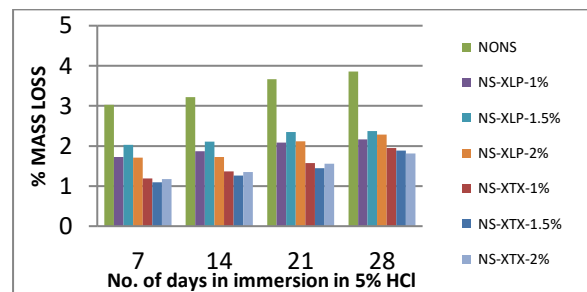


Fig. 3: % mass loss when immersed in 5% Hcl

From Fig. 3 it can be observed that the mass loss in normal SCC is more when compared to various percentages of nano silica addition. After 28 days of immersion Nano silica-XTX 2% has less percentage of mass loss in Hydrochloric acid.

4.2.2. Acid durability factor

The % loss of Compressive Strength and Acid Durability Factor (ADF) of the specimens were observed and plotted against the number of immersion days in acids as shown in the following Figs. 4, 5, 6 and 7.

From the Figs. 4, 5, 6 and 7 From the figures, the following observation are made:

- i. After 28 days of immersion in both the acid solutions percentage loss of compressive strength of 1.5 % Nano-XLP SCC is more when compared due to normal SCC.
- ii. Acid durability factor for cube immersed in 5% sulphuric acid is more for 1% Nano silica SCC of two grades. This implies that 1% addition is more durable when compared to other.
- iii. Acid durability factor for cube immersed in 5% Hydrochloric acid is almost same for all the specimens and but it is more for 2% Nano silica - XTX grade, also for 1% Nano silica SCC of two grades . This implies that 2% Nano silica SCC of XTX grade, 1% addition of both grades of nano silica is more durable in hydrochloric acid when compared to other.

It is observed that the percentage loss of compressive strength is more in sulphuric acid is more when compared to hydrochloric acid.

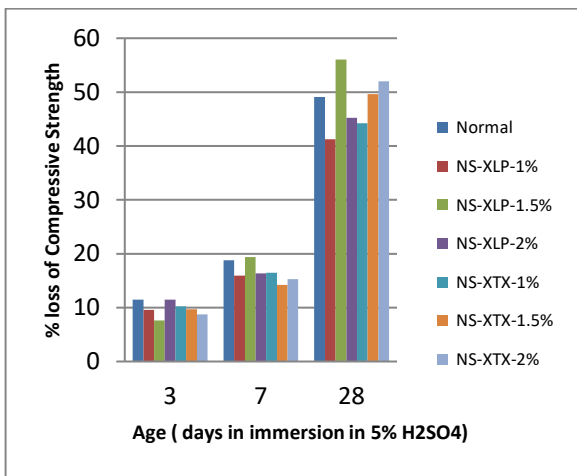


Fig. 4: % loss of Compressive Strength for cubes immersed in 5% H₂SO₄

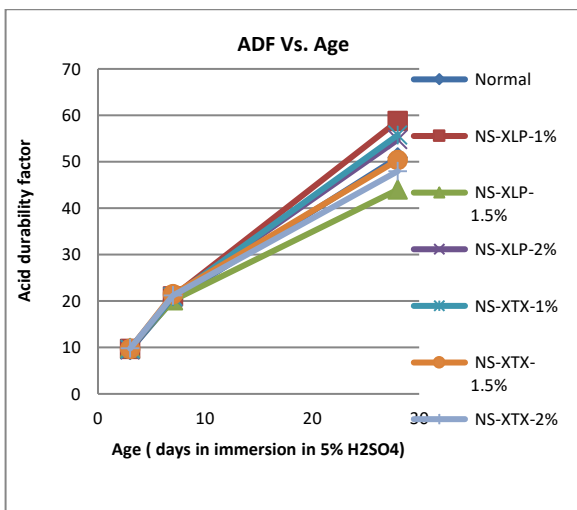


Fig. 5: Graph between Acid Durability Factor and No. of days in immersion in 5% H₂SO₄

4.2.3. Acid attack factor

The Acid Attack Factor (AAF) of the specimens were observed and plotted against the number of immersion days in acids as shown in the following Figs. 8 and 9.

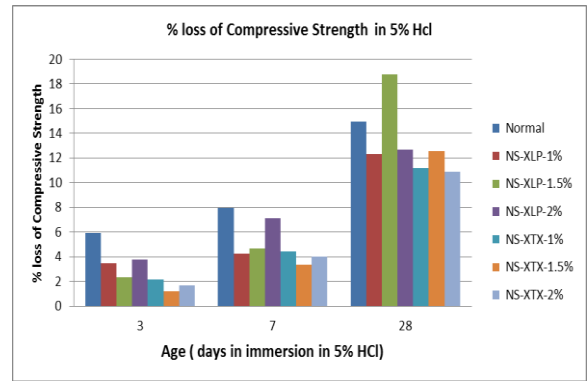


Fig. 6: % loss of Compressive Strength for cubes immersed in 5% HCl

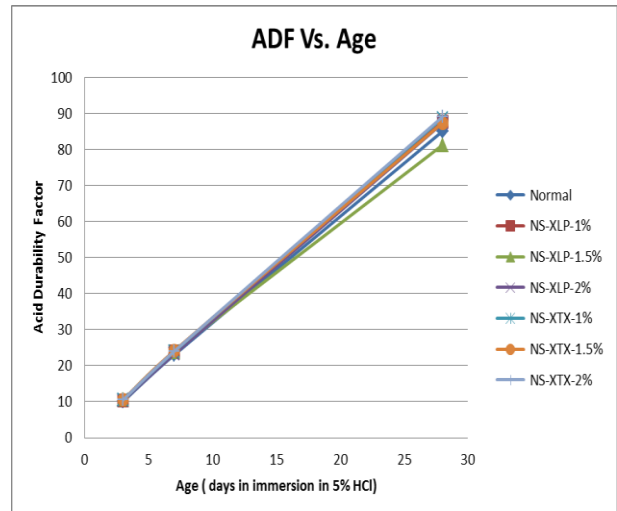


Fig. 7: Graph between Acid Durability Factor and No. of days in immersion in 5% HCl

From the figures, the following observations are made:

- i. After 28 days immersion in sulphuric acid solution of the specimen, the loss of diagonal lengths is more in SCC without nano silica when compared to nano additions.
- ii. After 28days of immersion of the specimen in sulphuric acid solution, 1% and 1.5% Nano silica-XLP is less attacked when compared to other nano percentages and normal SCC in terms of Acid attack factor.
- iii. Nano silica additions are less attacked and said to be more durable when compared with normal SCC in terms of Acid attack factor.
- iv. Acid Attack factor for cube immersed in 5% sulphuric acid is more when compared with solutions of 5% Hydrochloric acid.
- v. AAF values are almost same for the cubes immersed in 5% HCl after 28days.

4.2.4. Sorptivity

In the present investigation sorptivity tests were conducted on cube specimens of size 150*150*150mm. The weight recorded at the end of different intervals is noted down and sorptivity is calculated. The result can be observed from Fig. 10.

A general observation from figure is that sorptivity decreases with addition of nano silica

when compared with normal SCC. This shows nano-additions are better than SCC.

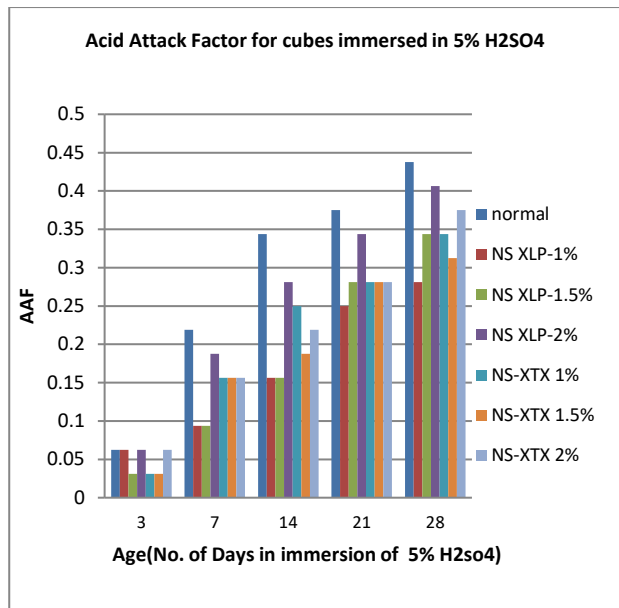


Fig. 8: Bar chart showing Acid Attack Factor of cubes immersed in 5% H₂SO₄

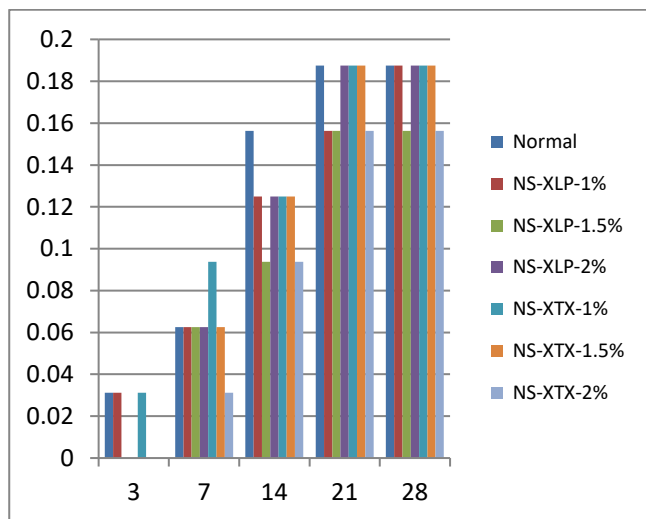


Fig. 9: Bar chart showing Acid Attack Factor for cubes immersed in 5% HCl

5. Conclusion

The present work deals with effect of nano silica additions on strength and durability properties on Self compacting concrete. The conclusions obtained from the study are:

1. There is a steep increase in the compressive strength at 28 days of about 45.2% and 41.13% with the addition of 1.5% Nano silica of XLP grade and XTX grade respectively. Hence 1.5% addition of nano silica is said to be optimum.
2. After 28 days, the percentage mass loss for Nano Silica XLP with 1.5% addition is 1.06% in 5% sulphuric acid, which is said to be less when compared to other percentage of nano silica.
3. After 28 days, the percentage mass loss for Nano Silica XTX with 2% addition is 1.81% in 5%

hydrochloric acid, which is said to be less when compared to other percentage of nano silica.

4. The percentage compressive strength loss is more for 1.5% Nano Silica-XLP and is about 56.02 % and 18.74% with 5% H₂SO₄ and 5% HCl respectively after 28 days of immersion. This may be due to higher pozzalonic content.
5. At 28 days, the loss of compressive strength is less for XLP- Nano-Silica of 1% addition which is about 41.23% and has more Acid Durability factor of about 58.77 in sulphuric acid, hence it is said to be more durable when compared to other nano additions.
6. Acid durability factor for cubes immersed in 5% Hydrochloric acid are almost same but after 28 days ADF is more for 2% Nano silica SCC of XTX grade, and also for 1% Nano silica SCC of two grades. This implies that 2% Nano silica SCC of XTX grade, 1% addition is more durable in hydrochloric acid when compared to other in terms of Acid durability factor.
7. Nano silica additions are less acid attacked and said to be more durable when compared with SCC without nano silica in terms of Acid attack factor.
8. Nano silica additions in SCC are almost impermeable, as there is no capillary suction. This might be due to the filling of nano materials into the pores.

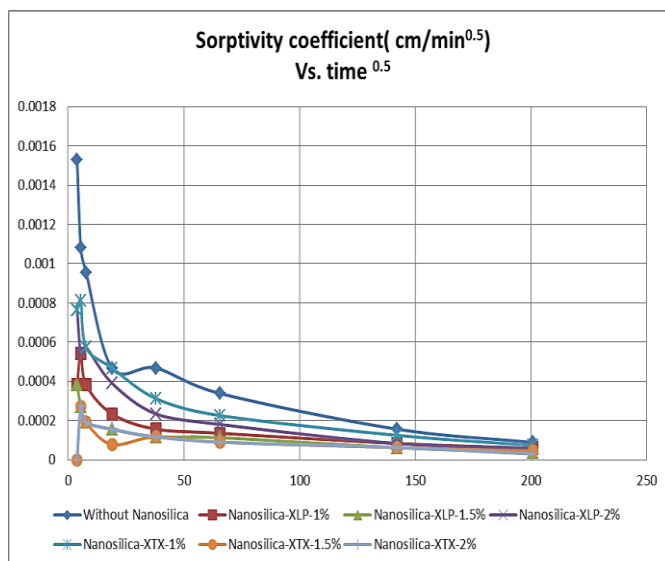


Fig. 10: Sorptivity of the cubes immersed up to 10mm in water

Hence, it can be concluded that nano silica additions in SCC is good enough to satisfy the requirements for compressive strength, durability and sorptivity. But it has failed in satisfying durability requirements.

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