Research Article

Journal of Environmental Nanotechnology

Study on the Mechanical Performance of Carbon Nanotube-modified Concrete with Partial Fly Ash Cement Replacement

Ashwini Balakumar*, K. Thavasiraj, R. Lokesh, H. Thasneem Firthos and B. Adhavan
Department of Civil Engineering, E.G.S. Pillay Engineering College, Nagapattinam, TN, India
Received: 24.06.2025 Accepted: 01.08.2025 Published: 30.09.2025
*ashwinibalakumar@gmail.com

ABSTRACT

The growing demand for concrete with enhanced mechanical and durability properties has led to increased research focused on improving concrete. This enhancement is achieved through various additives and replacements in cement-based composites. Carbon Nanotube (CNT)-reinforced concrete has emerged as a recent area of research in the construction sector. This study explores the effects of incorporating higher levels of carbon nanotubes, beyond previous studies, to evaluate their influence on the strength properties of concrete. Additionally, 20% of the total cement volume was replaced with fly ash to reduce cement consumption. The research focused on three key properties: compressive strength, flexural strength, and tensile strength, all of which are critical for concrete performance. Previous studies incorporated CNT levels ranging from 0.025% to 0.075% (with a 0.025% increase in cement weight), while the current research used increased CNT levels of 0.1% and 0.125%. Three specimens were cast for each of the four mix types: the Control Concrete (CC) mix of M30 grade, a concrete mix with 20% fly ash replacing cement (CF), a mix with 20% fly ash and 0.1% CNT (CNT 0.1), and a mix with 20% fly ash and 0.125% CNT (CNT 0.125). For the tests on compressive and split tensile strength, 12 cubes (150 mm side) for each test were casted totally 24 specimens and 12-cylinder specimens (150 mm diametre and 300 mm height) were casted for cylinder compressive strength test. Additionally, 12 prism specimens were casted for flexural strength analysis, making a total of 48 specimens for this study. In order to ensure proper dispersion of carbon nanotubes within the concrete, a surface treatment process was used involving Polycarboxylate Ether (PCE) additive and magnetic stirring.

Keywords: Concrete; Flyash; Carbon nanotubes; Compression strength; Split tensile strength; Polycarboxylate ether.

1. INTRODUCTION

Concrete is the most commonly used structural composite in the construction industry. It is well-established that improving concrete properties can be achieved by modifying or adding chemicals or minerals to the concrete mix. Over the past few decades, various studies have demonstrated that changes to the components of concrete, such as cement content, water-cement ratio, and aggregate properties, can significantly enhance the properties of concrete. While compressive strength has improved considerably, the improvement in flexural properties has been somewhat limited. In this regard, Foldyna *et al.* (2016) and Madhavi *et al.* (2013) highlighted the substantial increase in compressive strength but noted the minimal enhancement in tensile strength in their research. The formation of tensile cracks was observed during the early loading stages. Nanomaterials such as titanium oxide, nano silica, metakaolin, silica, nano clay, and carbon nanotubes (CNTs) have been incorporated into conventional cementitious composites, yielding improved mechanical and durability properties (Huber *et al.* 2009). Carbon allotropes like CNTs are particularly effective in enhancing the flexural properties of concrete (Karthik *et al.* 2014; Sanchez *et al.* 2010). The nanoscale dimensions of CNTs, including their length and diameter, significantly improve the micro-properties of concrete (Kaur *et al.* 2020; Khan *et al.* 2016). Carbon nanotubes possess a unique tubular structure with a length-to-diameter ratio of 1:132,000,000. Their remarkable thermal, mechanical, electrical, and chemical properties contribute to the enhancement of concrete's physical properties. Carbon nanotubes can be synthesized as Single-Walled Carbon Nanotubes (SWCNT), Multi-Walled Carbon Nanotubes (MWCNT), Polymerized Single-Walled Carbon Nanotubes, or Nanotorus, depending on the desired properties (Huber *et al.* 2009)]. The synthesis of carbon allotropes, such as fullerene, ultimately led to the development of CNTs. Typically, CNTs have a diameter ranging from 1 to 4 nanometres and lengths of approximately 100 nanometres. Research has shown that CNTs possess extraordinary strength, several times greater than steel, making them one of the strongest materials ever synthesized by humans (Kim *et al.* 2014; Kowald and Trettin, 2004; Norhasri *et al.* 2017; Reales and Filho, 2017). Various methods, such as Chemical Vapor Deposition (CVD), Electric Arc Discharge (EAD), and Laser Ablation, are used to synthesize CNTs, depending on the specific physical and

mechanical properties required (IS: 10262, 2009; Purohit *et al.* 2014). The incorporation of CNTs into different composites has been proved to increase both strength and stability. Specifically, concrete with CNTs has shown significant improvements in flexural strength (Haddad *et al.* 2013; Rhee and Roh, 2013; Ribeiro *et al.* 2017). Cwirzen *et al.* (2008) noted that the inherent brittleness of cementitious composites, which lack ductility, is a major disadvantage, often leading to structural failure.

2. LITERATURE REVIEW

Kowald and Trettin (2004) found that incorporating 0.5% CNT by weight of cement with a water-to-cement (W/C) ratio of 0.22 resulted in a 12% increase in compressive strength. However, they also noted a decrease in strength when the CNT content was raised to 2.5%. Their study concluded that the optimal CNT content for enhancing both flexural and compressive strength was 0.5%.

Cwirzen *et al.* (2008) explored various surface modification techniques for CNT in concrete. They studied the impact of CNT with and without surface modification on concrete properties. Surfactants such as polyacrylic acid and gum arabic were applied under ultrasonic treatment. Six sets of concrete were cast with varying CNT percentages (0.023%, 0.1%, 0.14%) and combinations of these surfactants. The study found that the tensile load-bearing capacity increased by 50% when 0.045% CNT with polyacrylic acid was used, leading to significant improvements in both workability and durability. The research concluded that surfactants play a crucial role in enhancing the properties of CNT-modified concrete.

Huber *et al.* (2009) demonstrated a 50% increase in flexural strength and a 25% improvement in the modulus of elasticity of cement mortar when 0.1% CNT was incorporated, with a W/C ratio of 0.5.

Collins *et al.* (2012) investigated CNT concrete with various dispersants, including lignosulfate, sulphonic acid, calcium naphthalene sulphate, naphthalene, and polycarboxylate. Incorporation of CNTs at 2%, 1%, and 0.5% by weight of cement showed that 0.8% polycarboxylate-based surfactant-modified cement mortar exhibited a 42% increase in compressive strength compared to the control mix.

Hamzaoui *et al.* (2012) studied the effects of CNT incorporation in cementitious composites, ranging from 0.001% to 0.004% in concrete and 0.01% to 0.06% in mortars, with 0.001% increments. The highest compressive strength increase (21.2%) was observed at 0.01% CNT in mortar, while 0.003% CNT showed a 17.65% increase in concrete. Further increases in CNT resulted in reduced strength, and the study concluded that the optimal CNT content was 0.01% for mortar and 0.003% for concrete.

Haddad *et al.* (2013) tested CNT incorporation at 0.2%, 0.4%, and 0.6% by weight of cement in mortar. The 0.4% CNT mix exhibited significant improvements in compressive, tensile, and flexural strengths, showing increases of 40%, 30%, and 15%, respectively, compared to the control mix. They concluded that 0.2% and 0.6% CNT were the optimal levels for strength enhancement.

Rhee and Roh (2013) studied the effects of CNT incorporation in cementitious composites at 0.25% to 1.5%, with increments of 0.5%. After sonication with surface-treated CNTs (using sulfonate formaldehyde and sodium naphthalene), they observed a 40% increase in compressive strength and a 72% increase in split tensile strength at 1.0% CNT incorporation. The study also noted reduced permeability, with strength increases observed up to a certain CNT dosage.

Sahranavard *et al.* (2014) conducted research on cementitious composites with MWCNTs at a 0.1% concentration. They found remarkable increases of 2%, 25.58%, and 1400% in flexural, compressive, and impact resistance, respectively, compared to the control mix. The study concluded that even a small amount of MWCNTs can significantly improve the properties of cementitious composites.

Samchenko *et al.* (2014) focused on CNT dispersion in polycarboxylate ether and other dispersive materials like Metaflux and water. The study showed that Polycarboxylate Ether (PCE) provided the best stabilization and minimized CNT agglomeration, resulting in improved dispersion and performance.

Foldyna *et al.* (2016) investigated the challenges associated with incorporating CNT into cementitious composites. They explored several dispersion methods, including ultrasonication, chemical dispersion, and other techniques, for effectively dispersing CNTs. The study concluded that proper dispersion of CNT in concrete significantly improves its properties.

3. EXPERIMENTAL ANALYSES

3.1 Specimen Casting

The literature review provided crucial insights for this research, including the appropriate dosage of CNT incorporation, concrete components and replacements, and surface decoration methods (IS: 456, 2000). Based on the findings from the review, it was decided to use CNT along with the surfactant PCE under a magnetic stirring process for dispersion. The M30 grade conventional concrete mix was selected as the control mix. As part of a sustainable approach to reduce cement usage, 20% of the cement volume was replaced with Class-F fly ash. The research then focused on two CNT mixes, one conventional mix (CC), and one mix with

cement replacement (CF), resulting in four types of mixes and a total of 48 specimens. The water-cement ratio was finalized through slump cone testing, followed by the determination of the proper mix designs for the concrete. The materials were collected, batched, and cast accordingly. The physical and chemical properties of the MWCNT, as provided by the manufacturer, are presented in Table 1, while the mix details and proportions are shown in Tables 2 and 3 (IS: 10262, 2009; IS: 2386, 1997; IS: 2386, 1997; IS: 383, 1992).

Table 1. Physical and chemical properties of carbon nanotubes

S. No.	Properties	Values
1	Higher Diameter	~10 nm
2	Maximum Length	6-9 micron
3	Percentage of Purity	>98%
4	Presence of Metal Particles	<1%
5	Amorphous Carbon Presence	<1%
6	Surface Area	250-300 sq.m/g
7	Bulk Density	0.10-0.06 g/sq. cm

Table 2. Specimen casted

S. No.	Mix Description	Fly Ash	CNT
1	Control Mix (CC)	-	-
2	CF	20%	-
3	CNT 0.1%	20%	0.1%
4	CNT 0.125%	20%	0.125%

Table 3. Mix proportion in ratio

Details	CC	CF	CNT 0.1%	CNT 0.125 %
Mix Ratio	1:2.06: 3.36	1:2.07: 3.38	1:2.07: 3.38	1:2.07: 3.38
W/C Ratio	0.40	0.40	0.40	0.40
MWCNT (%)	-	-	0.1	0.125
Surfactant (%)	-	-	2	2
Fly ash (%)	-	20	20	20

Table 4. Mix proportion in quantities

Material	CC	CF	CNT0.1%	CNT 0.125 %
Cement (kg/m^3)	380	304	304	304
Fine Aggregate (kg/m^3)	782	782	782	782
Coarse Aggregate (kg/m^3)	1276	1276	1276	1276
Fly ash (kg/m^3)	0	76	76	76
Water (lit/m^3)	152	152	152	152
MWCNT % (kg/m^3)	-	-	9.5	19
Surfactant @ 2% (lit/m^3)	-	-	7.6	7.6

In this study, compressive, flexural, and split tensile tests were conducted. The quantities of specimens used are provided in Table 4. The specimens included cubes with 150 mm sides, cylinders with a diameter of 150 mm and height of 300 mm, and prisms measuring 100 mm in width, 100 mm in breadth, and 500 mm in length. The details of the specimens cast for each test are presented in Table 5, and the quantity of specimens used for each test is shown in Table 6.

Table 5. Specimen testing details- based of specimens

S. No.	Mix Description	Cube	Cylinder	Prism
1	CC	6	3	3
2	CF	6	3	3
3	CNT 0.1%	6	3	3
4	CNT 0.125%	6	3	3

Table 6. Specimen testing details - mechanical testing

S. No.	Specimen	Compressive Test	Split Tensile Test	Flexural Testing
1	Cube	12	12	-
2	Cylinder	12	-	-
3	Prism	-	-	12

3.1.1 Surface Decoration

The dispersion or surface decoration process is a crucial step in incorporating CNT into concrete. Due to the nanoscale size of CNT, challenges such as agglomeration and poor distribution within the mix can occur. These issues reduce the effectiveness of CNT in enhancing concrete properties. In this study, PCE solution, known for its strong dispersion capability, was used to minimize agglomeration in the concrete (Zhang *et al.* 2020). The magnetic stirring method was employed for dispersion, where CNT and PCE were mixed in a glass jar and stirred at 600 rpm for 60 minutes (Norhasri *et al.* 2017). Ordinary Portland Cement (OPC) 53 grade was used for the concrete mix. The specimens underwent 28 days of immersion curing, after which mechanical testing was conducted (Kharissova *et al.* 2013; MacLeod *et al.* 2020; Shah *et al.* 2009). The dispersion process of CNT in the surfactant is shown in Fig. 1.

3.1.2 Specimen Testing

Compressive tests on cube and cylinder specimens, as well as split tensile tests on cubes, were conducted using a compressive testing machine. A flexural testing machine was utilized for flexural testing. The testing procedures followed the provisions outlined in the IS standards. Fig. 2 (a-d) display the various tests performed, including compressive, split tensile, and flexural tests.

The compressive strength of the cubes and cylinders, the split tensile strength of the cubes, and the flexural strength of the prisms were calculated using standard methods.



Fig. 1: CNT dispersion



Fig. 2: Mechanical testing of specimens (a) compressive testing – cube, (b) split tensile testing – cube, (c) compressive testing – cylinder and (d) flexural testing - prism

4. RESULTS ANALYSES

In this research, the results can be categorized into two primary comparisons: the variations in mechanical properties of CNT concrete in comparison to conventional concrete and fly ash concrete. The conventional concrete mix served as one reference, and the fly ash concrete was maintained as another reference mix. The strength variations of the mixes were compared to these two reference mixes, with the fly ash concrete also being compared to the conventional mix.

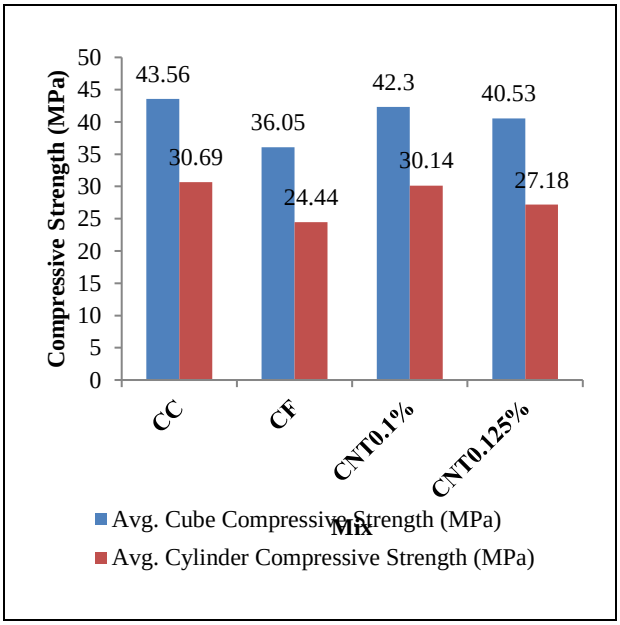


Fig. 3: Compressive strength of cube & cylinder specimens

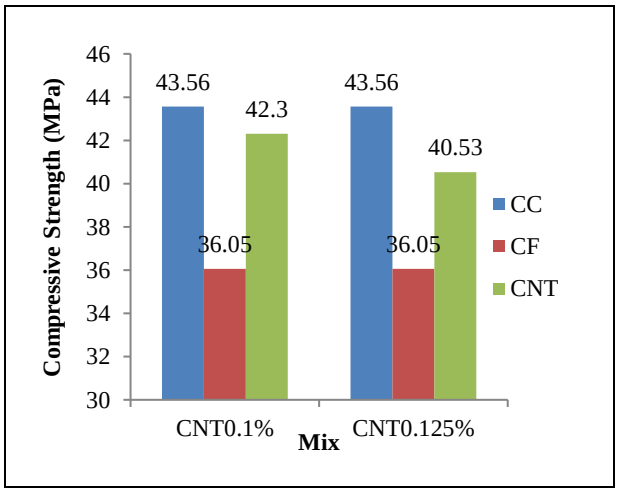


Fig. 4: Comparison between compressive test of cube specimens

4.1 Compressive Strength

For the cube compressive strength test, conventional concrete (CC) showed the highest value of 43.56 MPa. The concrete with partial cement replacement exhibited a compressive strength of 36.05 MPa. The CNT 0.1% and CNT 0.125% mixes demonstrated compressive strengths of 42.32 MPa and 40.53 MPa, respectively. The cylinder compressive strength for CC was the highest at 30.69 MPa, while the partially cement-replaced concrete showed 24.44 MPa. The CNT mixes at 0.1% and 0.125% achieved 30.14 MPa and 27.18 MPa, respectively. Tables 7 and 8 show the cube and cylinder compressive strengths and their

increases in comparison to the CC and CF mixes. The average compressive strengths for cubes and cylinders are presented in Fig. 3. The comparisons of cube and cylinder compressive strengths are shown in Fig. 4 and Fig. 5, respectively.

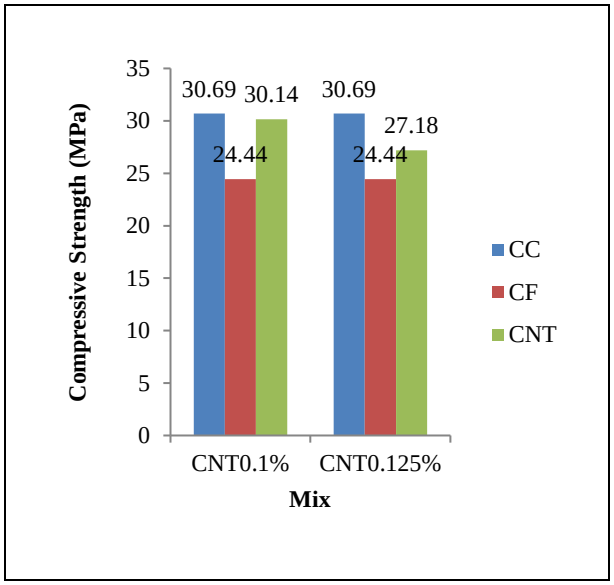


Fig. 5: Comparison between compressive test of cylinder specimens

Table 7. Cube compressive test results

Mix	Avg. Comp. Strength (MPa)	% of Increase than CC	% of Increase than CF
CC	43.56		
CF	36.05	-20.83	
CNT0.1%	42.30	-2.98	14.78
CNT0.125%	40.53	-7.48	11.05

Table 8. Cylinder compressive test results

Mix	Avg. Comp. Strength (MPa)	% of Increase than CC	% of Increase than CF
CC	30.69	-25.57	
CF	24.44	-1.82	
CNT0.1%	30.14	-12.91	18.91
CNT0.125%	27.18	-25.57	10.08

* Negative sign indicates the reduction in the values.

4.2 Split Tensile Strength

The split tensile strength of the concrete cubes from all mixes was tested. Among all the mixes, the CNT 0.1% mix exhibited the highest value of 4.8 MPa, followed by the CNT 0.125% mix with 3.87 MPa. The conventional concrete (CC) and the fly ash concrete (CF) showed values of 3.38 MPa and 2.64 MPa, respectively. It is clear that the incorporation of CNT in the concrete improved its tensile load-carrying capacity. The values are provided in Table 9.

Table 9. Average split tensile strength

Mix	Average Split Tensile Strength (MPa)
CC	3.38
CF	2.64
CNT0.1%	4.18
CNT0.125%	3.87

4.3 Flexural Strength

The concrete specimens used for flexural testing had dimensions of 100 mm × 100 mm × 500 mm. The CNT 0.1% mix exhibited the highest flexural strength at 4.93 MPa, followed by the CNT 0.125% mix with 4.35 MPa. Among all the mixes, the CNT 0.1% mix showed the highest value. The conventional concrete (CC) and the fly ash concrete (CF) recorded values of 4.26 MPa and 3.73 MPa, respectively. The flexural strengths of the concrete mixes are shown in Table 10.

Fig. 6 displays the average split tensile strength and flexural strength values of concrete. Fig. 7 shows the average split tensile test of cube specimens. Fig. 8 shows the flexural strength values.

Table 10. Average flexural strength

Mix	Flexural Strength (MPa)
CC	4.26
CF	3.73
CNT0.1%	4.93
CNT0.125%	4.35

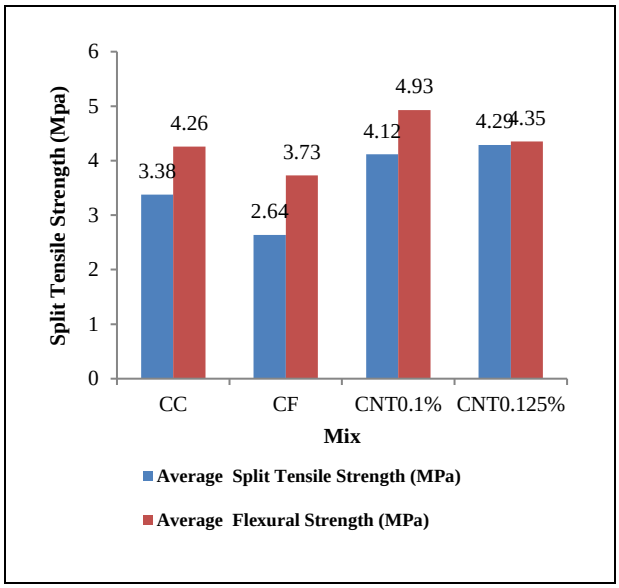


Fig. 6: Average split tensile and flexural strength

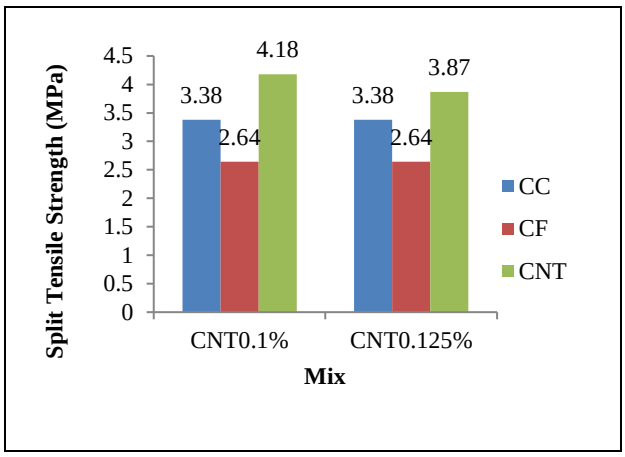


Fig. 7: Average split tensile test of cube specimens

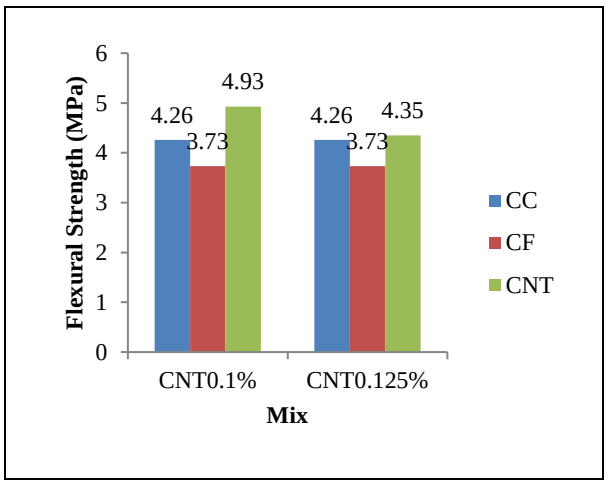


Fig. 8: Average flexural strength

5. DISCUSSION

The comparison was made between the control mix (CC) and fly ash concrete (CF) to analyse the effects and any increase or decrease in the concrete properties. The comparison with fly ash concrete (CF) is considered the primary reference, while the comparison with conventional concrete (CC) serves as a baseline for measuring improvements.

5.1 Compressive Strength - Cube

The compression tests for each mix were conducted after a 28-day curing period. The average of three specimens for each mix was tested, and the results were obtained from concrete cubes. The CF mix exhibited 20.83% lower strength than the CC mix. For the mix with CNT at 0.1%, the compressive strength decreased by 2.98% compared to CC but showed a 29.6% increase over the CF mix. The CNT 0.125% mix exhibited 7.48% lower strength than CC but had 11.05% higher strength than the CF mix. The highest compressive strength in this study was obtained from the CC mix. Interestingly, the CNT 0.1% mix with partial cement replacement demonstrated enhanced strength with minimal cement usage.

5.2 Compressive Strength - Cylinder

The results for the cylinder compressive strength were similar to those of the cubes. The highest cylinder compressive strength, 30.69 MPa, was obtained from the CC mix. The CF mix showed a lower strength of 24.44 MPa, which is 20.36% lower than CC. The CNT 0.1% mix showed a 1.79% decrease in strength, and the CNT 0.125% mix showed an 11.44% decrease compared to CC. However, compared to CF, the CNT 0.1% and 0.125% mixes showed strengths higher by 18.91% and 10.91%, respectively. This clearly indicates a significant increase in strength for CNT concrete compared to CF. Among all the mixes, the CNT 0.1% mix showed the highest strength with reduced cement usage.

5.3 Split-tensile Strength

The split tensile strength test of concrete cubes demonstrated significant results, supporting the benefits of CNT incorporation. The conventional mix (CC) had a split tensile strength of 3.38 MPa, while the CF mix showed 2.64 MPa. The CF mix showed a 21.89% reduction in split tensile strength compared to CC. In contrast, the CNT mixes (CNT 0.1% and CNT 0.125%) showed remarkable improvements. The CNT 0.1% mix exhibited a 19.14% and 36.84% increase in split tensile strength over the CC and CF mixes, respectively. The CNT 0.125% mix showed a 12.66% and 31.78% increase over the CC and CF mixes, respectively.

5.4 Flexural Strength

The flexural strength testing on concrete prism specimens showed that the CNT 0.1% mix had a 13.59% and 24.34% higher flexural strength compared to the CC and CF mixes, respectively. The CNT 0.125% mix showed a 2.07% and 14.25% increase over the CC and CF mixes, respectively. The CC mix had a flexural strength of 4.26 MPa, while the CF mix showed 3.73 MPa. The CF mix had a 12.44% reduction in flexural strength compared to the CC mix. Therefore, the highest flexural strength was observed in the CNT 0.1% mix, followed by the CNT 0.125% mix.

The increase in split tensile and flexural strength of the concrete is attributed to the bridging effect of CNT particles within the C-S-H gel matrix at the micro level. Proper dispersion or surface decoration of CNT in concrete enhances the load-carrying capacity of the C-S-H matrix by acting as a bridge between the C-S-H molecules. This increased load-carrying capacity enhances the overall tensile and flexural properties of the concrete. The increase in tensile and flexural properties was more pronounced in the CNT 0.1% mix, with a marginal decrease in the CNT 0.125% mix.

6. CONCLUSION

This research concludes that incorporating carbon nanotubes (CNTs) in concrete notably enhances its mechanical properties, including compressive, split tensile, and flexural strengths. In contrast, partial replacement of cement with fly ash alone reduces strength. However, when CNTs are added to fly ash-based mixes, mechanical performance improves significantly. The CNT-incorporated mix outperformed the fly ash concrete (CF mix) and showed comparable or superior results to conventional concrete (CC mix), particularly in tensile and flexural tests. These improvements are attributed to microstructural effects of CNTs, especially their bridging action within the C–S–H matrices. Among the tested concentrations, 0.1% CNT yielded the best performance, with a slight decline observed at 0.125%, indicating that 0.1% CNT incorporation is optimal.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

COPYRIGHT

This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).

REFERENCE

Abinayaa, U., Chetha, D., Chathuska, S., Praneeth, N., Vimantha, R. and Wijesundara, K. K., Improving the properties of concrete using carbon nanotubes, *Const. Mater.,* 201-204 (2016). https://doi.org/10.13140/RG.2.1.1863.1288

Collins, F., Lambert, J. and Duan, W. H., The influences of admixtures on the dispersion, workability, and strength of carbon nanotubes–OPC paste mixtures, *Cem. Concr. Compos.,* 34(2), 201-207(2012). https://doi.org/10.1016/j.cemconcomp.2011.09.013

Cwirzen, K. H., Penttala, V. and Cwirzen, A., Surface decoration of carbon nanotubes and mechanical properties of cement/carbon nanotubes composites, *Adv. Cem. Res.,* 20(2), 65-73(2008). https://doi.org/10.1680/adcr.2008.20.2.65

Foldyna, J., Foldyna, V. and Zeleňák, M., Dispersion of carbon nanotubes for application in cement composites, *Procedia Eng.,* 149, 94-99(2016).

Haddad, A. N., Morais, J. F. and Evangelista, A. C. J., Variation of Concrete Strength with the Insertion of Carbon Nanotubes, *Adv. Mater. Res.,* 818, 124-131 (2013). https://doi.org/10.4028/www.scientific.net/AMR.818.124

Hamzaoui, R., Bennabi, A., Guessasma, S., Khelifa, R. and Leklou, N., Optimal carbon nanotubes concentration incorporated in mortar and concrete, *Adv. Mater. Res.,* 587, 107-110(2012). https://doi.org/10.4028/www.scientific.net/AMR.587.107

Huber, M. L., Perkins, R. A., Laesecke, A., Friend, D. G., Sengers, J. V., Assael, M. J., Metaxa, I. N., Vogel, E., Mareš, R. and Miyagawa, K., New international formulation for the viscosity of H 2 O, *J. Phys. Chem. Ref. Data.,* 38(2), 101-125(2009). https://doi.org/10.1063/1.3088050

IS: 10262 -Guidelines for concrete mix design proportioning to IS, Bureau of Indian Standards, New Delhi, (2009).

IS: 2386 (Part 1)- Methods of Test for Aggregates for Concrete Part I Particle Size and Shape To IS, Bureau of Indian Standards, New Delhi, (1997).

IS: 2386 (Part 3)- Methods of Test for Aggregates for Concrete Part Ill Specific Gravity, Density, Voids ‘, Absorption and Bulking To IS, Bureau of Indian Standards, New Delhi, (1997).

IS: 516-1959 – Methods of Test for Strength of Concrete to IS, Bureau of Indian Standards, New Delhi, (2002).

IS: 456- Plain and Reinforced Concrete - Code of Practice to IS, Bureau of Indian Standards, New Delhi, (2007).

IS: 383 – Specifications for Coarse and Fine Aggregates from Natural Sources for Concrete to IS, Bureau of Indian Standards, New Delhi, (1992).

IS: 5816 -Splitting Tensile Strength of Concrete - Method of Test to IS, Bureau of Indian Standards, New Delhi, (2004).

Karthik, P. S., Himaja, A. L. and Singh, S. P., Carbon-allotropes: synthesis methods, applications and future perspectives, *Carbon lett.,* 15(4), 219-237(2014). https://doi.org/10.5714/CL.2014.15.4.219

Kaur, R., Kothiyal, N. C. and Arora, H., Studies on combined effect of superplasticizer modified graphene oxide and carbon nanotubes on the physico-mechanical strength and electrical resistivity of fly ash blended cement mortar, *J. Build. Eng.,* 30, 101304(2020). https://doi.org/10.1016/j.jobe.2020.101304

Khan, W., Sharma, R. and Saini, P., Carbon nanotube-based polymer composites: synthesis, properties and applications, *Carbon Nanotubes - Current Progress of their Polymer Composites,* (2016). https://doi.org/10.5772/62497

Kharissova, O. V., Kharisov, B. I. and Ortiz, E. G. C., Dispersion of carbon nanotubes in water and non-aqueous solvents, *Rsc Adv.,* 3(47), 24812-24852(2013). https://doi.org/10.1039/C3RA43852J

Kim, H. K., Nam, I. W. and Lee, H. K., Enhanced effect of carbon nanotube on mechanical and electrical properties of cement composites by incorporation of silica fume, *Compos. Struct.,* 107, 60-69(2014). https://doi.org/10.1016/j.compstruct.2013.07.042

Kowald, T. and Trettin, R., Influence of surface-modified carbon nanotubes on ultrahigh performance concrete, *International Symposium on Ultra High-Performance Concrete*, 195-203 (2004).

MacLeod, A. J., Fehervari, A., Gates, W. P., Garcez, E. O., Aldridge, L. P. and Collins, F., Enhancing fresh properties and strength of concrete with a pre-dispersed carbon nanotube liquid admixture, *Constr. Build. Mater.,* 247, 118524(2020a). https://doi.org/10.1016/j.conbuildmat.2020.118524

Madhavi, T. C., Pavithra, P., Singh, S. B., Raj, S. B. V. and Paul, S., Effect of multiwalled carbon nanotubes on mechanical properties of concrete, *Int. J. Sci. Res.,* 2(6), 166-168(2013). https://doi.org/10.15373/22778179/JUNE2013/53

Norhasri, M. M., Hamidah, M. S. and Fadzil, A. M., Applications of using nano material in concrete: A review, *Constr. Build. Mater.,* 133, 91-97(2017). https://doi.org/10.1016/j.conbuildmat.2016.12.005

Parveen, S., Rana, S. and Fangueiro, R., A review on nanomaterial dispersion, microstructure, and mechanical properties of carbon nanotube and nanofiber reinforced cementitious composites, *J. Nanomater.,* 2013(1), 710175(2013). https://doi.org/10.1155/2013/710175

Zhang, J., Ke, Y., Zhang, J., Han, Q. and Dong, B., Cement paste bjf v with well-dispersed multi-walled carbon nanotubes: Mechanism and performance, *Constr. Build. Mater.,* 262(46), 120746(2020). https://doi.org/10.1016/j.conbuildmat.2020.120746

Purohit, R., Purohit, K., Rana, S., Rana, R. S. and Patel, V., Carbon nanotubes and their growth methods, *Procedia Mater. Sci.,* 6, 716-728(2014). https://doi.org/10.1016/j.mspro.2014.07.088

Reales, O. A. M. and Filho, R. D. T., A review on the chemical, mechanical and microstructural characterization of carbon nanotubes-cement based composites, *Constr. Build. Mater.,* 154, 697-710(2017). https://doi.org/10.1016/j.conbuildmat.2017.07.232

Rhee, I. and Roh, Y. S., Properties of normal-strength concrete and mortar with multi-walled carbon nanotubes, *Mag. Concr. Res.,* 65(16), 951-961(2013). https://doi.org/10.1680/macr.12.00212

Ribeiro, B., Botelho, E. C., Costa, M. L. and Bandeira, C. F., Carbon nanotube buckypaper reinforced polymer composites: a review, *Polímeros*, 27(3), 247-255(2017). https://doi.org/10.1590/0104-1428.03916

Sahranavard, S., Haji-Kazemi, H. and Abbasi, S., Effect of multi-walled carbon nanotubes on mechanical properties of high-performance mortar, *Mag. Concr. Res.,* 66(18), 948-954(2014). https://doi.org/10.1680/macr.14.00037

Samchenko, S. V., Zemskova, O. V. and Kozlova, I. V., Stabilization of carbon nanotubes with superplasticizers based on polycarboxylate resin ethers, *Russ. J. Appl. Chem.,* 87(12), 1872-1876(2014). https://doi.org/10.1134/S1070427214120131

Sanchez, F. and Sobolev, K., Nanotechnology in concrete–a review, *Constr. Build. Mater.,* 24(11), 2060-2071(2010). https://doi.org/10.1016/j.conbuildmat.2010.03.014

Shah, S. P., Konsta-Gdoutos, M. S., Metaxa, Z. S. and Mondal, P., Nanoscale modification of cementitious materials, *Nanotechnol. Constr. 3.,* 125-130(2009). https://doi.org/10.1007/978-3-642-00980-8_16