

Performance Evaluation of Reinforced Concrete Structures Using Sustainable Nano-Modified Concrete Materials for Enhanced Durability: A Review

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ABSTRACT

This study focuses on the performance evaluation of reinforced concrete structures using nano-modified concrete materials. Nanomaterials such as nano-silica, graphene oxide, carbon nanotubes, nano-alumina, and nano-titanium dioxide improve concrete strength, durability, pore refinement, hydration, and resistance against chloride penetration and corrosion. The study highlights the role of nano-modified materials in enhancing mechanical properties, bond strength, retrofitting performance, and long-term structural reliability. It also emphasizes sustainability through reduced cement consumption, waste utilization, and improved service life. Despite challenges such as cost, dispersion, and standardization, nano-modified concrete offers strong potential for durable and sustainable infrastructure development.

Keywords: *Nano-Modified Concrete, Reinforced Concrete, Durability.*

I. INTRODUCTION

Reinforced concrete (RC) structures have remained the backbone of modern infrastructure due to their high compressive strength, durability, economic feasibility, and adaptability to different environmental and loading conditions. Rapid urbanization, industrial expansion, and the increasing demand for high-rise buildings, bridges, tunnels, and transportation systems have significantly increased the consumption of concrete worldwide. However, conventional concrete materials have exhibited several limitations related to durability, permeability, cracking, chloride penetration, shrinkage, and long-term structural degradation. Furthermore, the extensive use of Ordinary Portland Cement (OPC) in concrete production has contributed heavily to global carbon dioxide emissions, accounting for a substantial percentage of environmental pollution and climate change impacts. Researchers and engineers have therefore focused on developing sustainable and high-performance alternatives capable of improving the mechanical and durability characteristics of reinforced concrete structures while minimizing environmental impact. In this regard, nanotechnology has emerged as one of the most innovative and transformative approaches in construction engineering. Nano-modified concrete materials, including nano-silica, graphene oxide, carbon nanotubes, nano-alumina, nano-calcium carbonate, and nano-titanium dioxide, have demonstrated exceptional capability in enhancing the microstructural properties of concrete through pore refinement, accelerated hydration, interfacial strengthening, and improved bonding mechanisms. Balkis et al. (2026) reported that the incorporation of graphene oxide with GGBS and ultrafine GGBS significantly improved the strength and durability performance of high-strength concrete while reducing porosity and clinker content. Similarly, Li et al. (2025) observed that nanoparticles enhanced concrete performance through synergistic mechanisms such as micro-filling, nucleation effects, pozzolanic reactions, and interfacial strengthening, thereby improving mechanical properties and durability characteristics. These advancements have indicated the growing significance of nano-modified materials in the development of sustainable and resilient reinforced concrete infrastructure.

The incorporation of nanomaterials into reinforced concrete has also demonstrated remarkable improvements in structural performance under aggressive environmental conditions. One of the major concerns in reinforced concrete structures is the corrosion of steel reinforcement due to chloride penetration, moisture ingress, carbonation, and chemical attack. Corrosion not only reduces the service life of structures but also causes severe structural deterioration and economic losses. Nano-modified concrete materials have shown considerable potential in mitigating these durability-related issues by refining the pore structure and reducing permeability. Venkatraman (2026) investigated nano-fly ash and nano-cement in reinforced concrete and reported substantial improvements in corrosion resistance, bond performance, and compressive strength under chloride exposure conditions. Li (2021) further highlighted that nano-SiO₂, nano-CaCO₃, and carbon nanotubes effectively reduced chloride diffusion coefficients and enhanced hydration processes, thereby improving resistance against reinforcement corrosion. In addition to durability enhancement, nanotechnology has also contributed significantly to the strengthening and retrofitting of reinforced concrete members. Fernando (2024) reported that nano-modified epoxy resins containing graphene nanoplatelets and nanosilica considerably enhanced the bond performance between CFRP and concrete surfaces under saline and elevated temperature conditions. De Maio et al. (2023) similarly demonstrated that nano-modified epoxy improved bond strength and reduced slip behavior in FRP-plated RC structures, resulting in improved failure resistance and structural integrity. These findings have established that nanotechnology not only enhances the intrinsic properties of concrete but also improves the performance of repair, retrofitting, and strengthening systems used in reinforced concrete infrastructure. Consequently, nano-modified concrete materials are increasingly being recognized as an effective solution for extending the service life and structural reliability of reinforced concrete systems exposed to harsh environmental and loading conditions.

Apart from durability and strengthening applications, nano-modified concrete materials have also played a vital role in enhancing the mechanical behavior and sustainability performance of reinforced concrete structures. Researchers have explored the combined use of industrial byproducts, agricultural waste materials, and nanomaterials to produce eco-friendly and high-strength concrete systems. Babu and Rose (2025) investigated the incorporation of Cassava Peel Ash (CPA) and nano-silica in high-strength concrete and observed considerable improvements in compressive, tensile, and flexural strength at optimum replacement levels. Yong-cun (2020) also reported significant enhancement in compressive and splitting tensile strength due to the synergistic interaction of nano-silica, fly ash, and mineral powder in modified concrete. Similarly, Szymanowski and Sadowski (2024) identified optimal proportions of nano-SiO₂ and nano-TiO₂ that improved the mechanical performance and adhesive properties of high-strength cement mortars. The use of nano-modified materials has therefore contributed not only to performance enhancement but also to resource conservation, waste utilization, and reduction in cement consumption. Despite these advantages, several challenges remain associated with the practical implementation of nanotechnology in reinforced concrete structures. Issues such as high production cost, nanoparticle agglomeration, dispersion difficulties, lack of standardized design procedures, health concerns, and limited field-scale applications continue to restrict widespread adoption. Nevertheless, continuous advancements in material science, nanotechnology, and construction engineering are expected to overcome these limitations through the development of cost-effective synthesis methods, intelligent composite systems, and sustainable nano-engineered materials. Therefore, the performance evaluation of reinforced concrete structures using nano-modified concrete materials has become an important research area aimed at achieving durable, sustainable, and high-performance infrastructure systems for future construction practices.

II. RESEARCH BACKGROUND

Balkis et al. (2026) had reported that Ordinary Portland Cement (OPC), a key constituent of concrete, had contributed significantly to global CO₂ emissions, accounting for over 8%, thereby indicating the need for sustainable high-strength alternatives. The study had aimed to develop an eco-efficient M70-grade concrete through partial replacement of OPC with 20% Ground Granulated Blast-Furnace Slag (GGBS) and 10% Ultrafine GGBS (UGGBS), along with very low dosages of Graphene Oxide (GO) ranging from 0.01% to 0.09% by binder mass. It had been observed through experimental investigations, including compressive strength, porosity, durability, and microstructural analysis, that the ternary GO–GGBS–UGGBS system had enhanced strength and durability while reducing porosity and clinker content. An optimum GO content of about 0.05% had been identified, beyond which agglomeration had adversely affected workability and hydration. The study had further highlighted improved microstructural densification and had identified barriers such as high cost and dispersion challenges of GO for practical adoption, and had suggested the need for further optimization for large-scale application.

Venkatraman (2026) had investigated the effectiveness of nano-pozzolanic materials, namely nano-fly ash (CNF) and nano-cement (CNC), in improving the corrosion resistance and bond performance of reinforced concrete. It had been reported that concrete mixes were prepared by partially replacing cement with CNF (5–20%) and CNC (5–35%), along with a control mix without nanomaterials. The specimens had been subjected to accelerated chloride-induced corrosion using an impressed current in a 5% NaCl solution. Durability performance had been evaluated through half-cell potential measurements, water permeability tests, and rapid chloride penetration tests (RCPT), while compressive strength had been assessed before and after corrosion exposure. Bond-slip behaviour had been examined through pull-out tests, and reinforcement degradation had been determined by mass loss and residual tensile strength. The results had indicated that mixes containing 15% CNF and 30% CNC had exhibited superior performance, with significant improvements in compressive strength and reduced strength loss under chloride exposure, confirming enhanced durability.

Babu and Rose (2025) had reported that concrete was one of the most commonly utilized materials in construction projects due to the rapid growth of urbanization and industrialization. They noted that the scarcity of natural resources and ongoing environmental degradation had encouraged researchers to explore alternative or supplementary cementitious materials in concrete production. Cassava Peel Ash (CPA), an agricultural byproduct, had been identified as a promising supplementary material for cement in concrete manufacturing. The study aimed to develop high-strength concrete (HSC) by partially replacing cement with CPA and enhancing its performance through the incorporation of Nano Silica (NS). Although CPA had shown potential as a supplementary cementitious material, its application often resulted in reduced early-age strength. To overcome this limitation, the combined effects of CPA (5–25%) and NS (1–3%) on workability and mechanical properties were investigated. It had been observed that the mix containing 5% CPA and 3% NS achieved optimum performance, with enhanced compressive, tensile, and flexural strength.

Li et al. (2025) had reported that nanoparticles leveraged their unique nanoscale effects to optimize concrete performance through synergistic multi-mechanism interactions. It had been observed that the core mechanisms included micro-filling effects, such as graded pore filling and optimized pore structure, nucleation effects that promoted crystallization of hydration products and refined microstructure, chemical reactivity such as the pozzolanic reaction of nano-SiO₂ which enhanced the interfacial transition zone, and interfacial strengthening that improved ITZ structure and stress transfer. It had further been noted that commonly used nanomaterials like nano-SiO₂, Al₂O₃, and carbon nanotubes significantly

enhanced mechanical properties, durability, and functional performance of concrete, including self-sensing and electromagnetic shielding capabilities. However, it had also been identified that nano-modified concrete still faced challenges such as poor dispersion, high production cost, and potential environmental and health risks. The study had suggested that future research should focus on multi-scale mechanisms, green and low-cost synthesis methods, and intelligent composite systems for engineering applications.

Fernando (2024) had reported that debonding of Carbon Fibre Reinforced Polymer (CFRP) from concrete had remained one of the major challenges in the civil retrofitting industry. It had been observed that saline water exposure and elevated temperature conditions were among several factors that had promoted debonding at the interface. The study had aimed to identify failure mechanisms at the polymer–concrete interface and to develop improved strategies for enhancing epoxy resin performance through the incorporation of nanomaterials, leading to the development of nanohybrid adhesives. The primary intention behind using nanomaterials had been to strengthen the interfacial bond between CFRP and concrete and to improve durability under aggressive environmental conditions. A comprehensive review of previous studies on nanohybrid adhesives had been carried out to evaluate the effects of different nanoparticles on composite performance. It had been found that graphene nanoplatelets (0.25 wt.% and 0.5 wt.%) and nanosilica exhibited significant improvement potential. Experimental double shear tests had shown that 0.25 wt.% GNP-modified epoxy had outperformed neat epoxy by 181%, also enhancing stiffness performance.

Szymanowski and Sadowski (2024) had provided the results of an analysis on the mechanical performance of high-strength nano-modified cement mortars used for overlays. The study had aimed to determine the optimal dosage of nanoparticles that would lead to noticeable improvements in mechanical, functional, and adhesive properties of cement-based floor overlays. For this purpose, the mechanical performance ratio (MPR) had been employed as a key evaluation parameter. The mechanical performance analysis had been conducted across six commonly used variants of overlays to assess comparative effectiveness. It had been observed that nano-modification significantly influenced the overall performance of the mortars. The findings had indicated that the most effective enhancement in mechanical performance of high-strength overlays had been achieved with the incorporation of SiO₂ nanospheres at 0.5% and TiO₂ tetragonal crystalline nanoparticles at 1% of the cement mass. These proportions had been identified as optimal for improved structural behavior.

De Maio et al. (2023) had stated that the ability to manipulate concrete-based and composite materials at the nanoscale had represented an innovative approach for enhancing their mechanical properties and for designing high-performance building structures. In this context, a numerical investigation had been proposed on the reinforcing effect of nano-modified epoxy resin on the structural response of fiber-reinforced polymer (FRP)-plated reinforced concrete (RC) components. It had been observed that an integrated model based on a cohesive crack approach, in combination with a bond–slip model, had been employed to perform failure analysis of strengthened structures. The study had further indicated that cohesive elements placed at the concrete–FRP interface, along with an appropriate bond–slip law, had effectively described the reinforcing influence of nanomaterials in the epoxy resin. Preliminary analyses had revealed a 28% increase in bond strength, a 5.5% rise in failure load, and a 76% reduction in slip. The results had shown good agreement with experimental data, confirming model validity.

Kasatkin et al. (2022) reported that the development of concrete with targeted physical and mechanical properties required a rational selection of mix components, including the use of finely dispersed fillers, including those based on recyclable materials, and highly effective chemical additives with specific nature

and reactive action, which exerted complex effects on the concrete system. The effectiveness of the additive components was evaluated through variations in compressive strength and tensile strength in bending, which were assessed according to GOST 10180-2012, Concrete Methods for determining the strength of control samples. For experimental investigations, Portland cement CEM I 42.5N, natural sand, fine microsilica, and a complex chemical additive with enhanced plasticizing and reactive properties were utilized. It was further observed that the combined use of these materials improved overall structural performance and contributed to the optimization of durable concrete mixtures suitable for engineering applications under different service conditions in civil engineering practice.

Alwash et al. (2021) had reported that there was a high demand in the construction industry for high-strength and durable cement-based adhesives (CBAs) for various applications such as ground anchors, ground improvement, concrete repair, and as a substitute for epoxy resins for bonding carbon fibre reinforced polymers (CFRPs) to concrete structures, particularly where enhanced fire performance was required. It was noted that limited research had been conducted on the incorporation of nanomaterials such as graphene oxide (GO), graphene nanoplatelets (GNPs), and nano-silica (NS) to improve the mechanical properties and durability of CBAs. The study had presented a modified mix design consisting of ordinary Portland cement combined with GNP, GO, and NS to enhance strength and durability. It had further examined bond–slip behaviour between CFRP and CBA in concrete prisms. The results had indicated significant improvements in compressive and flexural strength, along with reduced chloride penetration and enhanced bond performance in FRP-to-concrete joints.

Li (2021) had reported that chloride permeability and chloride binding capacity were two crucial parameters for assessing the risk of rebar corrosion in reinforced concrete structures. In the study, the chloride permeability and binding capacity of concrete modified with nano-SiO₂ (NS), nano-CaCO₃ (NC), and multi-walled carbon nanotubes (CNT) were evaluated. The results had demonstrated that the incorporation of nanomaterials significantly reduced chloride diffusion coefficients by refining the pore structure and decreasing pore volume. The experimental findings had strongly indicated the existence of a percolation threshold (critical porosity), below which chloride permeability decreased sharply. It had been observed that the addition of NS reduced chloride binding capacity due to a lower pH of pore solution, leading to dissolution of Friedel’s salt. XRD analysis had suggested that NC restrained the formation of AFm phases responsible for chemical binding. TG/DTG results had confirmed that CNT enhanced hydrate formation, thereby improving chloride binding. Overall, NS and NC had reduced Friedel’s salt formation and weakened chemical binding.

Yong-cun (2020) had investigated the issue of insufficient durability and long-term performance of concrete by analyzing the compressive and splitting tensile properties of nano-silica modified concrete. The study had provided strong evidence regarding the synergistic interaction among nano-silica, fly ash, and mineral powder in improving the durability of concrete. Initially, both ordinary and high-performance concrete mixes had been prepared and modified. These mixes had then been separately combined with nano-silica, fly ash, and mineral powder to examine different composite effects. Subsequently, compressive strength and splitting tensile strength tests had been conducted to compare the mechanical performance of the modified concretes. The results had indicated that the combined effect of nano-silica, fly ash, and mineral powder had significantly enhanced concrete strength. The compressive strength increase had reached up to 10 MPa for ordinary concrete and 20 MPa for high-strength concrete. Overall, the study had concluded that nano-silica incorporation had improved concrete durability when used in appropriate proportions.

III. KEY FINDINGS FROM STUDY

Author & Year	Objective	Methodology	Key Findings
Balkis et al. (2026)	To develop eco-efficient high-strength concrete using GO, GGBS, and UGGBS	Experimental investigation on M70 concrete with GO (0.01–0.09%), compressive strength, porosity, and durability tests	Optimum GO dosage of 0.05% improved strength, durability, and reduced porosity
Venkatraman (2026)	To investigate nano-pozzolanic materials for corrosion resistance and bond strength	Partial replacement with nano-fly ash and nano-cement; chloride exposure and pull-out tests	15% CNF and 30% CNC significantly improved compressive strength and corrosion resistance
Babu & Rose (2025)	To evaluate nano-silica and CPA in high-strength concrete	Experimental analysis with CPA (5–25%) and NS (1–3%)	5% CPA and 3% NS achieved optimum compressive, tensile, and flexural strength
Li et al. (2025)	To review mechanisms and applications of nanoparticles in concrete	Analytical review of nano-modification mechanisms and applications	Nanoparticles enhanced durability, ITZ strength, and functional performance
Fernando (2024)	To improve CFRP-concrete bonding using nano-modified epoxy	Double shear tests with graphene nanoplatelets and nanosilica	0.25% GNP epoxy improved bond performance by 181%
Szymanowski & Sadowski (2024)	To determine optimum nanoparticle dosage in cement overlays	Mechanical performance ratio analysis of nano-modified mortars	0.5% nano-SiO ₂ and 1% nano-TiO ₂ gave best mechanical performance
De Maio et al. (2023)	To analyze reinforcing effect of nano-modified epoxy in RC structures	Numerical cohesive crack and bond-slip modelling	Bond strength increased by 28% and slip reduced by 76%
Kasatkin et al. (2022)	To develop high-performance nano-modified concrete	Experimental testing using microsilica and chemical additives	Improved compressive and tensile strength with enhanced durability
Alwash et al. (2021)	To develop nano-modified cement-based adhesives for FRP systems	Use of GO, GNP, and NS in cement-based adhesive mixtures	Enhanced bond-slip behavior, compressive strength, and chloride resistance
Li (2021)	To study chloride permeability in nano-modified concrete	Experimental chloride diffusion and binding tests	Nanomaterials reduced permeability and improved hydration products
Yong-cun (2020)	To investigate nano-silica modified concrete durability	Mechanical testing with nano-silica, fly ash, and mineral powder	Significant improvement in compressive and tensile strength

IV. CONCLUSION

Nano-modified concrete materials have emerged as an advanced and sustainable solution for improving the performance of reinforced concrete structures in modern civil engineering applications. The incorporation of nanomaterials such as nano-silica, graphene oxide, carbon nanotubes, nano-calcium carbonate, and nano-titanium dioxide has significantly enhanced the mechanical, durability, and interfacial properties of concrete systems. The reviewed studies demonstrated that nanomaterials improve concrete performance through mechanisms such as pore refinement, accelerated hydration, nucleation effects, interfacial strengthening, and enhanced bond behavior. These improvements resulted in higher compressive, tensile, and flexural strength, reduced permeability, enhanced corrosion resistance, and better long-term durability under aggressive environmental conditions. Nano-modified materials also contributed substantially to the strengthening and retrofitting of reinforced concrete structures by improving CFRP-to-concrete bonding and reducing debonding failures. Furthermore, the integration of industrial waste materials and agricultural byproducts with nanomaterials promoted sustainability through reduced cement consumption and lower environmental impact. Despite these advantages, challenges such as high material cost, nanoparticle agglomeration, dispersion difficulties, health concerns, and lack of standardized implementation methods continue to limit large-scale practical applications. Nevertheless, ongoing advancements in nanotechnology and material science are expected to overcome these limitations through the development of economical, eco-friendly, and intelligent nano-engineered concrete systems. Overall, nano-modified concrete has shown immense potential for producing high-performance, durable, and sustainable reinforced concrete structures capable of meeting future infrastructure demands.

V. FUTURE SCOPE

- **Development of Cost-Effective Nanomaterials:** Future research should focus on developing economical nanomaterials that can be commercially adopted in large-scale construction projects. Presently, materials such as graphene oxide, carbon nanotubes, and nano-silica are expensive, limiting their widespread application in reinforced concrete structures. Researchers may explore low-cost synthesis methods using industrial waste, agricultural byproducts, and recycled nanomaterials to reduce production costs while maintaining high performance. Sustainable manufacturing techniques for nanomaterials can further contribute toward eco-friendly infrastructure development.
- **Improvement in Dispersion Techniques:** One of the major challenges associated with nano-modified concrete is the agglomeration of nanoparticles within the cement matrix. Poor dispersion reduces the effectiveness of nanomaterials and negatively affects workability and structural performance. Future investigations should emphasize advanced dispersion methods such as ultrasonic mixing, chemical surfactants, and nano-coating technologies to ensure uniform distribution of nanoparticles throughout the concrete matrix. Proper dispersion techniques can significantly improve hydration reactions, pore refinement, and bonding characteristics.
- **Long-Term Durability Studies:** Most existing studies have focused primarily on short-term laboratory investigations. Future research should evaluate the long-term performance of nano-modified reinforced concrete structures under actual field conditions. Studies involving freeze–thaw cycles, marine exposure, sulphate attack, acid attack, carbonation, chloride penetration, and high-temperature exposure are necessary to determine service life performance. Long-term monitoring can provide valuable information regarding crack resistance, corrosion protection, and structural reliability.

- **Integration with Sustainable Construction Materials:** Future scope also includes combining nanomaterials with supplementary cementitious materials such as fly ash, silica fume, GGBS, rice husk ash, and agricultural waste ashes to produce sustainable high-performance concrete. Such hybrid systems can reduce cement consumption, minimize carbon emissions, and enhance environmental sustainability. The integration of recycled aggregates and green binders with nanotechnology can support the development of environmentally responsible construction practices.
- **Application in Smart and Self-Sensing Structures:** Nanotechnology offers significant potential for developing intelligent reinforced concrete structures with self-sensing and self-monitoring capabilities. Future studies may investigate the use of conductive nanomaterials such as carbon nanotubes and graphene for real-time structural health monitoring. These smart concrete systems can detect cracks, stress variations, moisture penetration, and structural damage at early stages, thereby improving maintenance efficiency and structural safety.
- **Enhancement of Structural Retrofitting Techniques:** Nano-modified adhesives and nano-enhanced CFRP systems can be further explored for retrofitting and rehabilitation of deteriorated reinforced concrete structures. Future research should focus on improving bond strength, fatigue resistance, thermal stability, and durability of nano-modified repair materials under aggressive environmental conditions. This can significantly extend the service life of aging infrastructure.
- **Use of Artificial Intelligence and Numerical Modelling:** Artificial intelligence, machine learning, and advanced numerical simulation tools can be integrated with nanotechnology research for predicting concrete behavior and optimizing mix design parameters. Future computational models can assist in evaluating mechanical properties, durability characteristics, crack propagation, and structural response more accurately, thereby reducing experimental costs and improving design efficiency.
- **Standardization and Field Implementation:** Future work should emphasize the development of standardized codes, specifications, and practical guidelines for the use of nano-modified concrete in construction industries. Pilot projects and field-scale applications are necessary to evaluate real-world performance and to increase confidence among engineers, contractors, and policymakers regarding the practical implementation of nanotechnology in reinforced concrete structures.

REFERENCES

1. Balkis, A., Shashank, B. S., Blanco, A., & Goyal, R. (2026). Strength and durability performance of high-strength concrete incorporating nano-modified graphene oxide materials and ultrafine GGBS from industrial waste sources. *Innovative Infrastructure Solutions*, 11(4), 175.
2. Venkatraman, Y. (2026). Revolutionising concrete performance: the impact of nanotechnology on corrosion and bond strength. *European Journal of Environmental and Civil Engineering*, 30(1), 2629032.
3. Babu, S. S., & Rose, A. L. (2025). Experimental investigations on performance of Nano-modified cassava Peel Ash for High-Strength concrete applications. *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, 1-18.
4. Li, H., Zhao, Y., Zhao, Y., Zhang, M., Niu, Y., & Cao, X. (2025). Advances in the mechanism and application of nanoparticles in concrete property modification. *Inorganics*, 13(9), 305.
5. Fernando, N. (2024). Impact of nano-modified epoxy on cfrp-strengthened concrete bond in aggressive environments.

6. Szymanowski, J. and Sadowski, Ł., 2024. Analysis of the mechanical performance of high-strength nano-modified cement mortars for overlays. *Buildings*, 14(1), p.248.
7. De Maio, U., Gaetano, D., Greco, F., Lonetti, P., Nevone Blasi, P., & Pranno, A. (2023). The reinforcing effect of nano-modified epoxy resin on the failure behavior of FRP-plated RC structures. *Buildings*, 13(5), 1139.
8. Kasatkin, S. P., Soloviova, V. Y., Stepanova, I. V., Kuznetsov, D. V., & Sinitsin, D. A. (2022). High-performance nano-modified concrete of increased strength and durability. *Nanotekhnologii v Stroitel'stve*, 14(6), 493-500.
9. Alwash, D., Kalfat, R., Du, H., & Al-Mahaidi, R. (2021). Development of a new nano modified cement based adhesive for FRP strengthened RC members. *Construction and Building Materials*, 277, 122318.
10. Li, C. (2021). Chloride permeability and chloride binding capacity of nano-modified concrete. *Journal of Building Engineering*, 41, 102419.
11. Yong-cun, Z. (2020). Mechanical properties of modified concrete based on nano-silicon dioxide. *Integrated Ferroelectrics*, 207(1), 37-48.