Nanotechnology In Concrete Engineering: Unravelling The Impact Of Nano Particles On Mechanical Strength And Durability

Haseem Baig[1*], Dr.Anduri[2]

[1*]Research Scholar, Bir Tikendrajit University
[2]Sreenivasulu, Research Supervisor, Bir Tikendrajit University

***Corresponding Author:-** Haseem Baig
*Research Scholar, Bir Tikendrajit University

Abstract:
The integration of nanotechnology into concrete engineering has emerged as a revolutionary approach to enhance the mechanical strength and durability of concrete structures. This paper investigates the profound effects of nano particles on the key properties of concrete, focusing on their potential to mitigate common challenges such as cracking, deterioration, and reduced lifespan. The study delves into the unique characteristics of nano particles, exploring their ability to modify the microstructure of concrete at the nanoscale. Various types of nano materials, including but not limited to nano silica, nano alumina, and carbon nanotubes, are examined for their role in improving the overall performance of concrete.Furthermore, the paper explores the mechanisms through which nano particles influence the mechanical properties of concrete, such as compressive strength, flexural strength, and tensile strength. Special attention is given to the interactions between nano particles and cementitious materials, as well as their impact on the hydration process.Durability is a critical aspect of concrete structures, and the paper investigates how nano particles contribute to increased resistance against factors such as corrosion, freeze-thaw cycles, and chemical attacks. The potential benefits of enhanced durability include extended service life, reduced maintenance costs, and improved sustainability.

Introduction:
The use of concrete as a primary construction material has been integral to the development of infrastructure worldwide. Concrete's versatility, strength, and durability make it a cornerstone in the construction industry. However, the constant evolution of construction demands, coupled with the need for sustainable and resilient structures, has prompted researchers and engineers to explore innovative ways to enhance the properties of concrete.In this context, nanotechnology has emerged as a cutting-edge field with the potential to revolutionize traditional construction materials. Nanoparticles, characterized by their size at the nanoscale (1 to 100 nanometres), exhibit unique properties that can be harnessed to address the limitations of conventional concrete. The exploration of nanomaterials in the realm of concrete technology has gained prominence as researchers seek solutions to improve both the mechanical strength and durability of concrete structures.
The mechanical properties of concrete, including compressive strength, tensile strength, and flexural strength, are crucial factors influencing the structural integrity of buildings and infrastructure. At the same time, the durability of concrete is essential for its long-term performance in various environmental conditions. Challenges such as corrosion, alkali-silica reaction, and sulphate attack have driven the search for innovative approaches to enhance the resilience of concrete structures.The integration of nano-sized particles, such as silica fume, titanium dioxide, and carbon nanotubes, into concrete formulations presents a novel avenue for achieving these objectives. The small size and high surface area of nanoparticles enable them to interact with cementitious materials at the molecular level, influencing the hydration process and modifying the microstructure of concrete. This interaction leads to improvements in mechanical strength and the creation of protective barriers that enhance durability.As the demand for sustainable and eco-friendly construction practices grows, the role of nanotechnology in concrete becomes increasingly significant. By refining the properties of concrete at the nanoscale, researchers aim to contribute to the development of structures that are not only robust and durable but also environmentally friendly. The exploration of nano-enhanced concrete aligns with the broader goals of sustainable development, aiming to create infrastructure that withstands the test of time while minimizing its impact on the environment.
In this backdrop, ongoing research and advancements in the integration of nano-sized particles into concrete formulations hold the promise of transforming the construction industry. The synergy between nanotechnology and concrete technology opens new possibilities for creating structures that meet the evolving needs of society, balancing strength, durability, and sustainability in a rapidly changing world.

Importance Of Enhancing Mechanical and Durability Properties:
Enhancing the mechanical and durability properties of construction materials, particularly in the context of concrete, is of paramount importance for the sustainable development and longevity of infrastructure. The mechanical properties, including compressive strength, tensile strength, and flexural strength, are critical factors determining the structural

integrity of buildings and other civil engineering structures. Improved mechanical properties ensure that structures can withstand various loads, environmental stresses, and potential external forces, thereby enhancing their overall safety and performance.

Durability, on the other hand, is a key aspect influencing the service life of structures. Concrete structures are often subjected to harsh environmental conditions, chemical exposure, and physical wear. Enhancing durability properties, such as resistance to corrosion, sulphate attack, and freeze-thaw cycles, is essential for preventing deterioration over time. Durable structures require less frequent maintenance and repair, reducing life-cycle costs and minimizing the environmental impact associated with ongoing construction activities.

Moreover, the importance of enhancing mechanical and durability properties extends beyond immediate structural considerations. In the face of evolving construction demands, the integration of advanced materials and technologies becomes essential for creating sustainable and resilient infrastructure. Enhanced properties not only contribute to the longevity of individual structures but also have broader implications for the overall efficiency and environmental impact of the construction industry.The pursuit of improved mechanical and durability properties is closely tied to the goal of developing structures that can withstand the challenges posed by climate change, population growth, and urbanization. As urban areas expand, there is an increasing need for infrastructure that can endure diverse environmental conditions and resist the detrimental effects of aging. Additionally, with a growing emphasis on sustainable construction practices, materials with enhanced properties contribute to the creation of eco-friendly structures, aligning with global efforts to reduce the environmental footprint of the construction industry.

In summary, the importance of enhancing mechanical and durability properties in construction materials, particularly concrete, lies in the pivotal role these properties play in ensuring the safety, longevity, and sustainability of infrastructure. By continually advancing the performance characteristics of construction materials, engineers and researchers contribute to the creation of resilient and environmentally responsible structures that can meet the challenges of the present and future.

Enhancing Mechanical Properties:

Within the realm of nanotechnology in construction materials, a pivotal focus revolves around the substantial augmentation of mechanical properties. The integration of nano-sized particles introduces a transformative dimension to the traditional composition of construction materials, unlocking a spectrum of opportunities for reinforcement and improvement. Key nanomaterials, such as silica fume, carbon nanotubes, and graphene, play instrumental roles in this enhancement process.

At the core of this transformation is the unique interplay between nanoparticles and the cementitious matrix. Nano-sized additives, due to their significantly increased surface area, engage in heightened interactions with the surrounding materials at the molecular level. This interaction instigates a cascade of effects that fundamentally alters the material's mechanical behaviour. For instance, the addition of silica fume, with its pozzolanic properties, accelerates the formation of additional hydration products, refining the microstructure and bolstering the compressive strength of the material.

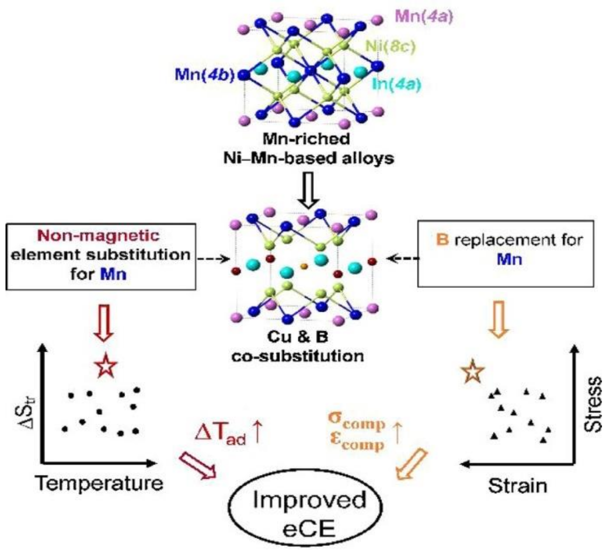

Fig 1: Mechanical Properties

Carbon nanotubes, on the other hand, act as reinforcing elements, intricately woven into the matrix, and contributing to improved tensile strength and ductility. The inherent strength and conductivity of carbon nanotubes make them particularly adept at fortifying the structural integrity of the material while introducing desirable electrical and thermal properties. Similarly, graphene, a single layer of carbon atoms arranged in a hexagonal lattice, offers exceptional strength and electrical conductivity, further elevating the mechanical capabilities of the construction material.

This pursuit of enhancing mechanical properties through nanotechnology goes beyond sheer strength metrics. The flexibility introduced by nanomaterials allows for the development of materials that can better withstand dynamic loads and deformations, thereby expanding the scope of application for these advanced construction materials. The refinement of the microstructure at the nanoscale not only enhances the material's inherent properties but also contributes to a more homogenous and dense matrix, minimizing vulnerabilities and increasing overall robustness.

In essence, the incorporation of nanotechnology to enhance mechanical properties signifies a departure from conventional material limitations, propelling construction materials into a realm of heightened performance and versatility. As research in this field advances, the promise of structures characterized by unprecedented strength, durability, and adaptability becomes increasingly tangible, paving the way for a new era in construction technology.

Strength, Flexibility, and Beyond:

Within the realm of nanotechnology's impact on construction materials, a significant focal point revolves around the profound enhancements it brings to the mechanical properties of these materials. The introduction of nano-sized additives, such as silica fume, carbon nanotubes, and graphene, marks a departure from conventional approaches, offering a pathway to redefine the very essence of material strength and flexibility. At the heart of this transformation is the interaction between nanoparticles and the cementitious matrix at the nanoscale. This interaction leads to a series of structural modifications, resulting in materials that exhibit superior mechanical performance.

The integration of nano-sized particles brings about a refinement in the microstructure of construction materials. This refinement, occurring at dimensions unimaginably small, translates into materials with heightened tensile strength, compressive strength, and flexibility. The nano-sized additives act as reinforcements, fortifying the structure and bridging the gaps within the material matrix. Carbon nanotubes, for instance, form a network within the material, enhancing its tensile strength in a manner akin to the reinforcement of steel in traditional concrete.

Moreover, the advancements in nanotechnology extend beyond conventional mechanical properties. The manipulation of materials at the nanoscale allows for tailoring properties such as hardness, ductility, and elasticity with unprecedented precision. This opens avenues for creating materials that not only withstand the rigors of structural loads but also possess adaptive qualities, responding to dynamic stresses and deformations in ways previously unattainable.

In the quest for stronger and more flexible construction materials, nanotechnology stands as a catalyst for innovation. By harnessing the unique characteristics of nanoparticles, researchers and engineers are pushing the boundaries of material science, paving the way for a new generation of construction materials that go beyond the limitations of traditional counterparts. As the exploration of nanotechnology in construction materials progresses, the prospect of structures that are not only robust and durable but also adaptable to evolving challenges becomes increasingly tangible.

Improving Durability and Longevity:

Nanotechnology in construction materials has emerged as a pivotal avenue for significantly enhancing the durability and longevity of structures. The challenges posed by environmental factors, such as corrosion, alkali-silica reaction, and harsh weather conditions, have long been focal points in the quest for more resilient building materials. The integration of nanoparticles into construction matrices facilitates the creation of protective mechanisms at the nanoscale. These protective barriers act as shields, mitigating the ingress of harmful substances and preventing the onset of deterioration processes.

One key aspect of improving durability through nanotechnology is the ability to tailor materials to withstand specific environmental stressors. For instance, the incorporation of nano-sized silica fume or titanium dioxide particles can enhance the resistance of concrete to chemical attacks and UV radiation. This not only safeguards the structural integrity of the material but also contributes to the overall longevity of the constructed infrastructure.

Furthermore, nanotechnology enables the modulation of the internal microstructure of materials, resulting in reduced porosity and improved cohesion. This refinement at the nanoscale contributes to enhanced resistance against freeze-thaw cycles, a critical factor in regions with fluctuating temperatures. The prevention of microcracking and damage due to cyclic freezing and thawing events is instrumental in extending the service life of structures, particularly in colder climates.

In the realm of reinforcing materials, such as carbon nanotubes and nanoparticles, the incorporation of these elements can augment the mechanical properties of composites, contributing to the longevity of structures subjected to dynamic loads and stresses. This reinforcement mechanism at the nanoscale provides added strength and durability, reducing the likelihood of structural failure over time.

The advancements in nanotechnology not only address current durability challenges but also hold promise for future innovations. As research progresses, the development of self-healing materials at the nanoscale, capable of autonomously repairing cracks and damage, presents a groundbreaking prospect for further extending the life expectancy of structures.

In essence, the application of nanotechnology in improving the durability and longevity of construction materials represents a paradigm shift in the construction industry, offering solutions that go beyond conventional approaches and open new horizons for the creation of enduring and resilient infrastructure.

Guarding Against Environmental Challenges:

In the realm of construction materials, the integration of nanotechnology introduces a transformative approach to guarding against environmental challenges that often undermine the longevity and structural integrity of conventional materials. One key aspect where nanotechnology excels is in providing solutions to combat corrosion, alkali-silica reaction, and other forms of deterioration induced by environmental factors. Nanoparticles, when strategically incorporated into construction materials, form protective layers at the nanoscale, acting as a shield against the ingress of harmful agents.

Corrosion, a pervasive issue particularly in structures exposed to aggressive environments, poses a significant threat to the durability of conventional materials. Nanoparticles, such as nano-silica, nano-titania, or nano-zinc oxide, can be engineered to create a barrier that limits the penetration of corrosive elements, thereby significantly reducing the risk of corrosion-related damage. This not only enhances the structural integrity of the material but also prolongs the service life of the entire structure.

Similarly, the alkali-silica reaction, a chemical process that can lead to cracking and deterioration of concrete, is mitigated through the incorporation of nanoparticles. The nanoscale interactions between these particles and the cementitious matrix contribute to a more compact and less porous microstructure, reducing the susceptibility of the material to deleterious reactions.

Furthermore, nanotechnology aids in enhancing resistance to various environmental stresses, including freeze-thaw cycles and chemical attacks. The finely tuned properties of nanoparticles allow for the creation of materials that can withstand these challenges, ensuring structural stability even in harsh climates.

The application of nanotechnology in guarding against environmental challenges is not just a reactive measure but also a proactive strategy. By addressing these challenges at the nanoscale, construction materials become more resilient and less prone to degradation over time. This proactive approach aligns with the broader goals of sustainable construction, where the emphasis is not only on building structures that last but also on minimizing the environmental impact associated with maintenance, repair, and replacement. As the exploration of nanotechnology in construction materials continues, the potential for developing materials that effectively guard against environmental challenges is a promising avenue that holds significant implications for the future of resilient and sustainable infrastructure.

Methodology:

Concrete mix design is a systematic process that involves selecting the appropriate proportions of ingredients to create a concrete mix with desired properties and performance characteristics. This crucial phase in concrete construction ensures that the resulting concrete meets the structural and durability requirements of a specific project. The mix design process integrates several key considerations, including the selection of materials, the determination of proportions, and the optimization of various properties to achieve the desired strength, workability, and durability.

Materials Selection:

The first step in concrete mix design involves selecting the materials that constitute the mix. This includes cement, aggregates, water, and often supplementary cementitious materials (SCMs) such as fly ash or silica fume. The choice of materials depends on factors such as project requirements, environmental conditions, and availability of local resources.

Proportioning:

Once the materials are selected, the next step is to determine the proportions in which they will be combined. The goal is to achieve a well-graded and workable mix that balances strength and durability. The proportions are influenced by factors such as the desired compressive strength, water-cement ratio, and specific project conditions.

Water-Cement Ratio:

The water-cement ratio is a critical factor in mix design, influencing the strength and durability of the concrete. It represents the amount of water relative to the cement content and plays a crucial role in the hydration process. Balancing the need for workability with the requirement to minimize water content is essential for optimizing the mix.

Workability and Consistency:

Workability is a key consideration in mix design, as it affects the ease of placement and compaction. Adjustments to the mix, such as the use of admixtures or alterations in aggregate gradation, may be made to achieve the desired workability. The consistency of the mix is also evaluated to ensure it meets project specifications.

Strength Requirements:

The required compressive strength of the concrete is a fundamental parameter in mix design. It is determined based on the structural demands of the project and is achieved by adjusting the mix proportions, particularly the amount of cementitious material.

Durability Considerations:

Durability is a critical aspect of mix design, addressing the concrete's ability to resist environmental factors such as freeze-thaw cycles, chemical exposure, and abrasion. The incorporation of supplementary materials, proper curing practices, and attention to specific durability requirements contribute to enhancing the durability of the mix.

Testing and Adjustments:
The final step in the mix design process involves testing the freshly mixed and hardened concrete to validate its properties. Adjustments to the mix may be made based on testing results to ensure that the concrete meets the specified requirements for strength, workability, and durability.

3. Testing parameters

Concrete testing is a comprehensive process that involves evaluating various parameters to ensure the material's quality, performance, and durability. These testing parameters are crucial for assessing the suitability of concrete mixes for specific applications and for verifying compliance with design and industry standards.

Compressive Strength Testing:
Compressive strength testing is a fundamental parameter that assesses the ability of concrete to withstand axial loads. It involves subjecting cylindrical or cubic specimens to compression forces, providing insights into the material's load-bearing capacity.

Tensile Strength Testing:
Tensile strength testing is essential for evaluating how well concrete resists forces attempting to pull it apart. Although concrete is inherently weak in tension, testing methodologies, such as the splitting tensile strength test, provide valuable information for structural design.

Flexural Strength Testing:
Flexural strength testing measures a concrete's ability to withstand bending or deformation under applied loads. This parameter is crucial for designing elements like beams and slabs subjected to flexural forces.

Shear Strength Testing:
Shear strength testing assesses a concrete's resistance to forces acting parallel to its surface. Testing methods, including the direct shear test, help determine the material's suitability for applications where shear forces are significant.

Elastic Modulus Testing:
Elastic modulus testing quantifies the stiffness of concrete and its ability to deform elastically under stress. This parameter is crucial for calculating deformations and predicting the material's behaviour under various loading conditions.

Poisson's Ratio Testing:
Poisson's ratio testing is conducted to determine the lateral contraction of concrete when subjected to axial deformation. Understanding this ratio is essential for analysing structural deformations and stability.

Durability Testing:
Durability testing involves assessing various properties related to the material's resistance to environmental factors. This includes tests for chemical resistance, freeze-thaw resistance, abrasion resistance, and resistance to sulphates, chlorides, and other aggressive substances.

Permeability Testing:
Permeability testing evaluates the ability of concrete to resist the penetration of water and other liquids. Low permeability is desirable to prevent the ingress of moisture and aggressive substances that can lead to deterioration.

Shrinkage Testing:
Shrinkage testing measures the reduction in volume as concrete hardens and loses moisture. Testing methodologies, such as the drying shrinkage test, are essential for preventing cracking and ensuring the material's long-term stability.

Setting Time Testing:
Setting time testing determines the time it takes for concrete to change from a plastic to a solid state. Both initial and final setting times are critical parameters for proper construction practices and are influenced by factors such as temperature and mix composition.

Workability Testing:
Workability testing assesses the ease with which concrete can be mixed, transported, placed, and compacted. Consistent workability is crucial for achieving uniformity in construction and ensuring proper consolidation without segregation.

Self-compacting concrete (SCC):
Jalal et al. conducted a study in which, different properties of superior execution self-compacting concrete (HPSCC) containing silica smolder (SF), silica nanoparticles (NS), and class F fy debris (FA) were researched. The water-to-binder ratio remained unchanged at 0.38 for NS, SF, and SF+NS, respectively, as Portland cement was replaced by a percentage of 2%, 10%, and 10%+2%. Rheological properties of HPSCC were estimated by V-pipe (s) and rut stream (mm). Results

showed that the expansion of 2% NS affected the functionality, while the expansion of FA expanded usefulness at various rates. V-pipe test results showed the least fow time for 10% and 15% expansion of FA which was 2.5 s and the most noteworthy for 2% expansion of NS which was 12 s.

Joshaghani et al. showed that the downturn stream width of SCC containing different kinds of nanoparticles displays a diminishing pattern because of the little molecule size of nanomaterials and their propensity to drink a higher measure of water. However, the V-funnel and L-box behaviors of SCC samples were enhanced by the addition of nanoparticles of up to 3%. For the higher measures of nanoparticles, the functionality of SCC diminished because of the development of a gooey combination. Flexural strength of HPSCC for 10% SF and 2% NS at cover measures of 400 and 500 kg/m3 , expanded by 23.5%, 58.9%, 47% and 20%, 52%, 52% at 7, 28, and 90 days, separately. Some researchers who have studied silica nanoparticles have provided the following explanation for this rise in flexural strength:

(a). The incorporation of nanoparticles contributes significantly to the filling of the cement pores, resulting in increased strength.

(b). Uniform scattering of little satisfied of silica nanoparticles in the concrete glue has driven the nanoparticles to associate with concrete hydrate emphatically, and the high movement of nanoparticles further develops the hydration cycle which then brings about strength augmentation of the concrete mortar.

(c). Limitation of the advancement of precious stones by the nanoparticles that assume an agreed part in the strength of the network. According to Langaroudi and Mohammedi, the modulus of elasticity of SCC was increased when NC was added to the cement by weight. Jalal and co. discovered that the splitting tensile strength increases when TiO2 nanoparticles up to 4% by weight are added, but that strength decreases as more nanoparticles are added. The splitting tensile strength increases as a result of the increased crystalline Ca (OH)2 at the early age of hydration, as reported by the authors, when up to 4% of TiO2 nanoparticles are replaced. The discoveries of Niewiadomski et al. show ideal impacts of various sorts of nanoparticles like SiO2, TiO2, and Al2O3 on the improvement of mechanical properties of SCC. The compressive strength of SCC was upgraded upon the expansion of nanoparticles. On account of fexural strength, the substantial examples containing 0.5% of nano-SiO2 and nano-TiO2 had higher strength values than the reference test. The writers likewise expressed that all SCC tests delivered with the expansion of nanoparticles had lower upsides of fexural strength at 90 days; in any case, they didn't make sense of the explanations for having lower strength. The review directed by Dolatabad et al. on the impacts of various sorts of nanomaterials like nanoSiO2, nano-TiO2, and nano-Al2O3 uncovered the upgraded corrosive obstruction and water porousness of lightweight SCC. A slope in the water porousness values was seen upon the expansion of nanoparticles. At curing ages of 28 and 56 days, respectively, the authors reported a reduction of 15% and 18% in the SCC sample's water penetration depth with NS containing 2% by weight. A less permeable structure was created as the number of nanoparticles increased. The expansion of nanoparticles worked on the obstruction of the combination against the acidic medium since all SCC tests created with nanoparticles had less weight reduction contrasted with the reference test following 70 days of drenching in an acidic vehicle of 5% H2SO4 arrangement.

At the point when Fig. is seen, the SCC samples with the lowest rate of weight loss are those with 4% nano-TiO2. In the review led by Jalal et al., it was seen that chloride penetrability diminished as how much TiO2 nanoparticles expanded up to an ideal level which was 4% in this review. Past 4%, chloride porousness somewhat expanded because of the more vulnerable pore construction of cement at high measures of TiO2 nanoparticles. The writers made sense of this frail pore structure and expressed that it very well may be credited to the space between nanoparticles which gets smaller as how much nanoparticles increments; this causes a diminishing in the precious stone amount since there isn't sufficient room for Ca(OH)2 gems to grow up; this outcomes in shrinkage and expansion in creep of the concrete grid; furthermore, consequently, feeble pore construction of concrete lattice prompts an expansion in the chloride entrance. In a review done by Quercia et al., it was presumed that consolidation of NS along with air acquainted specialist with concrete profoundly evolved obstruction against freezing and defrosting. The creators ascribed this advancement to the development of C-S-H gel and refined pore structure that impeded water entrance to concrete, so concrete became impervious to different temperatures near the substantial surface. Perceptions above demonstrate that the joining of nanoparticles can infer an ideal impact on the properties of SCC. The nanoparticles' effect on the particle size, which fills the cement matrix's pores and results in a denser structure, is responsible for the improved properties. When considering the permeability of concrete, this is an important consideration because the addition of nanoparticles reduces the number of capillary pores, preventing water and chemical substances from damaging the concrete. Therefore, worked on mechanical and toughness related properties can be gotten. Be that as it may, the consolidation of nanoparticles is seen to adversely influence the usefulness execution of SCC, because of the development of a thick construction inferable from the better size of nanoparticles. How much nanoparticles may differ starting with one concentrate then onto the next; subsequently, various outcomes can be accomplished. Enhancements on the measures of nanoparticles can give a superior outline of the ideal substance of the nanoparticles to be utilized to work on the exhibition of SCC.

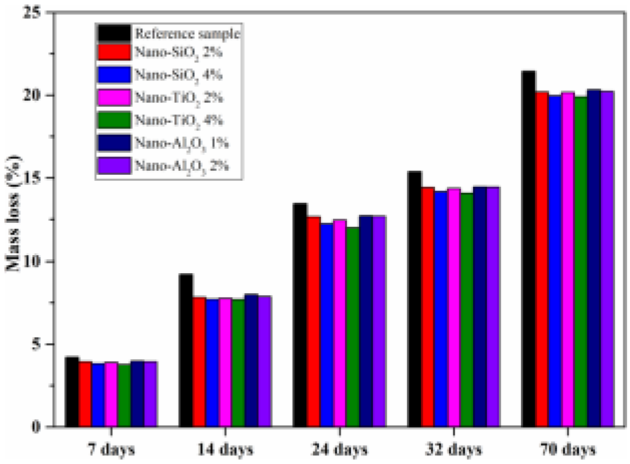

Fig. 2: Weight loss (%) versus time for SCC samples exposed to 5% of H2SO4 solutions

Conclusion:

The incorporation of nanoparticles, such as graphene or carbon nanotubes, in concrete has demonstrated a notable enhancement in abrasion resistance, a critical mechanical property for structures subjected to wear and friction. The nanomaterials function as reinforcing agents within the concrete matrix, forming a robust and durable network that effectively resists abrasion-induced damage. The increased surface hardness and improved interfacial bond strength between nanoparticles and the cementitious matrix contribute to the material's ability to withstand abrasive forces. This heightened resistance to abrasion is particularly advantageous in high-traffic areas, industrial floors, and pavements where concrete surfaces are exposed to continuous wear and tear. The application of nanoparticle-enhanced concrete, showcasing superior abrasion resistance, not only extends the service life of structures but also reduces maintenance requirements, offering a more sustainable and cost-effective solution in various construction applications.

References:

1. Chithra, S., Senthil Kumar, S. R. R., & Chinna Raju, K. (2016). The effect of Colloidal Nano-silica on workability, mechanical and durability properties of High-Performance Concrete with Copper slag as partial fine aggregate. Construction and Building Materials, 113, 794–804.
2. Du, H., & Pang, S. D. (2019a). High performance cement composites with colloidal nano silica. Construction and Building Materials, 224, 317–325.
3. Ganesh, P., &Reheman, M. M. S. (2016). Effect of nano silica on durability and mechanical properties of high-strength concrete. 68(5), 229–236.
4. Gowda, R., Narendra, H., Naga bushan, B. M., Rangappa, D., & Prabhakara, R. (2017). Investigation of nano-alumina on the effect of durability and micro-structural properties of the cement mortar. Materials Today: Proceedings, 4(11), 12191–12197.
5. Haruehansapong, S., Pulngern, T., &Chucheepsakul, S. (2014). Effect of the particle size of nano silica on the compressive strength and the optimum replacement content of cement mortar containing nano-SiO2. Construction and Building Materials, 50, 471– 477.
6. Isfahani, F. T., Redaelli, E., Lollini, F., Li, W., & Bertolini, L. (2016). Effects of Nano silica on Compressive Strength and Durability Properties of Concrete with Different Water to Binder Ratios. 2016.
7. Jaber, A., Gorgis, I., & Hassan, M. (2018). Relationship between splitting tensile and compressive strengths for self-compacting concrete containing nano- and micro silica. 02013, 1–8.
8. Jalal, M., Pouladkhan, A., Harandi, O. F., & Jafari, D. (2015). Comparative study on effects of Class F fly ash, nano silica and silica fume on properties of high performance self-compacting concrete. In Construction and Building Materials (Vol. 94, pp. 90–104).
9. Javad, A. S., Sahar, B., & Omid, A. (2018). The Effect of Recycled Concrete Aggregates and Metakaolin on the Mechanical Properties of Self-Compacting Concrete Containing Nanoparticles. Iranian Journal of Science and Technology, Transactions of Civil Engineering.
10. Kumari, K., Preetha, R., Ramachandran, D., & Vishwakarma, V. (2016). ScienceDirect Nanoparticles for enhancing mechanical properties of fly ash concrete. Materials Today: Proceedings, 3(6), 2387–2393.
11. Li, L. G., Zheng, J. Y., Zhu, J., & Kwan, A. K. H. (2018). Combined usage of micro silica and nano-silica in concrete: SP demand, cementing efficiencies and synergistic effect. Construction and Building Materials, 168, 622–632.
12. . Liu, J., Li, Q., & Xu, S. (2015). Influence of nanoparticles on fluidity and mechanical properties of cement mortar. Construction and Building Materials, 101, 892–901.
13. Madandoust, R., Mohseni, E., Mousavi, S. Y., &Namnevis, M. (2015). An experimental investigation on the durability of self-compacting. CONSTRUCTION & BUILDING MATERIALS, 86, 44–50.

14. Massana, J., Reyes, E., Bernal, J., León, N., & Sánchez-espinosa, E. (2018). Influence of nano- and micro-silica additions on the durability of a high-performance self-compacting concrete. Construction and Building Materials, 165, 93–103.
15. Mohseni, E., Miyandehi, B. M., Yang, J., & Yazdi, M. A. (2015). Single and combined effects of nano-SiO2, nano-Al2O3 and nano-TiO2 on the mechanical, rheological and durability properties of self-compacting mortar containing fly ash. Construction and Building Materials, 84, 331–340.
16. Mondal, P., Shah, S. P., Marks, L. D., &Gaitero, J. J. (2010). Comparative Study of the Effects of Micro silica and Nano silica in Concrete. 2141, 6–9.
17. Mukharjee, B. B., & Barai, S. v. (2014). Influence of Nano-Silica on the properties of recycled aggregate concrete. Construction and Building Materials, 55, 29–37.
18. Nazari, A., & Riahi, S. (2010). The effect of TiO2 nanoparticles on water permeability and thermal and mechanical properties of high strength self-compacting concrete. Materials Science and Engineering A, 528(2), 756–763.
19. Nejad, F. M., Tolouei, M., Nazari, H., & Naderan, A. (2018). Effects of Calcium Carbonate Nanoparticles and Fly Ash on Mechanical and Permeability Properties of Concrete Effects of Calcium Carbonate Nanoparticles and Fly Ash on Mechanical and Permeability Properties of Concrete.
20. Palla, R., Karade, S. R., Mishra, G., Sharma, U., & Singh, L. P. (2017). High strength sustainable concrete using silica nanoparticles. Construction and Building Materials, 138, 285–295.
21. Paul, S. C., van Rooyen, A. S., van Zijl, G. P. A. G., & Petrik, L. F. (2018). Properties of cement-based composites using nanoparticles: A comprehensive review. Construction and Building Materials,189,1019–1034.