LONG-TERM CREEP AND SHRINKAGE BEHAVIOR OF NANO ALUMINA POLYPROPYLENE CONCRETE

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ABSTRACT

This research explores the synergistic effects of nano alumina and polypropylene granules on the mechanical properties, shrinkage, and creep behavior of concrete. Modifications were made to a conventional M40 concrete mix by partially replacing cement with nano alumina (1%) and fine aggregate with polypropylene granules (10%). Results showed that the modified mix (D2) achieved higher compressive strength (53.72 MPa) compared to the control mix (D1) at 51.34 MPa. However, D2 exhibited greater creep strain and shrinkage, suggesting increased long-term deformation under sustained loading and curing conditions. Nano alumina enhanced the concrete's initial strength by densifying the cement matrix, yet contributed to higher creep due to stress concentrations in rigid zones. Polypropylene granules improved workability and flexibility but, due to their low stiffness, introduced greater deformation over time. These findings highlight the trade-off between improved strength and increased susceptibility to shrinkage and creep, offering insights into optimizing mix designs for applications where both initial strength and long-term durability are required.

Keywords: Concrete Creep, Shrinkage Deformation, LVDT Test, Compressive Strength, Nano Aluminum oxide, Polypropylene.

1. INTRODUCTION

Concrete remains a crucial material in the construction industry, continually evolving to address the increasing demands for enhanced performance, durability, and sustainability. One promising approach to improve concrete properties is the incorporation of nanomaterials and polymeric additives. This study investigates the long-term creep and shrinkage behavior of concrete modified with nano alumina and polypropylene granules, highlighting the significance of these materials in optimizing concrete performance over time. Polypropylene granules, a type of polymeric additive, not only improve concrete's toughness and resistance to cracking but also play a vital role in mitigating shrinkage. By evenly distributing stress across the concrete matrix, these granules help prevent the formation of microcracks and reduce the risk of volume changes due to drying and environmental influences. This enhancement in flexibility and resistance to dynamic loads is crucial for maintaining structural integrity throughout the lifespan of concrete elements, particularly under sustained loads.

On the other hand, nano alumina accelerates hydration and promotes the formation of calcium silicate hydrates (C-S-H), which strengthen the concrete matrix. Its incorporation not only improves early-age strength but also reduces long-term creep, a phenomenon that can lead to deformation and instability in structures over time. Moreover, the addition of nano alumina decreases permeability, offering increased resistance to environmental factors such as freeze-thaw cycles and chemical attacks, which are critical for maintaining durability and longevity. The combined effects of nano alumina and polypropylene granules significantly enhance the toughness, energy absorption capacity, and overall stability of concrete under both static and dynamic loads. This study aims to explore their influence on long-term creep and shrinkage behavior, which are vital for assessing the long-term performance and serviceability of concrete structures. By conducting both experimental tests and numerical analysis, this research will provide insights into the mechanisms governing creep and shrinkage in modified concrete, contributing to the development of advanced formulations that meet modern construction needs. Previous studies have shown that nanomaterials can significantly alter the viscoelastic properties of concrete, influencing its long-term behavior. Research indicates that the use of nano alumina can effectively reduce creep coefficients and shrinkage rates, making it a valuable addition for high-performance concrete in critical applications. Similarly, polypropylene granules have been found to enhance ductility and mitigate shrinkage-related cracking, further extending the service life of concrete structures. Furthermore, understanding the interplay between creep and shrinkage in nano alumina-polypropylene granules concrete is essential for effective design and material selection in construction projects. By systematically examining these interactions, this research aims to provide valuable insights into developing concrete that not only meets performance criteria but also withstands the test of time. Through both experimental and numerical methods, this study seeks to address the challenges posed by long-term deformations, ultimately leading to innovations in concrete technology that align with current and future infrastructure demands.

2. METHODOLOGY

2.1 Cement- Cement is a key binding material in construction, primarily used in concrete, where it undergoes a chemical reaction with water to form a solid mass that provides structural strength and durability. In this research, Ordinary Portland Cement (OPC) of 43 grade was utilized. Its properties, including fineness, specific gravity, consistency, and initial and final setting times, were evaluated in the laboratory according to IS:4031-1996, as these characteristics significantly influence the hydration process and overall performance of the concrete, results of these tests are presented in Table 1.

Table 1. Physical Properties of Cement

SN.	Properties	Result
1	Specific Gravity	3.21
2	Consistency	30%
3	Initial Setting	35 minutes
4	Final Setting	310 minutes
5	Fineness Modulus	6.11

2.2 Nano Alumina- Physical and Chemical composition of nano aluminum oxide are shown in Table 2 and Table 3 respectively.

Table 2. Nano Aluminum Oxide Physical Properties

SN.	Properties	Result
1	Size	70nm
2	Particle Shape	Sphere
3	Density	3.47 g/cm^3
4	Color	White

Table 3. Nano Alumina Chemical Composition

SN.	Properties	Result
1	Al_2O_3	> 99.999 %
2	SO_2	< 0.0005 %
3	Fe	< 0.0003 %
4	Mg	< 0.0002 %

2.3 Polypropylene- The properties of polypropylene pellets that used in this wok are shown in Table 4 below.

Table 4. Polypropylene Property

SN.	Properties	Result
1	Formula	$(C_3H_6)_n$
2	Density	940 kg/m^3
3	Size	1.5 mm

2.4 Aggregates- The properties of fine and coarse aggregate that used in this work are shown below in Table 5.

Table 4. Property of Aggregates

SN.	Properties	Result	
		Fine Aggregate	Coarse Aggregate
1	Specific Gravity	2.68	2.91
2	Water Absorption	1.11%	0.77%
3	Fineness Modulus	2.44	6.71
4	Grade Zone	2	2

2.5 Mix Design

Table 5: Design Mix for M40

Mix	Cement	Sand	Coarse Agg.	Nano-Alumina	Polypropylene	w/c ratio
D1	445.16 (kg/m^3)	700.11 (kg/m^3)	1187(kg/m^3)	0	0	0.35
D2	440.70 (kg/m^3)	630.09 (kg/m^3)	1187(kg/m^3)	4.45 (kg/m^3)	70.011 (kg/m^3)	0.35

3. RESULT AND DISCUSSIONS

3.1 Determination of Creep strain using Linear Variable Displacement Transducer (LVDT) test

The determination of creep strain using a Linear Variable Displacement Transducer (LVDT) involves a systematic approach to measure the deformation of concrete specimens subjected to sustained loading over time.

In this research, using concrete beams of size 700 mm x 150 mm x 150 mm for creep testing with a Linear Variable Displacement Transducer (LVDT) follows a similar approach to the one explained earlier but tailored for beam specimens. The beam specimens are cast and cured in line with standard procedures, ensuring consistency across all samples.

For the test setup, the beams are mounted in a loading frame where a sustained load is applied to simulate real-world conditions. The load is usually a fraction of the beam's compressive strength and is applied gradually. To measure the deformation under this load, LVDTs are installed at mid-span and on both ends of the beam. The LVDTs are positioned to accurately measure vertical displacement at key points on the beam, helping to capture any bending or deflection that occurs as a result of the sustained load. Before applying the load, initial length or height measurements of the beam are taken, ensuring precise baseline data for later calculations. The sustained load is applied, and the deformation is monitored using the LVDTs over the duration of the test, which is typically 28 days. The readings are taken at regular intervals to track how the beam deforms over time. Creep strain for the beams is calculated using the same formula:

$$\text{Creep Strain} = \frac{\Delta L}{L_O}$$

where ΔL represents the change in length or deflection measured by the LVDT, and L_O is the initial length or reference measurement. The strain values obtained from these measurements are recorded and plotted over time to analyze how the concrete beam behaves under sustained loading. Using beams instead of standard cylindrical specimens provides more realistic insights into the structural performance of modified concrete mixes, like the D2 mix with nano aluminum oxide and polypropylene granules and the control mix D1. By comparing the creep behavior of these two mixes using beam specimens, can assess how the modifications in D2 influence long-term deflection and deformation under load, providing valuable data for understanding its structural implications.

Test Setup: The concrete specimens beam, with dimensions 700 mm x 150 mm x 150 mm are placed in a creep testing apparatus or a loading frame designed for applying long-term loads. In this setup, weights or a hydraulic system apply a constant load to the specimens.

Application of Sustained Load: The sustained load is applied gradually to avoid any sudden deformation. The loading frame should allow for the application of this load in a controlled manner.

Cross-Sectional Area of the Beam: The cross-sectional area of a 150 mm x 150 mm (0.15 m x 0.15 m) beam is:

$Cross\ sectional\ Area = Width\ x\ Height = 0.15\ x\ 0.15 = 0.0225\ m^2$

Applying the Sustained Load Factor: Using the same sustained load factor of 0.4, represents a common proportion of the compressive strength applied to the specimen for long-term creep testing. It simulates realistic loading conditions. The load to be applied for each mix is calculated as follows:

$Load = Sustained\ Load\ Factor\ x\ Compressive\ Strength\ x\ Cross\ sectional\ Area$

For D1 (Control Mix) with Compressive Strength of 51.34 MPa:

$Load_{D1} = 0.4\ x\ 51.34\ x\ 0.0225 = 0.462\ kN$

For D2 (Modified Mix) with Compressive Strength of 53.72 MPa:

$Load_{D2} = 0.4\ x\ 53.72\ x\ 0.0225 = 0.484\ kN$

Thus, for the beam specimens, you would apply a sustained load of approximately 0.462 kN for D1 and 0.484 kN for D2 during the creep test. This constant load is maintained throughout the test period, 28 days. The applied load stays constant, simulating a long-term load that concrete might experience in actual structures.

During the Creep Test: Once the load is applied, deformations (strain) that occur in the specimen are measured using Linear Variable Displacement Transducers (LVDTs). These devices are installed at different points on the specimen to measure how much it deforms under the sustained load over time. The deformation recorded at regular intervals (e.g., daily or weekly) allows for the calculation of creep strain.

Use of the Load Value in Creep Calculations: The load (0.462 kN for D1 and 0.484 kN for D2) plays a role in determining how much the concrete will deform under these forces. By comparing the measured creep strain between the two mixes, can analyze the effects of nano alumina and polypropylene granules on the long-term behavior of the concrete. The deformation is recorded and the creep strain is calculated using:

$$\text{Creep Strain} = \frac{\Delta L}{L_O}$$

where ΔL represents the change in length or deflection measured by the LVDT, and L_O is the initial length or reference measurement.

Post-Test Analysis: After the 28-day test duration, the total deformation recorded by the LVDTs under the applied load will give insights into the creep behavior of both mixes, shown in Table 6. The higher the strain under the same load, the more the concrete mix is prone to long-term deformation (creep). By maintaining the same load level, the creep strain behavior of each mix can be compared directly, highlighting the effect of the material modifications in D2 on its long-term performance.

Table 6. LVDT Readings for Creep Test

SN.	Days	LVDT Test Reading (in mm)	
		For D1	For D2
1	0	0.00	0.00
2	1	0.03	0.05
3	7	0.08	0.11
4	14	0.10	0.13
5	21	0.11	0.15
6	28	0.12	0.18

Using the deformation values from the table, calculate the creep strain for both mixes.

For D1 at 28 Days:

$$\text{Creep Strain} = \frac{Deformation}{Gauge\ Length} = \frac{0.12}{700} = 0.00017$$

For D2 at 28 Days:

$$\text{Creep Strain} = \frac{Deformation}{Gauge\ Length} = \frac{0.18}{700} = 0.00026$$

The increased creep strain observed in D2, the modified mix, suggests that although it has higher compressive strength, it experiences more significant long-term deformation under sustained loads. This behavior may be influenced by the presence of nano alumina and polypropylene granules, which impact the concrete's microstructure and its response to continuous stress. Nano alumina, which enhances concrete strength by reducing micro voids and densifying the structure, may also contribute to increased creep strain due to the formation of rigid zones within the cement matrix. These areas, while strong, can create stress concentrations that promote gradual deformation under prolonged load, reducing the concrete's resilience to creep strain. Polypropylene granules, included to decrease the mix's density and improve flexibility, may further contribute to creep strain as a result of their relatively low stiffness. Although these granules enhance workability and reduce weight, they are more susceptible to deformation under long-term compression. As they adjust under sustained load, they can transfer strain to the surrounding matrix, leading to cumulative creep deformation over time.

Together, nano alumina and polypropylene granules in D2 produce a mix with higher initial strength but with greater long-term deformation under steady load. These findings indicate that while D2's modifications improve strength, they may reduce suitability for applications requiring minimal creep deformation over extended periods.

3.2 Shrinkage Test by Using Digital Caliper

Shrinkage is a critical property of concrete that affects its dimensional stability and can lead to cracking and structural deficiencies. This study examines the shrinkage characteristics of two concrete mixes, a control mix D1 and a

modified mix D2. Understanding the shrinkage behavior is essential for predicting long-term performance and durability of concrete structures.

Specimen Preparation: Prismatic specimens measuring 700 mm x 150 mm x 150 mm were prepared for shrinkage testing. The specimens were cast and cured in accordance with standard practices for 28 days, ensuring a consistent environment for all samples. After curing, the specimens were placed in a controlled environmental chamber set to maintain a temperature of 20°C and a relative humidity of 50%. This setup aimed to eliminate external factors that could influence shrinkage measurements. Following the curing period of 28 days, the initial length of each specimen was measured using a digital calliper. Each specimen's length was recorded accurately to establish a baseline.

Measurement of Shrinkage: After initial measurements, the specimens were removed from the curing environment and placed into the controlled environmental chamber. Length changes were monitored at specific intervals, till 28 days. Measurements were taken using the same digital calliper to ensure consistency. Any changes in length were recorded as negative values to indicate shrinkage. The shrinkage value in micro strain is calculated as

$$\text{Shrinkage Value} = \frac{Shrinkage}{Initial\ Length}(10^6)$$

The measurements collected during the shrinkage testing were documented in a structured format. The recorded lengths and corresponding shrinkage values for both mixes (D1 and D2) can be summarized in a table 7.

Table 7: Shrinkage Value

Mix	Initial Length (mm)	Length at 28-days (mm)	Shrinkage (mm)	Shrinkage Value (micro strain)
D1	700	699.87	-0.13	-185.71μɛ
D2	700	699.75	-0.25	-357.14μɛ

The shrinkage results indicate that the modified mix D2 experienced greater shrinkage -0.250 mm compared to the control mix D1 which showed less shrinkage -0.130 mm over the 28-day curing period. This difference in shrinkage behavior can be attributed to the effects of the added materials. The increased shrinkage in D2 can be influenced by the properties of polypropylene granules, which, while they enhance crack resistance and improve workability, may also contribute to higher water retention and evaporation rates during curing. As a result, the modified mix may be more susceptible to drying shrinkage, leading to greater deformation as it cures. On the other hand, the control mix, without any modifications, demonstrates less shrinkage, suggesting that its composition is more stable during the curing process. The absence of additional materials likely allows for a more uniform hydration process and reduces the potential for excessive evaporation, which can lead to shrinkage. In terms of performance, while D2 shows superior compressive strength at 53.72 MPa compared to D1's 51.34 MPa, the trade-off is evident in the increased shrinkage. This highlights the complexity of balancing the benefits of enhanced strength and durability with the potential drawbacks of higher shrinkage rates. Overall, the results suggest that while the addition of nano aluminum oxide and polypropylene in concrete can improve certain mechanical properties, it can also lead to increased shrinkage, which may impact the long-term durability of the structure.

4. CONCLUSION

In conclusion, the research findings demonstrate the impact of nano alumina and polypropylene granules on the mechanical properties and deformation characteristics of concrete. The modified mix, D2, achieved a higher compressive strength of 53.72 MPa compared to the control mix, D1, which had a compressive strength of 51.34 MPa. However, D2 exhibited both increased creep strain and shrinkage, indicating greater susceptibility to long-term deformation under sustained loads and curing conditions.

The increase in creep strain and shrinkage in the modified mix can be attributed to the microstructural adjustments introduced by nano alumina and polypropylene granules. Nano alumina contributes to a denser cement matrix but may introduce stress concentrations, resulting in gradual deformation under load. Polypropylene granules, while reducing density and enhancing flexibility, introduce potential for higher creep and shrinkage due to their low stiffness and water retention properties. These effects illustrate a complex trade-off: while nano alumina and polypropylene granules improve the concrete's initial strength and durability, they may reduce its resistance to long-term deformation. This study underscores the importance of evaluating both short-term and long-term material behaviors to achieve an optimal balance in concrete mix designs.

By understanding the interplay between enhanced strength and increased susceptibility to creep and shrinkage, engineers can make informed decisions about using such modifications in structural applications where sustained loading and durability are critical.

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