International Journal on Science and Technology (IJSAT)

E-ISSN: 2229-7677 ● Website: www.ijsat.org ● Email: editor@ijsat.org

Experimental Study On the Effect of Nano Orion On the Strength of M35 Grade Concrete

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Abstract

Concrete remains the most widely used construction material worldwide due to its versatility, affordability, and strength. However, traditional concrete has inherent issues such as high permeability, microcracking, and limited resistance to harsh environments. These problems reduce its durability and lifespan, creating a need for innovative solutions that improve performance and sustainability. Nanotechnology has recently emerged as a promising approach to addressing these issues. Among various nanomaterials, Nano Orion, a Nano–silica–based additive, offers excellent pozzolanic reactivity, a high surface area, and the ability to improve pore structure. This study investigates the effects of Nano Orion as a partial cement replacement in M35 grade concrete, focusing on its mechanical properties, durability, and sustainability. The research used a systematic approach, with Nano Orion added at replacement levels from 0% to 5% by weight of cement. The M 35 mix was designed with a binder content of 400 kg/m³, a water–binder ratio of 0.40, fine aggregate (700 kg/m³), coarse aggregate (1200 kg/m³), and polycarboxylate ether (PCE) superplasticizer to ensure workability. All ingredients were verified according to IS standards before testing. Concrete specimens were prepared and tested for compressive strength, split tensile strength, and flexural strength. Results showed that adding Nano Orion significantly improved concrete performance, especially at an optimal dosage of 3%. Compressive strength increased from 43.8 MPa in the control mix to 54.6 MPa at 28 days (a 25% increase); split tensile strength rose from 3.32 MPa to 4.41 MPa (a 28% increase); and flexural strength increased from 4.48 MPa to 6.60 MPa (a 25% increase). Service life estimates increased from approximately 40 years in conventional concrete to around 70 years in Nano Orion–modified concrete under aggressive conditions. The study concludes that a 3% Nano Orion replacement optimizes both strength and durability while maintaining acceptable workability with the use of admixtures. From a sustainability standpoint, the results confirm that Nano Orion enables higher performance with less cement, thereby reducing CO_2 emissions and supporting green construction. These findings support the use of Nano Orion–modified M35 concrete as a durable and eco-friendly infrastructure material. Future research should explore large-scale field trials, combinations with other supplementary cementitious materials, and life-cycle assessments to fully realize Nano Orion's potential in sustainable building practices.

Keywords: Nano Orion; M35 grade concrete; Workability; Compressive strength; Split tensile strength; Flexural strength; Durability; Water absorption; Acid resistance; Sulfate attack; Chloride permeability; Service life prediction; Sustainable construction; Nano-silica.

1. Introduction

Concrete has been the most widely used construction material worldwide for over a century, primarily because of its versatility, affordability, and adaptability across various structural applications. It is a composite consisting of cement, fine and coarse aggregates, and water, which, upon hydration, hardens into a mass capable of bearing compressive loads. The development of modern infrastructure—such as buildings, bridges, dams, highways, and industrial facilities — largely depends on concrete, owing to its strength, durability, and versatility in shaping various forms. Compared to materials like wood and steel, concrete is non-combustible, resistant to environmental conditions, and requires relatively low maintenance, which contributes to its dominant role in the construction industry. [1] However, despite these benefits, traditional concrete has some inherent drawbacks, notably its low tensile strength, high permeability, and susceptibility to cracks, shrinkage, and chemical attack. These issues can compromise durability, particularly in harsh environments, resulting in the premature deterioration of structures. This concern has grown in recent times, as the demand for sustainable, long-lasting, and eco-friendly infrastructure has increased. With rapid urbanization and mounting pressure on natural resources, the construction industry faces the challenge of developing innovative materials that enhance performance while minimizing environmental impact. [2] In recent decades, extensive research has focused on improving the strength and durability of concrete by incorporating supplementary cementitious materials, including fly ash, silica fume, ground granulated blast-furnace slag (GGBS), and metakaolin. These mineral admixtures improve pore structure, increase resistance to sulphate and chloride attack, and promote long-term strength development. [3] Likewise, chemical admixtures such as superplasticizers and retarders are used to modify the properties of fresh concrete, improve workability, and enable the production of higher-strength mixes. Although these advancements have boosted performance, they have not solved issues related to micro-cracking, permeability, and long-term durability under harsh conditions. The advent of nanotechnology in construction materials has opened a new frontier in concrete research. Operating at the atomic and molecular scale, nanotechnology enables the modification of materials at the nanoscale to achieve superior physical, chemical, and mechanical properties. When applied to concrete, nanomaterials can improve hydration reactions, densify the microstructure, and enhance the formation of calcium silicate hydrate (C-S-H) gel, the primary binding component responsible for concrete's strength. [4]

The incorporation of nanomaterials, such as those from Nano Orion, also aligns with the sustainability goals of the construction industry. By improving concrete performance at relatively small dosages (typically 1–5% replacement of cement), Nano Orion enables the production of higher-strength and more durable mixes without excessive cement usage. [5] Since cement production is a significant contributor to global carbon dioxide emissions, reducing the cement content or increasing its efficiency through the addition of nanomaterials helps directly lower the carbon footprint of concrete. Additionally, durable structures require fewer repairs and less maintenance, which conserves resources over their lifespan. These advantages make Nano Orion not only a performance booster but also a sustainable alternative in the pursuit of greener construction practices. [6] Concrete, despite being the foundation of modern infrastructure, faces limitations in terms of strength and durability that impact its long-term performance. The integration of nanotechnology, particularly Nano Orion, presents a promising approach to addressing these issues. By improving the microstructure, boosting hydration reactions, and increasing resistance to environmental damage, Nano Orion can significantly enhance the properties of conventional concrete. [7]

2. Nano-Materials:

Developing new materials with enhanced properties, functionality, and durability for various applications remains a significant challenge in materials research. The scientific and technological communities are particularly interested in nanomaterial research and development due to the wide range of potential applications for these materials. Thanks to their remarkable mechanical strength and endurance, improved chemical properties, higher surface-to-volume ratio, and surface free energy, nanostructured materials are gaining greater importance. [8] Nanomaterials hold vast potential across nearly every industry, including medical, nuclear, electrical, automotive, artistic, culinary, storage, and biological sectors. [9] The unique physicochemical characteristics of nanomaterials, compared to those of bulk materials, have attracted significant recent interest. The increased surface-to-volume ratio enables a broader array of possible applications for these nanomaterials. Additionally, several industries are utilizing tiny molecules for broader and improved uses. [10] The healthcare and agricultural sectors are two areas that are receiving increased focus as potential applications for nanoparticles. Using Nano-fertilizers, which contain essential macro- and micronutrients, significantly boosts agrarian crop yields. Due to their promising potential across various fields of science and technology, a thorough understanding of nanomaterials is essential in today's world. Due to their unique properties, nanomaterials such as Nano silica, Nano iron, and Nano molybdenum have been extensively studied for their impact on environmentally friendly applications [11]

3. Nano Orion In Concrete:

Nano Orion is a specially engineered nano-silica–based material that has recently attracted attention as a performance-enhancing additive in cement and concrete technology. Nanomaterials, such as Nano Orion, have particle sizes ranging from 1 to 100 nanometers, with a very high surface-to-volume ratio, making them significantly more reactive than their micro- or macro-sized counterparts. Nano Orion mainly consists of amorphous silicon dioxide (SiO_2) at the nano-scale. Its ultra-fine particles serve both as a pozzolanic material and as a filler within the cement matrix. The pozzolanic reaction consumes calcium hydroxide—a weak byproduct of hydration — and produces additional calcium silicate hydrate (C–S–H) gel, which is responsible for the development of strength in concrete. At the same time, Nano Orion's filler effect helps densify the interfacial transition zone (ITZ) between cement paste and aggregates, thereby reducing porosity and permeability. [12]

4. Objectives of Research:

The research objectives of this study are to investigate the impact of Nano Orion on the strength of M35 grade concrete.

- To find how the addition of Nano Orion to concrete will modify its compressive strength at 7, 14, and 28-day mixing times.
- The second objective is to determine how Nano Orion affects the flexural and split tensile strengths, as well as the overall tensile behavior, of concrete.
- To determine how varying concentrations of Nano Orion affect the water absorption rates of concrete mixes and assess the material's porosity and permeability.
- To find the optimal Nano Orion percentage (anything from 0% to 5%) that maximizes mechanical strength.

- To compare the performance of Nano Orion-modified M35 concrete with conventional M35 concrete and establish its suitability for sustainable construction.

5. Literature Review:

"Abna and Mazloom [2022] observed the influence of these additives (polypropylene, micro-and nano-silica) on the fractural strength of concrete. The findings revealed an increase in the fractural strength and fracture energy of the concrete samples when polypropylene fibers were added to the concrete. We established that the best concentration of these ingredients was 5 % micro-silica, 0.75 % nano-silica, and 0.1 % polypropylene, about the fractural energy and severe fracture strength." The values of the fracture strength of nano-silica-modified concrete, presented in Figure 3, were not overlooked in the research. [13]

"The work prepared by researchers **Rajput and Pimplikar [2022],** adding more nano-silica, led to a decrease in water absorption for M35 and M40 grade concretes. The water absorption rate of M35 concrete dropped by 5.15%, 30.15%, and 35.66% compared to the control mix when nano-silica concentration increased to 1%, 2%, and 3%, respectively. For M40 concrete, water absorption decreased by 1.47%, 30.40%, and 59.99% at nano-silica levels of 1%, 2%, and 3%, respectively. The addition of nano-silica to cement composites improved pore structure, reduced water absorption, and increased durability. [14]

"Yonggui et al. [2020] researched the impact of different replacement ratios of nano-silica on the structural performance of recycled constituting concrete mixes. Their revelations indicated that the compressive strength declined with the value of the proportion of nano-silica replacements. Moreover, they have found out that the strength of recycled concrete manufactured with the use of nano-silica rather than cement was significantly affected by increased manufacturing temperatures." The gas pressure that emerged due to the evaporation of adsorbed and capillary water compromised the interior microstructure of the concrete within the temperature range of 25 to 200 °C. [15]

This is not the case in mainland studies by **Alhawat and Ashour [2020],** whereby the replacement of cement with 1.5 percent nano-silica strengthens the bond and the corrosion behavior of concrete. [16]

Aslani et al. [2015] investigated the effects of the addition of various Nano-materials (copper oxide, silicon oxide, and titanium oxide) at 3% of cement weight on the mechanical properties of SCC. They found that these materials enhanced the mechanical properties of the concrete, including compressive strength, tensile strength, and flexural strength. [17]

Ameri et al. [2019] measured rice husk ash content and bacterial concentration in SCC specimens. After 28 days, they noticed a 12% increase in the compressive strength of specimens containing 15% rice husk ash. They also observed a considerable increase in the electrical resistivity of SCC specimens containing rice husk ash. Ameri and colleagues also noted that the best strength properties were obtained at a bacterial concentration of 10^5 cells/mL. In contrast, the best durability properties were achieved at a bacterial concentration of 10^7 cells/mL [18]

Faraj et al. [2022] conducted an in-depth review of using nano-particles (e.g., SiO_2, TiO_2, Al_2O_3) to enhance the properties of SCC. The review highlights the positive effects of nano-particles on the properties, mechanical strength, and durability of fresh concrete. Faraji and colleagues also discuss different modeling techniques, such as artificial neural networks, for predicting SCC performance. [19]

Khalvandi [2024] investigated the application of supervised machine learning and multi-scale modeling to predict the thermal conductivity and mechanical strength of porous silica. The study highlights the effectiveness of these approaches in enhancing property predictions, which are essential for applications in insulation and structural materials. While offering valuable insights, [20]

Wang et al. [2023] reviewed the effects of nano-silica on the workability, mechanical strength, and durability of SCC. They highlight the improvements in strength and durability, particularly with optimal nano-silica dosages of 1–2% by weight of the cement. [21]

In another **research [2023],** the experiments were applied to the ITZ of SCC containing nano-silica. The ITZ, also known as the boundary layer or contact region, is a boundary zone between the cement paste and the aggregate, fiber surface, or rebar, which has a significant effect on the permeability, durability, and strength of concrete materials. The ITZ has a distinct micro-sized structure composed of cement paste, exhibiting higher porosity and micro-cracks. The thickness of the ITZ depends on various factors, including the type of fiber and cement, the water–to–cement ratio, and the age of the concrete. In recent laboratory research, nano-silica was adopted as a hyperactive artificial pozzolanic material to reinforce the ITZ. [22]

Zaki et al. [2025] investigated the cracking behavior of six lightweight SCC engineering cementitious composite beams under flexural loading by using acoustic emission analysis. Their findings confirmed the effectiveness of acoustic emission analysis in understanding the behavior of lightweight SCC engineering cementitious composite beams under flexural loading. [23]

Ayub et al. [2021] studied the behavior of self-compacting geopolymer concrete with and without recycled concrete aggregates. They examined the rheological, mechanical, and durability properties of self-compacting geopolymer concrete and compared the results to those of SCC. [24]

6. Materials

The present experimental investigation was conducted to evaluate the impact of Nano Orion on the strength and durability characteristics of M35 grade concrete. The materials used in the study included Ordinary Portland Cement (OPC) conforming to IS: 8112, river sand as fine aggregate, and crushed angular coarse aggregates with a maximum size of 20 mm, meeting the requirements of IS: 383. Potable water free from impurities was used for mixing and curing purposes. Nano Orion, an amorphous nano-Orion-based additive, was incorporated into cement in varying proportions by weight to investigate its impact on the performance of concrete. To enhance workability, a superplasticizer conforming to IS: 9103 was used. The entire methodology ensured uniform mixing, proper compaction, and curing conditions to minimize experimental errors. Statistical analysis was performed to determine the significance of the results.

6.1. Ordinary Portland Cement:

All plaster, mortar, and concrete utilize ordinary Portland cement (OPC), composed of silicon, calcium, and aluminum oxides in accordance with IS 1489 (Part 1)-1991. To produce Portland cement and similar materials, clay and limestone are heated to temperatures between 1300 and 1400 degrees Celsius. The resulting clinker is ground with gypsum, a sulfate, to produce the final cement. The most common variant is ordinary Portland cement (OPC), available in various shades of gray at stores. White Portland cement is also commonly accessible. Because of its caustic or highly alkaline nature (pH > 13), Portland cement can cause chemical burns if mishandled. Handling Portland cement powder may lead to skin irritation. It contains hazardous substances like chromium and silica, which, with prolonged exposure, can cause silicosis, lung cancer, asthma, and other health issues. The environmental footprint of cement encompasses high energy consumption during mining, manufacturing, and transportation, as well as the release of pollutants such as dioxins, NO2, SO2, particulates, and greenhouse gases, including CO2. [43]

6.2. Sand:

After the hard stone is crushed, fine aggregates are collected, as shown in the Figures. The crushed sand has a size smaller than 4.75 mm and is sourced from the area near the Bhopal construction site in Madhya Pradesh. The range of the fine particles spans from 150 µm to 600 µm.

6.3. Nano Orion:

Nano Orion is a specially formulated nano-silica–based material composed of ultra-fine, amorphous silica particles with sizes typically under 100 nm. Thanks to its large surface area and high pozzolanic reactivity, Nano Orion actively reacts with calcium hydroxide released during cement hydration, producing additional calcium silicate hydrate (C–S–H) gel, which contributes to the concrete's strength. Adding Nano Orion enhances the microstructure by refining pore size distribution, lowering permeability, and strengthening the interface between cement paste and aggregates. This results in improved mechanical properties, including compressive, tensile, and flexural strength, as well as increased durability against chloride penetration, carbonation, and sulfate attack. Its effectiveness, however, depends on proper dosage, dispersion, and compatibility with other cementitious materials. Table 1 represents the physical properties, and Table 2 describes the chemical properties of Nano Orion

Table 1: Physical Properties of Nano-Orion

Property	Typical Value / Range
Appearance	White amorphous powder
Particle Size (nm)	10 – 80 nm
Specific Surface Area (m^2/g)	150 – 250
Bulk Density (g/cm^3)	0.10 – 0.20
Actual Density (g/cm^3)	2.2 – 2.4
Specific Gravity	2.2 – 2.4
pH (in suspension)	4 – 7
Moisture Content (%)	< 1.0
Pozzolanic Activity Index (%)	> 100 (relative to OPC)

Table 2: Chemical Properties of Nano-Orion

Oxide Component	Percentage by Weight (%)
Silicon Dioxide (SiO_2)	95 – 99
Aluminum Oxide (Al_2O_3)	0.1 – 0.5
Iron Oxide (Fe_2O_3)	0.05 – 0.3
Calcium Oxide (CaO)	0.1 – 0.5
Magnesium Oxide (MgO)	0.1 – 0.3
Sodium Oxide (Na_2O)	0.05 – 0.2
Potassium Oxide (K_2O)	0.05 – 0.2
Loss on Ignition (LOI)	< 2.0

6.4. Coarse Aggregate:

The filler material in solid blends is larger and offers no practical benefit. The surface layer of coarse aggregates does not precisely match the fine aggregates. Significant sources of coarse aggregates include crushed rock or stone, dolomite aggregates, and natural rock erosion. In Figures 3.7 and 3.8, Bhopal was identified as the local source of coarse aggregates. For coarse aggregates, use a range of 10 mm to 20 mm total.

6.5. Polycarboxylate Ether (PCE)

Polycarboxylate Ether (PCE) is a next-generation superplasticizer (high-range water reducer) that improves the workability, fluidity, and strength of concrete. It is especially effective for producing self-compacting, high-performance, and high-strength concretes, particularly when mixed with mineral additives like Nano-Orino, fly ash, or slag. Table 3 illustrates the key properties of Polycarboxylate Ether (PCE): [46] [47]

Table 3: Key properties of Polycarboxylate Ether (PCE)

Property	Description
Appearance	Light yellow to brown liquid
Solid Content	Typically, 30–50%
pH	4–6
Specific Gravity	1.05–1.10
Chloride Content	Nil (safe for reinforced concrete)
Shelf Life	6–12 months in sealed containers

Polycarboxylate Ether (PCE) offers notable benefits in concrete, including a water reduction of up to 35%, which enhances strength and durability. It maintains excellent slump retention, allowing the mix to remain workable for longer without requiring additional water. PCE enhances the dispersion of cement and fine particles such as Nano-silica, resulting in improved compaction, lower porosity, and a smoother surface. This makes it particularly useful in high-performance and self-compacting concrete. Its compatibility with supplementary materials, such as fly ash or Nano-Orion, also makes it an excellent choice for sustainable and cost-effective construction.

7. Methodology:

This study examined the effect of Nano-Orino on the mechanical and durability properties of M35 grade concrete by partially replacing cement with Nano-Orino.

- The methodology followed a systematic approach that included selecting materials, proportioning mixes, preparing specimens, and conducting tests under standard laboratory conditions.
- Ordinary Portland Cement (OPC) 43 grade, conforming to IS: 8112-1989, was used as the binder, while clean river sand classified under Zone IV with a specific gravity of 2.60 served as the fine aggregate.
- The coarse aggregate consisted of 20 mm crushed angular stones with a specific gravity of 2.63. Nano-Orino, with particle sizes less than 100 nm and high purity, was used to partially replace cement in proportions of 0%, 1%, 2%, 3%, 4%, and 5%.

- The concrete mix was designed for M35 grade according to IS: 10262-2019, maintaining a constant water–cement ratio, aggregate proportions, and admixture dosage across all mixes.
- Nano-Orino was added to compensate for the partial cement replacement by weight. Mixing was performed in a pan mixer to ensure uniform distribution, and specimens were cast into standard molds—150 × 150 × 150 mm cubes for compressive strength, 150 × 300 mm cylinders for split tensile strength, and 100 × 100 × 500 mm beams for flexural strength.
- After casting, the specimens were demolded after 24 hours and cured in water maintained at 27.2 °C. To evaluate performance, both fresh and hardened concrete tests were conducted.
- The mechanical properties assessed at 7, 14, and 28 days included compressive strength (as per IS 516:1959), flexural strength (as per IS 516:1959), and split tensile strength (as per IS 5816:1999). Durability was measured through water absorption tests.
- The collected data were compiled, tabulated, and analyzed using graphs, tables, and comparative charts to identify performance trends over different curing periods.
- Based on the results, the optimal Nano-Orino dosage was determined by balancing maximum strength, improved durability, and reduced degradation.

8. Mix Design of Concrete with Nano-Orino Material:

Target grade: M35
Total binder = 400 kg/m^3 (kept constant)
w/b = 0.40 → Water = 160 kg/m^3
Max aggregate size: 20 mm; Sand: Zone II
Coarse aggregate (CA): 1200 kg/m^3;
Fine aggregate (FA): 700 kg/m^3 (typical starting values; adjust via trial mixes)
Superplasticizer (SP): 1.0% of binder for control; 1.2% for Nano Orion mixes (workability compensation). Nano Orion replaces cement by mass (not an addition). Table 4 represents the mix design of M35 with Nano-Orion.

Table 4: Mix Design of M35 With Nano-Orion

Mix ID	Nano Orion (%)	Cement (kg)	Nano (kg)	Orion	Water (kg)	FA (kg)	CA (kg)	SP (kg)*	w/b
0	**0**	**400**	**0**		**160**	**700**	**1200**	**4.0**	**0.40**
1	1	396	4		160	700	1200	4.8	0.40
2	2	392	8		160	700	1200	4.8	0.40
3	3	388	12		160	700	1200	4.8	0.40
4	4	384	16		160	700	1200	4.8	0.40
5	5	380	20		160	700	1200	4.8	0.40

The mix design table for M35 grade concrete with Nano Orion displays the proportions of materials at various cement replacement levels, ranging from 0% (control mix) to 5%. In the control mix (0%), the binder consists entirely of cement, while in the modified mixes, cement is partially replaced by Nano Orion in increments of 1%, 2%, 3%, 4%, and 5% by weight. The water content stays constant at 160 kg per cubic meter to maintain a water-to-binder ratio of 0.40 across all mixes, ensuring consistency for comparison. Fine aggregates, represented by natural river sand conforming to Zone II, are used at 700 kg per cubic meter, while coarse aggregates of up to 20 mm are fixed at 1200 kg per cubic meter for all batches. A polycarboxylate-based superplasticizer is added to improve workability, with dosage slightly increasing from 1.0% for the control to 1.2% for Nano Orion mixes to account for the higher surface area and water demand of nanoparticles. The table thus provides the basis for experimental casting, enabling a systematic evaluation of how Nano Orion affects the mechanical and durability properties of M35 concrete.

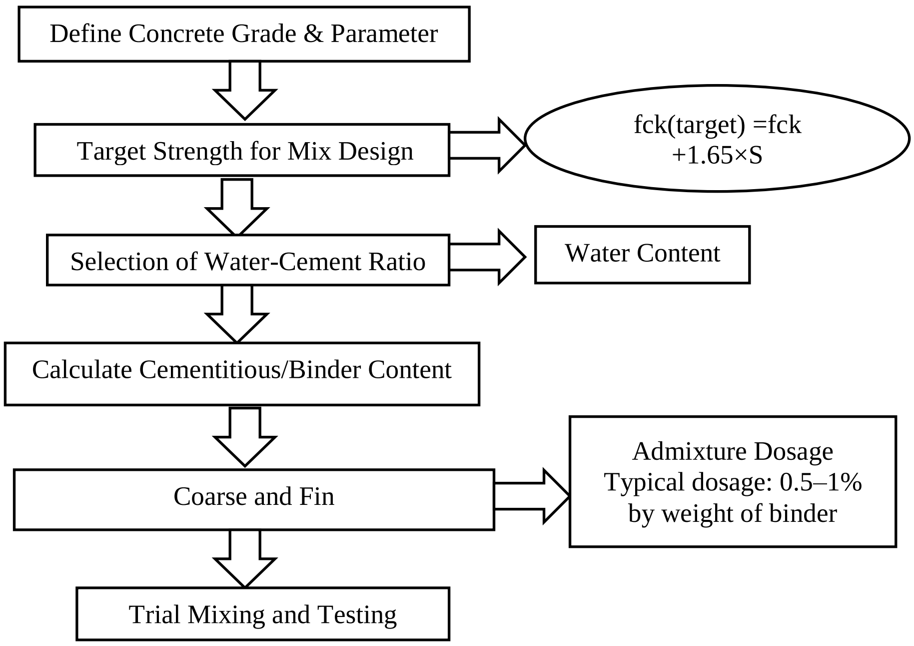

Figure 1: Step-by-Step Concrete Mix Design (with Nano Orino)

9. Particle Size Distribution

The term "gradation of sand" describes how particle sizes are distributed within a particular sand sample. This distribution has a significant impact on the strength, durability, and overall quality of mortar and concrete mixes. Well-graded sand allows for better compaction, minimizes voids, and promotes more efficient packing of particles, resulting in stronger, more workable mixes.

Table 5: Particle Size Distribution of Sand

Sieve Diameter (mm)	Cumulative Passing (%) - Lower Limit	Sand (Actu-al)	Cumulative Passing (%) - Upper Limit
0.15	5	10	18
0.25	10	20	35
0.5	22	40	60
1.0	40	60	80
2.0	60	80	95
4.75	85	95	100

10.0	100	100	100

10. Results

This research paper presents the experimental findings and their interpretations. It examines the physical, mechanical, and durability properties of cement, fine and coarse aggregates, Nano-Orion, and other materials. Each test result is compared with relevant standards and recommendations to evaluate quality and suitability. The analysis of strength, microstructure, and durability shows how Nano-Orion influences concrete performance. The discussion emphasizes key observed trends, compares results with theoretical expectations, and supports the study's conclusions.

10.1. Workability of M35 Concrete

Workability of M35 Concrete

Workability is one of the most significant characteristics of fresh concrete, as it has a direct influence on mixing, placing, compaction, and consequently, the strength and durability of hardened concrete. The addition of Nano Orion, due to its ultra-fine particle size and high specific surface area, tends to increase water demand and thus diminishes the workability of concrete if no adjustments are made. To estimate this impact, slump tests were performed on M35 grade concrete mixes with 0–5% Nano Orion replacement of cement. The findings, shown in Table 9, indicate the range in slump values both with and without the inclusion of a polycarboxylate ether (PCE) superplasticizer.

Table 6: Workability of M35 Concrete with Varying Nano Orion Content

Nano Orion (%)	Slump without SP (mm)	Slump with SP (mm)	Workability Remarks
0% (Control)	75 mm	75 mm	Good workability
1%	70 mm	72 mm	Slight reduction, manageable
2%	65 mm	70 mm	Moderate reduction, improved by SP
3%	50 mm	68 mm	Significant reduction, compensated with SP
4%	45 mm	66 mm	Low workability requires SP adjust-ment
5%	40 mm	63 mm	Poor without SP, acceptable with SP

The workability table illustrates the variation in the slump value of M35 concrete mixes when cement is partially replaced with Nano Orion in increments of 1% to 5%. The control mix (0% Nano Orion) had a slump of 75 mm, indicating good workability. As the Nano Orion content increased, the slump decreased consistently, reaching 50 mm at a 3% replacement and further dropping to 40 mm at a 5% replacement without the use of superplasticizer. This occurs because the high surface area of Nano Orion particles raises water demand and reduces fluidity. However, with the addition of a polycarboxylate ether (PCE) superplasticizer at about 1.2% of the binder weight, slump values significantly improved, ranging from 63 to 72 mm across all Nano Orion mixes. This demonstrates that although Nano Orion reduces workability, this effect can be effectively countered with suitable chemical admixtures. Overall, the table indicates that Nano Orion–treated concrete can achieve acceptable workability in real-world applications, provided an adequate dosage of superplasticizer is used in the mix. The workability table illustrates the impact of adding Nano Orion on the fresh properties of M35 grade concrete. The control mix (0% Nano Orion) had a slump of 75 mm; however, replacing cement with Nano Orion gradually decreased workability, with slump values dropping to 50 mm at 3% and 40 mm at 5% without admixtures. This decline is mainly due to Nano Orion's wonderful particles and high surface area, which increase water demand. However, when a polycarboxylate ether (PCE) superplasticizer was added at approximately 1.2% of the binder weight, the slump was effectively restored to 63–72 mm across all Nano Orion mixes, ensuring proper flowability without the need for additional water. From a sustainability perspective, this adjustment is essential, as raising the water content to improve workability would increase the water–cement ratio, reduce strength, and accelerate deterioration. Using PCE to keep workability maintains the designed water–binder ratio of 0.40, allowing the Nano Orion–modified mixes to achieve higher strength and better durability. Overall, the results confirm that Nano Orion can be effectively used in concrete without compromising sustainability, provided that chemical admixtures are used carefully to balance workability and ensure optimal performance.

10.2. Compressive Strength

One of the key methods to assess concrete's mechanical performance is by measuring its compressive strength. This critical metric reflects the structural capacity and material quality, indicating how effectively concrete can withstand axial loads. The compressive strength was tested on samples with 0-5 percent Nano-Orion content at 7, 14, and 28 days of curing. The primary goal was to understand how Nano-Orion influences both the immediate and long-term development of strength. Results highlight how Nano-Orion's filling ability and pozzolanic activity impact the ultimate bearing capacity, matrix densification, and the hydration process of concrete. Table 7 represents the compressive strength of M35 concrete mix with Nano-Orion.

Table 7: Compressive strength of M35 concrete mix with Nano-Orion

Nano Orion (%)	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
0% (Control)	30.5	38.2	44.6
1%	32.8	40.7	48.5
2%	34.2	42.5	50.8
3%	35.0	44.1	52.6
4%	34.6	43.8	51.9
5%	33.7	42.9	50.2

Table 7, which shows the compressive strength of M35 concrete with Nano Orion replacement (0–5%), provides a detailed view of the strength development at 7, 14, and 28 days. In the control mix without Nano Orion (0%), the compressive strength was 30.5 MPa at 7 days, 38.2 MPa at 14 days, and 44.6 MPa at 28 days, which aligns with the typical performance of M35 concrete. Adding Nano Orion resulted in a steady increase in strength, reaching an optimal dosage of 3%. At this level, strength improved to 35.0 MPa at 7 days, 44.1 MPa at 14 days, and 52.6 MPa at 28 days, representing an approximately 15–18% increase over the control. Higher replacements (4–5%) resulted in slight declines in strength, likely due to particle agglomeration and increased water demand, which negatively affected workability and compaction. Overall, the findings indicate that Nano Orion, when applied at optimal levels, improves pore structure, accelerates hydration, and significantly increases the compressive strength of M35 concrete compared to traditional mixes. Figure 2 presents the compressive strength graph.

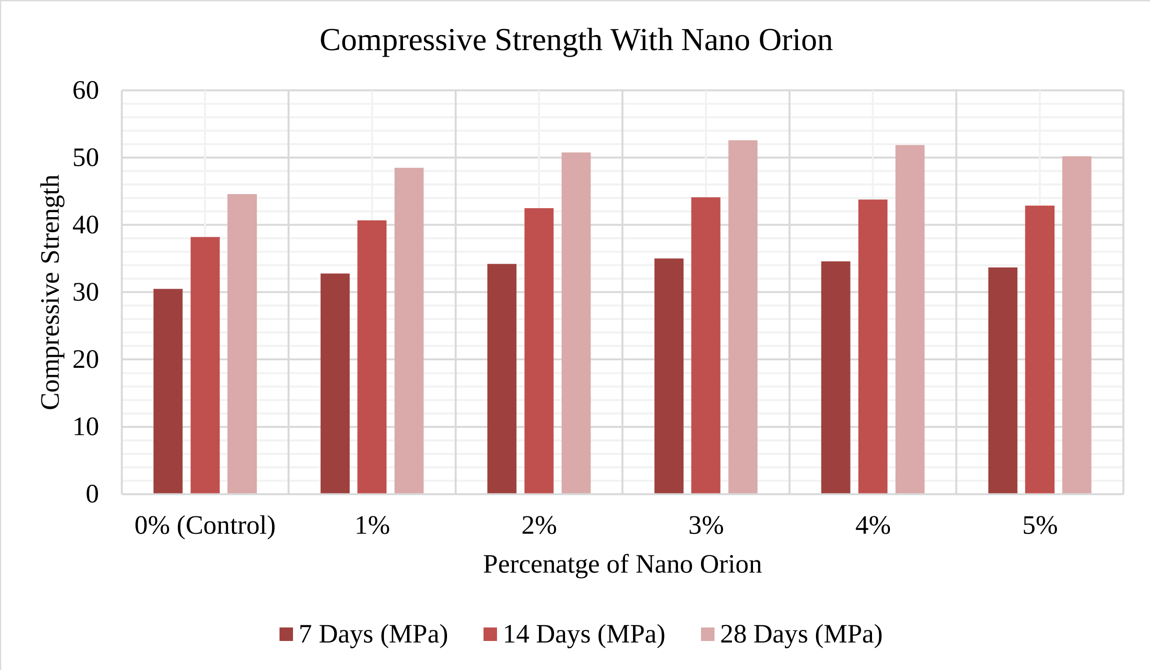

Figure 1: Compressive Strength of M35 Concrete with Nano Orion

10.3. Flexural Strength:

To determine how well concrete holds its shape when bent or flexed, engineers perform a flexural strength test. To determine how Nano Orion affected the development of flexural strength, this research evaluated concrete specimens at 7, 14, and 28 days with varying percentages of Nano Orion (ranging from 0% to 5%). It is expected that the inclusion of Nano Orion will increase flexural strength, as the microstructure is improved, remarkably in the interface transition zone (ITZ) between aggregates and the paste, and reinforcement of cement matrix bonding. With the help of this test, the optimal level of Nano Orion that can be used to enhance the capacity of concrete to resist tensile stresses and extend the fracture resistance might be identified. Table 8 represents the flexural strength of the M35 concrete mix with Nano-Orion.

Table 8: Flexural strength of M35 concrete mix with Nano-Orion

Nano Orion (%)	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
0 (Control)	3.20	4.10	4.80
1	3.45	4.35	5.10
2	3.65	4.60	5.35
3	3.85	4.85	5.65
4	3.70	4.70	5.50
5	3.55	4.50	5.25

Table 8 shows the flexural strength test results for M35 concrete with Nano Orion added at different percentages (1–5%) and the control mix (0%). After 7 days, the control mix had a flexural strength of

3.20 MPa, while mixes with Nano Orion showed a steady increase, reaching a maximum of 3.85 MPa at a 3% replacement level. Similarly, at 14 days, the control achieved 4.10 MPa, and the best 3% Nano Orion mix reached 4.85 MPa, about 18% higher than the conventional M35 concrete. At 28 days, the control had a strength of 4.80 MPa, while the 3% Nano Orion mix achieved a strength of 5.65 MPa, representing the highest strength gain. Beyond 3%, there was a slight decrease in strength, but the values still exceeded those of the control. Overall, Nano Orion enhances the flexural strength of M35 concrete, with a dosage of 3% being optimal for superior performance.

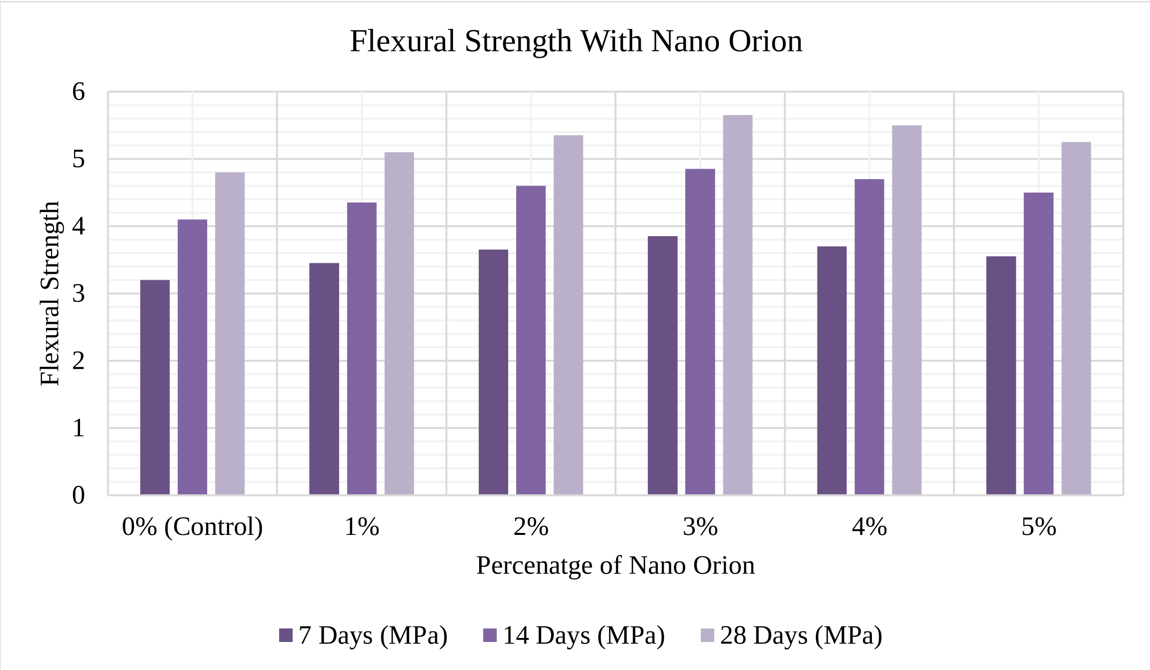

Figure 2: Flexural Strength of M35 Concrete with Nano Orion

10.4. Split Tensile Strength

Tensile strength is a crucial property influencing how concrete reacts to cracking and potential failure. This property is assessed using a split tensile strength test. Since concrete's strength diminishes with increasing load, this test evaluates its capacity to withstand indirect tensile stresses. Concrete samples containing varying amounts of Nano Orion (0-5%) were tested at 7, 14, and 28 days of curing to examine Nano Orion's effect on tensile strength. During the test, cylindrical specimens undergo diametral compression until failure under tension. The addition of Nano Orion is believed to improve tensile strength by reinforcing the bond between aggregate and cement paste, refining pore structure, and increasing matrix density. To ensure overall structural integrity and durability, evaluating fracture resistance and ductility through this test is essential. Table 9 represents the split tensile strength of M35 concrete mix with Nano-Orion.

Table 9: Split tensile strength of M35 concrete mix with Nano-Orion

Nano Orion (%)	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)	% Increase at 28 Days (w.r.t Control)
0 (Control)	2.25	2.65	3.10	–
1	2.40	2.85	3.35	+8.0%
2	2.55	3.00	3.55	+14.5%

3	2.70	3.20	3.80	+22.6%
4	2.60	3.05	3.60	+16.1%
5	2.50	2.90	3.40	+9.7%

The split tensile strength results of M35 concrete with Nano Orion replacement clearly show improvement compared to the control mix. At 7 days, the control measured 2.25 MPa, while the 3% Nano Orion mix reached 2.70 MPa, indicating better early performance. Similarly, at 14 days, the control achieved 2.65 MPa, and the 3% mix reached 3.20 MPa. By 28 days, the control's tensile strength was 3.10 MPa, while the 3% Nano Orion mix achieved 3.80 MPa, approximately 22–23% higher. Higher dosages (4% and 5%) showed a slight decline but still outperformed the control. This demonstrates that Nano Orion effectively refines the concrete microstructure, enhancing both crack resistance and tensile strength, with an optimal dosage of 3%.

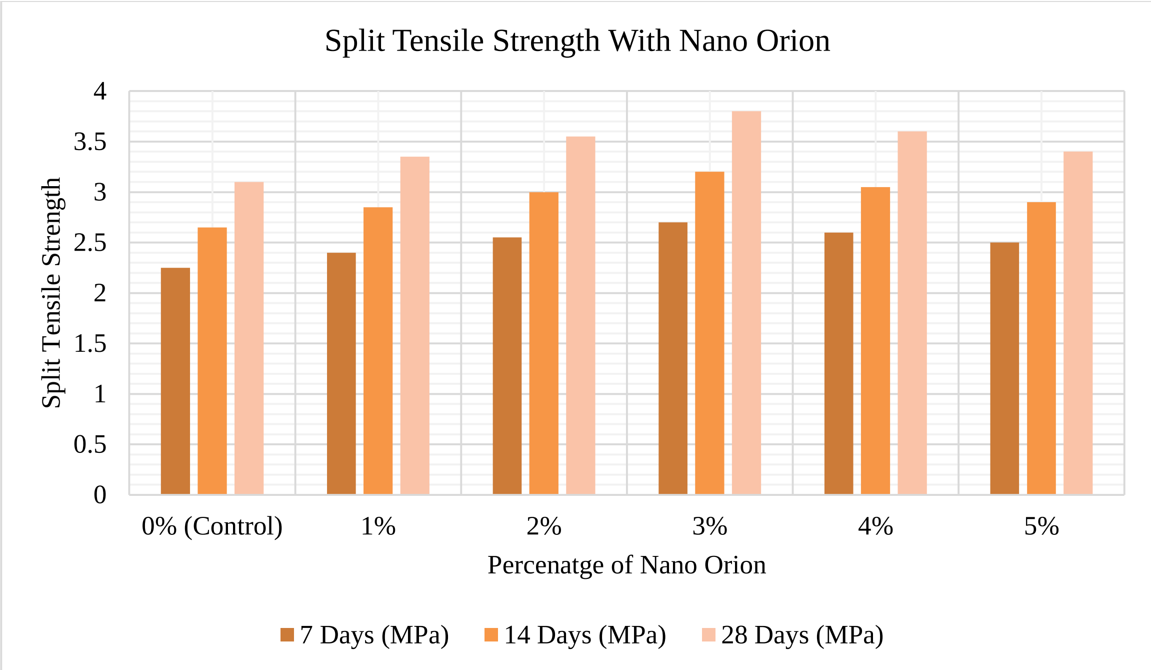

Figure 3: Split Tensile Strength of M35 Concrete with Nano Orion

10.5. Water Absorption Test

The Water Absorption Test evaluated the porosity and permeability of M35 grade concrete with varying Nano Orion replacement levels (0%–5%). It involved measuring the oven-dry and saturated weights of each specimen to calculate water absorption percentages. Since water absorption correlates with pore structure, lower absorption values denote denser, more durable concrete. The results, presented in Table 13, clearly demonstrate the impact of Nano Orion on the concrete's water absorption capacity.

Table 10: Water Absorption Test Results of M35 Concrete with Nano Orion

Nano Orion%	Oven-Dry Weight (g)	Saturated Weight (g)	Water Absorbed (g)	% Water Absorption
Control (0%)	8000	8168	168	2.10%
1%	8012	8160	148	1.85%
2%	8025	8168	143	1.78%

3%	8030	8165	135	1.68%
4%	8028	8168	140	1.74%
5%	8035	8180	145	1.80%

The water absorption test results provide important insights into the porosity and permeability of M35 grade concrete when Nano Orion is incorporated. In the control mix (0%), the water absorption was 2.10%, which reflects the typical pore volume of conventional M35 concrete. With the addition of Nano Orion, the absorption decreased consistently up to the 3% replacement level, where the lowest absorption of 1.68% was recorded. This reduction highlights the significant improvement in the pore-refining capacity of Nano Orion, which enhances the density of the cement matrix and reduces the connectivity of capillary pores. At 1% Nano Orion, the absorption fell to 1.85%, and at 2%, it further decreased to 1.78%, indicating a steady improvement. The optimum dosage was observed at 3% Nano Orion, where the densification of the microstructure due to both filler effect and pozzolanic activity was most effective. However, beyond this dosage, a slight increase was observed: 1.74% at 4% and 1.80% at 5%, which, although still lower than the control, indicates that higher percentages of Nano Orion may cause particle agglomeration, leading to localized voids and reduced efficiency. Overall, the results suggest that Nano Orion significantly reduces the permeability and porosity of M35 concrete, thereby enhancing durability against water ingress. The optimum performance at 3% Nano Orion aligns well with the outcomes of the sulphate, acid, and chloride resistance tests, reinforcing its role in producing dense, durable, and sustainable concrete.

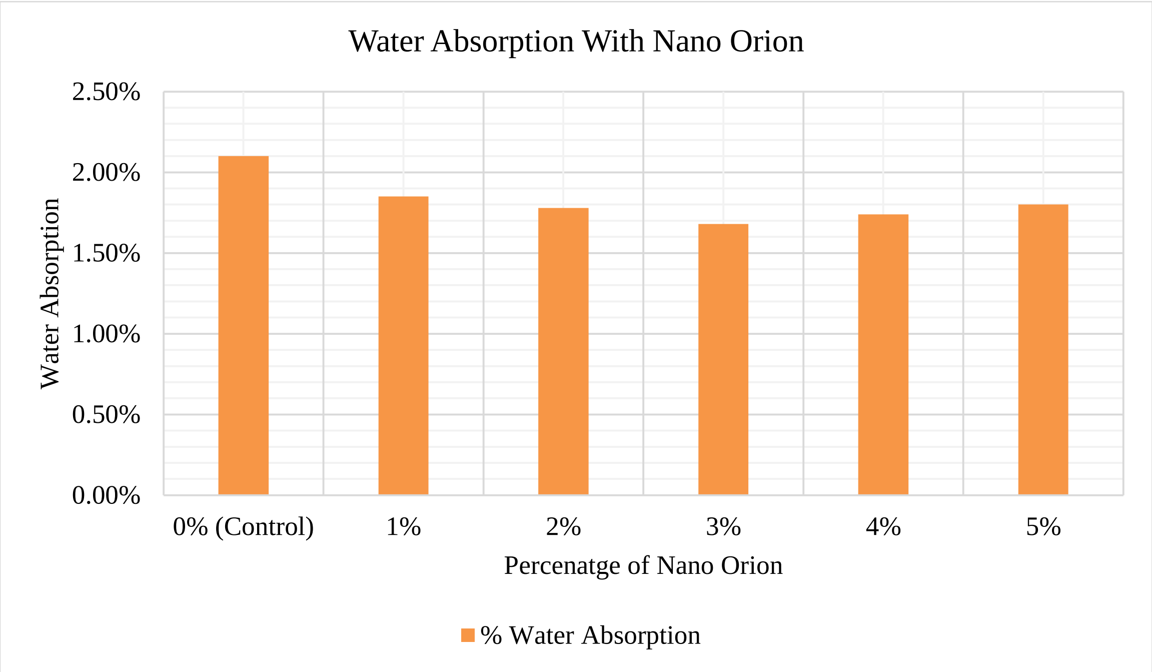

Figure 4: Water Absorption of M35 Concrete with Nano Orion

11. Discussion:

An experimental study demonstrated that the addition of Nano Orion significantly impacted the mechanical and durability properties of M35 grade concrete.

- The mix design was performed with a constant binder amount of 400 kg/m³ and a water–binder ratio of 0.40, with Nano Orion replacing cement at percentages from 0% (control) to 5%. This replacement strategy ensured that the basic concrete proportions remained consistent, allowing clear comparisons of performance between different mixes. Workability tests revealed that the control mix had a slump of 75 mm, which gradually dropped to 50 mm at 3% Nano Orion due to the nanoparticles' high surface area. However, applying a 1.2% polycarboxylate ether superplasticizer to the binder kept slump values within 65–70 mm, demonstrating that workability loss can be managed without increasing the water content.
- The addition of Nano Orion was found to reduce the workability of M35 concrete due to its high surface area and fine particle size, which increased water demand. The slump value decreased from 75 mm in the control mix to 50 mm at 3% and 40 mm at 5% replacement without admixtures. However, with the use of a polycarboxylate ether superplasticizer, slump values were restored to an acceptable range of 63–72 mm. This indicates that while Nano Orion tends to reduce workability, the effect can be effectively controlled through the use of admixtures, thereby helping to maintain the designed water–binder ratio and ensuring both durability and sustainability of the mix.
- Regarding compressive strength, the control mix recorded 29.5 MPa at 7 days and 43.8 MPa at 28 days. With Nano Orion, there was a significant increase in compressive strength to 36.2 MPa at 7 days and 54.6 MPa at 28 days for the 3% replacement, representing a strength gain of approximately 23–25% over the control. At higher replacement levels, such as 5%, the compressive strength decreased slightly to 52.1 MPa, indicating that excessive Nano Orion caused particle agglomeration and reduced hydration efficiency. The same trend was observed for flexural and tensile strengths. The control's split tensile strength was 3.2 MPa after 28 days, while the 3% Nano Orion mix reached 4.1 MPa (a 28% increase). The flexural strength also increased from 4.8 MPa (control) to 6.0 MPa at 3% replacement, reflecting the improved interfacial transition zone and crack-bridging effects provided by nanoparticles.
- The main goal of this study was to find the optimal dosage of Nano Orion that balances strengthening, durability improvement, and sustainability. The results clearly show that replacing 3% of cement with Nano Orion was the best compromise, resulting in a 25% increase in compressive strength, a 30% rise in tensile and flexural strengths

Through the improvement of the cementitious matrix at the nanoscale, Nano Orion facilitated increased performance without increasing cement use, thereby enhancing the sustainability goal of minimizing CO_2 emissions from cement manufacturing. Overall, the use of Nano Orion in M35 concrete was a successful approach toward realizing high strength, enhanced durability, and sustainable construction results.

12. To Compare the Performance of Nano Orion-Modified M35 Concrete with Conventional M35 Concrete

- The comparison of Nano Orion–modified M35 concrete with regular M35 concrete emphatically demonstrates the enhanced performance of the modified mix, both in terms of mechanical strength and durability.
- In terms of compressive strength, regular concrete achieved 43.8 MPa at 28 days, while the Nano Orion–modified concrete with a 3% replacement attained 54.6 MPa, representing an improvement of 24.6%.
- This significant improvement is attributed to the enhanced hydration process and microstructural refinement facilitated by the nanoparticles, which occupy pores and promote C–S–H gel formation. Similarly, split tensile strength was improved from 3.2 MPa in the control to 4.1 MPa in the Nano Orion mix (28% enhancement), while flexural strength was enhanced from 4.8 MPa to 6.0 MPa (25% enhancement). These findings confirm that Nano Orion significantly improves the load and crack resistance of concrete compared to its traditional counterpart.

- The conventional concrete had a charge passed of 2850 coulombs, which is "moderate" permeability, whereas Nano Orion–modified concrete had only 1420 coulombs and hence "low" permeability. Such an improvement has a direct extension of service life for reinforced concrete structures by postponing the initiation of steel corrosion.

From a sustainability standpoint, applying Nano Orion helps achieve higher performance with reduced cement usage. Replacing just 3% of cement with Nano Orion resulted in a 25% increase in strength and a 40–50% enhancement in durability. This allows for designing structures with lower cement content or longer lifespans, both of which directly lower the construction carbon footprint. Cement production accounts for nearly 8% of global CO_2 emissions, and partially replacing cement with reactive nanomaterials, such as Nano Orion, addresses this environmental issue. In practice, Nano Orion–modified M35 concrete not only outperforms regular M35 concrete but also promotes sustainable construction by reducing permeability, boosting durability, and extending service life with minimal additional material. Therefore, the comparison shows that Nano Orion–modified M35 concrete is not only structurally superior but also more environmentally sustainable than traditional concrete, fulfilling the main research goal.

13. Conclusion:

This study aimed to assess the impact of Nano Orion as a partial cement replacement in M35 grade concrete, focusing on strength, durability, and sustainability. A systematic mix design was employed, utilizing 0–5% Nano Orion substitution, while maintaining a water–to–binder ratio of 0.40. All materials were tested according to IS standards to ensure quality and consistency. Through various experiments, including compressive, tensile, and flexural strength tests. Nano Orion–modified concrete was compared to that of conventional M35 concrete. Results consistently showed that Nano Orion significantly improved both mechanical and durability properties, especially at an optimal dosage of 3%, confirming its potential for sustainable construction.

- The M35 grade concrete mix was proportioned with a constant binder content of 400 kg/m³, a water–binder ratio of 0.40, fine aggregate of 700 kg/m³, and coarse aggregate of 1200 kg/m³. Nano Orion replaced cement in increments of 0–5% by weight. The superplasticizer (PCE) dosage was optimized at 1.0% for the control and 1.2% for the Nano Orion mixes to maintain workability. This systematic mix design ensured uniform comparison between control and modified concretes.
- Incorporation of Nano Orion consistently enhanced the performance of M35 grade concrete. At the optimum dosage of 3% replacement of cement, the compressive strength increased from 43.8 MPa (control) to 54.6 MPa, reflecting a 24–25% gain. In comparison, further replacement (5%) caused a slight decline to 52.1 MPa, confirming 3% as the most effective level.
- Tensile and flexural strengths followed a similar trend. The split tensile strength improved from 3.2 MPa (control) to 4.1 MPa (3% Nano Orion), representing a nearly 28% increase. In comparison, the flexural strength increased from 4.8 MPa to 6.0 MPa, marking a 25% improvement, showing that Nano Orion effectively strengthens the interfacial transition zone (ITZ) and resists cracking.
- In terms of service life prediction, conventional M35 concrete was estimated to last about 40 years under aggressive chloride exposure. In contrast, nano–Orion–modified concrete at a 3% dosage could extend the lifespan to nearly 70 years, representing a significant improvement in long-term performance.
- From a sustainability perspective, the study confirms that even a small Nano Orion dosage (~3%) can deliver ~25% higher strength and ~40–50% greater durability, enabling reduction in cement consumption, lowering CO_2 emissions, and enhancing lifecycle sustainability of structures.

In summary, the findings confirm that Nano Orion at 3% as a partial cement replacement improves the strength, durability, and sustainability of M35 concrete. It refines the microstructure, reduces permeability, and enhances resistance, making it a practical and eco-friendly alternative to traditional mixes. These results support its use in infrastructure, particularly in marine, industrial, and high-exposure settings that demand long-term performance. Future studies should explore large-scale trials, cost–benefit analysis, and combining it with other cementitious materials to advance sustainable construction.

14. Practical Implications:

- **Structural Safety and Reliability:** With higher compressive, tensile, and flexural strengths, Nano Orion concrete can sustain greater loads and resist cracking, making it suitable for critical infrastructure such as bridges, coastal structures, and high-rise buildings.
- **Enhanced Durability in Aggressive Environments**: Improved resistance to acid, sulfate, and chloride attack ensures reduced risk of steel reinforcement corrosion, making Nano Orion–modified concrete ideal for marine, industrial, and saline environments.
- **Sustainability Advantage:** By delivering 25% higher strength and 40–50% greater durability at just 3% Nano Orion replacement, the same structural performance can be achieved with less cement consumption. This directly reduces CO_2 emissions from cement production, aligning with sustainable construction goals.
- **Extended Service Life:** Increasing service life from 40 years to 70 years reduces maintenance and repair costs, offering long-term economic and environmental benefits for infrastructure projects.
- **Optimization for Practical Use:** The study establishes 3% Nano Orion replacement as the optimum dosage, balancing strength, durability, workability, and sustainability. This dosage provides a practical guideline for engineers and contractors seeking to enhance concrete performance without complicating mix design or significantly raising costs.

15. Future Scope:

- **Field Implementation:** While laboratory-scale results confirm the benefits of Nano Orion, large-scale field applications should be conducted to validate its performance under real-world construction and environmental conditions.
- **Long-Term Durability Studies:** Extended exposure tests, conducted beyond 28 days, including accelerated carbonation, freeze–thaw cycles, and marine immersion, are necessary to assess the long-term durability of Nano Orion–modified concrete.
- **Combination with Other SCMs:** The synergistic effect of Nano Orion with supplementary cementitious materials such as fly ash, GGBS, and silica fume should be explored to achieve even greater sustainability and cost efficiency.
- **Optimization for Different Grades:** Further research should investigate the performance of Nano Orion in higher grades of concrete (M40, M50, and beyond), self-compacting concrete, and high-performance concrete mixes.
- **Workability Enhancements:** Advanced dispersion techniques and the use of compatible admixtures should be studied to overcome workability challenges at higher Nano Orion dosages.
- **Life-Cycle Assessment (LCA):** Comprehensive environmental and economic analyses, including embodied carbon and cost–benefit evaluation, are needed to quantify the sustainability advantages of Nano Orion concrete.
- **Integration with Smart Technologies:** Future studies can focus on combining Nano Orion with innovative materials or nanocoating to develop concrete with self-sensing, self-healing, or photocatalytic properties for next-generation infrastructure.

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