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EXPERIMENTAL INVESTIGATION ON NANO ALUMINA BASED CONCRETE

Kunchala Ashok, B. Kameswara Rao and B. Sarath Chandra Kumar
Department of Civil Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Andhra Pradesh, India
E-Mail: kunchalaashok96@gmail.com

ABSTRACT

The research work focuses on the effect of study of incorporating of Nano particle like Nano Alumina (NA) and also one of the supplementary cementitious (pozzolanic) material in concrete to enhance the mechanical properties of the concrete. Nano particle and pozzolanic material is partially substituted by the weight of cementitious material into concrete. The experimental investigation was carried out on Nano modified concrete were tested after 3, 7 and 28 days of water curing for different grades like M30, M40 and M50 to determine the mechanical properties of concrete like compressive strength, flexural strength and split tensile strength of concrete specimens. Nondestructive tests likeultra-sonic pulse velocity test and rebound hammer testis also conducted on the hardened concrete specimens. The workability property like slump test of traditional and Nano modified concrete were also studied. Based on the test results obtained the influence of Nano particle in concrete improves the behaviour of concrete in the fresh and hardened state.

Keywords: nano alumina, metakaolin, workability, nano technology, mechanical property, NDT.

1. INTRODUCTION

The traditional concrete comprises of ordinary Portland cement, fillers such as sand, coarse aggregates, admixtures and water. This combination of ingredients allows concrete to be produce in a fluid form that can be pumped and molded. The amount of CO_2 emitted from the worldwide production of OPC corresponds to approximately 8% of the emissions into the earth's atmosphere [1] [13]. To reduce of use of natural resources such as lime stone, shale, clay, natural river sand, rocks that are being consumed for the development of human mankind that are not given back to the earth and use of waste materials in concrete that also prevents huge area of land that is used for the storage of waste materials that results in the land, air and water pollution [2] [12] [16-23]. The concrete should result in the sustainable development without destruction of natural resources.

Nano technology can be used for construction processes and design in many areas sincethe Nano technology generated materials have many unique characteristics [3] [15]. The use of Nano particles in concrete will reduce significant amount of emissions and the use of thermal insulations the performance will result in efficient use of energy for air conditioning [4]. As the concrete material is most usable in the construction industry it has been required to improve its quality and performance over traditional concrete [5]. Nanomodified concrete is defined as the material made by filling the voids and pores in Normal concrete using Nano particles of lesser size than 30 Nano meters [6]. The different Nanoparticles are available like Nano silica, alumina, iron, carbon tubes and titanium dioxide [14]. In the existing generation Nano technology was developed with noticeable rate and also the innovative potential uses of Nano particles there is a global interest in investigation of incorporating of Nano particles in construction materials in cement mortar and concrete [7]. The use of Nano particles has recently been researched to overcome the deficiency of low early age compressive strength in concretes. The Nano particles have a high particle surface area to volume ratio and will act as a filler effect by occupying up the voids between cement grains with the right composition results in higher packing density [8].

In the research work the influence of Nano particle like Nano Alumina andalso one of the supplementary cementitious (pozzolanic) materials like metakaolin in concrete to improve the mechanical properties of standard and high strength concrete. The Nano particle like Nano Alumina and pozzolanic material like metakaolin were partially replaced with cement by 1% and 15% respectively in the concrete mixtures for different grades of concrete.

The Nano particle will result in greater performance in strength and sustainability. The partial replacement of cement by a mineral admixture called metakaolin will shows better performance in both higher performance and economy. The concrete introduced with a combination of Nano particle and mineral admixture improves the micro structure as well as decrease the calcium hydroxide concentration by consuming it through a pozzolanic reaction. The subsequent modification of the micro structure cement composites improves the mechanical properties, workability properties and increase the service life properties contributing to sustainably built environment.

2. PROPERTIES OF MATERIALS

Nano modified concrete comprises of cement, metakaolin, Nano alumina, fine aggregate, coarse aggregate, water, chemical admixture.

2.1 Cement

The binding material used in the present investigation is ordinary Portland cement of 53 grade and the basic properties of cement like fineness, specific gravity, consistency, initial setting time and final setting time have been investigated as per BIS 4031: 1996 and is presented in table 1. [10]

Table-1. Properties of 53 grade of ordinary Portland Cement (KCP).

S. No	Property	Test results
1.	Fineness	3.5%
2.	Specific gravity	3.1
3.	Standard consistency	29%
4.	Initial setting time	45 minutes
5.	Final setting time	450 minutes
6.	Compressive strength at 28 days	51.5 N/mm^2

2.2 Metakaolin

White coloured metakaolin of specific surface area of 150000 to 180000 cm^2/gm having specific gravity of 2.5 and mean grain size of less than 1 micron and having a fineness of 700 to 900 kg/m^2. The metakaolin is a highly reactive material which can compete silica fume. [4] [9]

2.3 Nano Particle (Nano Alumina)

The properties of Nano particles are particle size, purity, specific gravity, density and colour are shown in below tables. The physical properties of Nano particle like Nano alumina is represented in Table-2 and the chemical composition of Nano particle like Nano alumina was referenced in the Table-3. [14]

Table-2. Properties of Nano alumina.

Properties	Nano Alumina
Morphology	spherical
Colour	White
Purity	99.9%
Particle size	30 – 50 nm
Specific gravity	3.9
Density	90 (g/l)

* Properties of Nano Alumina is provided by the supplier.

Table-3. Chemical composition of Nano Alumina (Al_2O_3).

Al_2O_3	Cao	Fe_2O_3	Mgo	Ca
>99.5%	<0.017%	<0.035%	<0.01%	<0.05%

* Chemical Composition of Nano Alumina is provided by the supplier.

2.4 Aggregates

Fine aggregate passing through 4.75 mm IS sieve with fineness modulus 2.47 and specific gravity 2.67 was adopted for present work. Coarse aggregate less than 20 mm size with fineness modulus 7.05 and specific gravity 2.62 were used after testing. The testing was conducted as per BIS 2386:1963. [11]

2.5 Water

The water used in the present investigation is potable water which having a p^H value is 6.5 to 8. The limitsfor solids in water as mentioned in IS 456:2000.[14]

2.6 Super Plasticizer

FosrocConplast SP430 which appears in brown colour liquid based super having plasticizer was used in the study which having a specific gravity is 1.18. To provide excellent acceleration of strength gain at early ages and major increases in strength at all ages by significantly reducing water demand in a concrete mix. Particularly suitable for precast concrete and other high early strength requirements. To significantly improve the workability of site mixed and precast concrete without increasing water demand. The p^H value of SP 430 is 7 to 8 [4].

3. EXPERIMENTAL WORK

3.1 Mix Proportioning

The proportioning of mix for conventional concrete samples was designed as mentioned in IS 10262:2019 with Ordinary Portland Cement, fine aggregate, coarse aggregate, and water [12]. The Nano modified concrete was prepared by the partial replacement of normal concrete by Nano alumina and metakaolin by 1% and 15% of material is substituted by the weight of cement. The water cement ratios adopted for different grades are 0.48, 0.45 and 0.4. The different mixtures used in the research work for different grades and their proportions are presented in the Table-4. The specimen designation for different concrete grades like M30, M40 and M50 with and without Nano Alumina are represented like NC30, NAC30, NC40, NAC40, NC50 and NAC50.

- NC - Normal Concrete
- NAC - Nano Alumina Concrete

Table-4. Mix proportions for specimens.

Grade of concrete	Type of concrete	Cement (kg/m^3)	Metakaolin (kg/m^3)	Nano (Al_2O_3) (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)	SP (kg/m^3)
M 30	NC30	365	-	-	672	1194	175	-
	NA30	307	54.75	3.65	672	1194	175	3.65
M 40	NC40	378	-	-	662	1206	170	-
	NA40	317.5	56.70	3.78	662	1206	170	3.78
M 50	NC50	390	-	-	652	1242	156	1.95
	NA50	327.1	59.0	3.90	652	1242	156	5.85

The cementitious material in each sample was replaced by Nano alumina and metakaolin by 1% and 15% of the mass of cement. The super plasticizer solution with a dosage of 1 and 1.5% is added to Nanoconcrete mixtures for improving the flow and workability properties of concrete.

3.2 Preparation of Concrete Specimens

The concrete specimens containing Nano particle for different grades were prepared by initial drying mixing of cement, sand and metakaolin for about 2 minutes in pan mixer. The chemical admixture was dissolved in 30% of liquids and Nano particles were added and stirred at a rate of 350 RPM for about 5 minutes for uniform dispersion without any coagulation. Then this solution was added to the dry mixture with the remaining 70% of water followed by continuous mixing for about another 3 minutes in pan mixer. The control specimen was prepared in the similar way as described above, but without any addition of Nano particle. Cubes of standard in dimensions and cylinders of 150 mm in diameter and length of 300 mm were casted in steel mould and compacted. The beam moulds of size 100x100x500 mm in dimensions are also casted in steel moulds. The specimens were demoulded from the moulds 24 hours after casting, and were allowed to cure in water for 3, 7 and 28 days. After the curing periods the specimen's standard dimensions of cubes were used for the determination of compressive strength, 150x300 mm cylinders for indirect tensile strength and 100x100x500 mm beam for flexural strength were determined as per BIS codes. The non destructive tests like ultra pulse velocity and rebound were also determined on concrete at 28 days.

Figure-1. Metakaolin.

Figure-2. Nano alumina.

4. REACTION MECHANISM

The pozzolanic characterizes that the aluminous and siliceous materials that itself has an almost no cementitious material worth however that will , in finely separated structure within the sight of dampness artificially respond with calcium hydroxide at normal temperatures to frame compound having cementitious properties. The hydration of concrete improvement the calcium hydroxide and calcium silicate hydrate are discharged inside the hydration of two principle parts of concrete in particular tricalcium silicate and dicalciumsilicate. The job of Nano particles will go about as fillers in the voids or void spaces and all around scattered Nano particles will go about as a nucleation or crystallization focuses of the hydrated products, in this way expanding the hydration rate, i.e., Nano particles will helped towards the development of littler size CH precious stones and homogeneous groups of C-S-H structure. They improved the structure of the progress zone among totals and glue and the impact of Nano particles on the mechanical quality advancement of cementitious materials, the expansion of Nano particles to concrete glues was found to expand the axial strength to a degree that was reliant on the Nano molecule content, water-to-cover weight proportion (w/b), and relieving time. The Nano particles can improve the filler impact and furthermore the high pozzolanic reactivity of fine particles increments considerably the amount of C-F-H gel.

It can modify the microstructure in the ITZ progress zones and subsequently the estimation of C-F-H

gel brings about diminishing the water penetrability. The point of the use of ultra-fine added substances (Nano particles) in cementitious frameworks is to improve the attributes of the plastic and solidified material. The Nano particles have a filler impact by topping off the pores between the concrete grains with the correct creation; the higher pressing thickness brings about a lower water request of the blend and it. It likewise adds to quality improvement because of the decreased fine porosity. Likewise representing its durability studies, results show that expansion of Nano particles shows better strength execution of the concrete. Creating of Nano modified concrete will bring about better regarding quality, strength and maintainability. The incomplete substitution of concrete by a mineral admixture called Metakaolin will acquire both better and economy. Concrete blends are changed with expansion of admixtures and Nano particles, which improve the microstructure just as reduction the calcium hydroxide focus by consuming it through a pozzolanic reaction. The resulting change of the microstructure of concrete composites improves the mechanical properties, strength and builds the life service properties contributing to sustainably built environment.

5. RESULTS AND DISCUSSIONS

5.1 Workability

The workability property of Nanomodified concrete represents that the percentage of Nano particles are increased beyond the permissible value the slump values are decreasing for different grades for different water cement ratios. The workability property like slump test is conducted on concrete by replacing the Nano particles. The addition of Nano particles and combination of mineral admixtures also decreasing the water cement ratios. The slump values are tabulated below Table-5.

Table-5. Workability for different mixes.

Grade of concrete	Type of concrete	Slump (mm)	Density (kg/m^3)
M 30	NC30	65	2350
	NAC30	95	2360
M 40	NC40	60	2380
	NAC40	85	2390
M 50	NC50	60	2410
	NAC50	80	2420

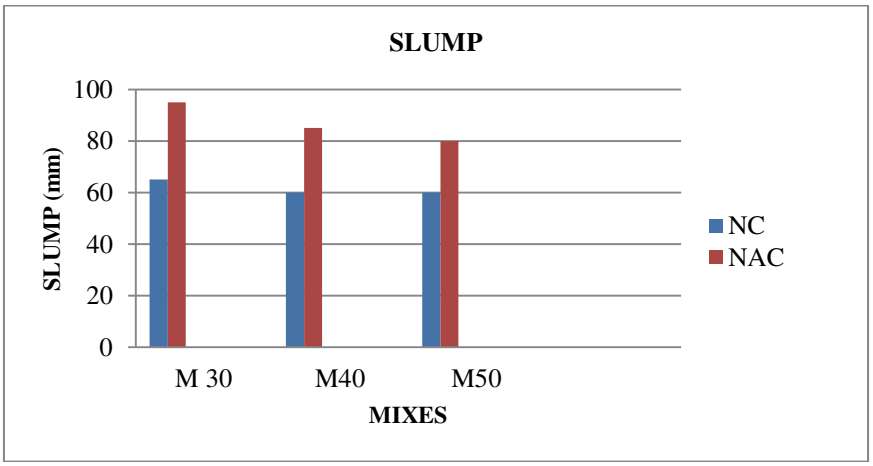

Figure-3. Slump for different mixes.

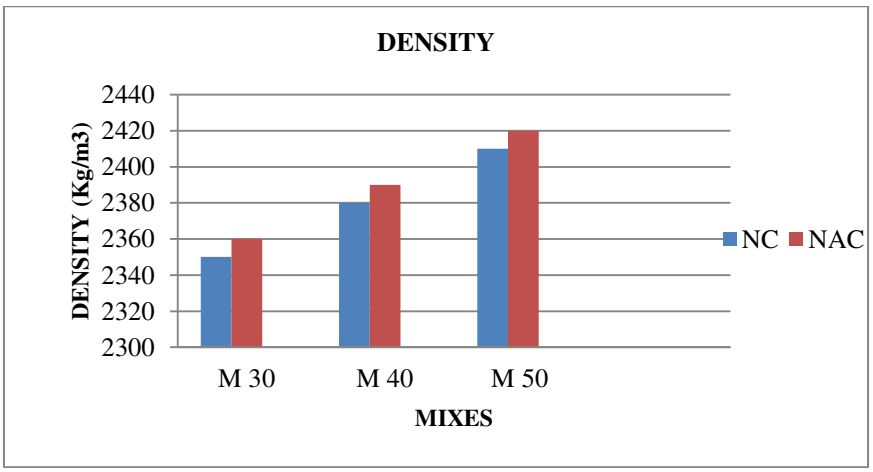

Figure-4. Density for different mixes.

From the above representation in graphically from Figures 3 and 4 the workability and density of Normal and Nano Alumina concrete are represented in graphically and the workability of Nano Alumina concrete decreases compared to Normal concrete due to the Nano particles and the mineral admixture introduced in concrete due to the water binder ratio decreased and also the Nano particles have a surface to volume ratio the Nano Alumina particle is less than 20 Nano meters in diameter. The particle have very high reactive and the behavior of such materials is mainly influenced by chemical reactions at the interface. The higher surface area is to be wetted; it decreases the free dispersant water in aqueous system available in mixture. The density of Nano Alumina concrete increased compared to Normal concrete for different grades like M30, M40 and M50 due to the particles exhibits huge surface area to volume ratio.

5.2 Compressive Strength Test

The compressive test was performed by the codalprovisionsi: e IS 516:1959 on specimens of cubes 150mm X 150mm X 150 mm for 3, 7 and 28 days of curing. The test results of compressive strength are shown in table 6 which was average of three samples. The results showed that the samples containing Nano particles showed an increase in concrete compressive strength compared to Normal concrete.

Table-6. Compressive strength of concrete.

Grade of concrete	Type of concrete	3 Days (N/mm^2)	7 Days (N/mm^2)	28 Days (N/mm^2)
M 30	NC30	16	25.9	39
	NAC30	34	37	46
M 40	NC40	19	31	48
	NAC40	40	44	55
M 50	NC50	22	38	58
	NAC50	43	48	66

Figure-5. Compressive testing machine.

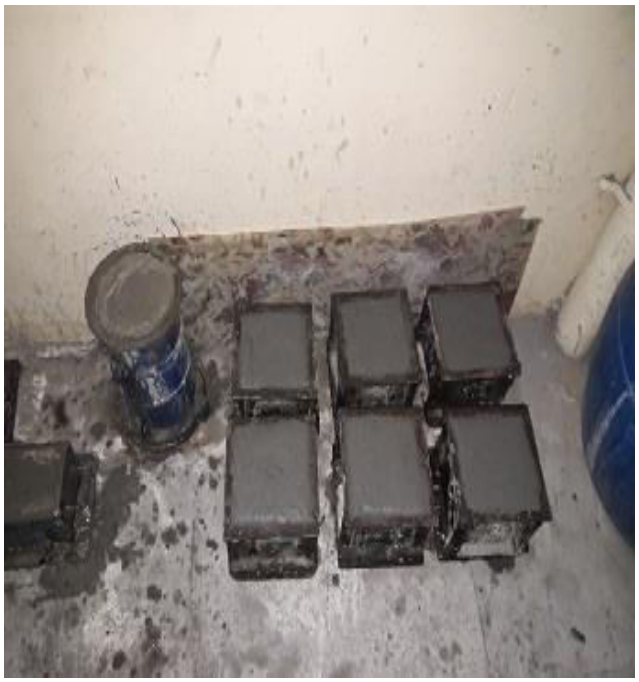

Figure-6. Samples casted.

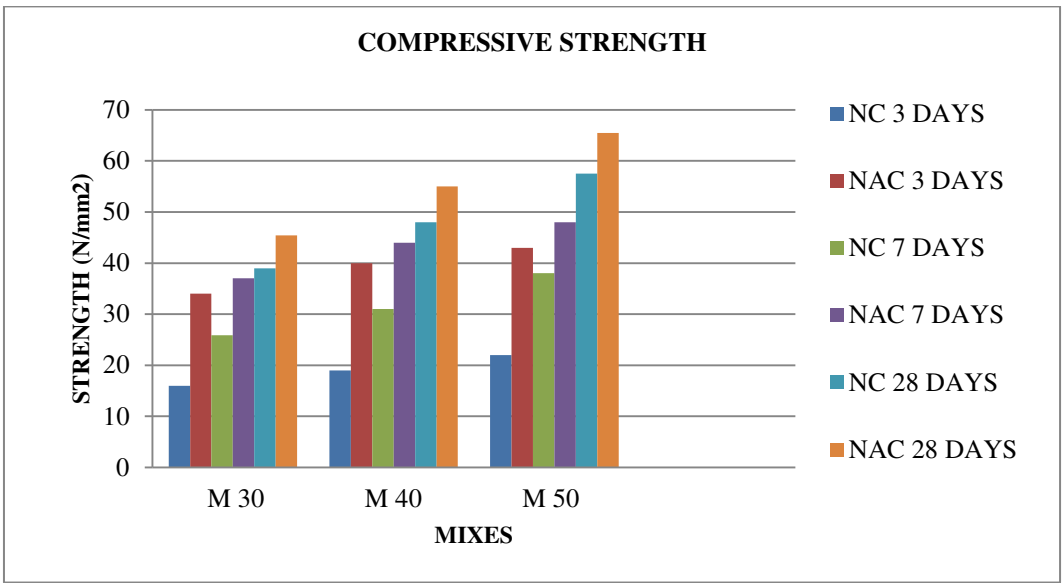

Figure-7. Compressive strength.

The significance of test results of obtained from the average of three samples as shown in Figure-7 the results exhibits that the specimens containing Nano particles shows an increase in compressive strength when compared with the Normal concrete. The results exhibits that the concrete modified by Nano Alumina of 1% respectively of 43%, 42%, 27% and 18%, 15%, 14% enhanced in compressive strength with that of Normal concrete for 7 and 28 days for different grades like M30, M40 and M50. The enhancement of compressive strength of concrete can be mainly due to that Nano particles act as nuclei in promoting the cement hydration and filling up of pores to increment in the compressive strength of concrete. The influence of Nano Alumina particle in concrete improves the low early age compressive strength in concrete.

5.3 Split Tensile Strength

The indirect tensile strength test was performed by the codal arrangement i:e IS 516:1959 on cylindrical specimens of 150 mm diameter and length of 300 mm for 3, 7 and 28 days of curing water. The Nano particle and other pozzolanic material mixes show preferable outcomes over the traditional concrete. The test results of compressive strength are exhibits in Table-7 which was average of three samples. The results show that the specimens containing Nano particles show an increase in concrete cubes strength compared to Normal concrete.

Table-7. Split tensile strength of concrete.

Grade of concrete	Type of concrete	3 Days (N/mm^2)	7 Days (N/mm^2)	28 Days (N/mm^2)
M 30	NC30	2.31	3.05	3.28
	NAC30	3.38	3.52	3.93
M 40	NC40	2.54	3.29	3.64
	NAC40	3.73	3.84	4.44
M 50	NC50	2.72	3.63	4.62
	NAC50	3.86	4.22	4.75

Figure-8. Cracks on specimen.

Figure-9. Split tensile testing.

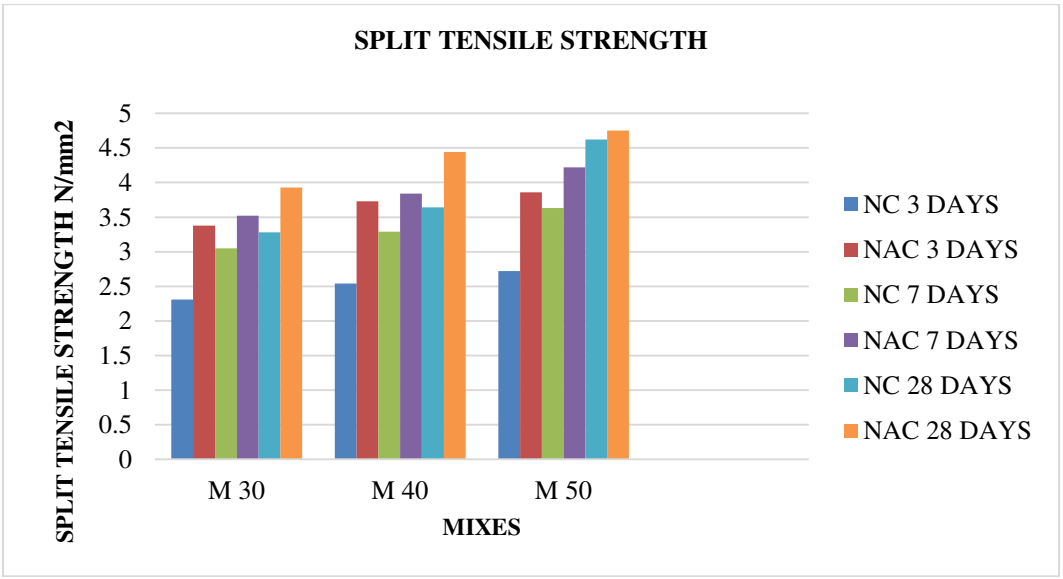

Figure-10. Split tensile strength results at 3, 7 and 28 days.

The test results of indirect tensile strength obtained from the average of three samples as shown in Figure-10 the results exhibits that the specimens containing Nano particles shows an increase in cubes strength when compared with the Normal concrete. The results exhibits that the concrete modified by Nano Alumina of 1% respectively of 16%, 17%, 16% and 20%, 22%, 28% enhanced in indirect tensile strength with that of Normal concrete for 7 and 28 days for different grades like M30, M40 and M50. The enhancement of indirect tensile strength of concrete can be due to that Nano particles induced in concrete which could be more C-S-H gel formation in the presence of Nano particle in concrete and the denser packing of material at their interfacial transition zone.

5.4 Flexural Strength

The results of Flexural strength was performed by the codalprovisionsi: e IS 516:1959 on specimens of beam 100mm X 100mm X 500 mm for 3, 7 and 28 days of curing. The test results are shown in Table-8 which was average of three samples. The results showed that the specimens containing Nano particles showed an increase in concrete compressive strength compared to Normal concrete. The Nano materials and other mineral admixtures mixes show preferable outcomes over the traditional concrete. The results showed that the specimens containing Nano particles showed an increase in concrete compressive strength compared to Normal concrete.

Table-8. Flexural strength results.

Grade of concrete	Type of concrete	3 Days (N/mm^2)	7 Days (N/mm^2)	28 Days (N/mm^2)
M 30	NC30	2.65	3.05	3.28
	NAC30	3.92	4.4	4.61
M 40	NC40	3.01	3.69	4.13
	NAC40	4.36	4.51	5.08
M 50	NC50	3.2	4.19	5.38
	NAC50	4.52	4.64	5.72

Figure-11. Flexural testing.

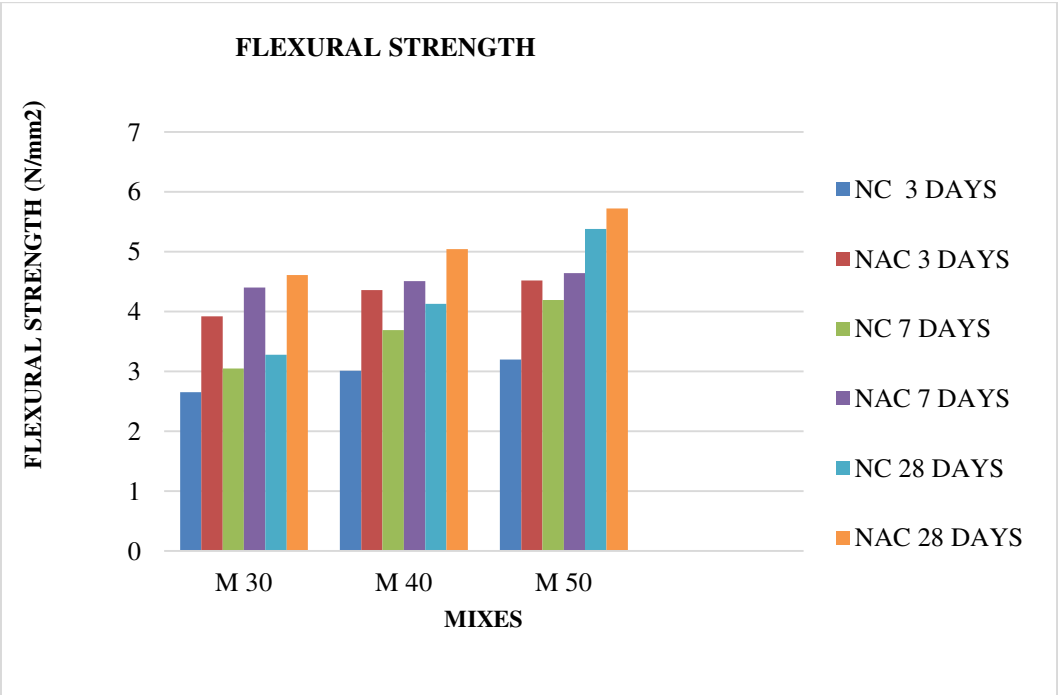

Figure-12. Flexural strength.

The test results of flexural strength of concrete obtained from the average of three samples as shown in Figure-12 the results shows that the specimens containing Nano particles shows an increase in flexural strength of concrete when compared with the Normal concrete. The results shows that the concrete modified by Nano Alumina of 1% respectively of 44%, 22%, 11% and 41%, 23%,7% enhanced in flexural strength with that of Normal concrete for 7 and 28 days for different grades like M30, M40 and M50. The enhancement of flexural strength of concrete can be mainly due to that Nano particles induced in concrete in promoting the cement hydration and filling up of pores to increase the flexural strength of concrete.

5.5 Non Destructive Tests

5.5.1 Ultra sonic pulse velocity

The UPV test criterion for concrete quality grading based on IS 13311:Part1. The Nano alumina concrete has high velocity compared to Normal concrete. This is due to the contribution of Nano alumina due to dense packing the ultrasonic pulse pass through the cube with high velocity. The Nano material in concrete results in less porous and impermeable concrete.

Table-9. Velocity ranges for concrete quality grading from IS 13311: Part 1.

S. No	Pulse Velocity (Km/sec)	Concrete Quality Grading
1.	Above 4.5	Excellent
2.	3.5 – 4.5	Good
3.	3.0 – 3.5	Medium
4.	Below 3.0	Doubtful

5.5.2 Rebound hammer test

The rebound hammer test is conducted by IS 13311:Part2 on concrete hardened surface. When the rebound hammer plunger is pressed against the concrete surface the spring controlled mass rebounds such rebounds depends upon concrete surface hardness. The surface hardness and therefore rebound is considered here to be related to compressive strength of concrete. The rebound is read off along a graduated scale and is designated as the rebound number or rebound index.

Table-10. Ultra sonic pulse velocity test and rebound hammer test at 28 days.

Grade of concrete	Type of concrete	UPV (28 Days)		Rebound Number (28 Days)	
		Velocity (km/s)	Quality	Rebound No	Compressive Strength
M 30	NC30	3.6	Good	40	42
	NAC30	4.5	Excellent	43	48
M 40	NC40	3.8	Good	44	51
	NAC40	4.6	Excellent	47	58
M 50	NC50	3.9	Good	48	60
	NAC50	4.8	Excellent	53	68

The test results of Rebound number and ultra-sonic pulse velocity obtained from table 10 shows that the quality of Nano Alumina concrete is increases compared to traditional concrete. The quality of Nano Alumina concrete is above 4.0 km/sec and the quality of Normal concrete is below 4.0 km/sec due to dense particle packing done by the influence of Nano Alumina particle in concrete which have huge surface area to volume ratio. The results derived from the rebound number of Nano Alumina concrete is more compared to Normal concrete due to more surface hardness due to the influence of Nano Alumina in mixes of concrete which improves more compactness.

5.6 Water Absorption

Water absorption test was done according to ASTM C 642-06 on sample of size 100 mm X 100 mm following 28 days of curing water. The test results are shown in Table-11 and based on the test results evident that NA has greater reduction in water permeation amongst addition of individual Nano particle due to lesser size of particles in effective filling of gel pores present in the concrete specimen.

Table-11. Water absorption test at 28 days.

Grade of concrete	Type of concrete	Water Absorption (%)
M 30	NC30	2.5
	NAC30	1.8
M 40	NC40	2.2
	NAC40	1.5
M 50	NC50	2.0
	NAC50	1.2

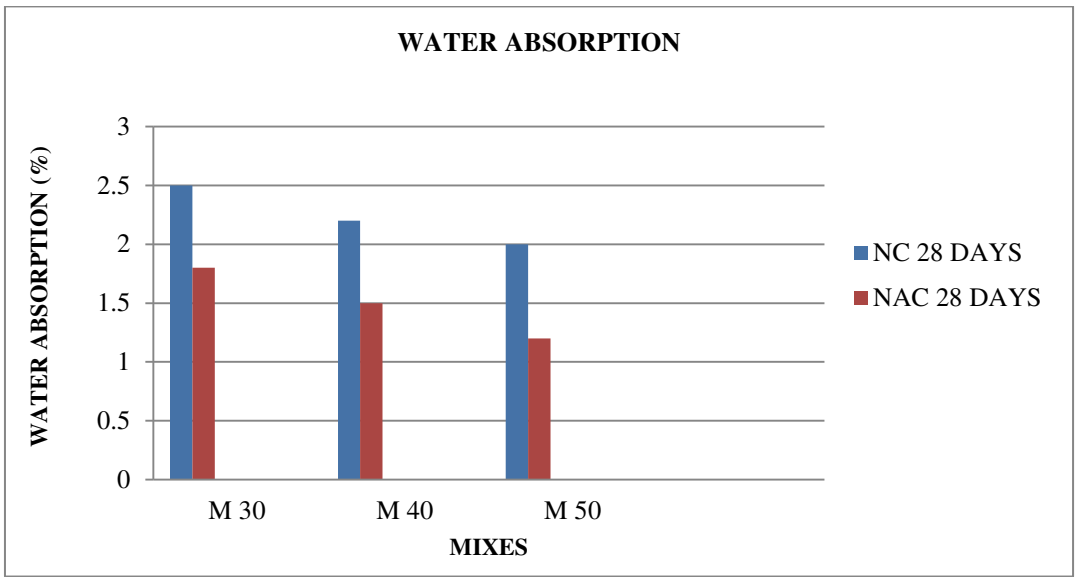

Figure-13. Water absorption test results at 28 days.

The test results obtained from Figure-13 represents in a graphically manner such that the influence of Nano particle in concrete reduces the water permeation amongst the addition of Nano particle in concrete. This is mainly due to the lesser size of particles less than 20 Nm in effective occupying of the voids and the gel pores present in the concrete specimen. From the test result obtained the values are 28%, 32% and 40% of water absorption is decreased compared to Normal concrete due to the reason filling of pores at Nano scale and densification results in reduction of permeable pores present in the concrete specimen

6. CONCLUSIONS

The following observations and conclusions are made on the basis of the experiments conducted on the normal concrete and Nano alumina concrete specimens are:

a) The compressive strength of Nano modified concrete is found to be increased to a maximum value of 43%, 42%, 27% and 18%, 15%, 14% with the partial substitution of Nano alumina with respect to control specimen at 7days and 28 days for M30, M40 and M50.

b) The split tensile strength of Nano modified concrete is found to be increased to a maximum valuesof 16%, 17%, 16% and 20%, 22%, 28% with the partial substitution of Nano alumina with respect to control specimen at 7days and 28 days for M30, M40 and M50.

c) The flexural strength of Nano modified concrete is found to be increased to a maximum value of 44%, 22%, 11% and 41%, 24%, 7% with the partial substitution of Nano alumina with respect to control specimen at 7days and 28 days for M30, M40 and M50.

d) The water absorption of Nano modified concrete is found to be decreased to a value of 28%, 32% and 40% with the partial substitution of Nano alumina with respect to control specimen at 28 days for M30, M40 and M50.

e) The contribution of Nano particle was significant in enhancement of strength which could be due to high specific area of 20 Nm size of particle. The use of Nano Alumina in concrete improves the early age development of strength in concrete.

f) The partial replacement of Nano particle in concrete exhibits high velocity which is excellent compared to Normal concrete. The setting time of concrete is decreased by the influence of Nano particle in concrete and also it modify the structure of ITZ between aggregates and cement paste.

g) Based on the trial mixes the increase of Nano particle in concrete reduces the workability and setting time of concrete is reduced. Nano particle reduces the water absorption of concrete and the Nano particle in cementitious systems is to improve the characteristics of the plastic and hardened material.

h) The influence of metakaolin and Nano Alumina will improves the micro structure as well as decrease the free calcium hydroxide concentration by consuming it through a pozzolanic reaction.

i) The modification of micro structure of concrete will improves the mechanical properties of the concrete and increase the service life properties contributing to sustainable built environment.

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