



Research Article

Mechanical and durability study of nano-SiO₂ and nano-TiO₂ on fiber reinforced concrete

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ABSTRACT

This work presents the results of an experimental investigation into the strength and durability properties of fiber-reinforced concretes that have polypropylene (PP) fibers added to the concrete by volume and nano-SiO₂ (silicon dioxide) and nano-TiO₂ (titanium dioxide) used as partial substitutes for cement. Nano-SiO₂ and nano-TiO₂ particles used ranged in size from 40 nm to 400 nm. The specimens were cast using cement blended nano-SiO₂ and nano-TiO₂ percentages of 1%, 2%, 3%, and 4% by weight of cement. M55 grade concrete was employed for the casting process. The addition of PP fibers to the concrete was 0.5% by volume. The specimens underwent a battery of mechanical tests, including microstructural testing, compression testing, split tensile strength testing, and rupture modulus testing. Furthermore, tests for durability factors such as porosity, sorptivity, and degradation were conducted, and the findings are presented. Flexural strength of 2% nano-SiO₂ or nano-TiO₂ increased by 8.09% and 6.89% and porosity decreased by 16.13% and 13.92% with respect to the reference concrete. By comparing the outcomes, it was shown that the inclusion of 0.5% PP fibers and 2% nano-SiO₂ or nano-TiO₂ improved the mechanical qualities, but this was followed by a decrease in strength. The findings demonstrated that 2% nano-SiO₂ combined with 0.5% PP fiber had a greater mechanical strength than 2% nano-TiO₂.

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1. Introduction

Concrete is the most often used construction material worldwide due to its reasonable cost and durability. One of the primary ingredients of concrete, cement, produces significant CO₂ emissions during its production –roughly two billion tons annually, or about 7% of all CO₂ emissions on Earth– during the process (Shi et al. 2011). It is projected that cement production will have grown to over six billion tons per year by 2060. (Pacheco-Torgal et al. 2013). Severe measures have been implemented to reduce the harmful effects of cement on the environment and climate change. There have been a lot of experiments done on finding cement substitutes, like adding pozzolanas and nanoparticles. It would be more accurate

to refer to nanoparticles as recently developed concrete additives. Because of their strong reactivity and large area of coverage, nanoparticles are generally employed in cement-based materials not only as additives but also as a substitute for cement to improve certain mechanical and durability-related properties. Over the past ten years, nanotechnology has garnered a lot of attention (Reches 2018; Kim et al. 2015). The use of nanoparticles in cement-based materials has been the subject of much research since their inception. Given their physical impacts (filling and nucleation effects) and chemical reactivity, nanoparticles are known to significantly improve the performance of cement-based materials (Murad 2021; Feng et al. 2023; Luo et al. 2023). For usage in cement-based materials, nano-SiO₂, nano-Al₂O₃, nano-

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TiO₂, nano-CaCO₃, nano-Fe₂O₃, and nanotubes have all been investigated. Among them, nano-SiO₂ and nano-CaCO₃ are frequently employed. This is because nano-SiO₂ can perform better because to its high specific area and pozzolanic activity, while nano-CaCO₃ is very inexpensive because it is readily available in limestone, chalk, and marble. The addition of nano- and micro limestone shortened the setting time of ultra-high-performance concrete (UHPC), according to this study's investigation of the material's early age properties (Karthikeyan et al. 2020; Karthikeyan and Dhinakaran 2018; Mohseni et al. 2016). Additionally, compared to a sample without any nano limestone, the inclusion of 2.5% to 5% nano-limestone may result in a 35%–74% boost in first day compressive strength. This study looked into how adding 3% nano-SiO₂ to the mass of cementation materials sped up the hardening process and improved the mechanical qualities of UHPC (Yoo et al. 2022; Hakeem et al. 2022; Marcos-Meson et al. 2020). This study looked into how nano-SiO₂ enhanced compressive strength and decreased UHPC workability, particularly at early stage. While nano-CaCO₃ and nano-SiO₂ have the potential to enhance mechanical qualities, their hydration tactics and hardening process are different. Although it is widely acknowledged that adding mineral admixtures, either conventional or nanosized, to concrete increases its strength, numerous researchers have also noted that concrete becomes more brittle as its strength rises (Khotbehsara et al. 2018; Sharmila et al. 2016). The researchers identified inadequate binding and low tensile strength as the causes of this brittleness. Fibers can be added to concrete to aid with the problem of reduced tensile strength. It is widely known that fibers increase the energy absorption capacity of concrete, making it more ductile and resistant to fatigue and impact loads. Numerous studies utilizing fibers in concrete have been conducted; among them, further reports are available for fibers such polymer, carbon, and steel. The impact resistance of concrete containing silica fume and polypropylene fiber—which was added in increments of 0.0%, 0.2%, 0.3%, 0.4% and 0.5% was examined in this study. According to the authors, adding 0.5% of fiber increased the impact resistance. Using silica fume as an ad-

ditional cementitious material, this study conducted experimental investigations using various fibers and combinations in a high strength concrete mix (Sharmila et al. 2016). While previous studies have focused on single nano material with most commonly steel fiber, our study is the first to investigate the effect of nano material such as nano silica and nano titanium dioxide with polypropylene fiber providing new insights into nanotechnology in concrete. Additionally, we employed different tests to know the optimum percentage of nanomaterials which gives best results in the field of concrete technology. The authors employed a total fiber volume fraction of 1% by volume of concrete using both steel and polypropylene fibers separately as well as in a combination of 0.85% steel and 0.15% polypropylene. According to reports, the combined use of polypropylene and steel performed better than either substance utilized alone. The purpose of this work was to conduct a mechanical, durability and microstructural analysis of ultra-high-performance concrete modified with the addition of nanoparticles. Nano-SiO₂ and nano-TiO₂ used in this research as a nano material with a percentage of 1%, 2%, 3% and 4% as a replacement of cement. In addition, to improve the ductile properties, polypropylene fibers were added with a weight percentage of 0.5% of volume of concrete.

2. Experimental Investigation

2.1. Materials

Ordinary Portland Cement (OPC 53 grade) was used in this study, confirming as per IS code 4031 (1996). Natural coarse aggregate and natural river sand (fine aggregate) was used in this study. All required test of aggregate as per the IS 383 (2016) and IS 2386 (1963). In this study nano-SiO₂ and nano-TiO₂ used size range from 40-300 nm provided from Delhi distributors. Polypropylene fiber (PP fiber) of length 12mm used in this research work provided from Kalyani fiber distributor. To gain required flowability Fosroc Conplast SP 430 superplasticizer was used. All experimental test data are showed in Table 1.

Table 1. Experimental test data of materials.

Designation	Results	IS codes
W/C ratio	0.33	-
Cement type	OPC 53	-
Initial setting time of cement	40 min	
Final setting time of cement	382 min	IS 4031:1988
Specific gravity of cement	3.01	
Specific gravity of fine aggregate	2.64	
Specific gravity of coarse aggregate	2.77	IS 383:2016
Coarse aggregate water absorption	0.5	&
Fine aggregate water absorption	0.9	IS 2386:1963
Fine aggregate zone	Zone II	

2.2. Mix proportion

High strength concrete of grade M55 used in this study. Mix proportion ratio 1:1.27:2.52 arrived as per the IS 10262 (2019). Total of 9 mix were constructed such as C1, CS1, CS2, CS3, CS4, CT1, CT2, CT3 and CT4. C1 represented the reference concrete, CS1, CS2, CS3 and CS4 represented the 1%, 2%, 3% and 4% nano-SiO₂

along with 0.5% PP fiber, and CT1, CT2, CT3 and CT4 represented the 1%, 2%, 3% and 4% nano-TiO₂ along with 0.5% PP fiber.

The mixing procedures followed as first dry mixing of nano materials and cement with fibers, after dry mixing all ingredients mixed properly in the drum mixer for 2 to 3 min. Table 2 represented the mix proportion of all concrete mix.

Table 2. Mix proportion data (kg/m³).

Mix ID	C1	CS1	CS2	CS3	CS4	CT1	CT2	CT3	CT4
Cement	477.96	473.18	468.40	463.62	458.85	473.18	468.40	463.62	458.85
Nano-SiO ₂ or Nano-TiO ₂	0.00	4.78	9.56	14.34	19.12	4.78	9.56	14.34	19.12
PP fiber	0.5% of concrete volume								
FA	611.40								
CA	1212.50								
Water	169.21								
SP	1% by weight of cement								

2.3. Testing methods as per standard

The Indian standard code IS 516 (2021) was followed when performing the compressive, split, and flexural tests. Table 3 shows all of the experimental tests, codal provisions, and specimen kinds that were used in the

testing. A specimen's impact resistance can be determined using a variety of techniques, including the drop weight method, instrumented impact, and explosive impact. Many researchers favor the drop weight method over other impact resistance testing techniques because of its ease of use.

Table 3. Test types and IS codes.

Tests	Property	IS codes	Specimen type and size
Strength	Compressive strength		Cubes (150x150x150mm)
	Split tensile strength	IS 516:2021	Cylinders (100x200mm)
	Flexural test		Beams (150x150x700mm)
Chloride attack	Degradation	BS 1881	Cubes (150x150x150mm)
Sorptivity	Water absorption	BS 1881-122	Cubes (150x150x150mm)
Porosity	Volume of pores	-	Cylinders (100x200mm)
Scanning electron microscope (SEM)	Microstructural study	-	Shards of samples

3. Results and Discussion

3.1. Compressive and split tensile strength

Fig. 1 represents the test results of the compressive strength test. CS2 has shown maximum compressive strength above all the mix proportions. CT4 registered a lowest compressive strength in all the mixes. All the concrete mix proportion passed the mean target strength of the concrete and CT4 was minimum. When nano-SiO₂ used in the concrete mix, CS1 and CS2 increased load gradually but after 2% of nano-SiO₂ strength reduces gradually up to CS4. When nano-TiO₂ was used in the concrete mix, strength increased gradually from CT1 to

CT2 but after that strength start decreasing. CS2 compressive strength is 0.76% more than CT4 and 3.48% more than C1.

3.2. Split tensile strength

Larger percentage variation of nano materials cannot increase strength because of the less quantity of cement, which degrade the bindings properties of the concrete and nano materials might be react with other minerals (Karthikeyan et al. 2020; Karthikeyan and Dhinakaran 2018). Fig. 2 represents the tensile strength of the concrete. As PP fiber used in the concrete mix, all concrete mix proportion strength in-

creased from a target strength, but above all CS2 concrete mix showed higher strength. Larger amount of nano material not much affected on the split tensile

strength properties on the concrete. Split tensile strengths of CS2 and CT2 were higher than C1 about 9.93% and 5.31% respectively.

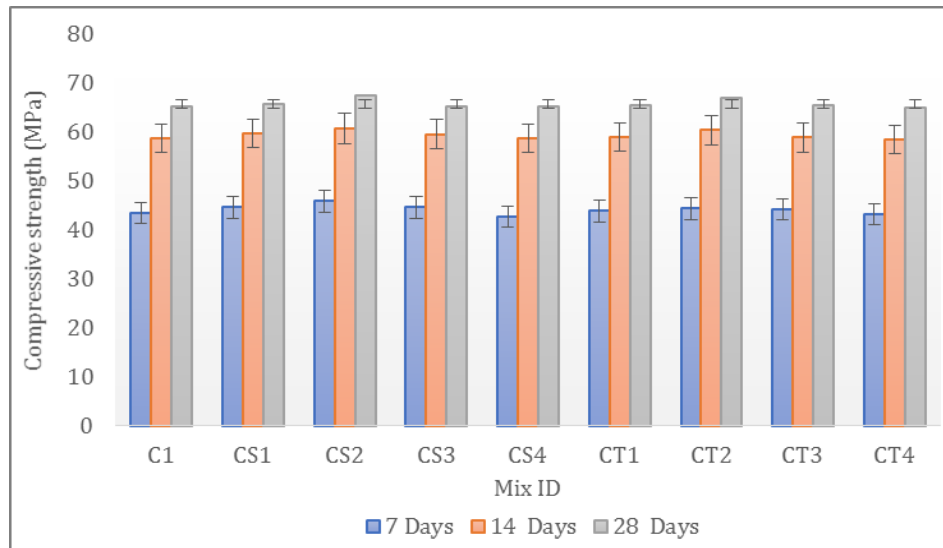


Fig. 1. Compressive strength of the concrete mix at 7, 14 and 28 days.

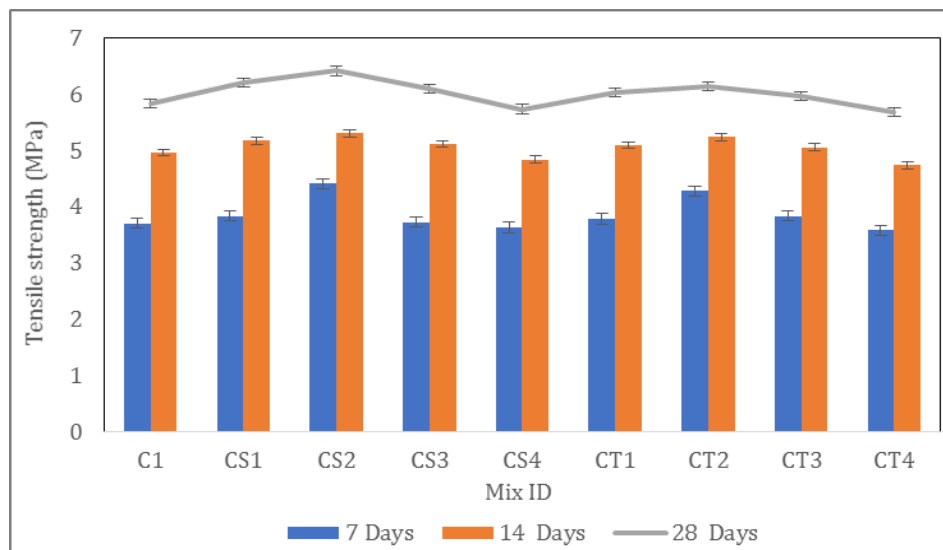


Fig. 2. Split tensile strength of the concrete mix at 7, 14 and 28 days.

3.3. Flexural strength

Fig. 3 represents the flexural strength of the concrete mixes. Flexural strength does not show the higher variation between the concrete mixes. PP fiber works as a reinforcement for the concrete specimens. PP fiber reduces the effects of brittle failures and makes a higher bond between the concrete ingredients and the fiber. CS2 and CT2 flexural strength increased by 8.09% and 6.89% respectively than C1.

3.4. Deterioration of concrete mixes

The elements that originate in the wet atmosphere, such as SO_2 , damage specimens exposed to acidic environments. More importantly, the sulphur compounds that are

present cause more deterioration because they react with C_3A and calcium hydroxide to form calcium sulphur aluminate, or ettringite, or CaSO_4 . Because both of these compounds typically occupy a larger volume than their parent compounds, they disrupt the concrete and cause it to become weak and porous. Concrete mixes with 0.5% PP fiber show a higher compressive strength for all the mixes along with flexural and split tensile strength. According to the data, specimens exposed to bases often show a lower percentage of deterioration than specimens exposed to acids (Son et al. 2023; Chithra et al. 2016; Rong et al. 2015; Razak et al. 2004). The rationale for this is that cement's calcium hydroxide can react with salts or other bases to generate aragonite, brucite, and gypsum. They can impede additional infiltration of the salt water and serve as a transient barrier or protective layer.

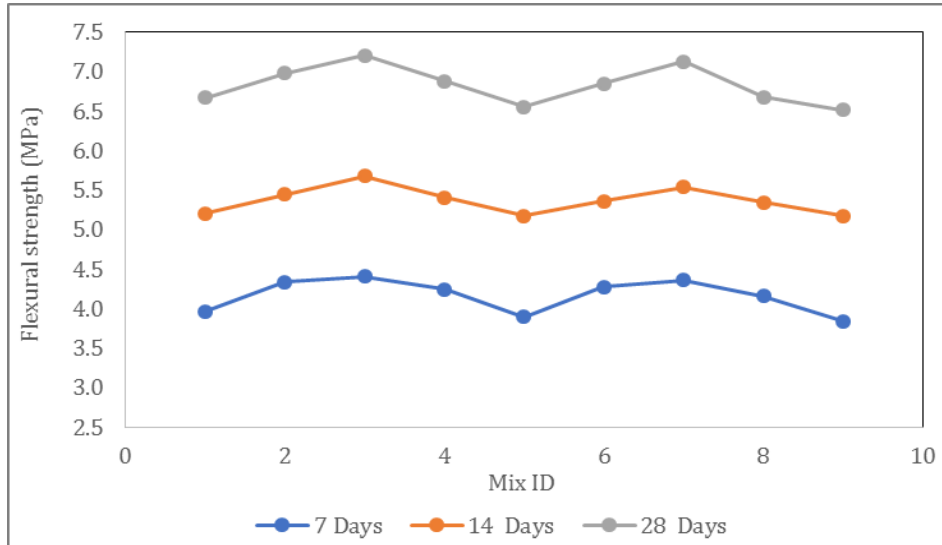


Fig. 3. Flexural strength of the concrete mix at 7, 14 and 28 days.

3.5. Sorptivity

Fig. 4 depicts the water absorption of the concrete mixes. CS2 and CT2 have less water absorption than C1 about 20% and 18.01% respectively. All the concrete mixes of water absorption lie below the 5%. When cement was replaced with nano-SiO₂ and nano-TiO₂ with 0.5% PP fiber, the water absorption gradually decreased up to 2% and then increased. It was discovered that increasing the amount of ultra-fine mineral additives had no effect on the durability characteristics. In the experimental study of Razak et al. (2013), it was found that us-

ing silica fumes as a mineral admixture could result in water absorption of 2.9% and 4.8%. Karthikeyan and Dhinakaran (2018) also noted that specimens containing 9.5% silica fume, 0.5% UFTiO₂, and 0.5% steel fiber showed water absorption of less than 1.5%.

3.6. Porosity

Fig. 5 represents the porosity value of all the concrete mixes. C1, CS4 and CT4 concrete mixes showed the higher porosity than the all-other concrete mixes. CS2 and CT2 were about 16.13% and 13.92% less than the C1.

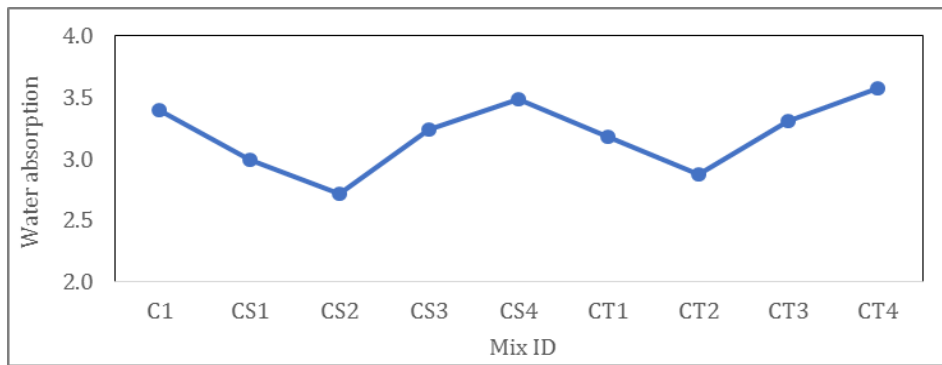


Fig. 4. Sorptivity of the concrete mix.

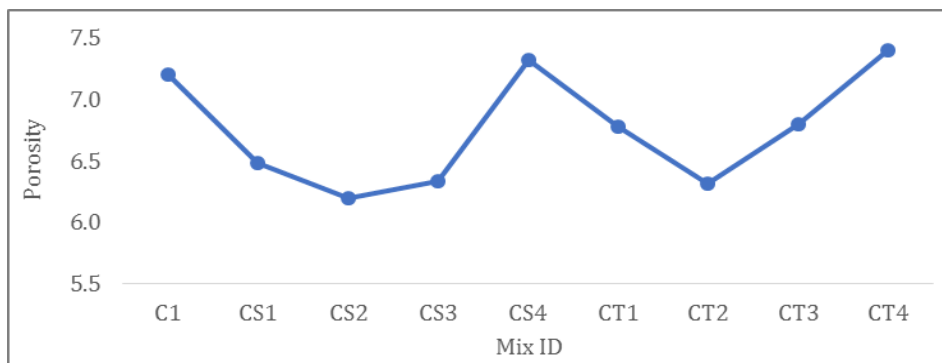


Fig. 5. Porosity of concrete mix.

Using nanoparticles of ZrO_2 , SnO_2 , and $CaCO_3$ in varying dosages along with fly ash, conducted experimental investigations to study the durability characteristics of self-compacting cement mortars and reported that use of the nanoparticles improved the durability properties, diminishing the porosity and chloride permeability. In their experimental efforts. This study revealed that the sorptivity characteristics of high strength concrete were improved by employing ultra-fine GGBS (Kim et al. 2015; Feng et al. 2023; Karthikeyan and Dhinakaran 2018).

3.7. Microstructural imaging

Scanning Electron Microscope (SEM) image of CS2 and CT2 are shown in the Figs. 6 and 7. In Fig. 6, incorporation of nano silica along with PP fiber shows the higher dense structure so as a results in higher mechanical strength and durability with less water absorption and porosity. While clearly observing the SEM image, it shows the less voids and proper bonding between all the ingredients. CS2 shows the higher compressive as well as flexural and split tensile strength. Fig. 7 shows the incorporation of nano- TiO_2 along with the PP fiber, TiO_2 provided a self-cleaning property to the concrete and reduces the pollution due to the CO_2 , SO_2 and NO_x . SEM image of clearly shows that, very less voids available in the CT2 mix compared to C1. CS2 have less voids compared to the CT2.

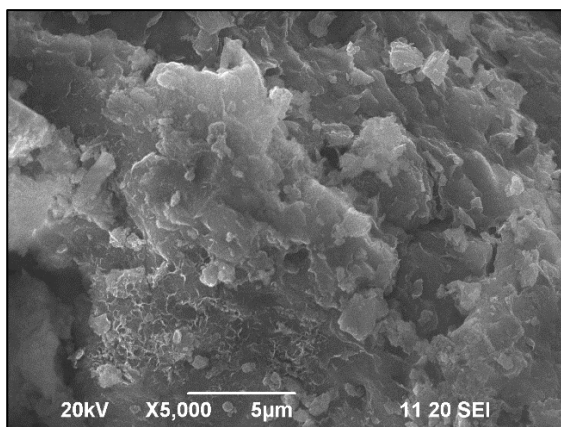


Fig. 6. SEM image of CS2.

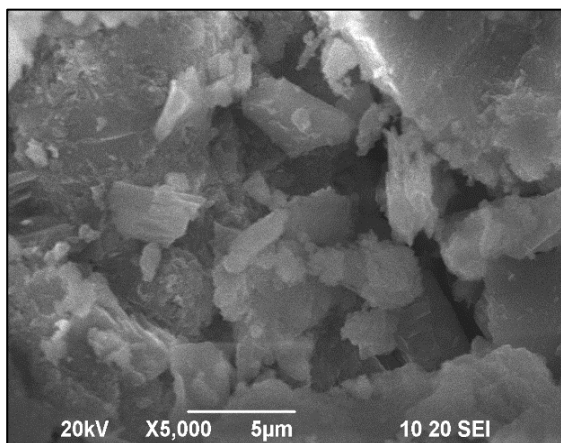


Fig. 7. SEM image of CT2.

4. Conclusions

The following conclusions were drawn from the carried-out experiments:

- All specimens in the fiber-reinforced concrete specimens have exceeded their mean target strength. Notably, the CS2 and CT2 mixes including PP fiber shown excellent performance in both standard water and hostile acid and base environments.
- The strength increased gradually at 1% and 2% of nano- SiO_2 and TiO_2 with 0.5% PP fiber and began to decrease at 3% and 4%; excessive replacement of cement with nano materials with fiber failed to provide suitable bonding.
- CS2 and CT2 flexural strength increased by 8.09% and 6.89% respectively than C1 after 28 days of curing.
- Porosity of CS2 and CT2 was about 16.13% and 13.92% less than the reference concrete.
- Nano- SiO_2 incorporation in concrete is more beneficial than the nano- TiO_2 due to their availability and higher mechanical strength.
- Water absorption value decrease as incorporation of nano materials in concrete at an optimum dosage. All concrete mix specimens have lower than 5%.
- Durability of nano materials concrete is more compared to the referenced concrete.

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Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

Author Contributions

All of the authors made substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data; were involved in drafting the manuscript or revising it critically for important intellectual content; and gave final approval of the version to be published.

Data Availability

The datasets created and/or analyzed during the current study are not publicly available, but are available from the corresponding author upon reasonable request.

REFERENCES

- Chithra S, Senthil Kumar SRR, Chinnaraju 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.
- Feng Y, Zhang B, Xie J, Xue Z, Huang K, Tan J (2023). Effects of recycled sand and nanomaterials on ultra-high performance concrete: Workability, compressive strength and microstructure. *Construction and Building Materials*, 378, 131180.
- Hakeem IY, Amin M, Abdelsalam BA, Tayeh BA, Althoey F, Agwa IS (2022). Effects of nano-silica and micro-steel fiber on the engineer-

- ing properties of ultra-high performance concrete. *Structural Engineering and Mechanics*, 82(3), 295-312.
- IS 383 (2016). Coarse and fine aggregate for concrete – Specification. Bureau of Indian Standards, New Delhi, India.
- IS 516 (2021). Testing of strength of hardened concrete. Bureau of Indian Standards, New Delhi, India.
- IS 2386 (1963). Methods of test for aggregates for concrete. Bureau of Indian Standards, New Delhi, India.
- IS 4031 (1996). Method of physical tests for hydraulic cement. Bureau of Indian Standards, New Delhi, India.
- IS 10262 (2019). Concrete mix proportioning – Guidelines. Bureau of Indian Standards, New Delhi, India.
- Karthikeyan B, Dhinakaran G (2018). Influence of ultrafine TiO₂ and silica fume on performance of unreinforced and fiber reinforced concrete. *Construction and Building Materials*, 161, 570-576.
- Karthikeyan B, Subin, A, Muthulakshmi, T (2020). High strength concrete using ultra-fine TiO₂ and basalt fiber-A study on mechanical and durability characteristics. *Revista Romana de Materiale*, 50(1), 51-58.
- Khotbehsara MM, Miyandehi BM, Naseri F, Ozbakkaloglu T, Jafari F, Mohseni E (2018). Effect of SnO₂, ZrO₂, and CaCO₃ nanoparticles on water transport and durability properties of self-compacting mortar containing fly ash: Experimental observations and ANFIS predictions. *Construction and Building Materials*, 158, 823-834.
- Kim J, Kim, DJ, Park SH, Zi G (2015). Investigating the flexural resistance of fiber reinforced cementitious composites under biaxial condition. *Composite Structures*, 122, 198-208.
- Luo Z, Zhi T, Liu X, Yin K, Pan H, Feng H, Su Y (2023). Effects of different nanomaterials on the early performance of ultra-high performance concrete (UHPC): C-S-H seeds and nano-silica. *Cement and Concrete Composites*, 142, 105211.
- Marcos-Meson V, Geiker M, Fischer G, Solgaard A, Jakobsen UH, Danner, T, Michel A (2020). Durability of cracked SFRC exposed to wet-dry cycles of chlorides and carbon dioxide–Multiscale deterioration phenomena. *Cement and Concrete Research*, 135, 106120.
- Mohseni E, Naseri F, Amjadi R, Khotbehsara MM, Ranjbar MM (2016). Microstructure and durability properties of cement mortars containing nano-TiO₂ and rice husk ash. *Construction and Building Materials*, 114, 656-664.
- Murad Y (2021). Compressive strength prediction for concrete modified with nanomaterials. *Case Studies in Construction Materials*, 15, e00660.
- Pacheco-Torgal F, Miraldo S, Ding Y, Labrincha JA (2013). Targeting HPC with the help of nanoparticles: an overview. *Construction and Building Materials*, 38, 365-370.
- Razak HA, Chai HK, Wong HS (2004). Near surface characteristics of concrete containing supplementary cementing materials. *Cement and Concrete Composites*, 26(7), 883-889.
- Reches Y (2018). Nanoparticles as concrete additives: Review and perspectives. *Construction and Building Materials*, 175, 483-495.
- Rong Z, Sun W, Xiao H, Jiang G (2015). Effects of nano-SiO₂ particles on the mechanical and microstructural properties of ultra-high performance cementitious composites. *Cement Concrete Composites*, 56, 25-31.
- Sharmila P, Dhinakaran G (2016). Compressive strength, porosity and sorptivity of ultra fine slag based high strength concrete. *Construction and Building Materials*, 120, 48-53.
- Shi C, Jiménez AF, Palomo A (2011). New cements for the 21st century: The pursuit of an alternative to portland cement. *Cement and Concrete Research*, 41, 750-763.
- Son DH, Hwangbo D, Suh H, Bae BI, Bae S, Choi CS (2023). Mechanical properties of mortar and concrete incorporated with concentrated graphene oxide, functionalized carbon nanotube, nano silica hybrid aqueous solution. *Case Studies in Construction Materials*, 18, e01603.
- Yoo DY, Oh T, Banthia N (2022). Nanomaterials in ultra-high-performance concrete (UHPC)—A review. *Cement and Concrete Composites*, 134, 104730.