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Research Article

Experimental Testing on Mechanical, Durability, and Adsorption Dispersion Properties of Concrete with Multiwalled Carbon Nanotubes and Silica Fumes

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The major goal of this research is to see how carbon nanotubes and silica fume affect the durability and mechanical qualities of high-performance concrete (HPC). Mechanical properties, such as split tensile strength, compressive strength, elasticity modulus, and flexural strength, and durability properties like water absorption, abrasion, chloride penetration, acid, and sea water resistance, impact resistance of HPC consisting silica fume (SF), and carbon nanotubes (CNT) were examined in this study. Varied trail combinations with different proportions of CNT and SF admixtures were created for this reason. Portland cement was partially replaced with 1 percent, 1.5 percent, 2 percent, and 3 percent CNT, while SF was substituted with 5 percent, 7.5 percent, and 10 percent. Both CNT and SF outperform conventional concrete in terms of mechanical and durability attributes, according to the findings. CNT produces superior results than SF due to its smaller size.

1. Introduction

In India, concrete is the most extensively used building material, with annual use of more than 1000 lakh m^3. It is generally recognized that traditional concrete fails to satisfy numerous functional criteria such as permeability, environmental resistance, frost resistance, and thermal cracking. As a result, additional material developments have been produced. To meet the current demand, it is thought essential to increase the performance and strength of concrete using appropriate admixtures. HPC has gained popularity in construction because to its improved mechanical qualities and endurance. It is generally understood that admixtures such as CNT, SF, nanosilica (NS), fly ash (FA), and ground granulated glass blast-furnace slag (GGBS) are required for the manufacturing of HPC. These admixtures can increase one or both of concrete's durability and strength attributes [1].

HPC is a type of concrete with the best qualities in the fresh and hardened concrete stages. HPC is considerably better than traditional concrete because the components in HPC contribute to the different qualities most effectively and efficiently. It contains concrete that offers significantly higher structural capacity while maintaining appropriate durability or substantially better resistance to environmental impacts

Figure 1: Silica fume.

Table 1: Physical features of SF.

Property	Value
Specific gravity	2.22
Bulk density	480–720 kg/m^3
Surface area	13,000–30,000 m^2/kg
Particle size	<1 μm
Fineness modulus	20,000 m^2/kg
Bulk modulus	240 kg/m^3
Colour	Dark grey

Table 2: Chemical features of SF.

Oxides	Percentage
SiO_2	92.1
Al_2O_3	0.5
Fe_2O_3	1.4
CaO	0.5
MgO	0.3
K_2O	0.7
Na_2O	0.3
SO_3	0.17
C	0.5-1.4
S	0.1-2.5
Loss of ignition (C+S)	0.7-2.5

Table 3: Properties of fine aggregate.

Specific gravity	2.66
Fineness modulus	2.7
Bulk density	1.65 kg/m^3
Type of sand	Medium sand (zone 2)

Table 4: Superplasticizer properties.

Appearance	Light brown liquid
Relative density	1.08 ± 0.01 at 25°C
pH	>6
Chloride ion content	<0.2%

Table 5: Mix proportions of trial mixes.

S. no.	Identification of mix	Replacement of CNT (%)	Replacement of SF (%)	Superplasticizer (%)
1	Normal mix	—	—	0.4
2	1 CNT	1	—	0.4
3	1.5 CNT	1.5	—	0.45
4	2 CNT	2	—	0.5
5	3 CNT	3	—	0.6
6	5 SF	—	5	0.5
7	7.5 SF	—	7.5	0.7
8	10 SF	—	10	0.8

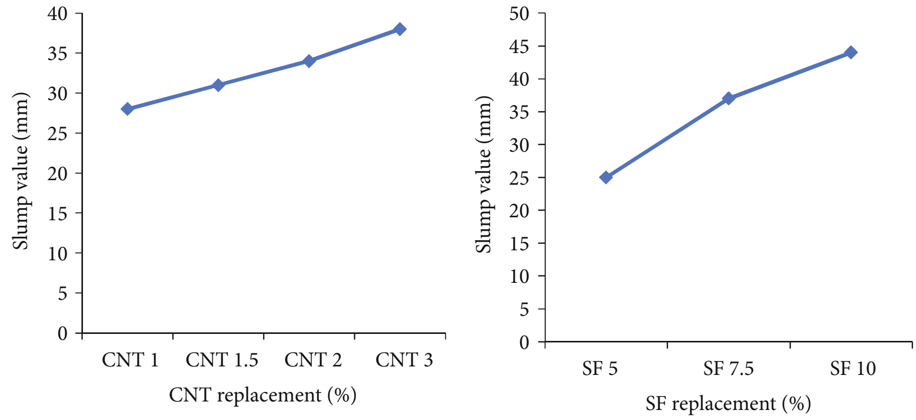
Table 6: Results of workability tests.

Identification of mix	Superplasticizer (%)	Workability in terms of		
		Slump (mm)	Compaction factor	Vee-bee (secs)
Normal mix	0.4	56	0.95	4.3
1 CNT	0.4	29	0.83	22.4
1.5 CNT	0.45	32	0.85	20.4
2 CNT	0.5	35	0.88	17.2
3 CNT	0.6	39	0.9	12.5
5 SF	0.5	26	0.8	18.2
7.5 SF	0.7	38	0.88	11.1
10 SF	0.8	45	0.93	10.2

(durability in service). Nanotechnology is a burgeoning topic of study with applications in various fields. To improve the performance of nanocomposites, only a minimal amount of nanomaterial is required. Fibers are introduced into the cementitious matrix to overcome these flaws, and the application of this microfiber reinforcement improves the mechanical characteristics of cement-based products. This microfiber addition will assist to postpone the onset of microcracks, but it will not stop them from forming. This problem can be solved by including nanofibers or nanoparticles in cement. It has paved the way for the development of "nanoengineered ultra-high-performance materials" and the development of a new era of "crack-free materials." Conventional concrete will be transformed into a self-monitoring, crack-resistant, multipurpose smart material.

One of the most significant components in improving the microstructure of concrete is silica. In concrete, adding microsilica pozzolan gives the greatest results. This substance is made of 0.01 millimeter spherical grains that include 90% percent amorphous silica. Because it has a larger percentage of amorphous silica (greater than 99 percent) and smaller particles, its performance can be better than microsilica (1-50 nanometer). Compared to other pozzolan, it has the smallest particle size and the highest amount of amorphous silica, so its reactivity should be stronger. Because of its great reactivity, its usage is substantially lower than others'.

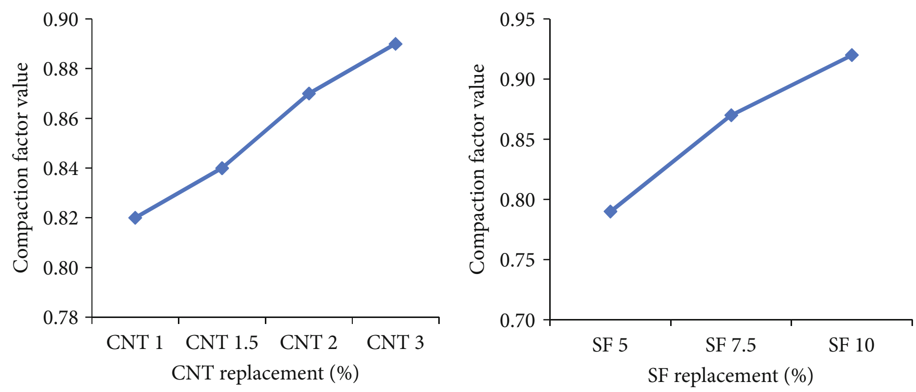
The goal of this study is to look at the mechanical and durability qualities of M60 grade HPC after replacing 1 percent, 1.5 percent, 2 percent, and 3 percent of the mass of



(a) % of CNT replacement

(b) % of SF replacement

Figure 2: Variation of slump value.



(a) % of CNT replacement

(b) % of SF replacement

Figure 3: Variation of compaction factor value.

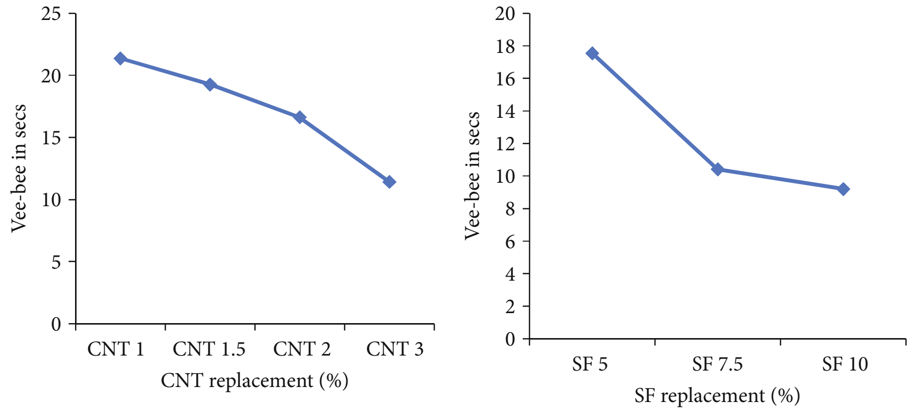
cement with CNT and 5 percent, 7.5 percent, and 10 percent of mass of cement with SF at a fixed water to binder (W/B) ratio, i.e., 0.31. This study is aimed at discovering the optimum amount of CNT and SF for cement substitution that would offer HPC exceptional durability and mechanical properties.

2. Literature Review

Wille and Loh studied the influence of CNT on the fresh and rheology characteristics of cement paste and mortar [2]. The influence of amorphous CNT particles added in cement pastes is investigated. Rheological experiments reveal after 75 minutes of mixing, mortar containing 2.5 percent by weight CNT has inadequate flowability to be monitored continuously in a Viskomat PC viscometer. Compared to plastic viscosity, the effect of CNT concentration on yield stress is more noticeable. When CNT was added, the spread, setting time, and time to achieve maximum temperature all lowered by 33 percent, 60 percent, and 51.3 percent, compared to specimens that did not have CNT. After 9 hours, X-ray diffraction in the sample containing 2.5 weight percentage CNT reveals the existence of calcium hydroxide. When CNT is introduced, the air content increases by 79 percent but the apparent density decreases by 2.4 percent.

Elahi et al. [3] investigated the mechanical and long-term durability of HPC adding extra cementitious materials. The compressive strength was used to evaluate the mechanical features, while the electrical resistivity, chloride diffusion, water absorption, and air permeability were used to study the durability characteristics. The kind and amount of extra cementitious materials were among the test variables (GGBS, FA, and SF). GGBS, FA, and SF were used to substitute portland cement up to 70 percent, 40 percent, and 15 percent, respectively. According to the findings, in terms of bulk resistivity and strength development, SF outperforms other supplemental cementitious materials. The mixes comprising GGBS, FA, and SF performed the best of all the mixes to resist chloride diffusion. Permeation findings were favourable in the mix including FA. All of the ternary mixes have produced HPC with good durability.

Coppola et al. [4] published a research that compared the impacts of CNT and NS in concrete. The local mechanical characteristics of cement pastes with 0 percent and 15 percent CNT replacement were measured using nanoindentation and scanning probe microscope imaging. The



(a) % of CNT replacement

(b) % of SF replacement

Figure 4: Variation of vee-bee consistometer.

Table 7: Results of compressive strength.

Identification of mix	Average compressive strength (N/mm^2) 1st day	3rd day	7th day	28th day	56th day	90th day
Normal mix	12.6	37.1	38.8	62.4	64.9	67.4
1 CNT	18	40	46	67	70.2	70.5
1.5 CNT	21.5	44	48.3	69	70.7	71.9
2 CNT	22	48	52.6	72.1	73.2	78.9
3 CNT	21.9	48.4	51.7	70.2	71	72.9
5 SF	13.3	40.1	44	63.9	74.7	77.1
7.5 SF	13.7	42.6	46.2	69	76.7	78.3
10 SF	16.1	38.7	45.7	64.6	75.2	77.9

presence of pozzolanic reaction is demonstrated by a decrease in volume percentage of $Ca(OH)_2$ in sample containing CNT. NS considerably enhances the durability of concrete, according to a parallel investigation of cement pastes containing NS. The impacts of NS on cement paste nanostructure are described in this paper and their impact on concrete durability. According to the nanoindentation investigation, the volume percentage of the high-stiffness calcium silicate hydrate (C-S-H) gel rose dramatically with the addition of NS. The findings of nanoindentation on cement paste samples containing equivalent amounts of CNT and NS are compared. CNT samples contained about double the quantity of high-stiffness C-S-H as NS samples. The volume proportion of high-stiffness C-S-H was as high as 50% in samples containing 15 percent CNT.

Lu et al. [5] studied the impact of polypropylene fibers on physical and mechanical characteristics of CNT mortars. Four fiber fractions 0 percent, 0.1 percent, 0.3 percent, and 0.5 percent are taken. In the first phase of the research, 6 batches were made to determine the optimal quantity of CNT in regular cement mortar. In the second stage, 0.1 percent, 0.3 percent, and 0.5 percent polypropylene fibers were added to the ordinary and optimum mixtures selected in the first stage, to determine the impact of the polypropylene fibers on the shrinkage and strength properties. According to the findings, using polypropylene fibers in the cement matrix resulted in a small increase in flexural and compressive strength. The influence of increasing the fiber content to mechanical strength was negative. The inefficient dispersion of polypropylene fibers in mortar, which increases pore volume and causes additional micro flaws in the cement matrix, might be one explanation for this result. The addition of CNT particles boosted the efficiency of the fiber reinforcement in terms of mechanical strength. This might be owing to a decrease in internal porosity, particularly in the fiber/matrix transition zone, which has a greater contact surface and thus friction between 2. The addition of CNT to mortars reduced water absorption. The inclusion of CNT in the cement matrix enhanced the dying shrinkage of mortar. Fiber reinforcing in cement mortar might help to mitigate this impact. However, using a high fiber content (more than 0.3 percent) did not affect shrinkage strain.

The mechanical characteristics of concrete containing CNT and NS were examined by Hawreen and Bogas [6]. This study is aimed at looking at the impact of adding NS to regular concrete and compare it to CNT. CNT and NS are partly replaced with cement in this study by 2 percent, 4.5 percent, and 7.5 percent cubic samples of 10 cm with breaking three samples from each plan for seven compressive strength experiment mixtures aged 3, 7, 28, 90, and 180 days. In primary ages, the importance of CNT in compressive strength is inferred. However, as time passes, this decreases, and its peak activity is between 7 and 28 days old. They discovered that adding 3 to 12 percent CNT to mortar increases its strength by three to four times.

The influence of CNT on the mechanical characteristics and microstructure of cement mortar was studied by Baloch et al. [7]. The impact of the size and amount of CNT particles on the mechanical characteristics and microstructure of manufactured cement mortar are examined in this work. The measurements are taken on the 7th day after the cement mortar is produced. Compared to the pure cement mortar, the cement mortar incorporating CNT had improved mechanical qualities. Because the manufacturing procedure utilized here resulted in a uniform spreading of CNT in cement, its mechanical characteristics improved even when

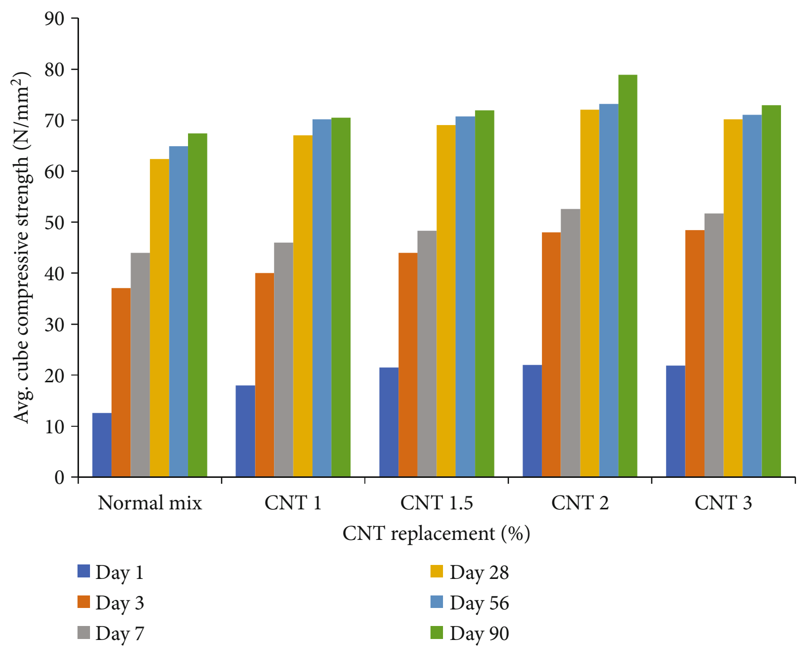


Figure 5: Fluctuation of compressive strength for % of CNT replacement.

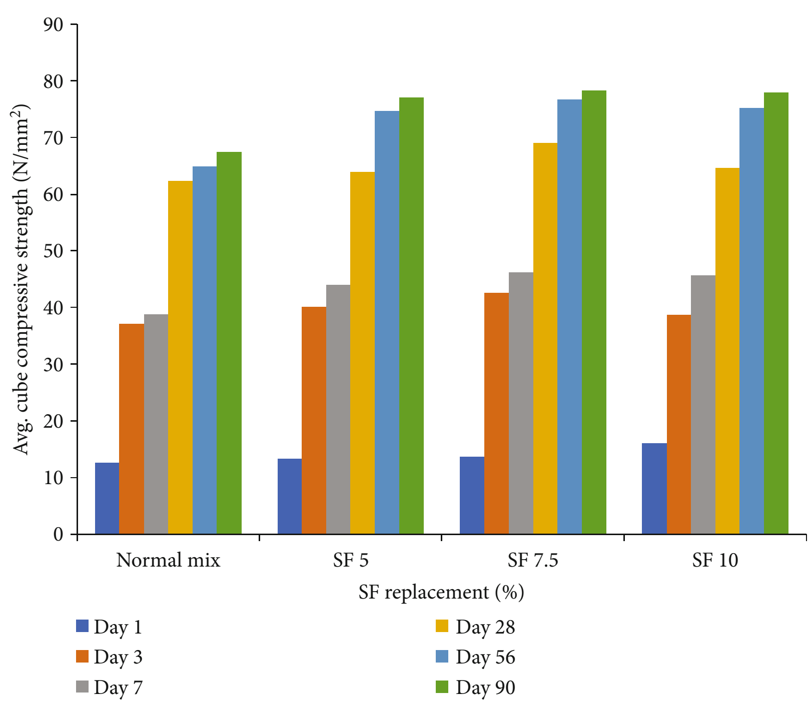


Figure 6: Fluctuation of compressive strength for % of SF replacement.

just 1% CNT were added. In other words, adding a critical quantity of CNT enhanced the compressive strength. The addition of CNT to regular cement mortar improves its mechanical qualities (compressive, flexural, and tensile strengths).

The influence of CNT on concrete with ordinary cement and ordinary cement + Class F fly ash binders was examined in this study. Hawreen and Bogas [8] studied the characteristics of CNT-infused concrete. In terms of strength development, reactivity, densification of the interfacial transition zone, and pore refinement mixes including CNT showed significant improvement. The enormous surface area of CNT particles, which has pozzolanic and filling effects on the cementitious matrix, is primarily responsible for this enhancement. According to microstructural and thermal studies, the impact of filler and pozzolanic effects on pore

Table 8: Split tensile strength of concrete at the 28th day.

Identification of mix	CNT (%)	SF (%)	Split tensile strength (N/mm^2)
Normal mix	0	0	5.78
1 CNT	1	0	6.6
1.5 CNT	1.5	0	6.83
2 CNT	2	0	7.21
3 CNT	3	0	7
5 SF	0	5	6.30
7.5 SF	0	7.5	7.25
10 SF	0	10	6.89

structure improvement was shown to be dependent on the dose of CNT.

Electrical resistivity, water absorption, and chloride penetration of HPC incorporating NS and SF were studied by Jalal et al. [9]. This work explored the durability-related aspects of high strength self-compacting concrete incorporating NS and SF, including electrical resistivity, water absorption, and chloride penetration. Varied combinations with different SF and NS admixtures are created for this purpose. Microsilica, NS, and a combination of micro- and nanosilica are used to substitute portland cement in varied proportions of 10 percent, 2 percent, and 10 percent + 2 percent, respectively. The influence of binder content on concrete qualities is also explored using different binder contents. Capillary absorption, water absorption, resistivity tests, and chloride ion percentage are used to assess durability attributes. The findings demonstrate that in combinations including admixtures, such as a blend of SF and NS, capillary absorption, water absorption, and chloride ion percentage, all fell dramatically. The admixtures boosted the resistivity of the self-compacting concrete mixes, which might reduce corrosion risk.

The influence of W/C ratio on permeability, porosity, and abrasive strength of CNT concrete was studied by Hawreen et al. [10]. This study is aimed at seeing how the water-cement ratio affects the porosity, abrasive strength, and coefficient of hydraulic conductivity of CNT concrete. The water-cement ratios directly or indirectly affect abrasion resistance, porosity, efficiency, and other properties. When CNT was combined with cement mortar, it resulted in an upgraded concrete with great strength and abrasion resistance. The water-cement ratios were adjusted in this study to analyze and assess concrete specimens' abrasive and compressive strength. The water-cement ratios in the mixture ranged from 0.33, 0.36, 0.4, 0.44, and 0.5 in the produced concrete samples, which contained 3 percent CNT. In all concrete samples, the other components of the mixture were kept constant. The abrasion strength of concrete was enhanced by 36 percent by lowering the W/C ratio from 0.5 to 0.33. The hydraulic conductivity coefficient of concrete decreases from 31.71×10^{15} to 2×10^{15} m/sec when the W/C ratio is decreased from 0.5 to 0.33. In addition, the concrete's porosity was lowered, and the W/C ratio was decreased from 0.5 to 0.33. The abrasion depth decreased as the W/C ratio grew from 0.33 to 0.5 for silica fume and natural pozzolanas on sulfuric acid.

The characteristics of concrete adding SF and NS were given by Tavakoli and Heidari [11]. The study looks at the usage of NS and SF in concrete simultaneously. To achieve this, SF in concentrations of 5 and 10% and NS in concentrations of 0.5 and 1% were substituted with cement and a total of eight mixture designs were used to conduct compressive strength and water absorption tests. Compared to the control sample, using both 10 percent SF and 1 percent NS as a cement substitute resulted in a 42.2 percent improvement in compressive strength. Furthermore, it was discovered that using these components simultaneously had a greater impact than using them separately. Finally, the findings revealed that employing such components enhances concrete quality.

3. Materials Used in HPC

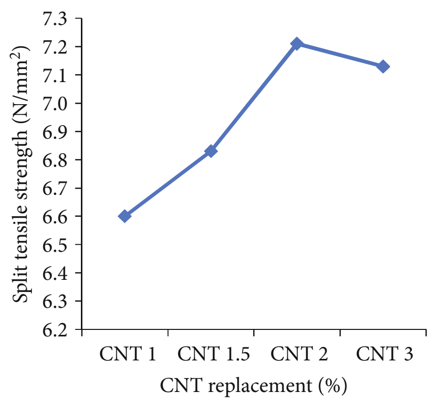
3.1. Cement. The cement utilized in this investigation was 53 grade ordinary portland cement, often used in the construction sector. The physical characteristics of cement were determined using a pycnometer and Vicat's apparatus, as per IS 12269:1987 (reaffirmed 2004). The results show that cement's specific gravity, initial, final setting time, and standard consistency are 3.12, 125 min, 281 min, and 32%, respectively.

3.2. Silica Fume. For many years, SF has already been employed worldwide in the construction of high-strength, long-lasting concrete. Both fresh and hardened concretes benefit from the addition of SF. SF is a by-product of the smelting process in silicon and ferrosilicon industries. At high temperatures approximately 2,000°C, the reduction of high-purity quartz to silicon produces SiO_2 vapours, which oxidize and condense in the low-temperature zone to microscopic particles. The SF is indicated in Figure 1.

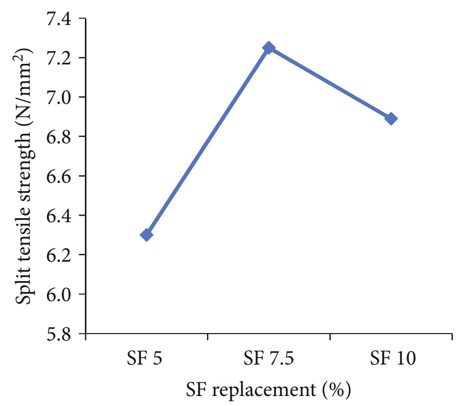
Tables 1 and 2 show SF physical and chemical features.

3.3. Carbon Nanotubes. CNTs are a relatively new addition to the concrete industry as a nanoscale reinforcement. These materials are single-walled or multiwalled hollow cylinder graphite sheets [12]. In this study, multiwalled carbon nanotubes were used. With Young's modulus of one TPa, these materials have a high rigidity. It has a tensile strength of above 100GPa and can endure strain elongation of up to 15%-16% [13]. It also offers greater adsorption capabilities due to its larger specific area (approx. 1000 m^2/g). CNT acts in cement-based composites because it increases the interfacial contact area and efficiently stabilizes the concrete mixture.

3.4. Coarse Aggregate. The aggregate strength and the binding between the aggregate and paste become crucial considerations in HPC. Crushed-stone aggregates have a greater compressive strength than gravel aggregate in concrete. Crushed aggregate with a size of 12.5 mm and an angular form was employed in this investigation.



(a) % of CNT replacement



(b) % of SF replacement

FIGURE 7: Split tensile strength variation at the 28th day.

TABLE 9: Concrete flexural strength at the 28th day.

Identification of mix	CNT (%)	SF (%)	Flexural strength (N/mm^2)
Normal mix	0	0	7.5
1 CNT	1	0	8.0
1.5 CNT	1.5	0	8.5
2 CNT	2	0	10.5
3 CNT	3	0	9
5 SF	0	5	8
7.5 SF	0	7.5	9.5
10 SF	0	10	9

3.5. Fine Aggregate. According to the IS:2386 (Part-3):1963 limitations, the fine aggregate was examined. Table 3 give the properties of fine aggregates.

3.6. Water. Water is a significant component of cement paste because it participates chemically in the events that lead to the formation of the hydration product, C-S-H gel. The binding activity of C-S-H gel is primarily responsible for the strength of cement paste. The compatibility of the provided cement with the chemical and mineral admixtures and the water used for mixing is critical for HPC. The quality and quantity of water must be constantly monitored.

3.7. Superplasticizer. Chemical admixtures like superplasticizers, water reducers, and retarders are required. They assist in getting the least practicable W/B ratio by making better use of enormous quantities of cement in HPC.

GLENIUM B233 polycarboxylic ether based superplasticizer is employed in this work. Table 4 lists the characteristics of GLENIUM B233. The product was designed particularly for use in HPC applications that demand excellent workability, performance, and durability. GLENIUM B233 keeps rheoplastic concrete workable for more than 45 minutes at +25°C. Temperature and the kind of cement, the manner of transport, the nature of aggregates, and starting workability all influence workability loss. Trial mixes should be used to find the best dose of GLENIUM B233.

4. Experimental Investigations

4.1. Proportion of Mix Achieved by Phase I. Various mixes for M60 grade are determined using the ACI [14] technique of mix design. The mix percentage is determined by testing both fresh and hardened concretes based on the trail mixes. The compressive strength and workability tests are used to determine the mix percentage. The final mix percentage for partial cement replacement by SF of 5 percent, 7.5 percent, and 10 percent and CNT of 1 percent, 1.5 percent, 2 percent, and 3 percent is chosen to achieve both compressive strength and workability of concrete. With a W/B ratio of 0.31, the mix percentage obtained from the trail mixes is 1 : 0.82 : 2.07.

4.2. Mix Proportions for Replacement. At a steady water-binder ratio of 0.31, the cement was partially substituted with CNT by 1 percent, 1.5 percent, 2 percent, and 3 percent and SF by 5 percent, 7.5 percent, and 10 percent, based on the mix proportions determined in phase I. For the M60 grade, a total of 7 trail mixes have arrived. A polycarboxylic ether-based superplasticizer is utilized in all of the combinations above to make workable concrete. The amount of superplasticizer used varies by % to obtain the desired slump. Table 5 shows the varying percentages of CNT and SF replacement.

The details of concrete specimens cast for the M60 grade of HPC mixes are as follows:

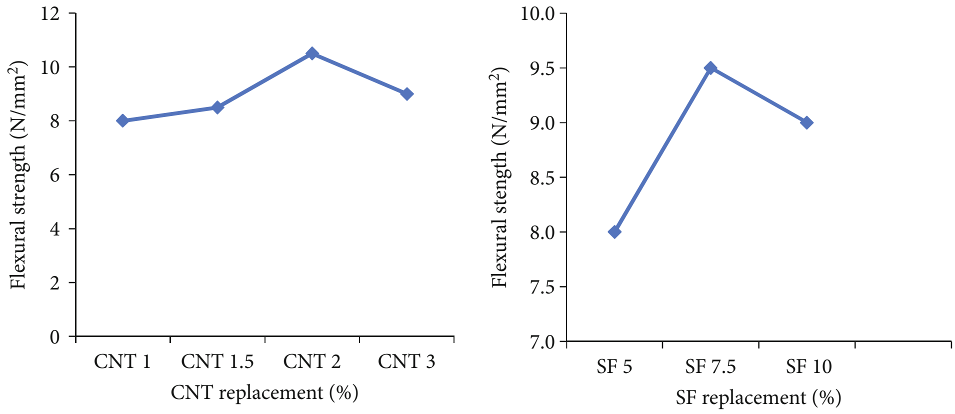
(i) 144 nos. of cube specimen of size 100 × 100 mm

(ii) 28 nos. of cylindrical specimens of size 150 mm × 300 mm

(iii) 32 nos. of cylindrical specimens of size 100 mm × 200 mm

(iv) 21 nos. of prisms of size 100 mm × 100 mm × 500 mm

(v) 21 nos. of cylindrical specimens of size 150 mm × 63 mm



(a) % of CNT replacement

(b) % of SF replacement

Figure 8: Variation of flexural strength at the 28th day.

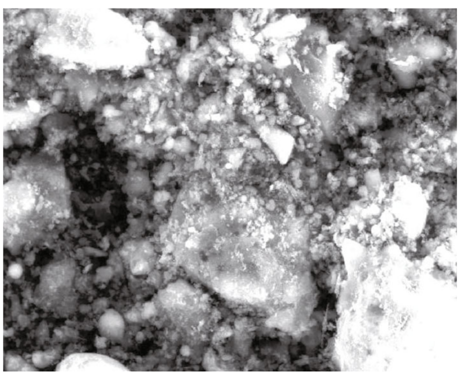


Figure 9: SEM image.

Table 10: Modulus of elasticity of concrete at the 28th day.

Identification of mix	CNT (%)	SF (%)	Modulus of elasticity (N/mm^2)
Normal mix	0	0	45000
1 CNT	1	0	55000
1.5 CNT	1.5	0	68000
2 CNT	2	0	77000
3 CNT	3	0	71000
5 SF	0	5	50000
7.5 SF	0	7.5	68000
10 SF	0	10	60000

(vi) 21 nos. of cylindrical specimens of size 70 mm × 70 mm × 35 mm

(vii) 42 nos. of cube specimens of size 150 mm

5. Results and Discussions

5.1. Workability of Concrete. The results of workability tests on fresh concrete such as the compaction factor test, vee-bee consistometer test, and slump test were done according to BIS [15] requirements, and the results are displayed in Table 6.

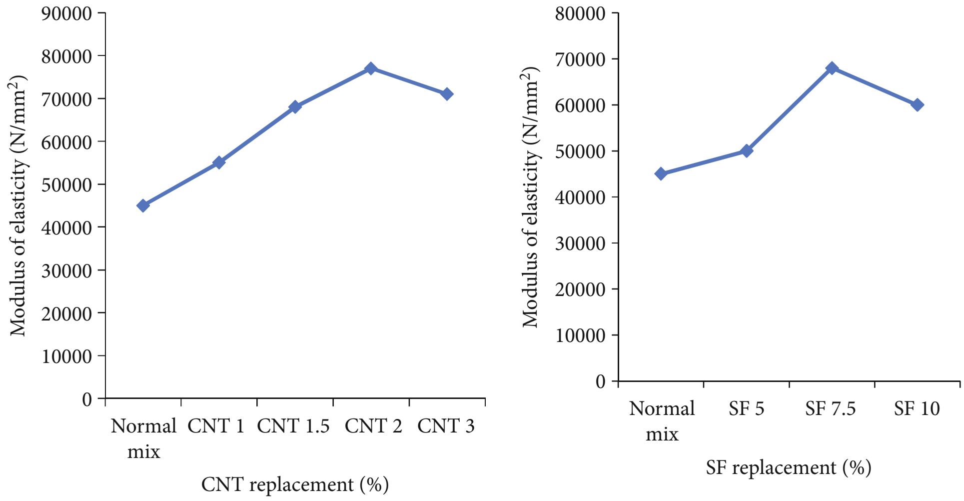
For all of the mixtures, the W/B ratio was kept consistent at 0.31. The test findings show that increasing the superplasticizer content improved the workability of concrete when CNT and SF were largely replaced for cement. Workability is reduced because of the inclusion of CNT and microsilica with a high specific surface area. To maintain a consistent slump, such an impact may increase water use. To keep water demand equivalent to that of the control, superplasticizers should be dosed by weight of CNT and microsilica. Figures 2–4 depict the variance of workability test results.

5.2. Concrete Compressive Strength. Compressive strength tests were performed on cube specimens at various ages including 1, 3, 7, 28, 56, and 90 days, and the findings are presented in Table 7.

When CNT and SF are introduced to concrete, the compressive strength of the mixture changes dramatically. This is mostly owing to improved aggregate-paste bonding and microstructure. The test findings show that when CNT is partially replaced with cement, the compressive strength of concrete is enhanced at an earlier age. The blend containing 3 percent CNT and 7.5 percent SF yielded the highest compressive strength. The synthesis of C–S–H was generated by the interaction of CNT and SF with calcium hydroxide created during the hydration of cement. It was partly because of the filling role of very tiny CNT and SF particles. Furthermore, early compressive strength gains were lower in concrete containing various amounts of SF. Figures 5 and 6 demonstrate the fluctuation in compressive strength for a mix including CNT and SF at various ages.

5.3. Split Tensile Strength. Table 8 shows the split tensile strength of concrete containing CNT and SF after 28 days of testing.

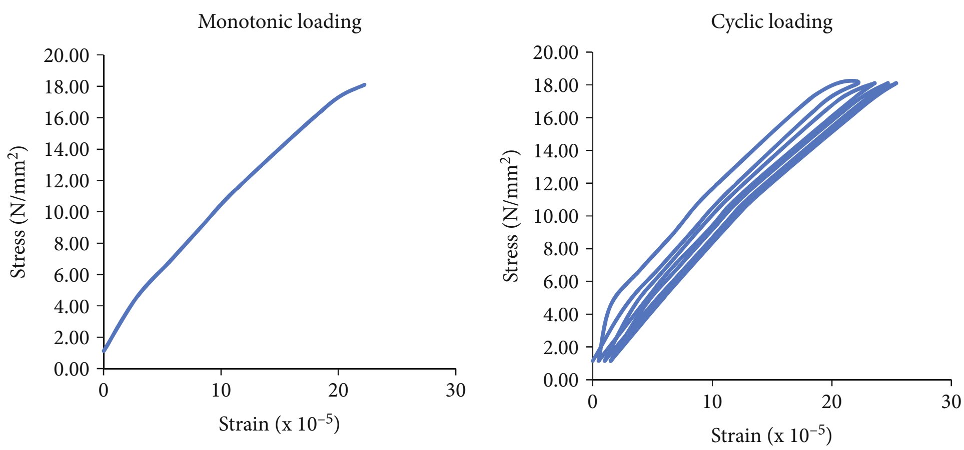
According to the test findings, the split tensile strength improved steadily as the % of CNT content was raised. When SF was partially replaced, however, the split tensile strength was raised until it reached 7.5 percent replacement, after which it was lowered. The variation of split tensile strength for the mix containing CNT and SF is shown in Figure 7.



(a) % of CNT replacement

(b) % of SF replacement

Figure 10: Variation of modulus of elasticity.



(a) Monotonic loading

(b) Cyclic loading

Figure 11: Stress-strain curve for 1% of CNT.

5.4. Flexural Strength. Table 9 shows the concrete flexural strength test results on the 28th day.

The variation of the flexural strength concrete containing CNT and SF is depicted in Figure 8.

Compared to splitting tensile strength, adding CNT and SF to the concrete significantly influences flexural strength. Even extremely high percentages of CNT and SF boost flexural strengths dramatically. It was also discovered that the flexural strength increased steadily when the SF replacement % was increased.

5.5. Adsorption Characteristics of Carbon Nanotubes. A micrograph of shattered concrete species was seen after the compressive strength test at 28 days. The CNT samples with dispersion with other components may be observed. The CNT samples, as well as SF samples, are visible in Figure 9. A closed cluster of CNT can be seen in some parts of the micrograph.

5.6. Modulus of Elasticity of Concrete. The test results of the modulus of elasticity of concrete containing CNT and SF are shown in Table 10.

The slope of a stress-strain curve formed during compressive testing on a sample of the material can be calculated experimentally. According to the test findings, the concrete elastic modulus was raised for the concrete containing CNT and SF. The rise in Young's modulus of CNT-containing concrete is greater than that of SF-containing concrete due to the higher specific surface. Figure 10 depicts the modulus of elasticity change for CNT and SF mixes.

Strain curve under monotonic loading and cyclic loading are shown in Figure 11.

5.7. Saturated Water Absorption. Table 11 shows the saturation water absorption test results for HPC trail mixes at the ages of 28 and 90 days.

On the 28th and 90th days, the trail mixes' saturation water absorption varied from 1.5 to 1.65%. The Concrete

Table 11: Saturated water absorption test results.

Identification of mix	CNT (%)	SF (%)	Saturated water absorption (%) 28th day	90th day
Normal mix	0	0	1.656	1.652
1 CNT	1	0	1.59	1.551
2 CNT	2	0	1.565	1.519
3 CNT	3	0	1.517	1.51
5 SF	0	5	1.586	1.576
7.5 SF	0	7.5	1.553	1.591
10 SF	0	10	1.541	1.576

Table 12: Results of porosity.

Identification of mix	CNT (%)	SF (%)	Effective porosity (%) 28th day	90th day
Normal mix	0	0	2.534	2.529
1 CNT	1	0	2.413	2.411
2 CNT	2	0	2.316	2.312
3 CNT	3	0	2.312	2.309
5 SF	0	5	2.514	2.510
7.5 SF	0	7.5	2.418	2.412
10 SF	0	10	2.396	2.391

Table 13: Results of sorptivity.

Identification of mix	CNT (%)	SF (%)	Sorptivity $(mm/min)^{0.5}$ 28th day
Normal mix	0	0	0.085
1 CNT	1	0	0.073
2 CNT	2	0	0.06
3 CNT	3	0	0.05
5 SF	0	5	0.081
7.5 SF	0	7.5	0.064
10 SF	0	10	0.053

Table 14: Rapid chloride permeability results.

Identification of mix	CNT (%)	SF (%)	Charge passed as per ASTM equivalent (coulombs)	Chloride ion penetrability
Normal mix	0	0	1368	Low
1 CNT	1	0	917.1	Very low
2 CNT	2	0	982.8	Very low
3 CNT	3	0	1053	Low
5 SF	0	5	909	Very low
7.5 SF	0	7.5	881.1	Very low
10 SF	0	10	558.9	Very low

Table 15: Acid resistance test results.

Identification of mix	CNT (%)	SF (%)	Acid resistance Loss in weight (%)
Normal mix	0	0	0.39
1 CNT	1	0	0.3
2 CNT	2	0	0.35
3 CNT	3	0	0.3
5 SF	0	5	0.56
7.5 SF	0	7.5	0.45
10 SF	0	10	0.43

Society of the United Kingdom describes that concrete with a saturated water absorption limit of roughly 3%, as excellent concrete. This indicates that the performance of CNT and SF in filling the pores in the concrete was excellent due to their particle size. According to the test findings, the combination CNT 3 and SF 10 has the lowest saturated water absorption value [16].

5.8. Porosity. The porosity test results at the 28th and 90th day for the various HPC trail mixes are given in Table 12.

The effective porosities for the trail mixes at the 28th day are ranged from 2.31 to 2.53 percent. The results show that the effective porosity value is lower for the mix containing 3% of CNT and 10% of SF [17]. This was due to the microfilling effect of CNT and SF, and it concludes that CNT and SF have a good durability characteristic [18].

5.9. Sorptivity. The test results of sorptivity are given in Table 13 for HPC trail mixes at the age of 28 days.

The results are varied from 0.05 to 0.08 for both CNT and SF replacements. The test results can be concluded that CNT replacement performs better than the SF [19].

5.10. Rapid Chloride Permeability Test. Table 14 shows the results of the rapid chloride permeability test on the 28th day for the various HPC trail mixes.

The test results show that the lowest amount of charge is passed for the specimens containing 3% of CNT and 10% of SF [20]. The charges that passed through the specimens are ranged from 550 to 1050 coulombs [21]. The chloride penetration resistance is much higher for the mix containing 3% of CNT and 10% SF [22]. The charges that passed through the conventional concrete are higher than the HPC mix containing CNT and SF. This is due to the pozzolanic reactivity and microfilling effects of CNT and SF [23].

5.11. Acid Resistance. The test results of acid resistance are shown in Table 15 for the various HPC trail mixes at the age of 28 days.

The percentage loss in weight for the mixes containing CNT ranges from 0.3 to 0.35 and for SF ranges from 0.43 to 0.56 [24]. The test results show that the CNT performs better than the SF against acid attack [25].

Table 16: Sea water resistance test results.

Identification of mix	CNT (%)	SF (%)	Sea water resistance Loss in weight (%)
Normal mix	0	0	0.86
1 CNT	1	0	0.5
2 CNT	2	0	0.60
3 CNT	3	0	0.7
5 SF	0	5	0.7
7.5 SF	0	7.5	0.52
10 SF	0	10	0.4

Table 17: Abrasion resistance test results.

Identification of mix	CNT (%)	SF (%)	Abrasion resistance Average loss of thickness (mm)
Normal mix	0	0	0.92
1 CNT	1	0	0.42
2 CNT	2	0	0.35
3 CNT	3	0	0.29
5 SF	0	5	0.67
7.5 SF	0	7.5	0.48
10 SF	0	10	0.35

Table 18: Impact resistance test results.

Identification of mix	Average number of drops for initial crack	Average number of drops at failure	Energy at initial crack (E_1) (N mm)	Energy at failure (E_2) (N mm)	Ductility index (s)
Normal mix	301	305	6327517	6411604	1.01329
1 CNT	346	351	7273492	7378600	1.01445
2 CNT	367	372	7714947	7820055	1.01362
3 CNT	384	390	8072315	8198445	1.01562
5 SF	396	402	8324574	8450704	1.015
7.5 SF	338	342	7105319	7189405	1.01183
10 SF	352	366	7399622	7693925	1.03977

5.12. Sea Water Resistance. The results of sea water resistance are shown in Table 16 for the various trail mixes of HPC at the age of 28 days.

The percentage loss in weight for CNT ranges from 0.5 to 0.7 and for SF is 0.4 to 0.7 [26]. The test results have been observed that the HPC trail mixes have high resistance against sea water. Especially for 1% of CNT and 10% of SF, they are less attacked by the sea water [27].

5.13. Abrasion Resistance. The results of abrasion resistance also shown in Table 17 for various trail mixes of HPC at the age of 28 days.

The average loss of thickness for the HPC mix containing CNT ranges from 0.29 to 0.42 mm and for SF ranges from 0.35 to 0.67 mm [28]. Thus, the mixes containing CNT showed less average thickness loss than those containing SF [29]. Both CNT and SF have high abrasion resistance than the normal mix concrete [30].

5.14. Impact Resistance. The impact resistance tests are given in Table 18 for the HPC trail mixes at the age of 28 days.

Due to admixtures like SF and CNT, the concrete was well packed. The average number of drops at failure for the mixes is ranged from 305 to 402. The mix containing 3% of CNT shows better resistance than the other mixes. The impact resistance of the concrete is increased due to the conversion of calcium hydroxide to the calcium hydrates by CNT and SF in the concrete.

6. Conclusions

From the acquired experimental data, the following conclusions may be drawn:

(i) The HPC mixes require more water due to the specific surface area and particle size of SF and CNT. The superplasticizer dose is adjusted from 0.4 to 0.8 percent by weight of cement to produce the desired workability

(ii) When utilizing SF, the superplasticizer dose is greater than when using CNT

(iii) The average compressive strength at 28 days rose by 1.41 percent, 1.8 percent, 2.2 percent, and 2 percent for the mixes containing 1 percent, 1.5 percent, 2 percent, and 3 percent of CNT, respectively. At the 56th and 90th days, the compressive strength increases

(iv) The average cube compressive strength increases until it reaches 2 percent of CNT, which begins to decline. As a result, predicting the optimal CNT replacement content is challenging

(v) The average compressive strength at 28 days rose by 1.2 percent, 1.5 percent, and 0.8 percent for the mixes containing 5 percent, 7.5 percent, and 10 percent of SF, respectively

(vi) The flexural strength and split tensile strength of the mix comprising 1 percent, 1.5 percent, 2 percent, and 3 percent CNT are rising up to 2 percent CNT. The flexural strength and split tensile strength of the mix including SF only increase up to 7.5 percent SF

(vii) Concrete having CNT has a greater elasticity modulus than concrete containing SF. Substantial deformation increases in a linear fashion

(viii) Porosity, sorptivity, and water absorption are lower in trail mixes with the CNT substitution than in SF. This suggests that the size of the CNT particles is important in making the concrete impermeable

(ix) Concrete mixes including SF and CNT are more resistant to abrasion, impact load, acid, and seawater assault and chloride penetration. This is owing to the microstructure improvement brought about by the filler actions of SF and CNT, which result in discontinuous and fine pore structure

(x) The performance level of CNT is superior to that of SF and normal concrete in terms of durability and mechanical qualities. As a result, it can be inferred that CNT replacement has higher durability and mechanical properties by up to 3 percent. According to the test results, the ideal SF replacement content is just 7.5 percent

(xi) The partial substitution of SF and CNT with cement results in a reduction in cement use

Data Availability

The data used to support the findings of this study are included within the article. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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References

[1] P. C. Aitcin, *High Performance Concrete*, E & FN Spon An imprint of routledge publications, 1998.

[2] K. Wille and K. J. Loh, "Nanoengineering ultra-high-performance concrete with multiwalled carbon nanotubes," *Transportation Research Record*, vol. 2142, no. 1, pp. 119–126, 2010.

[3] A. Elahi, M. Basheer, S. Nanukuttan, and Q. U. Z. Khana, "Mechanical and durability properties of high performance concretes containing supplementary cementitious materials," *Construction and Building Materials*, vol. 24, no. 3, pp. 292–299, 2010.

[4] L. Coppola, A. Buoso, and F. Corazza, "Electrical properties of carbon nanotubes cement composites for monitoring stress conditions in concrete structures," *Applied Mechanics and Materials*, vol. 82, pp. 118–123, 2011.

[5] L. Lu, D. Ouyang, and W. Xu, "Mechanical properties and durability of ultra high strength concrete incorporating multi-walled carbon nanotubes," *Materials*, vol. 9, no. 6, p. 419, 2016.

[6] A. Hawreen and J. A. Bogas, "Influence of carbon nanotubes on steel–concrete bond strength," *Materials and Structures*, vol. 51, no. 6, p. 155, 2018.

[7] W. L. Baloch, R. A. Khushnood, and W. Khaliq, "Influence of multi-walled carbon nanotubes on the residual performance of concrete exposed to high temperatures," *Construction and Building Materials*, vol. 185, pp. 44–56, 2018.

[8] A. Hawreen and J. A. Bogas, "Creep, shrinkage and mechanical properties of concrete reinforced with different types of carbon nanotubes," *Construction and Building Materials*, vol. 198, pp. 70–81, 2019.

[9] M. Jalal, A. R. Pouladkhan, H. Norouzi, and G. Choubdar, "Chloride penetration, water absorption and electrical resistivity of high performance concrete containing nano silica and silica fume," *Journal of American Science*, vol. 8, no. 4, pp. 278–284, 2012.

[10] A. Hawreen, J. A. Bogas, and R. Kurda, "Mechanical characterization of concrete reinforced with different types of carbon nanotubes," *The Arabian Journal for Science and Engineering*, vol. 44, no. 10, pp. 8361–8376, 2019.

[11] D. Tavakoli and A. Heidari, "Properties of concrete incorporating silica fume and nano-SiO_2," *Indian Journal of Science and Technology*, vol. 6, no. 1, pp. 1–5, 2013.

[12] M. Jung, Y. S. Lee, S. G. Hong, and J. Moon, "Carbon nanotubes (CNTs) in ultra-high performance concrete (UHPC): dispersion, mechanical properties, and electromagnetic interference (EMI) shielding effectiveness (SE)," *Cement and Concrete Research*, vol. 131, p. 106017, 2020.

[13] P. Mudasir and J. A. Naqash, "Impact of Carbon Nano Tubes on Fresh and Hardned Properties of Conventional Concrete," *Materials Today: Proceedings*, pp. 1–6, 2021.

[14] N. D. K. R. Chukka and M. Krishnamurthy, "Seismic performance assessment of structure with hybrid passive energy dissipation device," *Structure*, vol. 27, pp. 1246–1259, 2020.

[15] N. D. K. R. Chukka, L. Natrayan, and W. D. Mammo, "Seismic fragility and life cycle cost analysis of reinforced concrete structures with a hybrid damper," *Advances in Civil Engineering*, vol. 2021, Article ID 4195161, 17 pages, 2021.

[16] S. Praburanganathan, N. Sudharsan, Y. B. S. Reddy, N. D. K. R. Chukka, L. Natrayan, and P. Paramasivam, "Force-deformation study on glass fiber reinforced concrete slab incorporating waste paper," *Advances in Civil Engineering*, vol. 2022, Article ID 5343128, 10 pages, 2022.

[17] S. Justin Abraham Baby, S. Suresh Babu, and Y. Devarajan, "Performance study of neat biodiesel-gas fuelled diesel engine," *International Journal of Ambient Energy*, vol. 42, no. 3, pp. 269–273, 2021.

[18] V. S. Nadh, C. Krishna, L. Natrayan et al., "Structural behavior of nanocoated oil palm shell as coarse aggregate in lightweight concrete," *Journal of Nanomaterials*, vol. 2021, Article ID 4741296, 7 pages, 2021.

[19] Y. Devarajan, G. Choubey, and K. Mehar, "Ignition analysis on neat alcohols and biodiesel blends propelled research compression ignition engine," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 42, no. 23, pp. 2911–2922, 2020.

[20] A. Sedaghatdoost and K. Behfarnia, "Mechanical properties of Portland cement mortar containing multi-walled carbon nanotubes at elevated temperatures," *Construction and Building Materials*, vol. 176, pp. 482–489, 2018.

[21] A. Naqi, N. Abbas, N. Zahra, A. Hussain, and S. Q. Shabbir, "Effect of multi-walled carbon nanotubes (MWCNTs) on the strength development of cementitious materials," *Journal of Materials Research and Technology*, vol. 8, no. 1, pp. 1203–1211, 2019.

[22] A. B. H. Bejaxhin, G. Paulraj, and M. Prabhakar, "Inspection of casting defects and grain boundary strengthening on stressed Al6061 specimen by NDT method and SEM micrographs," *Journal of Materials Research and Technology*, vol. 8, no. 3, pp. 2674–2684, 2019.

[23] C. M. Kansal and R. Goyal, "Analyzing mechanical properties of concrete with nano silica, silica fume and steel slag," *Materials Today: Proceedings*, vol. 45, no. 6, pp. 4520–4525, 2021.

[24] H. Y. Leung, J. Kim, A. Nadeem, J. Jaganathan, and M. P. Anwar, "Sorptivity of self-compacting concrete containing fly ash and silica fume," *Construction and Building Materials*, vol. 113, pp. 369–375, 2016.

[25] A. B. H. Bejaxhin and G. Paulraj, "Experimental investigation of vibration intensities of CNC machining centre by microphone signals with the effect of TiN/epoxy coated tool holder," *Journal of Mechanical Science and Technology*, vol. 33, no. 3, pp. 1321–1331, 2019.

[26] A. S. Rassokhin, A. N. Ponomarev, and O. L. Figovsky, "Silica fumes of different types for high-performance fine-grained concrete," *Magazine of Civil Engineering*, vol. 2, pp. 151–160, 2018.

[27] Y. Lin, J. Yan, Z. Wang, F. Fan, and C. Zou, "Effect of silica fumes on fluidity of UHPC: experiments, influence mechanism and evaluation methods," *Construction and Building Materials*, vol. 210, pp. 451–460, 2019.

[28] Y. Devarajan, D. B. Munuswamy, B. T. Nalla, G. Choubey, R. Mishra, and S. Vellaiyan, "Experimental analysis of Sterculia foetida biodiesel and butanol blends as a renewable and eco-friendly fuel," *Industrial Crops and Products*, vol. 178, p. 114612, 2022.

[29] S. M. M. Karein, A. A. Ramezanianpour, T. Ebadi, S. Isapour, and M. Karakouzian, "A new approach for application of silica fume in concrete: wet granulation," *Construction and Building Materials*, vol. 157, pp. 573–581, 2017.

[30] V. Gayatri, N. Bhanu Teja, D. K. Sharma, J. Thangaraja, and Y. Devarjan, "Production of biodiesel from phoenix sylvestris oil: Process optimisation technique," *Sustainable Chemistry and Pharmacy*, vol. 26, p. 100636, 2022.