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Nano silica cement composite for high strength concrete reinforced with steel fiber

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Abstract
It is well researched that concrete is weak in tension and thus has brittle characteristics resulting in less post-cracking ductility. To alleviate this problem, nano-silica and hook ended steel fibers which were never studied together added to the concrete mix. The main objective of this research is to enhance the durability, bond and mechanical properties of concrete by adding nano-silica and steel fiber to cement paste in high strength concrete. Nano silica of (-0.5%, 1%, and 1.5%-) by weight of cement and steel fiber of 1% volume fraction are added to the concrete mix, and then the compressive, tensile, shear, pull-out, and UPV tests have been conducted on standard specimens as per the ASTM standard for high strength concrete. From the experiment results, the workability of the fresh concrete mixture decreases as the percentage of nano-silica percentage increases. Optimum percentage is found at concrete mix of 1.5% nano-silica and 1% of steel fiber. Significant enhancement in mechanical strength of concrete is observed relative to control specimens, which is explained by the fact that high surface area, nano-filler effect, and pozzolanic reaction of nano silica and post crack stiffening of concrete by steel fiber. By introducing Nano silica and Steel fiber in high strength concrete mix, there was a relative strength gain of 11.4%, 16.2%, 24.61% in compression, indirect tensile strength and shear strength respectively from control specimen at the age of 28 days. Formation of secondary CHS due to addition of nano silica is observed in the study of microstructure tests, i.e., XRD and FTIR. A good correlation between actual compressive strength, UPV and pullout test results has been observed. It is concluded that the concrete mix containing 1.5% of nano silica with 1% steel fiber exhibits better performance the control concrete mix and has a potential to be used as a construction material.

Keywords: Concrete, high strength concrete, supplementary cementitious material, rice husk, nano-silica

Introduction

For the past one and half decades, researchers have been looking at the usage of nanomaterials in cement concrete, such as nano-SiO2, nano-titanium, nano-calcium carbonate, and nano-graphene. There has been an increasing demand for using nano-materials, including characterizing nano-scale materials and enhancing the performance of cement composites. Nanomaterials were found to be effective in construction and building materials by increasing the rate of hydration due to their surface area, better mechanical strength, and increased durability due to the pore filling nature of nano-scale materials [1-3].

In the study by (D. vivak *et al.*, 2023) [4], concrete with 2% of Bio-NS and polypropylene fiber showed a 15.5% increases in compressive strength when compared to normal concrete. Compressive strength was increased by 12.2% for a mix containing 1% nS and 2% fiber in comparison to nominal concrete. The pore-filling action of nS and other features, including the surface of the fiber, surface roughness, and the binding between mortar and aggregates, are the main causes of the aforementioned behavior. Additionally, SEM imaging and chloride penetration revealed that the inclusion of Bio NS and polypropylene fiber increased the durability of concrete. In this investigation, the inclusion of bio-NS and polypropylene fiber reduced the consistence of fresh concrete [4]. In contrast, it is reported that NS improved the workability of fresh and hardened concrete and 4% NS addition could enhance mechanical properties concrete of at all ages due to formation of excess CSH and pore-filling nature of Nano silica [5]. Similar study revealed that stabilized NS increased compressive strength and secant modulus of elasticity of concrete [6].

In the presence of water, the nano-silica actively reacts with $Ca(OH)_2$ liberated during cement hydration (pozzolanic reaction) and produces additional calcium silicate hydrate (CSH), which is responsible for the binding capacity of cementitious material [7-10]. However, the aforementioned advantages of nano-materials have been investigated on normal-strength

concrete, mortar, and high-performance cement composite. In this study effect of nano-silica and steel fiber on the mechanical strength, durability, and microstructure behavior of high-strength concrete (C-60) was explicitly investigated.
In the study, the effect of nano-SiO2 on the mechanical properties, microstructure, and hydration process of cementitious materials incorporating hydrophobic admixture (CM-HA), the addition of nano-SiO2 by 2% was the optimal composition which increased the strength of cement paste incorporating hydrophobic admixture. This result indicated that the mechanical properties and strength development of CM-HA could be significantly improved by nano-SiO2 due to the nucleus effect, hydration activity, and Nano-filling function [8]. Unlike other studies mentioned in this literature, this study dealt with cement paste characterization after the addition of nano-silica and hydrophobic admixtures.
The agglomerated nano silica particles served as filler materials, which decreased porosity and improved early age strength, the study claims. The agglomeration of the NS particles also caused a long time for its reaction with excess CH to generate CSH gel. According to, the ideal 3% dose of NS increased bond strength and durability in comparison to the control sample [9]. A similar conclusion was drawn by Torabian *et al.* [10] who proved the addition of nano-silica showed a progressive rise from the control value at 1.5% NS addition in the publication "Effects of Nano silica on Compressive Strength and Durability Properties of Concrete with Different Water to Binder Ratios." Additionally, the compressive strength got improved gradually from the reference value of for the addition of 1.5% Nano silica.
In this study, nano-silica was added up to 6% and a linear improvement was found in Concrete compressive strength in mixes with fly ash replacing 30% of the cement and 3-6% NS than in mixtures without NS. Similarly, when 3% and 6% NS were included, respectively, the mixes' tensile strength increased significantly. The porosity was evaluated using the rapid chloride ion penetration test and mercury intrusion porosimetry. The inclusion of Nano silica greatly improved the values of the passing charges in chloride ion penetration resistivity, according to the results. The porosity was decreased and the pore structure was improved by adding NS [11]. Abhilash et.al also reported a linear improvement in compressive strength was achieved by adding 1.5%, 3%, and 4.5% Nano Silica dosage in Nano Silica concrete at 7 days and 28 days [12].
The main justification for using fibers as many Researchers have reported is that the ductility of high-strength concrete is increased with the addition of fibers as the fiber controls cracking and deflection. In the study of Tomas *et al.* [13] The maximum increase in tensile strength, specifically the split tensile strength and modulus of rupture due to the addition of steel fibers (1% volume fraction), was found to be optimal dosage in various grades of concrete 35, 65, and 85 MPa. In this study steel fiber with an aspect ratio of 70 was added to high strength concrete mix by 1% volume fraction to make the study comprehensive so that the nano-silica could enhance the compressive strength and the fiber improve the tensile strength of concrete. Most works of literature including the literature mentioned in this literature review proved 1% volume fraction of steel fiber is best suitable for the enhancement of the tensile strength of concrete. The study of zulkifi et al. [14] and mohod et al. [15] stipulated when analyzing the tensile strength of a normal-strength concrete, the ideal fiber content was discovered to be 1%.
In the study where M-30 grade concrete as per IS: 10262-2009 was designed it yielded a proportion of 1:1.86: 2.41 with a w/c ratio of 0.45. The steel fiber was added at the rate of 0.5%, 0.75%, 1.0%, 1.25%, 1.50%, 1.75%, and 2.0% by volume fraction. Based on the compressive strength and tensile strength it is concluded that the optimum percentage of steel fiber to be added to the concrete mix is found to be 1% by volume fraction of concrete mix [16].
The aspect ratio and orientation of fiber could alter the effect of fiber in the concrete mix. Relative toughness and strength decline after an aspect ratio of 75. It was also found that fibers aligned parallel to the applied load offered greater tensile strength and toughness [17, 18].
In the study of steel fiber extracted from waste tyres and waste lathe fiber on mechanical performance of concrete proved that the compressive strength was not enhanced as much as tensile strength did [19]. Significant improvement of tensile and bending strength was gained in the study of reinforced concrete beam and column due to addition of those fibers [20-22].
Even if there is no noticeable difference in the first crack load, there is flexural strength increment as the steel fiber dosage increases. There was 47% increment in flexural strength due to addition of 4% steel fiber [23]. Similar study by Seun Kyun *et al.* [24] Nano-silica and silver coated steel fiber inclined at 45° verified enhancement of interfacial frictional resistance at the fiber matrix interface which leads to enhancement of post crack tensile performance. In addition a steel fiber volume of 2% increased stiffness up to 70% and alleviate the mean crack width by 23-50% [25].
Studies of mathematical models revealed that performance of ultra-high performance fiber-reinforced concrete not only influenced by dosage of fibers in concrete but also paste properties, aggregate volumetric ratio, and filler volumetric ratio [26, 27].
Beside other mechanical properties, steel fiber also enhances the bond of reinforcing bars to concrete matrix. At this study the fiber was fixed at a volume of 2% [28]. Plus to this inclusion of waste glass powder in UHPFRC reduces cement consumption and increases workability, compressive and bending strength [29]. Steel fiber also served as a good crack-absorbent in infilled cementitious composite (ICC), compressive strength increases regardless of type of steel fiber and aggregate type [30].
In this paper a comprehensive study has performed by adding nano-silica and steel fiber on high-performance concrete to get better mechanical properties of concrete. Because of that, the objective of this paper is to investigate the enhancement of mechanical, and microstructure behavior of high-strength concrete due to the addition of nano-silica and hook ended steel fiber which never be studied with nano silica. Beside that nano-silica was extracted from locally available rice husks from Worota, South Gondor, Ethiopia by simple chemical method.

Materials and Methods

Materials

Cement

For this study, National cement of grade 42.5R, which is produced in Ethiopia, satisfying ASTM C150-07(2009) standard specification for Portland cement has been used with a specific gravity of 3.15 and chemical properties as shown in Table 1.

Table 1: Chemical composition of OPC Cement

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O
19.56	5.68	3.24	63.49	0.66	3.2	0.58

Aggregates

The coarse aggregate for this study was basaltic stone obtained from a local quarry site, called Taffo, around Addis Ababa. It was washed to remove dirt and air dried in the sun; after that it was sieved in a serious range of sieves and the gradation tests are performed as per ASTM C33/C33M. A coarse aggregate of nominal aggregate size 19mm, fineness modules 3.1, and specific gravity of 2.87 was used in this study.

The fine aggregate used in this study was obtained from local river sand taken from Alem Ketema, North Shewa Zone, Amhara region. It was washed and air-dried in the sun to improve its quality, and it has a fineness module of 2.8 and specific gravity of 2.83.

Water

In this research, drinking water supplied by the city of Addis Ababa water and sewerage authority was used in the mixing of the concrete and curing of test samples.

Nano Silica

Silica nanoparticles could be prepared from Rice husk by a simple chemical method, shown in Figure 1, which involves Silica refluxing with HCl acid for 1 hour, Followed by thermal treatment at 650ºc for 3 hours and then mixing Silica with (2.5N) NaOH solution and then H_2SO_4 adding to neutralize the solution [31]. SiO_2NPs best average particle size (28.31nm) was achieved at the best drying time (48 hours) of silica solution. It has a density of 1.42 g/ml and a surface area of 129 m^2/g. SiO_2NPs powder has a white color and has a hydroxyl group on its surface as shown in the FTIR test result. A detail specification of nano-silica is tabulated in Table 2.

Table 2: Specification of Nano-silica

Property	Value
Appearance form	Powder
Density (g/ml, 20ºC)	1.42
PH	8.5
Surface area (m^2/g)	129
Particle size (nm)	28.31
Color	White

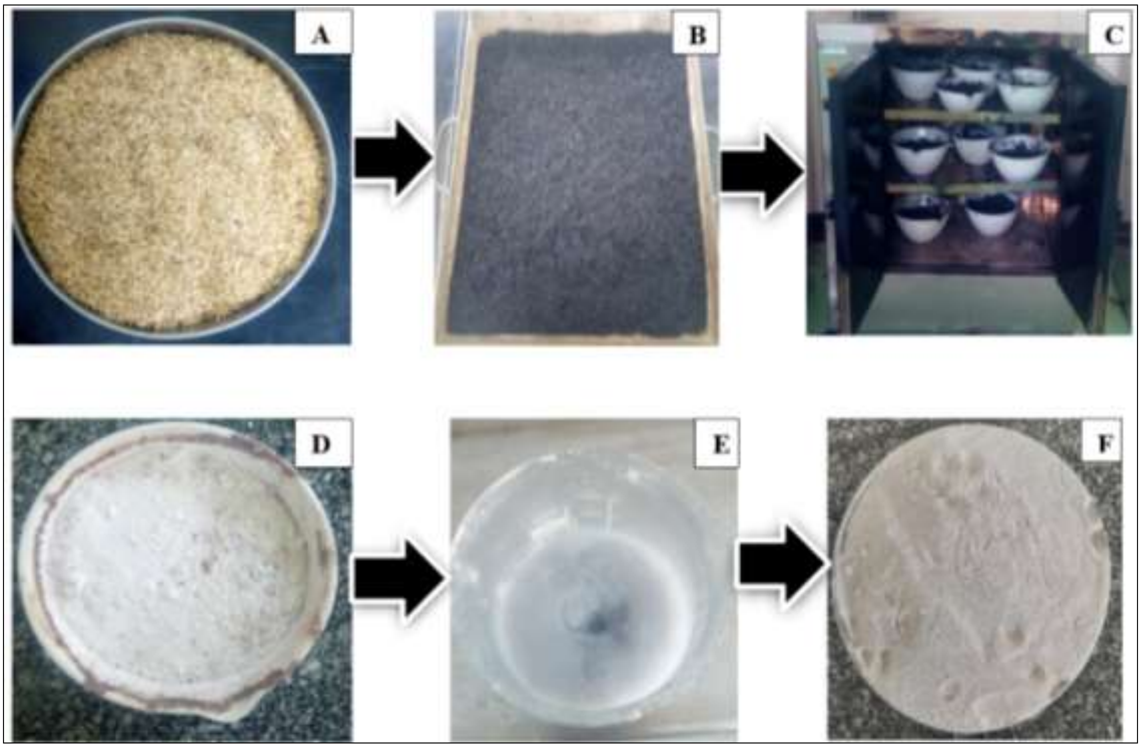

Fig 1: A) Rice husk B) Rice husk burned at 400 ºC for 3 hours C) Rice husk ash refluxed by HCL(2N) at 70 ºC for 1 hour D) RHA heated at 650 °C for 3 hr, E) Nano silica gel, F) Nano silica

Steel Fiber

The steel fiber used in this study has an aspect ratio of 70 (length of 35 c.m and a diameter of 0.5 mm) as shown in Figure 2 and is mixed with concrete by a volume fraction of 1%. Material properties of steel fiber are mentioned in Table 3.

Table 3: Material properties of steel fiber

Fiber properties	Dramix RC-65/35
Length(mm)	35
Diameter(mm)	0.5
Aspect ratio	70
Ultimate tensile strength(MPa)	1100
End condition	Hooked End

Fig 2: Steel fiber

2.2 Concrete mix design

Among the various standard methods of concrete mix design, the American Concrete Institute (ACI 211-4R-08) recommended practice for selecting proportions of high-strength concrete used in this research. This design method is based on the fact that crushing strength is primarily dependent upon the water/cement ratio, the aggregate concentration, the maximum size, and the grading of the aggregate.

Table 4: Ingredients for 1m^3 concrete

Ingredients for 1m^3 concrete							
Concrete mix	**Cement (kg/m^3)**	**F. Agg (kg/m^3)**	**C. Agg (kg/m^3)**	**Water (kg/m^3)**	**Steel Fiber (kg/m^3)**	**NS (kg/m^3)**	**SP (ml/m^3)**
NS 0SF0	697.24	666.91	957.1	195.23	0	0	453.2
NS 0SF1	697.24	666.91	957.1	195.23	3.486	3.49	455.4
NS 1SF1	697.24	666.91	957.1	195.23	3.486	6.97	457.7
NS 1.5SF1	697.24	666.91	957.1	195.22	3.486	10.5	460

F. Agg: fine aggregate C. agg: coarse aggregate NS: nano-silica SP: superplasticizer

2.4 Test procedure

A slump test was done on the fresh mixes of the concretes on a standard slump cone of 300 mm height, 200 mm top diameter, and 100mm bottom diameter as per ASTM C 192/ C192 M. This test was done by filling the cone before the addition of HRWRA in approximately equal three layers of compaction. Each layer was pocked 25 times by a tampering rod to avoid air bubbles. Then the top of the molds was struck off with the rod and then the outside of the molds was cleaned well. After that the mold was stripped off carefully, then the value of slump was taken as the distance from the underside of the rod to the highest point of concrete, to the nearest 5mm.

Compressive strength test was done on standard 100*100*100mm cubic specimens as per ASTM C38/39 at the age of 7 and 28 days of curing. A compression testing machine was used to apply the load gradually parallel to the longitudinal axis of pre-molded and properly cured specimens at a rate of 0.28 MPa /sec. After conducting the test, the maximum load was obtained at the point at which the cubical specimen crushes.

Pull-out test; once the concrete cube (15 cm) is cast with a rebar of diameter 14mm embedded at the center of the cube, the rebar is coated with plastic 2.0 cm from the top and bottom of the cube to avoid slippage. By exerting a tensile force failure load and bond stress are examined. The value of the average nominal bond stress can be calculated as the normal force divided by the surface area of the rebar embedded in the concrete.

Ultrasonic pulse Velocity Test (UPV) is used to investigate the quality and homogeneity of concrete through the determination of pores and cracks. In other words, determining the concrete quality and detecting structural component damage caused by the surrounding conditions, corrosion, wear, etc. The UPV testing instrument is calibrated with a standard rod with a pulse travel time of 57.8 microseconds. Once the calibration was done, 10x20cm cylinders were tested in their respective compositions as per the guideline of ASTM C579-2.

Tensile strength test; Splitting tests were performed to know the tensile strength of concrete. The splitting tensile strength test was carried out on a standard cylinder, and tested on its side in diametrical compression.

Results and Discussions

Characterization of Nano silica

FTIR of Nano Silica Particle

FTIR measurements were carried out to identify the functional groups that are present on the SiO2NPs surface. The measurements were carried out in the range from 4000-400 cm^{-1}.

In this experiment, the major chemical groups of silica are identified. The bands located at 796.24 cm-1 and 454.69 cm-1 are assigned to the Si–O symmetry stretching vibration and bending vibration, respectively. The band at 1633.59 cm-1 belonged to the -OH stretching vibration of the silanol or adsorbed water molecules on the silica surface. As shown in Figure 3 the peak 1075.18cm^{-1} can be attributed to C=O stretching vibration groups. The broad band at about 3446.61cm^{-1} can be attributed to hydroxyl groups which will precipitate in hydrogen bonding with proton-donor and proton acceptor sites in the cement paste matrix and will contribute to a better dispersion of Nano silica filler [31].

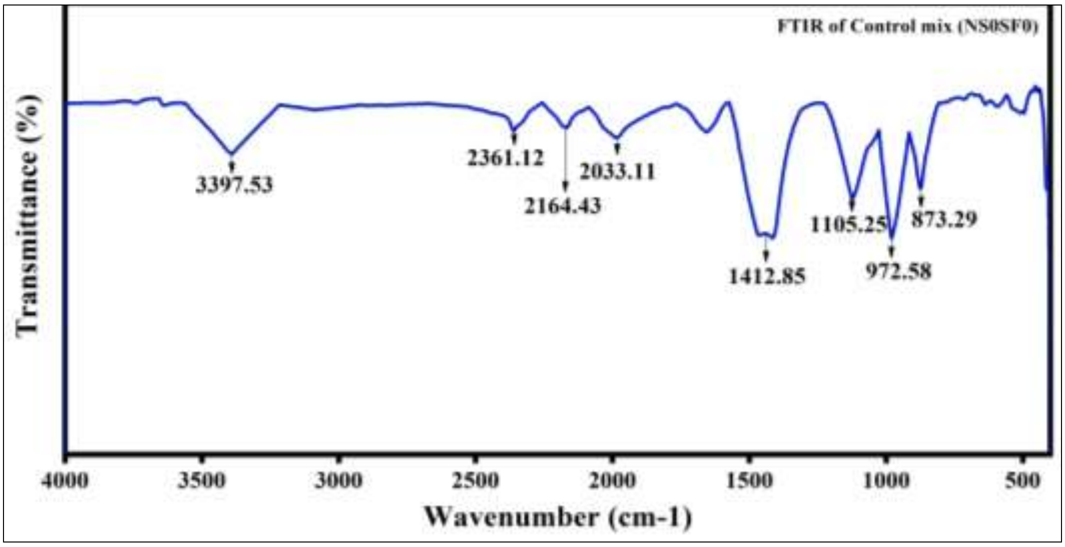

Fig 3 FTIR of Nano Silica

Size Distribution of Nano silica

The Zeta seizer of model 30-L625 is used to determine whether the size of silica is nano-scale or not. The instrument performs size measurements using a process called Dynamic Light Scattering (DLS), also known as PCS -Photon Correlation Spectroscopy, which measures Brownian motion and relates this to the size of the particles. The samples were sonicated with distilled water for about 10 minutes before testing since the test should be performed in solution form. A hundred tests have been done for the same specimen and the average size of the silica was found 28.31nm and the polydispersity index (PDI) was 0.09 which indicates the existence of little agglomerations between particles. Figure 4 shows the particle size distribution of nano-silica. Ahmad A. Moosa *et al.* [31] examined SiO_2NPs size as a function of the mixing time of NaOH (2.5N) solution with silica and SiO2NPs drying time in the oven. An average particle size of 53nm was achieved at 14 hours of mixing time of NaOH (2.5N) solution with silica and 48 hour drying time of SiO_2NPs. In the study of Honjian Du [2], SiO_2NPs with an average particle size of 20nm were used to investigate its effect on high-performance cement composite.

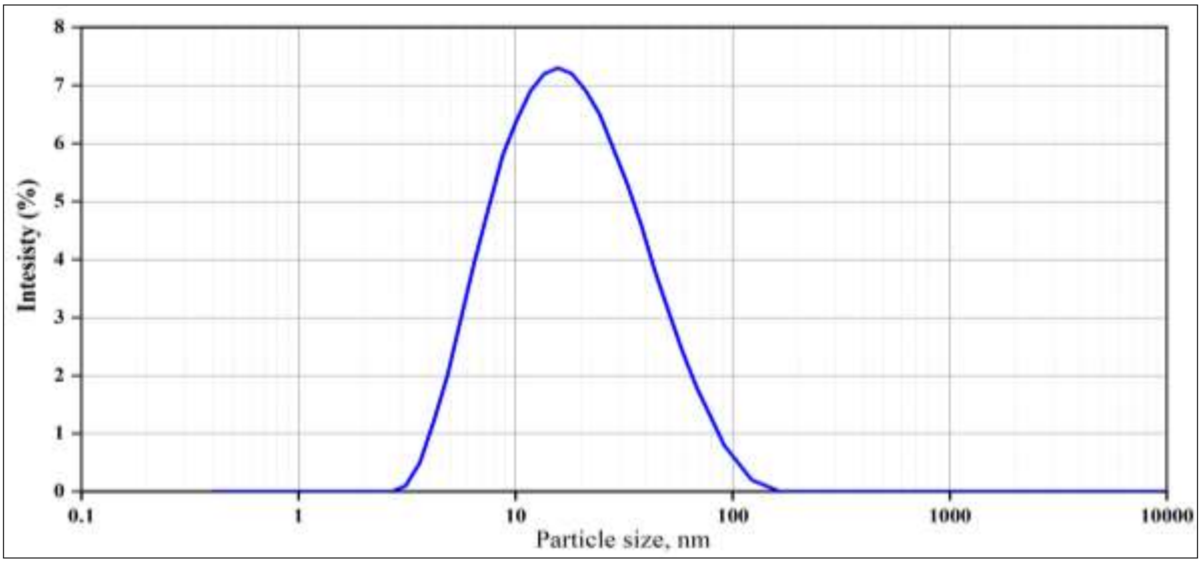

Fig 4: Particle size distributions of nano-silica particles

Workability test of HSC

Slump test result

Besides the adverse effect of Nanoparticles on the workability of concrete it can be concluded that the addition of fibers in plastic concrete changes its mobility. The loss of mobility occurs primarily by the fibers blocking the relative movement of the aggregates which is less intense when reducing the aspect ratio of the fiber, which provokes a reduction of hardened FRC post-crack strength [34, 35]. In the study of cement paste and mortar, the addition of nano-silica required more water to keep its workability due to its high surface area [3, 36-38]. In this study also, the slump cone test result showed that workability gets reduced as the content of nano-silica increases as shown in Table 5.

Table 5: Slump test result

Sample Code	Slump value before the addition of HRWRA (cm)	Recommendation as per (ACI 211-4R-08)
NS0SF0	4.8	Recommended
NS0.5SF1	3.9	Recommended
NS1SF1	3.6	Recommended
NS1.5SF1	3.3	Recommended

Mechanical Strength Test Results

Compressive Strength Test Result

As shown in **Figure 5** as the nano-silica percentage increases, the compressive strength increases from 61.48 MPa to 68.49 MPa. It has a relative strength gain of 7.01MPa which is the effect of steel fiber and nano-silica. Because of the speeding impact, pozzolanic reaction, decreased porosity, and improved interfacial transition zone, they discovered that applying tiny doses of nano silica enhances the early age and the 28-day strength of concrete [43, 44].

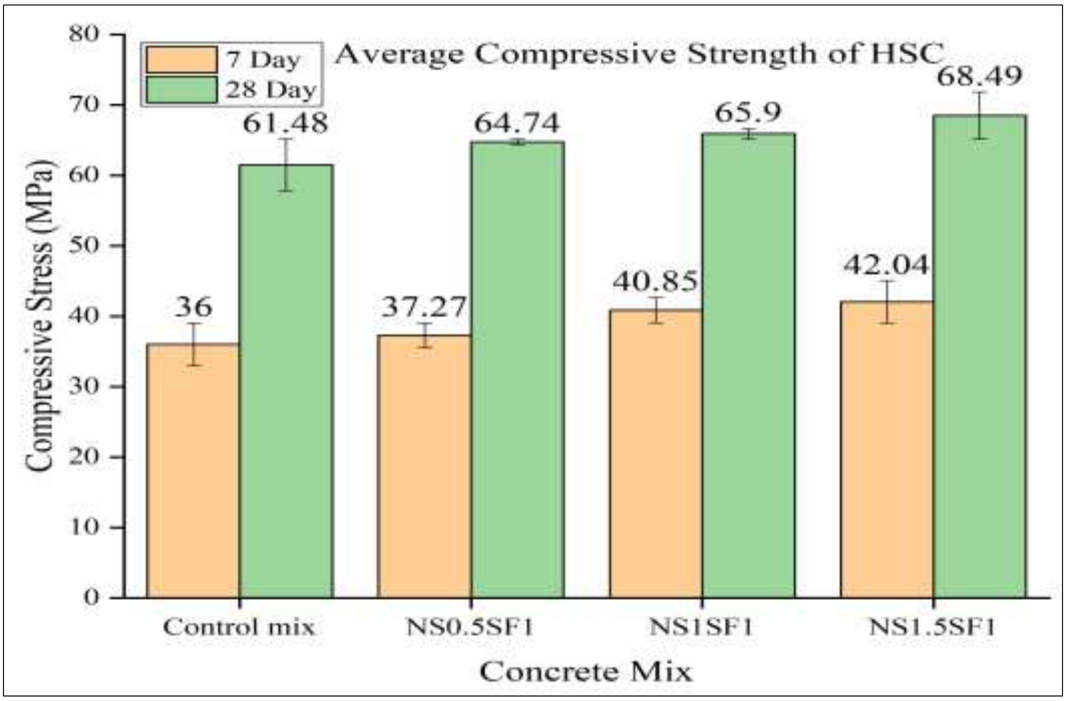

Fig 5: Compressive strength test results

Hameed *et al.* [45] studied the effect of nano-silica on the compressive strength of concrete and reported compressive strength increased by 29.3-48.1% from plain concrete. Similar studies revealed that even a small dosage of nano-silica could enhance the compressive strength of concrete [12, 46, 47]. Gustavo *et al.* [6] also reported 11% enhancement in compressive strength was achieved due to addition of NS in the concrete mix.

Ultrasonic Pulse Velocity Test Result

As per the study of Nuralia *et al.*, 2021, the SFRC develops voids and non-homogeneity, which significantly slows down the UPV test. However, SFRC-1% has increased quality of concrete compared to SRFC-0%, SRFC-0.5%, and SFRC-1.5% [47]. As shown in Table 6, UPV tests reveal an incremental pattern as nano silica dosage increases since secondary CHS are produced which filled the voids in the concrete and steel fiber with 1% volume fraction and had no adverse effect on the quality of concrete. However, all mix series had excellent grades of concrete as per IS 13311-2020 standards.

Table 6: Ultrasonic Pulse Velocity (UPV) result

Ultrasonic Pulse Velocity (UPV) (km/sec)		
Sample ID	Average Velocity (Km/sec)	Quality of concrete IS 13311-2020
NS0SF0	4.52	Excellent
NS0.5SF0.5	4.6	Excellent
NS1SF0.5	4.79	Excellent
NS1.5SF0.5	5	Excellent

Pullout test Results

The bond stress between concrete and reinforcement steel increases as the percentage of nana silica increases. It has an enhancement of 18.62% from the control mix. This result proves nano silica can improve the cement`s past strength and adhesive properties. The tensile force required to pull out the rebar from the concrete and its corresponding bond stress is presented in Table 7.

The agglomerated nano silica particles served as filler materials, which decreased porosity and improved early-age strength. The agglomeration of the nano-silica particles also took a long time for its reaction with excess CH to generate CSH gel. According to, the ideal 3% dose of nano silica increased bond strength by 38.5% in comparison to the control sample [31].

Table 7: Pullout Test Result

Sample ID	Average Tensile Force(KN)	Embedded Area (mm2)	Bond Stress (MPa)
NS0SF0	46.63	16924.6	2.755
NS0.5SF1	50.685	16924.6	2.995
NS1SF1	52.533	16924.6	3.104
NS1.5SF1	55.316	16924.6	3.268

Tensile strength

Splitting tensile Strength test

All specimens of the tensile strength test have the same area of stress. The 7th and 28th-day split tensile strength test results showed that the ultimate load and the corresponding tensile stress of the specimens increase as the percentage addition of Nano silica increases even if the role of steel fiber was significant.

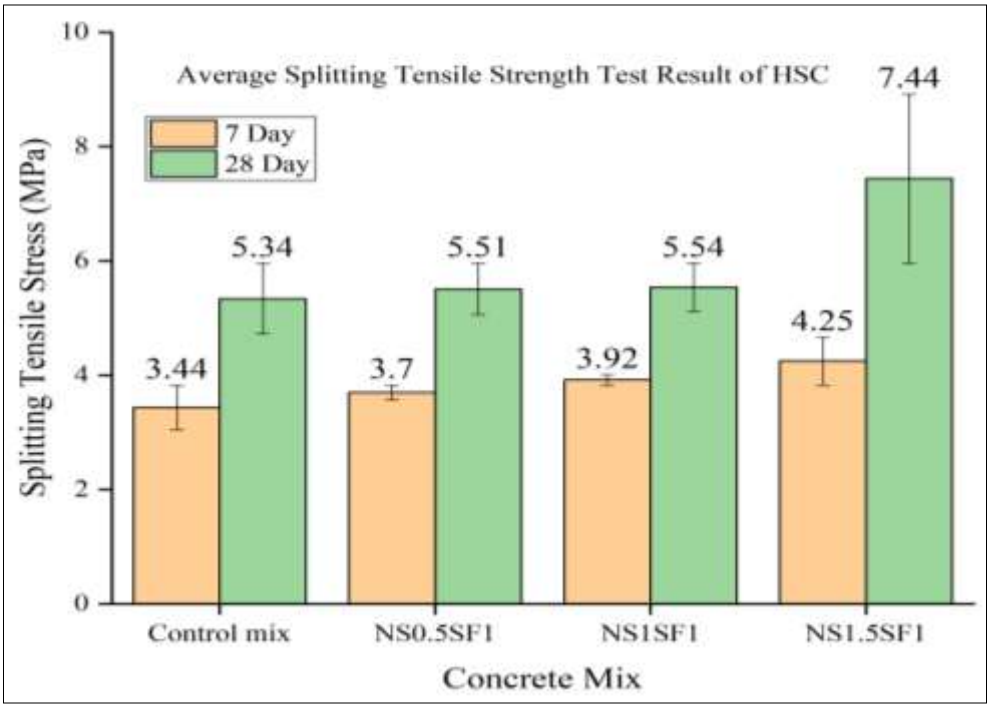

Fig 6: Splitting tensile test result

The average ultimate load and the corresponding mean tensile stress at the 7th-day test for the optimal specimens were 300.26 KN and 4.25 MPa, respectively. There was a relative tensile strength gain of 23.73% compared to the control sample.

The 28th-day test results tell that the mean ultimate load and the corresponding mean tensile stress for the control specimens were 335.022KN and 4.742 MPa, respectively. There was a relative tensile strength gain of 16.82% compared to the control sample. The mean splitting tensile strength for the 7th day and 28th day is presented in Figure 6.

To evaluate the strength and durability of concrete, as reported by Jalal *et at.* [48]; cement was replaced with Nano Silica at a weight-based ratio of 2%. When compared to concrete without Nano Silica, the splitting tensile strengths increased by 13.64%. A similar study was performed by U. Sivasankaran *et al.* [49]; the ultimate tensile strength of concrete with 1% nano-silica achieved 46% improvement relative to plain concrete at the age of 87th- day. In the study of D. Vivek *et al.* [5] there was 16.07% enhancement in tensile strength due to addition of 4% NS in concrete mix.

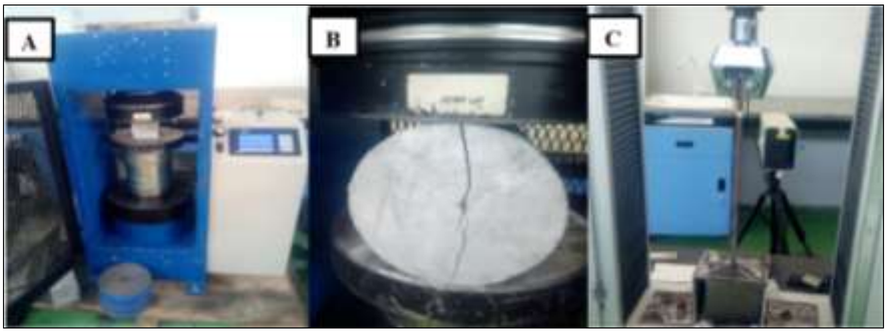

Fig 7: Test Set up A) Compressive strength test of Concrete B) Splitting tensile strength test C) Pullout Test

3.4 Microstructural (Physiochemical) tests result

Microstructure analyses have been done only for the control and the optimal percentage (NS1.5SF1) samples due to inaccessibility of testing equipment's.

Fourier transformation infrared spectroscopy

The investigations were conducted on selected concrete specimens of control sample and sample having 1.5% Nano silica and 1% steel fiber. Sample powder was taken by grinding and sieving by 75µm sieve form hardened concrete to determine the functional group.

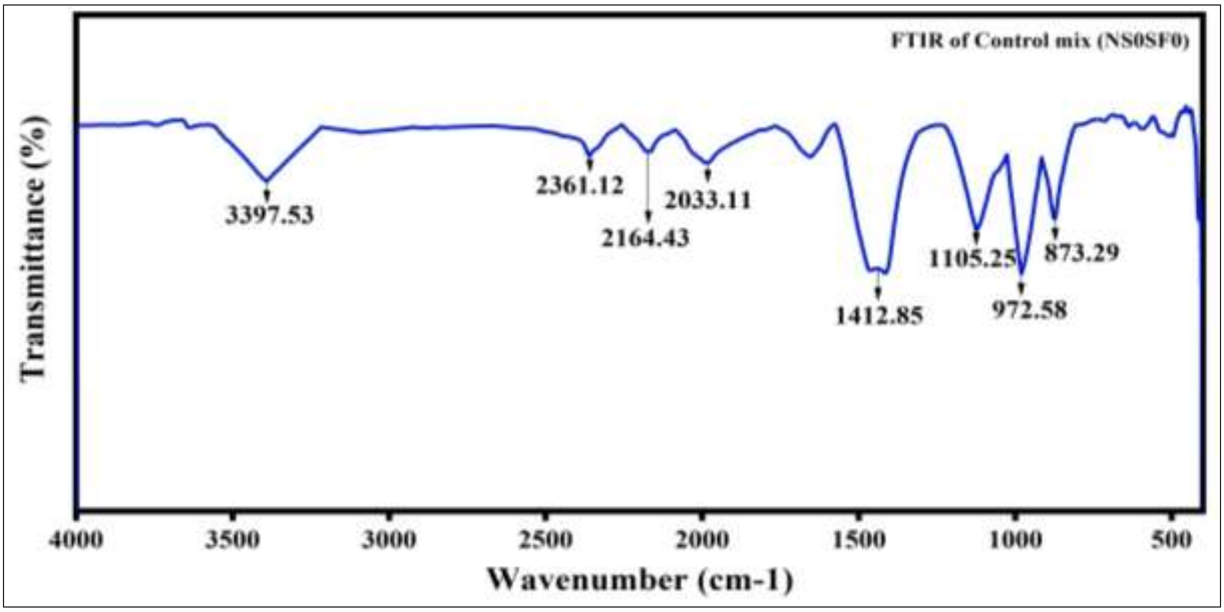

Fig 8: FTIR graph of control sample, NS0SF0

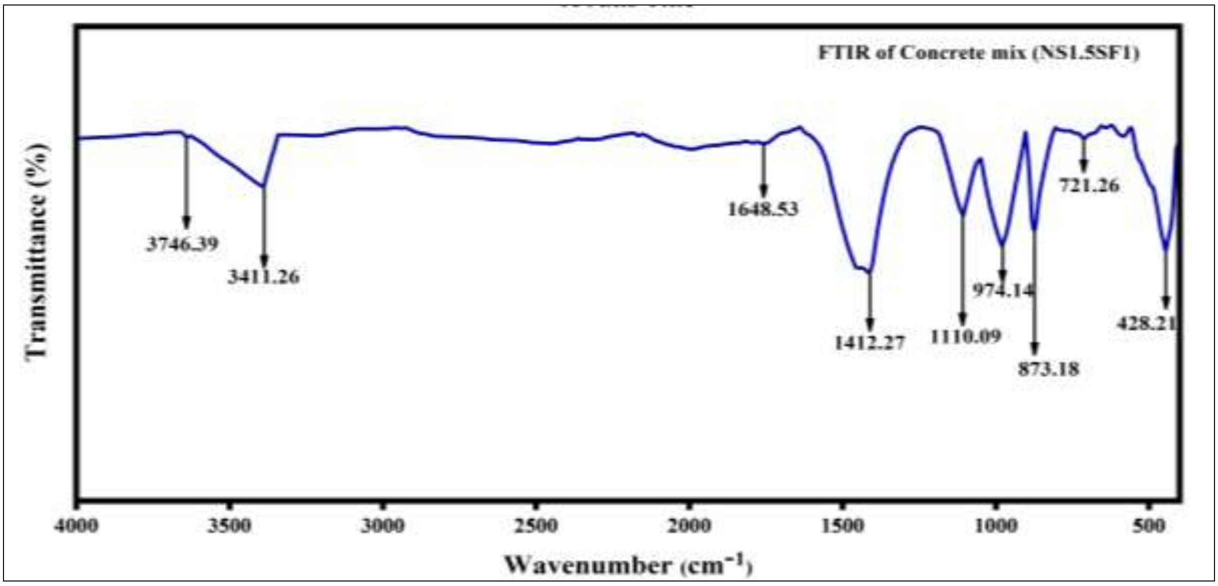

Fig 9: FTIR graph of NS1.5SF1

FTIR spectra of cement paste hydrated for 28 days containing 1.5% nano-silica and control mix is shown in Figure 8 and 9. The observed broad bands located at 3411.26 cm^{-1} and 1640–1650 cm^{-1} are due to stretching and bending vibrations of water bound to the hydrated silicates. The band around 1412.27 cm^{-1} is attributed to the C–O bond stretching of CO_3^{2-}. The band that appeared in the range of 950–980 cm^{-1} is assigned to the formation of the tobermorite-like phase (CSH) [55].

It is well known that, the phases of non-ordered structures exhibit broad bands with lower intensity in comparison with those of crystalline structures. The results show that the peak intensity of the –OH group from the portlandite phase decreases with NS content, due to the pozzolanic reaction of NS with the free lime liberated from OPC hydration. But, the peaks related to the stretching and bending vibrations of lattice water in the hydrated silicates and alumino-silicates (CSH and CASH) behave in the opposite manner to that of portlandite; their intensities increase with NS content [56].

All samples had a complex region of bands in the range of 800-1200 cm-1 indicating asymmetric and symmetric stretching vibration of Si-O bands. The specimens showed bands at ~970 cm-1 indicating the presence of C-S-H. Both the control mix and concrete mix with NS 1.5% samples had sharp peaks at 970 cm-1 region as shown in Figures 8 and 9. Peaks at ~875 cm^{-1} and 1400-1500 cm-1 are related to carbonate bands. Furthermore, the peaks associated with 1480 cm-1, 875 cm-1, and 720 cm-1 are related to calcite.

Interestingly, a satellite peak at 873.18 cm-1 was observed for the NS 1.5% sample indicating the presence of aragonite. The addition of NS above 1% leads to aragonite, which was not observed among other combinations. The presence of aragonite and calcite in NS 1.5% indicates the presence of orthorhombic and trigon crystal structures, respectively [57].

X-ray diffraction analysis

Figure 10 shows the XRD curves of samples, the phase change was analyzed to investigate the effects of nano-silica on the microstructure and hydration of cement; C3S was consumed continuously, and its diffraction peak decreased. Comparing the consumption of C3S in the samples, it can be seen that the consumption of C3S in specimen NS1.5SF1 was greater than that of the control specimen, indicating that the addition of nano-SiO_2 can promote hydration and form secondary CHS. At the same time, the diffraction peak of $Ca(OH)_2$ decreased with the increase of the content of nano-SiO_2, indicating that increasing the content of nano-SiO2 depletes $Ca(OH)_2$ and can increase the hydration rate of cement clinker. In summary, nano-SiO2 can quickly react with $Ca(OH)_2$ to generate hydrated calcium silicate gel, accelerating the early hydration process. At the same time, the rapid reaction between nano-SiO2 and $Ca(OH)_2$ produced a large amount of hydration heat and accelerated the hydration process of other components of cement, making the consumption rate of cement clinker greater than the baseline. Within the proper range, the hydration rate of cement paste accelerated with the increase of the content of nano silica [58].

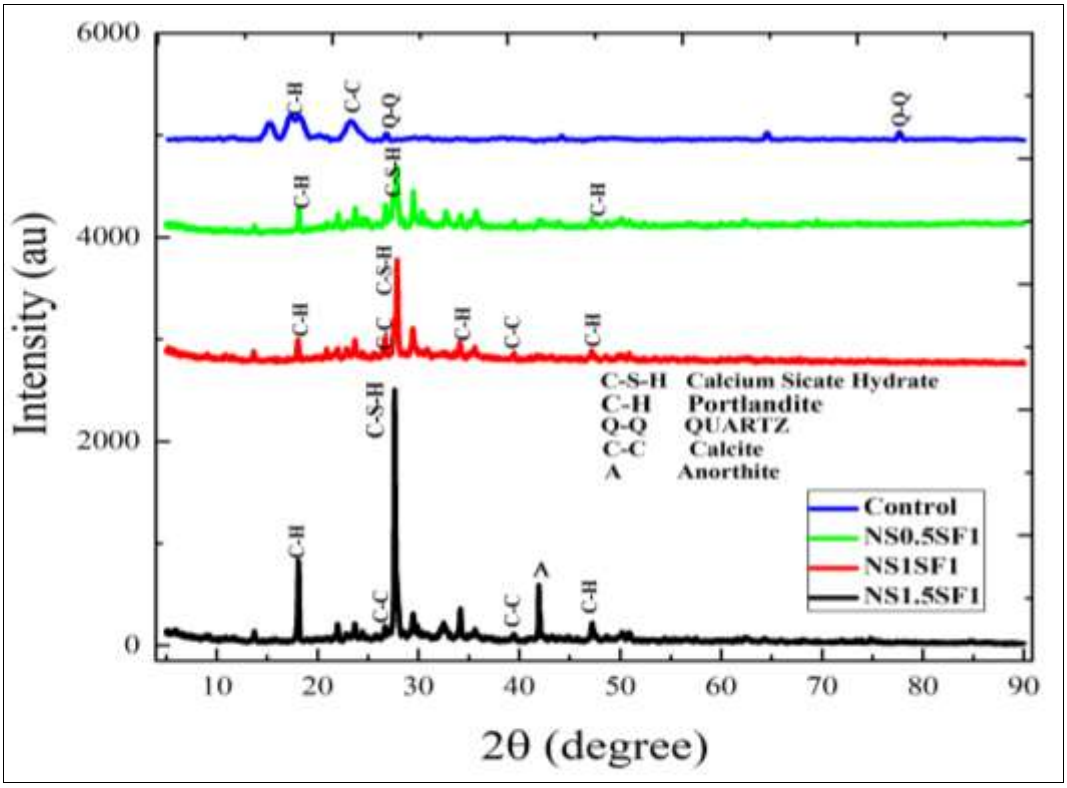

Fig 10: XRD graph of the control sample, NS0.5SF1, NS1SF1, and NS1.5SF1

XRD patterns show peaks of portlandite, CSH, and $CaCO_3$ as well as anhydrous phases. The intensity of CSH peaks increases with increasing the age of the hydration, whereas the peaks corresponding to $Ca(OH)_2$ decrease with hydration age. This is attributed to two opposing processes; the first is the continuous hydration reaction of cement phases (portlandite production), and the second is the pozzolanic reaction of nano-silica with free portlandite, leading to the formation of excessive calcium silicate hydrates (lime capture). The peak intensity of $CaCO_3$ decreases with increasing hydration age due to the increased consumption of CH in the pozzolanic reaction of nano-silica with the formation of additional amounts of CSH [59].

4. Conclusion

This experimental study has been focused on the consistency and workability of concrete, compressive strength of cement paste, durability, mechanical strength, and physiochemical analysis of high-strength concrete mix with the addition of Nano silica and steel fiber. From the test result, there was lesser workability and enhancement of quality and strength of high-strength concrete by applying of Nano Silica and Steel fiber. The following conclusions are drawn from experimental investigation.

- There was a reduction in consistency and workability of concrete mix with Nano-silica and steel fiber; since Nano silica has more surface area due to its size due to that it can absorb more water, and steel fiber hinders the flow of the concrete mix.
- There was a significant increment in test results of compressive strength, tensile strength and pullout test due to addition of Nano silica and steel fiber in high strength concrete mix. So, high strength concrete mix with Nano silica and steel fiber could enhance the mechanical properties of concrete.
- From the test result of ultrasonic pulse velocity test, addition of nano-silca and steel fiber enhance concrete

quality.

- From physiochemical analysis of FTIR and XRD , it`s proved that Nano silica generate secondary CHS which filled the pores between cement paste and aggregates and pores within cement paste which improved the quality of high strength concrete.

Data Availability

Data used to support the findings of this study are included in this manuscript.

Conflict of Interest

The author declares that he has no conflicts of interest.

Authors' Contributions

The author made all contributions to the manuscript and agreed to its publication.

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