

EXPERIMENTAL INVESTIGATION ON MECHANICAL PROPERTIES OF CONCRETE MODIFIED WITH NANO-ALUMINA AND GLASS FIBER

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Abstract - The present study explores the mechanical and durability behavior of M35 grade concrete modified with nano-alumina (Al_2O_3) and glass fiber. Nano-alumina was incorporated as a partial replacement of cement at 1%, 2%, and 3%, while glass fibers were added in proportions of 0.2%, 0.3%, and 0.4% by volume of concrete. The experimental program included workability, compressive strength, split tensile strength, and flexural strength evaluated at curing ages of 7, 14, and 28 days. The findings reveal that nano-alumina significantly enhances hydration kinetics and reduces pore size due to its nano-scale filler effect, while glass fibers contribute to improved crack resistance and post-cracking behavior. The optimum performance was observed at 2% nano-alumina and 0.3% glass fiber, showing substantial improvements in compressive strength (~22%), split tensile strength (~41%), and flexural strength (~19%) at 28 days. However, excessive fiber content resulted in reduced workability and slight strength reduction due to fiber agglomeration. The study demonstrates that hybrid nano-modification combined with fiber reinforcement can effectively produce high-performance and durable concrete suitable for structural applications.

Key Words: Nano-alumina, Glass fiber, Compressive strength, Tensile strength, Flexural strength

1. INTRODUCTION

Concrete continues to be the most widely utilized material in construction due to its versatility and cost-effectiveness. However, its inherent brittleness, low tensile capacity, and susceptibility to microcracking limit its structural efficiency. In recent years, the incorporation of nano-materials and fibers has emerged as a promising approach to overcome these deficiencies. Nano-alumina (Al_2O_3), owing to its extremely fine particle size and high reactivity, plays a crucial role in improving cement hydration. It acts as a nucleation site for hydration products and significantly refines the pore structure, leading to enhanced density and strength. Unlike conventional mineral admixtures, nano-alumina operates at

the microstructural level, thereby improving the interfacial transition zone (ITZ) between aggregates and cement paste. On the other hand, glass fibers are known for their high tensile strength and ability to control crack propagation. When uniformly distributed within the concrete matrix, they bridge microcracks and delay crack growth, resulting in improved ductility and toughness. The combined use of nano-alumina and glass fiber introduces a multi-scale strengthening mechanism, where nano-particles enhance the matrix quality and fibers improve crack resistance. Although similar hybrid approaches have been studied using nano-silica and basalt fiber, limited research exists on nano-alumina and glass fiber, particularly for M35 grade concrete. Therefore, this study aims to fill this gap through systematic experimental investigation.

2. METHODOLOGY

2.1 Material Used

2.1.1 Cement

Ordinary Portland Cement (OPC) of 43 grade conforming to IS: 8112 (2013). Physically tested for fineness, standard consistency, setting time, and specific gravity as per IS: 4031(1996). All the test results are shown in Table 1.

Table-2.1: Cement test results

TEST	RESULTS
Consistency	30.12%
Initial setting time	48 min
Final setting time	430 min
Fineness	6.10%
Specific gravity	3.13

2.1.2 Fine Aggregate

River sand with a fineness modulus 2.8, 7.7% silt content. Free from silt, organic impurities; confirming to Zone II as per IS: 383–2016. Table 2 represents all the property of fine aggregate.

Table-2.2: Fine aggregate results

TEST	RESULTS
Zone	II
Silt content	7.7%
Water absorption	0.4%
Fineness modulus	2.8
Specific gravity	2.6

2.1.3 Coarse Aggregate

Crushed granite aggregates of 20 mm and 10 mm sizes. Proportioned and graded to conform to IS: 383–2016. Coarse aggregate has specific gravity 2.6 and water absorption 0.2%.

2.1.4 Water

Potable water is used for mixing and curing.

2.1.5 Nano-Alumina (Al₂O₃)

Commercially available nano-alumina powder with an average particle size in the range of 20–50 nm was utilized as a partial replacement of cement. The material possessed a high purity level of approximately 99% and a specific gravity of about 3.2. Due to its ultra-fine particle size and large specific surface area, nano-alumina exhibits high reactivity and acts as an effective micro-filler within the cement matrix. It is typically white in appearance and crystalline in nature. The incorporation of nano-alumina enhances the hydration process by providing nucleation sites for the formation of hydration products, leading to improved microstructure and strength development.

2.1.6 Glass Fiber

Chopped glass fibers with an average length of 12 mm and a diameter of approximately 10–14 μm were used in this study. The fibers possess a tensile strength of about 2000 MPa and a modulus of elasticity of nearly 70 GPa. The specific gravity of glass fiber is around 2.6. These fibers are non-corrosive, chemically stable, and exhibit good resistance to alkali

environments when properly treated. They were uniformly dispersed throughout the concrete mix to ensure effective crack-bridging action. The inclusion of glass fibers contributes to improved tensile strength, flexural performance, and ductility by controlling crack initiation and propagation within the concrete matrix.

Table-2.3: Properties of Glass fiber

Material	Property	Test Results
Basalt Fiber	Specific Gravity	2.6
	Fiber Length	12 mm
	Tensile Strength	2000 MPa
	Young's Modulus	70 GPa

2.1.7 Super Plasticizer

(SP)430 superplasticizer was used as a water-reducing agent. The dosage used in the mixer was 1% of the weight of cementitious material. The specific gravity of superplasticizer is 1.316

2.2 Mix Proportion

Mix design of M40 grade of concrete done as per IS 10262: 2019 and a target slump of 100 mm. Concrete mix were prepared varying from 1-3% of Nano Silica as cement replacement and 0.3-0.5% Basalt fiber respectively. The mix proportion used in the study is shown in Table 2.4.

Table-2.4: Mix proportion used in the study.

MATERIALS	QUANTITY (kg/m ³)
Cement	380
Fine aggregate	700
Coarse aggregate	1200
Water	160
Water Cement ratio	0.42
Admixture	3.95 (1% by weight of cement)
Nano Al ₂ O ₃	1-3% as a cement replacement
Glass fiber	0.2-0.4% as addition in concrete

2.3 Experimental Procedure

2.3.1 Workability Test

The slump cone test was employed in accordance with IS code 1199 part 2 (2018) to verify the flowability of concrete samples.

- A steel cone (frustum) with dimensions of 300 mm in height, 200 mm in lower diameter, and 100 mm in upper diameter was filled with fresh concrete in three equal layers.
- Each layer was tamped 25 times with a standard tamping rod.
- The concrete has to be carefully and gently lowered vertically to remove the mould as soon as possible.
- The reduction in height of the concrete specimen is measured as the slump value, which represents the workability of the mix.

2.3.2 Density Test

This allows the concrete to sink, and the slump may be easily measured by figuring out how much the concrete has risen over the mould. The concrete cube's weight was determined after 28 days. The weight of the test specimen was first ascertained, and its volume was then divided by its weight using Eq. (2.1) to find the density.

$$\text{Density} = \text{Mass} / \text{Volume} \quad (2.1)$$

2.3.3 Water Absorption Test

A 150 mm cubic specimen that was 28 days old was employed in the water absorption test. After the wet concrete cubes were weighed, they were stored at 110°C in an oven. Next, the dried sample weight was ascertained as per Eq. (2.2).

$$\text{Water absorption in \%} = \frac{\text{Wet Concrete} - \text{Dry Concrete}}{\text{Dry Concrete}} \quad (2.2)$$

2.3.4 Compressive Strength

Compressive strength is the ability of a material or structure to bear loads on its surface without breaking or deflecting. A compression testing machine was used to conduct compression tests on concrete cube specimens measuring 150 mm at 7, 14, and 28 days in accordance with IS 516-part 1 standard. The compressive test results for the three cubic specimens were averaged to determine the compressive strength of each mixture.

2.3.5 Split Tensile Strength

The split tensile test was performed using cylindrical specimens having a diameter of 100 mm and a height of 200 mm, in compliance with the IS 516-part 1 standard. Concrete tensile strength is far less than its compressive strength, tension stresses are carried by fibers in the concrete. The three samples were tested at ages 7, 14, and 28 days, with each sample being tested on a compression testing machine according to eq. (2.3).

$$\text{Split Tensile Strength} = 2P / \pi LD \quad (2.3)$$

where P: maximum applied load, D: specimen diameter and L: specimen length.

2.3.6 Flexural Strength

The concrete beam specimens for concrete mixes measured 150mm×150mm×700mm. Concrete has a far lower tensile strength than compressive strength, hence steel is used to bear the tension forces in the material. It is believed that 10% of compressive strength is equal to tensile strength in concrete. The specimens, which had an effective span of 600 mm, were tested as supported structures. According to Eq. 4, the load was given to two places that were each 100 mm from the centroid of the beam as per eq. (2.4).

$$\text{Flexural strength} = \frac{PL}{BD^2} \quad (2.4)$$

where P: maximum applied load, B and D: specimen lateral diameter and L: specimen length.

3. RESULTS AND DISCUSSION

3.1 Compressive Strength Test

The compressive strength of concrete increases with the addition of nano-alumina up to an optimum level of 2%, primarily due to enhanced hydration and improved particle packing, which leads to a denser microstructure. The nano-particles act as nucleation sites, promoting the formation of hydration products and reducing porosity. However, a slight decrease in strength is observed at higher dosages (3%) due to particle agglomeration and poor dispersion. The inclusion of glass fibers further improves strength by bridging microcracks and enabling effective stress redistribution within the matrix. Together, these effects result in improved overall mechanical performance when used in optimal proportions.

Table-3.1-Compressive Strength of different concrete mix

Mix ID	Compressive Strength (MPa)			% Increase (28d)
	7d	14d	28d	
CM	24.8	31.6	38.5	0
NA1	27.2	34.5	42.2	+9.6%
NA2	29.1	37.8	45.6	+18.4%
NA3	26.5	33.2	41.8	+8.6%
NA2GF0.2	30.4	39.2	46.8	+21.6%
NA2GF0.3	31.2	40.5	47.5	+23.4%
NA2GF0.4	30.1	38.9	46.2	+20.0%

combination significantly enhances the tensile performance of concrete.

Table-3.2: Split tensile Strength of different concrete mix

Mix	Split tensile Strength (MPa)			% Increase (28d)
	7 d	14 d	28 d	
CM	2.10	2.85	3.42	0
NA1	2.28	3.05	3.72	+8.7%
NA2	2.41	3.22	3.85	+12.6%
NA3	2.25	2.98	3.60	+5.3%
NA2GF0.2	2.85	3.75	4.75	+38.8%
NA2GF0.3	2.95	3.90	4.82	+40.9%
NA2GF0.4	2.80	3.70	4.60	+34.5%

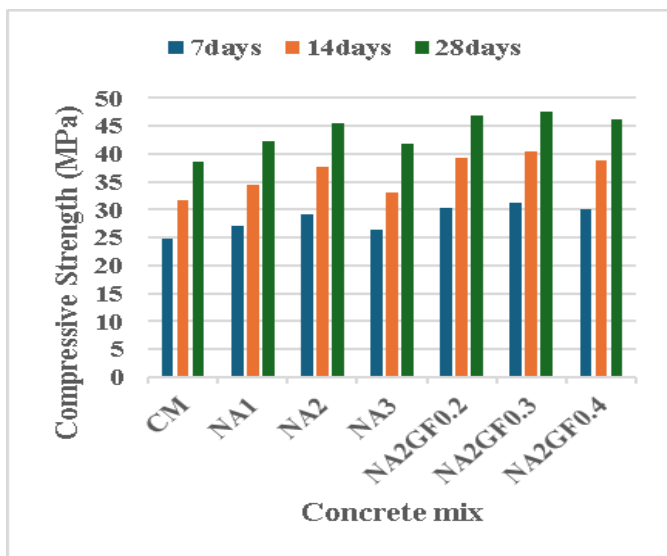


Chart-3.1: Compressive Strength of concrete mix

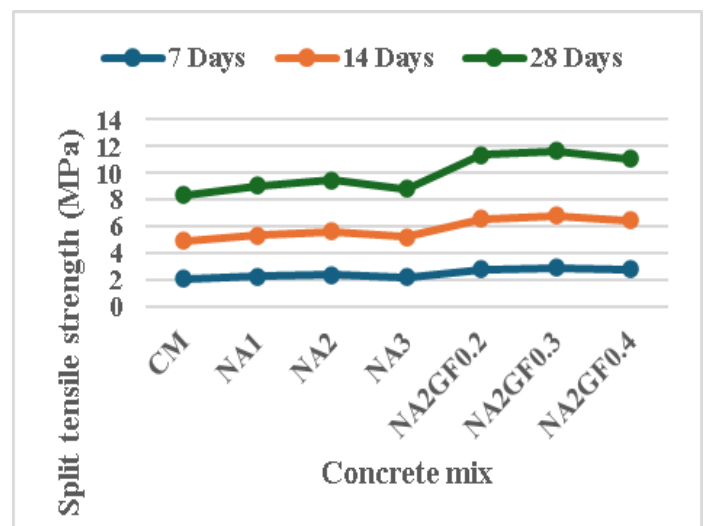


Chart-3.2: Split tensile Strength of different concrete mix

3.2 Split Tensile Strength

Table 2 shows that the split tensile strength increases with the incorporation of nano-alumina and glass fiber compared to the control mix. The maximum tensile strength is achieved in the mix containing 2% nano-alumina and 0.3% glass fiber, indicating the optimum proportion. This improvement is mainly due to effective crack-bridging action of fibers along with matrix densification caused by nano-alumina. Beyond this level, a slight reduction in strength is observed due to fiber clustering and reduced workability. Overall, the hybrid

3.3 Flexural Strength

Flexural strength of concrete, also known as modulus of rupture, measures the tensile strength of concrete indirectly or the stress in the material can resist without yielding in an unreinforced concrete flexure test. Flexural strength of concrete reflects the concrete's resistance to bending. Understanding the flexural strength of concrete helps to

predict how buildings behave under bending loads. Table 3.3 represents flexural strength of different concrete mix after 28 days of testing using a two-point load flexural testing apparatus.

Table-3.3 Flexural Strength of different concrete mix

Mix	Flexural Strength (MPa)			% Increase (28d)
	7 d	14 d	28 d	
CM	3.20	3.75	4.10	0
NA1	3.35	3.90	4.35	+6.0%
NA2	3.55	4.15	4.65	+13.4%
NA3	3.30	3.85	4.30	+4.8%
NA2GF0.2	3.85	4.55	4.90	+19.5%
NA2GF0.3	3.95	4.65	4.95	+20.7%
NA2GF0.4	3.80	4.50	4.80	+17.0%

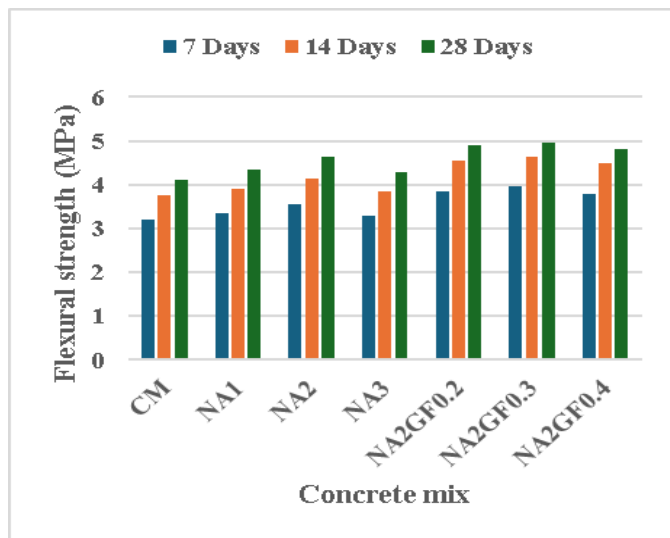


Chart-3.3: Flexural strength of concrete mixes

4. CONCLUSIONS

4.1 Introduction

Based on the comprehensive experimental investigation, it can be concluded that the incorporation of nano-alumina and glass fiber significantly improves the mechanical

performance of M35 grade concrete. The optimum combination was identified as 2% nano-alumina as partial cement replacement along with 0.3% glass fiber addition, which yielded the best results across all strength parameters. At this optimum level, the concrete exhibited substantial improvements in compressive, split tensile, and flexural strength at 28 days of curing. The observed enhancement in compressive strength is mainly attributed to the filler effect and accelerated hydration induced by nano-alumina, which results in a more compact and less porous microstructure. Meanwhile, the increase in tensile and flexural strength is primarily due to the crack-bridging capability of glass fibers, which enhances the ductility and load redistribution capacity of the material. However, it is important to note that excessive inclusion of either nano-material or fiber can lead to reduced workability and potential strength loss due to agglomeration and poor dispersion. Overall, the study confirms that the hybrid approach of combining nano-scale materials with fiber reinforcement is highly effective in producing high-performance concrete with improved structural reliability. Such modified concrete can be considered a promising material for advanced construction applications where strength, durability, and crack resistance are critical requirements.

4.2 Future Scope

The present study demonstrates the beneficial effects of incorporating nano-alumina and glass fiber in M35 grade concrete; however, several areas remain open for further investigation. Future research can focus on evaluating long-term durability under aggressive environmental conditions such as chloride ingress, sulfate attack, carbonation, and freeze-thaw cycles to assess field performance. Detailed microstructural analysis using advanced techniques like Scanning Electron Microscopy (SEM), X-ray Diffraction (XRD), and Thermogravimetric Analysis (TGA) can provide deeper insight into hydration behavior and the interfacial transition zone. Further studies may also explore optimization of fiber length, aspect ratio, and dispersion methods to minimize clustering and improve workability. In addition, the combined use of nano-alumina and glass fiber with supplementary cementitious materials such as fly ash, slag, or recycled aggregates can be investigated to enhance sustainability. The application of this hybrid concrete in self-compacting systems, precast elements, and large-scale structural members also offers promising research opportunities.

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