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Research Paper

Strength and durability enhancement of self compacting concrete using multi walled carbon nano tubes and nano titanium dioxide: A comparative analysis

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ABSTRACT

Multi-walled carbon nanotubes (MWCNTs) have been widely used, especially in concrete applications. Further studies reveal that nano titanium dioxide (TiO_2) is also used in concrete to intensify the properties of concrete. This study investigates the effects of adding various percentages (0.1%, 0.3%, and 0.5%) of MWCNTs and nano TiO_2 to M40 grade self-compacting concrete. The mechanical properties compressive, split tensile, and flexural strength along with durability aspects such as water absorption, rapid chloride penetration, and acid resistance were evaluated. The findings indicate that with the addition of 0.1%, 0.3% and 0.5% multi-walled carbon nanotubes (MWCNTs) 2%,8% and 21% average increment, respectively in compressive strength for various molds casted is observed after 28 days, whereas other tested parameters are also showing significant increment. Similarly, with the addition of 0.1%, 0.3% and 0.5% of nano titanium dioxide (TiO_2) 5%, 6%, and 10% average increment, respectively, in compressive strength was observed after 28 days. The durability parameters are also enhanced for both the nano materials, but MWCNTs show a greater increment when compared to nano TiO_2. The cost comparison of both the nano materials is also taken into consideration, which shows that around 14 lakhs of material cost is required for 0.1% MWCNT is more when compared to 0.1% nano TiO_2 required for casting 100 m^3 of self-compacting concrete.

1. Introduction

Self-compacting concrete constitutes a breakthrough in concrete technology, eliminating the need for vibration during placement and compaction. It has the remarkable capacity to flow under its own weight, because of which filling of formwork becomes easy and full compaction is achieved, especially in regions with densely packed reinforcement. Once hardened, this concrete exhibits a dense, uniform structure with better strength and durability when compared to traditional vibrated concrete. One of the key advantages of self-compacting concrete is its rapid placement, leading to a decrease in construction duration. Its ability to flow smoothly around congested reinforcement ensures efficient construction practices. An absolute level of homogeneity is guaranteed because of the fluidity and resistance to segregation, along with minimizing the voids and ensuring uniform strength throughout the concrete structure. This quality not only enhances the structural integrity but also offers the potential for superior finishing and long-term durability. Furthermore, the removal of vibrating equipment improves the working environment at construction sites, reducing noise and vibration-related hazards. These advancements in construction processes, together with the safety and health advantages, make self-compacting concrete an enticing option for both precast concrete and onsite concrete alternatives [1]. Its remarkable capacity to be cast effectively in structural elements with complex shapes and limited spaces, including precast concrete moulds and crowded reinforcing zones, without running the risk of segregation or lacking infill. This feature is especially beneficial in modern construction practices involving stay-in-place formworks, precast components, and columns with complex cross-sections, where traditional concrete may struggle to achieve uniform compaction [2, 3]. Nanotechnology emerges as a burgeoning scientific domain dedicated to comprehending and manipulating matter at the Nano scale, ranging from 1 to 100 nanometres [4]. This multidisciplinary field integrates Nanoscale science, engineering, and technology to explore, measure, model, and manipulate matter at this minute scale. Through nanotechnology, the properties of materials can be precisely tailored to meet specific requirements by engaging at the atom or molecule level [5]. The introduction of nanotechnology has aided the development of concrete with improved substantial, mechanical, and durability properties. Concrete includes nanotechnology by including nanoparticles [6, 7]. Carbon nanotubes, recognized for their extraordinary features such as high Modulus of Elasticity, strength, electrical and thermal conductivity, have great potential for reinforcing the cement matrix, resulting in materials with better performance characteristics [8]. The imbibement of nanotubes affects the shape of cement hydration products, including both early C_3A and C_3S hydration products. Furthermore, carbon nanotubes speed the process of hydration by acting as a matrix for the formation of C-S-H and Ca $(OH)_2$, both of which are key hydration products. Oxygen-containing groups grafted onto the surface of carbon nanotubes promote chemical interaction with the cement matrix [9–11]. Furthermore, during cement hydration, carbon nanotubes operate as nucleating agents, encouraging more reaction sites and making it easier for reaction products to develop [12]. This thorough incorporation of carbon nanotubes into the cement matrix shows how they can be used to greatly improve the properties and functionality of concrete [13]. When the composites of cement are reinforced with nanotubes, the initiation of C-S-H around the nanotubes slows down the creation of a C-S-H layer on the cement grains' surface. This process accelerates the suspension and growth of hydration products in comparison to conventional cement paste [14].

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Nomenclature

SCC	Self-Compacting Concrete	*EFNARC*	European Federation of Specialist Construction Chemicals and Concrete
MWCNT	Multi Walled Carbon Nano Tubes	*NTD*	Nano Titanium Dioxide
TiO_2	Nano Titanium Dioxide	*RCPT*	Rapid Chloride Penetration Test
IS	Indian Standards	*SCN*	Mix Id's
ASTM	American Society for Testing and Materials	*OPC*	Ordinary Portland Cement

Concurrently, the surface of Nano Titanium Dioxide has photocatalytic sterilizing properties, which make it useful as an additive in construction materials. Also, Nano Titanium Dioxide shows the ability of air purification, self-cleaning, and disinfection characteristics when mixed with cementitious material [15–17]. In the earlier researches, however, there is currently no direct and systematic comparison in the literature between SCC reinforced with MWCNTs and that with Nano TiO_2 under the same mix proportions and testing conditions. The purpose of this research is to probe and compare the compressive strength, tensile strength, flexural strength, water absorption, and rapid chloride penetration properties in self-compacting concrete (SCC) reinforced with multi-walled carbon nanotubes and Nano Titanium Dioxide in 0.1%,0.3%, and 0.5% of the weight of cement. The proportions are being fixed after referring to various earlier research done in the same context [12, 15, 18–20]. This study stands out for directly comparing the mechanical and durability performance of SCC modified with two distinct nanomaterials, MWCNTs and Nano TiO_2, at multiple dosages. It also includes a detailed cost analysis and sustainability perspective, which are rarely addressed together in prior studies.

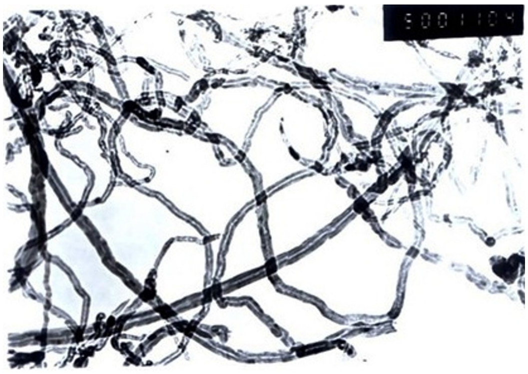


Figure 1. Transmission electron microscopy image of CNT (source: Cheap Tubes Inc).

Table 1. Multi-walled carbon nanotubes-physical properties (source: Cheap Tubes Inc).

Purity	Outer Diameter	Inner Diameter	Length	Specific Surface Area	Bulk density	True density
90%	20-40 (nm)	5-10 (nm)	10-30 (μm)	> 110 (m^2/g)	0.07 (g/cm^3)	2.1 (g/cm^3)

Table 2. Properties of Nano TiO_2 (source: Ad Nano Technologies).

Purity	Average particle size	SSA	Molecular Weight	Bulk density	Physical Form	Color
99.9%	<100 (nm)	150 (m^2/g)	79.8658 (g/mol)	0.9 (g/cm^3)	Powder	White

2. Experimental program

2.1 Materials used for testing

The cement utilized in this investigation is OPC Grade 53 (IS269). Fine Aggregates with 2.82 fineness modulus were used. Two different types of coarse aggregates were used: Type A, passing 20*mm* sieve, and Type B, passing 10 *mm* sieve (IS383). As the filler material, Fly ash was used. The same was procured Class F (ASTM C 618) from the Thermal Plant located in Wanakbori, Gujarat. Glenium ACE 30 RJ was the superplasticizer utilized in the experiment. Multi-walled carbon nanotubes purchased from Cheap Tubes located in the USA, characterized by properties outlined in Table 1, were employed.

The transmission electron microscope image of MWCNT is depicted in Fig. 1. Nano TiO_2, procured from Ad Nano Technologies in powdered form, was incorporated into the mixture after dispersion, characterized by properties outlined in Table 2. Additionally, SEM images of Nano TiO_2 are presented in Fig. 2.

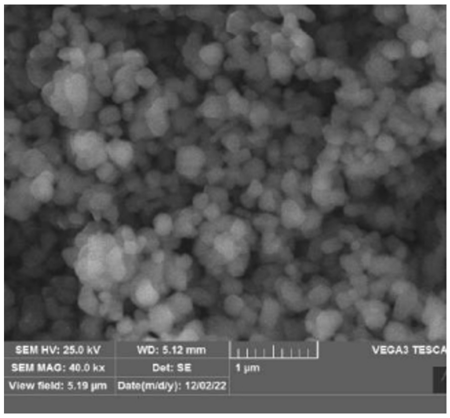


Figure 2. Scanning electron microscopy image of nano titanium dioxide (source: Ad Nano Technologies).

Figure 3. Slump Flow Test for SCC.

Table 3. Mix proportion of self-compacting concrete for Grade-M40, (1 m^3).

Cement	Coarse Agg–I	Coarse Agg–II	Fine Agg	Fly Ash	Super Plasticizer	Water
393 (Kg)	315 (Kg)	213 (Kg)	601 (Kg)	107 (Kg)	0.5 $Lit.$	178 $Lit.$

Table 4. Mix designations of SCC.

Mix designation	SCN 0	SCN 0.1	SCN 0.3	SCN 0.5
Multi-walled Carbon Nano Tubes & Nano TiO_2 dosage % of Cement weight (individually)	0	0.1	0.3	0.5

2.2 Proportion of the SCC Mix

The mix proportions of self-compacting concrete were set according to the European standard ËFNARC"[21]. The quantities of various materials for a one cubic meter volume are shown in Table 3. The mix design was finalized on trial and error basis as per the EFNARC standard, which is widely accepted and passes all the required tests for workability and flowability. Various combinations, as presented in Table 4, were formulated by incorporating different amounts of multi-walled carbon nanotubes and nano titanium dioxide.

2.3 Verification of self compacting concrete as per EFNARC standards

To analyze the flowability, passing ability, and filling capacity of the SCC, a series of experiments, including flow tests, L-box tests, and U-box tests, were carried out on all mixes in line with EFNARC requirements. Tests for both materials were done, average values of the same are presented below in the results. The characteristics of all the flow mixtures were assessed using the slump flow test. The flow diameter measured after completion of 30 seconds for each test fell within the boundaries specified by EFNARC regulations. Figure 3 depicts a representative flow pattern, and Table 5 provides corresponding flow values for all mixes. The slump flow tests were used to determine the workability and consistency of fresh concrete. The mixture's flowability, passing, and filling characteristics were examined using L-box and U-box tests. The test results complied with the specified limits outlined in the EFNARC regulations. The results of the L-box and U-box tests are shown in Table 6 and Table 7, respectively.

Table 5. Slump flow test results.

Mix ID	SCN 0	SCN 0.1	SCN 0.3	SCN 0.5
Flow obtained in half minute	66 cm	65 cm	69 cm	67 cm
Permissible range as per EFNARC	60-85 cm			

Table 6. L Box test results.

Mix ID	SCN 0	SCN 0.1	SCN 0.3	SCN 0.5
H_2/H_1	0.83	0.86	0.82	0.88
Permissible limits of H_2/H_1	0.8-1.0			

where, H_1= Horizontal distance on L box filled with concrete.
And, H_2= Vertical distance on L box filled with concrete.

Table 7. U Box test results.

Mix ID	SCN 0	SCN 0.1	SCN 0.3	SCN 0.5
H_2-H_1	0	0	0	0
Permissible limits of H_2-H_1	0-30 cm			

where, H_1= Distance on U box right side filled with concrete.
And, H_2= Distance on U box left side filled with concrete.

3. Tests for strength and durability

Compressive strength tests, split tensile tests, and flexural strength tests were conducted to evaluate the strength parameters of all SCC samples. Additionally, water absorption, rapid chloride penetration tests, acid and sulphate attack tests were performed to assess durability parameters.

3.1 Compressive strength

Compressive strength, [22], is an important characteristic of concrete. After a hardened state of concrete is achieved, the load carrying capacity under compressive forces of concrete is determined by the compressive strength. $150 \times 150 \times 150$ *mm* cube specimen was prepared and tested on a 2000 *kN* capacity testing machine. The cubes were tested at 7 and 28 days with different proportions of MWCNT and NTD.

3.2 Split tensile strength

To determine the tensile strength of concrete, split tensile strength, [23], is performed. A 150 *mm* dia. and 300 *mm* depth cylinder is cast and is placed under the testing machine, subjected to compression. Transverse tensile stress is produced because of the compressive stress. The cylinder was tested at 28 days with different proportions of MWCNT and NTD.

3.3 Flexure strength

For determining tensile strength in bending, flexural strength, [22], is used. 150×150 *or* 100×100 *mm* beams with a span three times their depth are cast and placed to resist failure in bending.

3.4 Water absorption test

Water absorption tests (ASTM C1585), [24], with $5 \times 5 \times 5$ *cm* cubes for different dosages of multi-walled carbon nanotubes and nano titanium dioxide (ranging from 0% to 0.5%), were used to evaluate the endurance of self-compacting concrete under water, helping to evaluate its performance in water or humid environments. The cubes cast were cured in the curing tank for 28 days. Then the cubes were oven-dried at 105 degrees in a drying oven for 72 hours. On removal from the oven, each specimen was cooled for 24 hours at room temperature. The weight of each specimen was taken and was immediately immersed in the water tank for 30 minutes. The specimen was removed from the water tank and was weighed again. The percentage difference was calculated to measure the water absorption.

3.5 Rapid chloride penetration test

For conducting RCPT (ASTM C1202), [25], a 50 *mm* thick and 100 *mm* diameter core was cut from the cylinder after curing for 28 days. The sample was placed between two chambers, one containing a 3% sodium chloride (NaCl) solution and the other containing a 0.3 *M* sodium hydroxide (NaOH) solution, and non-reactive electrodes were attached to each side of the sample. 60 *V* DC voltage was supplied across the sample for 6 hours. With the help of an LCD connected to the cell, the current passing through the sample at different time intervals was measured, and the total charge passed through the same was calculated. The RCPT test was conducted to evaluate concrete durability by measuring its resistance to chloride ion penetration

3.6 Acid and sulphate attack tests

For conducting Acid test (IS 14959), [26], the standard-sized concrete cubes were made and after 28 days of curing in Acid with combination of 5% H_2SO_4 (Sulphuric Acid) and 5%HCL (Hydrochloric Acid) (both concentrated) were taken into consideration to the weight of water (litre) were tested with different concentrations of nano titanium dioxide and multi-walled carbon nano tubes, ranging from 0% to 0.5%. Similarly, for testing of sulphate attack (IS 4203), [27], a combination of 5% of Na_2SO_4 (Sodium Sulphate) and 5% of Ma_2SO_4 was taken to the weight of water(litre) for both nano materials. The acid and sulphate attack tests were performed to evaluate the durability of concrete under acid and Sulphur attack, respectively.

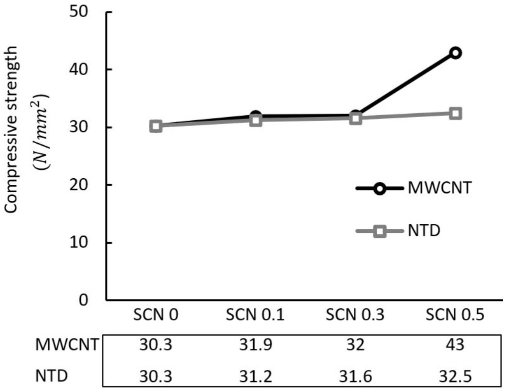
4. Results and discussions

4.1 Compressive strength

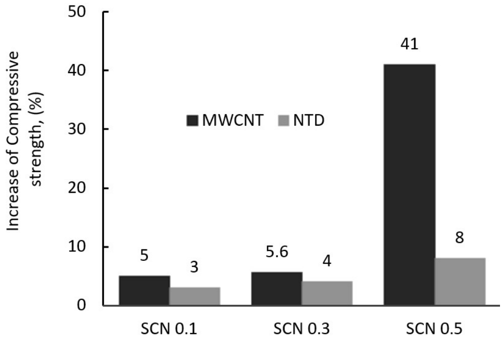
The casted cubes ($150 \times 150 \times 150$ *mm*) were tested after 7 and 28 days of curing with varying dosages of multi-walled carbon nanotubes and Nano Titanium Dioxide, ranging from 0% to 0.5%. Comparative results of compressive strength are depicted in Fig. 4 (7 Days) and Fig. 5 (28 Days), where the plotted values represent the average obtained from three individual samples of respective mix designs. From the observation done in compressive strength parameters, it can be derived that for 0.1% of NTD the percentage increase is more compared to MWCNT, whereas for 0.3% and 0.5% the percentage increase is significantly more for MWCNT compared to NTD. The reason for the same is that the larger surface area enhances reactivity and aids in filling micro- and nanopores within the concrete matrix, resulting in significant improvements in strength and durability. Simultaneously, as compared with the literature [10] and [13] specific increment of compressive strength is observed even at this proportion of Concrete.

4.2 Split tensile strength

The concrete cylinders (150 *mm* in diameter × 300 *mm* in height), were cast and tested at 28 days for specimens containing 0%, 0.1%, 0.3%, and 0.5% dosages of multi-walled carbon nanotubes and Nano Titanium Dioxide. The split tensile strength results, representing the average values obtained from three individual samples for each mix design, are illustrated in Fig. 6 (28 Days). Based on the above observation, it can be inferred that there is a notable increment in split tensile strength for both nanomaterials. However, the increase demonstrated by MWCNT is particularly high compared to NTD. As, nanomaterials improve the hydration process of cement, which produces calcium-silica-hydrate (C-S-H). C-S-H gel increases the tensile strength of the hardened cement stone matrix.

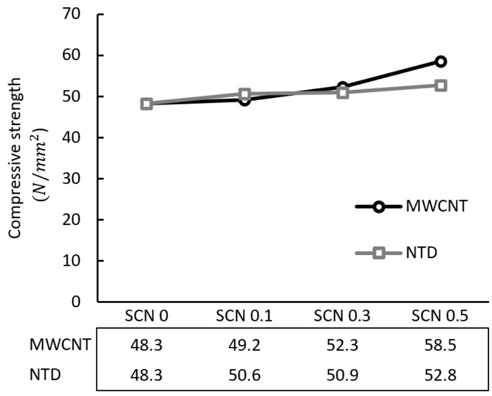


(a) Compressive strength values.

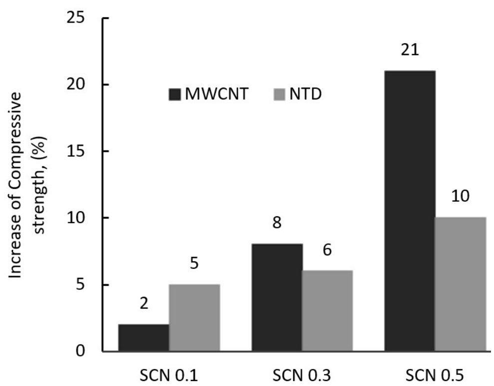


(b) Compressive strength percentage.

Figure 4. Various mixes' response after 7 days of curing for compression test.

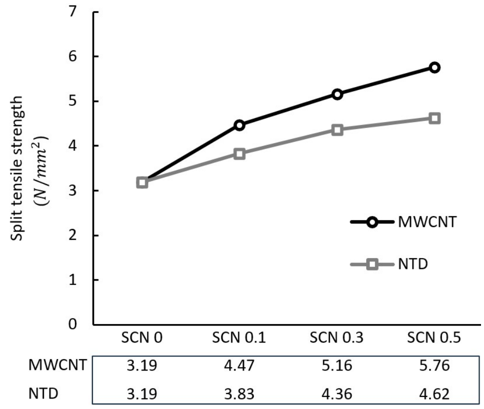


(a) Compressive strength values.

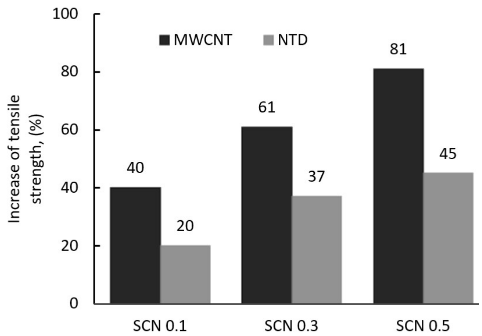


(b) Compressive strength percentage.

Figure 5. Various mixes' response after 28 days of curing for compression test.

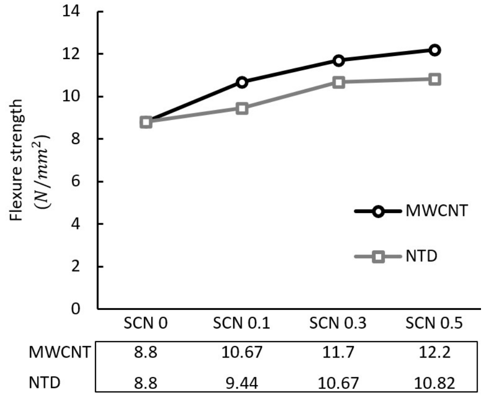


(a) Split Tensile Strength values.

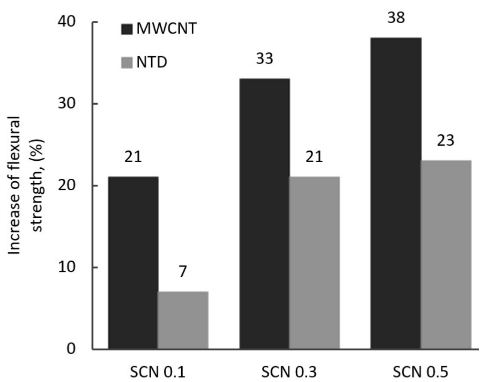


(b) Tensile Strength percentage.

Figure 6. Various mixes' response after 28 days duration for split tensile test.

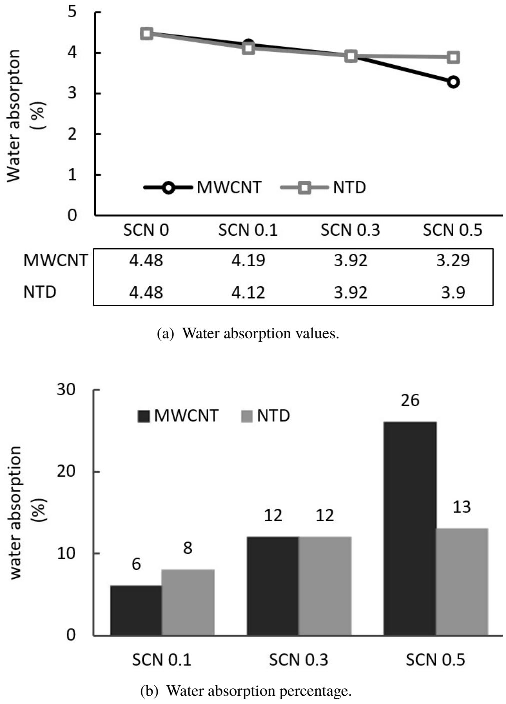


(a) Flexural strength values.



(b) Flexural Strength percentage.

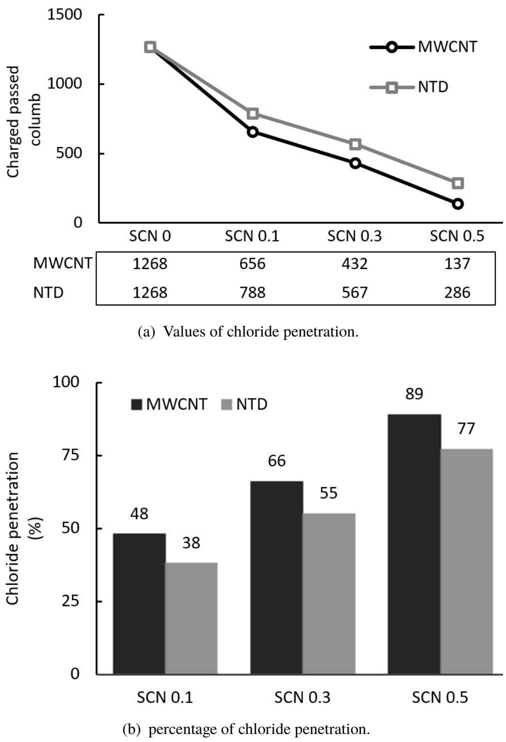
Figure 7. Various mixes' response after 28 days duration for flexure test.



(a) Water absorption values.

(b) Water absorption percentage.

Figure 8. Water absorption for various mixes.



(a) Values of chloride penetration.

(b) percentage of chloride penetration.

Figure 9. The chloride penetration for various Mixes.

4.3 Flexural strength

The beam ($500 \times 100 \times 100$ *mm*) was cast and tested under two-point bending for 28 days with varied dosages of multi-walled carbon nanotubes and Nano Titanium Dioxide ranging from 0% to 0.5%. The results of the flexural strength tests are presented in Fig. 7, where the plotted values represent the average obtained from three individual samples for each mix design. As depicted in Fig. 7, the flexural strength values after curing for 28 days exhibit notable increases. As per the above observation, it can be inferred that there is a notable increase in flexural strength for both nanomaterials. However, the increase demonstrated by MWCNT is particularly remarkable compared to NTD. The flexure strength in concrete is improved because Nanomaterials fill in cement pores and increase the surface area of the concrete.

4.4 Water absorption

Water absorption tests with $50 \times 50 \times 50$ *mm* cubes for different dosages of multi-walled carbon nanotubes and nano titanium dioxide (ranging from 0% to 0.5%), were used to evaluate the endurance of SCC. Figure 8 shows the outcomes of the water absorption experiments. Thus, based on the Fig. 8, it can be inferred that there is a significant increase in water absorption capacity for both nanomaterials, with the increases being approximately similar for 0.1% and 0.3%, but MWCNT shows a high increase in 0.5% proportion as compared to NTD.As the pores are being filled by the nanomaterials water absorption capacity of nano-modified concrete enhances.

4.5 Rapid chloride penetration test

The standard-sized concrete cubes were made, and after 28 days of curing, they were tested with different concentrations for the chloride penetration of Nano titanium dioxide and multi-walled carbon nanotubes, ranging from 0% to 0.5%. Figure 9 displays the findings from the Rapid Chloride Penetration test. As illustrated in Fig. 9, it can be inferred that there is a notable decrease in chloride penetration for both nanomaterials, with the decreases varying with respect to proportion. As the concrete's microstructure and packing level are improved by nano materials, there is a decrease in chloride penetration.

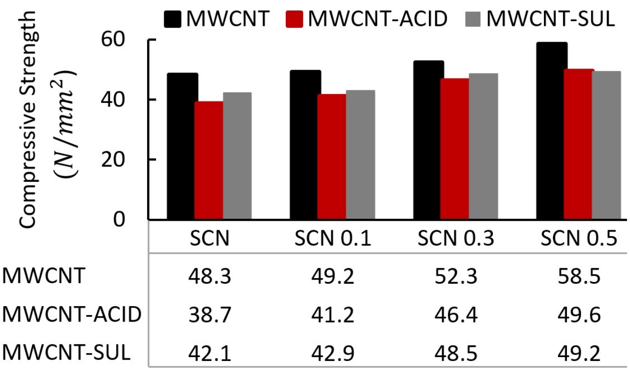


Figure 10. Comparison for Compressive strength for Acid and Sulphur attack for MWCNT.

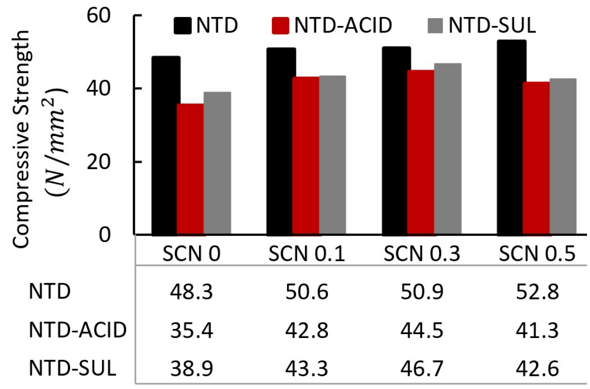


Figure 11. Comparison of Compressive strength for Acid and Sulphur attack for NTD.

4.6 Acid attack & sulphate attack test

The standard-sized concrete cubes were made, and after 28 days of curing, Acid and Sulphate Attack Tests for both nano materials were carried out. Results of the same are displayed in Fig. 10 and Fig. 11. As per the above results, it can be observed that with an increase in the proportion of Nano Materials, the resistance towards Acid and Sulphur of the concrete specimen increases. As the microstructure of concrete after adding nanomaterials becomes dense and the hydration of the binding gel is increased, more resistance to Acid and Sulphur is observed.

4.7 Cost analysis of MWCNT and NTD

The actual cost of Multi-Walled Carbon Nano Tubes used in this experiment is $Rs.52000/kg$ (purchased from Cheap Tubes USA), whereas the cost of Nano Titanium Dioxide used is $Rs.12,000/kg$ (purchased from Ad Nano Technologies-India). The cost analysis for 100 m^3 of concrete is shown in Fig. 12. As shown in Fig. 12 for casting of 100 m^3 of self compacting concrete difference in cost for 0.1% of Nano material in SCC is around 15 *Lakhs*, whereas the difference rises up to around 48 Lakhs for 0.3% of Nano material in SCC and 77 Lakhs for 0.5% Nano materials in SCC. Comparison chart (percentage increment/decrement) for $MWCNT$ and Nano TiO_2 is shown below in Table 8. Table 8 listed the detailed description of the comparison of strength as well as durability aspects for both materials. There is an increment shown in each and every property of concrete, but the split tensile strength rises significantly. In the durability part, the water absorption capacity shows a maximum increment.

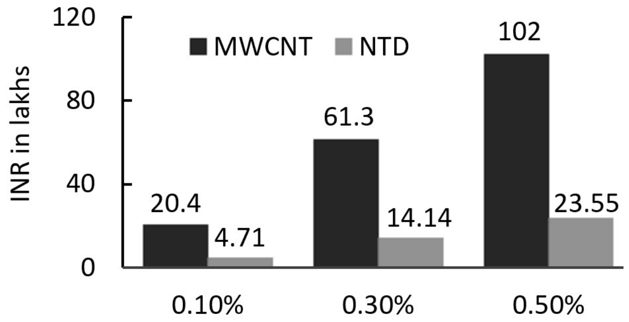


Figure 12. Cost Analysis of two Nano materials for different proportions for 100 m^3 SCC.

Table 8. Comparison Chart for increment and decrement for various tests conducted for MWCNT and NTD.

Test	Proportion, %	MWCNT, %	NTD, %
Compression	0.1	02	05
	0.3	08	06
	0.5	21	10
Split Tensile	0.1	40	20
	0.3	61	37
	0.5	81	45
Flexure	0.1	21	07
	0.3	33	21
	0.5	38	23
Water Absorption	0.1	06	08
	0.3	12	12
	0.5	26	13
RCPT (decrease)	0.1	48	38
	0.3	66	55
	0.5	89	77
Acid (decrease)	0.1	16	15
	0.3	11	12
	0.5	15	22
Sulphur (decrease)	0.1	13	14
	0.3	07	08
	0.5	16	19
Cost	0.1	20.40 Lakh	04.71 Lakh
	0.3	61.30 Lakh	14.14 Lakh
	0.5	102.0 Lakh	23.50 Lakh

5. Conclusions

Based on the test results and comparisons between multi-walled carbon nanotubes (MWCNT) and Nano Titanium Dioxide (NTD) in SCC, the following conclusions can be derived:

- There is a significant increase in compressive strength parameter for both the nano materials. The values after 7 days exhibit 5%, 5.6%, and 41% increment for MWCNT, whereas 3%,4% and 8% for NTD with 0.1,0.3, and 0.5% proportions, respectively. Simultaneously, for values after 28 days exhibit 2%,8%, and 21% increment for MWCNT, whereas 5%,6%, and 10% for NTD with the same proportions. Thus, it can be inferred from the above observation that there is a difference in compressive strength after 7 & 28 days for all three contents of nano materials. Further, it is observed that for a proportion of 0.1% of NTD, the increase in compressive strength after 28 days is more than MWCNT, which is reverse for the other two proportions. The increased surface area affects reactivity and contributes to filling micro- and nano-pores within the concrete matrix, leading to noticeable improvements in both strength and durability metrics.
- The split tensile strength values after 28 days exhibit a substantial increase. Specifically, at a 0.1% content relative to cement weight, there is a 40% increase for MWCNT and a 20% increase for NTD. This increase further escalates to 61% for MWCNT and 37% for NTD at a 0.3% content, and significantly rises to 81% for MWCNT and 45% for NTD at a 0.5% content. Hence, it can be concluded that the split tensile strength parameter shows a significant increase in split tensile strength for both the Nano materials, but the increase shown by MWCNT is remarkable as compared to NTD.
- The flexural strength values after 28 days exhibit notable increases. Specifically, at a 0.1% content relative to cement weight, there is a 21% increase for MWCNT and a 7% increase for NTD. This increase further escalates to 33% for MWCNT and 21% for NTD at a 0.3% content, and significantly rises to 38% for MWCNT and 23% for NTD at a 0.5% content. Therefore, based on the above observation, it can be inferred that there is a notable increase in flexural strength for both nano materials. However, the increase demonstrated by MWCNT is particularly remarkable compared to NTD. Also, there is not much substantial rise in flexure of NTD for 0.3 and 0.5% proportion.
- The water absorption capacity after 28 days exhibits noticeable increases. Specifically, at a 0.1% content relative to cement weight, there is a 6% increase for MWCNT and an 8% increase for NTD. This increase further escalates to 12% for MWCNT and 12% for NTD at a 0.3% content, and significantly rises to 26% for MWCNT and 13% for NTD at a 0.5% content. Hence, it can be derived that for 0.1 and 0.3% content, both the materials are showing similar increment in water absorption capacity.
- The rapid chloride penetration after 28 days demonstrates substantial decreases. Specifically, at a 0.1% content relative to cement weight, there is a 48% decrease for MWCNT and a 38% decrease for NTD. This decrease further intensifies to 66% for MWCNT and 55% for NTD at a 0.3% content, and significantly declines to 89% for MWCNT and 77% for NTD at a 0.5% content. Thus, based on the above observation, it can be inferred that there is a significant decrease in chloride penetration for both nano materials, with the decrease being greater in MWCNT as compared with CNT.
- Simultaneously, as per Acid and Sulphate attack tests, results show that with an increase in the proportion of nano materials, resistance to Acid and Sulphate increases.

Indeed, based on the observations, it can be derived that on increasing the proportion of multi-walled carbon nanotubes (MWCNT) and Nano Titanium Dioxide (NTD), significant enhancements in the properties of self-compacting concrete (SCC) are observed. However, when considering cost comparison, NTD emerges as a preferable option, particularly in situations where the construction budget is limited for big constructions. Also, considering the future aspects, other parameters of durability, which include corrosion resistance, etc, can be considered- simultaneously, comparison of other nano materials like Graphene oxide, Nano Aluminium Oxide, Nano fibres, etc can be made on similar grounds. Nano Titanium Dioxide can also be individually used for its property of self-cleaning, as its photocatalytic activity allows it to break down organic matter and remove pollutants when exposed to UV light or sunlight. Additionally, its super-hydrophilic properties help water spread out on the surface, washing away dust and dirt.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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