IARJSET
ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology
International Conference on Interdisciplinary Global Research in Adaptation, Transformation & Engineering
INTEGRATE 2025
Geetanjali Institute of Technical Studies (GITS)
Vol. 12, SPECIAL ISSUE 2, NOVEMBER 2025
DOI: 10.17148/IARJSET/INTEGRATE.2025.12219

Nanotechnology Applications in Construction Materials

Kumavat Yogesh[1], Lakshita Mali[2], Gunjan Badgujar[3]

Student, Civil Engineering Department, GITS, Udaipur, India[1, 2, 3]

Abstract: Nanotechnology has brought the innovations in the ways and methods of materials process, it is now used in many sectors. For engineering specifically, there are very few applications where this technology is incorporated; nevertheless the ones which exist are limited. One key area that affects structures engineers a lot is the use over construction materials that are utilised for different projects all over the world. And if you look closely you'll note that these are natural materials which are non- renewable hence their use suffer from sustainability issue since once they have been used cannot be reused. Nanotechnology can be employed to cut down on the utilization of natural resources without compromising their functionality in various applications. Considering construction as presently the greatest industry in terms of value, nanotechnology would find ample room for its application. Nanotechnology promises to make building process faster, cheaper, safer, and more convenient as well. Automation of nanotechnology-based construction could mean an ability to build anything from upgraded homes to huge skyscrapers significantly quicker and at much lower costs. The chapter provides brief discussion focusing on nano technology application and opportunity in construction material with critical view point. It is essential to point out that nanotechnology is also an area in the field of construction that opens up new perspectives for using novel, advanced or smart materials that are durable and high performing. Scientists and engineers are working on development of nano-engineered cementitious composites, coatings and reinforcing materials which have higher strength, autonomously healing ability and durability against various environmental degradation processes by tailoring at the nanoscale. The paper identified some of the primary ways in which nanotechnology is incorporated into building materials carbon nano tubes, nano-silica, nano-titanium dioxide and nano-clays. They find their application in enhancement of mechanical, chemical and durability properties of concrete as well as other building materials.

Keywords*:* Nanotechnology, Construction Materials, Nano-silica, Carbon Nanotubes, Durability

I. INTRODUCTION

Nanotechnology is concerned with objects between 1 and 100nm in size. 1Nanometer = 1 x10^{-9}m. The nanotechnologies can be defined as the design, characterization, production and application of structures, devices and systems by controlling shape and size at the nanoscale. Nanotechnology requires advanced imaging techniques for studying and improving the material behaviour and for designing and producing very fine powders, liquids or solids of materials.
The application of nanotechnology has been proved successful in making insulators, nano sensors, and smart and eco-friendly materials. In fact nanotechnology is not either a new science or technology but an enhancement of existing technology. The word "Nano" was derived from the Greek word dwarf which indicates a billionth part. Nano meter means billionth of a meter. There are two approaches to the nano scale one is from the top down another is from the bottom up. The top down approach refers to reduction of size from large to smallest size whereas bottom up approach refers to the construction of materials from atomic or molecular components.

II. NANOMATERIALS USED IN CONSTRUCTION

A. Nano-Silica

Nano-silica improves the hydration of cement, refines pore structure, and enhances compressive strength. Among all the nanomaterials, nanosilica is the most widely used material in the cement and concrete to improve the perfor-mance, because of its pozzolanic reactivity besides the pore-filling effect. Due to the rapid development of infrastructure, it is neces-sary to develop a high strength, durable, sustainable and environment friendly cementitious composites.

Cement mortar with well dispersed nanoparticles into it has adense microstructure even if the nanoparticles are added small quantity, but if nanoparticles are not dispersed properly, it may results in voids and weak zones formation [20]. Accelerated hydra-tion of cement paste and faster formation of calcium hydroxideat initial period was observed in the nanosilica added cement paste. This is because rate of hydration depends upon the sur-face area of nanosilica particles added. Nanosilica particles act as nucleation sites to accelerate the hydration. Due to high surfacearea and thus high reaction rate heat of hydration was also higher. It can be inferred that there may be an optimum amount of surface area at which peak heat evolution will take place. The set-ting time of fresh cement paste and mortar were decreased by increasing the content of silica nanoparticles. Singhet al. mentioned that the compressive strength of cement paste containing 5% nanosilica was 64% higher at 1 day and 35% at 28 days than that of control cement paste. Nanosilica added cement paste showed reduction in setting time, shortened dura-tion of dormant and induction period of hydration, shortening of time to reach peak heat of hydration and increased production of calcium hydroxide at early ages. Accelerated C3S dissolu-tion was observed with nanosilica addition. Dense and com-pact microstructure with lesser amount of calcium hydroxide crystals was observed and the heat evolution was quite higher than ordinary Portland cement paste.

B. Carbon Nanotubes (CNTs)

CNTs provide superior tensile strength, crack-bridging ability, and self-sensing properties in cementitious composites. Carbon nanotubes can be visualized as a modified form of graphite. Graphite is formed from many layers of carbon atoms that are bonded in a hexagonal pattern in flat sheets, with weak bonds between the sheets and strong bonds within them. A CNT can be thought of as a sheet or sheets of graphite that have been rolled up into a tube structure. CNT can be single walled nanotubes (SWNT), as if a single sheet had been rolled up, or multiwalled (MWNT), similar in appearance to a number of sheets rolled together. Figure 1 shows a schematic of a single walled nanotube.

C. Nano-Titanium Dioxide (TiO_2)

TiO_2 is widely used for self-cleaning surfaces and photocatalytic pollution reduction..TiO_2 nanoparticles give surfaces photocatalytic qualities in addition to mechanical advantages. This results in self-cleaning structures where pollutants and organic matter break down in the sun. Modern "green" architecture in Europe and Japan already makes use of this feature.Because of its special photocatalytic and self-cleaning qualities, nano-titanium dioxide (TiO_2) is one of the most extensively studied and used nanomaterials in the construction sector. TiO_2 starts a photocatalytic reaction when exposed to ultraviolet (UV) light, which breaks down pollutants and organic materials left on building surfaces. Because of this phenomenon, materials coated with TiO_2 become "self-cleaning," greatly lowering maintenance costs and extending the structural longevity of an attractive design. Apart from their ability to clean themselves, TiO_2 coatings have the ability to break down dangerous air pollutants like nitrogen oxides (NO_x) and volatile organic compounds (VOCs), which helps to improve the quality of the air in crowded cities. Because of this property, "eco-active" building materials that passively purify the air around them have been developed.

D. Nanoclays and Graphene

While graphene offers unparalleled strength and electrical conductivity, nanoclays improve barrier resistance and fire retardancy. Through embedded sensors, graphene can support energy-efficient designs while improving sustainability and durability when added to concrete or asphalt.The mechanical and barrier qualities of building composites can be significantly improved by using nanoclays, which are layered silicate minerals with a high surface area and aspect ratio. Nanoclays enhance moisture stability, gas impermeability, and fire resistance when added to cement or polymer matrices. By improving durability against chemical attack and decreasing permeability, their addition refines the pore structure of concrete. Additionally, nanoclays help other nanomaterials disperse better within the matrix and exhibit better rheological behavior. However, one of the strongest and most conductive materials is graphene, which is a sheet of carbon atoms arranged in a hexagonal lattice that is only one atom thick. By strengthening the microstructure at the nanoscale, graphene improves the compressive, tensile, and flexural strength of cement or asphalt composites III.

III. APPLICATIONS IN CONSTRUCTION MATERIALS

A. Cement and Concrete

1) Cement

Nanomaterials optimize hydration, reduce porosity, and increase strength and durability. Addition of nanoscale materials into cement could improve its performance. In [7], Li (2004) found that nano-SiO2 could significantly increase the compressive for concrete, containing large volume fly ash, at early age and improve pore size distribution by filling the pores between large fly ash and cement particles at nanoscale. The dispersion/slurry of amorphous nanosilica is used to improve segregation resistance for self-compacting concrete [8]. It has also been reported that adding small amount of carbon nanotube (1%) by weight could increase both compressive and flexural strength [9]. Cracking is a major concern for many structures. University of Illinois Urbana-Champaign is working on healing polymers, which include a microencapsulated healing agent and a catalytic chemical trigger [8]. When the microcapsules are broken by a crack, the healing agent is released into the crack and contact with the catalyst. The polymerization happens and bond the crack faces. The self-healing polymer could be especially applicable to fix the microcracking in bridge piers and columns. But it requires costly epoxy injection.

2) Concrete

Concrete is one of the most common and widely used construction materials. The rapid development of new experimental techniques makes it possible to study the properties of cementitious materials at micro/nano-scale. Research has been conducted to study the hydration process, alkali-silicate reaction (ASR), and fly ash reactivity using nanotechnology [6]. The better understanding of the structure and behavior of concrete at micro/nano-scale could help to improve concrete properties and prevent the illness, such as ASR.

B. Steel and Coatings

1) Steel.

Steel is a major construction material. Its properties, such as strength, corrosion resistance, and weld ability, are very important for the design and construction. FHWA together with American Iron and Steel Institute and the U.S. Navy started to develop new, low carbon, high-performance steel (HPS) for bridges in 1992 [10]. The new steel was developed with higher corrosion-resistancea and weld ability by incorporating copper nanoparticles from at the steel grain boundaries. Sandvik NanoflexTM is new stainless steel with ultra-high strength, good formability, and a good surface finish developed by Sandvik Nanoflex Materials Technology. Due to its high performance, Sandvik NanoflexTM is suitable for application which requires lightweight and rigid designs. Its good corrosion and wear resistance can keep life-cycle costs low. Attractive or wear resistant surfaces can be achieved by various treatments (Sandvik Nanoflex Materials Technology). MMFX2 is nanostructure-modified steel, produced by MMFX Steel Corp. Compared with the conventional steel, it has a fundamentally different microstructure- a laminated lath structure resembling “plywood”. This unique structure provides MMFX2 steel with amazing strength (three times stronger), ductility, toughness, and corrosion resistance. Due to high cost, the stainless steel reinforcement in concrete structure is limited in high risk environments. The MMFX2 steel could be an alternative because it has the similar corrosion resistance to that of stainless steel, but at a much lower cost (MMFX Steel Corp.)

2) Coating

The coatings incorporating certain nanoparticles or nanolayers have been developed for certain purpose. It is one of the major applications of nanotechnology in construction. For example, TiO2 is used to coat glazing because of its sterilizing and anti-fouling properties. The TiO2 will break down and disintegrate organic dirt through powerful catalytic reaction [10]. Furthermore, it is hydrophilic, which allow the water to spread evenly over the surface and wash away dirt previously broken down. Other special coatings also have been developed, such as anti-fraffiti, thermal control, energy sawing, and anti-reflection coating.

C. Glass and Ceramics

Nano-TiO_2 and silica coatings provide self-cleaning and UV-protection features. Architectural glass that has been treated with nano-TiO_2 stays clear while also blocking UV rays and fogging up, which makes buildings more comfortable and environmentally friendly.The performance and functionality of glass and ceramic materials in contemporary construction have been greatly enhanced by nanotechnology. Nano-TiO_2 coatings work especially well to make self-cleaning glass, in which organic pollutants and dirt are broken down by photocatalytic reactions under UV light. The coating's hydrophilic properties guarantee that water disperses uniformly across the surface during rainy seasons, removing any debris. This lowers the frequency of cleaning and maintenance expenses, which is particularly advantageous for glass façades, solar panels, and skyscrapers in contaminated urban areas. Furthermore, it is possible to engineer nanostructured glass to control heat transfer, improving building energy efficiency. Thermal stability, transparency, and scratch resistance can all be enhanced by adding nano-silica or nano-alumina.

D. Smart and Sustainable Materials

Self-healing concrete, energy-efficient insulation, and nano-enhanced sensors for structural health monitoring. A significant step toward intelligent, self-regulating infrastructure systems is represented by smart materials created with nanotechnology. Without outside assistance, these materials can sense changes in their surroundings, adjust, and even mend themselves. For example, when exposed to air or water, self-healing concrete embedded with microcapsules containing bacteria or healing agents can automatically seal cracks, preserving structural integrity and halting the corrosion of reinforcement steel. In order to transmit real-time data for structural health monitoring (SHM), nanosensors embedded in steel or concrete frameworks can continuously monitor parameters like temperature, vibration, and strain. Early damage detection is made possible by this technology, which guarantees prompt maintenance and averts catastrophic failures. Additionally, energy-efficient insulation is being made with nanomaterials like phase-change materials and aerogels, which offer better thermal regulation and lower building energy consumption.

Vol. 12, SPECIAL ISSUE 2, NOVEMBER 2025 DOI: 10.17148/IARJSET/INTEGRATE.2025.12219

IV. ADVANTAGES AND CHALLENGES

A. Advantages
- Improved mechanical properties
- Increased durability and sustainability
- Smart functionalities (self-cleaning, self-sensing, self-healing)

B. Challenges
- High cost of nanomaterials
- Lack of large-scale production techniques
- Health and environmental concerns

V. CONCLUSION

Nanotechnology offers immense potential to revolutionize construction materials by improving strength, durability, and sustainability. While research is advancing rapidly, widespread adoption requires overcoming economic and environmental challenges. The future of construction lies in integrating nanotechnology into mainstream practices to achieve innovative, sustainable, and smart infrastructure. Nanotechnology could change the way buildings are made by allowing the creation of materials that are not only stronger and longer-lasting, but also smarter and better for the environment. The next generation of civil infrastructure might be able to heal itself, use less energy, and keep an eye on its own health. But for this vision to come true, materials scientists, civil engineers, and policymakers need to work together across disciplines. Nanotechnology could be the foundation of a long-lasting and adaptable built environment if more research is done and it is used responsibly

REFERENCES

[1]. F. Sanchez and K. Sobolev, "Nanotechnology in concrete – A review," *Construction and Building Materials*, vol. 24, no. 11, pp. 2060–2071, 2010.

[2]. A. Nazari and S. Riahi, "The effects of TiO_2 nanoparticles on physical, thermal and mechanical properties of concrete," *Materials Science and Engineering A*, vol. 528, no. 3, pp. 356–364, 2011.

[3]. K. Poonia, P. Kansara, and S. Choudhary, "Use of GIS mapping for environmental protection in Rajasthan – A review," *International Advanced Research Journal in Science, Engineering and Technology (IARJSET)*, vol. 10, no. 5, pp. 812–814, 2023.

[4]. S. Choudhary, H. Shrimali, and J. Shreemali, "Stages and challenges in implementation of smart city project, Udaipur," *International Journal of Innovative Science and Research Technology (IJISRT)*, vol. 8, no. 5, pp. 2451–2456, May 2023.

[5]. K. Sobolev and M. Gutiérrez, "How nanotechnology can change the concrete world," *American Ceramic Society Bulletin*, vol. 84, no. 10, pp. 14–17, 2005.

[6]. S. Choudhary, H. Shrimali, and J. Shrimali, "Techno-managerial phases and challenges in development and implementation of Smart City Udaipur," in *Proc. 4th Int. Conf. Emerging Trends in Multi-Disciplinary Research*, 2023. [Online]. Available: https://www.researchgate.net/publication/370402952

[7]. S. Choudhary, M. Hasan, M. Suthar, A. Saraswat, and H. Lashkar, "Design features of eco-friendly home for sustainable development," *International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering*, vol. 10, no. 1, pp. 88–93, 2022.

[8]. S. Choudhary, S. Chouhan, M. Jain, K. Panchal, and Y. Bhardwaj, "Development of rain water harvesting system through national highway profiles by using GIS and field survey," *SSRN Electronic Journal*, Paper No. 3348303, 2019.

[9]. L. P. Singh, S. R. Karade, S. K. Bhattacharyya, M. M. Yousuf, and S. Ahalawat, "Beneficial role of nanosilica in cement-based materials – A review," *Construction and Building Materials*, vol. 47, pp. 1069–1077, 2013.