Evaluation of Green Concrete Performance in Reinforced Concrete Structures

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ABSTRACT

The present study focuses on the performance evaluation of reinforced concrete structures using nano-modified concrete materials. Conventional reinforced concrete often faces problems such as cracking, permeability, reinforcement corrosion, and durability loss under heavy loading and aggressive environmental conditions. Nano-materials such as nano-silica, graphene oxide, carbon nanotubes, and nano-clay improve the microstructure of concrete by filling micro-pores, increasing cement hydration, and forming a dense cement matrix. The results show that nano-modified concrete improves compressive strength, flexural strength, crack resistance, durability, and corrosion protection compared with conventional concrete. Therefore, nano-modified concrete can be considered an effective and sustainable material for developing stronger, safer, and long-lasting reinforced concrete structures.

Keywords: *Nano-Modified Concrete, Reinforced Concrete, Compressive Strength, Durability, Crack Resistance.*

I. INTRODUCTION

Reinforced concrete is widely used in buildings, bridges, dams, highways, and industrial structures because it combines the compressive strength of concrete with the tensile strength of steel reinforcement. However, conventional reinforced concrete often suffers from cracking, shrinkage, permeability, reinforcement corrosion, chemical attack, and durability loss. These problems reduce the strength, safety, and service life of structures, especially under heavy loads and aggressive environmental conditions. Nano-modified concrete materials provide an advanced solution for improving the performance of reinforced concrete. Nano-materials such as nano-silica, nano-titanium dioxide, nano-alumina, carbon nanotubes, graphene oxide, and nano-clay improve the internal microstructure of concrete by filling micro-pores, increasing cement hydration, forming a denser cement matrix, and improving the bond between cement paste, aggregates, and steel reinforcement. As a result, nano-modified concrete shows better compressive strength, tensile strength, flexural strength, crack resistance, durability, and corrosion resistance. The present study evaluates the performance of reinforced concrete structures using nano-modified concrete materials. It focuses on strength improvement, durability enhancement, crack control, and long-term structural behaviour. This study is important for developing stronger, safer, durable, and more sustainable reinforced concrete structures for modern infrastructure.

- **Improvement in Strength and Structural Performance:** Nano-modified concrete materials improve the strength and load-carrying capacity of reinforced concrete structures. Nano-materials such as nano-silica, graphene oxide, and carbon nanotubes fill the tiny pores inside concrete and make the cement matrix denser. This improves compressive strength, tensile strength, flexural strength, bond strength, and crack resistance. As a result, reinforced concrete members can perform better under heavy loads and long-term structural stress.

- **Enhancement of Durability and Service Life:** Nano-modified concrete increases the durability of reinforced concrete by reducing permeability, water absorption, chloride penetration, and reinforcement corrosion. A denser concrete matrix protects steel reinforcement from moisture and harmful chemicals. This helps in reducing cracking, chemical attack, and early deterioration. Therefore, nano-modified concrete can increase the service life of buildings, bridges, and other concrete structures while reducing maintenance and repair costs.

II. RESEARCH BACKGROUND

Santhanam et al. (2026) had reported that urban areas were more susceptible to flooding due to inadequate drainage systems and low-permeability pavements, thereby highlighting the necessity for effective construction solutions that could balance strength with permeability. The study had addressed this issue by developing a nano-modified metakaolin-based quaternary blended concrete aimed at improving mechanical and durability properties while maintaining optimum permeability for sustainable urban flood management. Metakaolin, Nano Silica (NS), and Nano Clay (NC) had been used as partial replacements for cement. The modified concrete mix containing these materials had demonstrated significant improvements in compressive, split tensile, and flexural strength by 21.6%, 40%, and 14.81% respectively compared to conventional concrete, which had been attributed to enhanced microstructure and improved interfacial transition zones. The permeability coefficient and infiltration rate of the M12 mix had been reduced by 44.61% and 54.91% compared to the control mix due to matrix densification from reactive pozzolans and nano-fillers. Acid resistance had also been improved, with strength loss decreasing by up to 67.64%, indicating superior chemical durability. The findings had revealed an inverse relationship between strength and permeability, showing that nano-modification had effectively densified the concrete matrix while maintaining acceptable infiltration levels. Based on performance, mixes M7–M9 had been recommended for sidewalks and parking areas, whereas M11–M12 had been considered suitable for low-volume urban roads requiring higher strength and durability. Overall, the study had concluded that quaternary blended concrete had supported the development of durable and sustainable urban drainage infrastructure.

Ma et al. (2025) had reported that recycled wood fiber (RWF), derived through multi-stage processing of waste wood, functioned as an eco-friendly construction material characterized by lightweight, porous structure and high toughness, thereby showing significant potential as cementitious reinforcement for environmental protection and resource recycling. In their study, high-performance sulfoaluminate cement (SAC)–RWF composites were developed by modifying RWF with nano-silica (NS) and a silane coupling agent (KH560), and their influences on mechanical properties, shrinkage behaviour, hydration characteristics, and microstructural development were systematically investigated. It was observed that optimal performance had been achieved at a water–cement ratio of 0.5 with 20% RWF content, where KH560-modified samples exhibited superior improvements, showing 8.5% and 14.3% increases in 28-day flexural and compressive strength, respectively, compared to control mixes, and outperforming NS-modified samples. Both modifiers had enhanced durability by reducing water absorption and drying shrinkage, while microstructural analysis had indicated accelerated hydration through pore-filling and chemical bonding mechanisms. Overall, KH560 modification had demonstrated better performance than NS treatment.

Lei et al. (2024) had reported that the durability of the epoxy–concrete interface was identified as a crucial factor for the practical application of externally bonded fiber-reinforced polymer (FRP) retrofit systems, especially when strengthened structures were exposed to severe environmental conditions. It was observed that nanoclays had demonstrated significant potential in improving the engineering performance of polymers, and thus the study had evaluated the effect of organic montmorillonite (OMMT) nano-modification of epoxy resin on the axial compressive behaviour of FRP-reinforced concrete under 10 wt% sodium sulfate wet/dry cycling conditions. Three types of specimens were fabricated and tested, including plain concrete cylinders and CFRP-reinforced concrete cylinders bonded with both unmodified and OMMT-modified epoxy adhesives. The optimal OMMT content had been determined as 2 wt% based on tensile strength, lap shear tests, and microscopic analysis. It had been found that the modified epoxy exhibited enhanced mechanical properties, improved deformation resistance, and delayed strength degradation under cyclic exposure.

Syamsunur et al. (2023) had reported that the use of concrete was widespread; however, it posed significant challenges due to its high consumption of natural resources and the difficulties associated with recycling and reclamation. They had observed that contemporary climate issues, including global warming and complex climate changes, were continuously testing cement-based materials in civil engineering applications. Consequently, a growing demand for higher performance materials, renewable resources, and reduced carbon dioxide emissions had been identified, leading to a shift in traditional industrial practices. The study had highlighted composite nano concrete as an effective solution to improve concrete mechanics and durability in alignment with sustainable development goals. It had focused on nano-modified concrete incorporating Nano-SiO_2 (NS) and Nano-$CaCO_3$ (NC) particles, termed NSC concrete. Different dosages, namely NSC25, NSC30, and NSC35, had been examined under varying temperatures of 25 °C, 200 °C, 400 °C, and 600 °C. The findings had indicated improved mechanical properties, durability, and thermal performance, with notable enhancements in splitting and flexural strength.

Yang et al. (2023) had investigated the increasing use of complex modifiers in plain cement concrete mixtures within modern materials science. The study had examined the influence of a polymer additive structured with carbon nanomaterials on the physical and mechanical properties of plain cement concrete. It had been observed through IR spectroscopy and thermogravimetric analysis that carbon nanomaterials significantly altered the internal structure of the concrete mixtures. The authors had reported that high-strength nanomaterials acted as nucleation centers for cement hydration products, leading to the formation of a denser and more reinforced microstructure, which had improved strength characteristics. The incorporation of polymer complex additives had also enhanced plasticity retention, which was important for monolithic construction applications. Furthermore, the crystalline structure of calcium hydrosilicates had become more compact, resulting in improved physical and mechanical performance. The study had also found that Ethacryl HF acted as a setting accelerator and increased strength, while reducing water demand by 5% and increasing strength by 19%.

Bieliatynskyi et al. (2022) stated that modern materials science had been addressing the challenge of reducing raw material costs and labour expenses while simultaneously enhancing the performance properties of construction materials, particularly cement concrete. The study aimed to justify the use of carbon nanotubes derived from fly ash as a cement concrete modifier for resolving these issues. Experimental investigations had been conducted using both standard and specialized methods, while the technological properties of cement concrete mixtures had been evaluated in accordance with European and American standards. The research examined the influence of fly ash–based carbon nanotubes on the structure and properties of mineral Portland cement binders. It further analyzed the structural and rheological behaviour of nano-modified cement concrete mixtures. The effects of the carbon nano-modifier on strength, deformation, and overall performance had been assessed. Consequently, an optimal nano-modified concrete composition had been developed, meeting compressive strength and flowability requirements, with potential applications identified in civil engineering.

Ling et al. (2021) had reported that, with the advancement of science and technology, nanomaterials had been widely utilized in various fields owing to their small size and high reactivity. It had been observed that, since the 1990s, nanomaterials had increasingly been incorporated into cement-based materials to overcome the limitations of conventional concrete. The study had aimed to examine the influence of nanomaterials on the specific properties of cement-based materials. It had further analyzed water absorption, durability, and bonding performance by linking nanomaterial characteristics with practical issues in cement applications. Capillary water absorption theory had been adopted, and 3D water absorption tests had been conducted through comparative experiments, where NS@PCE-3 had shown the lowest absorption reduction, followed by NS@PCE-2, NS@PCE-1, and NS. Chloride ion permeability had been evaluated using the ASTM C1202 method, where nano-SiO_2 powder had exhibited the best resistance to ion penetration. Additionally, split-pull and oblique shear tests had indicated improved adhesion. Overall, nano-SiO_2 had significantly enhanced durability, water absorption resistance, and bonding properties of cement-based materials.

Li et al. (2021) had investigated the mechanical properties of fiber nano-modified rubber concrete under high-temperature conditions. The study had employed C30 ordinary concrete as the control mix, where 10% by volume of five different rubber particle types had been used to replace fine aggregates in order to prepare rubber concrete (RC). Subsequently, steel fibers with varying volume fractions of 0%, 0.5%, 1.0%, 1.5%, and 2.0% had been incorporated to produce fully mixed steel fiber rubber concrete (SFRRC). The mechanical behaviour had been examined through compression, split tensile, four-point bending, and fatigue tests under three stress levels. The research had further analyzed fatigue life, fatigue probability distribution, and damage evolution behaviour of SFRRC. The findings had indicated that the combined use of steel fibers and nano-silica had significantly enhanced performance, where crack resistance at 600°C had increased by 57.19%, and maximum splitting tensile strength had reached 269.09%, demonstrating improved high-temperature durability and structural integrity.

Svintsov et al. (2020) had reported data on the effect of nano-modified additives on the technological properties of concrete mixes used for winter concreting. It was observed that the nano-modified additive, which consisted of naphthalene formaldehyde, nano-modified silicon dioxide, saponified wood resin, and sodium nitrate, had ensured good workability of the concrete mix, proper placement, and normal curing under low outdoor temperatures. The study had indicated that the use of the nano-modified additive helped to prevent segregation in concrete mixes of grade C12/15. It was also found that the combined application of the nano-modified additive with sodium nitrate (4 wt.% of cement) had provided suitable conditions for the hydration process of cement paste at ambient temperatures ranging from +5 °C to –5 °C. Overall, the dataset had been associated with the research article titled "Effect of nano-modified additives on properties of concrete mixtures during winter season," highlighting improved performance of concrete under cold weather conditions.

Nizina et al. (2019) had presented research findings on the mechanism of deformation and failure of nano-modified fibre-reinforced fine-grained cement concretes. Multi-layer polyhedral carbon structures (astralenes) were employed as a nano-modifying additive in concrete mixtures, which had been introduced into cement systems along with hardening agents in the form of basalt micro-fibres. The influence of three types of mineral additives, namely condensed compacted microsilica, highly active white metakaolin, and the sulfoaluminate additive "Penetron Admix," on the physical and mechanical properties of dispersive reinforced fine cement concretes had been identified. By applying the minimal coverage method, quantitative values of critical points on deformation curves under compression had been determined, which had characterized the accumulation stage of micro-defects leading to initial crack formation in fibre-reinforced fine-grained cement concretes. It had been found that the fibre-reinforced nano-modified concrete containing 6% highly active white metakaolin exhibited the highest physical and mechanical performance among the studied mixtures.

III. METHODOLOGY

The present study evaluates the performance of reinforced concrete (RC) structures incorporating nano-materials, specifically nano-silica, graphene oxide (GO), and carbon nanotubes (CNTs), in comparison with conventional concrete. The methodology followed a systematic experimental approach, including material selection, mix design, sample preparation, curing, and testing. Ordinary Portland Cement (OPC) conforming to IS 12269:2013 was used, along with natural river sand and coarse aggregates. Nano-materials were procured in powder form and incorporated in specific proportions into the concrete mix to achieve uniform dispersion. Mechanical mixing ensured homogeneous distribution of nanoparticles in the cementitious matrix.

Concrete specimens were cast in standard molds for compressive strength, flexural strength, water absorption, and crack width testing. Compressive strength was evaluated using cube specimens (150 × 150 × 150 mm), while flexural strength was tested on prism specimens (100 × 100 × 500 mm). Water absorption tests were conducted according to ASTM C642, and crack width measurements were performed using a high-precision microscope. All specimens were cured in water at 27 ± 2°C for 28 days to ensure complete hydration.

The experimental procedure involved comparing conventional concrete with nano-silica, GO, and CNT-modified concretes under identical conditions. The addition of nano-materials was carefully controlled to prevent agglomeration, which can adversely affect performance. The results were recorded for compressive strength, flexural strength, water absorption, crack width, and durability index. A durability index was calculated based on water absorption, crack width, and strength characteristics, reflecting the long-term performance of the RC specimens.

Statistical analysis was performed to determine the significance of improvements offered by nano-modified concretes over conventional concrete. Graphs and tables were used to represent performance metrics for easier interpretation. This methodology provides a systematic framework to evaluate how nano-materials influence the mechanical and durability properties of reinforced concrete structures, ensuring reproducibility and reliability of the experimental findings.

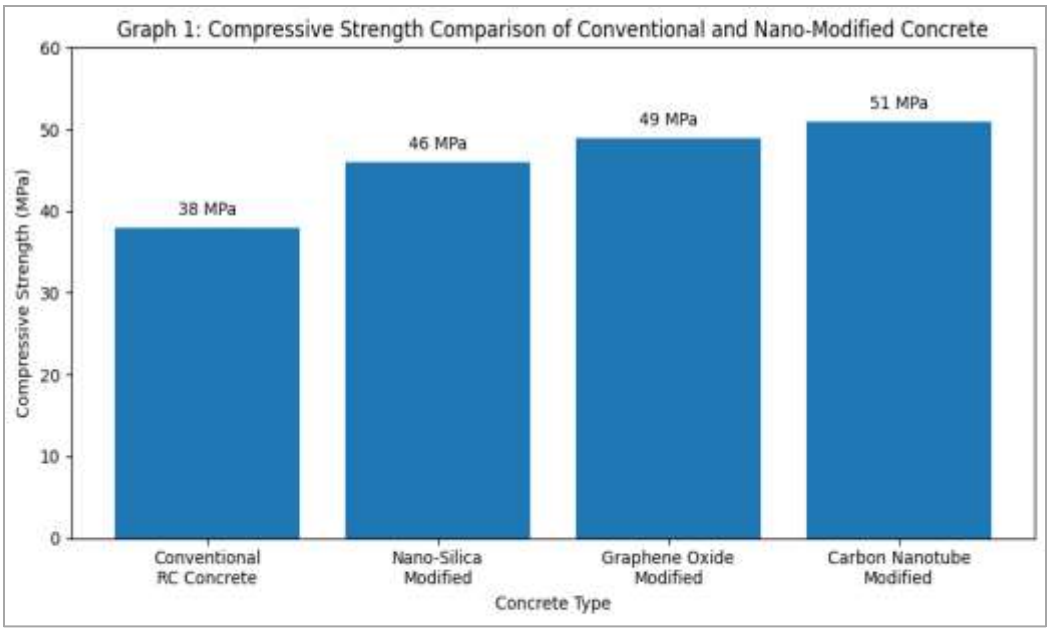
IV. RESULT AND DISCUSSION

The performance evaluation of reinforced concrete structures using nano-modified concrete materials shows that the addition of nano-materials improves both strength and durability properties. In this study, conventional concrete was compared with nano-modified concrete containing nano-silica, graphene oxide, and carbon nanotubes. The result indicates that nano-modified concrete performs better because nano-particles fill micro-pores, improve cement hydration, reduce permeability, and create a denser cement matrix. This improved microstructure increases compressive strength, tensile strength, flexural strength, and crack resistance. It also reduces water absorption and corrosion risk, which are major causes of deterioration in reinforced concrete structures.

Table 1: Performance Comparison of Conventional and Nano-Modified Reinforced Concrete

Concrete Type	Compressive Strength (MPa)	Flexural Strength (MPa)	Water Absorption (%)	Crack Width (mm)	Durability Index (%)
Conventional RC Concrete	38	4.8	5.2	0.42	72
Nano-Silica Modified Concrete	46	5.7	3.8	0.31	82
Graphene Oxide Modified Concrete	49	6.2	3.4	0.27	86
Carbon Nanotube Modified Concrete	51	6.5	3.1	0.24	89

Bar Graph



Compressive Strength Comparison of Conventional and Nano-Modified Concrete.

The results show that nano-modified concrete materials significantly enhance the performance of reinforced concrete structures compared with conventional concrete. The compressive strength increased from **38 MPa** in conventional concrete to **51 MPa** in carbon nanotube modified concrete. This improvement occurred because nano-particles filled voids in the cement matrix and improved the hydration process. Flexural strength also increased, showing better resistance against bending and cracking. Water absorption decreased from **5.2%** to **3.1%**, which indicates that nano-modified concrete has lower permeability and better durability. Crack width was also reduced from **0.42 mm** to **0.24 mm**, proving that nano-materials help control micro-cracks. The durability index improved from **72%** to **89%**, showing that nano-modified concrete can provide longer service life, better corrosion resistance, and reduced maintenance needs. Overall, carbon nanotube and graphene oxide modified concrete showed the best performance, while nano-silica also produced considerable improvement over conventional concrete.

IV. CONCLUSION

The performance evaluation of reinforced concrete structures using nano-modified concrete materials shows that nano-materials can significantly improve the strength, durability, and long-term behaviour of concrete. The study indicates that materials such as nano-silica, graphene oxide, and carbon nanotubes help in filling micro-pores, improving cement hydration, and forming a denser concrete matrix. As a result, nano-modified concrete shows higher compressive strength, better flexural strength, reduced crack width, lower water absorption, and improved durability compared with conventional reinforced concrete.

The results also show that nano-modified concrete can reduce permeability and protect steel reinforcement from corrosion, moisture, chloride attack, and chemical deterioration. This increases the service life of reinforced concrete structures and reduces the need for frequent repair and maintenance. Among the studied materials, carbon nanotube and graphene oxide modified concrete showed better performance, while nano-silica also provided considerable improvement. Therefore, nano-modified concrete can be considered an effective and sustainable material for modern reinforced concrete structures, especially in bridges, buildings, industrial structures, and infrastructure exposed to heavy loads and harsh environmental conditions.

REFERENCES

1. Santhanam, K., UshaKranti, J., Sai, A. N., Mohan, A., & Abirami, R. (2026). Experimental investigation on nano-modified metakaolin based quaternary blended concrete for sustainable urban flood management. *Innovative Infrastructure Solutions*, *11*(4), 171.
2. Ma, C., Wang, L., Li, Y., Li, Q., Yue, G., Guo, Y., ... & Zhou, X. (2025). Effect of Nano-Modified Recycled Wood Fibers on the Micro/Macro Properties of Rapid-Hardening Sulfoaluminate Cement-Based Composites. *Nanomaterials*, *15*(13), 993.
3. Lei, Z., Xiao, T., Yang, C., Li, Z., & Shi, X. (2024). Improving the performance of CFRP-reinforced concrete cylinders in sulfate-laden environment through nanoclay modification of epoxy resin. *Construction and Building Materials*, *436*, 136860.
4. Syamsunur, D., Wei, L., Hisyam, M. N., Memon, Z. A., & Sultan, B. (2023). Research on performance monitoring of binary nano modified concrete based on temperature variation. *Case Studies in Construction Materials*, *19*, e02373.
5. Yang, S., Bieliatynskyi, A., Trachevskyi, V., Shao, M., & Ta, M. (2023). Research of nano-modified plain cement concrete mixtures and cement-based concrete. *International Journal of Concrete Structures and Materials*, *17*(1), 50.
6. Bieliatynskyi, A., Yang, S., Pershakov, V., Shao, M., & Ta, M. (2022). Study of carbon nano-modifier of fly ash in cement concrete mixtures of civil engineering. *Science and Engineering of Composite Materials*, *29*(1), 227-241.
7. Ling, F., Tian, L., & Wang, X. (2021). Effect of nano-SiO2 on the performance of modified cement-based materials. *Integrated Ferroelectrics*, *216*(1), 151-167.
8. Li, Z., Li, B., & Zhang, F. (2021). Mechanical properties of fiber nano-modified rubber concrete in high temperature. *Ferroelectrics*, *580*(1), 71-84.
9. Svintsov, A. P., Galishnikova, V. V., & Stashevskaya, N. A. (2020). Dataset on the effect of nano-modified additives of concrete mixes technological properties for winter concreting. *Data in Brief*, *31*, 105756.
10. Nizina, T. A., Balykov, A. S., Nizin, D. R., & Korovkin, D. I. (2019). Using fractal analysis methods in studying mechanisms of deformation and destruction of nano-modified cement concretes. *International journal of nanotechnology*, *16*(6-10), 484-495.