

High Strength Nano Silica Based Concrete

Ibadur Rahman, Nirendra Dev



Abstract: *There is a substantial curiosity in academia, the investment community and among manufacturers about the exhilarating opportunities offered by nano materials. Although a lot of applications for nanotechnology remain hypothetical, construction is one area where numerous 'here and now' applications have already emerged. While existing use is restricted, the market is likely to approach more than 500 million dollars within ten years. Concrete is most likely exceptional in the construction field, that it is the distinct material exclusive to business and hence, is the recipient of a reasonable quantity of research and development capital from the construction industry. SiO₂ (Silica) usually is an integral part of concrete in the normal mix. On the other hand, one of the innovations made by the study of concrete at nano scale level is that particle stuffing in concrete can be enhanced by means of adding nano silica (NS), which results in the densification of the micro and nano structure of cementitious composite resulting in enhanced mechanical properties. In this research paper, the result of a thorough investigational analysis on the utilization of NS in addition to cement so that the strength and quality of concrete can improve has been achieved. The effect of various proportions of NS in concrete has been premeditated to evaluate the properties of NS based hardened concrete according to the standard concrete. The obtained outcomes after testing indicate that the addition of NS together with concrete has improved the mechanical behavior of concrete. The NS blended high strength concrete (HSC) shows a better compressive strength (CS) of 66.00 N/mm² (MPa) after standard twenty eight days, which is an exceptional development over standard concrete. Each and every mixture containing NS in various proportions gave enhanced outcomes in comparison with the standard predictable concrete. RH (Rebound Hammer), UPV (Ultrasonic Pulse Velocity), SEM (Scanning Electron Microscope) and TEM (Transmission Electron Microscope) examinations further authenticate the above results.*

Keywords: SEM, TEM, RH, UPV, NS, HSC

I. INTRODUCTION

Concrete, out of all the available materials is the most vital material world wide in state-of-the-art civil engineering buildings and structures. Besides fulfilling the obligations of increased compression and tension resistibility, concrete is simple to form and its elevated compressive strength (CS), impermeability and toughness properties can be sustained over a long period of time. The addition of Nano Silica (NS) in the cement based composites can manage the degradation of the calcium silicate hydrate (CSH) reaction of concrete caused by calcium leaching in water which leads to the improvement in the durability properties. NS covering is implemented upon the faces of concrete, which in result averts the quantity of carbonization of concrete.

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* Correspondence Author

Ibadur Rahman*, Assistant Professor, CED, JMI, New Delhi, India.
Nirendra Dev, Professor and Head, CED, DTU, Delhi, India.

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The basis being that the NS particle decreases the microscopic imperfections inside the concrete. It also reduces the dent and injury to polymer molecules which is caused by ultraviolet waves [1]. Ma et al. [2] established that in various dosages, the bunch of hydrated CSH gels and ettringite crystal steadily improves with the increment of the amount of NS. Addition of NS will amend the pore structures of recycled aggregate based concrete. It restricts the dispersion capability of chloride ions [3]. Addition of NS in the cementitious composites accelerates the preliminary concrete hydration, which is quite helpful to strengthen the initial potency of concrete [4]. Flexural strength of concrete matrix through a 3 point bending test was studied by Li et al. [5]. Bending strength of a concrete matrix gets enhanced however; its brittle property was proportionally amplified with an addition of NS.

The adding of NS particles doesn't only considerably enhance the mechanical properties but it also significantly decreases the infiltration of chloride ions and facilitates to stop the steel bars corrosion in the concrete [6]. The surface fortification resources can be made by utilizing NS and SF (silica fume) customized mortar paste. The new customized material so far prepared is encrusted on the concrete facade, showing that the concrete exhibits excellent impermeability [7]. NS particles are also helpful in increasing the CS of mortar because NS not only seals the voids within the cementitious composite but it also acts as a catalyst to encourage pozzolanic effect [8]. Coalesced effect of NS and SF composes the concrete more intensely and makes it impenetrable. Moreover, it makes silica fume activity insufficient [9]. In the year 2019, one of the researchers established the encouraging consequences of mixing NS in concrete. The author concluded that the volume and allocation of voids in NS customized concrete illustrates that NS facilitates to finely segregate the pore size which makes the concrete impermeable. He also in addition concluded that the weakest section in concrete composite is the interface connecting the cementitious composites and the aggregates [10].

With the addition of NS in a suitable quantity, the concrete matrix improves the interface strength and purifies the pore, which leads to decrease in the water percolation within the concrete [11]. NS also optimizes the micro structure of used concrete. The silica particles initiate the effect of hydration to generate intense gel materials that further enhances the strength of the interface among the used cement and concrete mortar mix [12]. Another Researcher studied and evaluated the development properties of colloidal NS and pulverized NS on the basis of mechanical properties of concrete. The author concluded that pulverized NS initiated the production of more CSH in mortar mix. Hence, NS powder is more efficient in improving the properties of the hardened concrete [13].

The pores in the cement mortar paste made by substituting a partial amount of cement together with NS is decreased by 13.4% and it doesn't affect the permeability and porosity of cement mortar paste [14]. In the year 2018, one of the researchers experimented on the axial compressive properties of NS reinforced concrete packed round stainless steel short columns. The author concluded that the effect of NS dosage was found to be distinct. The axial bearing capacity was highest at 1% nano-SiO₂ dosage [15]. Lin et al. [16] studied that the amounts of freeze & thaw cycles have very slight consequences regarding the bearing capability of circular NS concrete packed stainless steel tube stub columns. He et al. [17] investigated that the capacity of load bearing and early rigidity increases as the NS based concrete CS increases.

II. EXPERIMENTAL PROGRAMME

To investigate the consequences of NS on the concrete composite, nano ranged silica in various proportions has been administered in M50 grade concrete composite to verify its CS. 72 concrete specimens were cast and were presented in tabular form with the particular description assigned to them. Different tests were carried out on the hardened NS based concrete specimens to find out the various properties of novel NS based concrete. A detailed explanation of the work map is specified in Table A. Different construction resources utilized for the making of the composite are super plasticizer, coarse aggregate, fine aggregate and cement. Cement Analysis was carried out with the assistance of SEM. These SEM images illustrate the particle size and morphological properties of grains of cement (Figure 1). The NS was monitored and examined under TEM. Figure 2 describes the morphology as well as the nano size of silica particle. Lastly, concrete specimens were cast and their CS was calculated according to the recommendations of relevant Indian Standard Code of Practices.

Table A: Work Map for CST (Compressive Strength Test) on M50 grade Concrete Mix

M50 grade Concrete		
Cube Description	Nano-SiO ₂ (% NS Dosage in Cement by weight)	Tests Performed on Hardened Concrete
S0	NS 0%	1. CS in Normal Environment 2. CS in Destructive Environment (4% NaCl in water) 3. RH Test 4. UPV Test
S0.5	NS 0.5%	
S1	NS 1%	
S1.5	NS 1.5%	

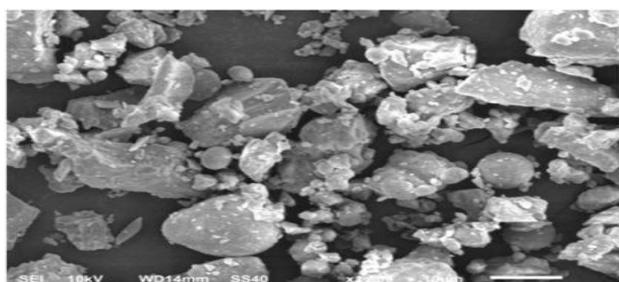


Fig. 1: SEM imaging presenting particle size and morphology of the ACC 43 grade cement (Rahman & Dev N., 2020 [21])

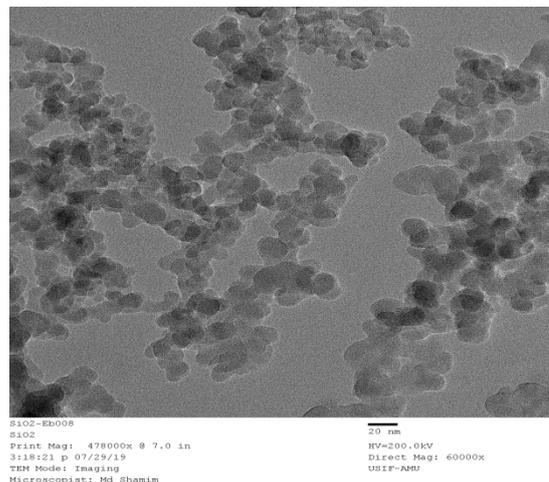


Fig. 2: TEM imaging describing the particle size and morphology of NS

Table 1: Properties of Cements

S. No.	Type of Cement	Normal Consistency	Initial Setting Time (minutes)	Final Setting Time (minutes)
1.	Cement (ACC 43 OPC)	29.50 %	62	296

Cement

ACC brand 43 grade OPC was utilized. Physical properties of cement were examined in the Concrete Lab and are tabulated in the table 1.

Fine Aggregate (FA)

Locally available Red Badarpur sand was utilized in the concrete preparation. Lumps of clay, other overseas and toxic substance were alienated and screened out from the sand and it was later on cleaned with water and afterward air dried for 24 hours. The fineness modulus and grading property of Fine Aggregate sand is tabulated in the table 2.

Table 2: Sieve Analysis of FA

S. No.	Sieve Designation	Weight Retained (gram)	% Weight Retained (gram)	% Cumulative Weight Retained
1.	4.75 mm	143.00	7.15	7.15
2.	2.36 mm	93.00	4.65	11.80
3.	1.18 mm	277.00	13.85	25.65
4.	600 micron	569.00	28.45	54.10
5	300 micron	575.00	28.75	82.85
6.	150 micron	342.00	17.15	100.00

$$\text{Fineness Modulus} = \frac{281.55}{100} = 2.81$$

Table 3: Properties of Nano Silica (Technical Data of Nano Silica was provided by Fiberzone India based in Ahmadabad, Gujarat, India)

Nano Silica	Unit	Typical Value
Specific Surface Area (BET)	m ² /g	100 ± 16
Average primary particle size Tamped density* According to DIN EN ISO 787/11, August, 1983	nm	15
	g/l	approx. 50

Moisture* Two hours at 105 ^o C	wt. %	≤ 4.0
Ignition Loss Two hours at 1000 ^o C, based on material Dried for 2 hours at 105 ^o C	wt. %	≤ 3.0
pH in 4 % dispersion		5.0 – 5.5
SiO ₂ - content Based on ignited material	wt. %	≥ 99.7
Sieve residue (by Mocker 45 μm) According To DIN EN ISO 787/18, April, 1984	wt. %	≤ 0.045

Coarse Aggregate (CA)

CA of neighboring area available quartzite was utilized in the concrete composite.

Nano Silica (NS)

Nano Silica was procured from Fiberzone India based in Ahmadabad, Gujarat, India. The properties of Nano Silica were tabulated and shown in the Table 3.

2.1 Compressive Strength Test (CST) of HSC in Normal Environment

To estimate the behavior of NS powder and its blend, the concrete specimens of size 150 mm each were cast in the concrete laboratory as shown in figure 3. Overall twenty four concrete specimens were cast & explicit descriptions were allocated to them. Ingredient resources utilized for concrete cube mix design were CA, FA, cement, water, super plasticizer and NS. Normal water was used for the making of concrete composite. M50 HSC grade concrete was used in this particular research. Subsequent to casting of the concrete specimens, the specimens were removed from the moulds after twenty four hours and healed for standard seven and twenty eight days in the water tank as presented in figure 4. Specimens were finally tested under the CTM (Compression Testing Machine) shown in figure 5 up to the breakdown to determine their CS. CS of concrete specimens is tabulated in table 4. From the table 4, it can be seen that the specimens having NS powder in the mix reveal outstanding strength both at seven and twenty eight days. Therefore the material system can absolutely be allocated for the future applications in the construction industry.



Fig. 3: Casting of Concrete Specimens in the laboratory



Fig. 4: Curing of Concrete Specimens



Fig. 5: Testing of Concrete Specimens



Table 4: CS of HSC in Normal Environment

Specimen Description	SiO ₂ (% Dose)	7 days (MPa)	28 days (MPa)
S0	0 %	33.41	50.66
S0.5	0.5 %	36.27	55.21
S1	1 %	41.07	62.23
S1.5	1.5 %	43.50	66.00

2.2 CST of HSC in Destructive Environment (NaCl solution- 4% salt in water by weight)

To examine the effect of nano additive and their composites in the destructive environment, the concrete specimens were cast in the laboratory same as mentioned above in section 2.1. Total twenty four concrete cube models were cast and explicit title were allocated to them. In this casting also the concrete grade was kept same as in section 2.1. Subsequent to casting of the concrete models, the cubes were removed from the moulds after twenty four hours and healed in saline water (4% NaCl in water by weight) for standard twenty eight days in the water reservoir. After curing the concrete cubes for 28 days, the cubes were finally analyzed for the crushing strength in the CTM up to the collapse to establish their CS. CS of concrete specimen acquired is presented in table 5. From the table it is clearly noticeable that the cubes having NS in the mix show signs of improved strength both at seven and twenty eight days even if it was placed in destructive environment.

Table 5: CS of HSC in Aggressive Environment (4% NaCl solution in Water by weight)

Specimen Description	SiO ₂ (% Dose)	7 days (MPa)	28 days (MPa)
S0	0 %	29.12	43.70
S0.5	0.5 %	29.90	45.22
S1	1 %	36.59	55.44
S1.5	1.5 %	39.80	60.28

2.3 CST of HSC using Rebound Hammer (Non Destructive Testing Technique)

Concrete cube models of size 150 mm each were cast in the laboratory to assess the strength via Non Destructive Testing Technique (NDT). RH test is one of the NDT techniques. A total twelve concrete specimens were cast and explicit labels were allotted to them. After casting and labeling, the same whole procedure is adopted as mentioned in section 2.1 above. The prepared cube models were then tested with Schmidt Rebound Hammer as shown in figure 6. The different readings of RH on each surface of the cube were witnessed and demonstrated in table 6. The average readings of RH on concrete cubes surface validates the normal compressive strength test performed in CTM.

Table 6: CS of HSC using Rebound Hammer

Specimen Description	SiO ₂ (% Dose)	Rebound Hammer Number
S0	0 %	48
S0.5	0.5 %	50
S1	1 %	55
S1.5	1.5 %	59



Fig. 6: RH Test

2.4 CST of HSC through Ultrasonic Pulse Velocity (Non Destructive Testing Technique)

Twelve concrete cube samples were cast and cured in the same manner as in section 2.1 above. The cubes were then tested through Ultrasonic Pulse Velocity (UPV) tester as shown in figure 7. UPV test is another NDT technique just like RH test. The Average Pulse Velocity (APV) readings on each surfaces of the cube were noted and then tabulated below in table 7.

The concrete quality grade as reported by the UPV test authenticates CST and RH Test.

Table 7: CST of HSC through UPV

Specimen Description	SiO ₂ (% Dose)	APV (km/sec)	Concrete Quality
S0	0 %	4.27	Good
S0.5	0.5 %	4.38	Good
S1	1 %	4.51	Excellent
S1.5	1.5 %	4.62	Excellent



Fig. 7: UPV Test

III. RESULTS AND DISCUSSION

Debate on the above consequences and results is shown here with a vision to illustrate qualitative and quantitative finish. Results attained from various tests performed on hardened concrete cube models are shown in tables 4 to 7 above. The results of the various tests performed above have been graphically represented in figures 8, 9, 10 and 11.

3.1 CST of HSC in Normal Environment

The result obtained from twenty four numbers of cubes tested above is tabulated in table 4. The graphs illustrate the difference mostly where the NS are utilized. The disparities are argued in detail. Graph in figure 8 reflects the CS of cubes containing NS for seven and twenty eight days is greater than the CS of regular usual concrete. Percentage enhancement in the CS of NS based concrete in comparison with the regular usual concrete at twenty eight days is 9, 23 and 30 % correspondingly. The major cause of increase in the CS at different phases is due to the presence of nano particle i.e. NS, which creates a bigger surface area of silica to get in touch with the cement and water respectively which further reduces the voids volume within the concrete and for this reason the strength get enhanced as the fracture need gap or voids to transmit through.

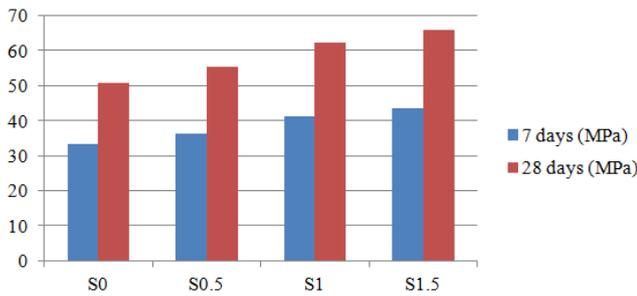


Fig.8: Graph Showing CS of HSC under Normal Environment

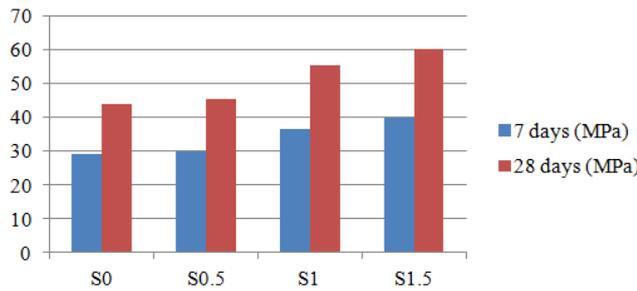


Fig. 9: Graph Showing CS of HSC under Destructive Environment

3.2 CST of HSC in Destructive Environment (NaCl solution- 4% salt in water by weight)

The outcomes of 24 numbers of concrete cube models are prearranged in table 5. The graphs illustrate the deviation where NS is utilized. In figure 9, the CS of cubes having NS for seven and twenty days is greater than the CS of regular conventional concrete cube. Percentage enhancement in the CS of NS based concrete in comparison with the regular conventional concrete in hostile environment at twenty eight days is 3.4, 27 and 38 % correspondingly. Moreover NS based concrete performs well both at seven and twenty eight days even when it was kept in the destructive environment.

3.3 CST of HSC using Rebound Hammer (Non Destructive Testing Technique)

The consequence of twelve numbers of concrete specimens is tabulated in the table 6. The graph reveals the disparity where NS powder is utilized. It is obviously visible in figure 10 that the RN (Rebound Number) of cubes having NS powder for twenty eight days is more than the RN of regular conventional concrete cube. Percentage discrepancy in the CS and the RN is 5, 10, 14 and 12.14 % respectively. From the clause 7.1.5 of IS: 13311 (Part-II) – 1992, the percentage variations are within the acceptable limits.

Rebound Hammer Number

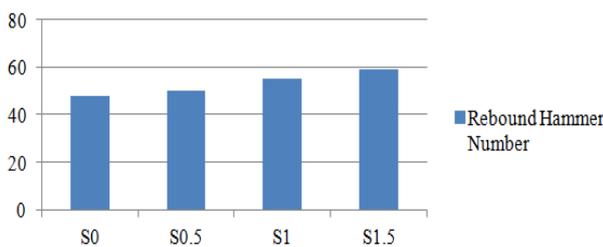


Fig. 10: Graph representing RH Number

3.4 CST of HSC through Ultrasonic Pulse Velocity (Non Destructive Testing Technique)

The outcome of twelve numbers of concrete specimens of size 150 mm are tabulated in the table 7. The graphs illustrate the deviation where the NS powder is used. Graph in figure 11 reflects the APV (Average Pulse Velocity) of concrete specimen having NS for 28 days is more than the APV of normal concrete cube. APV values of S0, S0.5, S1 and S1.5 are 4.27, 4.38, 4.51 and 4.62 km/sec correspondingly. As per table 2 of clause 7.1.1 of IS: 13311 (Part-I) – 1992, S0 and S0.5 falls under the category of the good quality rating concrete while, S1 and S1.5 falls in the category of excellent quality rating concrete.

APV (km/sec)

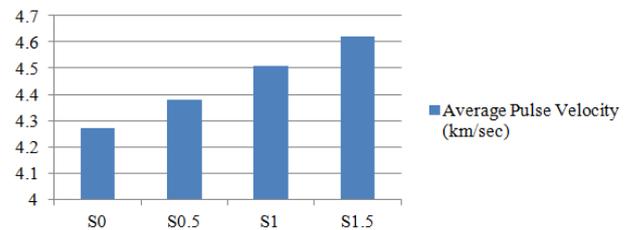


Fig. 11: Graph Showing Average Pulse Velocity of Concrete Specimens

IV. CONCLUSIONS

The investigational study above presented provides the subsequent conclusions. It was seen clearly from above that all properties of hardened concrete composites are better as we increase the percentage of NS as an additive. The NS constituent parts have affinity to fill the voids among the granules of cement due to its larger specific surface area and it also reduces the calcium hydroxide content ensuing in the creation of more CSH bond which auxiliary enhances the interface composition of the concrete. The increase in the strength at various phases can be attributed to the extreme fine quality of NS powder which causes bigger surface area of silica to get in touch with the water and cement and consequently it creates a micro fabric closely compact, restricting the quantity and volume of voids in the concrete. The diverse concrete blends having NS powder with different proportions give strength in an array of 55.21 to 66.00 MPa which are greater than the regular conventional concrete composite (50.66 MPa). Composite containing simply 1.5% NS powder has recorded 66.00 MPa, twenty eight days CS. An exceptional enhancement of 30% has been recorded for concrete composite having NS as evaluated with the regular usual concrete. The NS based concrete executes healthier even in the destructive environment. RH and UPV results substantiate the above findings. The NS based concrete is more efficient for exterior stiffness in addition to concrete quality grading as evaluated with regular usual concrete. NS particles in concrete composite improves the compactness of the concrete, which further leads in diminishing the cracking pattern inside the internal concrete composite and therefore it further leads to the elevated UPV value when assessed with the regular conventional concrete.

REFERENCE

- 1 Li G, Hu W, Cui H.Y, Zhou J.C, "Long Term Effectiveness of Carbonation Resistance of Concrete Treated with Nano SiO₂ Modified Polymer Coatings", Construction Building Materials, 2019, 201, 623-630.
- 2 Ma Q.Y, Zhu Y, "Experimental Research on the Microstructure and Compressive and Tensile Properties of Nano SiO₂ Concrete Containing Basalt Fibers", Underground Space 2017, 2(3), 175-181.
- 3 Ying J.W, Zhou B, Xiao J.Z, "Pore Structure and Chloride Diffusivity of Recycled Aggregate Concrete with Nano SiO₂ and Nano TiO₂", Construction Building Materials, 2017, 150, 49-55.
- 4 Liu M, Tan H.B, He X.Y, "Effects of Nano SiO₂ on Early Strength and Microstructure of Steam Cured High Volume Fly Ash Cement System", Construction Building Materials, 2019, 194, 350-359.
- 5 Li Q.H, Gao X, Xu S.L, "Multiple Effects of Nano SiO₂ and Hybrid Fibers on Properties of High Toughness Fiber Reinforced Cementitious Composites with High Volume Fly Ash", Cement Concrete Composite, 2016; 72; 201-212.
- 6 Eskandari H, Vaghefi M, Kowsari K, "Investigation of Mechanical and Durability Properties of Concrete Influenced by Hybrid Nano Silica and Micro Zeolite", Procedia Material Science, 2015, 11, 594-599.
- 7 Zhang B.L, Tan H.B, Shen W.G, Xu G.L, Ma B.G, Ji X.L, "Nano Silica and Silica Fume Modified Cement Mortar used as Surface Protection Material to Enhance the Impermeability", Cement Concrete Composite, 2018, 92, 7-17.
- 8 Jo W.B, Kim C.H, Lim A.H, "Investigations on the Development of Powder Concrete with Nano SiO₂ Particles", KSCE Journal Civil Engineering, 2007, 11(1), 37-42.
- 9 Wang Y.S, Xu Z.H, Wang J.B, Zhou Z.H, Du P, Cheng X, "Synergistic Effect of Nano Silica and Silica Fume on Hydration Properties of Cement Based Materials", Journal Thermal Analysis Calorimetry, 2019, 1-11.
- 10 Prashanth R, Selvan S.S, Balasubramanian M, "Experimental Investigation on Durability Properties of Concrete Added with Nano Silica", Rasayan Journal Chemistry, 2019, 12(2), 685-690.
- 11 Liu R, Xiao H.G, Liu J.L, Guo S, Pei Y.F, "Improving the Microstructure of ITZ and Reducing the Permeability of Concrete with Various Water Cement Ratios Using Nano Silica", Journal Material Science, 2019, 54(1), 444-456.
- 12 Hosseini P, Booshehrian A, Madari A, "Developing Concrete Recycling Strategies by Utilization of Nano SiO₂ Particles", Waste Biomass Valorization, 2011, 2(3), 347-355.
- 13 Singh L.P, Goel A, Bhattacharyya S.K, Ahalawat S, Sharma U, Mishra G, "Effect of Morphology and Dispersibility of Silica Nano Particles on the Mechanical Behavior of Cement Mortar, International Journal Concrete Structures Materials, 2015, 9(2), 207-217.
- 14 Mohammed B.S, Liew M.S, Alaloul W.S, Khed V.C, Hoong C.Y, Adamu M, "Properties of Nano Silica Modified Pervious Concrete", Case Studies in Construction Materials, 2018, 8, 409-422.
- 15 Chen X.X, Sheng X.S, Zhang X.Y, Chen Y, "Research on Axial Compression Behavior of Nano SiO₂ Reinforced Concrete Filled Stainless Steel Circular Tube Short Columns after High Temperature", Industrial Construction, 2018, 49, 189-193.
- 16 Lin Q.J, Chen Y, Liu C, "Mechanical Properties of Circular Nano Silica Concrete Filled Stainless Steel Tube Stub Columns after Being Exposed to Freezing and thawing", Nanotechnology. Rev., accepted.
- 17 He K, Chen Y, Xie W.T, "Test on Axial Compression Performance of Nano Silica Concrete Filled Angle Steel Reinforced GFRP Tubular Column", Nanotechnology. Rev., accepted.
- 18 IS: 13311 (Part-I) - 1992, "Indian Standard Code for Method of Test for Ultrasonic Pulse Velocity Test", BIS, New Delhi, 1992.
- 19 IS: 13311 (Part-II) - 1992, "Indian Standard Code for Method of Test for Rebound Hammer", BIS, New Delhi, 1992.
- 20 IS: 516-1959, "Indian Standard Code for Method of Test for Strength of Concrete", BIS, New Delhi, 1959.
- 21 Rahman I, Dev N, "Nano Alumina Based High Strength Concrete", IJITEE, ISSN: 2278-3075, Volume-9 Issue-4, February 2020.



Prof. (Dr.) N. Dev Professor and Head CED, DTU, Delhi-110042

AUTHORS PROFILE



Mr. I. Rahman Research Scholar CED, DTU, Delhi-110042 Assistant Professor CED, JMI, New Delhi-110025