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Influence of Nanosilica on the Properties of Concrete

A PROJECT REPORT

submitted by

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Reg No: IGW24CESC02

to

The APJ Abdul Kalam Technological University

in partial fulfilment of the requirements for the award of the Degree of

MASTER OF TECHNOLOGY

In

STRUCTURAL ENGINEERING AND CONSTRUCTION MANAGEMENT (CIVIL ENGINEERING)

DEPARTMENT OF CIVIL ENGINEERING INDIRA GANDHI INSTITUTE OF ENGINEERING & TECHNOLOGY, KOTHAMANGALAM

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DECLARATION

I undersigned hereby declare that the project report “Influence of Nanosilica on the properties of Concrete”, submitted for partial fulfilment of the requirements for the award degree of Master of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by me under supervision of Asst Prof. Geethika G Pillai. This submission represents my ideas in my own words and where ideas or words of others have been included, I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

Place: Kothamangalam

KEVIN K CHARLY

Date: 0 6 /05/2026

CERTIFICATE

This is to certify that the report entitled, **“INFLUENCE OF NANOSILICA ON THE PROPERTIES OF CONCRETE”** submitted by **KEVIN K CHARLY (IGW24CESC02)** to the APJ Abdul Kalam Technological University in partial fulfilment of the requirements for the award of the Degree of Master of Technology in Structural Engineering and Construction Management (Civil Engineering) is a bonafide record of the project work carried out by her under my guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.

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Engineering and Technology was also valuable in making this report.

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ABSTRACT

Nanosilica is a nano product by its addition in concrete leads to the improvement of performance of concrete. One of the major inherent factors that cause deterioration of structural component is the corrosion of the steel reinforcement accelerated by the formation of micro cracks. By the introduction of nanosilica into the concrete matrix this problem can be resolved to a certain extent. This study investigated the effect of colloidal nanosilica on concrete incorporating single (ordinary cement) and binary (ordinary cement and Class F fly ash) binders. In addition to the mechanical properties, the experimental program included tests for durability properties and flexural properties on reinforced concrete beams. The nanosilica having size only 17nm is used for experimental studies. The properties of nanosilica concrete were studied and compared with control mix. Based on the preliminary investigation, total 7 different mixes are prepared. Three mixes are prepared by replacing cement by 25% of fly ash (kept constant) and varying the percentage of nanosilica in 0.5%,1.5% and 3% of the total weight of cementitious materials. The other three mixes are prepared by replacing cement by nanosilica in 0.5%,1.5% and 3% of the total weight of cementitious materials. Standard specimens were tested to study the properties of hardened concrete viz, compressive strength, flexural strength, split tensile strength, modulus of elasticity, and impact strength. The durability study includes sulphuric acid test, sulphate attack test and bulk diffusion test. The parameters considered for flexural study were deflection, crack pattern, crack width, first cracking load and ultimate load carrying capacity. Significant improvement was observed in mixtures incorporating nanosilica in terms of workability, mechanical and durability properties. The higher strengths are attributed to accelerated cement hydration, pozzolanic reaction, reduced pores and improved interface bonding between hardened cement paste and aggregate and also due to the filler effect of nanosilica.

Keywords: Nano silica, Fly ash, Durability, Pozzolanic reaction, Filler effect

LIST OF SYMBOLS

NS	Nanosilica
SCM	Scanning electron microscopy
ITZ	Interface transition zone
UF	Ultrafine
nm	Nanometer
f_7	Seventh day cube compressive strength
f_{28}	Twenty eighth day cube compressive strength

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f_{cr}	Modulus of rupture of concrete
f_t	Split tensile strength of concrete
E_c	Modulus of elasticity of concrete
l	Effective span of beam
m	Mass of drop weight
g	Acceleration due to gravity
Pcra	Load at First Crack
Pcra,sta	Standardized Load at First Crack
Pu	Ultimate Load
Pu,sta	Standardized Ultimate Load
Pu,th	Theoretical Ultimate Load
Pu,exp	Experimental Ultimate Load
Kpre	Pre cracking Stiffness
Kpre,sta	Standardized Pre cracking Stiffness
Kpost	Post cracking Stiffness
Kpost,sta	Standardized Post cracking Stiffness
Mcr	Cracking Moment
Mu	Ultimate Moment
Mu,th	Theoretical Ultimate Moment
Pcra,0.3	Load at 0.3mm Crack width

LIST OF FIGURES

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Building materials form the backbone of civil engineering construction. Of all the modern building materials, concrete is one of the oldest, but most versatile materials, with an annual worldwide production of over 4.5 billion metric tons. It is a manufactured material that can, with appropriate knowledge, be tailored for optimum performance when compared with other construction materials. It possesses many advantages including relatively good compressive strength, freedom to form, low cost, general availability of raw materials, adaptability, low energy requirement, and utilization under different environment conditions. With the advancement of technology and use of modern building materials it has become possible to construct high rise structures having even more than 100 storeys.

The cement industry is considered to be one of the most energy consuming industries, with a high rate of carbon dioxide (CO_2) emissions. Every year, it is responsible for approximately 5% of the global manmade CO_2 emissions 50% of these emissions are caused by chemical manufacturing processes and 40% are due to burning fuel. Extensive research efforts have been directed to reduce the effect of the cement industry on greenhouse gases either by improving the efficiency of the cement manufacturing process or by using supplementary cementitious materials (SCM), which partially replace ordinary cement. Various SCM have been investigated, including fly ash, ground granulated blast furnace slag, natural pozzolans, and silica fume. Recent studies have indicated that the use of new technologies may lead to industrial breakthroughs for the manufacture of SCM. It is believed that nanotechnology is one of the most promising research fields that may significantly improve the mix design, as well as the performance and production of cement-based materials. In recent years, there has been a growing interest in the use of nanosilica in concrete. It is believed that nanosilica exhibits much finer particle sizes and higher pozzolanic reactivity than silica fume, thus can act as fillers, pozzolanas and seeds more effectively.

1.2 NANO SILICA IN CONCRETE

Nanosilica is a nano product by its addition in concrete leads to the improvement of performance of concrete. The nano particles in powder are often in an aggregated (firmly-held clusters) or agglomerated (loosely held clusters) form with final grain size from submicron to as high as 100nm due to their very high specific surface area and energy. Even in the well-dispersed colloidal dispersion, the nano-particles still exist as aggregates with grain size in submicron. By using colloidal silica sol, it is often assumed that the mono-dispersed nano-particles can act as fillers and seeds much more effectively than those agglomerates in powder or dispersion. Neverthless, the investigations revealed that the silica sol will gel or coagulate immediately when the cement is mixed in to the water containing sol due to rapid increase of ionic strength in paste. As a result, no matter what source of nanosilica is used, it is the behaviour of final agglomerates, rather than that of individual nano-particles, which controls the filling, pozzolanic and seeding effects on cement hydration and microstructure improvement. At first, it was believed that the improvement in concrete performance due to the addition of nanosilica is attributed to its filler

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effect and its pozzolanic reaction. But recently, however, it has been reported that the small particle size of nanosilica provides a larger surface area, which speeds up the rate of cement hydration and pozzolanic reactions. Recent developments in nana-technology and availability of nanosilica (NS) have made the use of such materials in improving concrete properties possible. Several researches show that early-age and 28-day strength of cement mortars and concrete are increased by using a small amount of NS. Higher strengths of pastes mortars and concrete with NS are also reported in comparison to those with silica fume. The higher strengths are attributed to accelerated cement hydration and pozzolanic reaction reduced pores and improved interface bonding between hardened cement paste and aggregate. Nanosilica has also been used to increase early strength of concrete with fly ash.

1.3 CHEMISTRY OF NANO SILICA AND ITS ACTION

Soluble silicates are manufactured by fusing high purity quartz sand (SiO_2) with sodium or potassium carbonate (Na_2CO_3 or K_2CO_3) in an open-hearth furnace at 1100 – 1200°C. The resulting glass is then dissolved using high pressure steam to form liquid silicate or "waterglass" which is clear and slightly viscous. The key parameter that determines the properties of soluble silicate solutions is the weight ratio of SiO_2/Na_2O. For example, a "3.2" ratio sodium silicate has 3.2 kg of SiO_2 for every 1kg of Na_2O. The typical range of commercially available ratios is 1.6 to 3.2. At the molecular level, the fundamental building block of silicate species is the silica tetrahedron consisting of the silicon atom at the centre of an oxygen-cornered pyramid. Each oxygen atom may be associated with a hydrogen atom an alkali metal (Na, K, Li), or it may be linked to another silica tetrahedron. The silica can link to form chains, cyclic and larger polymeric structures. The species typically carry an overall negative charge having the mono valent alkali atoms in loose association**.**

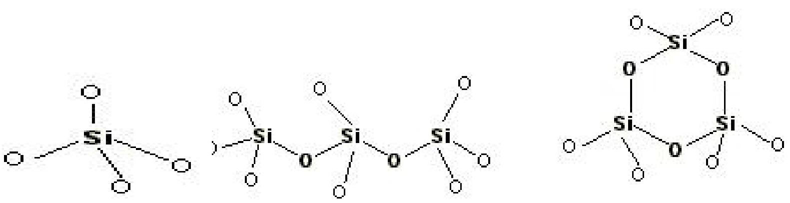

Fig 1.1 Monomer Silica Tetrahedron, Linear and Planar Cyclic Silica Species

Soluble silicates then are inorganic, polymeric, alkaline materials. They are also moderately strong buffers and can be involved in four basic types of chemical reactions, each of which can play a role in binder applications. The chemical reactions are:

- Gelation.
- Metal Ion Reactions / Precipitation.
- Hydration / Dehydration.
- Surface Charge Modification.

The final product obtained is the nano particle of silica. The particle size of silica varies from 10 nm – 100 nm.

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1.4 ADVANTAGES OF NANO SILICA IN CONCRETE

Along with new developments in concrete technology and an increasing environmental awareness, the construction industry is looking for alternative ways to blend improved concrete performance with both economic and environmental concerns. The use of nanosilica in concrete applications can help prevent segregation and bleed in self-compacting concrete. It can also improve the utilization of cement due to its strength providing properties. In applications for well cementing, when nanosilica is mixed with cement, the slurry becomes extremely stable and free water is eliminated. Due to its low specific gravity nanosilica works extremely well in lightweight slurries. In the low temperatures of deep and ultra deep waters, nanosilica provides substantial enhancement of early compressive strength, thereby shortening the setting time of the cement slurry. Some of the important advantages of nanosilica are described below

- Improves workability
- Improves pumpability
- Reduction in corrosion of steel
- Improves seismic resistance
- C-S-H reaction increases
- Improves durability
- Improves steel bond
- Can resist thermal shocks
- Saves time and money
- Can be used in water proofing
- Improves the speed of construction
- Arrest structural cracks
- matrix densification increases

1.5 DIFFERENT FORMS OF NANO SILICA

Nanosilica is available in two main forms compacted dry grains and colloidal suspension. Dry nanosilica requires a special preparation procedure before mixing in order to insure the thorough dispersion of the nano-particles in the mixing water, or other liquid admixtures, so that it can be well distributed in the concrete mixture. On the other hand, colloidal nanosilica, which is manufactured as a suspension stabilized by a dispersive agent, is already to-use form of nanosilica. It is indicated that better behaviour was achieved when colloidal nanosilica was added to mortar mixtures, compared to dry grained nanosilica. This was attributed to the better dispersion of colloidal nanosilica with highly reduced agglomeration, in contrast to the dry form.

1.6 OBJECTIVE AND SCOPE OF THE PRESENT STUDY

Based on the literature reviewed in the previous session, it was seen that addition of nanosilica improves the properties of concrete. It was found that the number of literatures comparing the mechanical and durability

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properties of nanosilica in concrete is less in number. In the present study the mechanical and durability properties of nanosilica concrete prepared from fly ash, and cement were compared.

1.6.1 Objective of the work

- To design a mix of characteristic compressive strength of 30 MPa and to prepare concrete mixes by replacing cement by nanosilica in 0.5%,1.5% and 3% of the total weight of cementitious materials.
- Prepare mixes by replacing cement by 25% of fly ash (kept constant) and varying the percentage of nanosilica in 0.5%,1.5% and 3% of the total weight of cementitious materials.
- To study the mechanical and durability properties of concrete containing nanosilica and fly ash and to compare the results with that of control mix.
- To study the flexural behaviour of RCC beam by conducting two-point loading.

1.6.2 Scope of the work

The study is limited to 0.5%, 1.5%, and 3% replacement of OPC with nanosilica. The strength tests are carried out after 28-day water curing except for compressive strength test which was carried out after 3, 7, 28, 56 and 90 day water curing. Durability tests are carried out by 7 days

water curing (for initial hydration) after which the specimens will be exposed to the respective chemical solution for a time period of 56 and 90 day.

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CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

The present work focuses on the effects of nanosilica in plain and in reinforced concrete. A detailed review of literature related to the scope of this work is presented in this chapter.

2.2 LITERATURE REVIEW

Rakesha K J (2024) conducted experiment on influence of nano silica on properties of cement concrete. Nanosilica enhances concrete by promoting additional calcium silicate hydrate formation, refining the microstructure, and reducing permeability. these improvements make nanosilica beneficial for concrete properties and repair mortars. hence the impact of nanosilica on different concrete qualities achieved by substituting different percentages of cement (0.5%, 1.0%, 1.5%, and 2.0%) for m25-grade concrete mix is demonstrated in this research work. to ascertain the mechanical properties, such as compressive strength, split tensile strength, and flexural strength, specimens were cast using nano-silica concrete. split tensile and flexural strength are assessed at the age of 28 days, whilst compressive strength is assessed at 7, 14, 28, and 56 days. Results indicate that using nanosilica powder in concrete was able to increase the mechanical characteristics and reduce the density compared to a conventional mix of concrete. when 1.5% nanosilica is substituted for cement, the resulting material exhibits superior

Mayank Nigam al., (2023) conducted study on effect of nano-silica on the fresh and mechanical properties of conventional concrete. The study shows that might eventually affect every other area of research and development. Many scientists have proposed various definitions of nanotechnology. Nano-materials could be a good product for the repair and rehabilitation of structures due to their particle size. It increases the packing density of the concrete and makes the concrete impervious easily. This research, checks the setting time, workability, compressive strength, splitting tensile, and flexural strength of different mix designs after the incorporation of nano-silica in conventional concrete at different ratios. The nano-silica incorporation varies from 0.0% to 3.0% by the interval of 0.5%. After the experimental investigation, the mechanical properties strength increases with the increment of nano-silica ingression in the concrete but it also decreases the workability of the concrete.

Sneff Luciano et al., (2009) conducted study on the effect of nanosilica on rheology and fresh properties of cement pastes and mortars. Fresh mortars were prepared with binder/aggregate weight ratio (B/A) of 1:2 and water/binder (W/B) ratio of 0.35. The cement paste was prepared with the same W/B ratio. Mortars and paste were produced with 0%, 1.0%, 1.5%, 2.0% and 2.5% NS in weight, replacing cement. The amount of SP was 2.0 % wt of the binder. The flow table test is widely used to evaluate the workability of cement pastes, since it is easy to operate, and allows some parameters such as viscosity to be inferred.

Result shows that there is an evident increase of torque values at early testing times when NS is incorporated into the mixture. The mortar with NS showed the higher torque along all the testing period due to the plastic viscosity and yield stress. Nano-SiO_2 modified the characteristics of fresh mortars. In formulations having fixed values of

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W/B and SP amount, the presence of NS decreases the amount of lubricating water available in the mixture. The yield stress increases considerably when NS is incorporated in the paste, being the most affected rheological parameter. The addition of NS also increases the spread diameter on the flow table of these mortars, due to the gain in cohesiveness of the paste. The relationship between spread and yield stress values better describes the effects of NS addition.

Min Hong Zhang and Jahidul Islam., (2011) conducted experiments to study the use of nanosilica to reduce setting time and increase early strength of concretes with high volumes of fly ash**.** Eight mortar mixtures were included in the study .All the mortars had a water-to-cementitious material ratio (w/cm) of 0.45 and a sand-to-cementitious material ratio of 2.75. Dosages of the Type 1 NS varied from 0 to 0.5%, 1.0% and 2.0% by mass of the cementitious materials. Mortars with 1% Type1 or Type 2 NS were compared with that with the same amount of silica fume to evaluate the effect of specific surface area and particle size of silica.Results show reduction of initial and final setting time by considerable amount, when 2% NS was used in comparison to the reference slag concrete. However, incorporation of 2% silica fume did not affect the initial and final setting time significantly compared to those of the reference slag concrete. The reduction of the setting times of the NS concrete may be related to the finer particle size and higher surface area of the NS compared with those of silica fume which reduced the dormant period and increased cement hydration.

Deyu Kong et al., (2012) conducted experiments to study the influence of nanosilica agglomeration on microstructure and properties of the hardened cement-based materials. Influence of nanosilica agglomeration on microstructure of concrete was studied through SEM observation and MIP analysis. The pastes were prepared with water cement ratio of 0.30. The additions of nanosilica and SP were 1.0% and 0.75% (in mass) respectively. After the pastes were cured at 20 ± 1 ^{0}C and for 28 and 180 days, they were crushed, washed twice with acetone, vacuum-dried at 105 ± 5 ^{0}C for 12 h and then detected by SEM and MIP . The microstructure of the ITZ (interfacial transition zone) in mortar was also observed by using SEM. After the mortar with 1.0% nanosilica addition was cured in water for 28 days, a small part containing ITZ was cut out, washed twice with acetone, vacuum-dried at 105 ± 5 _C for 12 h, and then detected by SEM.

The results confirmed an improved microstructure in the hardened cement paste with nanosilica introduction. In blank sample, the voids among cement particles have been occupied by the hydration products after curing for 28 and 180 days, but many connected capillary pores were observed.

Kontoleontos. F et al ; (2012) conducted experiments to study the effect of influence of colloidal nanosilica on ultrafine cement hydration. The influence of colloidal nanosilica addition on an ultrafine cement have been studied in terms of physic-mechanical and microstructure properties. Primarily, experiments were carried out to produce an ultrafine cement (UF) with a Blaine specific surface area greater than 10.500 cm^2/g. Nanosilica was added in amounts of 2% and 4% on UF cement basis. All cements were tested for initial and final setting times, consistency of standard paste, flow of normal mortar and compressive strengths after 1, 2, 7 and 28 days. The hydration products were determined by X-ray diffraction analysis and by Fourier transform infrared spectroscopy, at 1, 2, 7 and 28 days. The microstructure of the hardened cement pastes and their morphological characteristics were examined by scanning electron microscopy, where as porosity and pore size distribution were evaluated by mercury intrusion porosimetry.

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Results shows that the addition of colloidal nanosilica in ultrafine cement marks a novelty in the high performance cements technology. Colloidal nanosilica behaved not only as a filler to improve cement microstructure (porosity decrease), but also as a promoter of pozzolanic reaction by transforming portlandite into C–S–H gel. Nano-silica was proved an agent that improves the microstructure of the ultra fine cement paste. The cements with nanosilica presented a denser microstructure. At early ages, the main hydration component was C_3S, whereas silica nano particles provided nucleating sites for the precipitation of hydration products (especially Ca $(OH)_2$. At later ages, nanosilica modified the internal structure of the C–S–H gel, increasing the average chain length of the silicate chains, leading to a denser structure. Ca $(OH)_2$ evolution was diminished due to the pozzolanic reaction, whereas the large pores were partially or completely filled with hydration products (especially secondary C–S–H).

Min Hong Zhang et al ; (2012) conducted experiments on the use of nanosilica to increase early strength and reduce setting time of concretes with high volumes of slag. The effects of nanosilica (NS) on setting time and early strengths of high volume slag mortar and concrete have been experimentally studied. Effects of NS dosages, size and dispersion methods on strength development of high volume slag mortars were also investigated. A constant water-to cementitious materials ratio (w/cm) 0.45 was used for all mixtures. The results indicate that the incorporation of a small amount of NS reduced setting times, and increased 3- and 7-day compressive strengths of high-volume slag concrete, significantly, in comparison to the reference slag concrete with no silica inclusion. Compressive strength of the slag mortars were increased with the increase in NS dosages from 0.5% to 2.0% by mass of cementitious materials at various ages up to 90 days. The strengths of the slag mortars were generally increased with the decrease in the particles size of silica inclusions at early age. Ultra-sanitation of nanosilica with water is probably a better method for proper dispersion of nanosilica than mechanical mixing method.

Said A.M et al., (2012) carried out experiments to study the properties of nanosilica in concrete. This study investigated the effect of colloidal nanosilica on concrete incorporating single (ordinary cement) and binary (ordinary cement and Class F fly ash) binders. In this study, total six different types of mixes are prepared out of which three mixtures included only cement as a binder (single binder) while the other three mixtures had 30% of the cement replaced by Class F fly ash (binary binder). The cementitious materials content (390 kg/m3) and the water-to-cementitious material ratio (0.40) were kept constant for all the mixtures. Variable dosages of nanosilica were used (0%, 3%, and 6% by total mass of cementitious materials) in each of the two groups of mixtures (A and B). The amount of mixing water was adjusted for each mixture to account for the water content of the nanosilica solution.

Results indicated that the addition of nanosilica to Portland cement concrete marginally increases the workability of the concrete. Significant improvement was observed in mixtures incorporating nanosilica in terms of reactivity, strength development, refinement of pore structure and densification of interfacial transition zone. This improvement can be mainly attributed to the large surface area of nanosilica particles, which has pozzolanic and filler effects on the cementitious matrix. Micro-structural and thermal analyses indicated that the contribution of pozzolanic and filler effects to the pore structure refinement depended on the dosage of nanosilica.

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CHAPTER 3

EXPERIMENTAL PROGRAMME

3.1 GENERAL

The properties of concrete both in fresh and hardened state depend largely on the properties of constituent materials used for its preparation. Detailed characterization tests were conducted in the laboratory to evaluate the required properties of the individual materials. The relative quantities of cement, aggregate, nanosilica, chemical admixtures and water together, controls the properties of concrete in the fresh state. The compacting factor, slump, flow test, vee bee degree test was conducted to assess the workability.

This chapter presents, the details of the experimental investigation carried out to study the strength and durability characteristics of nanosilica concrete. The test program includes the determination of mechanical properties by cube compressive strength, cylinder compressive strength, spilt tensile strength, flexural strength of impact resistance, modulus of elasticity.

3.2 MATERIAL PROPERTIES

The properties of each material in a concrete mix were studied at the early stage. Different tests were conducted for each material as specified by relevant IS codes. Ordinary Portland cement, fine aggregate, coarse aggregate, super plasticiser, nanosilica and water were used for making the various concrete mixes considered in this study.

3.2.1 Cement

Ordinary Portland cement (OPC) conforming to IS 12269 (53 Grade) was used for the experimental work. Laboratory tests were conducted on cement to determine specific gravity, fineness, standard consistency, initial setting time, final setting time and compressive strength. The results are presented in Table 3.1.

Table 3.1 Properties of Cement

Particulars	Values
Grade	OPC 53 Grade
Manufacturer	Dalmia
Specific gravity	3.13
Fineness	4%
Initial setting time	186 minutes
Final setting time	396 minutes
Standard	30.5%

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3.2.2 Nanosilica

Nanosilica was supplied by Visa chemical Industries Chemical Analysis of nanosilica was done by the manufacturer itself. The size of nanosilica (i.e. the mean particle diameter) was only 17.00 nm. The results given by the manufacturer are presented in Table.3.2.

Table 3.2 Properties of Nanosilica

Supply form	Liquid
Manufacturer	Visa chemical industries Mumbai
Colour	White
Silica(w/w)%	30.50
pH	9.78
Specific surface area	160 m^2/g
Mean particle diameter	17.00 nm
Specific gravity at 25 deg	1.214
Viscosity at 27 deg	12.60 sec

3.2.3 Fly ash

The fly ash, also known as pulverized fuel ash, is produced from burning pulverized coal in electric power generating plants. It is generally finer than Portland cement. Diameter of fly ash particles ranges from less than 1–150 µm. Fly ash color depends upon its chemical and mineral constituents. It can be tan to dark gray. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline), aluminum oxide (Al_2O_3) and calcium oxide (CaO), both being endemic ingredients in many coal bearing rock strata. Fly ash was collected from Tuticorin Thermal Power Plant and confirms to ASTM Class F. The specific gravity of fly ash was given by the manufacturer and is 2.08. The chemical composition of Fly ash is shown in Table 3.3

Table 3.3 Chemical composition of Fly ash

Compound	Percentage
CaO	0.72
SiO_2	60.28
Al_2O_3	31.76

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Fe_2O_3	0.89
SO_3	0.97
MgO	0.52
P_2O_5	1.42
TiO_2	0.64

3.2.4 Fine aggregate

Locally available good quality river sand was used. Laboratory tests were conducted on fine aggregates to determine the different physical properties as per IS 383 (Part III)-1970. River sand having fineness modulus 2.87 and specific gravity 2.63 was used as fine aggregate.

Fineness modulus is the index of coarseness or fineness of material. It is an empirical factor obtained by adding cumulative percentage of aggregate retained on each of the standard sieves and dividing this by 100.

The properties of fine aggregate are shown in Table 3.4. The sieve analysis details of fine aggregate are presented in Table 3.5. Fine aggregate used conforms to IS 383:1970 specification (Zone II). The gradation curve of fine aggregate is shown in Fig 3.1.

Table 3.4 Properties of Fine aggregate

Sl. No.	Particulars	Values
1	Specific gravity	2.63
2	Fineness modulus	2.87
3	Effective size	0.18mm
4	Uniformitycoefficient	3.83
5	Sand type	Medium

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Table 3.5 Sieve analysis of Fine aggregate

Sieve size (mm)	Weight retained in each sieve (kg)	Cumulative weight retained (kg)	Cumulative % weight retained	Percentage weight passing	IS Range for zone II
4.75	0.00	0.00	0.00	100	90 – 100
2.36	0.004	0.004	0.4	99.60	75 – 100
1.18	0.317	0.321	32.1	67.90	55 – 90
0.60	0.329	0.650	65.0	35.00	35 – 59
0.30	0.267	0.917	91.7	8.30	8 – 30
0.15	0.063	0.98	98.00	2.00	0 – 10

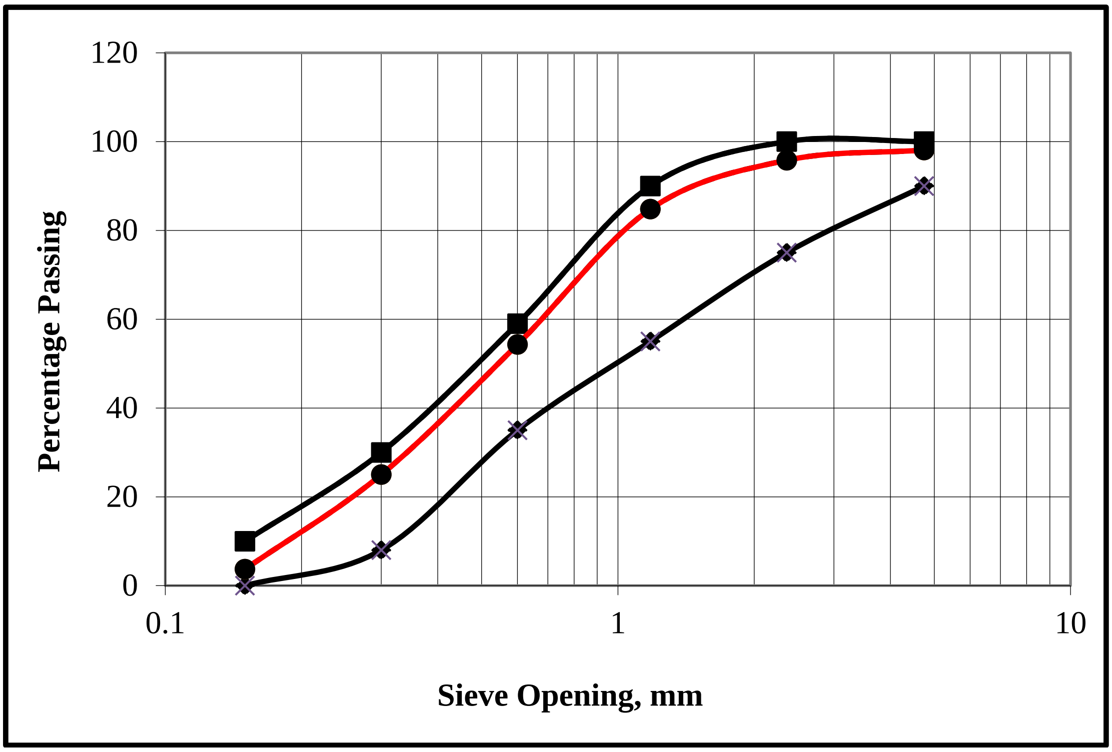

Fig 3.1: Grading curve for Fine aggregate

3.2.5 Coarse aggregate

The size of aggregate between 20mm and 4.75mm is considered as coarse aggregate. Laboratory tests were conducted on coarse aggregates to determine the different physical properties as per IS 383 (Part III)-1970.This

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test was conducted for 20mm size aggregate. This method is useful for finding the particle size distribution of aggregates. They were considered as per IS 2386 – Part I. The sieve analysis details of coarse aggregate are presented in Table 3.6. The properties of coarse aggregate are shown in Table 3.7.

Table 3.6 Sieve analysis of Coarse aggregate

Sieve size (mm)	Weight retained (kg)	Cumulative weight retained (kg)	% weight retained	Cumulative% weight retained	Percentage of passing
40	0	0	0	0	100
20	0.339	0.339	11.3	11.3	88.7
10	2.611	2.950	87.03	98.33	1.67
4.75	0.050	3.00	1.67	100	0
2.36	0	3.00	0	100	0
1.18	0	3.00	0	100	0
0.60	0	3.00	0	100	0
0.30	0	3.00	0	100	0
0.15	0	3.00	0	100	0

Table 3.7 Properties of Coarse aggregate

Sl No	Particulars	Values
1	Specific gravity	2.76
2	Fineness modulus	7.09
3	Water absorption	0.34%

3.2.6 Superplasticizer

The superplasticizer used was SikaViscocrete 20 HE is a high-performance new generation superplasticizer cum retarding admixture which lowers the surface tension of water and makes cement particles hydrophilic, resulting in excellent dispersion as well as controls the setting of concrete, depending on dosage. This increases the workability of concrete drastically and also facilitates excellent retention of workability. The workability offered at a lower water-cement ratio eliminates chances of bleeding and increased workability retention allows increased travel time. Reduced water-cement ratio reduces capillary porosity and improves water tightness. Improved workability facilities easy placing and good compaction, resulting in production of dense, impermeable concrete. The properties of SikaViscocrete 20 HE are listed in Table 3.8.

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Table 3.8 Properties of SikaViscocrete 20 HE

Supply form	Liquid
Colour	Light Brown
Chemical base	Modified Polycarboxylates
Relative density	1.08 kg/l at 30^0C
Recommended dosage	0.2% to 0.8% by weight of cement
Effect of over dosing	Bleeding may occur
Chloride content	Free
Manufacturer	Sika chemicals

Advantages of superplasticizer SikaViscocrete 20 HE is:

- Reduction in water-cement ratio of the order of 12-20 %
- Flowing, pumpable concrete
- Excellent workability and workability retention even in extreme temperatures
- High quality concrete of improved durability, reduces heat of hydration even with very high strength cements
- Compatible with mineral admixtures
- Waterproofing effect by drastic reduction in permeability of concrete

3.2.7 Water

Potable water is generally considered as being acceptable. Hence clean drinking water available in the college water supply system was used for casting as well as curing of the test specimens.

3.2.8 Reinforcement

HYSD bars of diameter 10mm and 8mm were used as main reinforcement and stirrup holders respectively. Two-legged 8mmΦ stirrups at 125mm c/c spacing were used as shear reinforcement. The properties of the bars are shown in Table 3.9

Table 3.9 Properties of Reinforcement Bars

Property	10mm diameter bars	8mm diameter bars
Young's Modulus (GPa)	247.48	225.42

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Yield stress (MPa)	455.45	434.54
Ultimate stress (MPa)	524.35	501.24

3.3 MIX PROPORTION

3.3.1 Introduction

The mix proportion for the **M_{30}** grade of concrete was arrived through trial mixes. The mix design was done with the help of **IS:10262-2009**.The mix proportion is shown in Table 3.10.

Table 3.10 Details of mix (M_{30})

Mix	Water	Cement	Coarse aggregate	Fine aggregate	Super plasticiser	W/C Ratio
1	157.07	365.33	1325.406	594.34	0.3%	0.43

3.3.2 Test specimens

Mixing was done in a laboratory type pan mixer. Pan mixers with revolving star of blades were used. While preparation of NS aggregates, cement and mineral admixtures were mixed in the revolving pan. After proper mixing, mixture of water and plasticizer was added. The mixing was continued until a uniform mix was obtained. The concrete was then placed into the moulds which were properly oiled. After placing of concrete in moulds proper compaction was given using the table vibrator. Specimens were demoulded after 24 hours of casting and were kept in a curing tank for water curing.

Standard moulds were used for casting 150mm cube specimen, 150mm diameter and 300mm height cylinders, 100mm diameter and 200mm height cylinders, 150mm diameter and 50mm height discs and 100x100x500mm beam specimens. A total of 343 specimens were casted and the details are given in Table 3.11.

Table 3.11 Details of test specimens

Serial no:	Specimen	Size(cm)	Numbers
1	Cubes	15x15x15	84
2	Cylinder	15 x 30	63
3	Cylinder	10 x 20	56
4	Beam	10 x 10 x 50	21
5	Cylindrical Disc	15 x 5	70
6	Cubes	10 x 10 x10	42
7	RC Beam	165 x 16 x 20	7
		Total	343

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3.3.3 Mix Designation

The study is limited to the preparation of 7 different types of mixes. One control mix and other three concrete mixes by replacing cement by NS in 0.5%,1.5% and 3% of the total weight of cementitious materials. The remaining three mixes are prepared by replacing cement by 25% of fly ash (kept constant) and varying the percentage of NS in 0.5%,1.5% and 3% of the total weight of cementitious materials. The various mix designation is shown in table 3.12

Table 3.12 Mix Designation

Mix Designation	Cement (%)	Fly ash (%)	Nano Silica (%)
R1	100	0	0
R2	74.5	25	0.5
R3	73.5	25	1.5
R4	72.0	25	3.0
R5	99.5	0	0.5
R6	98.5	0	1.5
R7	97	0	3.0

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Fig 3.2 Details of specimens after casting

3.4 WORKABILITY PROPERTIES OF FRESH CONCRETE

Fresh concrete or plastic concrete is freshly mixed material, which can be moulded into any shape. The relative quantities of cement, aggregate, nanosilica, chemical admixtures and water mixed together, control the concrete properties in the fresh state. Workability is defined as the ease with which concrete can be compacted. It is the property of concrete which determines the amount of useful internal work necessary to produce full compaction. The compacting factor tests as per IS: 1199:1959 specification is more appropriate in the case of high strength concrete which has low water binder ratio. Slump test was also done to measure the workability of nanosilica concrete. Also Vee bee and Flow test are used for finding out the workability of fresh concrete. **[**Shetty, *M. S., Concrete Technology Theory and Practice]*

3.5 MECHANICAL PROPERTIES OF HARDENED CONCRETE

3.5.1 Compressive strength

Testing of hardened concrete is important for controlling the quality of concrete. The main purpose of testing hardened concrete is to conform that the concrete has developed required strength. The compressive strength is one of the most important properties of hardened concrete and in general it is the characteristic value for classification of concrete in various codes. Compression test of cubes is the most common test conducted on hardened concrete because it is an easy test to perform and most of the desirable properties of concrete are comparatively related to its compressive strength. The compression test was carried out on cubical specimen of size 150mm × 150mm × 150mm in a compression testing machine of capacity 2000 kN, at a loading rate of 14N/mm^{2}per minute as per IS 516:1959 specification. The test was done on all the seven mixes for determining the 3rd day, 7th day, 28th day, 56th day and 90th day compressive strength.

To find cylinder compressive strength, the cylinder of size 150mm dia and 300mm height is kept on the bottom plate of the machine and the position of the cylinder is carefully checked to be in the centre of the plate. The cylinder is loaded at the rate of 14 N/mm^2/min up to failure. The cylinder compressive strength was determined for various NS mixes after 28 day water curing. Fig 3.3 shows compressive strength test on cube and cylinder.

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Fig 3.3 Compression test on cube and cylinder

3.5.2 Split tensile strength

The split tensile strength test is a well-known indirect test used for determining the tensile strength of concrete. Test was carried out on concrete cylinder of size 150mm × 300mm as per IS 5816:1999 specification. In split tensile strength test, concrete cylinder was placed with its axis horizontal, between the loading surface of a compression testing machine and the load was applied until the failure occurred due to a splitting in the plane, containing the vertical diameter of the specimen. In order to reduce the magnitude of high compression stress near the points of application of the load, narrow packing strips of plywood were placed between the specimen and loading plates of the testing machine. Fig 3.4 shows split tensile strength test on cylinder.

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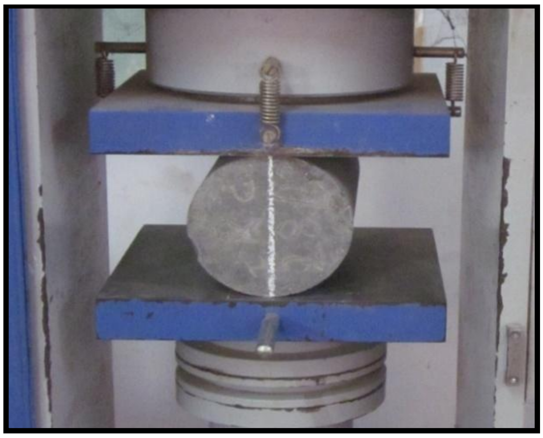

Fig 3.4 Split tensile strength test on cylinder

3.5.3 Modulus of elasticity

The modulus of elasticity was determined by subjecting cylinder specimen having 150 mm diameter and 300 mm height to uniaxial compression as per IS 516:1959 specification. The corresponding deformation by means of compressometer has been taken at each increment of loads. The gauge length of the compressometer is 20 cm. Dial gauge of compressometer gives the deformation under each increment of loading. Dial gauge reading divided by gauge length will give the strain and load applied divided by area of cross section gives the stresses. A series of reading were taken and the stress-strain graphs were plotted. From the stress-strain graph, the modulus of elasticity was obtained as slope of the graph. The modulus of elasticity was determined for all the seven NS mixes after 28 day and 56 day water curing. Fig 3.5 shows test setup for determining modulus of elasticity.

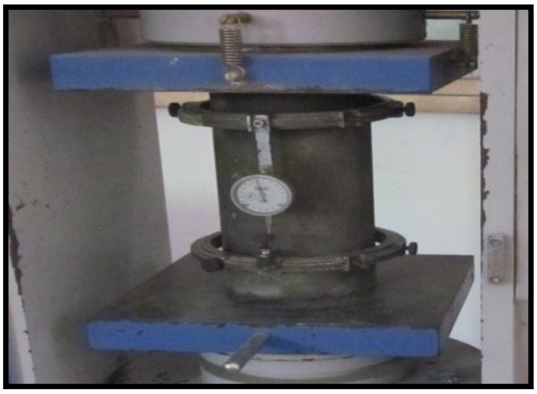

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Fig 3.5 Young's modulus test on cylinder

3.5.4 Flexural strength

Beam tests are found to be dependable to measure flexural strength property of concrete. Three beam specimens of size 100mm×100mm×500mm were tested for determining the flexural strength as per IS 516:1959 specification. Two-point loading was applied and breaking load was noted. The flexural strength was determined for all NS mixes after 28 day water curing. Fig 3.6 shows flexural strength test on beam.

Fig 3.6 Flexural strength test on beam before and after loading

3.5.5 Impact resistance

Impact resistance is one of the important attributes of concrete. Depending upon the impacting mechanism and parameters, there are different tests and among them the drop weight test or the repeated impact is the simplest one. According to this test, impact resistance is characterized by a measure of the number of blows in a repeated impact test to achieve a prescribed level of distress. This number serves as a qualitative estimate of the energy absorption capacity by the specimen at the levels of distress specified.

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As per the ACI 544-2R-89, the equipment for the drop-weight impact test consists of:

- A standard, manually operated 4.54 kg compaction hammer with 457-mm drop
- A 63.5 mm diameter hardened steel ball, and
- A flat base plate with positioning bracket.

Concrete samples of size 150 mm diameter and 50 mm thickness were used. The samples were coated on the bottom with a thin layer of petroleum jelly or heavy-duty grease and placed on the base plate within the positioning legs keeping the finished (cast) face up. The positioning bracket is then bolted in place, and the hardened steel ball is placed on top of the specimen within the bracket. Foamed elastomer pieces are placed between the specimen and positioning legs to restrict movement of the specimen during testing, till the first visible crack. The drop hammer is placed with its base upon the steel ball and held there with just enough down pressure to keep it from bouncing off the ball during the test. The base plate should be bolted to a rigid base, such as a concrete floor or cast concrete block. The hammer is dropped repeatedly, and the number of blows required to cause the first visible crack on the top and to cause ultimate failure were both recorded. The foamed elastomer is removed after the first visible crack is observed. Ultimate failure is defined as the opening of cracks in the specimen sufficiently so that the pieces of concrete are touching three, out of the four, positioning legs on the base plate.

A general arrangement of drop weight test is illustrated in Fig. 3.7. The impact strength for all the mixes was determined after 28 day water curing. Fig 3.8 shows the test equipment for impact strength test.

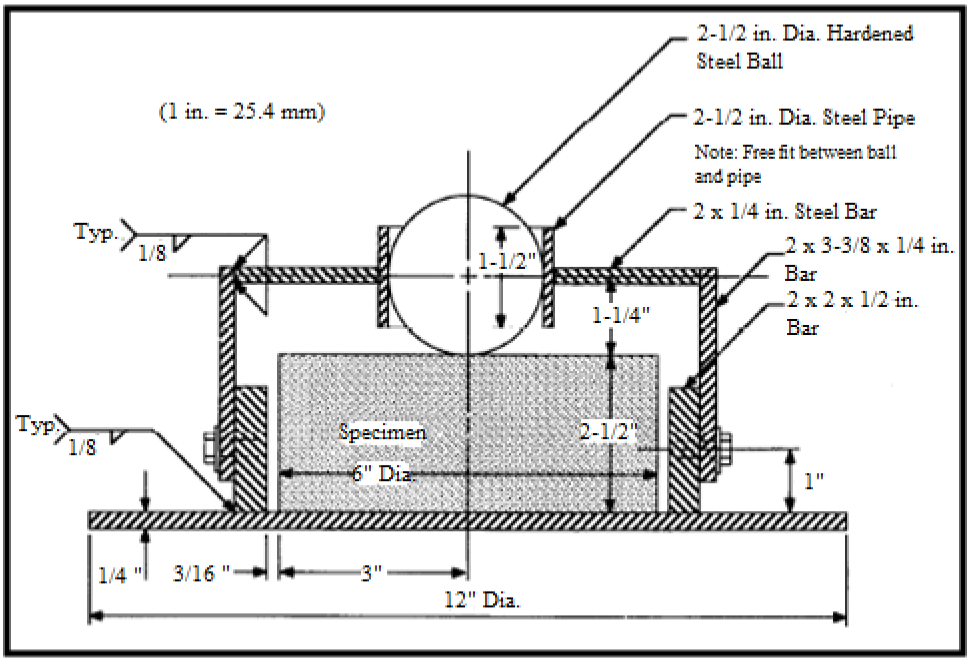

Fig.3.7 Section of test equipment for impact strength test

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Fig.3.8 Test equipment for impact strength test

3.6 DURABILITY TESTS ON HARDENED CONCRETE

Durability study of concrete is very important for controlling the quality of any concrete. The main purpose of durability study on concrete is to record the durability performance of the concrete under different environment condition. The main tests carried out to determine durability of high-performance concrete are acid test, sulphate resistance test, bulk diffusion test and rapid chloride permeability test.

3.6.1 Sulphuric acid attack test

To check the durability of NS mixes against sulphuric acid, 100mm concrete cube specimens were tested based on modified ASTM C 267-01 test method. After 7 days of water curing, the concrete specimens were exposed to 3% sulphuric acid solution for 56 days and 90 days, and the surface colour change and surface deterioration were studied.

The 3% sulphuric acid solution was prepared by diluting 98% concentrated sulphuric acid with tap water. After 56 days and 90 days of acid exposure, specimens were tested for compressive strength. The compressive strength of NS in water curing is then compared with NS mixes exposed to acid environment. Fig. 3.9 shows specimen exposed to 3% sulphuric acid solution.

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Fig 3.9 Specimens exposed to 3% sulphuric acid solution

3.6.2 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, after 7 days of water curing, were exposed to sodium sulphate solution for 56 days and 90 days. The sulphate solution was prepared by dissolving 52 gm of $MgSO_4.7H_2O$ in one lite of water. The test was conducted based on ASTM C 452-02 test method. After 56 days and 90 days of sulphate exposure, specimens were tested for compressive strength. The compressive strength of NS in water curing is then compared with NS mixes exposed to sulphate environment. Fig 3.10 shows specimen exposed to sulphate solution.

Fig 3.10 Specimens exposed to sulphate solution

3.6.3 Bulk diffusion test

The test proposes to assess the chloride attack on concrete specimen by measuring the depth of chloride penetration into the concrete specimen. This test method was based on Italian Standard (UNI) in which a chemical manifests a colour change boundary in response to the quantity of chloride ions present. In this test, cylinder of

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100 mm diameter and 200mm length was used as test specimen. After 7 days of water curing, the concrete specimens were exposed to 1.8 Molar NaCl solution for 56 days and 90 days. After 56 days and 90 days of exposure the specimens were split by applying splitting tensile force. To the split face, 0.1 Molar Silver Nitrate ($AgNO_3$) solution was sprayed to observe the colour changes ie, up to the penetrated depth of chloride ion, a white precipitation will form and thus the depth of chloride ions can be found out. Fig 3.11 shows specimen exposed to chloride solution.

Fig 3.11 Specimens exposed to NaCl solution

3.7. STUDY OF FLEXURAL BEHAVIOUR OF RCC BEAMS

3.7.1 General

Beams were tested after 28 days of water curing. Flexure test was performed under two point loading with pure bending at central zone of 50cm.Schematic diagram of flexure testing is shown in Fig.3.12. A proving ring of capacity 500 kN was used to measure the applied load. Load was applied at an increment of three divisions of proving ring which was calibrated with the help of UTM. The load for three div is obtained as 2.234kN from its calibration chart. A square rod was used as the spreader beam. Three dial gauges of accuracy 0.01mm were used to measure the deflection at mid span and at the load points. The load at which first crack occurred was noted and the propagation of cracks were marked on the surfaces for every intervals of loading. The crack width for every increment of loads until failure was noted using a micrometer microscope of accuracy 0.1mm. The details of the test setup for flexure are shown in Fig. 3.13.

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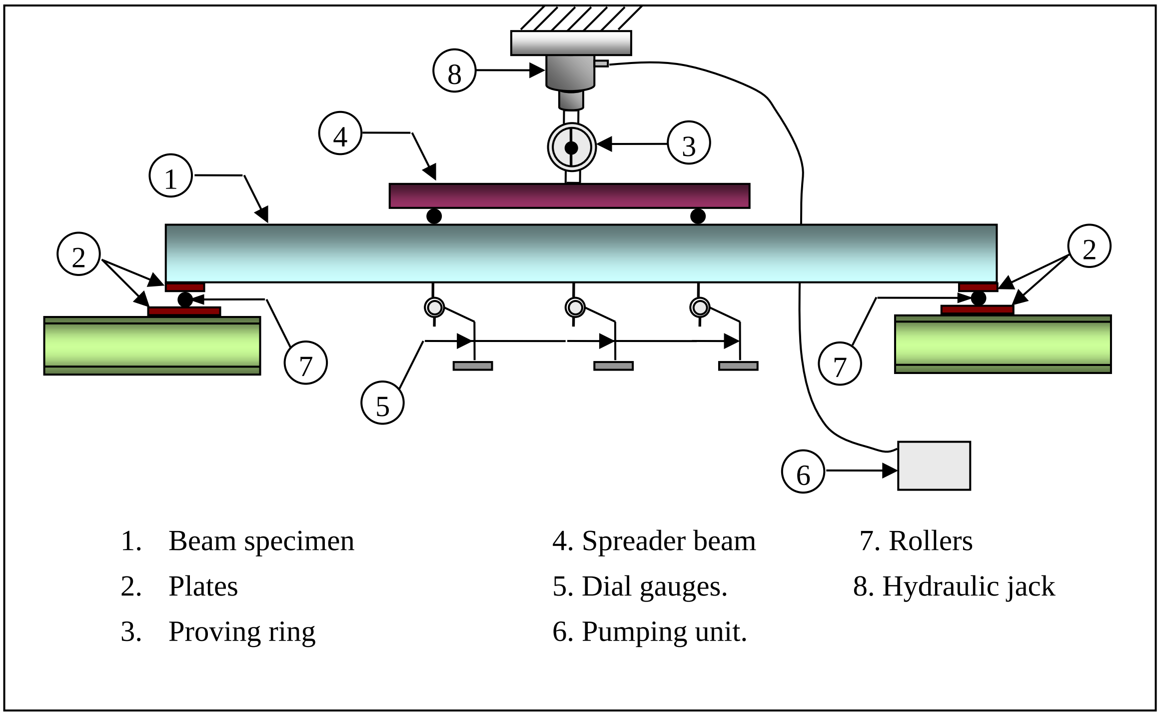

Fig. 3.12 Schematic Diagram of Flexure Test

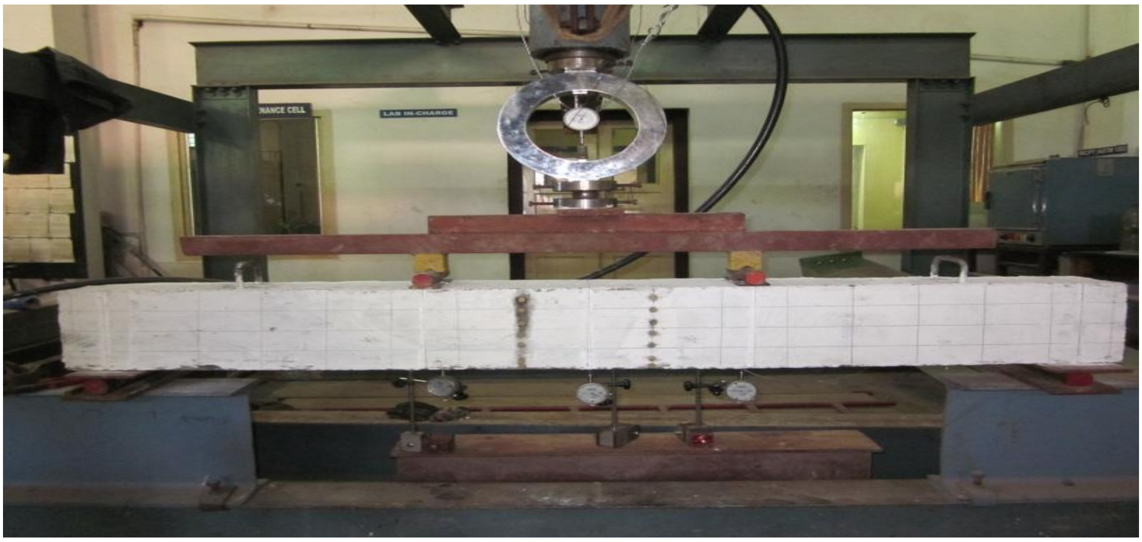

Fig. 3.13 Test Setup for Flexure

3.7.2 Design of reinforced concrete beams

The beams were designed as under reinforced sections as per IS 456:2000 stipulations. All the beams have the same dimensions of overall length 1.65m with effective span of 1.5m. The cross-sectional area of the beam is 150mm×200mm with an effective depth of 162mm. The clear cover provided was 25mm. Two 10mmΦ HYSD bars of 415 grades were provided at bottom as tension reinforcement and two 8mmΦ HYSD bars of 415 grades at top as stirrup holders. Two-legged 8mmΦ stirrups at a spacing of 123mm c/c were provided as shear reinforcement. [Park, R., and T. Paulay, Reinforced concrete structures] The details of the reinforcement provided are shown in Fig. 3.14.

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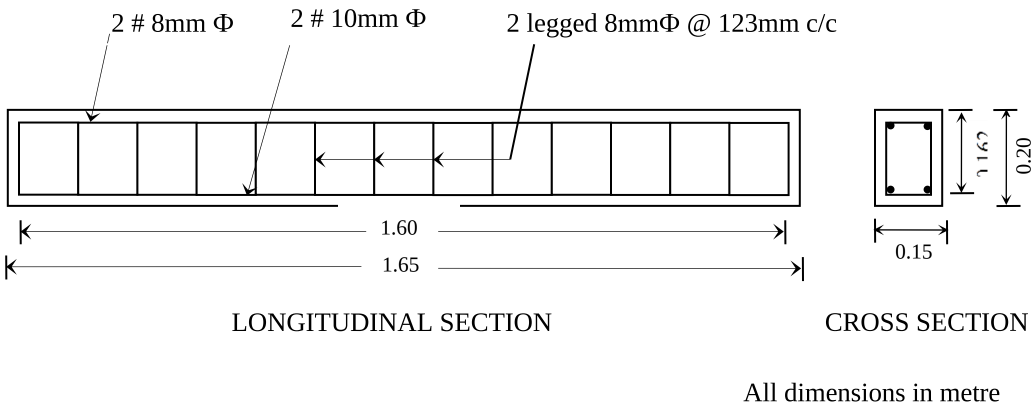

Fig. 3.14 Reinforcement Configuration

3.7.3 Preparation of test specimens

Mixing of concrete is done in a laboratory type pan mixer. Pan mixers with revolving star of blades are reported to be more efficient. The bottom and inner sides of mould was oiled before laying the concrete. Reinforcement cage was properly placed and proper covering was ensured by providing covering blocks at bottom as well as at the sides of the reinforcement cage. Then concrete was placed in the mould in layers and compaction was given using needle vibrator. Slump test and compacting factor test were conducted for each mix to assess the workability. Moulds for beams were fabricated using well-seasoned wooden planks. To avoid leakage, Plaster of Paris was used to seal the gaps and joints inside the mould Fig. 3.15 shows the details of the mould used for casting beam specimens.

Fig. 3.15 Mould for Beam Specimen

Control specimens were also cast for each series of beams and compaction was done by table vibration. Fig. 3.16 shows the details of casting of beam specimens.

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Fig. 3.16 Casting of Beam Specimens

All the specimens were demoulded after 24 hours. Control specimens were kept in a curing tank for water curing for the next 28 days. The control specimens to be tested were taken from the curing tank on 7th and 28th day of curing. The casted beams were water cured by covering it with wet gunny bags for 28 days. Fig.3.17 shows curing of beam specimens. Before testing, a coat of white wash was applied to the beam specimens to facilitate the observations of crack pattern during the test.

Fig. 3.17 Curing of Beam Specimens

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CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 GENERAL

The strength and durability studies were conducted on according to the procedures described in the previous chapter. For determining the fresh properties of concrete workability test were carried out. The results obtained were tabulated and detailed analysis and discussion on the results is presented in this chapter. The test results cover the effect of nanosilica and fly ash as cement replacement on the fresh, mechanical and durability properties of NS concrete.

4.2 WORKABILITY TEST RESULTS

At present standard methods are available to measure the workability of NS concrete. The slump test, compacting factor test, flow test, vibe test are the standard test available to measure the workability of NS concrete. The workability of various mixes was assessed as per the IS 1199:1959 specification. Table 4.1 shows the results of workability tests for various mixes.

Table 4.1 Workability results of various mixes

Type of Mix	Workability			
	Compacting Factor	Slump(mm)	Flow Test (%)	Veebee (sec)
R1	0.926	42	50.66	6.8
R2	0.946	47	56	6.3
R3	0.953	50	59.87	6.1
R4	0.962	52	61.3	5.9
R5	0.935	45	53.2	6.5
R6	0.942	46	54.7	6.4
R7	0.951	49	57.33	6.3

The values of compacting factor ranged between 0.926 and 0.962. The degree of workability was found to be high for all nanosilica concrete mixes compared to the control mix. The values of compacting factor and slump, vee bee time, and flow percentage showed same pattern. The minimum workability for control mix R1 and for mixes R2 R3 and R4 the workability gradually increases and it is maximum for mix R4. The higher workability of R4 mix may be due to the filling of complete voids in the mixes by the nanosilica and increases the flowability of the

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mix. Another reason for this is the small particle size of nanosilica which provides a larger surface area, and speeds up the rate of cement hydration and pozzolanic reactions. For mixes R5 R6 and R7 the workability of the concrete increases with reference to the control mix and not as much of mixes from R2 to R4. The reason for this is the fly ash used for the purpose is more fine fly ash the surface area for the same is more. So for the mixes containing fly ash and NS have more workability than mixes containing only cement and NS. The values of compacting factor, slump flow percentage, and vee bee time follow the same pattern. The details of variation of workability are shown in Fig 4.1 to Fig 4.4.

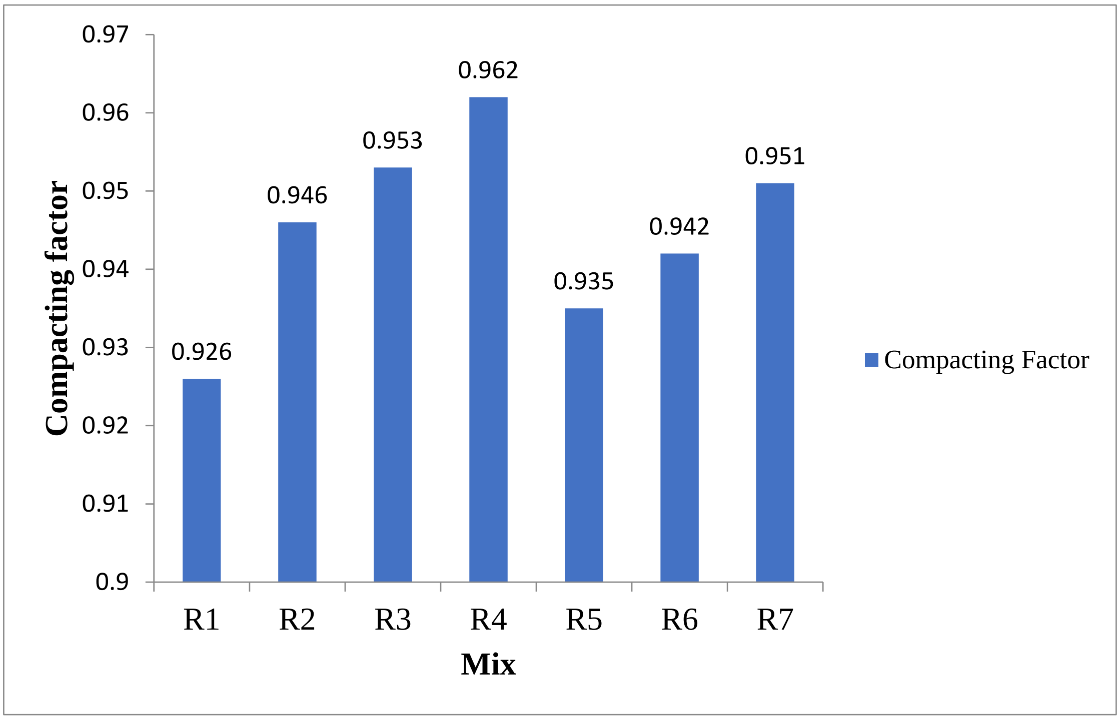

Fig 4.1 Compacting factor for various mixes

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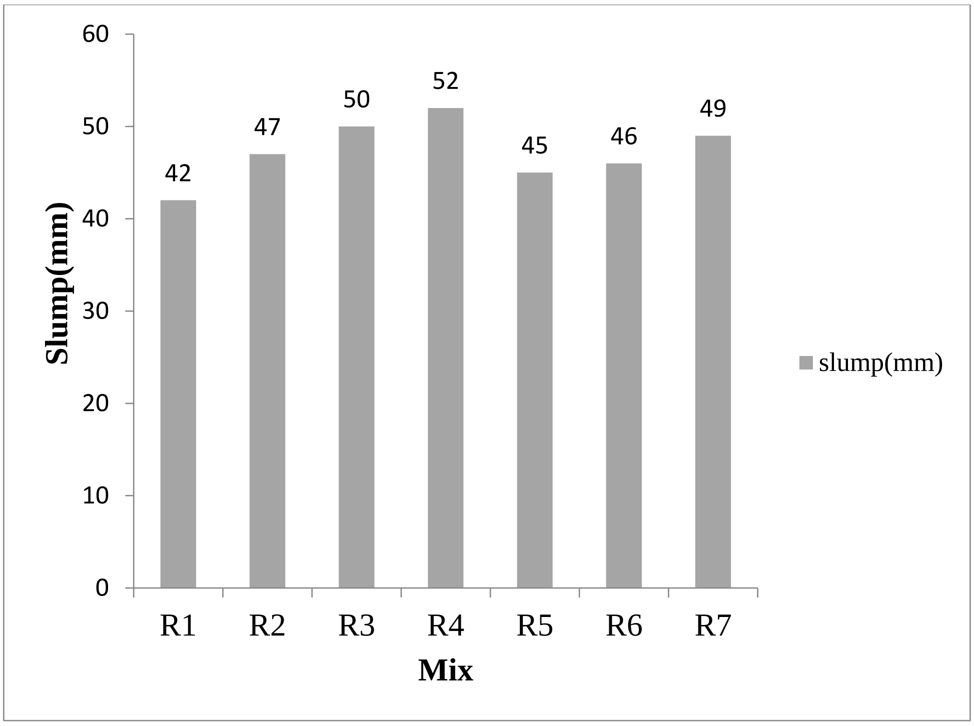

Fig 4.2 Slump values for various mixes

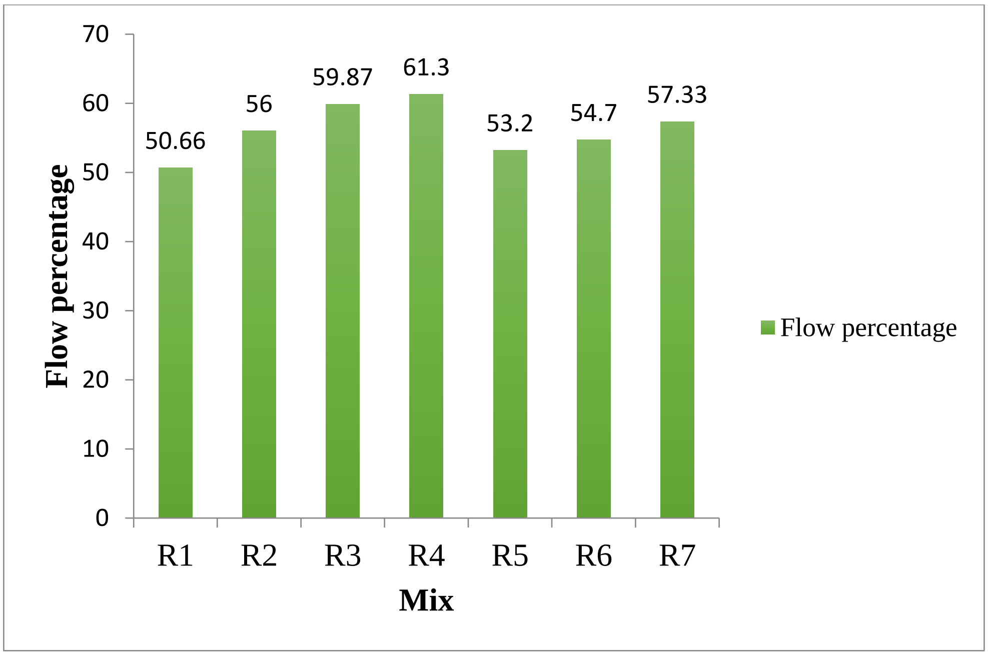

Fig 4.3 Flow percentage for various mixes

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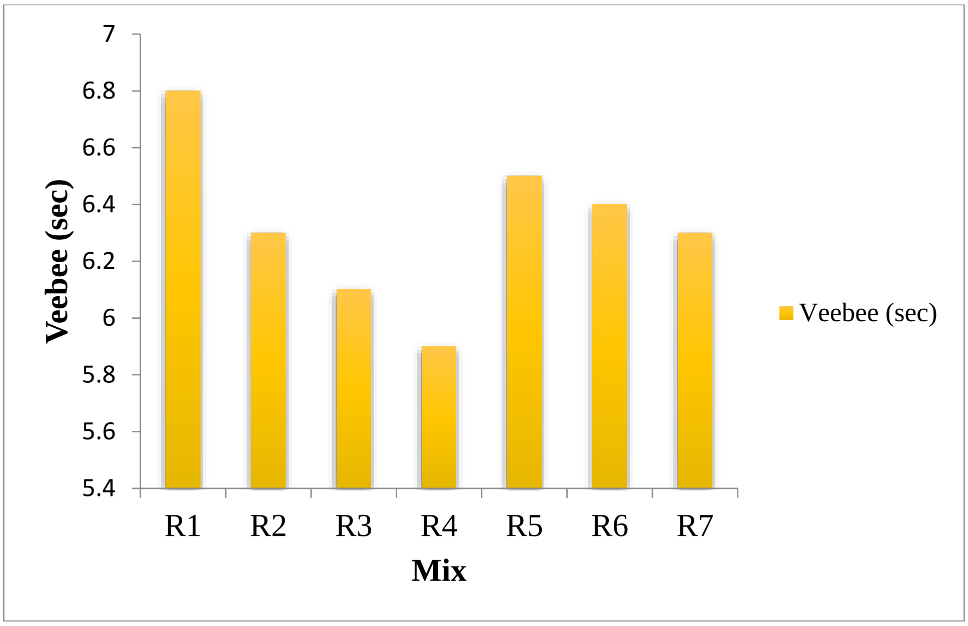

Fig 4.4 Vee bee time for various mixes

4.3 RESULTS OF MECHANICAL PROPERTIES

Testing on hardened concrete is important for controlling the quality of concrete. The main purpose of testing hardened concrete is to conform that the concrete has developed required strength. The various tests carried out to determine the mechanical properties of hardened concrete are compressive strength, split tensile strength, modulus of elasticity, flexural strength and impact resistance.

4.3.1 Compressive strength

For each NS mix, three cube specimens of size 150mm × 150mm × 150mm and cylinder specimens of 150mm dia and 300mm height were tested for compressive strength. Cubes were tested after 3, 7, 28, 56 and 90 days of water curing and cylinders after 28 day and 56 day of water curing. The average cube compressive strength for the various NS mixes is shown in Table 4.2. Fig 4.5 shows the cube compressive strength for NS mixes at different ages.

Table 4.2 Average cube compressive strength for various mixes

Mix	Cube Compressive strength for various mixes (N/mm^2)				
	3 day	7 day	28 day	56 day	90 day
R1	29.48	39.36	51.56	56	60.14
R2	25.19	32.74	47.26	51.26	54.81
R3	25.63	33.04	48.29	52.59	55.70
R4	26.22	34.22	49.78	53.78	56.14
R5	30.81	41.92	53.62	58.81	63.70
R6	31.85	42.81	54.81	59.90	64.88
R7	33.11	45.03	57.92	61.77	66.22

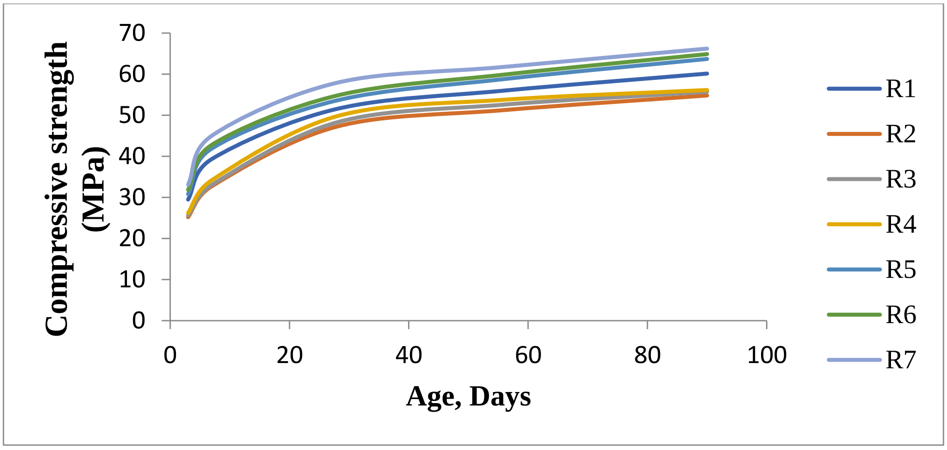

Fig 4.5 Cube compressive strength for various mixes at different ages

From Figure 4.5 it is clear that NS mix has greater strength than control mix at all ages due to its extreme fineness and faster pozzolanic reaction. The compressive strength was found to be high for mixes (R5 R6 and R7) which might be due to the addition of nanosilica. In the case of mixes R2 R3 and R4 the compressive strength get reduced. The reduction in compressive strength is due to the presence of fly ash, but when the percentage of nanosilica increases the reduction in compressive strength is getting reduced. The maximum compressive strength is obtained for mix R7. The percentage increase in the strength of R7 mix is about 8%. The increase in the strength due to the addition of nanosilica is due to the fine size of NS fill the complete voids in the mixes and increases the matrix densification of the mix. Another reason for this is the small particle size of nanosilica provides a larger surface area, which speeds up the rate of cement hydration and pozzolanic reactions.

Table 4.3 and Fig 4.6 show the average cylinder compressive strength for the 28day and 56day water cured mixes. 28 and 56day cylinder strength variation was similar to that of the 28 and 56day cube compressive strength variation. The maximum cylinder compressive strength is for R7 mix and minimum cylinder compressive strength for R2 mix. In the case of mixes R2 R3 and R4 the compressive strength gets reduced due to the presence of fly ash.

Table 4.3 Average cylindrical compressive strength for various mixes

Mix	Cylindrical Compressive strength for various Mixes (N/mm^2)	
	28 day	**56 day**
R1	35.06	38.80
R2	31.66	35.77
R3	32.99	37.08
R4	33.85	33.18
R5	36.72	43.63
R6	38.09	43.67
R7	41.12	45.09

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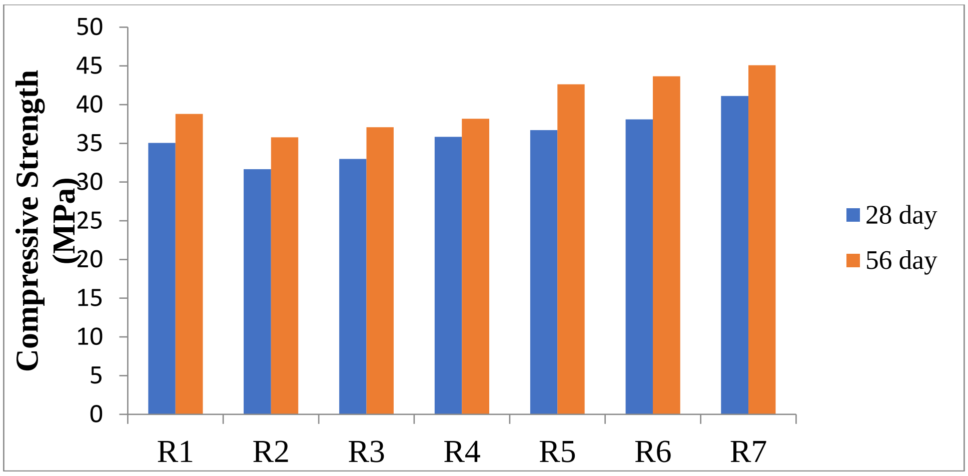

Fig 4.6 Average cylinder compressive strength for various mixes

4.3.2 Split tensile strength

For each NS mix, cylinder specimens of size 150mm dia and 300mm height were tested for determining the split tensile strength. Table 4.4 shows the details of test results for split tensile strength. Fig 4.7 shows the variation of split tensile strength for various NS mixes. Split tensile strength also showed a similar variation as that of compressive strength. By replacement of cement by NS from mixes R5 to R7 there is a gradual increase in the strength due to the presence of NS. From mixes R2 to R4 the strength gets reduced by the introduction of fly ash, but the percentage of nanosilica increases the reduction in strength gets decreases.

Table 4.4 Average cylindrical split tensile strength for various mixes

Mix	Split Tensile strength for various Mixes (N/mm^2)	
	28day	56day
R1	4.24	4.46
R2	4.67	3.75
R3	3.81	3.89
R4	4.03	4.04
R5	4.52	4.67
R6	4.74	4.81
R7	4.88	5.02

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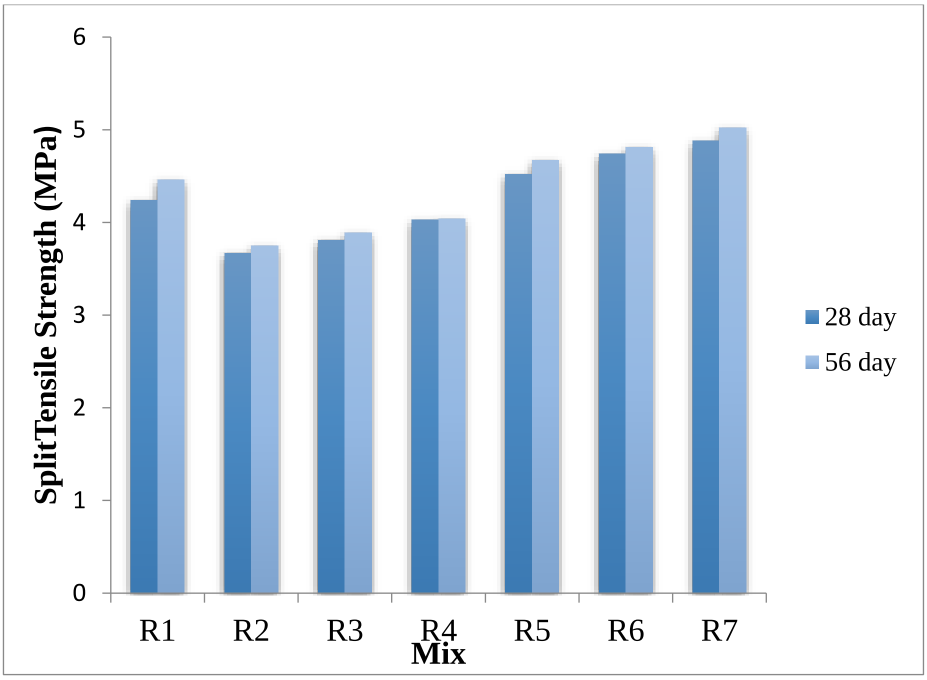

Fig 4.7 Split tensile strength for various mixes

The higher split tensile strength for NS mix 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

4.3.3 Modulus of elasticity

The Young's modulus values are obtained from stress-strain diagram obtained by carrying out the test on 150mm dia and 300mm height cylinders. Fig 4.8 shows the Modulus of elasticity for the 28- and 56-day mixes. 28 and 56 day variation Modulus of elasticity was similar to that of the 28 day and 56 day compressive strength with maximum strength for Modulus of elasticity R7 mix and minimum Modulus of elasticity for R2 mix. In the case of mixes from mixes R2 to R4 Modulus of elasticity get reduced. From R2 to R4 the percentage of nanosilica increases the reduction in Modulus of elasticity get reduced. From the results nanosilica shows some later stage strength development due to its pozzolanic action. Table 4.5 and fig 4.8 shows the variation of modulus of elasticity.

Table 4.5 Modulus of elasticity for various mixes

Mix	Modulus of Elasticity for various mixes (N/mm^2)	
	28 day	56 day
R1	36.2	36.8
R2	31.23	31.29

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R3	32.63	33.1
R4	34.24	34.89
R5	37.1	37.3
R6	38.9	39.1
R7	39.59	39.97

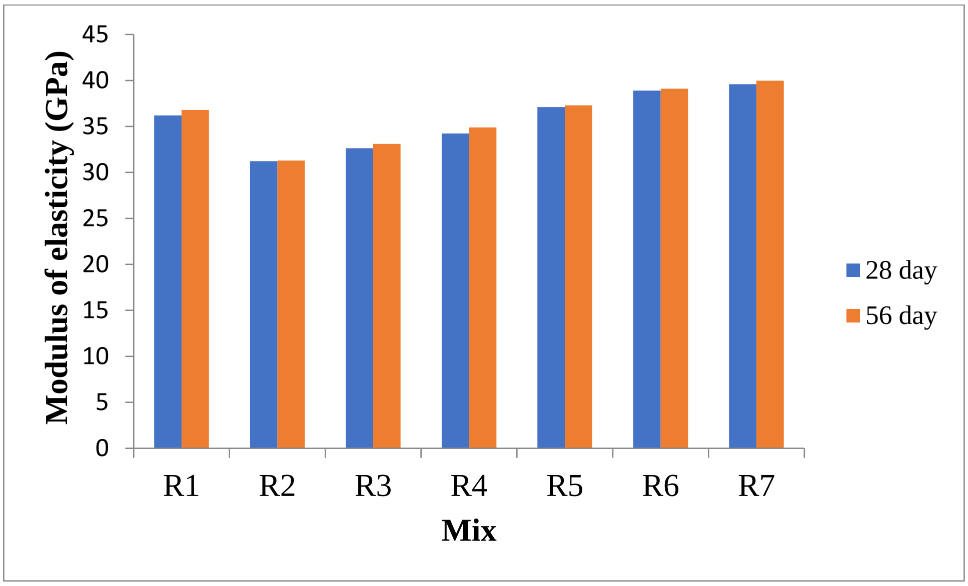

Fig 4.8 Modulus of elasticity for various mixes

4.3.4 Flexural strength

Beam specimens of size 100mm×100mm×500mm were tested for determining the flexural strength of various NS mixes. Table 4.6 and fig 4.9 shows the variation of flexural strength for NS mixes. From the values it can be seen that the variation of flexural strength for various NS mixes is similar to that of the variation of split tensile strength with a maximum value for R7 mix and a minimum value for R2 mix. The higher flexural strength for R7 mix may be due to the additional binding property of nanosilica because of high pozzolanic reaction and cement paste – aggregate interfacial refinement leading to higher bond strength.

Table 4.6 Flexural strength for various mixes

Mix	Flexural strength for various mixes (N/mm^2)	
	28 day	56 day
R1	4.46	4.59
R2	3.78	3.79
R3	4.05	4.19

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R4	4.19	4.32
R5	4.72	4.86
R6	4.88	4.99
R7	5.04	5.27

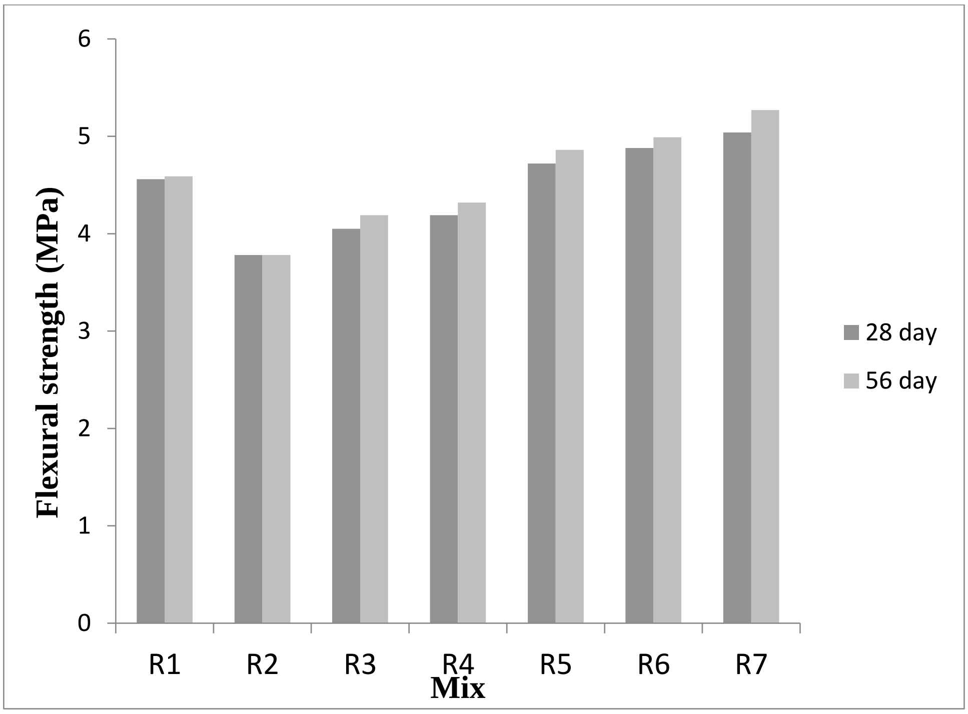

Fig 4.9 Flexural strength for various mixes

4.3.5 Impact resistance

Dynamic energy absorption or strength is called as impact resistance and is one of the major attributes of concrete. Here the repeated impact test or drop weight test was conducted to determine the number of blows to achieve a prescribed level of distress of the specimen. To determine the impact resistance of concrete the first crack and ultimate failure of specimens were determined. The resistance offered by the concrete was found out using this test. Fig 4.10 shows the variation of impact resistance for different NS mixes. The results obtained from the experimental investigation are given in Table 4.7 and Fig 4.10

It can be seen that the pattern of variation of impact resistance for various NS mixes is similar to that of the variation of compressive strength. Compared to all other mixes R7 mix has a higher impact resistance this 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.

Table 4.7 Impact resistance for various mixes

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Mix	No of blows for first crack(X)	No of blows for ultimate failure(Y)	Y-X
R1	32	39	7
R2	24	30	6
R3	25	32	7
R4	27	34	7
R5	31	37	6
R6	33	39	6
R7	36	43	7

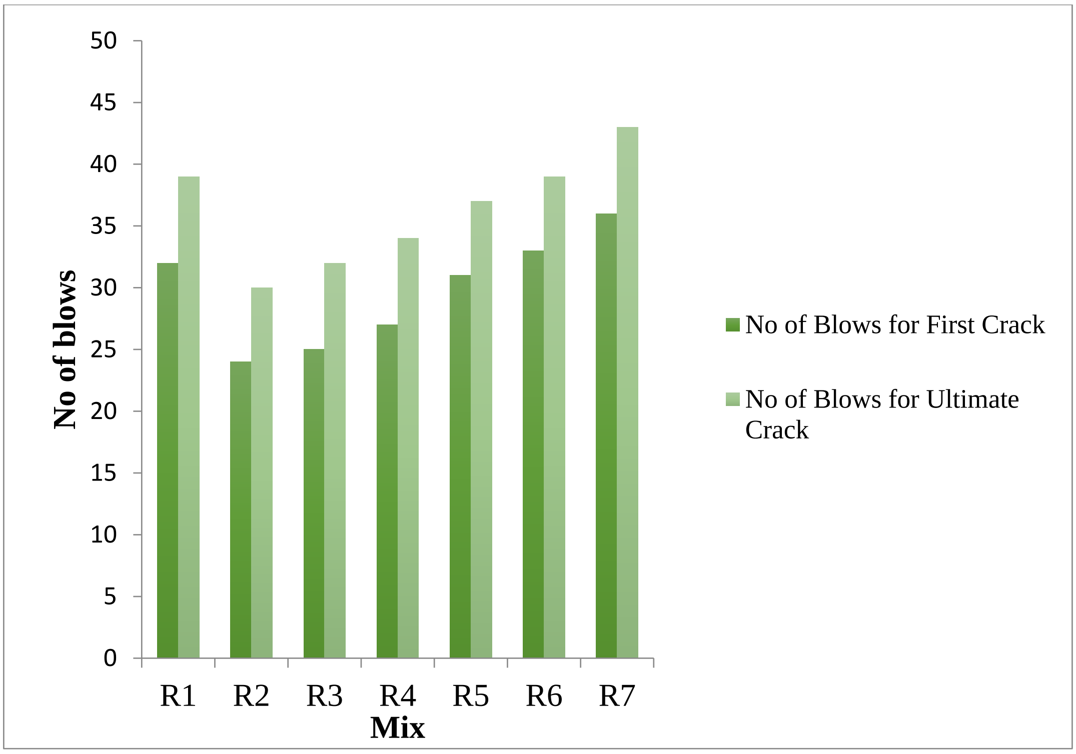

Fig 4.10 Impact resistance for various mixes

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4.4 DURABILITY TEST RESULTS

Durability study of concrete is very important for controlling the quality of any concrete structure. The main purpose of durability study on concrete is to record the durability performance of the concrete under different environment condition. The main tests considered in this study on the durability of NS are acid attack test, sulphate attack test, bulk diffusion test

4.4.1 Sulphuric acid attack test

Strength Loss

The strength loss of cubes in 3% sulphuric acid solution was determined by the cube compressive strength. Table 4.8 shows the values of loss in compressive strength due to acid attack. Fig 4.11 shows the appearance of concrete cubes after exposure to acid environment. 7day water cured cube specimens of size 100mm×100mm×100mm, after being exposed to sulphuric acid solution for 56 and 90 day were tested, and the result is compared with 28day water cured specimens of the same mix. Fig 4.12 shows the compressive strength variation for various NS mixes exposed to acid environment.

Table 4.8 Compressive strength of various mixes subjected to acid attack

Mix	Compressive strength (N/mm^2)		
	28 day water Curing	7 day water curing	
		56 day acid exposure	90 day acid Exposure
R1	51.56	34.02	28.87
R2	47.26	33.90	29.60
R3	48.59	34.80	31.84
R4	49.78	35.96	32.65
R5	53.62	37.13	34.43
R6	54.81	38.99	35.89
R7	57.92	40.94	37.77

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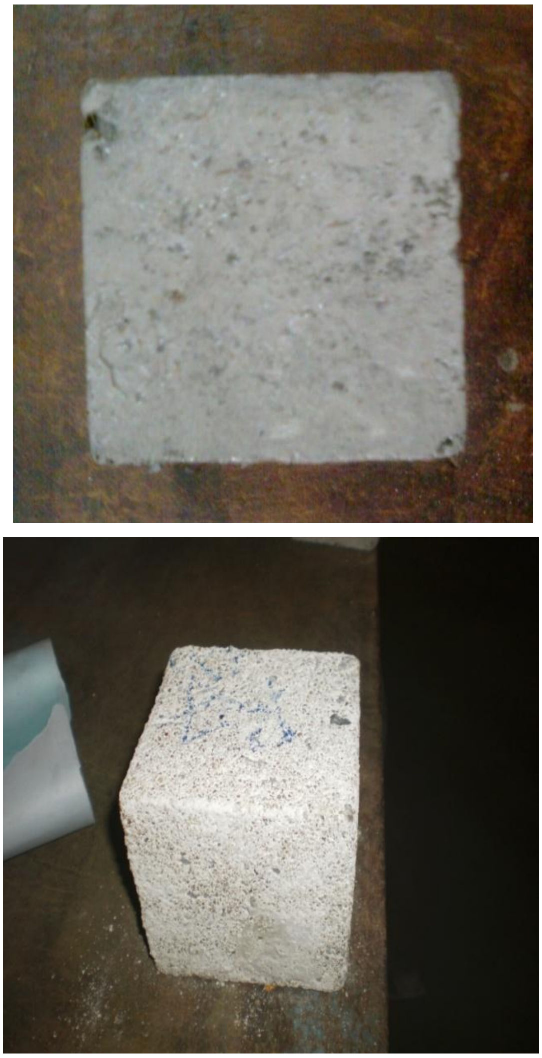

Fig 4.11 Appearance of concrete cube before and after acid exposure

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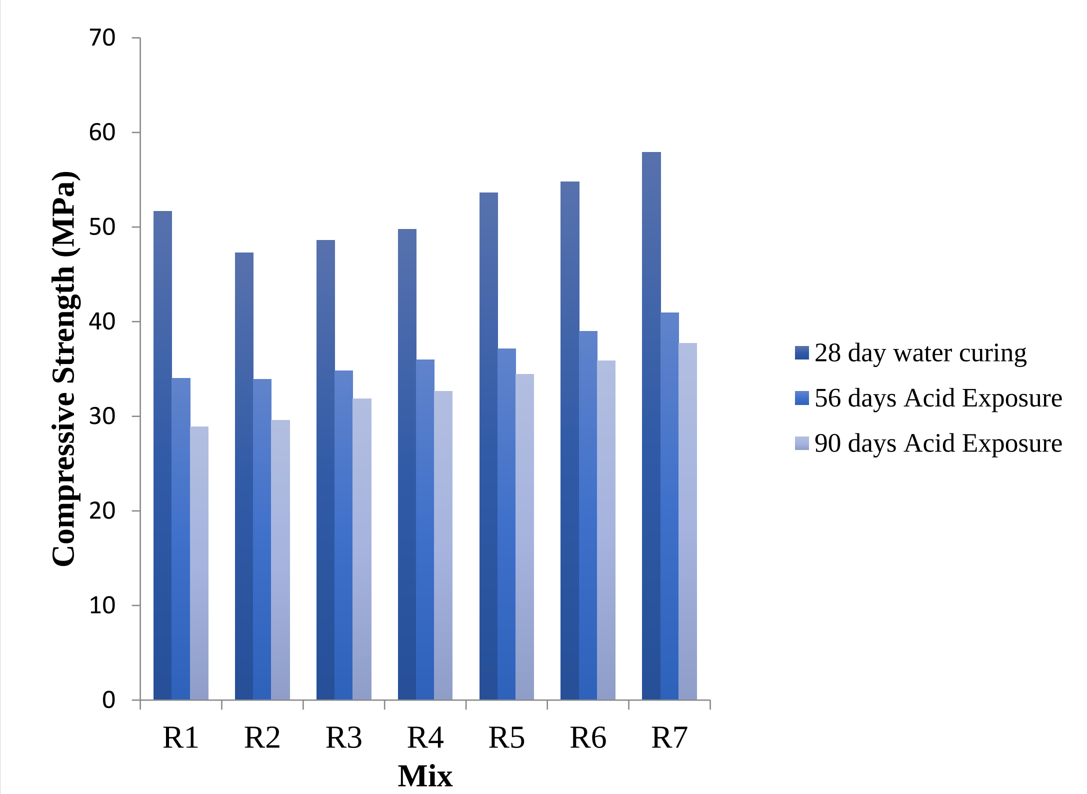

Fig 4.12 Strength loss due to acid attack

But the percentage of nanosilica increases the percentage of strength reduction reduces. The reason for this is during the hydration reaction nanosilica reduces the amount of Ca $(OH)_2$. The reduction in strength 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. From the table it is clear that compared to all other mixes the strength loss is maximum for R1 mix than the others. By comparing the compressive strength at 56 day and 90day acid exposure it can be seen that the rate of strength loss was minimum for nanosilica mixes than the control mix.

Mass Loss

The percentage of mass loss was found for 56 day and 90day acid exposed specimens by comparing the mass with 28day water cured specimen mass. Table 4.9 shows the mass loss percentage for various NS mix when exposed to 3% sulphuric acid after 7day water curing. Table 4.9 gives the values of mass loss due to acid exposure. Fig 4.13 shows the variation of mass loss percentage for various NS mixes exposed to acid environment.

Table 4.9 Mass loss % when exposed to 3% sulphuric acid after 7day water curing

Mix	Mass(kg) After 28day water curing	mass (kg) After 56day acid curing	mass (kg) After 90day acid curing	% of mass loss on 56day acid exposure	% of mass loss on 90day acid exposure

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R1	2.485	2.399	2.344	3.48	5.69
R2	2.489	2.411	2.361	3.13	5.15
R3	2.494	2.417	2.369	3.05	5.02
R4	2.498	2.424	2.377	2.95	4.84
R5	2.520	2.447	2.414	2.91	4.20
R6	2.535	2.470	2.430	2.56	4.14
R7	2.569	2.508	2.478	2.37	3.54

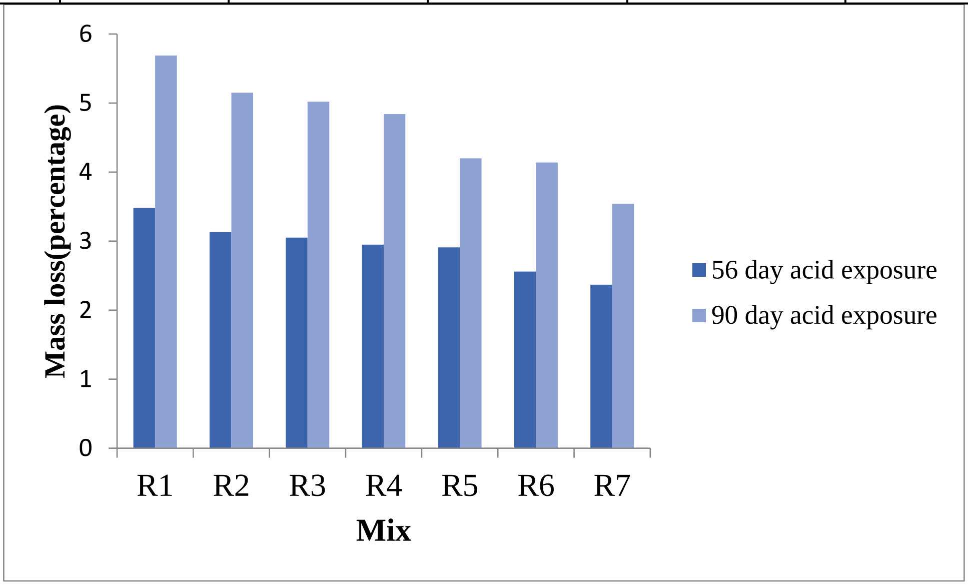

Fig 4.13 Mass loss percentage for various NS mixes

From the experimental investigation it is clear that the percentage of mass loss is maximum for the control mix compared to all other mix. The mass loss percentage was minimum for R7 mix for 7day water curing. For all NS mix the mass loss percentage should be decreasing by the increase in the percentage of nanosilica mass loss can be considerably decreased. The main reason for the same is the larger surface area of NS. Concrete with NS shows good resistance against acid attack.

4.4.2 Sulphate attack test

The concrete cubes were found visually intact after immersion of cubes in (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). Table 4.10 shows the test results for various NS mixes subjected to sulphate attack. Fig 4.14 shows the appearance of cube specimens after sulphate exposure. Fig4.15 shows the compressive strength variation for various NS mixes exposed to sulphate solution.

Table 4.10 Compressive strength of various mixes subjected to sulphate attack

Mix	**Compressive strength (N/mm²)**		
		7 day water curing	
	28 day water	**56 day acid**	**90 day acid**

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	curing	**exposure**	**Exposure**
R1	51.56	49.87	49.43
R2	47.26	45.1	44.38
R3	48.59	46.58	46.28
R4	49.78	47.86	47.53
R5	53.62	52.06	51.57
R6	54.81	53.4	53.82
R7	57.92	56.55	56.01

Fig 4.14 Appearance of cube after sulphate exposure

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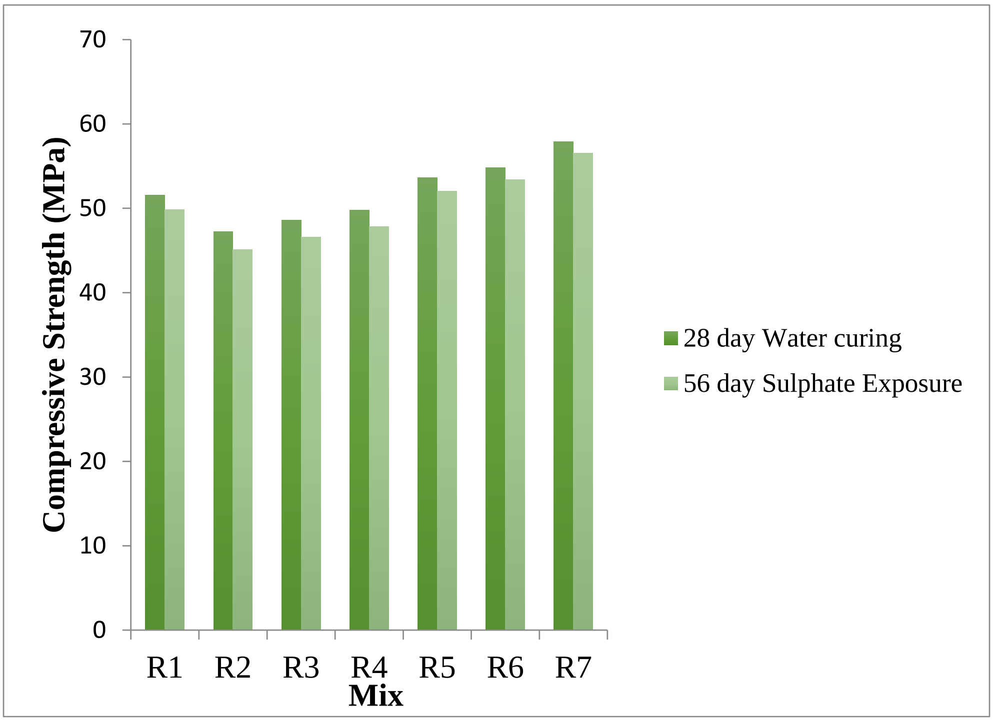

Fig 4.15 Effect of sulphate attack on various mixes (7day water curing)

From this study it is observed that when the concrete specimen is immersed in the 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 figure it is clear that compared to all other mixes the strength loss is maximum for the R1 (ordinary concrete) mix than NS mix. Comparing the strength corresponding to 56 and 90day sulphate exposure the rate of strength loss was found to be minimum for R7 mix compared to other mixes. By the addition of nanosilica the sulphate resistance of concrete mix was improved.

4.4.3 Bulk diffusion test

The test was carried out to determine the depth of penetration of chloride ions by spraying 0.1M $AgNO_3$ solution to the split face of the cylinder exposed to 1.8 M Nail 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. Table 4.11 shows the depth of penetration of chloride ions for various NS mixes subjected to chloride attack.

Table 4.11 Depth of penetration of chloride ions for various NS mixes

Mix	Depth of penetration of chloride ions (mm)	
	7 day water curing	
	56 day chloride exposure	90 day chloride Exposure
R1	9.25	11.15

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R2	8.39	9.13
R3	7.88	8.65
R4	7.56	8.18
R5	6.19	7.32
R6	5.67	6.57
R7	5.1	6.05

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. From Fig 4.16 and fig 4.17 the depth of chloride ion penetration was maximum for R1 mix and minimum for R7 mix after 7 day curing condition. By the addition of NS, chloride ion penetration can be considerably reduced. The fine particles of NS forms the entry of chloride ions in to the concrete specimens and is protected it from chloride attack.

Fig 4.16 Depth of penetration of chloride ions

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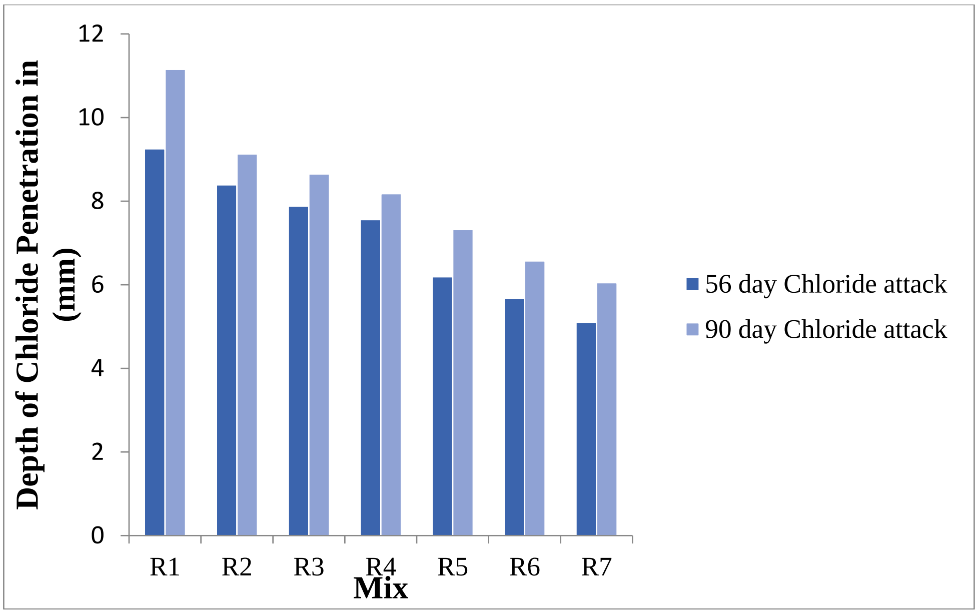

Fig 4.17 Penetration of chloride ions on various mixes

4.5 RESULTS OF FLEXURE TEST ON RCC BEAMS

4.5.1 Load-Deflection Characteristics

The deflection values obtained under mid span and the point loads for various series of beams are shown in Table 4.12 to Table 4.19. Based on the observation, the Load Vs Deflection graph was plotted. The Load Vs Deflection for the different series is shown in Fig.4.18 to Fig.4.25. From the graph, it is observed that the Load Vs Deflection graph is bilinear for all the series of beams. After the first crack, the deflection is seen to increase for all the series of beams. The load Vs deflection for the 7 series of beams at mid span was plotted to assess the effect of NS on deflection. Fig.4.25, show the Load Vs Deflection graph at mid span for various beams respectively. In the pre-cracking and post-cracking region, NS beams undergo less deflection for same load compared to control RC beams. This shows that the beams are more matrixes bonded than the ordinary concrete beams at both pre-cracking and post-cracking regions.

Table 4.12 Deflection of R_1 Beam Specimen

Load (kN)	Deflection (mm)		
	Load point 1	Mid span	Load point 2
0	0	0	0
2.234	0.14	0.14	0.15
4.469	0.26	0.27	0.28
6.703	0.38	0.4	0.39
8.938	0.52	0.54	0.5
11.172	0.64	0.67	0.64

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13.406	0.81	0.82	0.8
15.641	0.98	1.02	0.98
17.875	1.2	1.27	1.21
20.11	1.43	1.55	1.45
22.344	1.93	2.02	1.95
24.578	2.46	2.51	2.48
26.813	2.66	2.74	2.66
29.791	2.86	3.19	2.89
33.514	3.29	3.57	3.31
37.237	4.12	4.38	4.12
40.957	4.50	4.62	4.55
44.677	4.85	5.03	4.82
52.117	5.14	5.45	5.17
Ultimate Load = 54.36 kN			

Table 4.13 Deflection of R_2 Beam Specimen

Load (kN)	**Deflection (mm)**		
	Load point 1	**Mid span**	**Load point 2**
0	0	0	0
2.234	0.2	0.19	0.18
4.469	0.39	0.4	0.36
6.703	0.56	0.6	0.54
8.938	0.6	0.64	0.58
11.172	0.75	0.81	0.74
13.406	0.89	0.92	0.85
15.641	1.05	1.08	1.02
17.875	1.2	1.22	1.14
20.11	1.39	1.44	1.35
22.344	1.74	1.87	1.71
24.578	1.95	2.05	1.9
26.813	3.21	3.27	3.21
29.791	3.69	3.74	3.68

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33.514	4.04	4.11	4.03
37.237	4.24	4.33	4.24
40.957	4.39	4.53	4.37
44.677	4.72	4.91	4.76
52.117	5.01	5.31	4.98
Ultimate Load = 55.85 kN			

Table 4.14 Deflection of R_3 Beam Specimen

Load (kN)	Deflection (mm)		
	Load point 1	Mid span	Load point 2
0	0	0	0
2.234	0.13	0.17	0.13
4.469	0.31	0.36	0.33
6.703	0.49	0.55	0.52
8.938	0.63	0.68	0.66
11.172	0.79	0.85	0.82
13.406	0.94	1.04	0.97
15.641	1.17	1.28	1.16
17.875	1.46	1.6	1.49
20.11	1.73	1.88	1.7
22.344	1.97	2.16	1.94
24.578	2.22	2.44	2.18
26.813	2.52	2.78	2.51
29.791	2.84	3.2	2.86
33.514	3.37	3.73	3.36
37.237	3.89	4.25	3.88
40.957	4.29	4.44	4.26

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44.677	4.61	4.79	4.63
52.117	4.89	5.15	4.87
Ultimate Load = 58.828 kN			

Table 4.15 Deflection of R_4 Beam Specimen

Load (kN)	**Deflection (mm)**		
	Load point 1	**Mid span**	**Load point 2**
0	0	0	0
2.234	0.19	0.18	0.19
4.469	0.37	0.36	0.38
6.703	0.45	0.55	0.44
8.938	0.63	0.67	0.62
11.172	0.82	0.84	0.82
13.406	0.96	1.04	0.97
15.641	1.23	1.26	1.22
17.875	1.62	1.65	1.61
20.11	1.86	1.88	1.85
22.344	2.09	2.17	2.09
24.578	2.43	2.47	2.42
26.813	2.87	2.92	2.86
29.791	3.31`	3.34	3.31
33.514	3.38	3.48	3.39
37.237	3.87	4.05	3.91
40.957	4.39	4.51	4.36
44.677	4.58	4.70	4.62
52.117	4.79	4.99	4.75
Ultimate Load = 59.57kN			

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Table 4.16 Deflection of R_5 Beam Specimen

Load (kN)	Deflection (mm)		
	Load point 1	Mid span	Load point 2
0	0	0	0
2.234	0.20	0.18	0.19
4.469	0.40	0.36	0.39
6.703	0.55	0.55	0.54
8.938	0.69	0.71	0.68
11.172	0.77	0.84	0.80
13.406	0.87	0.96	0.88
15.641	0.99	1.19	1.05
17.875	1.32	1.59	1.36
20.11	1.67	1.80	1.71
22.344	2.19	2.2	2.17
24.578	2.45	2.48	2.42
26.813	2.89	2.93	2.86
29.791	3.18	3.29	3.26
33.514	3.33	3.41	3.31
37.237	3.82	4.01	3.80
40.957	4.14	4.23	4.12
44.677	4.31	4.40	4.28
52.117	4.63	4.74	4.61
Ultimate Load = 62.55kN			

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Table 4.17 Deflection of R_6 Beam Specimen

Load (kN)	Deflection (mm)		
	Load point 1	Mid span	Load point 2
0	0	0	0
2.234	0.18	0.17	0.19
4.469	0.36	0.36	0.36
6.703	0.51	0.55	0.52
8.938	0.65	0.69	0.64
11.172	0.79	0.84	0.80
13.406	0.88	0.93	0.88
15.641	1.01	1.09	1.02
17.875	1.32	1.59	1.33
20.11	1.63	1.68	1.64
22.344	2.15	2.23	2.16
24.578	2.42	2.48	2.42
26.813	2.98	3.02	2.99
29.791	3.1	3.21	3.1
33.514	3.52	3.60	3.51
37.237	3.86	3.97	3.87
40.957	3.98	4.07	3.97
44.677	4.23	4.30	4.21
52.117	4.39	4.51	4.42
Ultimate Load = 63.29kN			

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Table 4.18 Deflection of R_7 Beam Specimen

Load (kN)	Deflection (mm)		
	Load point 1	Mid span	Load point 2
0	0	0	0
2.234	0.21	0.23	0.24
4.469	0.31	0.32	0.34
6.703	0.44	0.46	0.47
8.938	0.6	0.62	0.61
11.172	0.73	0.76	0.74
13.406	0.9	0.92	0.89
15.641	1.03	1.06	1.02
17.875	1.2	1.25	1.18
20.11	1.36	1.46	1.36
22.344	1.71	1.86	1.73
24.578	1.9	2.06	1.91
26.813	2.18	2.36	2.18
29.791	2.6	3.02	2.59
33.514	3.1	3.33	3.06
37.237	3.55	3.83	3.51
40.957	3.81	3.93	3.79
44.677	3.95	4.02	3.92
52.117	4.14	4.25	4.15
Ultimate Load = 65.53kN			

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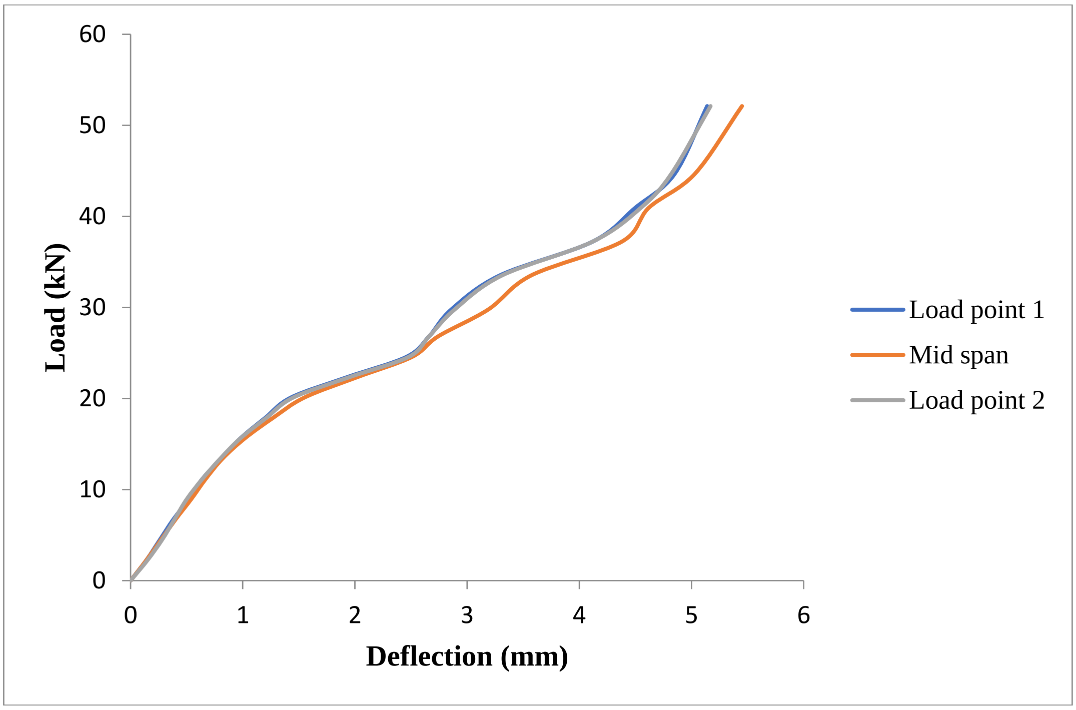

Fig. 4.18 Load Vs Deflection for R1 Beam Specimen

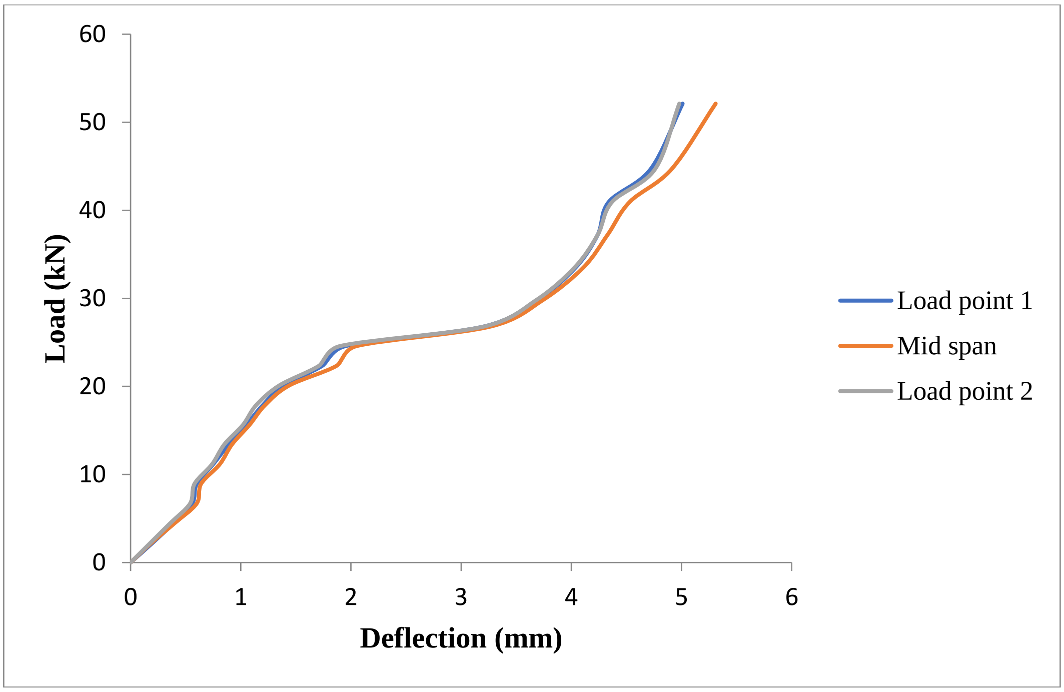

Fig. 4.19 Load Vs Deflection for R2 Beam Specimen

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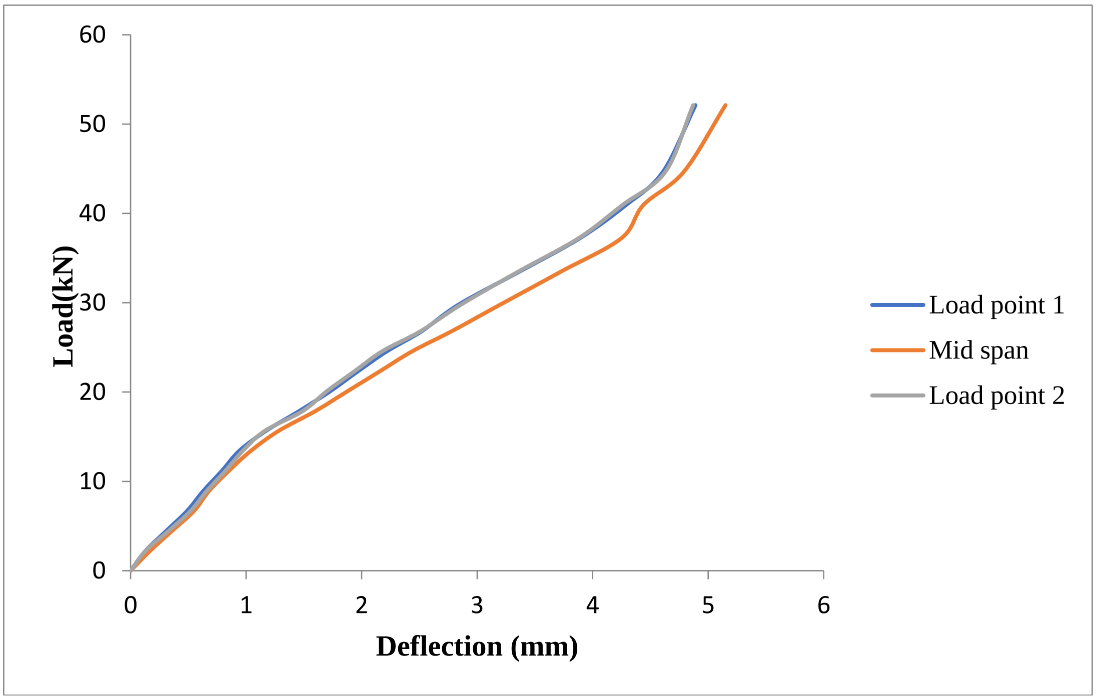

Fig. 4.20 Load Vs Deflection for R3 Beam Specimen

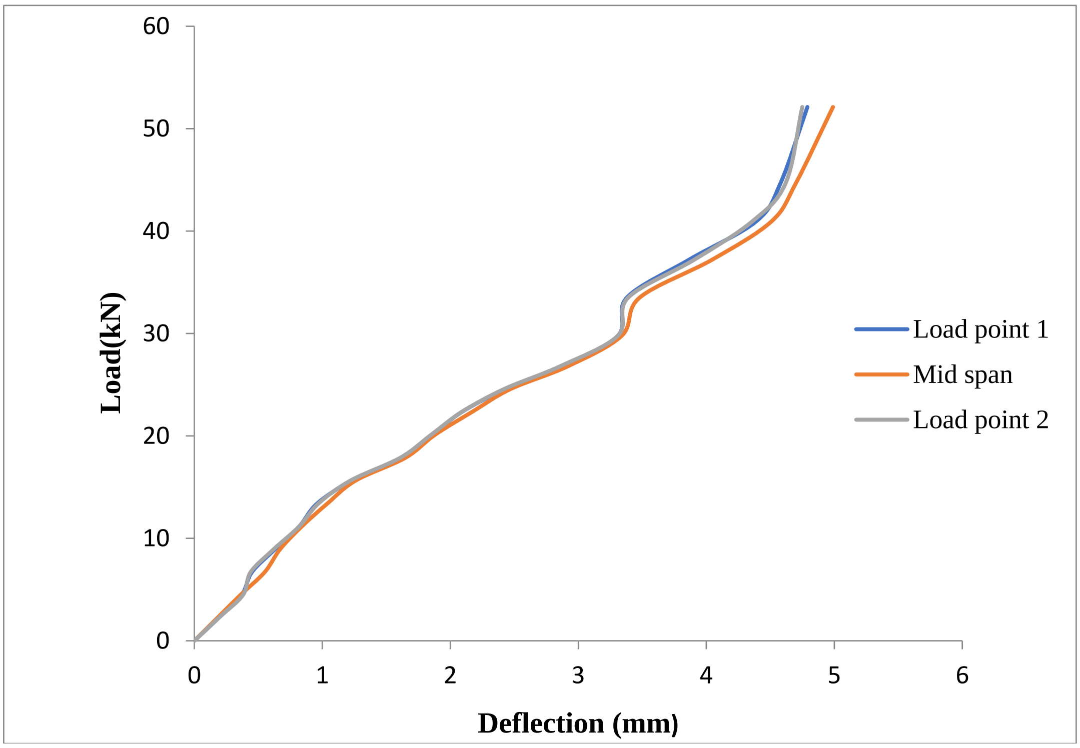

Fig. 4.21 Load Vs Deflection for R4 Beam Specimen

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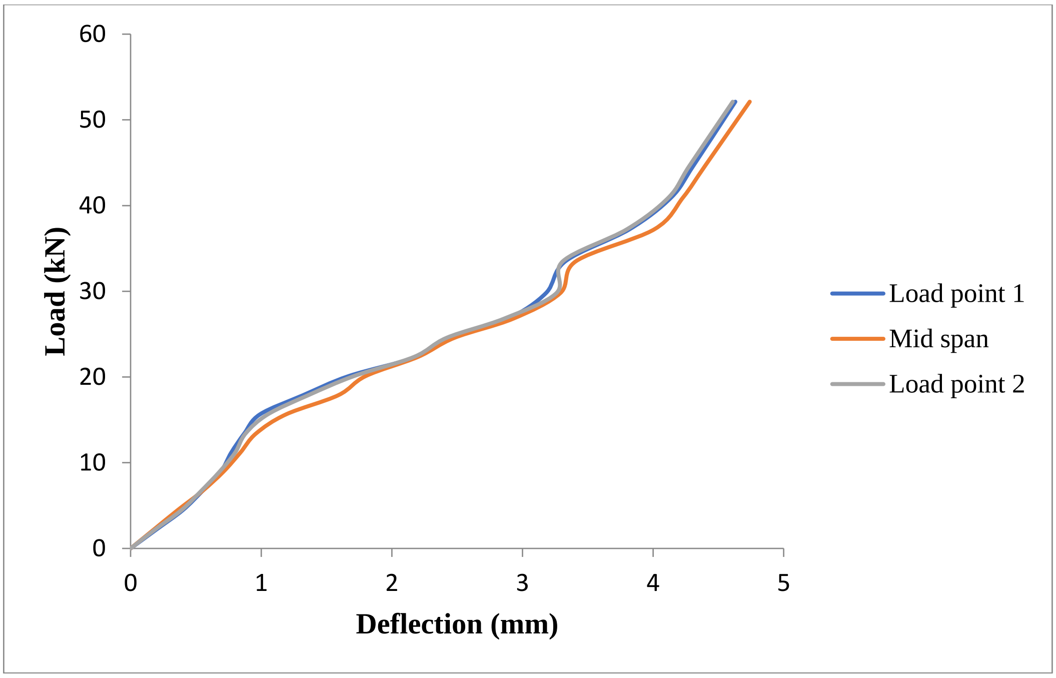

Fig. 4.22 Load Vs Deflection for R5 Beam Specimen

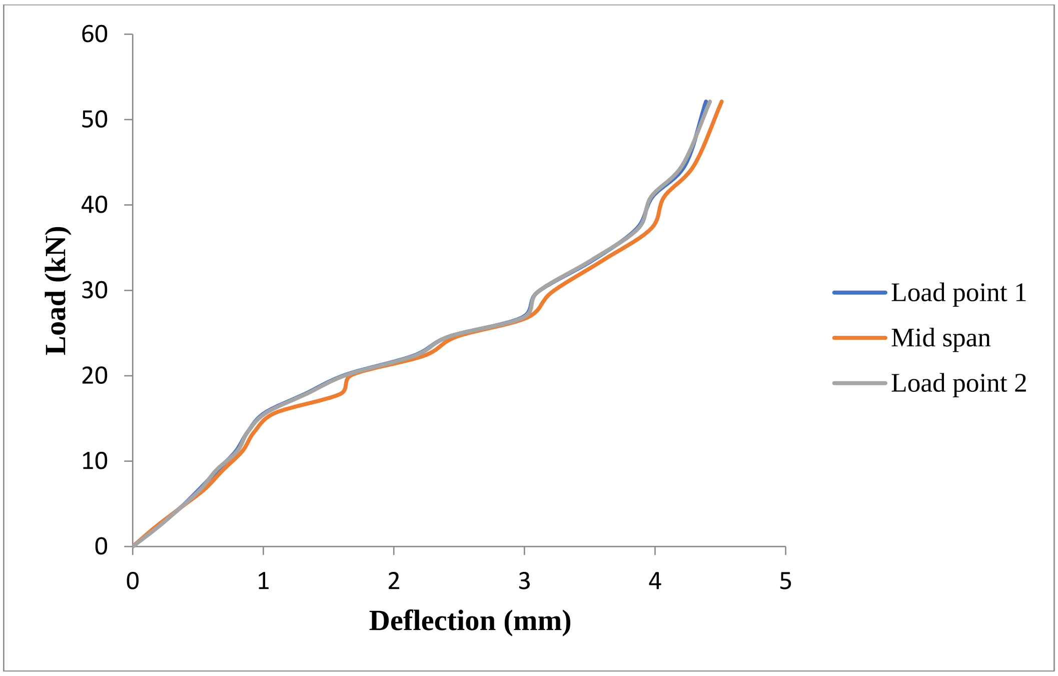

Fig. 4.23 Load Vs Deflection for R6 Beam Specimen

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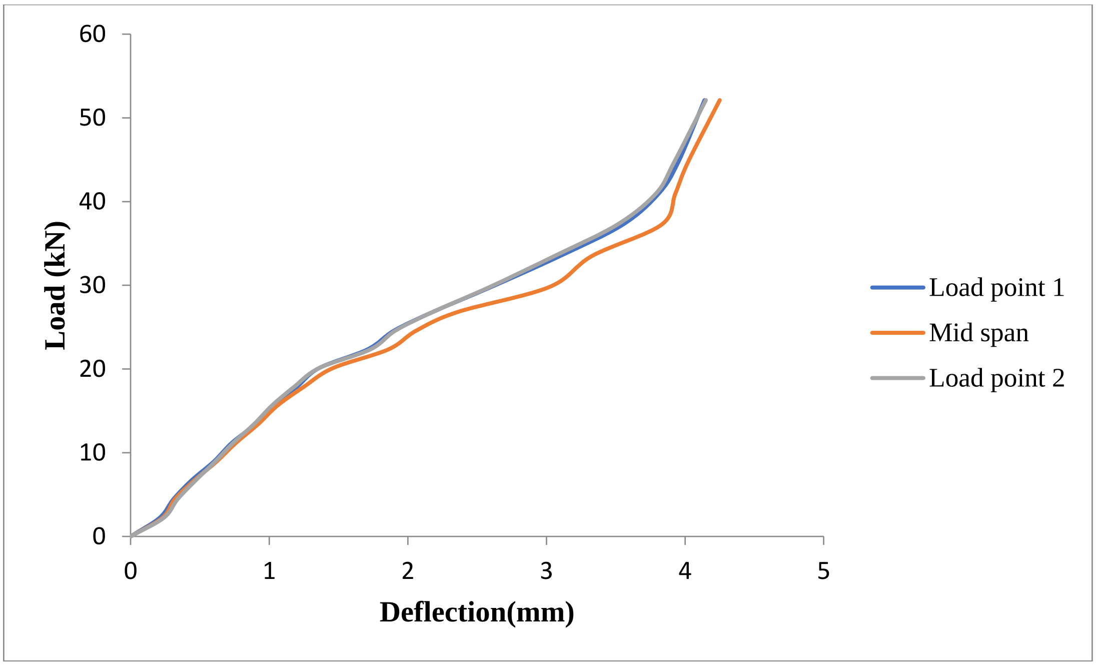

Fig. 4.24 Load Vs Deflection for R7 Beam Specimen

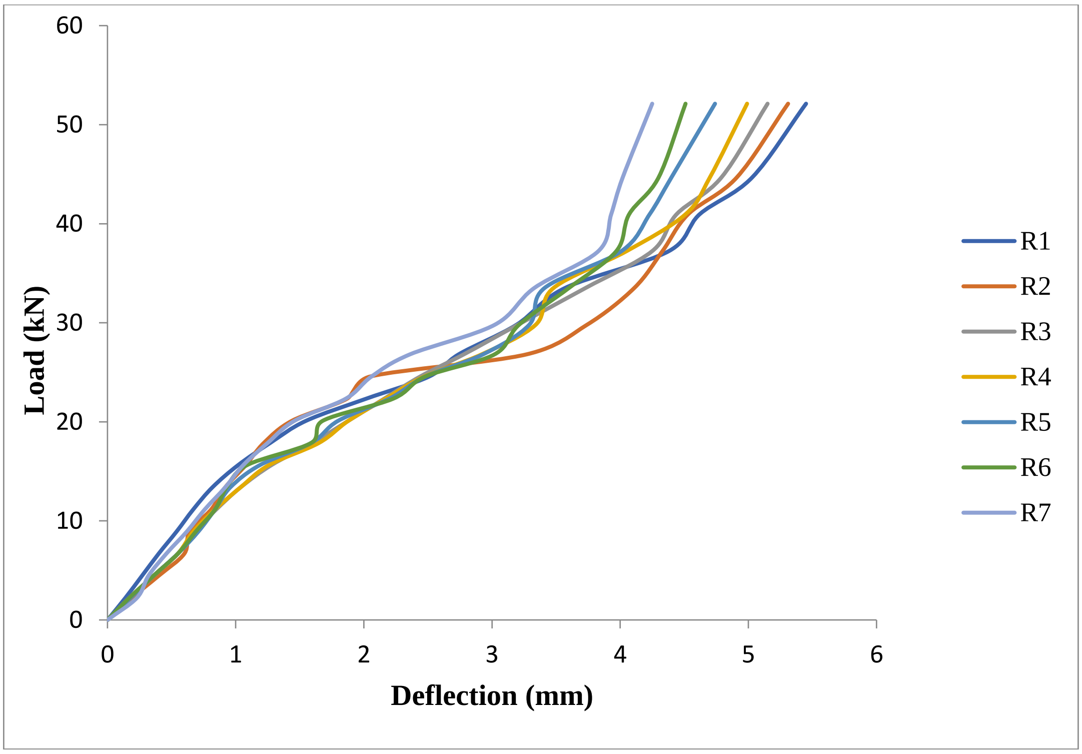

Fig. 4.25 Mid Span Deflection of all beams

4.5.2 Cracking Load and Ultimate Load

The load for first crack observed and the ultimate load are shown in Table 4.19. The standardized values of load at first crack and ultimate load are calculated. It is seen that the load at first crack and ultimate load slightly increases for NS specimens. The variation of first crack load is shown in Fig 4.26 and the variation of ultimate load is shown in Fig4.27

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Table 4.19 First Crack Load and Ultimate Load of Beam Specimens

Mix	Load at first crack P_{cra} (kN)	Ultimate Load P_u (kN)	P_u / P_{cra}
R1	22.34	54.36	2.49
R2	23.08	55.85	2.41
R3	24.57	58.82	2.39
R4	25.31	59.57	2.35
R5	26.80	62.55	2.33
R6	27.55	63.29	2.29
R7	29.04	65.53	2.26

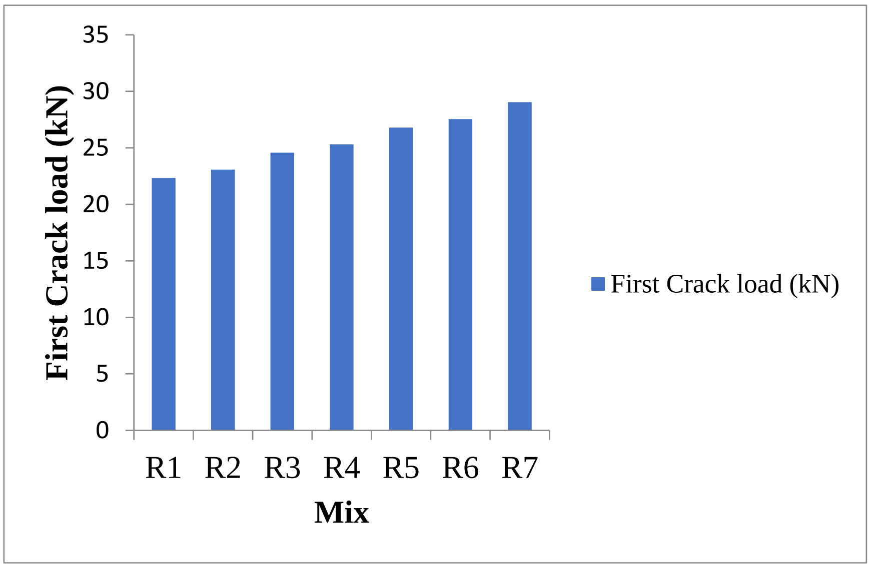

Fig. 4.26 Variation of First crack Load

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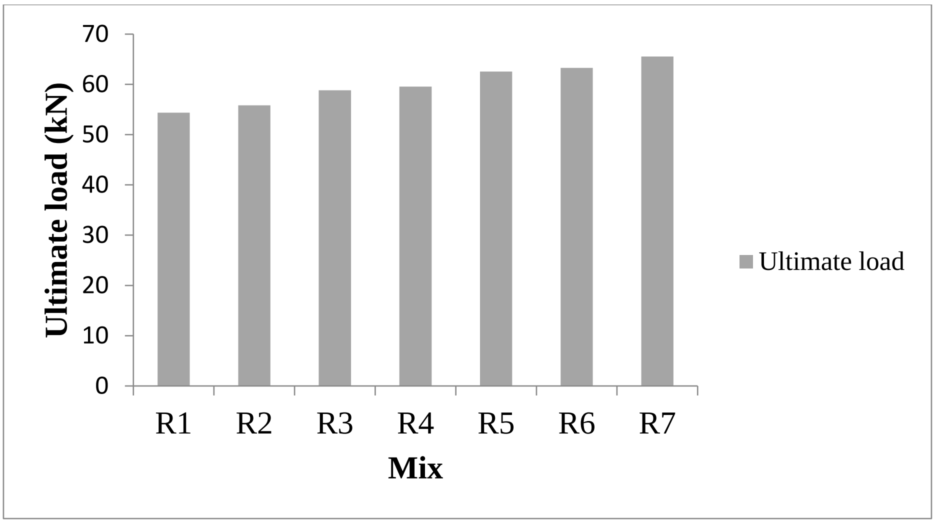

Fig 4.27 Variation of Ultimate Load

Addition of NS results increase in the ultimate load. The average increase in ultimate load for NS alone beams is 9.43% and beams containing flyash and nanosilica is 3.72% than that of ordinary beams. The increase in the ultimate load is due to the small particle size of nanosilica provides a larger surface area, which speeds up the rate of cement hydration and pozzolanic reactions. The average increase in first crack load for nanosilica beams is 5.46% and beams containing flyash along with nanosilica is 1.98% than that of ordinary beams. It clearly indicates that the nanosilica is more effective in arresting the development of cracks due to its large surface area.

The theoretical ultimate load was found out by IS method and compared with ultimate load obtained experimentally. Table 4.20 shows the load at failure and corresponding theoretical load for various series of beams. It can be seen that the experimental ultimate load obtained is conservative. The average theoretical load predicted is 70% of the actual experimental ultimate load for nanosilica beams and 77% for beams containing flyash alone with nanosilica. The average factor of safety for NS beams series is 1.37 and beams containing flyash along with nanosilica is 1.29, whereas the factor of safety obtained for ordinary beams is 1.21 Thus the percentage increase in factor of safety for NS beams is 13.49% and that of beams containing flyash alone with nanosilica is 6.88% than that of control beams.

Table 4.20 Experimental and Theoretical Ultimate load

Mix	Theoretical Ultimate load $P_{u,th}$ (kN)	Experimental Ultimate load $P_{u,exp}$ (kN)	$P_{u,\exp} / P_{u,th}$
R1	44.80	54.36	1.21
R2	44.80	55.85	1.25
R3	44.80	58.82	1.31

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R4	44.80	59.57	1.32
R5	44.80	62.55	1.39
R6	44.80	63.29	1.41
R7	44.80	65.53	1.46

4.5.3 Pre-cracking and Post-cracking Stiffness

The pre-cracking and post-cracking stiffness of beams were found from the slopes of Load-Deflection graph. Pre-cracking and post-cracking stiffness of different series of beams are presented in Table 4.21 To avoid the effect of variation in strength of concrete from one specimen to other on the experimental results obtained, the standardisation factor for each specimen is found out and standardized post- cracking and pre-cracking stiffness values are calculated. Addition of NS is found to improve both the pre-cracking stiffness and post-cracking stiffness of RC beams when subjected to flexure. For NS beams, the average increase in pre-cracking stiffness is 2% and nanosilica along with flyash beams is 1.13%. The average increase in the post-cracking stiffness is 17.85% in case of NS beams and the case of nanosilica along with flyash beams is 6.59% when compared to ordinary concrete beams. Fig. 4.28 shows the variation of Pre and Post cracking stiffness in RC beams

Table 4.21 Pre-cracking and Post-cracking Stiffness

Mix	Pre-cracking Stiffness K_{pre} (kN/mm)	Post-cracking Stiffness K_{post} (kN/mm)	K_{post}/K_{pre}
R1	11.75	8.89	0.76
R2	11.83	9.15	0.77
R3	11.87	9.52	0.80
R4	11.95	9.76	0.81
R5	11.97	10.23	0.86
R6	11.98	10.52	0.88
R7	12.03	10.68	0.89

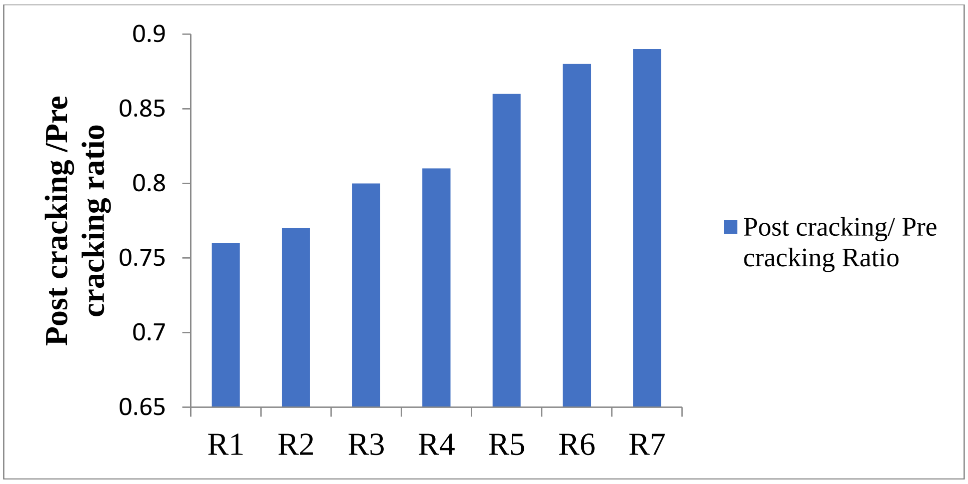

Fig. 4.28 Variation of Pre and Post cracking stiffness

4.5.4 Crack-width

The crack-width for all the beam specimens was observed using a micrometer microscope of accuracy 0.1mm. The crack-width was noted from the first crack observed till the ultimate load reached. From the study it was found that at ultimate load, the crack width of NS beams was lesser than that of conventional concrete because of the larger surface area fills all the voids in the concrete. Table 4.22 shows the maximum crack width at ultimate load. Fig 4.29 shows the variation of maximum crack width in RC beams.

Table 4.22 Maximum Crack Width at Ultimate Load

Mix	Ultimate load P_u (kN)	Maximum crack width (mm)
R1	54.36	1.9
R2	55.85	1.7
R3	58.82	1.6
R4	59.27	1.4
R5	62.55	1.4
R6	63.29	1.2
R7	65.53	1.0

The crack width for NS beams is lesser than that for ordinary concrete beams when subjected to flexural loading. It was also observed that beams with NS have crack width lesser than 0.1mm at the time of first cracking. It is justified as the NS effectively acts as crack width lesser than 0.1mm at the time of first cracking. It is justified as the NS effectively acts as crack arresters until the matrix bridge zone breaks. Thus NS in the matrix is found to

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increase the serviceability of beams when compared to ordinary concrete beams. As per IS 456: 2000, clause 35.3.2 (pertaining to limits of serviceability), the surface width of the cracks should not, in general exceed 0.3mm for mild exposure conditions. From the Table 4.23, the load for a crack width of 0.3mm. This clearly indicates that the NS beams are safe in the mild exposure condition. Fig. 4.30. shows the variation of load for 0.3mm crack and ultimate load.

Table 4.23 Load at 0.3mm Crack Width

Mix	Load at 0.3mm Crack width $P_{cra,0.3}$ (kN)	Ultimate load P_u (kN)
R1	37.21	54.36
R2	39.45	55.85
R3	41.68	58.82
R4	44.68	59.29
R5	48.39	62.55
R6	51.38	63.29
R7	54.35	65.53

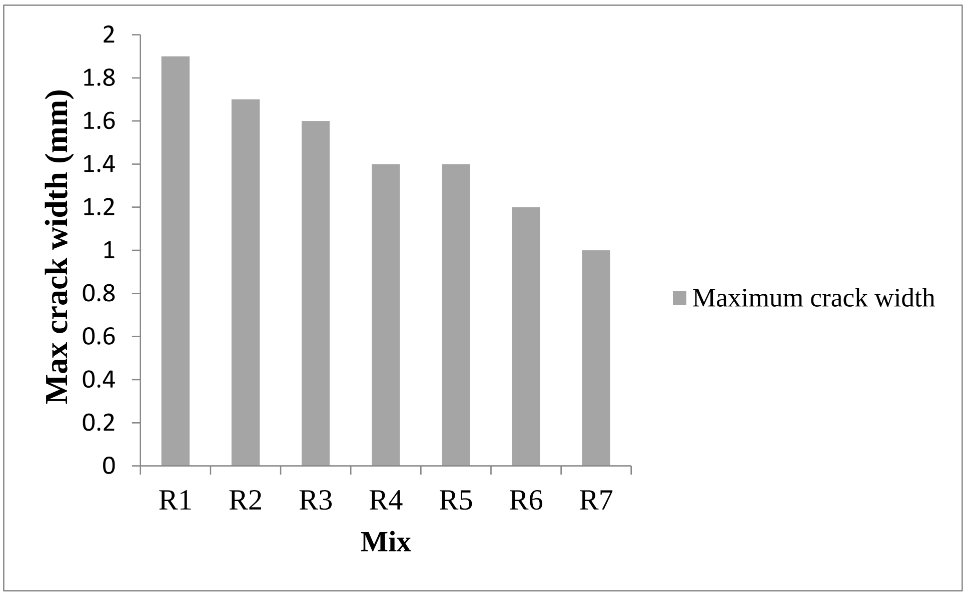

Fig 4.29. Variation of maximum crack width

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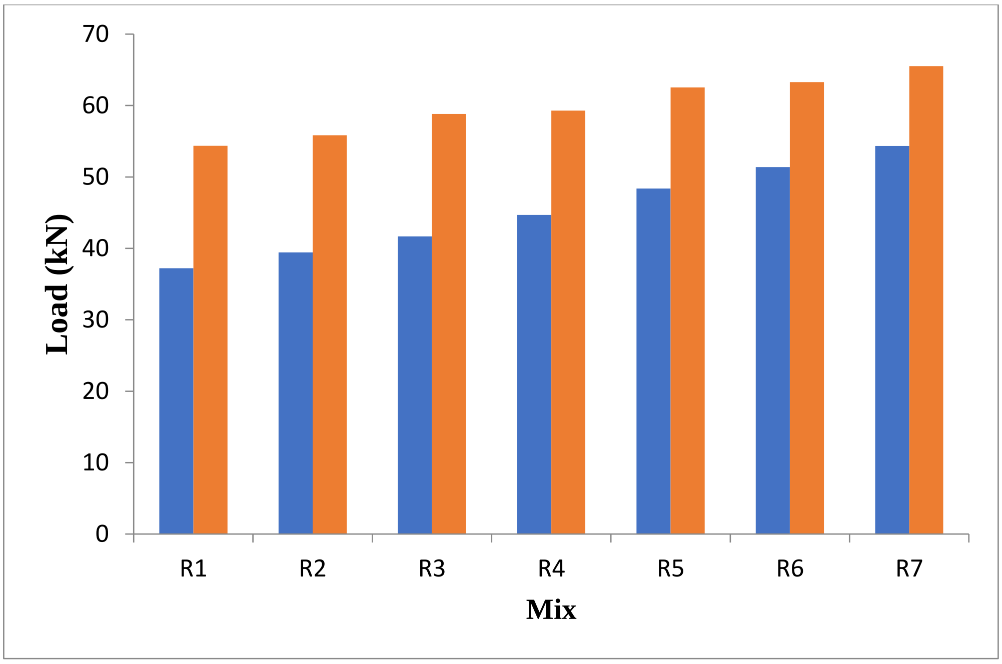

Fig. 4.30. Variation of load for 0.3mm crack and ultimate load

Fig 4.31 gives the values of crack width in all beams by each load increment and is measured with the help of micrometer.

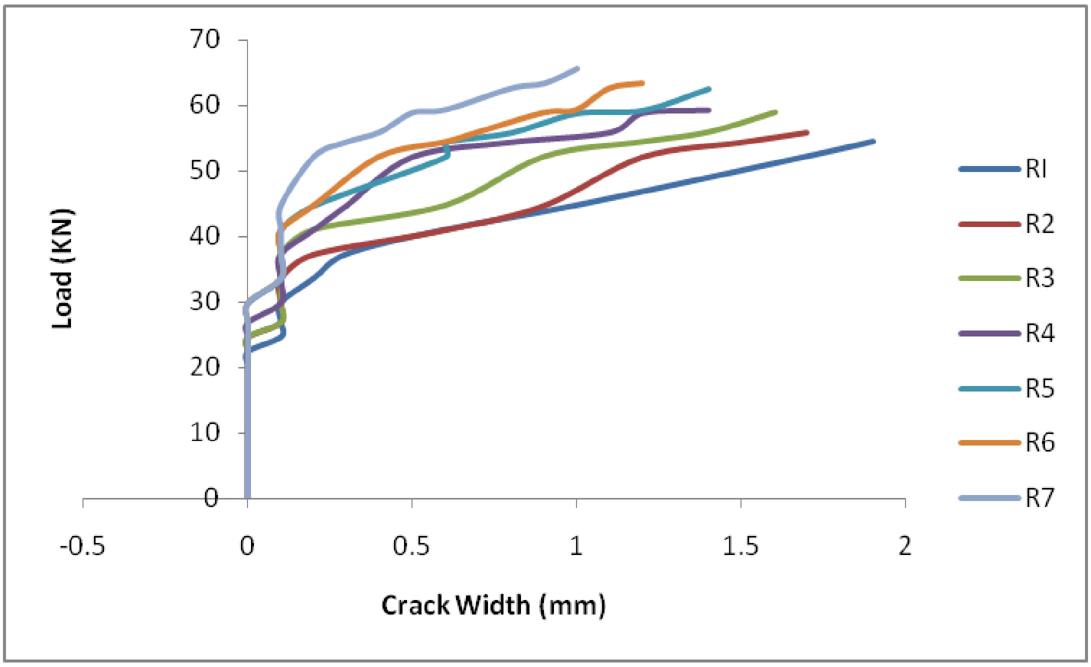

Fig. 4.31. Variation of crack width in different beams

4.5.5 Crack Pattern

The cracks formed on the beam specimens when loaded were marked. The crack patterns for different series of beams are shown from Fig4.32. to Fig. 4.38. From the study, it is seen that the number of cracks formed for both

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control and NS beams were same. But the rate of crack propagation for NS beams is found to be slower than that for control beams. This is due to the reason that the development of major cracks are controlled by the bond strength between main reinforcement and concrete whereas the rate of propagation of crack in NS beams was controlled by the strong matrix bonding between reinforcement and concrete. It was observed that, once the matrix bond breaks, the rate of crack propagation increases till the ultimate load is reached.

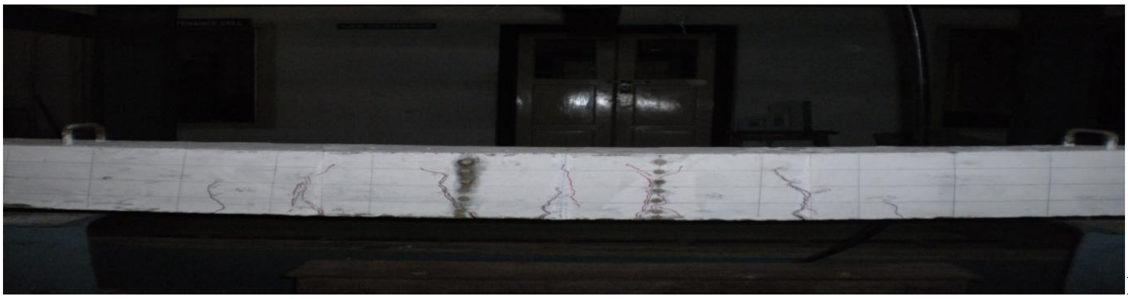

Fig. 4.32 Crack Pattern of R_1 Beam under Flexure

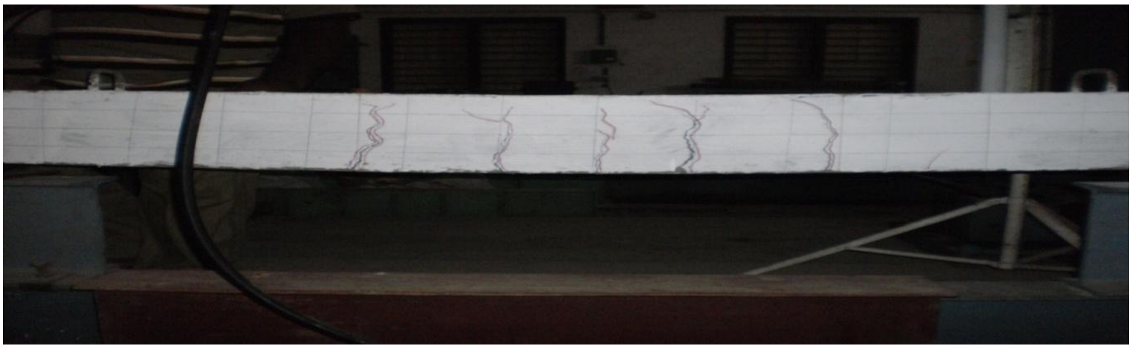

Fig. 4.33 Crack Pattern of R_2 Beam under Flexure

Crack Pattern of R_2 Beam under Flexure

Fig. 4.34 Crack Pattern of R_3 Beam under Flexure

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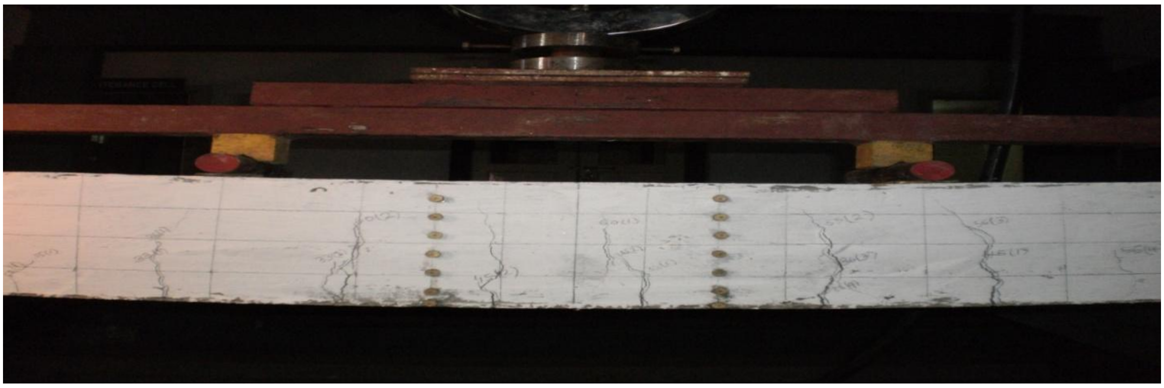

Fig. 4.35 Crack Pattern of R_4 Beam under Flexure

Fig. 4.36 Crack Pattern of R_5 Beam under Flexure

Fig. 4.37 Crack Pattern of R_6 Beam under Flexure

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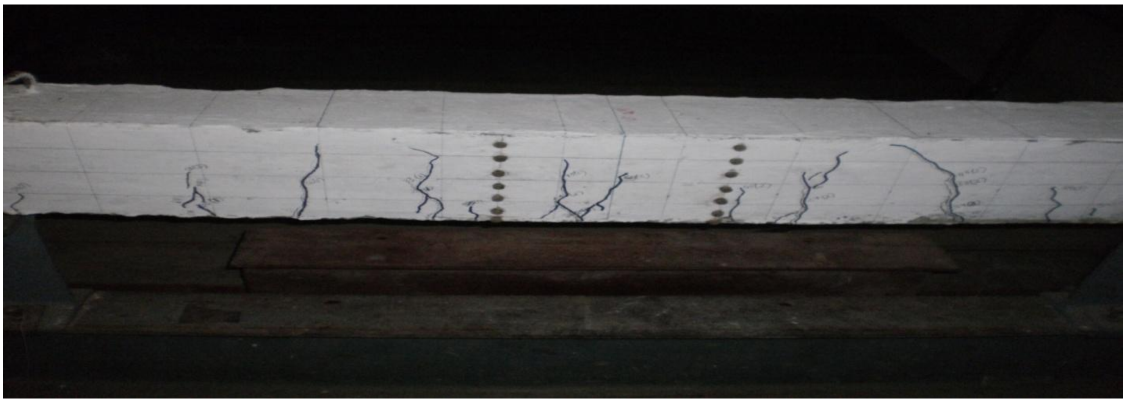

Fig. 4.38 Crack Pattern of R_7 Beam under Flexure

CHAPTER 5

CONCLUSIONS

5.1 GENERAL

The main objective of the present investigation was to study the effect of nanosilica on the mechanical and durability and flexural properties of concrete. From the present investigation the performance of nanosilica concrete with and without fly ash was studied and they were compared to the performance of control mix. Fresh properties of the concrete were determined by carrying out the workability test, compacting factor, vee bee, and flow test. The mechanical properties are determined by compressive strength, split tensile strength, modulus of elasticity, flexural strength and impact resistance. The durability properties are determined by acid attack test, sulphate attack test, bulk diffusion test. The behavior of nanosilica beam under flexure was also studied by two-point loading flexure test.

The conclusions drawn from the present investigation and the scope for the future work are presented in this chapter.

5.2 CONCLUSIONS

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

- Addition of nanosilica is found to increase the workability of concrete. The mixes having flyash content have more workability than that of other mixes.

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- The mechanical properties such as compressive strength, flexural strength, modulus of elasticity, and impact resistance for mixes R5 R6 and R7 gets improved due to the addition of nanosilica.
- The average increase in the compressive strength of the specimen R7 in 28th day is about 8% compared to the control mix. This may be due to the addition of nanosilica
- The values of mechanical properties such as compressive strength, flexural strength, modulus of elasticity, and impact resistance for mixes R2 R3 and R4 get reduced due to the addition of flyash. But the addition of nanosilica slightly improves the mechanical properties.
- The resistance to acid attack, sulphate attack, and chloride attack gets improved due to the addition of nanosilica.
- Flexural behaviour gets improved due to the addition of nanosilica.
- For flexural behaviour of nanosilica beams the load-deflection relation is bilinear.
- In the pre-cracking region and post cracking region nanosilica beams undergo less deflection for same load compared to ordinary reinforced concrete beams.
- Addition of nanosilica results in a marginal increase in the load at first crack. In case of nanosilica beams the average increase is 5.46% and beams containing flyash along with nanosilica is 1.98% than that of ordinary beams.
- Addition of nanosilica also results in a marginal increase in the ultimate load The average increase in ultimate load for beams with nanosilica 9.43% and beams containing flyash and nanosilica is 3.72% than that of ordinary beams.
- Addition of nanosilica is found to marginally increase the pre-cracking stiffness. The average increase in pre-cracking stiffness is 2% for nanosilica beams and nanosilica along with flyash beams is 1.13%.
- The average increase in the post-cracking stiffness is 17.85% in case of NS beams and the case of nanosilica along with flyash beams is 6.59% when compared to control beam specimen.
- Crack width for nanosilica beams is lesser when compared to control beams.
- The rate of crack propagation is lesser for nanosilica beams than that of control beams.
- Nanosilica increase the factor of safety. The percentage increase in factor of safety for NS beams is 13.49% and that of beams containing flyash along with nanosilica is 6.88% than that of control beams.

5.3 SCOPE FOR FUTURE WORK

From the present scope of study, more research is needed in the area of nanosilica concrete. The following are the suggestions:

- The effect of corrosion control by the use of NS can be studied.
- Effect of micro level properties of concrete by the use of NS can be studied
- The performance of NS under impact loading can be studied
- The performance of NS under elevated temperature can be investigated

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