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Enhancement of Performance of Concrete with Nano Materials

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Abstract

Nano technology is a new emerging area in field of engineering. Development of nanotechnology in the field of material science and evolution of advanced instrumentation have paved way for application of nanotechnology in the construction field. Incorporation of nano sized particles in cement composites makes a significant change in structural and non-structural properties of cement paste, mortar and concrete. The particles converted from micron size to nano size results in more specific surface area. The increase in surface area leads to surface changes in morphology, increase in the chemical reactivity, structural modification of cement hydrates and enhancement in the property of concrete. Nano particles are produced by two approaches. In "top down" approach in which larger particles are reduced to smaller particles without altering the original properties and in "bottom down" approach very small nanoscopic molecules and atoms combine to form bigger structures wherein the particles properties can be altered. The scaled down particles are to be checked for their size and some of the equipment's available to determine particle size are scanning electron microscope, atomic force microscope and transmission electron microscope. Specific surface area plays a very important role in determining the properties of cement-based materials. The cement in nano scale has more specific surface area and reacts faster with water and results in faster rate of development of strength. The different types of nano particles possess different property. Many techniques like Energy dispersive X-ray analysis, X-ray diffraction, X-ray absorption spectroscopy, Fourier transform infrared spectroscopy, Nuclear magnetic resonance spectroscopy, Thermal gravimetric analysis, Low-energy ion scattering spectroscopy, UV-V's spectroscopy, v Photoluminescence spectroscopy, Dynamic light scattering are available for the surface chemical analysis and characterization of nano materials. The recent research on nano materials and nanotechnology have highlighted the potential use of nano materials as building materials. However, the research with incorporation of large percentage of nano materials carried out so far is very less. Therefore, finding the mechanical and durability properties of cement mortar and concrete with large amount of nano particles is the need of the hour. In the present investigation, an attempt has been made to study the behaviour of concrete with nano materials. Ball grinder was used to grind micron sized particle to nano size. Nano cement, nano fly ash, nano silica and nano silica fume were the nano materials considered for the study. Cement, fly ash, silica and silica fume when converted into nano size particles, the specific surface area becomes more and hence results in enhanced performance. The size of the particles was determined through surface morphology studies using SEM. The specific surface area was found by Braeuer Emmett Teller theory using BET apparatus and the elemental compositions were found by X-ray spectroscopic method using EDAX. Studies indicated that micron sized particles were converted to nano size without much change in the chemical composition but with an enormous increase in specific surface area. The nano particles produced were used as a partial replacement material for cement. The consistency and setting *time of the cement with nano particles were determined by using Vicat's apparatus and the results were found to be within the prescribed limits given in relevant bureau of Indian standard code. Compressive strength on cement mortar with nano particles was found to give more strength compared to normal cement mortar. Workability vi of fresh concrete was found to increase with the addition of nano particles. The fine particles act as a lubricant thus enhancing the workability. The mechanical and durability properties were found for M20, M30, M40 and M50 grades of concrete in which 10, 20, 30, 40 and 50 percentage of cement was replaced with nano particles. The compressive strength, tensile strength, flexural strength, and modulus of elasticity were found for concrete with different proportions of nano materials and the optimum replacement levels were obtained. The strength characteristics were investigated on 28, 56 and 90 days. The increase in the compressive strength was found to range between 2% and 71% for different replacement percentages of nano materials. It was also found that the gain in the compressive strength of concrete with nano cement was significantly higher than that of the concrete with nano fly ash, nano silica and nano silica fume. The durability studies such as permeability, rapid chloride penetration, porosity, water absorption, corrosion, acid resistance and impact strength were also carried out on concrete with nano materials. Results indicated that nano particles act as a filler material producing denser concrete. They also block the continuity of pores thus resulting in decrease in permeability, chloride ion penetration, porosity, water absorption, acid resistance and corrosion. Ductility factor and the impact strength of concrete with nano materials were found to be significantly better than those of the normal cement concrete. Air pressure resistance test were carried out to determine the internal radial pressure sustaining capacity. The test set up was fabricated to carry out the test and the results indicated that the air pressure resistance of concrete increased with addition of nano particles. From the experimental studies conducted, it is concluded that micron sized particles cement, fly ash, silica and silica fume are converted to nano sized particles on ball grinding. The size of nano particles was found to vii range between 45nm to 173nm.The addition of nano particles have pivotal role in the development of strength and durability aspects of concrete. It is found that the compressive, split tensile and flexural strength increases by 31.5%, 96.8% and 25.3% respectively on incorporation of nano particles. Similarly, there was a reduction in permeability, porosity, chloride penetrability, water absorption and acid resistance up to 96%. The overall performance of concrete with nano particles was found to be much better than that of the normal cement concrete. Hence it can be concluded that this concrete with nano materials has a lot of scope for structural applications.*

KEYWORDS: *Cement, Fine Aggregate, Coarse Aggregate, Crushed Tiles and Silica Fume,Fly Ash.*

1. Introduction

1.1. General

Nanotechnology is an advanced technology that has received a lot of attention for its ability to make use of the unique properties of nano sized materials. Nanotechnology is capable of manipulating and controlling material structures at nano level and offering new and excellent material properties. A nano meter is 1/1000 of a micron, or 1 billionth of a meter which is about three atoms set side by side. The grain size is of the order of 10-9 m.

Currently nano technology is being used for the creation of new materials, devices, and systems at molecular, nano, and micro level. The nano scale particles can result in vividly improved properties from conventional grain size materials of the same composition. Nano materials show unique physical and chemical properties that can lead to the development of more effective materials than the ones which are currently available. The use of nano materials in concrete and understanding the properties of concrete with nano materials results in stronger and more durable concrete with desired stress-strain behaviour.

Nano technology in construction may

i. Minimize the amount of cement and thereby help in minimizing CO2 emission.
ii. Enhance the properties of cementitious material and concrete composites. Protect the concrete and steel from aggressive environment.
iii. Protect the concrete and steel from aggressive environment.
iv. Help in improving the fire resistance and thermal comfort.
v. Improve the mechanical, electrical, optical, structural and durability properties.

Nano materials are chemically very active due to their smaller grain size and large specific surface area which helps in manifesting the structural and non-structural properties resulting in stronger materials.

1.3 USE OF NANO MATERIALS IN CONCRETE

Nano particles are added to concrete to improve its material properties. Research proves that there will be considerable changes in chemical reactivity and mechanical properties when the particles are converted to nano size. When the size is reduced, more atoms will be found at the surface of particle which significantly imparts a change in the morphology and energy at the surface. The changes in the chemical reactivity will improve catalytic ability in paints and pigments which impart self-cleaning and self-healing properties. NP can be used to enhance the mechanical properties of ceramic materials and rubbers. Nano TiO2 is used as a self-cleaning material in glass and as anti-corrosive element in steel. Carbon nano tubes (both single walled and multi walled) and carbon nano fibres are used in concrete to prevent cracks and to improve ductility. Nano ferric oxide due to its super para magnetic property can improve the strength property of concrete. They are also used in paints as colouring agents and act as an anticorrosive agent. Nano Al2O3 is used to resist abrasion of concrete in pavements. NFA acts as a promoter to enhance the pozzolanic property. NS with different quality and properties are used as an additive material in concrete. The property of NS produced from olivine is different from NS produced from rice husk ash. In common, NP is used to enhance mechanical and durability properties of concrete and to develop sustainable concrete materials and structures.

1.2 PRODUCTION OF NANOMATERIALS

Nano materials can be produced by atom manipulation, plasma arcing, chemical vapour deposition, electro-deposition, sol–gel synthesis and using a high intensity ball milling. In direct atom manipulation, the atoms are moved individually mostly using scanning tunnelling microscope. The second method is plasma arcing. In this method very high temperature needed to form plasma is used to effectively separate the atomic species. These atoms quickly recombine to form nano sized particles with new compositions. In chemical vapour deposition method, gases react in a chamber to form substrate in which fine particles are deposited as a coating. The electro-deposition method follows the deposition method where the coating is deposited by applying an electric field. In the sol–gel synthesis, compounds are produced with chemicals which are hydrolysed to form gels. In the last method, high intensity ball milling is used to reduce the materials to nano size. The main limitation in using nano materials in civil engineering construction is its high production cost. Carbon nano tubes, NS, nano ferric oxide, and nano titanium oxide are probably the most reported nano additives used in construction field. Nano materials enhance strength, modulus, and ductility of concrete. Nano materials improve the tensile strength of concrete by acting as a bridge across voids and cracks.

1.3 NEED FOR THE PRESENT INVESTIGATION

Nanotechnology can be defined as the science used to modify the performance of materials or composite at molecular scale by using nano scale particles. Nanotechnology is used in many disciplines like medicine, biotechnology, engineering etc. Usage of this technology motivates scientists, engineers, innovators, academicians and researchers to find new materials which helps in sustainable development. These studies aim at understanding the behaviour of materials and controlling them at the molecular level and thereby improving the properties of the material. These studies have been extended to civil engineering field to enhance the properties of cement and concrete. Since nanotechnology can be used to incorporate specific properties in concrete, studies are needed to understand the behaviour of materials and adopted for practical use. Many bridges and buildings constructed before few decades with concrete are structurally deficient and must be repaired or replaced. According to Birgisson et al. (2010), the introduction of nanotechnology to concrete promises to improve mechanical performance, prevents cracks, reduce shrinkage, improve sustainability and reduce calcinations and carbon dioxide. According to Jim Grove et al. (2010), incorporating nano materials has the ability to modify the performance of concrete and cement, reduce the volume changes due to change in temperature and loss of moisture. According to Taylor et al. (2007), nanotechnology modifies the properties of recycled materials making them usable in concrete. Nanotechnology can create new efficient materials, which can contribute in extending life of pavement, bridges and concrete structures and can bring revolution in construction field. The field of concrete technology can be improved by incorporating nanotechnology. Research has been done on industrial waste materials like fly ash, silica fume, GGBS and agro wastes like rice husk ash, palm oil fuel ash, wood waste ash and bagasse ash as a partial replacement to cement to improve the mechanical and durability properties of concrete. It was also reported that silica fume and metakaolin increase the resistance to abrasion at an early age. If these materials are converted to nano scale, the properties of materials can be enhanced, and the behaviour of concrete can be improved to a larger extent. Hence there is much scope for research work in areas of cement and concrete with nano materials. This thesis aims to study the behaviour of cement and concrete with nano materials for sustainable development. In the literature, mostly researchers have used NS, nano carbon tubes, nano TiO_2, nano Fe_2O_3 and $CaCO_3$ nano particles. Reports on use of 6 supplementary cementitious materials in nano form are not available in the literature. Mostly Sol gel process was used for the production of NP. This process could make particles whose size will range between 16nm to 48 nm. However, the cost of production is very high. Hence there is an need to find an alternative, cost effective method to produce nano particles ball grinding mill was used to produce NP for this research work. Also many investigations are done on cement mortar with nano materials and only few investigations are carried out in concrete with nano materials. Also additions of only 1% to 5% of nano particles were used to study the properties of cement mortar and concrete. Hence it is need of the hour to study the properties of cement mortar and concrete with large quantity of nano particles. Since nano particles enhance the mechanical and durability properties of concrete, an elaborate study is needed on cement mortar and concrete

1.4 RESEARCH OBJECTIVES

The main objectives of the present investigation are

- To study the properties of cement paste in which cement was replaced partially with NP.
- To carry out an experimental and microstructure investigation on cement mortar with Nano Cement (NC), Nano Fly Ash (NFA), Nano Silica (NS) and Nano Silica Fume (NSF).
- To compare the strength parameters of normal cement mortar with cement mortar containing NP.
- To study the properties of fresh concrete with NC, NFA, NS and NSF.
- To carry out strength and durability studies on concrete with NC, NFA, NS and NSF.
- To compare the workability, strength, and durability properties of concrete with nano materials with that of Normal Cement Concrete (NCC).

- To carry out air pressure resistance of NCC and to compare the resistance of concrete with NC, NFA, NS and NSF.

2. REVIEW OF LITERATURE

A detailed review of literature on the behaviour of mortar and concrete with nano materials is reported to completely understand the behaviour of cement mortar and concrete with NP, it is necessary to consider all the parameters that influence the test results. Grade of concrete, type of nano materials, type of aggregates, type of admixture, percentage replacement of NP are few factors that influence the performance of cement mortar and concrete.

Zhi Ge and Zhili Gao (2008) emphasized that nanotechnology should focus on improving the overall competitiveness of the construction industry like lighter and stronger structural composites. It was highlighted that the structure and behaviour of concrete should be understood at micro and nano scale. It was reported that NS and NFA in concrete act as a filler medium and nano carbon tube increased the compressive and flexural strength of concrete. The corrosion resistance of steel was enhanced by incorporating nano copper particles.

Bhuvaneshwari et al. (2011) reported that efforts were taken to evolve new nano material towards a green and sustainable solution in cement-based materials and their composites for the construction applications. They used NP to improve the toughness, shear, tensile and flexural strength of cement-based materials. It was reported that the study of cement-based material at nano level will result in a new generation construction material with enhanced strength and durability properties. Florence Sanchez and Konstantin Sobolev (2010) reviewed the state of nano technology in concrete. They reported that the measurement and characterization of nano structure of cement and concrete materials is nano science and use of nano materials in cement and concrete composite is nano engineering. The study of both is necessary to improve the performance of cementitious composite. The nano structure study of nano materials was done by atomic force microscope, nano indentation technique, nuclear techniques, neutron, and X ray scattering technique. Experimental study and micro structural study on nano materials is essential to study the effect of nano particles in concrete. They reported that mechanical properties of concrete can be enhanced with incorporation of nano particles in concrete.

Sada Abdalkhaliq Hasan Alyasri et al.(2017)investigated the economic feasibility of producing NC in a large scale through the cement factories. The production in large scale is elaborated in which the mineral admixtures such as fly ash and slag should be added with crushed clinker where the moisture content should be maintained below 3%. The mixture was ground for 30 to 40 min to get NC. It was found that concrete with high strength, impermeability, acid resistance was achieved by this NC and used in construction to enhance the life span of structures. The specific gravity of nano cement was found to be 2.11 and specific surface area was 3,582,400cm2 /g.

3. PROPERTIES OF MATERIALS AND CEMENT MORTAR WITH NANO MATERIALS

Concrete is considered to be a composite material containing a binder medium within which aggregate particles are embedded. The mineral admixtures like fly ash and silica fume improve the performance of concrete. Nano materials are of size 10-9m. When the micro sized particles are replaced with nano sized particles produced by ball grinding, the mechanical and durability characteristics of concrete composites can be enhanced. The materials used in this experimental investigation are cement, fine aggregate, coarse aggregate, fly ash, silica fume, silica, and water.

3.2.1 Cement

Ordinary Portland Cement (OPC) of 53 grade conforming to IS: 12269-2013 and procured from a single source was used for this investigation. The specific surface area of cement was 370m2 /kg. The initial setting time was 50 minutes and final setting time was 510 minutes. The compressive strength of cement mortar for 3days, 7days, 21days and 28days was found to be 42.5N/mm2 , 48 N/mm2 , 57 N/mm2 and 63.5 N/mm2 .

Table .1 Chemical and physical properties of 53grade OPC

Particulars	Results (%)	Requirements of IS:12269
SiO_2	21.8	-
Al_2O_3	4.8	-
Fe_2O_3	3.8	-
CaO	63.3	-
SO_3	2.2	-
MgO	0.9	Maximum6
Na_2O	0.21	-
K_2O	0.46	-
Cl	0.04	Maximum0.1
P_2O_5	<0.04	-
Loss of ignition	2.0	Maximum4
Insoluble residue	0.4	Maximum3
Specific surface area,m^2/kg	370	Minimum225
Initial setting time, minutes	50	Minimum30
Final setting time, minutes	510	Maximum600
Standard consistency,%	34	-
Soundness, Le-chatelier, mm	1.0	Maximum10

Compressive Strength, MPa 3–days 7–days 28– days	42.5 48.0 63.5	Minimum27 Minimum37 Minimum53
Specific gravity	3.15	-

3.2.2. Fine Aggregate

The locally available clean and dry natural sand from Cauvery River basin, Karur free from debris was used as fine aggregate. The specific gravity of fine aggregate was found to be 2.65. Sieve analysis was conducted and it was found that the sand was conforming to Zone II grading. Bulk density of fine aggregate was found to be 1520kg/m^3. Fineness modulus of sand was found to be 2.32. The properties of fine aggregate were found to confirm with IS: 383-1970.

3.2.3. Coarse Aggregate

The coarse aggregate used was natural hard broken granite stones. Crushed granite metals of size 20mm were used. The specific gravity of coarse aggregate was 2.79 and it is confirming to IS: 383-1970.

3.2.4. Water

Potable water available in laboratory was used for casting and curing all specimens in this investigation. The quality of water was found to satisfy the requirements of IS: 456-2000.

3.2.5. Fly Ash

Class F fly ash procured from Mettur Thermal Power station conforming to IS: 3812- 1981 was used for the investigation. Fly ash is an inorganic residue, and its constituents are silica, alumina and iron oxide with smaller amount of calcium, magnesium and sulphur

3.2.6. Silica Fume

Silica fume procured in dry densified form from ELKEM India (P) limited, Mumbai conforming to IS: 15388-2003 was used. The particle size of silica fume was found to be in the range of 100µm to 10µm.The physical and chemical properties of the silica fume are given in Table 2.

Table.2 Physical and chemical properties of silica fume

Particulars	Results	Requirements
Bulk density D (kg/m³)	600-700(when packed)	500-700
Bulk density U (kg/m³)	200-350(when packed)	----
Specific gravity	2.2	21-2.3
Specific surface (m²/gm)	16.9	15 minimum
SiO2	90-96	85 minimum
Al2O3	0.5-0.8	-
Fe2O3	0.2-0.8	-
MgO	0.5-1.5	-
CaO	0.1-0.5	-
Na2O	0.2-0.7	1.5 maximum
K2O	0.4-1.0	-
C	0.5-1.4	2.5 maximum
S	0.1-0.4	-
Loss of ignition (c + s)	0.7-2.5	4 maximum

3.2.7. PRODUCTION OF NANO MATERIALS

In this present study, NC, NFA, NS and NSF were produced in a high intensity ball grinder shown in Figure .1

Figure 1 Ball grinder

In high energy ball grinding milling machine shown in Figure 3.1, high impact collisions were used to reduce microcrystalline materials down to nano crystalline structure without chemical change. OPC was ground for 12 hours to produce NC. Similarly fly ash was ground for 30 hours, silica fume was ground for 3 to 5 hours and sand rich in silica was ground for 5 days to produce nano sized particles. Care was taken to avoid balling effect and agglomeration.

3.1. MICROSTRUCTURE ANALYSIS OF NANO MATERIALS

The particles ground in ball grinding mill were taken to determine images of Nano cement, Nano Fly Ash and Nano Silica Fume are shown respectively

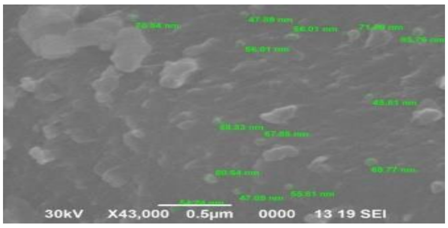


Figure 2. SEM image of NC

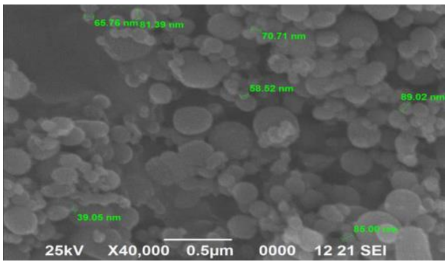


Figure 3. SEM image of NFA

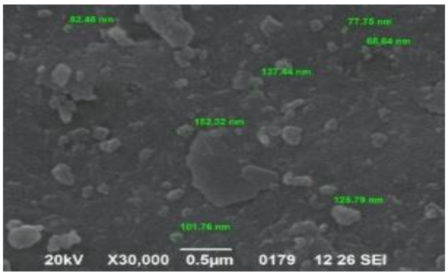


Figure 4. SEM image of NS

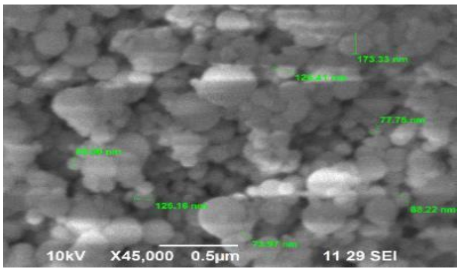
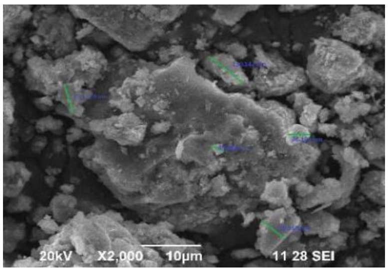


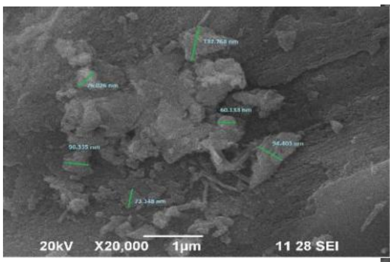
Figure 5.SEM image of NSF

3.5.1.1. Microstructure study on cement mortar with Nano Cement

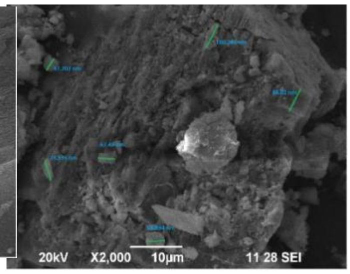
SEM images of cement mortar cubes in which cement was replaced with 10%, 20%, 30%, 40% and 50% of NC are shown



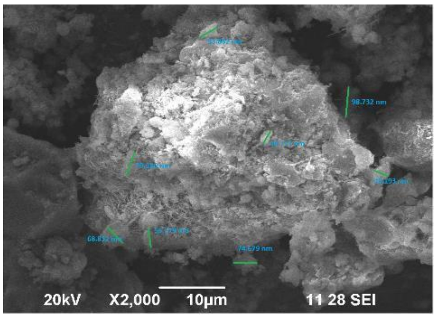
(a)



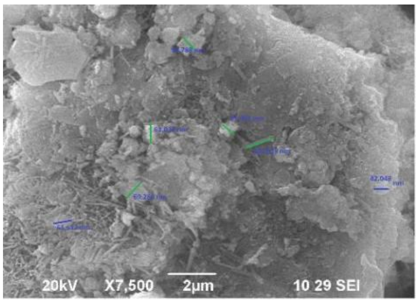
(b)



(c)



(d)

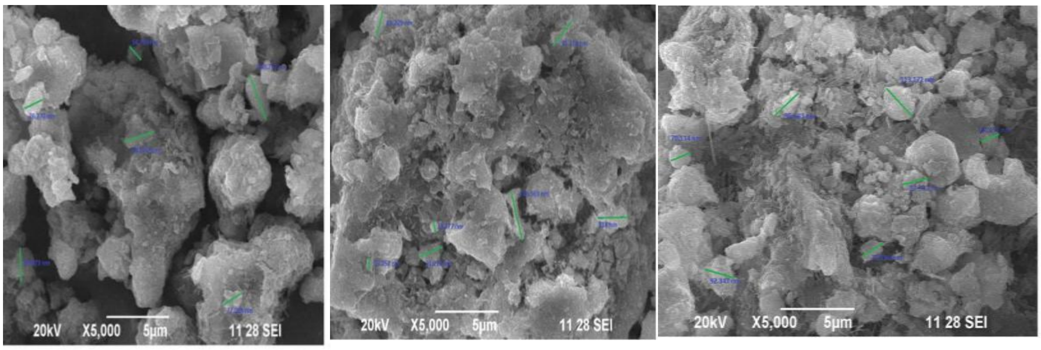


(e)

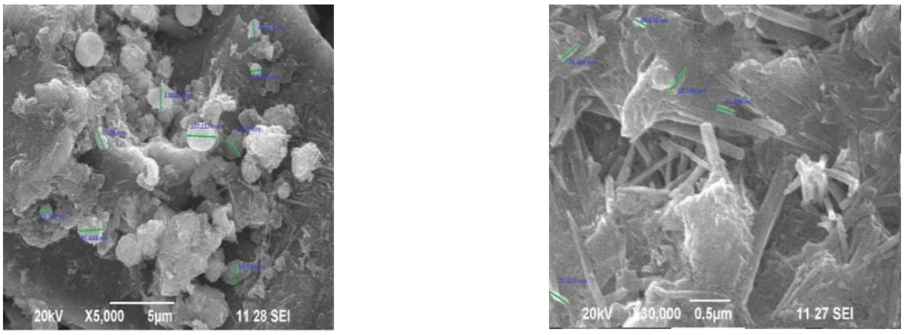
Figure 6. SEM images of cement mortar on 28th day with NC(a) 10% replacement of NC (b) 20% replacement of NC (c) 30% replacement of NC (d) 40% replacement of NC (e) 50% replacement of NC

3.5.1.1. Microstructure study on cement mortar with Nano Fly Ash

SEM images of cement mortar cubes in which cement was replaced with 10%,20%, 30%, 40% and 50% of NFA are shown



(a) (b) (c)

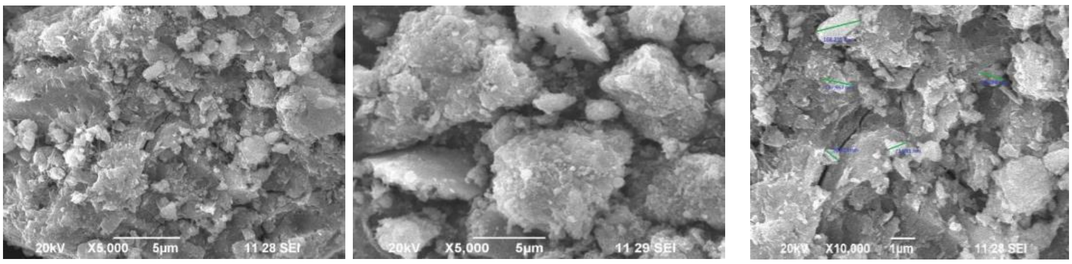


(d) (e)

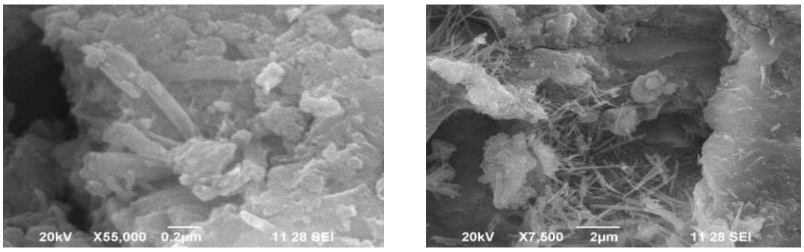
Figure 7. SEM images of cement mortar on 28th day with NFA(a) 10% replacement of NFA (b) 20% replacement of NFA (c) 30% replacement of NFA (d) 40% replacement of NFA(e) 50% replacement of NFA

3.5.1.1 Microstructure study on cement mortar with Nano Silica Fume

SEM images of cement mortar cubes in which cement was replaced with 10%, 20%, 30%, 40% and 50% of NSF are shown



(a) (b) . (c)

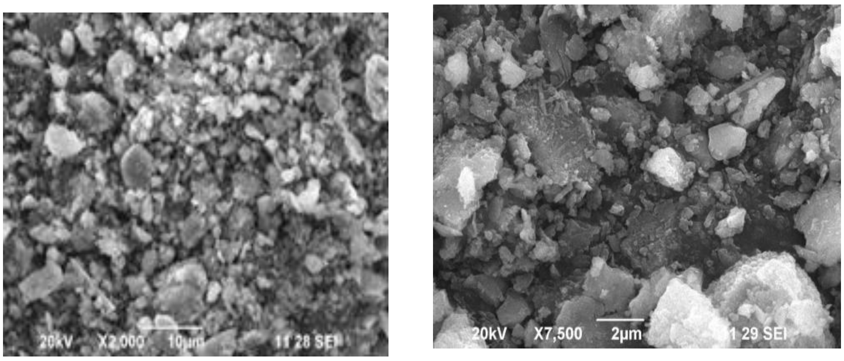


(d) (e)

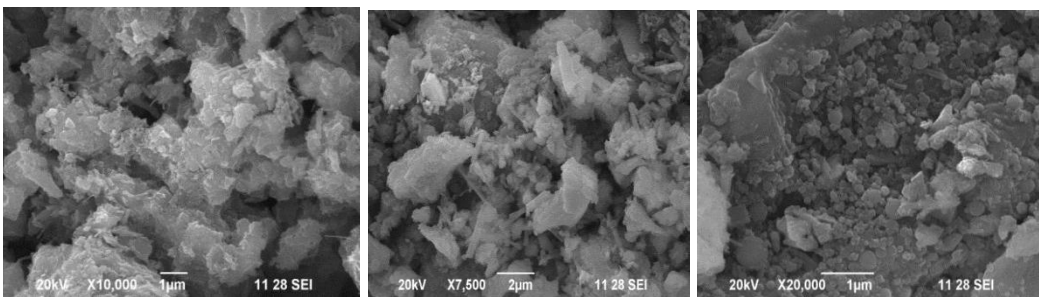
Figure 8. SEM images of cement mortar on 28th day with NSF (a)10% replacement of NSF (b) 20% replacement of NSF (c) 30% replacement of NSF (d) 40% replacement of NSF(e) 50% replacement of NSF

3.5.1.2 Microstructure study on cement mortar with Nano Silica

SEM images of cement mortar cubes in which cement was replaced with 10%, 20%, 30%, 40% and 50% of NS are shown.



(a) (b)



(c) (d) . (e)

Figure 9. **SEM images of cement mortar on 28th day with NS(a)10% replacement of NS (b) 20% replacement of NS (c) 30% replacement of NS (d) 40% replacement of NS(e) 50% replacement of NS**

From the properties of nano materials, the properties of cement paste on replacement of cement with nano materials and the optimum replacement level of cement with NC, NFA, NS and NSF were discussed. It was found that the optimal replacement levels of cement with NC, NFA, NS and NSF were found to be 50%, 40%, 30% and 40% respectively. The initial and final setting time of cement paste with NC, NFA, NS and NSF were found. As per the IS 12269-2013, the initial and final setting time of cement paste should not be more than 30 and 600 minutes. Hence the percentage replacement of cement with NC should not be more than 50%, the percentage replacement of cement with NFA and NSF should not exceed 40% whereas the percentage replacement of cement with NS should be limited to 30%.

4. MECHANICAL PROPERTIES OF CONCRETE WITH NANO MATERIALS

4.1 . GENERAL

Concrete is a heterogeneous composite material consisting of aggregates, cement, water and admixtures. The coarse aggregates give strength and the inter-granular pores are filled with fine aggregate. Cement acts as the binding medium with the addition of water. Ordinary Portland Cement (OPC) of size up to 300µm was used for the study. When the size of the cement particles is reduced to nano size, the properties of concrete can be modified and enhanced. Admixtures improve the strength and durability of concrete. Mineral admixtures such as fly ash and silica fume possess pozzolanic property and these admixtures in nano scale when added to concrete will result in novel properties. Nano size particles have extremely large specific surface area and they modify the properties of concrete resulting in stronger and more durable concrete. Nano particles are chemically active and they also fill the pores of concrete so as to minimize the penetration of aggressive agents. Concrete is good in compression. The compressive strength can be much enhanced by decreasing the size of the pores. The nano particles used also take part in hydration process and help in increasing the strength.

4.1. MIX PROPORTIONING

Mix proportioning for M20, M30, M40 and M50 grades of concrete was done based on IS: 10262-2009and IS: 456-2000. The properties of the materials used for making concrete were experimentally determined and given below.

- Specific gravity and bulk density of 20 mm aggregate were found tobe2.96 and 1550 kg/m^{3}respectively.
- Specific gravity fine aggregate was found to be 2.72.
- Fineness modulus of fine aggregate was found to be 2.66.

- Fine aggregate was river sand falling under Zone II.

Table 3. Mix proportions

GC	Particulars	Water	Cement	Fine aggregate	Coarse aggregate	%RCNP				
						10%	20%	30%	40%	50%
M 20	kg/m^3	211	383	594	1406	38	77	115	153	192
	Ratio	0.6	1	1.55	3.67	0.1	0.2	0.3	0.4	0.5
M 30	kg/m^3	190	431	483	1263	43	86	129	172	216
	Ratio	0.4	1	1.12	2.93	0.1	0.2	0.3	0.4	0.5
M 40	kg/m^3	178	480	456	1320	48	96	144	192	240
	Ratio	0.4	1	0.95	2.75	0.1	0.2	0.3	0.4	0.5
M 50	kg/m^3	158	510	377	1199	51	102	153	204	255
	Ratio	0.3	1	0.74	2.35	0.1	0.2	0.3	0.4	0.5

Where GC = grade of concrete.

4.1 DETAILS OF TEST SPECIMENS

The details of the specimens cast for determining the strength are given in Table4.

Table 4. Details of specimens cast for determining the mechanicalproperties

S. No	Shape	Dimensions in mm	No. of specimens cast	Age in days	GC	Type of test carried out
1	Cube	150x150x150	756	28,56, &90	M20, M30, M40 and M50	Compressive strength
2	Cylinder	150Ø x 300height	756	28,56, &90	M20, M30, M40 and M50	Split tensile strength
3	Prism	100x100x500	756	28,56, &90	M20, M30, M40 and M50	Flexural strength
4	Cylinder	150Ø x 300height	756	28	M20, M30, M40 and M50	Modulus of elasticity

5. EXPERIMENTAL STUDIES ON DURABILITY OFCONCRETE WITH NANO MATERIALS

5.1. GENERAL

Durability of concrete is its ability to sustain the present behaviourof concrete withstanding the chemical attack and weathering action to avoid significant deterioration. Durability is very important in determining the structure's lifespan. Inadequate durability will result in deterioration which can be due to external factors or internal causes within the concrete itself. The deterioration may be physical, chemical or mechanical. External chemical attack occurs mainly through the action of aggressive ions, such as chloride or sulphate as well as many natural or industrial liquids and gases. The durable concrete not only increases the life span of the structure but also indirectly reduces CO_2 emission into the atmosphere. Therefore it is essential to study the durability of concrete.

5.1. DETAILS OF TEST SPECIMENS

The details of the specimens cast for determining the durability properties are given in Table 5.

Table 5. Details of the specimens cast for determining the durability properties

S. No.	Shape	Dimensions in mm	Number of Specimens Cast	Age in Days	Grade of Concrete	Type of Test Carried
1	Cylinder	100 Ø x 100 ht	1260	7, 14, 28, 56, 90	M20,M30, M40, M50	Permeability
2	Cylinder	100 Ø x 100 ht	756	28, 56, 90	M20,M30, M40, M50	Chloride ion penetration
3	Cylindrical Disc	152 Ø x 63.5 ht	756	28, 56, 90	M20, 30, M40, M50	Impact strength
4	Slab	800 x 800 x 80	756	28, 56, 90	M20,M30, M40, M50	Corrosion resistance
5	Cube	150x150x 150	756	28, 56, 90	M20, M30, M40, M50	Porosity
6	Cube	150x150x 150	756	28, 56, 90	M20, M30, M40, M50	Water absorption
7	Cube	70 x 70 x 70	756	28,56, 90,120	----	Acid resistance (H_2SO_4, HCL, HNO_3

6. AIR PRESSURE RESISTANCE TEST ON CONCRETEWITH NANO MATERIALS

6.1. GENERAL

Nowadays concrete with nano materials are used in composite structures. Concrete with nano materials are gaining prominence due to its higher strength and better durability. The pressure in concrete structures is significant and results in cracks propagating through the structures which may result in reduced service life. Pipes carrying fluids with large pressure, large water tanks, nuclear reactors will have to resist large amount of hoop and longitudinal pressure. Such reinforced concrete units must be made of concrete with high compressive and tensile strength. During the present study, an air pressure test was carried on hardened concrete hollow cylinder specimens with nano materials to determine the internal radial pressure sustaining capacity.

6.2. EXPERIMENTAL INVESTIGATION

The experimental investigation was carried out on hollow cylinderspecimens in which cement was replaced with10%, 20%, 30%, 40%, and50% of NC, NFA, NS and NSF. Seven hundred and fifty six specimens were cast during the experimental investigation. Concrete of grades M20, M30, M40 and M50 were designed as per IS: 10262-2009(Table 4.1). The air pressure tests were carried out on the 28th, 56th and 90th days.

6.3. RESULTS AND DISCUSSION

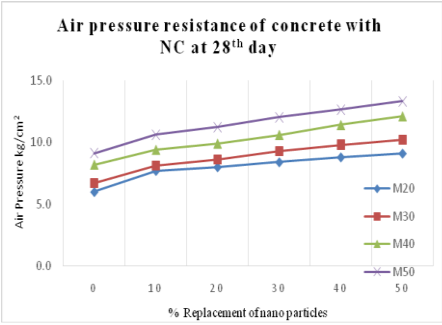
The result of the air pressure resistance on concrete with nano materials are given in Table.6.

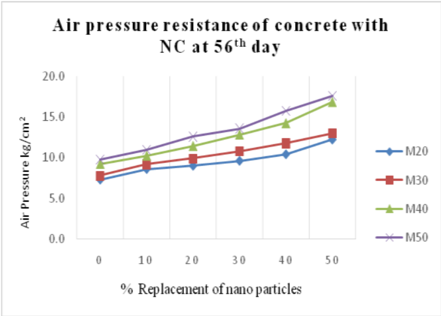
Table 6. Air pressure resistances for M20, M30, M40 and M50grades of concrete

GC	%RCNP	Air pressure resistance kg/cm^2											
		NC			NFA			NS			NSF		
		28th day	56th day	90th day	28th day	56th day	90th day	28th day	56th day	90th day	28th day	56th day	90th day
M 20	0	6.00	7.30	9.60	6.00	7.30	9.60	6.00	7.30	9.60	6.00	7.30	9.60
	10	7.70	8.60	12.4	7.30	8.30	13.2	7.50	8.00	11.0	7.40	8.20	12.3
	20	8.00	9.00	14.2	7.60	8.80	14.8	7.70	8.30	12.9	7.70	8.60	13.8
	30	8.40	9.60	15.2	8.10	9.40	15.4	8.00	9.00	14.1	8.10	9.20	14.9
	40	8.80	10.4	16.3	8.40	10.3	17.0	7.60	9.60	15.7	8.30	10.0	15.9
	50	9.10	12.2	18.1	8.00	10.2	16.4	6.70	8.80	15.1	8.20	9.09	15.7
M 30	0	6.70	7.80	10.2	6.70	7.80	10.2	6.70	7.80	10.2	6.70	7.80	10.2
	10	8.10	9.20	13.8	8.00	8.90	14.2	7.60	8.40	12.8	7.90	8.90	13.4
	20	8.60	9.90	15.8	8.40	9.70	16.2	8.00	9.20	13.7	8.30	9.50	14.7
	30	9.30	10.8	17.2	8.80	10.6	17.8	8.40	9.90	15.8	9.00	10.4	16.2
	40	9.80	11.8	18.2	9.10	11.4	18.6	8.30	10.6	16.9	9.60	11.6	17.8
	50	10.2	13.0	19.6	8.60	11.1	18.3	7.80	10.3	16.5	9.50	11.4	17.5
M 40	0	8.20	9.20	10.6	8.20	9.20	10.6	8.20	9.20	10.6	8.20	9.20	10.6
	10	9.40	10.2	14.8	8.40	9.80	15.2	8.30	9.30	13.8	8.30	9.70	14.2
	20	9.90	11.4	17.2	8.90	11.2	18.0	8.60	10.6	15.6	8.70	11.0	16.8
	30	10.6	12.8	18.4	9.40	12.6	18.8	9.30	11.3	17.7	9.40	11.9	18.2
	40	11.4	14.2	19.8	9.90	13.9	20.4	8.80	12.2	18.6	10.6	13.7	19.4
	50	12.1	16.8	21.1	9.10	13.8	20.2	8.50	12.0	18.3	9.90	13.2	19.1
M 50	0	9.10	9.80	11.2	9.10	9.80	11.2	9.10	9.80	11.2	9.10	9.80	11.2
	10	10.6	11.0	16.2	9.50	10.8	17.1	9.40	10.5	15.3	9.50	10.8	15.8
	20	11.2	12.6	18.6	9.80	12.4	19.1	9.80	11.7	17.8	10.0	12.2	18.4
	30	12.0	13.6	20.4	10.2	13.2	21.0	10.4	12.9	19.6	10.8	13.2	20.2
	40	12.6	15.8	22.2	10.5	14.8	22.9	10.1	13.9	20.9	11.9	15.6	21.7
	50	13.3	17.6	23.6	10.0	14.6	22.7	9.9	13.7	20.7	11.3	15.2	21.4

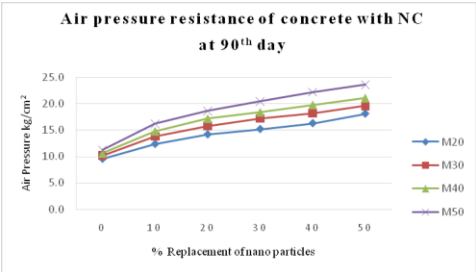
6.2.1Discussion on Air Pressure Resistance of Concrete with NC

Figure 6.8shows the air pressure resistance at failure of concretewith respect to the percentage replacement of cement with NC.





(a) (b)



(c)

Figure 10. Air pressure resistance of concrete with NC(a) Concrete at28th day (b) Concrete at 56th day (c) Concrete at 90th day.

From the Table 6.1 and Figure 6.8, it can be seen that the replacement of cement with NC increases the air pressure resistance. The increase in air pressure resistance at failure continues even upto 50% in replacement level of NC. The correlation coefficients between the air pressure resistance and percentage replacement of cement with NC were found to be 0.9292, 0.9756, 0.9946 and 0.9861 for M20, M30, M40 and M50 concrete respectively.

6.2.4.1. Effect of Percentage Replacement of Cement with NC on the AirPressure Resistance

The percentage increase in air pressure resistance for different replacement levels of cement with NC was found with respect to that of the NCC. The percentage increases in the values of air pressure resistance at failure for specimens with NC are given in Table 6.2

Table 7. Percentage increase in the air pressure resistance at failurefor concrete with NC

%RCNP	Percentage increase in the air pressure resistance at failure											
	M20			M30			M40			M50		
	28th day	56th day	90th day	28th day	56th day	90th day	28th day	56th day	90th day	28th day	56th day	90th day
10	28.3	17.8	29.2	20.9	17.9	35.3	14.6	10.9	39.6	16.5	12.2	44.6
20	33.3	23.3	47.9	28.4	26.9	54.9	20.7	23.9	62.3	23.1	28.6	66.1
30	40.0	31.5	58.3	38.8	38.5	68.6	29.3	39.1	73.6	31.9	38.8	82.1
40	46.7	42.5	69.8	46.3	51.3	78.4	39.0	54.3	86.8	38.5	61.2	98.2
50	51.7	67.1	88.5	52.2	66.7	92.2	47.6	82.6	99.1	46.2	79.6	110.7

From Table 7., it can be seen that as the percentage replacement of NC increases, the air pressure resistance at failure also increases.

The ranges of percentage increase in the air pressure resistance fordifferent percentage replacements of cement with NC are given in Table 6.3.

Table 8. Ranges of percentage increase in air pressure resistance forconcrete with NC

%RCNP	10%	20%	30%	40%	50%
Range of % increase	12.20 to 44.60	20.70 to 66.10	29.3 to 82.10	38.50 to 98.2	46.20 to 110.70

From the Table 8., it can be seen that the NC is very effective in increasing the air pressure resistance of concrete. Replacement level of 50% gave a maximum increase of 110.70.

The ranges of percentage increase in the air pressure resistance fordifferent grades of concrete with NC are given in Table 6.4.

Table 9. Ranges of percentage increase in air pressure resistance for different grades of concrete

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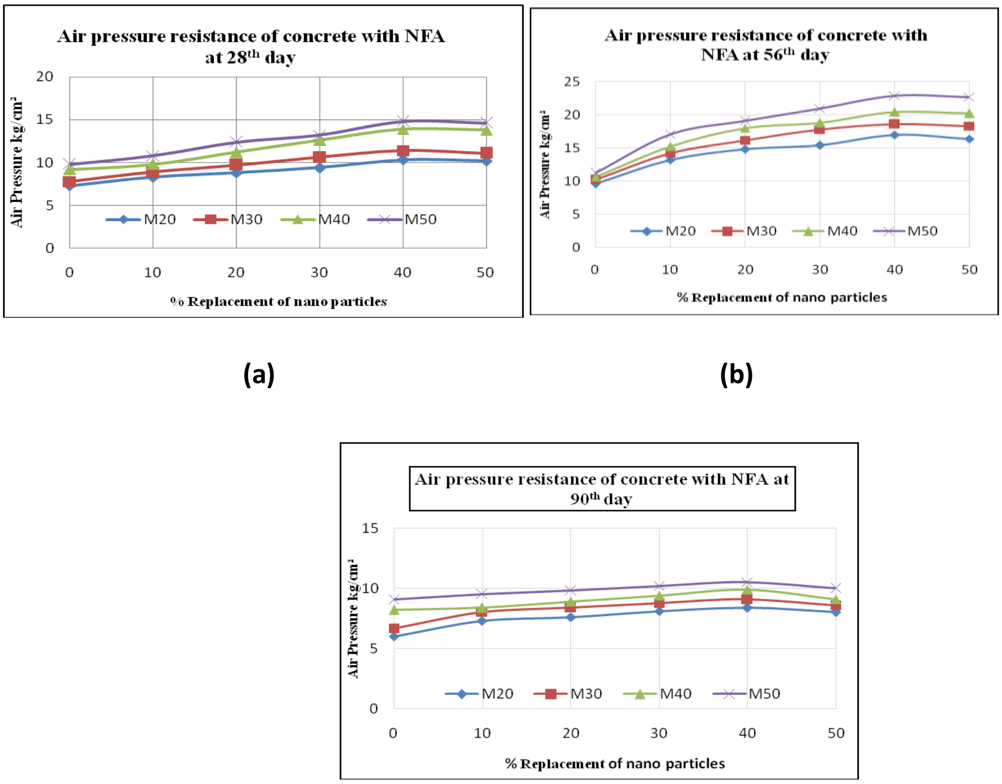
M 20	M30	M40	M50
17.8 to 88.5	17.90 to 92.2	10.90 to 99.10	12.2 to 110.7

From the Table 9., it can be seen that the increase in the air pressure resistance of M50 grade was found to be higher than that of M20 grade of concrete.

6.2.5. Discussion on Air Pressure Resistance of Concrete with NFA

Figure 11. shows air pressure resistance at failure of concrete with respect to the percentage replacement of cement with NFA.



(a) (b) (c)

Figure 11. Air pressure resistance of concrete NFA (a) Concrete at 28thday (b) Concrete at 56th day (c) Concrete at 90th day

From the Table 6.1 and Figure 6.9, it can be seen that the replacement of cement with NFA increases the air pressure resistance. The increase in air pressure resistance at failure continues up to 40% in replacement level of NFA. When NFA is added beyond 40%, Ettringite(hexacalcium aluminate trisulphate) was formed. This reduces the air pressure resistance beyond 40% in replacement.

6.2.5.1. Effect of percentage replacement of cement with NFA on the airpressure resistance

The percentage increase in air pressure resistance for different replacement levels of cement with NFA was found with respect to that of the NCC. The percentage increases in the values of air pressure resistance at failure for specimens with NFA are given in Table 6.5.

Table 10. Percentage increase in the air pressure resistance at failurefor concrete with NFA

%RCNP	Percentage increase in the air pressure resistance at failure											
	M20			M30			M40			M50		
	28th day	56th day	90th day	28th day	56th day	90th day	28th day	56th day	90th day	28th day	56th day	90th day
10	21.7	13.7	37.5	19.4	14.1	39.2	2.4	6.5	43.4	4.4	10.2	52.7
20	26.7	20.5	54.2	25.4	24.4	58.8	8.5	21.7	69.8	7.7	26.5	70.5
30	35.0	28.8	60.4	31.3	35.9	74.5	14.6	37.0	77.4	12.1	34.7	87.5
40	40.0	41.1	77.1	35.8	46.2	82.4	20.7	51.1	92.5	15.4	51.0	104.5
50	33.3	39.7	70.8	28.4	42.3	79.4	11.0	50.0	90.6	9.9	49.0	102.7

From Table 10., it can be seen that as the percentage replacement of NFA increases, the air pressure resistance at failure also increases.

The ranges of percentage increase in the air pressure resistance fordifferent percentage replacements of cement with NFA are given in Table 6.6.

Table 11. Ranges of percentage increase in air pressure resistance forconcrete with NFA

%RCNP	10%	20%	30%	40%	50%
Range of % increase	2.4 to 52.7	7.7 to 70.5	12.1 to 87.5	15.4 to 104.5	9.9 to 102.7

From the Table 11., it can be seen that the NFA is very effective inincreasing the air pressure resistance of concrete. Replacement level of 40% gave a maximum increase of 104.5.

The ranges of percentage increase in the air pressure resistance fordifferent grades of concrete with NFA are given in Table 11.

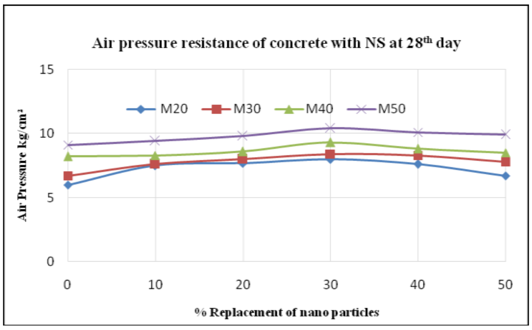
Table 12. Ranges of percentage increase in air pressure resistance fordifferent grades of concrete

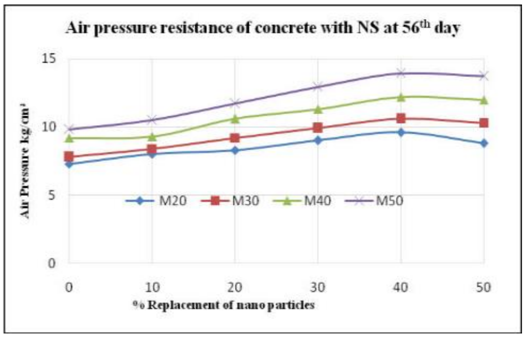
M 20	M30	M40	M50
13.7 to 77.1	14.1 to 82.4	2.4 to 90.6	4.4 to 102.7

From the Table 12, it can be seen that the increase in the air pressure resistance of M50 grade was found to be more than that of M20 grade of concrete.

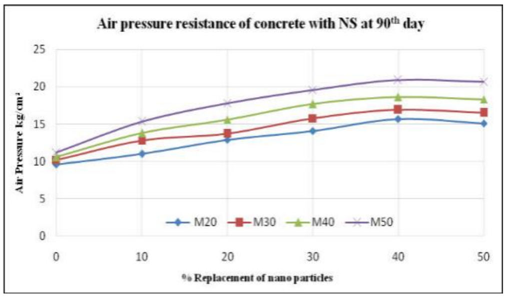
6.3.3. Discussion on air pressure resistance of concrete with NS

Figure 12. shows the air pressure resistance of concrete with respect to the percentage replacement of cement with NS.





(a) (b)



(c)

Figure 12. Air pressure resistance of concrete with NS(a) Concrete at28th day (b) Concrete at 56th day (c) Concrete at 90th day

From the Table 6.1 and Figure 6.10, it can be seen that the replacement of cement with NS increases the air pressure resistance. The increase in air pressure resistance at failure continues upto 30%in replacement level of NS on the 28th day and upto 40%in replacement level of NS on the

56th and 90th day.

6.3.3.1. Effect of percentage replacement of cement with NS on the air pressure resistance

The percentage increase in air pressure resistance for different replacement levels of cement with NS was found with respect to that ofNCC. The percentage increases in the values of air pressure resistance at failure for specimens with NS are given in Table 6.8.

Table 13. Percentage increase in the air pressure resistance at failurefor concrete with NS

%RCNP	Percentage increase in the air pressure resistance at failure											
	M20			M30			M40			M50		
	28th day	56th day	90th day	28th day	56th day	90th day	28th day	56th day	90th day	28th day	56th day	90th day
10	25.0	9.6	14.6	13.4	7.7	25.5	1.2	1.1	30.2	3.3	7.1	36.6
20	28.3	13.7	34.4	19.4	17.9	34.3	4.9	15.2	47.2	7.7	19.4	58.9
30	33.3	23.3	46.9	25.4	26.9	54.9	13.4	22.8	67.0	14.3	31.6	75.0
40	26.7	31.5	63.5	23.9	35.9	65.7	7.3	32.6	75.5	11.0	41.8	86.6
50	11.7	20.5	57.3	16.4	32.1	61.8	3.7	30.4	72.6	8.8	39.8	84.8

From Table 13, it can be seen that as the percentage replacement of NS increases, the air pressure resistance at failure also increases.

The ranges of percentage increase in the air pressure resistance fordifferent percentage replacements of cement with NS are given in Table 13.

Table 14. Ranges of percentage increase in air pressure resistance forconcrete with NS

%RCNP	10%	20%	30%	40%	50%
Range of % increase	1.1 to 36.6	4.9 to 58.9	13.4 to 75.0	7.3 to 86.6	3.7 to 84.8

From the Table 14, it can be seen that the NS is very effective in increasing the air pressure resistance of concrete. Replacement level of 40% gave a maximum increase of 86.6.

The ranges of percentage increase in the air pressure resistance fordifferent grades of concrete with NS are given in Table 6.10.

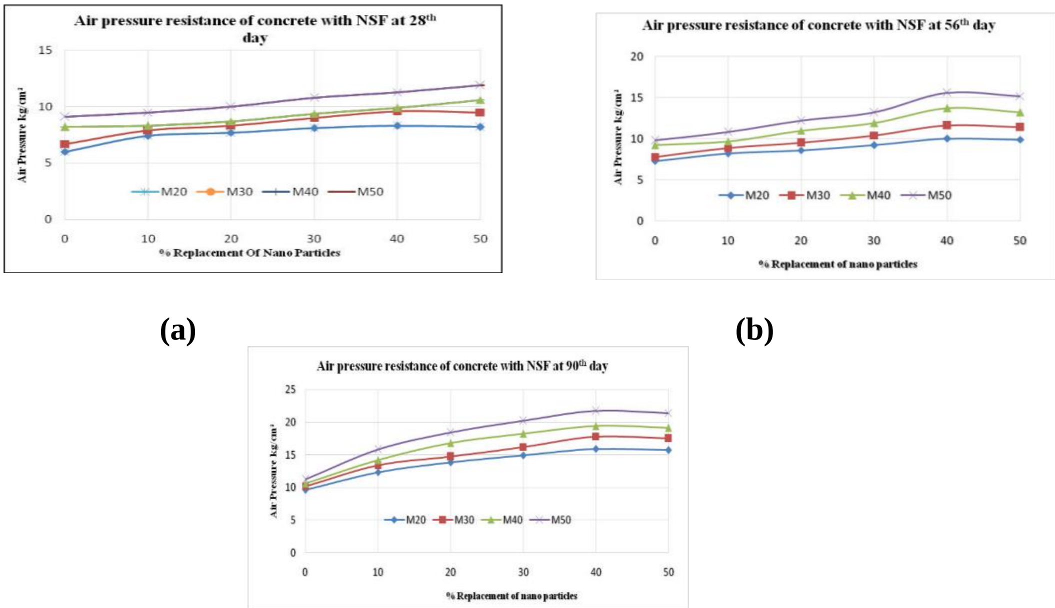
Table 15. Ranges of percentage increase in air pressure resistance fordifferent grades of concrete

M 20	M30	M40	M50
9.6 to 63.5	7.7 to 61.8	1.1 to 75.5	3.3 to 86.6

From the Table 15, it can be seen that the increase in the air pressure resistance of M50 grade was found to be more than that of M20 grade of concrete.

6.2.6.Discussion on Air Pressure Resistance of Concrete with Nano SilicaFume

Figure 6.11 shows the air pressure resistance at failure of concrete withrespect to the percentage replacement of cement with NSF.



(a) (b)

(c)

Figure 13. Air pressure resistance of concrete with NSF(a) Concrete at28th day (b) Concrete at 56th day (c) Concrete at 90th day

It can be seen that the replacement of cement with NSF increases the air pressure resistance. The increase in air pressure resistance at failure continues upto 40% in replacement level of NSF.

6.3.3.2Effect of Percentage Replacement of Cement with NSF on the AirPressure Resistance

The percentage increase in air pressure resistance for different replacement levels of cement with NSF was found with respect to that of the NCC. The percentage increases in the values of air pressure resistance at failure for specimens with NSF

Table 16. Percentage increase in the air pressure resistance at failurefor concrete

with NSF

%RCNP	Percentage variation in the air pressure resistance at failure											
	M20			M30			M40			M50		
	28th day	56th day	90th day	28th day	56th day	90th day	28th day	56th day	90th day	28th day	56th day	90th day
10	23.3	12.3	28.1	17.9	14.1	31.4	1.2	5.4	34.0	4.4	10.2	41.1
20	28.3	17.8	43.8	23.9	21.8	44.1	6.1	19.6	58.5	9.9	24.5	64.3
30	35.0	26.0	55.2	34.3	33.3	58.8	14.6	29.3	71.7	18.7	34.7	80.4
40	38.3	37.0	65.6	43.3	48.7	74.5	29.3	48.9	83.0	30.8	59.2	93.8
50	36.7	24.5	63.5	41.8	46.2	71.6	20.7	43.5	80.2	24.2	55.1	91.1

From Table 16, it can be seen that as the percentage replacementof NSF increases, the air pressure resistance at failure also increases.

The ranges of percentage increase in the air pressure resistance fordifferent percentage replacements of cement with NSF are given in Table 17

Table 17 Ranges of percentage increase in air pressure resistance forconcrete with NSF

%RCNP	10%	20%	30%	40%	50%
Range of % increase	1.22 to 41.1	6.1 to 64.3	14.6 to 80.4	29.3 to 93.8	20.7 to 91.1

From the Table 17, it can be seen that the NSF is very effective in increasing the air pressure resistance of concrete. Replacement level of 40% gave a maximum increase of 93.8.

The ranges of percentage increase in the air pressure resistance fordifferent grades of concrete with NSF are given in Table 6.13.

Table 18. Ranges of percentage increase in air pressure resistance fordifferent grades of concrete

M20	M30	M40	M50
12.33 to 65.6	14.10 to 74.5	1.22 to 83.0	4.40 to 93.8

From the Table 6.10, it can be seen that the increase in the air pressure resistance of M50 grade was found to be higher than that of M20 grade of concrete.

6.4. DISCUSSIONS ON AIR PRESSURE RESISTANCE

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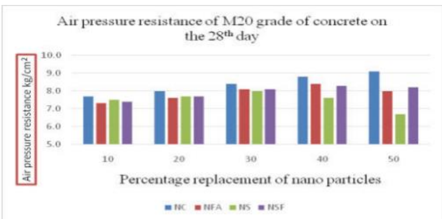
An attempt has been made to find out the effect of replacement of cement by nano materials on the air pressure resistance. It is found that replacement of cement with NC increased the air pressure resistance upto 50% in replacement level. The increase in air pressure is almost linear for all grades and all ages of concrete with NC. The failure pressure continues to increase as the replacement percentage increases. However the replacement percentage of cement with NC cannot cross 50% since the concrete will set fast. The maximum increase in the safe internal pressure was found to be around 110.70%. It was found that the replacement of cement with NFA, NS and NSF increased the air pressure resistance upto 40 % in replacement forall grades and all ages of concrete. Figure 6.12 shows the air pressure resistance of concrete with respect to the percentage replacement of nano particles for different grades at 28th day.

14



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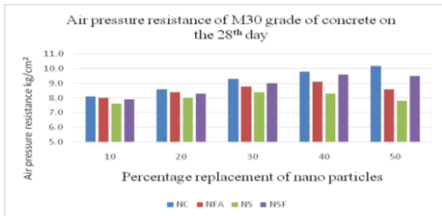

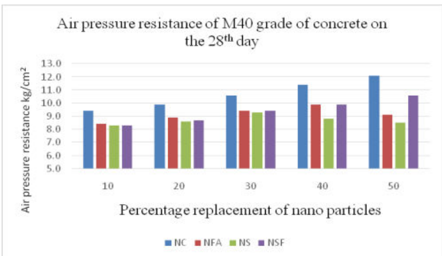

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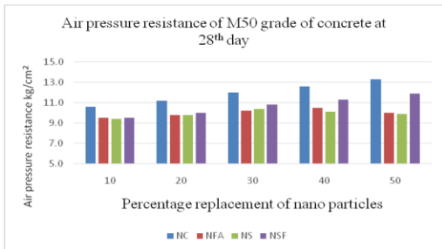

17

Figure 14. Air pressure resistance of concrete with nano particles at28th day

From Figure 6.12, it can be seen that the concrete with NC showeda better performance at all the replacement level and for all grades of concrete considered. The pozzolanic property present in concrete with NC, NFA and NSF plays a vital role in improving the air pressure resistance compared to concrete with NS. It was found that the particles in nano size have much higher the specific surface area compared to particles in microsize which enhances the reactivity and the air pressure resistance of concrete.

7. SUMMARYAND CONCLUSIONS

7.1. SUMMARY

i. An experimental investigation has been carried out to understand the properties of NC, NFA, NS and NSF produced by grinding the cement, fly ash, sand and silica fume respectively in ball grinding mill.

ii. An experimental investigation has been carried out to understand the behaviour of cement mortar with nano materials.

iii. An experimental investigation has been carried out to understand the strength and durability behaviour of concrete specimens with nano materials.

iv. An experimental set up has been fabricated and experiments havebeen performed to study the air pressure resistance of concrete specimens with nano materials.

v. Mechanical properties of M20, M30, M40 and M50 grades of concrete specimens with nano materials were found on the 28th, 56thand 90thdays.

vi. One thousand and eight numbers of cement mortar cubes of size70mm x70mm 70mm, 756 number of concrete cubes of size 150mm x150mm x150mm, 1512 numbers of concrete cylinders of size 150mmdiameter x 300mm height, 252numbers of concrete cylinders of size 200mm diameter x 100mm height, 1260numbers of concrete cylinders of size 100mm diameter x 100mm height, 756 numbers of cylindrical discs of size 152mm diameter x63.5mm height,756 numbers of prisms of size 500mm x100mm x100mm and 756 numbers of hollow cylinders ofsize150mm outer diameter, thickness 25mm and 300mm height werecast and tested.

7.2. CONCLUSIONS

7.2.1. Effect of Grinding on Materials

The micro-sized cement was converted to nano size by grinding it in a ball grinding mill for 12 hours and the particle size was found to range from 45nm to 86nm. Similarly fly ash, sand and silica fume were converted to nano size by grinding for 30 hours, 5 days and 5 hours respectively and theparticle size was found to range between 39nm and 173 nm.

The specific surface areas of NC, NFA, NS and NSF increased by 13008.11%, 14431.25%, 12019.11% and 128.4% when compared with cement, fly ash, sand and nano silica fume respectively.

The chemical properties of nano sized particles were found to be the same as the particles before grinding.

7.2.2. Effect of Nano Materials on Properties of Cement Paste andCement Mortar

The normal consistency of cement paste with NC, NFA and NSF was found to range between 33% and 35 % whereas for NS it was found to range between 37% and 39%.

The initial setting time of cement paste with NC, was found to decrease to 30 minutes at 50% replacement level while the cement paste withNFA, NS and NSF was found to increase to 110, 125 and 96 minutes respectively when compared to normal cement paste whose initial settingtime was 50 minutes.

The final setting time of cement paste with NC, was found to decrease to 245 minutes at 50% replacement level while for the cement paste with NFA and NSF, the final setting time was found to increase to 618 and600 minutes at 40% replacement level respectively and 615minutesat 30% replacement level of NS respectively when compared with the final setting time of510 minutes for the normal cement paste.

The percentage increase in compressive strength of cement mortar with nano particles was found to range between 23.76 and 64.91 whencompared with the normal cement mortar.

The optimum replacement level of nano particles was found to be 50% in case of NC, 40% in case of NFA and NSF and 30% in case of NS.

7.2.3. Effect on Workability and Strength of Concrete

The workability of concrete was found to increase as the percentage replacement of NP increase. The maximum increase was obtainedat 50% in replacement level of cement with NC. The percentage increase in slump was found to range between 2.6% and 92.7% and the compaction factor ranges between

1% and 20.3%.

The compressive strength of concrete with NC was found to increase upto 50% in replacement of cement with NC for all grades ofconcrete and for all curing days considered. The optimum replacement of cement with NFA and NSF was found to be 40% whereas in case of NS, it was found to be 30%. The percentage increase in strength was found to vary between 2% and 32% for NC, 1% and 20% for NFA, 1% and 18% for NS
and 2% and 20% for NSF.

The split tensile strength of concrete with NC was found to increase upto 50% in replacement of cement with NC for all grades ofconcrete and for all curing days considered. The optimum replacement of cement with NFA and NSF was found to be 40% whereas in case of NS, it was found to be 30%. The percentage increase in the split tensile strength was found to vary between 4% and 97% for NC, 3% and 80% for NFA, 1% and 38% for NS and 3% and 67% for NSF.

The flexural strength of concrete with NC was found to increase upto 50% in replacement of cement with NC for all grades of concrete andfor all curing days considered. The optimum replacement of cement with NFA and NSF was found tobe 40% whereas in case of NS it was found to be 30%. The percentage increase in the flexural strength was found to vary between 2% and 63% for NC, 1% and 45% for NFA, 1% and 18% for NS
and 2% and 47% for NSF.

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