Effect of Nanosilica on the Strength and Durability Properties of Glass Fibre Reinforced Self Compacting Concrete

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Abstract— Modern structures are being designed with congested reinforcement making the placement of concrete a menace; there arises the need of self compacting concrete. Self-Compacting Concrete is a highly flowable and coherent concrete able to compact under its own weight. Use of Alkali- Resistant Glass fibre in Self Compacting Concrete can improve surface quality, impact resistance and durability. Recently, a more pozzolanic- reactive material, nanosilica, has been used to improve the properties of cementitious materials, and it shows an excellent enhancing effects on the early-age properties. This investigation attempts to study the effect of nanosilica on the workability, strength and durability properties of Glass Fibre Reinforced Self Compacting Concrete. Control Self Compacting Concrete mix of 50MPa was obtained. 0.1% (by volume of concrete) glass fibre was adopted as optimum percentage (based on compressive strength variation with varying dosage of fibre). Nanosilica with varying dosage (0.5%, 1.5%, 2.5% and 3.5%) was added as a cement replacement material. Workability studies include Slump flow test, V-Funnel test and L-Box test. Results obtained were compared with control mix. Presence of nanosilica in optimal percentage improved the strength and durability properties of Self Compacting Concrete significantly.

Keywords—Self Compacting Concrete; Alkali-Resistant Glass fibre; Nanosilica

I. INTRODUCTION

Self Compacting Concrete (SCC) is that concrete which is able to flow under its own weight and completely fill the formwork without segregation, even in the presence of dense reinforcement, without the need of any vibration whilst maintaining homogeneity.SCC is an increasingly attractive choice for optimizing site manpower (through reduction of labour and possibly skill level), lowering noise levels, and allowing for a safer working environment. Addition of fibre reinforcement in discrete form improves many engineering properties of concrete [7]. Fibres include steel fibres, glass fibres, synthetic fibres and natural fibres – each of which lends varying properties to the concrete. In addition, the character of fibre reinforced concrete changes with varying concretes, fibre materials, geometries, distribution, orientation, and densities. Recent studies show that incorporating glass fibre enhances several properties of concrete. Recently nanotechnology is being used or considered for use in many applications and it has received increasing attention also in building materials, with potential advantages and drawbacks being underlined. In this field, a new pozzolanic material, produced synthetically in the form of slurry of ultra-fine particles of amorphous silica, also called ‘‘nanosilica’’, was introduced into the market [3-6]. The aim of the present investigation is to study the effect of nanosilica on the strength and durability properties of glass fibre reinforced SCC.

II. EXPERIMENTAL INVESTIGATION

A. Materials

As per IS Standards different tests were conducted on the materials in the concrete mix. The properties of each material in concrete mix were studied at the early stage.

Cement

Tests were conducted to ensure the quality of cement conforming to **IS 12269–1987** [21] and the details are OPC 53 Grade cement with specific gravity 3.15 and fineness 4% was used.

Fine Aggregate

M sand was used as fine aggregate and tests were conducted on fine aggregates to determine the different physical properties as per **IS 383-1970** [14].Specific Gravity of fine aggregate was 2.5 and belongs to zone II. Fineness modulus was found to be 3.062.

Coarse Aggregate

Crushed natural stone of maximum size 16mm and minimum size 4.75mm was used as coarse aggregate and tests were conducted on coarse aggregates as per **IS 383:1970** [14].The properties of coarse aggregate are specific gravity 2.80, fineness modulus-6.927 and water absorption was 0.48%.

Nanosilica

The nano-silica used was in a colloidal form with 30.50% SiO_2 content. The mean particle size of the nanosilica was 17 nm, specific gravity1.214, pH 9.78 and specific surface area 160 m^2/g.

Alkali Resistant Glass Fibre (AR Glass Fibre)

AR glass fibre with 19% zirconia content was used in this study. Fibre length and diameter are 13mm and 12micron respectively. Fibre having a tensile strength of 3500MPa, modulus of elasticity of 74GPa and density $2.8\times10^3 kg/m^3$

Flyash

Flyash was collected from Tuticorin Thermal Power Plant and confirms to ASTM Class F. By laboratory tests the specific gravity of fly ash was obtained as 2.08. Residue on 45micron sieve by wet sieve analysis (**IS 3812 (Part I):2003**) [42] was 30%.

Superplasticizer

Cera Hyperplast XRW40 which is a new range water reducing admixture having specific gravity 1.09-1.11 was used. It is a Modified polycarboxylate based brown colour liquid.

Water

Generally, water suitable for drinking is considered fit for making concrete. Hence clean drinking water available in the college water supply system was used for making concrete and curing.

B. Mix proportioning

There are no standard methods for the mixture proportions of self compacting concrete. Several researches were done and many different proportion limits have been listed in various publications. EFNARC [3] method is adopted for this particular study. Trial and error method was done and the obtained mixes were subjected to workability tests. Table 1 shows the M50 Grade SCC mix obtained after trial and error method.

Table 1: Mix proportion

Water (kg)	Cement (kg)	Coarse aggregate (kg)	Fine Aggregate (kg)	Fly ash (kg)	Super plasticizer (% of binder)
180	350	740	950	200	1.8

A laboratory type pan mixer with revolving star of blades was used for mixing concrete. During preparation of SCC mix, aggregates, cement, flyash and AR glass fibre were mixed in the revolving pan. After proper mixing, mixture of water, nano silica and plasticizer were added. Inorder to maintain constant water content in the SCC mixes, water was added after deducting the amount of water in colloidal nanosilica. The mixing was continued until a uniform mix was obtained. Mixing time was longer for SCC comparing with conventional concrete. Workability parameters were checked for each mixes. The concrete was then poured into the properly oiled moulds without any manual compaction. Specimens were demoulded after 24 hours of casting and were kept in a curing tank for water curing.

This study was done in two stages. In the preliminary stage AR glass fibre with varying content (0%, 0.025%, 0.05%, 0.1% and 0.15% by volume of concrete) was added to the control mix to find out the compressive strength development in SCC. Fig 1 shows the variation in the compressive strength with different percentage of AR glass fibre. It can be seen that 0.10% glass fibre increases the compressive strength considerably comparing with other percentage of glass fibre. Main study was limited to the preparation of 6 different types of mixes. One control mix and other five SCC mixes reinforced with 0.10% of AR glass fibre and by replacing cement by nanosilica in 0%, 0.5%, 1.5%, 2.5% and 3.5% of the total weight of cement. For all the six mixes the grade of concrete used was M50. The various mix designation are shown in Table 2

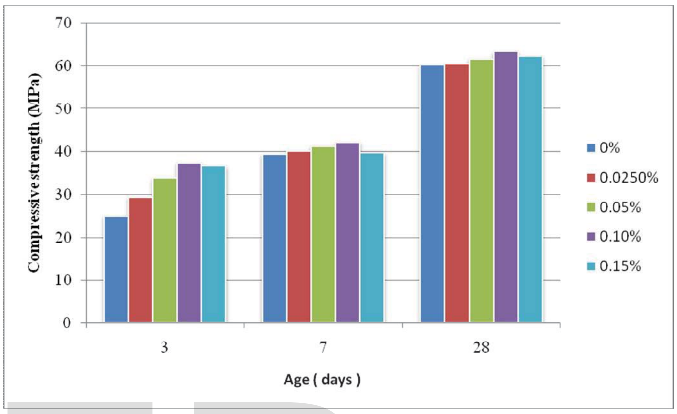

Fig 1 Compressive strength variation of glass fibre reinforced SCC

Table 2: Mix Designation

Mix Designation	Nano Silica (% weight of cement)	AR Glass fibre (%volume of concrete)
S	0	0
GS	0	0.10
GSN1	0.5	0.10
GSN2	1.5	0.10
GSN3	2.5	0.10
GSN4	3.5	0.10

C. Test methods

Workability: Important workability parameters of SCC are filling ability, passing ability and segregation resistance. Slump test, V funnel test and L box test were conducted as per EFNARC standards to assess these workability parameters of the SCC mixes.

Compressive strength: The compression test was carried out on cubical specimen of size 100mm × 100mm × 100mm in a compression testing machine of capacity 2000 kN, at a loading rate of 14N/mm^2 per minute as per **IS 516:1959** [16] specification. The test was done on all the mixes for determining the 3rd day, 7th day, 28th day, 56th day and 90th day compressive strength.

Split tensile strength: Test was carried out on concrete cylinder of size 150mm × 300mm as per **IS 5816:1999** [17] specification.

Modulus of elasticity: Test specimen used was a concrete cylinder of 150mm diameter and 300mm height. The test was conducted as per **IS: 516 – 1959**[16]. Compressometer of standard gauge length 200 mm was connected to the cylindrical specimen and placed in a universal testing machine with its axis vertical. The specimen was subjected to a cyclic loading and deformations corresponding to various loads were determined from the compressometer dial gauge

Flexural strength: To determine flexural strength of a PCC beam, test was done on a PCC beam of size 100mm×100mm×500mm. Three beam specimens were tested for determining the flexural strength as per **IS 516:1959**[16] specification.

Impact resistance: The impact test was performed in accordance with the impact testing procedures recommended by ACI Committee **544-2R-89** [12]. Concrete samples of size 150 mm diameter and 50 mm thickness were used.

Sulphuric acid attack test: 100 mm concrete cube specimens were tested based on modified **ASTM C 267-01** test method to check the durability of SCC mixes. After 7 days of water curing, the concrete specimens were exposed to 3% sulphuric acid solution for 56 days and 90 days, and then are tested for compressive strength.

Sulphate attack test: This test proposes to assess the sulphate attack on concrete specimen by determining the deterioration of compressive strength of 100 mm concrete cube specimens. The concrete specimens were exposed to sodium sulphate solution for 56 days and 90 days after 7 days of water curing. A 20000 ppm sulphate solution was prepared by dissolving 52 gm of $MgSO_4.7H_2O$ in one litre of water. The test was conducted based on **ASTM C 452-02** [16] test method. After 56 days and 90 days of sulphate exposure, specimens were tested for compressive strength.

III. RESULTS AND DISCUSSIONS

Test results cover the effect of nanosilica and glass fibre on the workability, strength and durability properties of self compacting concrete.

Workability: To obtain workable mix superplasticizer dosage was varied. Table 2 shows the amount of superplasticizer used in SCC mixes inorder to attain desired workability. It can be seen that amount of superplasticizer needed to attain a SCC mix slightly increases as AR glass fibre is added to concrete. Nanosilica addition results in more superplasticizer dosage. Table 3 shows the workability test values of mixes

Table 2: Superplasticizer dosage

Mix Designation	Superplasticizer (% wt of binder)
S	1.8
GS	1.82
GSN1	1.92
GSN2	1.98
GSN3	2.15

Table 3: Workability parameters

Test	Range of suggested values	Mix					
		S	GS	GSN1	GSN2	GSN3	GSN4
Slump flow	600-800mm	750	700	695	693	690	686
T50 slump	3-5 sec	3	5	4	5	5	5
V funnel	3-12 sec	10	12	11	11	12	12
V funnel at T5 min	3-15sec	12	15	13	14	15	15
L box	0.8-1.0	0.93	0.88	0.90	0.89	0.87	0.86

SCC incorporated with AR glass fibre shows a slight reduction in slump flow value comparing with control SCC mix. Also T50 slump time and V funnel time increases with addition of 0.1% AR glass fibre. Based on visual inspection it was found that addition of 0.1% AR glass fibre shows a reduction in bleeding. From the mixes GSN1 to GSN2 the tests shows a reduction in workability of SCC. Since nanosilica has large effective surface, it absorbs too much water and thus reduces concrete's workability. This would also increase the concrete's shear strength against flowability and viscosity of SCC. Mix with small dosage of nanosilica has greater workability comparing with the mixes with higher dosage of nanosilica. Reduction in bleeding was found in SCC mixes with nanosilica.

Compressive strength: GS mix shows greater compressive strength than the conventional mix S at all ages. With increase in AR glass fibre content upto 0.1% (vol of concrete) compressive strength of SCC increases. This result was expected because the addition of fibres enhances energy-absorbing property. Both early age and later age strength of GFRSCC was more than control SCC mix. Percentage increase in compressive strength of GS mix at 28 day was 4.97%.

With addition of 0.5% nanosilica to GFRSCC mix, 3 and 7day strength increases. But there was a slight decrease in later age strength comparing with control SCC. Addition of 1.5% and 2.5% nanosilica in SCC causes an increase in both early and later age strength. For GSN4 (3.5% nanosilica) mix both early and later strength was less comparing with other mixes with nanosilica. Increase in compressive strength with the addition of nanosilica is due to its high pozzolanic activity. Nanosilica, due to its high special 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 (3.5%) 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 cement mortar 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. Reduction in strength can also be due to the defect in dispersion of nanoparticles that causes weak zones. From the Fig 2, it can be seen that early age strength achievement was greater for nanosilica mixes because pozzolanic reaction of nanosilica is more prominent at early ages.

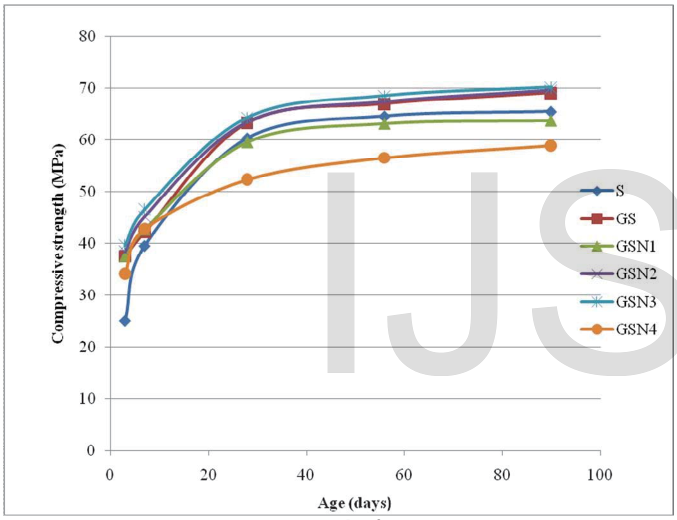

Fig 2: compressive strength of various SCC mixes

Split tensile strength: Fig 3 shows the split tensile strength of different SCC mixes. Addition of AR glass fibre causes an increase in split tensile strength of SCC at both ages. This improvement can be attributed to the larger contact area between fibres and mortar resulting in more friction and higher performance of the concrete. By the replacement of cement by nanosilica from mixes GSN1 to GSN3 there is a gradual increase in split tensile strength. Split tensile strength of GSN3 mix is increased by 7.52% and 8.17% at 28 and 56 days comparing with GS 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 (3.5%) shows a reduction in split tensile strength as seen in compressive strength.

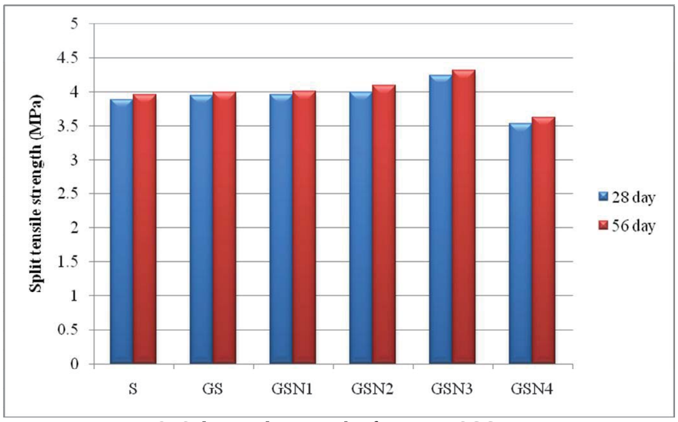

Fig 3: Split tensile strength of various SCC mixes

Modulus of elasticity: Fig 4 shows the Modulus of elasticity for the 28 and 56 day mixes. With addition of 0.1% AR glass fibre, modulus of elasticity is increased by 5.28% and 3.78% at 28 and 56 day. Incorporating nanosilica as a cement replacement material up to 2.5% increased modulus of elasticity. Modulus of elasticity of GSN3 is increased by 12.03% and 9.99% comparing with the mix GS. Later age strength development can be observed in the mixes with nanosilica due to its pozzolanic reactivity.

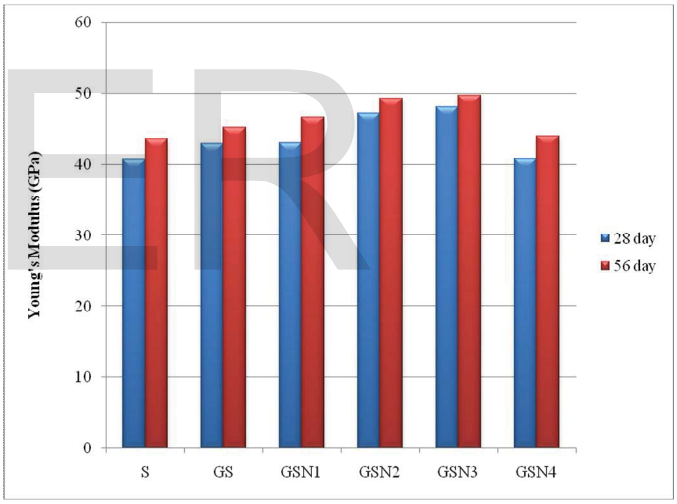

Fig 4 : modulus of Elasticity of various SCC mixes

Flexural strength: Fig 5 shows the variation of flexural strength for SCC mixes. Variation in the flexural strength of SCC mixes shows similar trend like that of splitting tensile strength. With addition of 0.1% AR glass fibre, flexural strength is increased by 3.28% and 3.42% at 28 and 56 day. With increase in nanosilica content flexural strength increases and then decreases after optimum dosage. GSN3 (2.5% nanosilica) shows greater flexural strength comparing with other mixes. Flexural strength is increased by 9.24% and 10.26% at 28 and 56 day respectively for the mix GSN3. 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.

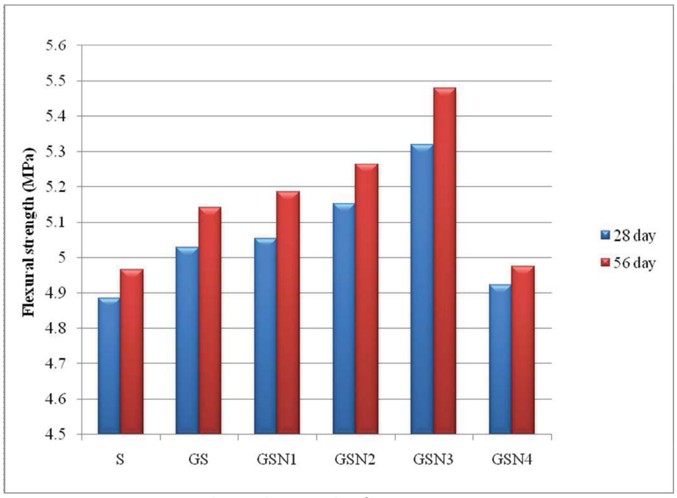

Fig 5 : Flexural strength of various SCC mixes

Impact resistance: Fig 6 and 7 shows the variation of impact resistance for different SCC mixes at 28 and 56 day. Amount of glass fibre in SCC increased impact resistance to a greater extent. This increase in impact resistance by adding fibre is due to its strength and adherence to cement matrix. Impact resistance of SCC increases with increasing content of nanosilica up to 2.5% replacement and then decreases. Increase in the impact resistance can be attributed to the densified structure due to the pozzolanic reaction in concrete. Decrease in impact strength with high dosage may be due to agglomeration of nano particles.

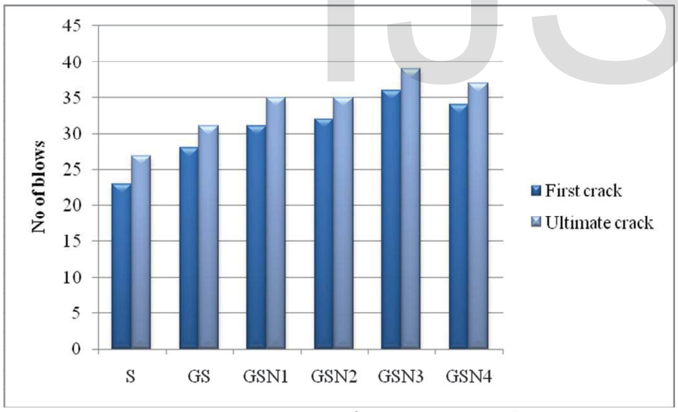

Fig 6: Impact resistance of SCC mixes at 28days

Sulphuric acid attack test: All SCC mixes after acid exposure shows reduced strength comparing with that of water cured strength. Fig 8 shows that the strength loss of SCC mixes subjected to sulphuric acid. It can be seen that percentage strength loss reduces with addition of 0.1% AR glass fibre and variable dosage of nanosilica content. AR glass fibre used in this study is having acid resistivity so the strength loss is less comparing with the mix S. 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 SCC is because during the hydration reaction nanosilica reduces the amount of $Ca(OH)_2$. So formation of expansive components will be less compared with control SCC. It can be seen that strength loss is maximum in control mix. Reduction in strength loss is seen with increasing nanosilica content

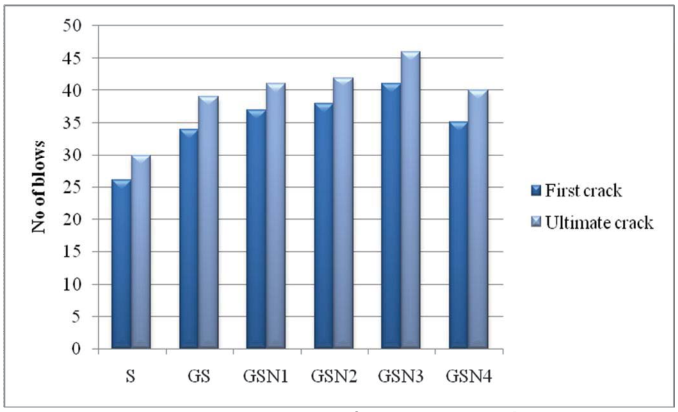

Fig 7: Impact resistance of SCC mixes at 28days

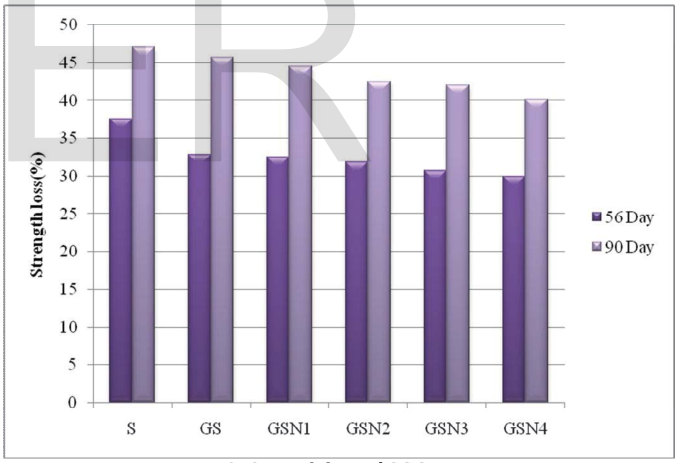

Fig 8: Strength loss of SCC mixes

Sulphate attack test: After exposure to sulphate solution, white patches were found on the surface of concrete specimens. Concrete cubes immersed in sulphate solution were found to be visually intact after 56 and 90 days. Fig 9 shows the percentage strength loss variation in SCC mixes . It can be seen that percentage strength loss after sulphate exposure decreases with increase in fibre content. Also the pozzolanic effect of nanosilica helps in reducing the % strength loss. 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. Sulphate resistance increases with addition of 0.1% AR glass fibre and varying dosage of nanosilica.

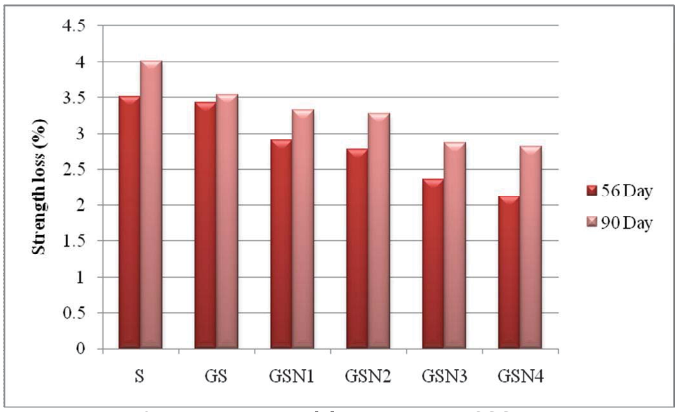

Fig 9 Percentage strength loss variation in SCC mixes

IV. CONCLUSIONS

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

- Workability of SCC decreases with addition of AR glass fibre and nanosilica. Workability of control SCC mix is greater than all other mixes. To maintain the workability requirement of SCC mixes, superplasticizer dosage was varied. AR Glass fibre and nanosilica reduces bleeding in SCC.
- Addition of 0.1% AR glass fibre increases compressive strength by 4.97% at 28 days. Mix GSN1 shows greater compressive strength at 3 and 7 days but after that compressive strength is less than that of control SCC mix. Replacing cement with 2.5% nanosilica shows greater compressive strength comparing with other replacement levels.
- Maximum split tensile strength is obtained for GSN3 mix. Split tensile strength increases with addition of 0.1% AR glass fibre.
- Modulus of elasticity, flexural strength and impact resistance of GFRSCC is more than control SCC mix
- Modulus of elasticity, flexural strength and Impact resistance increases with nanosilica content upto mix GSN3 and then decreases.
- Percentage strength loss reduces with increasing dosage of nanosilica content when the specimen is subjected to suphuric acid and sulphate solution. And it is less for the mix GSN4.
- Optimum dosage of nanosilica was found to be 2.5%.

Acknowledgement

The authors acknowledge the support of all faculties, students and other staff members of M.Tech, Department of Civil Engineering, TKM CE, Kollam, for their immense help and support given at various phases of this work.

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