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Performance and Bond Evaluation on Nano Iron Admixed Concrete

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Abstract - *This paper reviews the experimental study and bond evaluation of Nano Iron admixed concrete. The influence of Nano Iron on various properties of concrete is obtained by replacing the cement with various percentages of Nano Iron. Nano Iron is used as a partial replacement for cement in the range of 1%, 2%, 3% and 4% for M40 mix. Using Universal Testing Machine (UTM) pulling out strength values and slip are determined. The result shows that the bond strength is decreased for normal nano concrete compared to Nano Iron admixed concrete. The replacement of cement with 2% Nano Iron results in higher strength, but it decreased the workability of concrete.*

***Key Words*: Nano Iron, Strength, Workability, Pullout strength, Bond behaviour**

1. INTRODUCTION

Nano-technology is one of the most active research areas which has wide applications in almost all the fields like electronics, bio-mechanics, coatings, civil engineering and construction materials. Nanotechnology ("nanotech") is manipulation of matter on an atomic, molecular, and supramolecular scale.

The term 'nanotechnology' was used first by the Japanese scientists Norio Taniguchi (1912-1999) in a 1974 paper on production technology that creates objects and features on the order of a nanometer is credited with the development of molecular nanotechnology, leading to nanosystems machinery manufacturing. The prefix "nano" comes from a Greek word, that means "dwarf". This prefix is used in the International System of Units (SI) to denote a factor of 10−9.

Nano concrete is a new generation concrete made by filling the pores in traditional concrete using nano particles. If cement with Nano-size particles can be manufactured and processed, it will open up a large number of opportunities in the fields of ceramics, high strength composites and electronic applications.

Nanomaterials are gaining widespread attention to be used in construction sector so as to exhibit enhanced performance of materials in terms of smart functions and sustainable features. Nanomaterials such as nanosilica, nanotitania, carbon nanotubes, nanoironoxide, nanoalumina etc... have been explored. Among them Nanoiron is the important material for improving the strength of concrete. It increases the density of concrete mix and are well dispersed compared to other nanomaterials. It is also cost effective, non-toxic, increases viscosity of the liquid phase and help to suspend the cement grains.

The main objective of this study is as follows.

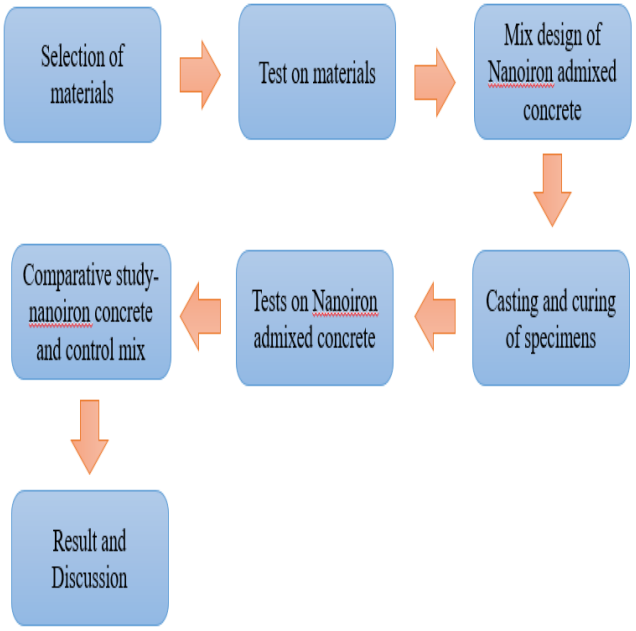
1. To find out the effect of Nanoiron dosages on compressive strength, tensile strength and Flexural strength of concrete.
2. To determine the optimum Nanoiron content in concrete.
3. To study the fresh properties of Nanoiron admixed concrete with fully replacement of 20mm aggregate by 5-10mm Aggregates.
4. To compare the bond strength of nanoiron admixed concrete and conventional concrete.

2. METHODOLOGY

The following steps are involved in the experimental work.

1. Initially the materials used are tested and the test results are shown in table.
2. Cubes, cylinders and prisms are casted for different percentages of Nanoiron and they are used for determining the compressive strength, split tensile strength, flexural strength and bond strength of concrete.
3. Tests are conducted using compression testing machine, Universal testing machine and flexural strength testing machine.
4. After determining the test results suitable percentage of Nanoiron is determined.
5. The replacement of cement with 2% Nanoiron results in higher strength.
6. The experimental works were conducted in concrete laboratory by applying load.

The following flow chart shows the methodology of this project



3. MATERIAL PROPERTIES

3.1 CEMENT

Ordinary Portland Cement of 53 grade is used. The properties of cement tested are as follows,

TABLE 1
Properties of cement

Properties	Test results	IS Specifications(IS:1 2269-1987)
Fineness	8.66%	Shall not Exceed 10%
Specific Gravity	3.17	3.15-3.19
Standard Consistency	30%	26-33%
Initial Setting Time	60 Minutes	Should not be Less Than 30 Minutes
Final Setting Time	-	Should not More Than 10 Hours

All test results are with in limit and confirms to IS specification.

3.2 FINE AGGREGATE

Fine aggregate used is M- sand. M sand is defined as a purpose made crushed fine aggregate produced from suitable source materials. Manufactured sand has been produced by variety of crushing equipment's including cone crushers, impact crushers, roll crushers, road rollers etc... The raw material for M sand production is the parent mass of rock. The properties of fine aggregate tested are as follows,

TABLE 2
Properties of fine aggregate

Properties	Test Results	Range	IS Specifications
Fineness Modulus	2.602	2 .6 - 3.0	IS 383-1970
Specific Gravity	2.5	2.5 - 2.9	IS 2386(PART III)-1963
Bulking	11.28%	-	-
Bulk density	1.39g/cc	-	-
Porosity	36.5%	-	-
Voids ratio	0.48	-	-
Water absorption	0.6%	0.3 – 2.5%	IS 2386(PART III)-1963

Fine aggregate used is a medium sand belongs to zone II as per IS 2386 part I 1963 and IS 383-1970. Also bulking of sand is less than 30%, thus it can be used in making concrete.

3.3 COARSE AGGREGATE

Coarse aggregate of nominal size of 5-10mm is chosen in this research work. The properties of coarse aggregate tested are as follows,

TABLE 3
Properties of coarse aggregate

Properties	Test Results	Range	IS Specifications
Fineness Modulus	2.98	2.9-3.2	IS 383-1970
Specific Gravity	2.94	2.5-3.0	IS 2386(PART III)-1963
Water Absorption	1.8%	0.1-2.0%	IS 2386(PART III)-1963
Bulk Density	1.8 g/cc	-	
Porosity	46.6%	-	
Void Ratio	0.257		

All properties of coarse aggregate confirms to the IS specification. So it can be used to make concrete.

3.4 NANO IRON

Nano iron powder is non-toxic in nature and it readily forms oxides.It possess high magnetic nature, high surface area, electrical and thermal conductivity. Nano Iron with average particle size of 15 nm was used as received.

TABLE 4
Properties of Nano Iron

Property	Test results
Specific Gravity	7.2

As nano iron powder is an ultrafine material with dense packing, it's density and specific gravity is found to be higher than cement. Thus it increases the density of Nano Iron admixed concrete.

4. MIX PROPORTIONING OF CONCRETE

Concrete mix design is the process of finding right proportion of cement, sand and aggregates for concrete to achieve target strength in structures. Based on the test results of materials, the mix proportion for M40 concrete is done according to IS method(IS 10262: 2019). Mix proportion of M40 concrete without Nano Iron content(control mix) and with different percentages of Nano Iron are shown below,

TABLE 5
Mix Proportion of concrete

Sample	Proportion	w/c ratio
Control Mix	1:1.39:1.78	0.41
Mix with 1% Nano iron	1:1.4:1.79	0.41
Mix with 2% Nano iron	1:1.42:1.81	0.42
Mix with 3% Nano iron	1:1.43:1.83	0.42
Mix with 4% Nano iron	1:1.45:1.85	0.43

5. CASTING AND CURING OF CONCRETE

Casting is a manufacturing process in construction in which a concrete mix paste is usually poured into a mould of desired shape. Usually cube, cylinder and prism specimens are moulded for testing the mechanical properties of concrete.

Curing is the maintenance of a satisfactory moisture content and temperature in concrete for a period immediately following placing and finishing so that the desired properties may develop. Curing has a strong influence on the properties of hardened concrete; proper curing will increase durability, strength, water tightness, abrasion resistance, volume stability, and resistance to freezing and thawing.

6. RESULT AND DISCUSSION

6.1 WORKABILITY TEST ON FRESH CONCRETE

A high-quality concrete is one which has acceptable workability in the fresh condition and develops sufficient strength. Basically, the bigger the measured height of slump, the better the workability will be, indicating that the concrete flows easily but at the same time is free from segregation.

Maximum strength of concrete is related to the workability and can only be obtained if the concrete has adequate degree of workability because of self-compacting ability.

Slump cone test is conducted to determine the workability of fresh concrete. The slump test is the most simple workability test for concrete, involves low costand provides immediate results. Generally concrete slump value is used to find the workability, which indicates water-cement ratio, but there are various factors including properties of materials, mixing methods, dosage, admixtures etc. also affect the concrete slump value. The slump value results of control mix and concrete with different percentages of Nano Iron are shown below,

Fig. 1. Slump cone apparatus and obtained slump

TABLE 6
Workability test results

Concrete Mix	Slump Value(mm)
Control mix	85
Mix with 1% Nano iron	59
Mix with 2% Nano iron	45
Mix with 3% Nano iron	41
Mix with 4% Nano iron	28

The results show that unlike the control mix without Nano Iron, all investigated Nano Iron particles blended mixtures had low slump values and non-acceptable workability. This may be due to the increasing in the surface area of powder after adding nanoparticles that needs more water to wetting the cement particles.

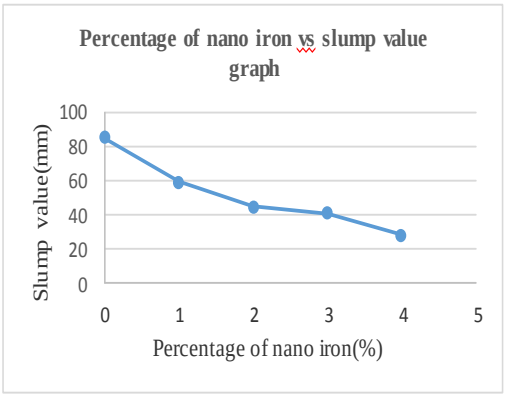


Chart-1 Workability variations

The graph shows the influence of nano iron powder content on the workability of mixtures. As the % of nano iron powder increases workability of fresh concrete is decreased.

6.2 COMPRESSIVE STRENGTH OF CONCRETE

Fig. 2. Compression test on cube

One of the important properties of concrete is its strength in compression. The strength in compression has a definite relationship with all the other properties of concrete i.e. these properties are improving with the improvement in compressive strength. Compressive strength is determined by casting cubes of size 150x150x150 mm and allowed for 7, 14, 28 days curing, and the test results were obtained for control mix and various percentage of Nano Iron. Rate of application of Compressive load is 1.40 KN/cm2/min and is tested in a compression-testing machine. The compressive strength results are shown below,

TABLE 7
Compressive strength of Concrete on varying nano iron content

Percentage of nano iron	7 days strength (N/mm^2)	14 days strength (N/mm^2)	28 days strength(N/mm^2)
0%	20.5	30.2	41.5
1%	24.4	34.5	43.1
2%	28.9	39.7	46.2
3%	25.7	33.9	45.8
4%	22.1	31.7	42.4

Comparison of the results from the 7, 14 and 28 days samples shows that the compressive strength increases with Nano Iron particles up to 2.0% replacement and then it decreases, although the results of 4.0% replacement is still higher than those of the control mix. It was shown that the use of 3.0% Nano Iron particles decreases the compressive strength. Therefore the maximum limit of Nano Iron content should be taken as 2.0%.

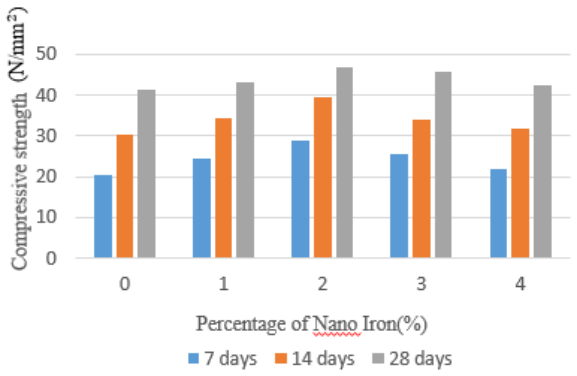


Chart-2 Compressive strength variations

This may be due to the fact that the quantity of nano- Fe2O3 particles (pozzolan) present in the mix is higher than the amount required to combine with the liberated lime during the process of hydration thus leading to excess silica leaching out and causing a deficiency in strength as it replaces part of the cementitious material but does not contribute to strength.

6.3 SPLIT TENSILE STRENGTH OF CONCRETE

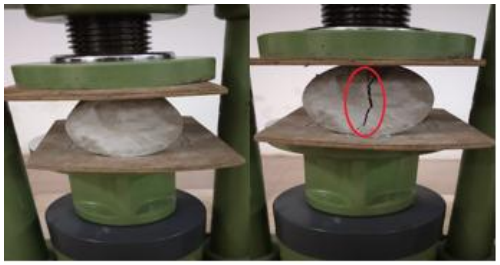


Fig. 3. Split tensile test on cylinder

The test is Carried out by placing a cylinder specimen of height 300 mm and diameter 150 mm horizontally between the loading surfaces of a compression test machine and the load is applying until failure of the cylinder, along the vertical diameter. The splitting test is simple to perform and gives more uniform results than other tension tests. Strength determined in the splitting test is believe to be closer to the true tensile strength of concrete, than the modulus of rupture. The Split tensile strength results are shown below,

TABLE 8
Splitting strength of concrete on varying Nano Iron content

Percentage of Nano Iron	7 days strength (N/mm^2)	14 days strength (N/mm^2)	28 days strength(N/mm^2)
0%	1.25	1.54	2.37
1%	1.94	2.13	2.89
2%	2.63	2.86	3.78
3%	2.43	2.58	3.2
4%	1.54	1.81	2.56

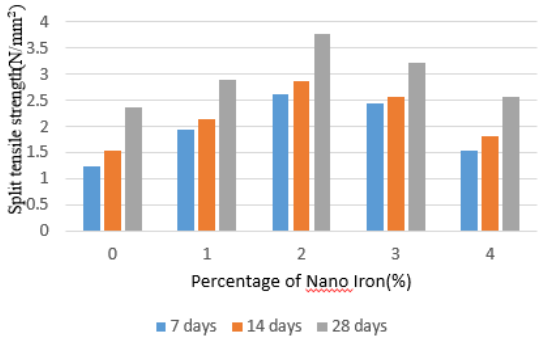


Chart-3 Split tensile strength variations

The split tensile strength results of 7, 14 and 28 days is greater for specimens having 2% replacement of Nano Iron. It increases with Nano Iron particles up to 2.0% replacement and then it decreases, although the results of 4.0% replacement is still higher than those of the control mix. Generally the value of split tensile strength is very less for these specimens, so better fibre reinforcements can be provided to increase the split tensile strength of concrete.

6.4 FLEXURAL STRENGTH TEST OF CONCRETE

Flexural strength is determined by casting beam of size 500mm x 100mm x 100mm. Flexural test evaluates the tensile strength of concrete indirectly. It tests the ability of unreinforced concrete beam or slab to withstand failure in bending. The results of flexural test on concrete are expressed as modulus of rupture. It is tested in a flexural strength testing machine.

Fig. 4. Flexural strength test on beam

The flexural strength results are shown below,

TABLE 9
Flexural strength of specimen on varying nano iron content

Percentage of nano iron	7 days strength (N/mm²)	14 days strength (N/mm²)	28 days strength(N/mm²)
0%	4.12	4.24	4.81
1%	4.78	4.98	5.64
2%	5.19	5.41	6.32
3%	5.12	5.23	5.86
4%	4.32	4.8	5.42

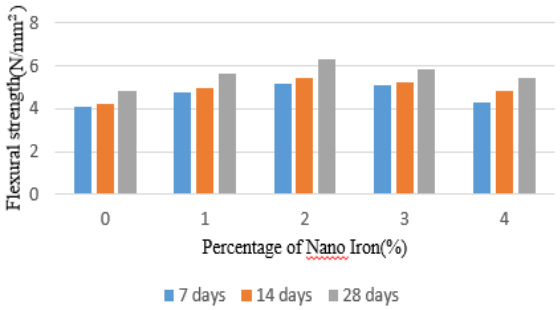


Chart-4 Flexural strength variations

Similar to the tensile strength, the flexural strength of the specimens increases with Nano Iron particles up to 2.0% replacement and then it decreases, although the results of 4.0% replacement is still higher than those of the control mix. Again, the increase in the flexural strength is due to the rapid consuming of Ca(OH)2 which was formed during hydration of Portland cement specially at early ages related to the high reactivity of nano- Fe2O3 particles.

6.5 BOND STRENGTH OF CONCRETE

The pullout test is conducted on the Universal Testing Machine of capacity 1000 kN for finding out the bonding strength of concrete specimens. The fundamental principle behind pull out testing is that the test equipment designed to

a specific geometry will produce results (pull-out forces) that closely correlate to the compressive strength of concrete. Concrete cubes of size 150mm x 150mm x 150mm with 12 mm diameter steel bars embedded on it are used as pullout specimens.

Fig. 5. Pullout test of specimens

TABLE 10
Bond strength of specimens

Specimen	Maximum pullout load(kN)	Bond strength(Mpa)	AverageBond strength(Mpa)
Contro mix	21.05	3.72	3.96
	24.27	4.29	
	22	3.89	
Concrete with 2% Nano iron	34.88	6.17	6.01
	32.86	5.81	
	34.14	6.04	

Concrete with 2% nano iron replacement shows higher bond strength compared to concrete without nano iron. Splitting type of failure mode is observed for all pullout specimens. The presence of nano iron powder in cement increases the strength properties to a great extend. Also the bond strength between concrete and reinforcements is greater for nano iron admixed concrete.

7. CONCLUSIONS

From the compressive strength test results, it is evident that the compressive strength increases with Nano Iron particles up to 2.0% replacement and then it decreases, although the results of 4.0% replacement is still higher than those of the control mix. When the Nano Iron content is increased above 2.0%, it decreased the compressive strength. This may be due to the fact that the quantity of nano- Fe2O3 particles (pozzolan) present in the mix is higher than the amount required to combine with the liberated lime during the process of hydration thus leading to excess silica leaching out and causing a deficiency in strength as it replaces part of the cementitious material but does not contribute to strength.

Split tensile strength also increases with Nano Iron particles up to 2.0% replacement and then it decreases, although the results of 4.0% replacement is still higher than those of the control mix. Also the flexural strength of the specimens increases with Nano Iron particles up to 2.0% replacement and then it decreases. Also the bond strength between concrete and reinforcements is greater for nano iron admixed concrete.

With the addition of Nano Iron in concrete, the workability considerably reduced due to increase in water demand. Usually increasing the fine particles content in cements changes the rheological properties of pastes and consequently influences the workability of mortars and fresh concrete mixtures.

It is found that the cement could be advantageously replaced with Nano Iron particles up to maximum limit of 2.0% with average particle sizes of 15 nm. Partial replacement of cement by Nano Iron particles decreased workability of fresh concrete, but it can be solved by using suitable superplasticizers. As the overall split tensile strength is less, the split tensile strength of the concrete could be improved by using more suitable fibre reinforcements economically.

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