iJRASET
International Journal For Research in Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 10 **Issue:** XI **Month of publication:** November 2022

DOI: https://doi.org/10.22214/ijraset.2022.46192

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue XI Nov 2022- Available at www.ijraset.com

Experimental and Analytical Investigation of R.C Beam with HPC Containing Nano Silica

Anjana Prem Mini[1], Suji. P[2]
[1]*PG Scholar, Mahaguru Institute of Science and Technology, Civil Engineering Department, Kerala Technical University*
[2] *Assistant Professor, Civil Engineering Department, Kerala Technical University, Mahaguru Institute of Science and Technology, Kerala*

Abstract: ***Concrete is the most widely used construction material in the world. It is a heterogeneous material composed of cement, fine aggregate, course aggregates and water. The proportion of these constituents affect the mechanical properties and durable properties of concrete. Also it is a versatile material due to the continuous demand. In recent years, lot of researches has been focused on improving the quality of concrete. This lead to the extension in the limitations to improve the performance of concrete with the addition of various admixtures super plasticizers subsidiary cementitious materials like silica fume, fly ash, blast furnace slag, metakaoiln, rice husk, etc. the properties like compressive strength, flexural strength, durability and workability of concrete enhances due to the addition of these materials. The concrete thus formed with high strength and durability compared to normal concrete are called High Performance Concrete. The compressive strength of HPC may be greater than 50Mpa. This HPC with compressive strength greater than 50Mpa can be used for structural members like beam, column, slab etc In this investigation the cement is replaced by 1%, 2% and 3% of Nano silica. Experimental and analytical investigation were done to investigating the flexural behaviour of conventional RC beam and R.C beam with HPC containing optimum percentage of Nano silica. Analytical investigation was done by ANSYS. This chapter discusses about the HPC, its mechanical strength properties like compressive strength, split tensile strength, flexural strength, effect of Nano materials like Nano Silica in HPC, determining the optimum percentage of Nano silica which gives maximum strength, investigating its durability property, investigating the strength development of RC beam with HPC containing optimum percentage of Nano silica, examining the load deflection behaviour of beam with HPC containing Nano silica and finally analysing the deflection of beam using Ansys. The key objective of this project is to investigate the importance of Nano silica as a replacement for cementitious materials in normal concrete and this paper presents strength and durable properties of HPC containing Nano silica.***

Keywords: High Performance Concrete, Nano Silica, Durability, Tensile Strength, Compressive Strength, ANSYS

I. INTRODUCTION

The usage of concrete is increasing day by day. An estimate says that around 2 billion tons of concrete is being produced every year around the world. A lot of researches has been focused on improving the quality of concrete. This leads to the addition of various admixtures, super plasticizers, subsidiary cementitious materials like silica fume, rice husk, fly ash, ground granulated blast furnace slag, etc. High Performance Concrete is a type of concrete which possess high strength and durability when comparing with normal concrete. It is a heterogeneous mixture of cement, fine aggregate, coarse aggregate, water, admixtures and super plasticizers. The usage super plasticizers like High Water Reducing Agents and the addition of mineral admixtures plays a vital role in the strength and durability properties of concrete mix. HPC concrete will helps to make the concrete denser and workable. This will help to control the slump loss to a great extent. The compressive strength of HPC is greater than 50 Mpa can be used for structural members like beam, column, slab etc. In this investigation the cement is replaced by 1%, 2% and 3% of Nano silica. Experimental and analytical investigation were done to investigating the flexural behaviour of conventional RC beam and R.C beam with HPC containing optimum percentage of Nano silica. Analytical investigation was done by ANSYS. This chapter discusses about the HPC, its mechanical strength properties like compressive strength, split tensile strength, flexural strength, effect of Nano materials like Nano Silica in HPC, determining the optimum percentage of Nano silica which gives maximum strength, investigating its durability property, investigating the strength development of RC beam with HPC containing optimum percentage of Nano silica, examining the load deflection behaviour of beam with HPC containing Nano silica and finally analysing the deflection of beam using Ansys. The key objective of this project is to investigate the importance of Nano silica as a replacement for cementitious materials in normal concrete and this paper presents strength and durable properties of HPC containing Nano silica.

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ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue XI Nov 2022- Available at www.ijraset.com

II. METHODOLOGY

The first step in this study is to determine the material properties of cement, fine aggregate, coarse aggregate which are used for the concrete production. The cement is replaced with 1%, 2% and 3% of Nano silica. To study the strength properties like compressive strength, tensile strength and durable properties, specimens were casted with conventional concrete and concrete containing different percentages of NS and cured for 7, 14, 28 days and tested. RC beam of conventional concrete and RC beam with HPC containing optimum percentage of Nano silica were casted and tested after 28 days of curing to investigate the strength development. Examining the load deflection behaviour of beam with HPC containing Nano silica and finally analysing the deflection of beam using ANSYS.

III. EXPERIMENTAL PROGRAM

A. Materials

OPC 53 grade confirming to IS: 12269-1987 was used. Material tests on cement were conducted as per IS 4031-1988. The specific gravity of cement is 3.13g/cc. Fine aggregate conforming to zone II of IS 383 of specific gravity 2.56 g/cc were used. Coarse aggregate of maximum size 12.5 mm of specific gravity 2.60g/cc were used. Water used for the study is free from harmful impurities. Poly carboxylic ether based super plasticizer named Master Glenium Sky 8233 were used. Admixture used here is Nano silica of specific gravity 1.15 g/cc.

B. MIX Design

The mix proportion were done by using the properties obtained from material tests and as per recommendations of ACI 211.4R
The mix proportion for M60 grade concrete is shown in Table 1 and mix proportion for M6o grade concrete containing Nano silica is shown in Table 2.

Table 1 Details of M60 grade concrete mix

Material	Cement	Fine aggregate	Coarse aggregate	Water	Super plasticizer	Slump mm
Weight (Kg/m3)	538	666	1049	156.17	3.766	100
Ratio	1	1.238	1.95	0.29	0.007	

Table 2 Mix proportion of M60 grade concrete containing Nano silica

Mix ID	Cement (kg/m^3)	Nano silica (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (%)	Super plasticizer (%)	Slump (mm)
1 (1% N.S)	533.295	5.38	657.754	1049	0.29	0.825	70
2 (2% N.S)	527.908	10.77	650.297	1049	0.29	0.99	55
3 (3% N.S)	522.522	16.16	640.82	1049	0.29	1.209	30

C. Specimen Preperation

For determining compressive strength, split tensile strength and flexural strength concrete cubes of size 15 x 15 x 15 cm, cylindrical specimens having 15 cm dia and 30 cm height and beams of size 10 x 10 x 50 cm of size were casted then cured for 28 days and tested. To determine the workability of concrete standard test as described in IS BIS 1199-1959 are conducted. To determine the strength development of RC beam with HPC containing optimum percentage of Nano silica RCC beam of size 200 x 250 x 1000 mm were casted and tested after 28 days of curing.

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D. Investigation On RC Beam

In order to investigate the effect of Nano silica on the strength and behavior of RCC beam, two RCC beams each of size 200 × 250 × 1000mm were casted with one of them is normal mix and the other one is with 2% Nano silica.

The beams are designed as under reinforced, and the reinforcement detailing is done as per the design as per the criteria in IS 456:2000.

Table 3 Reinforcement details

Bottom reinforcement	3# 20mm diameter bars
Top reinforcement	2# 12mm diameter bars
Stirrups	8mm diameter bars @ 150mm c/c

IV. RESULTS AND DISCUSSIONS

A. Compressive Strength

The compressive strength at 28days obtained for normal M60 mix is 62.96N/mm2. The partial replacement of cement with different percentages of Nano silica increases the compressive strength of cube up to 2% N.S, and then decreases with percentage increase in Nano silica. Fig.1 shows the compressive strength for various mixes with age.

B. Split Tensile Strength

The split tensile strength of normal M60 mix is 3.95MPa. The split tensile strength of concrete with Nano Silica increases by 9.36% and 23.5% for 1% N.S and 2% N.S. Then there comes a slight reduction in strength with further increase in N.S percentage. Fig 2 shows the split tensile strength values for various mixes with age.

C. Flexural Strength

The flexural strength of normal M60 mix is 6.28N/mm2. Flexural strength increases with increase in percentage of N.S is shown in fig 3

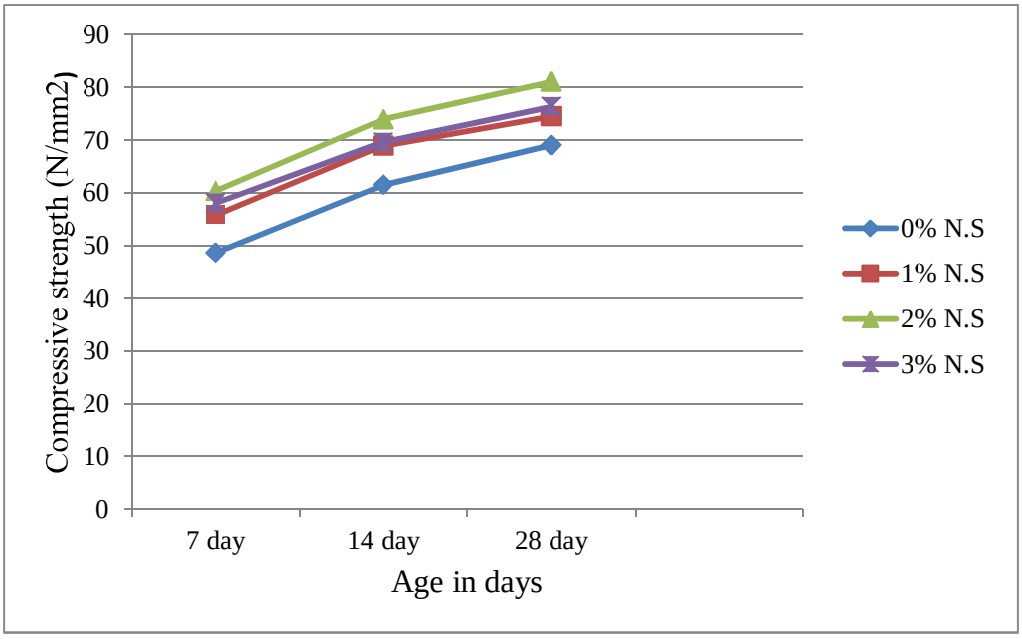


Fig.1 compressive strength values of various mixes with age

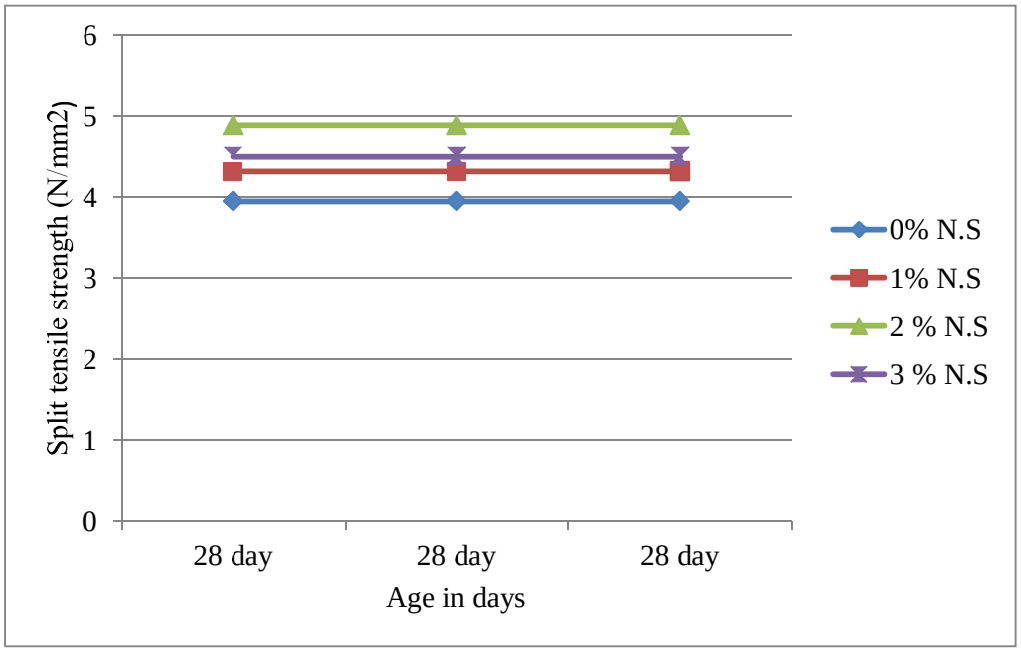


Fig. 2 split tensile strength values of various mixes with age

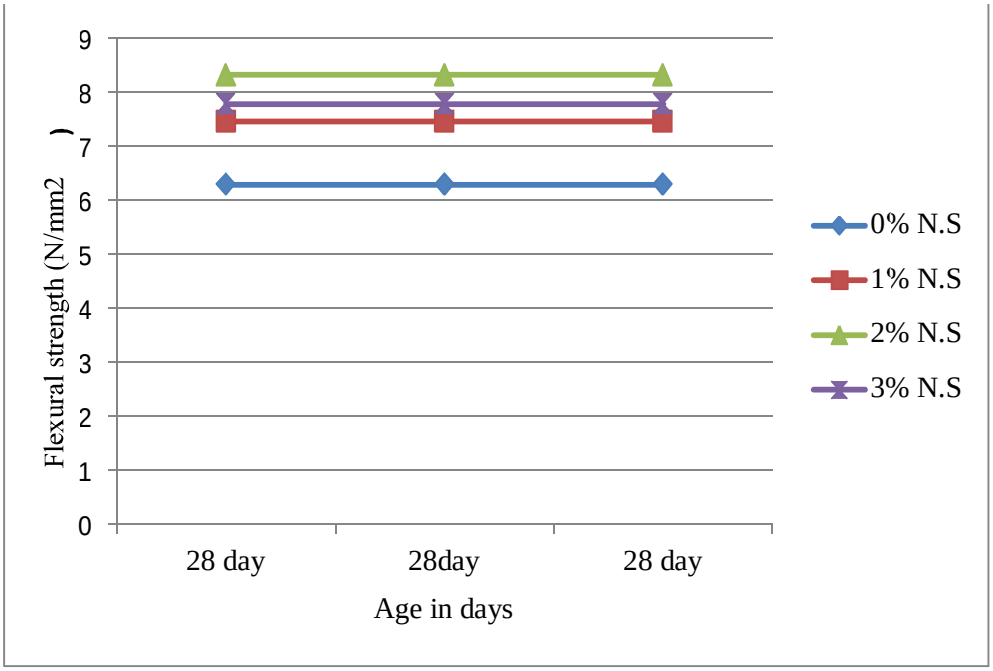


Fig. 3 flexural strength values of various mixes with age

D. Durability Tests

Durability study is important for determining the quality of concrete. The main purpose of this study is to investigate the durability performance of concrete at different environmental conditions. The tests carried out for determining the durability properties of normal M60 concrete and M60 concrete with N.S include water absorption test.

1) *Water Absorption Test:* The amount of water absorbed by the specimen when immersed in water for a stipulated period of time is water absorption. 150mm cubes cured for 28days were used for water absorption test.

Table 4 Water absorption test values

Mix id	Sample No:	$W1$	$W2$	$\frac{W2-W1}{W1}\times 100$
0 % N.S	1	8.05	8.319	3.34
	2	8.12	8.396	3.399
	3	8.035	8.308	3.397
	Average	8.068	8.341	3.383
2% N.S	1	8.005	8.22	2.68
	2	7.98	8.193	2.66
	3	8.07	8.28	2.602
	Average	8.018	8.231	2.656

From the table, it is seen that the water absorption for concrete cubes with partially replacing cement by 2% N.S is 2.656% , which is 21.489 % lesser than that of normal M60 grade concrete cubes.

E. Experimental Investigation On RC Beam

The load deflection behaviour, ultimate load carrying capacity and crack patterns of two RC beams were investigated (1 beam with normal M60 mix (CB), 1 beam with mix containing 2% N.S (NSB).

1) *Load deflection behaviour of RC Beam:* The mid span deflection of all the two RC beams corresponding to each load is observed. Also the load which causes the development of initial crack is recorded. The load deflection behavior of beams is shown in f5g 4 .

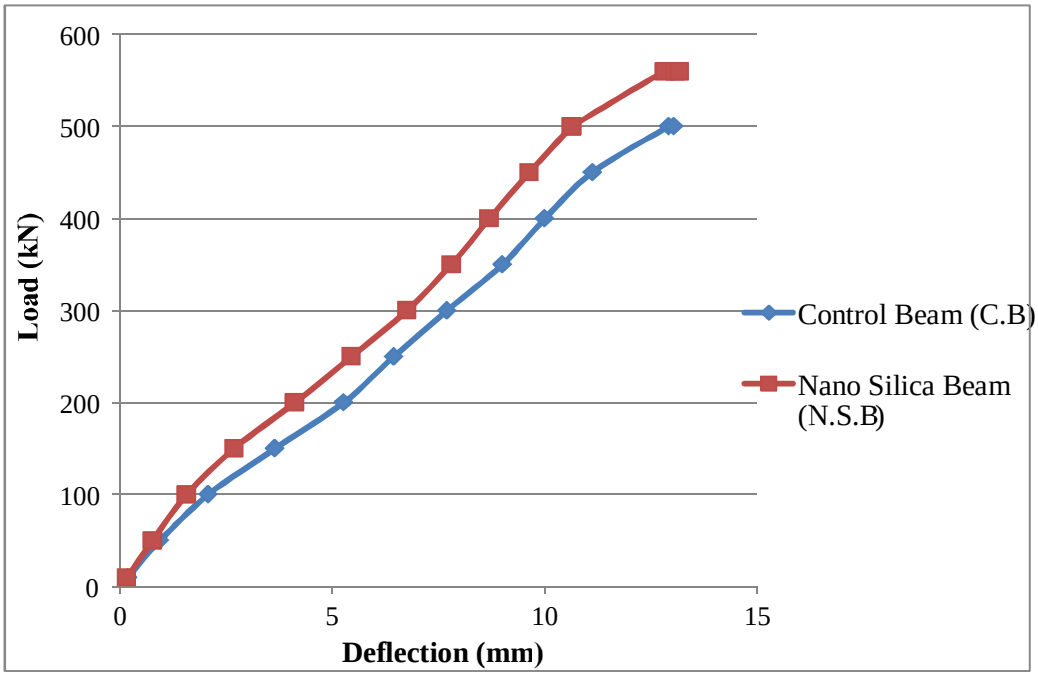


Fig. 4 Load deflection behavior of beam

2) *Failure Modes:* All the two beams fail by flexural mode of failure. Cracks get initiated at tension zone and propagated towards the compression zone. Shear cracks are then formed as secondary cracks from the supports and are propagated diagonally towards the centre.

3) *Ultimate Load Carrying Capacity:* Control Beam CB containing normal M60 grade failed at a load of 500kN, and NSB containing concrete with 2% N.S failed at an average load of 560kN respectively.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
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V. ANALYTICAL PROGRAM

The software used for the study is Ansys Mechanical Apdl (Ansys Parametric Design Language). ANSYS can carry out advanced engineering analyses quickly, safely and practically by its variety of contact algorithms, time based loading features and nonlinear material models.

A. Material Property

Material properties are required for most of the elements. Depending upon the application, material properties may be linear or non linear; Isotropic, orthotropic or anisotropic; constant temperature or temperature independent. Here, steel of Fe415 grade and concrete of M60 grade are the two materials selected. Beam B1 is modeled using properties of normal M60 mix, and Beam B2 is modelled using properties of concrete containing 2% of N.S. The material properties given in ANSYS are shown in Table 5, 6 and 7.

Table 5 Linear Isotropic properties of concrete and steel

Material	Linear Isotropic properties		
	Modulus of elasticity (MPa) of Beam1	Modulus of Elasticity(MPa) of Beam B2	Poisson's ratio
Concrete	41542	45008	0.1
Steel	200000	200000	0.3

Table 6 Nonlinear inelastic property of concrete

Properties	Reinforced concrete – SOLID65
ShrCf-Op	0.3
ShrCf-Cl	0.9
Un Tenst	10
Un Compst	-1

Table 7 Bilinear isotropic property of steel

Yield stress	415
Tangent modulus	20

B. Creating the model geometry

The next step in the analysis is generating a finite element model, nodes and elements that describe the geometry. There are two methods to create the finite element model, Solid modeling and direct generation. In solid modeling, it is required to describe the geometric shape of the model. Then instruct the ANSYS program to automatically mesh the geometry with nodes and elements. There is a control over the size and shape of the elements that program creates. In the case of direct generations, it is required to define the location of each node and connectivity of each element manually. Here, the method of solid modeling is adopted for creating model. Model is created as volume. Model is then meshed with an edge length of 25mm. Mesh model is shown in Fig 5.

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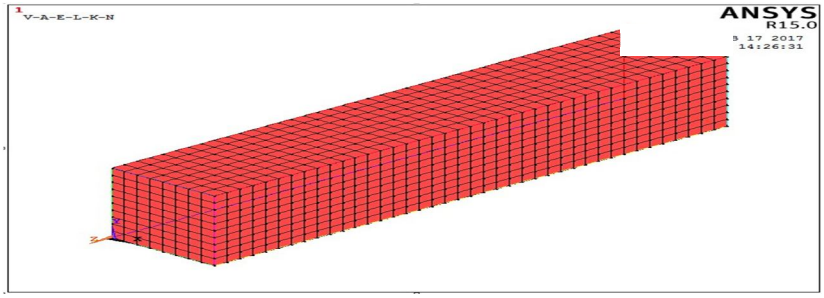


Fig.5 Mesh model

Reinforcement is generated by connecting the specific nodes by Beam 188 element.
Reinforcing bars is shown in Fig 6.

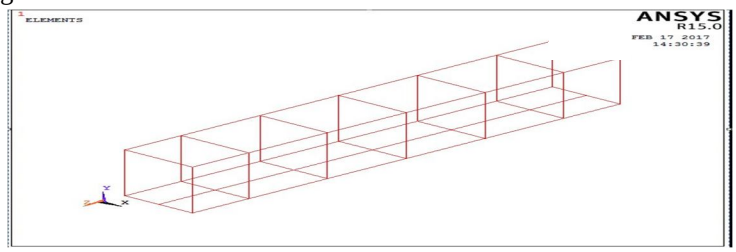


Fig. 6 Reinforcing bars

C. Solution Stage

Solution stage includes the loading and applying constraints.

D. Applying Loading Conditions

Loads can be applied either by solution processor or pre-processor. Loading conditions includes boundary conditions i.e. constrains or supports, other externally or internally applied loads. Loads in ANSYS program are divided into different categories: DOF constraints, forces, surface loads, body forces, inertia loads and coupled field nodes. Most of these loads are applied in the key points, nodes, lines or areas of finite element model.

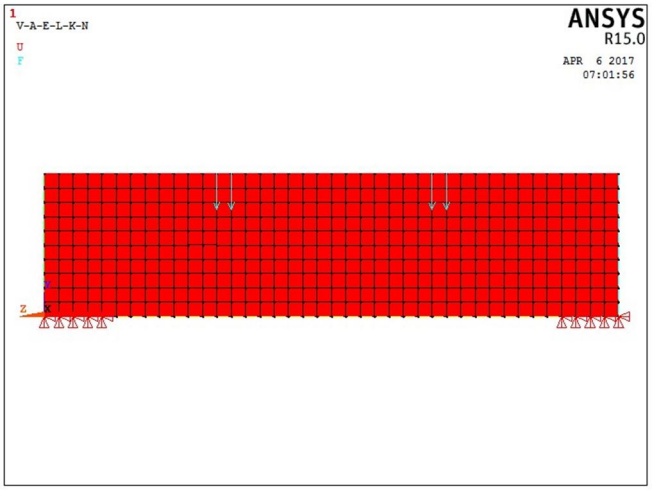


Fig 7 Model after applying load and support conditions

E. FEM Analysis

The ANSYS program offers the following analysis types: Static, Modal, Transient, harmonic, spectrum, Eigen buckling, and sub structuring/ CMS. Analysis options allow customization of analysis types. It is required to select the analysis type and begin the solution.

VI. RESULTS AND DISCUSSION FROM FEM ANALYSIS

Load deflection behaviour and ultimate load carrying capacity of RC beams were analyzed using ANSYS software.

A. Load Deflection Behaviour Using Ansys Software

Various loads are applied on RC beam model with load increment of 10kN. Static analysis is performed in two RC beams with different properties (Beam B1 with normal M60 concrete, Beam B2 with concrete containing N.S also), in order to determine the load deflection behaviour. The maximum deflection corresponding to each load is shown in fig 8.

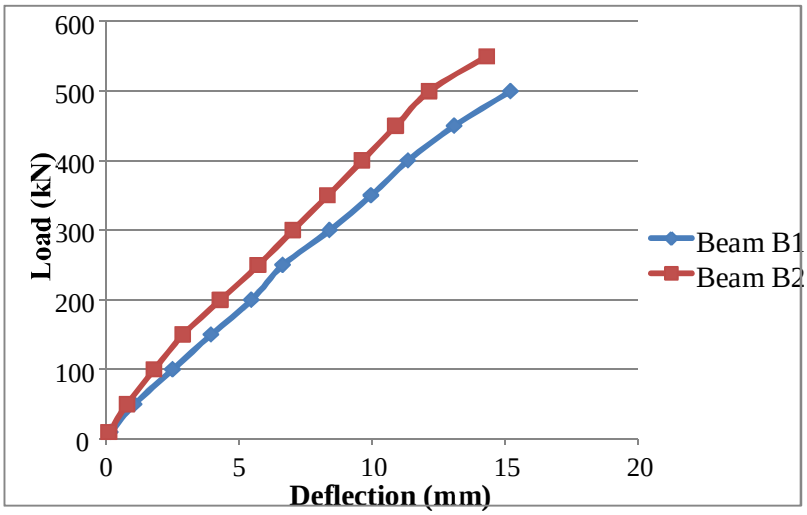


Fig. 8 Load deflection behavior of beam

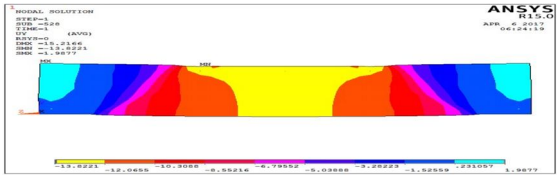


Fig 9 Deflection of normal M60 beam for 500Kn

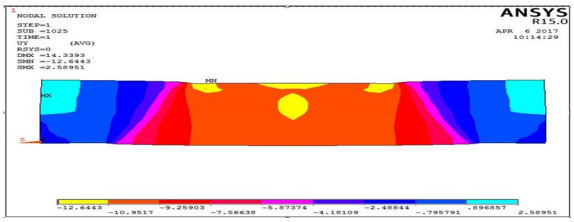


Fig 10 Deflection of M60 beam with Nano silica for 550kN

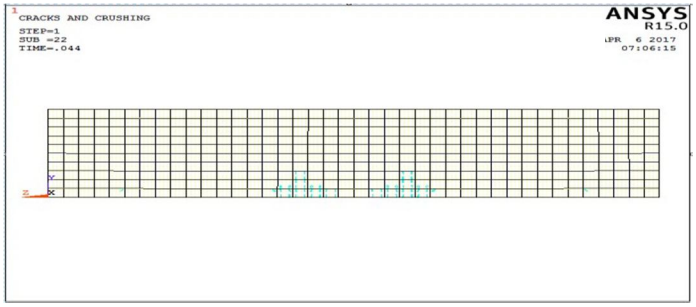


Fig.11 Initial crack obtained for Beam B1

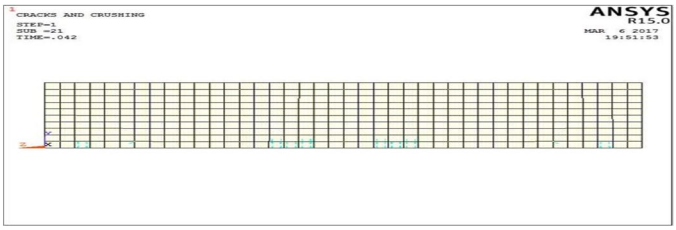


Fig.12 Initial crack obtained for Beam B2

B. Ultimate Load Carrying Capacity of Beam

The ultimate load carrying capacity of normal M60 (B1) beam is 500kN, and that of beam (B2) with concrete containing Nano silica is 550kN.

VII. COMPARISON OF EXPERIMENTAL AND ANALYTICAL RESULTS

The experimental and analytical values obtained for load deflection, crack patterns and ultimate load carrying capacity of beams were compared.

A. Comparison of Load Deflection Values

The maximum deflection obtained for normal M60 beam (CB) from experimental study is 12.93mm and for beam B1 from analytical study is 15.216mm. The maximum deflection for beam with M60 grade concrete containing 2% N.S is 12.83 mm from experimental study and from analytical study is 14.32mm.

B. Failure Modes and Crack Patterns

For all the beams, it is observed that initial crack starts from the tension zone and propagated to the compression zone for both experimental study and analytical study.

The failure of beam is by flexure failure.

C. Ultimate Load Carrying Capacity

The ultimate load carrying capacity from the experimental study of beam CB is 500kN, and that of NSB is 560kN. Analytical study shows the failure of Control beam B1 at 500kN and Beam with concrete containing N.S, B2 at 550kN.

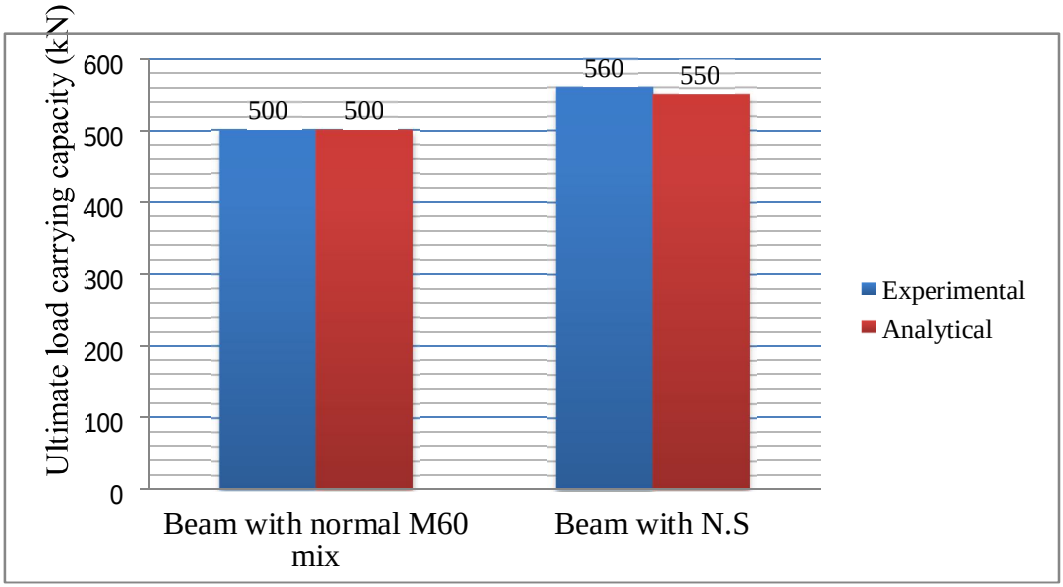


Fig 13 Comparison of Experimental and Analytical values

VIII. CONCLUSION

1) Characteristics compressive strength obtained for M60 grade mix is 69.03%.
2) Slump values indicate that workability of fresh concrete decreases with the increase in percentage of Nano silica. This is due to high surface area and high reactivity of Nano particles.
3) Compressive strength, split tensile strength and flexural strength of concrete increases with increase in percentage of Nano silica up to 2%, and further increase in Nano silica causes decrease in compressive strength. So the optimum percentage of Nano silica which gives maximum strength is 2%.
4) Compressive strength of cube for mix with partial replacement of cement by 2% of Nano silica is 81.03MPa, which is 17.4% more than normal M60 mix.
5) Split tensile strength of cylinder for mix with partial replacement of cement by 2% of Nano silica is 4.88MPa, which is 23.5% more than that of normal M60 mix
6) Flexural strength of beam for mix with partial replacement of cement by 2% of Nano silica is 8.308MPa which is 32.29% than that of normal M60 mix.
7) Durability tests such as water absorption test indicates that,

There is decrease in water absorption by 21.489% in N.S mix than normal M60 mix

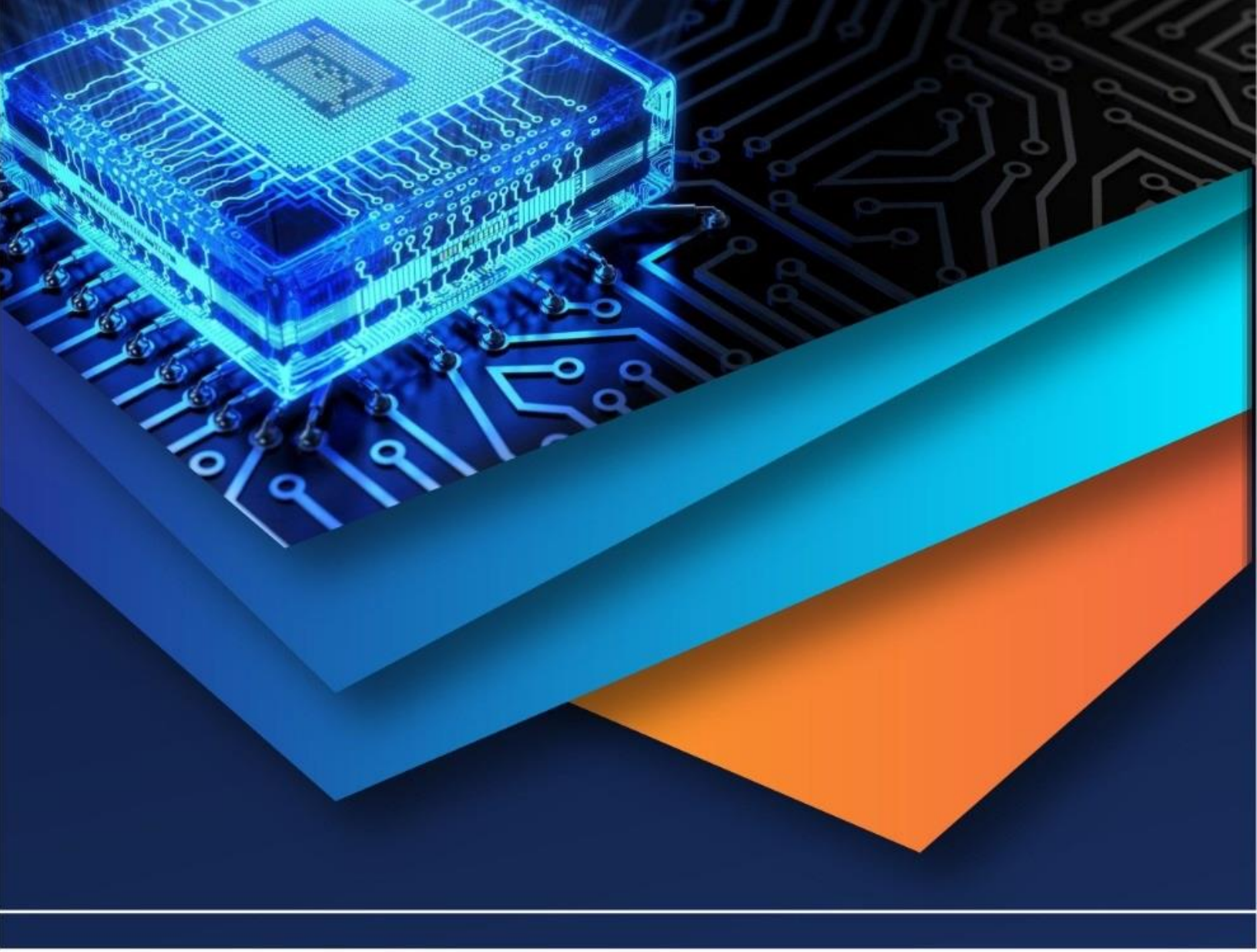
a) The ultimate load carrying capacity of RC beam with normal M60 grade concrete (CB) is 500kN, beam with M60 grade containing Nano Silica (NSB) is 560kN.
b) The maximum deflection of RC beam with normal M60 grade concrete is 12.83mm, beam with M60 grade containing Nano Silica is 12.93mm.
c) From FEM analysis, it is obtained that maximum load carrying capacity of normal M60 beam is 500kN and that of beam with concrete containing N.S is 550kN.

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