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EXPERIMENTAL INVESTIGATION OF NANO CEMENTS IN CONCRETE

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ABSTRACT

The purpose of experimental investigation of addition of nano scale materials to cement can be improved the durability of concrete. The addition nano scale material to cement is known as nano cement. The compressive and split tensile strength of concrete by partial replacement of cement with nano-phase Fe_2O_3 and Al_2O_3 particles has been studied. Fe_2O_3 and Al_2O_3 nanoparticles used with four different contents of 0.5%, 0.1%, 1.5% and 2.0% by weight. The results showed that the use of nano Fe_2O_3 and Al_2O_3 particles up to maximum replacement level of 2.0% produces concrete with improved compressive and split tensile strength. However, the ultimate strength of concrete was gained at 1.0% of cement replacement. The compressive and split tensile strength of fresh concrete was increased by increasing the content of Fe_2O_3 and Al_2O_3 nanoparticles.

1. INTRODUCTION

1.1 .CONCRETE AND ENVIRONMENT

Concrete is a newer construction material compared to steel and stone. Use of concrete in constructions and buildings may have begun less than a century ago. But in recent century, very wide and effective research has seen on improving the properties of concrete with incorporating wide range of supplementary cementing materials such as pozzolans and nanoparticles due to increasing the use of concrete from decade to decade. The trading of carbon dioxide (CO_2) emissions is a critical factor for the industries, including the cement industries, as the greenhouse effect created by the emissions is considered to produce an increase in the global temperature that may result in climate changes. The production of cement is increasing about 3% annually. The production of one ton of cement liberates about one ton of CO_2 to the atmosphere, as the result of de-carbonation of limestone in the kiln during manufacturing of cement and the combustion of fossil fuels. The contribution of Portland cement production worldwide to the greenhouse gas emission is estimated to be about 1.35 billion tons annually or about 7% of the total greenhouse gas emissions to the earth's atmosphere. Cement is also among the most energy intensive construction materials, after aluminium and steel. Furthermore, it has been reported that the durability of Ordinary Portland Cement (OPC) concrete is under examination, as many concrete structures, especially those built in corrosive environments start to deteriorate after 20 to 30 years, even though they have been designed for more than 50 years of service life. The concrete industry has recognized these issues. In order to produce environmentally friendly concrete, Mehta (2002) suggested the use of fewer natural resources, less energy, and minimize carbon dioxide emissions. He categorized these short-term efforts as 'industrial ecology'. The long-term goal of reducing the impact of unwanted by-products of industry can be attained by lowering the rate of material consumption. The amount of carbon dioxide (CO_2) emissions by the cement industries can be reduced by decreasing the amount of calcined material in cement, by decreasing the amount of cement in concrete, and by decreasing the number of buildings using cement.

1.2 NANO TECHNOLOGY

Concrete is one of the most common and widely used construction materials.Conventional concrete suffers from a number of inherent deficiencies, such as its low tensile strength. As a result, concrete structures undergo significant shrinkage cracking.One way of improving the tensile strength of concrete is by improving the mechanical properties of the binder, cement paste. Recently, nanotechnology has attracted great scientific attention because of the new potential uses of particles in nanometer (10^{-9} m) scale. This may be due to the nanoscale size of particles being able to result in significantly improved properties from predictable grain-size materials of the same chemical composition. As a consequence, industries can be able to design new and novel products and to re-engineer many existing products that function at unprecedented levels.

These methods have improved the tensile capacity of the concrete structure but also increase the cost of construction. In addition, many concrete infrastructures are deteriorating faster than expected due to the corrosion of steel in marine environments. The deterioration of concrete structures has resulted in a need to understand the internal structure of concrete and its effect on concrete properties (strength).Researchers are now investigating alternative approaches for enhancing the performance of cement paste by means of manipulating the internal structure of cement paste.

1.3 NANO CEMENT

1.3.1 General

Nano-materials show unique physical and chemical properties that can lead to the development of more effective materials than ones which are currently available. The extremely fine size of nano-particles yields favorable characteristics. Application of nano-materials into the production of cement and concrete can lead to improvements in civil infrastructure because the mechanical strength and life of concrete structures are determined by the micro-structure and by the mass transfer in nano-scale.

1.4 TYPES OF NANO SCALE MATERIALS

Addition of Nano scale material in to cement is known as Nano cement. Some of the nano particles are **Sio_2, Tio2, Zno, Fe_2O_3** and **Al_2O_3** etc.,

Ferric or Iron Oxide (**Fe_2O_3**) particles improves the split tensile and flexural strength of concrete but decreases its setting time.

Aluminium Oxide (Al_2O_3) particles improves the split tensile and flexural strength of concrete but decreases its setting time.

1.4.1 Advantages Of Nano Cement

- Better understanding of the structure and behavior of concrete at micro/nano-scale could help to improve concrete properties and prevent the illness.
- Nano particles are Lighter and stronger structural composites

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● Addition of nanoscale materials into cement could improve its performance. Significantly increase the compressive strength for concrete

● Improve segregation resistance for self-compacting concrete. Increasing workability and act as water reducer in concrete.

● Reducing cement content in concrete. It will used as low maintenance coating

● Compressive strength of concrete will be increased Act as porous filler will results increased durability of concrete.

● Increased flexural strength to concrete.Increased split tensile strength to concrete.

1.5 ALUMINIUM OXIDE

Aluminium oxide is an amphoteric oxide with the chemical formula Al_2O_3. It is commonly referred to as alumina, or corundum in its crystalline form, as well as many other names, reflecting its widespread occurrence in nature and industry. Its most significant use is in the production of aluminium metal, although it is also used as an abrasive due to its hardness and as a refractory material due to its high melting point.

Aluminum oxide is an electrical insulator but has a relatively high thermal conductivity for a ceramic material. In its most commonly occurring crystalline form, called corundum or α-aluminium oxide, its hardness makes it suitable for use as an abrasive and as a component in cutting tools.

Aluminum oxide is responsible for resistance of metallic aluminium to weathering. Metallic aluminum is very reactive with atmospheric oxygen, and a thin passivation layer of alumina (4 nm thickness) forms in about 100 picoseconds on any exposed aluminium surface. This layer protects the metal from further oxidation. The thickness and properties of this oxide layer can be enhanced using a process called anodising. A number of alloys, such as aluminium bronzes, exploit this property by including a proportion of aluminium in the alloy to enhance corrosion resistance. The alumina generated by anodising is typically amorphous, but discharge assisted oxidation processes such as plasma electrolytic oxidation result in a significant proportion of crystalline alumina in the coating, enhancing its hardness.Composite materials that traditionally incorporate micron scale reinforcements in a bulk matrix offer opportunities to tailor material properties such as hardness, tensile strength, ductility, density, thermal and electrical conductivity, and wear resistance. With the advent of nanomaterials, nanocomposites are envisioned, and are being developed, with properties that overcome the limitations for metals or composites that contain micron scale reinforcements.

1.5.1 Properties of Metal Matrix Nanocomposites

The greatest challenges facing the development of MMNCs for wide application are the cost of nanoscale reinforcements and the cost and complexity of synthesis and processing of nanocomposites using current methods. As with conventional metal matrix composites with micron-scale reinforcements, the mechanical properties of a MMNC are strongly dependent on the properties of reinforcements, distribution, and volume fraction of the reinforcement, as well as the interfacial strength between the reinforcement and the matrix.

Due to their high surface area, nanosize powders and nanotubes will naturally tend to agglomerate to reduce their overall surface energy, making it difficult to obtain a uniform dispersion by most conventional processing methods. In addition, due to their high surface area and surface dominant characteristics, these materials may also be highly reactive in metal matrices.

1.6 IRON OR FERRIC OXIDE

Iron (III) oxide or ferric oxide is the inorganic compound with the formula Fe_2O_3. It is of one of the three main oxides of iron, the other two being iron(II) oxide (FeO), which is rare, and iron(II,III) oxide (Fe_3O_4), which also occurs naturally as the mineral magnetite. As the mineral known as hematite, Fe_2O_3 is the main source of the iron for the steel industry. Fe_2O_3 is paramagnetic, reddish brown, and readily attacked by acids. Rust is often called iron (III) oxide,the term is applied to red oxides, formed by the reaction of iron and oxygen in the presence of water or air moisture. There are also other forms of rust, such as the result of the reaction of iron and chlorine in an environment deprived of oxygen, such as rebar used in underwater concrete pillars, which generates green rust. Several forms of rust are distinguishable visually and by spectroscopy, and form under different circumstances. Rust consists of hydrated iron (III) oxides $Fe_2O_3 \cdot nH_2O$ and iron (III) oxide-hydroxide (FeO(OH), $Fe(OH)_3$). Given sufficient time, oxygen, and water, any iron mass will eventually convert entirely to rust and disintegrate. Surface rust provides no protection to the underlying iron unlike the formation of patina on copper surfaces. Rusting is the common term for corrosion of iron and its alloys, such as steel. Many other metals undergo equivalent corrosion, but the resulting oxides are not commonly called rust.

2. STUDY OF MATERIALS

2.1 NANO ALUMINIUM OXIDE

Aluminium oxide in the form of nano size has been searched through Sigma-Aldrich chemical products company and purchased from Ponmani chemicals Coimbatore. The product number 544833 and <50 nm particle size (TEM Transmission Electron Microscope).

3.2 NANO IRON OXIDE

Iron oxide in the form of nano size has been searched through Sigma-Aldrich chemical products company and purchased from Ponmani chemicals Coimbatore. The product number 544884 and <50 nm particle size (TEM Transmission Electron Microscope).

2.3 CEMENT

43 grade ordinary Portland cement (OPC) is used for control concrete and the specific gravity of cement was found to be 2.85.

2.4 AGGREGATES

2.4.1 Fine aggregate

For ordinary Concrete River sand was used in preparing the concrete as it is locally available in sand quarry. The specific gravity was found to be 2.66.

2.4.2 Coarse aggregate

For ordinary concrete 20mm normal size grades aggregate was used. The specific gravity was found to be 2.58.

2.4.3 Particle size distribution

2.4.3.1 Particle size distribution of fine aggregate

Weight of sample taken = 1000gm

Table 3.1 Particle size distribution of fine aggregate

Sieve size	Cumulative percentage of aggregates retained
4.75mm	1.2
2.36mm	3.4
1.18mm	9.4
600µm	25.2
300µm	72.6
150µmm	96.2
Retaining	100

3.4.3.2 Particle size distribution of coarse aggregate

Weight of sample taken = 5000gm

Table 3.2 - Particle size distribution of coarse aggregate

Sieve size	Cumulative percentage of aggregates retained
80mm	-
40mm	-
37.5mm	-
20mm	29.8
12.5mm	97.4
10mm	98.8
Retaining	100

3.4.4 Specific Gravity

The pycnometer is cleaned for presence of dust or moisture inside and its empty weight is taken. A small quantity of dry sand is put inside the pycnometer and its weight with sand is taken. The pycnometer shall be topped up with distilled water to remove any froth from the surface dried on the outside and weighted. The pycnometer is filled with distilled water to the same level as before, dried on the outside and weighed

Specific gravity = [W2 -W1]/ [(W2-W1) – (W3-W4)]

Where,

W1-Weight of empty pycnometer

W2-Weight of pycnometer and dry sand

W3-Weight of pycnometer, sand and water

W4 -Weight of pycnometer and water

2.4.4.1 Specific Gravity of fine aggregate

Specific gravity = [W2 -W1]/ [(W2-W1) – (W3-W4)]

Specific gravity of fine aggregate = 2.66

2.4.4.2 Specific Gravity of coarse aggregate

Specific gravity = [W2 -W1]/ [(W2-W1) – (W3-W4)]

Specific gravity of fine aggregate = 2.85.

2.5 WATER

Ordinary tap water of S.K.P. Engineering College was used in the preparation and curing of concrete.

3. EXPERIMENTAL INVESTIGATION

3.1 GENERAL

Table 3.2 - Mix proportions for Nano Concrete

Mix	Mix proportion	W/C Ratio	Cement (kg)	Aggregates Fine (kg)	Aggregates Coarse (kg)	Nano Al2O3 & Fe2O3 (%)	Nano Al2O3 & Fe2O3 (kg)	water (kg)
M20	1:1.5:3.1	0.50	372	558.00	1153.2	0.50	1.86[NC1]	186.00
M20						1.00	3.72[NC2]	
M20						1.50	5.58[NC3]	
M20						2.00	7.44[NC4]	
M25	1:1:2	0.40	465	930.00	465.00	0.50	2.325[NC5]	186.00
M25						1.00	4.65[NC6]	
M25						1.50	6.975[NC7]	
M25						2.00	9.30[NC8]	

Mix proportion = 1: 1.50: 3.10: 0.5

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The desired properties of concrete can be obtained by using the ingredients in a certain proportion and determining the relative amount of material is known as mix design. Thus mix design is defined as the process of selecting suitable ingredients of concrete and determining their relative quantities for producing the concrete of desired properties as economically as possible. The object of mix design is to decide the proportions of materials, which will produce concrete having the required desirable properties. The mix proportions should be selected in such a way that the resulting concrete is of desired workability while fresh and it could be placed and compacted easily for the intended purpose.

3.2 MIX PROPORTIONS

The design mix was calculated for M20 and M25 grade of concrete. The cement was replaced by nano Aluminium oxide and Iron oxide for nano concrete. Percentage of partially replacement by addition of nano Aluminium oxide and Iron oxide 0.5% to 2% by weight of cement for the required water cement ratio.

3.4 MIXING

For control concrete**,** Ordinary OPC 43Grade, fine aggregate, Coarse aggregate and water cement ratio are taken as per mix design and thoroughly mixed. Nano concrete also mixed by addition nano scale materials of Aluminium oxide and Iron oxide replaced by weight of cement as 0.5% to 2.0%.

3.5 CASTING

The concrete cubes, cylinders and beams were cast in moulds in such away as to produce full compaction of the concrete with neither segregation nor excessive laitance. The concrete is filled into the mould in three layers approximately 5cm deep. Each layer was well compacted. After the compaction, the top surface is finished level with the top of the mould using a trowel.The standard tamping rod was used and the strokes of the rod were distributed in a uniform manner over entire mould. The number of stokers per layer required to produce the specified conditions, vary according to the type of concrete.

3.6 Curing

The specimens were demoulded after 24 hours. Necessary identification marks were made in the specimens and kept under water in a curing tank. The specimens were kept under water for 7 days and 28 days. After curing, they were taken out from the curing tank and air dried before testing.

4. RESULTS AND DISCUSSIONS

4.1 RESULTS

4.1.1 Slump Test

The mould for the specimen is in the form of the frustum of a cone of bottom diameter 20cm, top diameter 10cm and height 30cm. The internal surface of the mould is thoroughly cleaned, and placed on a smooth, horizontal rigid and non absorbent surface, the mould being firmly held in place when it is being filled. The mould is filled with fresh concrete in four layers, each approximately one quarter of the height of the mould. Each layer shall be uniformly distributed over the cross section of the mould and for the second and subsequent layer shall penetrate into the underlying layer. After the top layer has been rodded, the concrete is struck off level with a trowel so that mould is exactly filled. The

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mould is removed from the concrete by raising it slowly in a vertical direction. The concrete subsides and the slump is measured immediately by determining the difference between the height of the mould and the highest point of the specimen being tested. Any slump specimen whom collapses or shears off laterally gives incorrect result and if this occurs the test is repeated with another sample. If in the repeat test also, the specimen shears the slump is measured and the fact that the specimen sheared is recorded.

Table 4.1 - Slump value of control concrete and nano concrete

Mix	Slump (mm)	
	Control concrete	nano concrete
M20	40	42[NC1]
		43[NC2]
		45.5[NC3]
		48[NC4]

Mix	Slump (mm)	
	Control concrete	nano concrete
M25	42	43.5[NC5]
		46[NC6]
		48.5[NC7]
		50[NC8]

4.1.2 Compaction factor test

This test is more precise and sensitive than the slump test and is useful for concrete mix of very low workability which may consistently fail to slump. The sample of concrete to be tested is placed gently in the upper hopper, using the hand scoop. The hopper is filled level with its brim and the trap door is opened so that the concrete fails into the lower hopper. Immediately after the concrete has come to rest, the trap door of the lower hopper is opened, and the concrete is allowed to fall into the cylinder. The excess of concrete remaining above the level of the top of cylinder is removed by using a trowel and cylinder with the concrete is weighted. The cylinder is than refilled with concreted from the same sample in layer approximately 5cm deep, the layers being heavily rammed or vibrated so as to obtain full compaction. The top surface of the fully compacted concrete is carefully struck off level with the top of the cylinder and the cylinder is weighted. The compacting factor is defined as the ratio of the weight of the partially compacted concrete to the weight of fully compacted concrete.

Model Calculations

Weight of empty cylinder, W1 = 5.50 kg

Weight of cylinder=partially compacted concrete W2 = 9.00 kg

Weight of cylinder = fully compacted concrete W3 = 9.50 kg
Compaction factor = (W2-W1)/(W3-W1) =0.88

Table 5.2 - Compaction factor for control concrete and nano concrete

4.1.3 Compressive strength test

For Compressive strength 150x150x150 mm size concrete cube were cast using mix proportion given in table 4.2. During molding the cubes were compacted by manually. After 24 hours, the specimens were demoulded and submerged in clean fresh water. After 7 and 28 days of curing, the cubes were then allowed to become dry for some hours. The cubes were tested in compression testing machine. In the ultimate load, the cube get cracked that load was taken for calculating the compressive strength.The compressive strength of concrete cube is calculated by using equation

Table 4.3 – Compressive strength of control concrete and nano concrete

MIX	Age at test (Days)	Compressive Strength		% of increase
		Control concrete	Nano concrete	
M 20	7	17.36	18.31[NC1]	05.47 %
			20.16[NC2]	16.13 %
			19.80[NC3]	14.05 %
			19.70[NC4]	13.48 %
	28	25.63	26.47[NC1]	03.28 %
			28.21[NC2]	10.06 %
			28.56[NC3]	11.43 %
			27.12[NC4]	05.81 %
M 25	7	21.06	21.95[NC5]	04.23 %
			22.35[NC6]	06.13 %
			23.53[NC7]	11.73 %
			22.16[NC8]	05.22 %
	28	30.67	32.42[NC5]	05.70 %
			33.27[NC6]	08.48 %
			33.68[NC7]	09.81 %
			32.92[NC8]	7.34 %

4.1.4 SPLIT TENSILE STRENGTH TEST

Split tensile strength of concrete is usually found by testing on plain concrete cylinder as per ASTM C 496-90. Concrete cylinders of size 150mm dia and 300mm height were cast. During molding, the cylinders were compacted manually. After 24 hours, the specimens were removed from the mould and subjected to water curing for 28 days. After the curing period was over, the concrete cylinders were subjected to split tensile test by using Universal Testing Machine. One of the plywood strips is centered along the centre of the lower platen. The wet specimen is placed on the strip horizontally with its axis perpendiculars to the loading direction. The second plywood strip is then placed lengthwise on the cylinder centrally. The load is then applied without shock and increased continuously at a rate to produce approximately a splitting tensile stress of 14 to 21 kg/cm2/min until failure. The tests were carried out on triplicate specimens and average split tensile strength values were recorded.

The splitting tensile strength is calculated by using the equation.

$T=2P/(\pi DL)$

Where, T-Tensile strength in N/mm^2

P-Failure load in N

L-Length of the specimen in mm

D-Diameter of the specimen in mm

For M20, M25 grade of concrete split tensile strength results at the age of 7 days, 28 days are tabulated in table

Mix	**Compaction factor**	
	Control concrete	**nano concrete**
M20	**0.82**	**0.85[NC1]**
		0.86[NC2]
		0.88[NC3]
		0.87[NC4]
M25	**0.84**	**0.84[NC5]**
		0.86[NC6]
		0.85 [NC7]

Table 4.4 - Split tensile strength of control concrete and nano concrete

MIX	**Age at test (Days)**	**Split tensile Strength**		**% of increase**
		Control concrete	**Nano concrete**	
M 20	7	1.57	1.72[NC1]	09.55 %
			1.90[NC2]	21.02%
			1.95[NC3]	24.20%
			1.80[NC4]	14.65%
	28	2.80	3.20[NC1]	14.30 %
			2.96[NC2]	05.71%
			3.18[NC3]	13.60%
			3.05[NC4]	08.93%
M 25	7	1.80	2.18[NC5]	21.11 %
			2.24[NC6]	24.44%
			2.06[NC7]	14.44%
			2.10[NC8]	16.70%
	28	3.16	3.72[NC5]	17.72 %

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			3.35[NC6]	06.01%
			3.63[NC7]	14.87%
			3.44[NC8]	08.86%

4.2 DISCUSSIONS

4.2.1 Slump value

The slump value of nano concrete is 1.12 times more than the Control concrete.

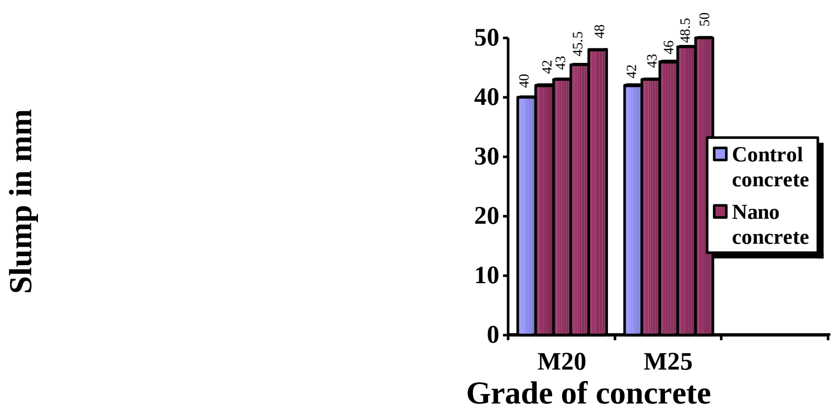

Fig. 4.3 Comparison of Slump value of control concrete and nano concrete

4.2.2 Compaction factor

The compaction factor of nano concrete is 1.05 times more than the Control concrete.

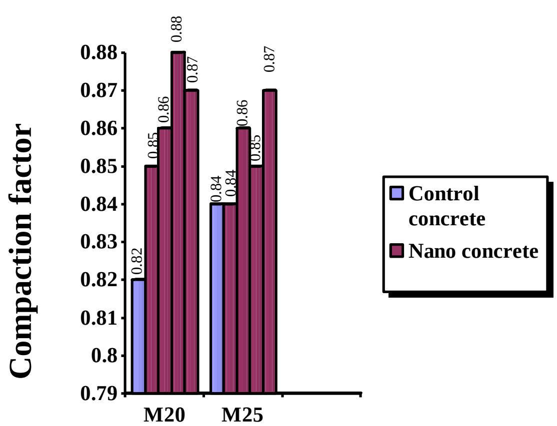

Fig. 4.4 Comparison of compaction factor of control concrete and nano concrete

4.2.3 Compressive strength

M20 grade concrete

For M20 grade concrete, when compared with control concrete, compressive strength of nano concrete is

(i) 5.47%[NC1],16.13%[NC2],14.03%[NC3],13.48%[NC4] more in 7 days,

(ii) 3.28%[NC1],10.06%[NC2],11.43%[NC3],5.81%[NC4] more in 28 days,

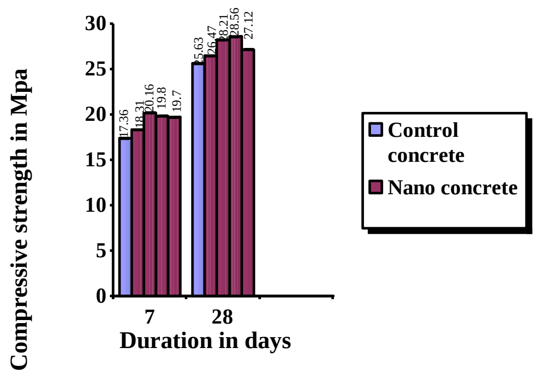

Fig. 4.5 Comparison of compressive strength of M20 grade control concrete and nano concrete

M25 grade concrete

For M25 grade concrete, when compared with control concrete, compressive strength of nano concrete is

(i) 4.23%[NC5],6.13%[NC6],11.73%[NC7],5.22%[NC8] more in 7 days,

(ii) 5.70%[NC5],8.48%[NC6],9.81%[NC7],7.34%[NC8] more in 28 days,

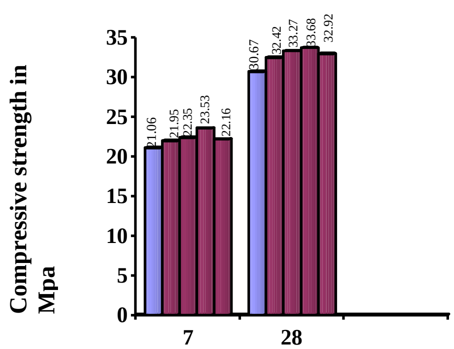

Fig. 4.6 Comparison of compressive strength of M25 grade control concrete and nano concrete

4.2.4 Split tensile strength

M20 grade concrete

For M20 grade concrete, when compared with control concrete, split tensile strength of nano concrete is

(i) 9.55%[NC1],21.02%[NC2],24.20%[NC3],14.65%[NC4] more in 7 days,

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(ii) 14.30%[NC1],5.71%[NC2],13.60%[NC3],8.93%[NC4] more in 28 days,

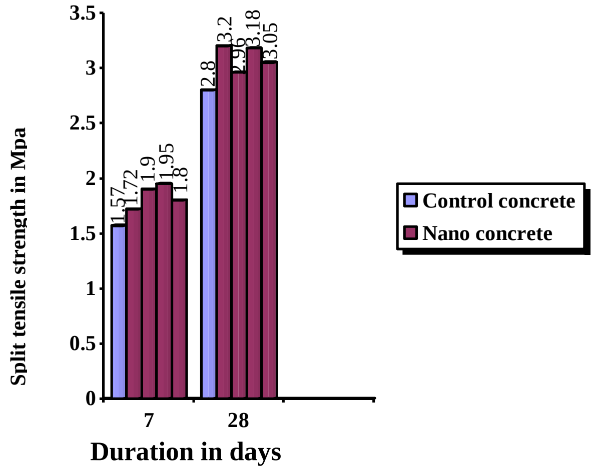

Fig. 4.7 Comparison of split tensile strength of M20 grade control concrete and nano concrete

M25 grade concrete

For M25 grade concrete, when compared with control concrete, split tensile strength of nano concrete is

(i) 21.11%[NC5],24.44%[NC6],14.44%[NC7],16.70%[NC8] more in 7 days,

(ii) 17.72%[NC5],6.01%[NC6],14.87%[NC7],8.86%[NC8] more in 28 days,

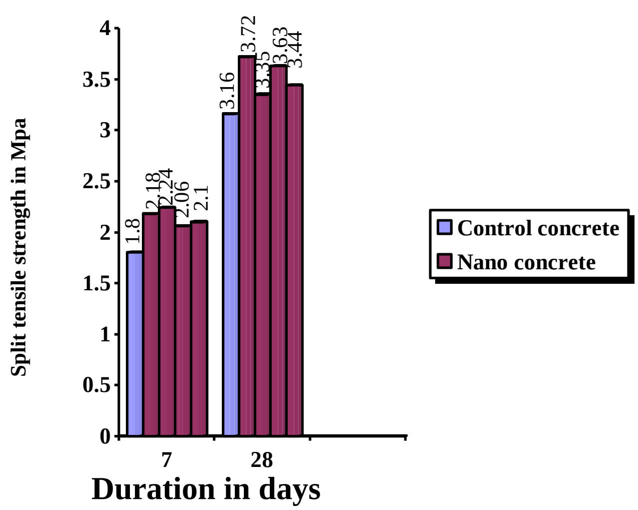

Fig. 4.8 Comparison of split tensile strength of M25 grade control concrete and nano concrete

CONCLUSION

- The mix proportion for M20, M25 grade of Nano concrete were determined.The 7 days and 28 days compressive strength and split tensile strength of Control concrete and Nano concrete were found and tabulated respectively.

- The results of control concrete and Nano concrete were compared.It was found that partially replacement of cement by addition nano Aluminium oxide and Iron oxide concrete gives better resuts than control concrete.

- For M20 grade concrete, when compared with control concrete, compressive strength of nano concrete is 5.47%[NC1],16.13%[NC2],14.03%[NC3],13.48%[NC4] more in 7 days,

  3.28%[NC1],10.06%[NC2],11.43%[NC3],5.81%[NC4] more in 28 days,
- For M25 grade concrete, when compared with control concrete, compressive strength of nano concrete is
  4.23%[NC5],6.13%[NC6],11.73%[NC7],5.22%[NC8] more in 7 days,
  5.70%[NC5],8.48%[NC6],9.81%[NC7],7.34%[NC8] more in 28 days,
- For M20 grade concrete, when compared with control concrete, split tensile strength of nano concrete is
  9.55%[NC1],21.02%[NC2],24.20%[NC3],14.65%[NC4] more in 7 days,
  14.30%[NC1],5.71%[NC2],13.60%[NC3],8.93%[NC4] more in 28 days,
- For M25 grade concrete, when compared with control concrete, split tensile strength of nano concrete is
  21.11%[NC5],24.44%[NC6],14.44%[NC7],16.70%[NC8] more in 7 days,
  17.72%[NC5],6.01%[NC6],14.87%[NC7],8.86%[NC8] more in 28 days,

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