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Experimental Study on Partial Replacement of Cement with Nano Materials

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ABSTRACT
In recent times, there has been a significant focus on utilizing Nano materials to enhance the properties of conventional concrete. The primary objective behind introducing Nano materials into concrete is to enhance its strength and durability. By incorporating ultrafine Nano materials, it becomes possible to reduce the amount of cement used in the concrete mixture, as the Nano materials partially replace cement on a weight basis, thereby improving the binding effect. Additionally, the ultrafine particles of Nano materials act as filler agents, leading to a reduction in the formation of micro pores. As a result, the concrete becomes highly compact, and the growth of micro pores in Ultra High Performance Concrete structures is automatically reduced. This paper will further explore the advantages and benefits of using Nano materials to enhance concrete properties. Concrete is the one of the powerful ingredient for construction field this concrete can improved by adding extra additives such as Nano powders to concrete can significantly enhance its strength, making it a powerful ingredient in the construction field but Nano powder of zirconia is very advantageous in reducing temperature effects and high hardness property, so it used in highly temperature condition as a coatings and paints, the requirement of journals by using Nano zirconia powder in concrete is minimum. The use of Nano iron oxide (Fe_2O_3) powder as an admixture in concrete has a lot of benefits in reducing the amount of waste requiring disposal. This aimed to study the effect of Nano metakaolin (NMK), Nano- Fe_2O_3 (NF) & Zirconium oxide (ZrO_2) on some properties (compressive strength, splitting tensile strength & water absorption etc.) of concrete. Nano materials could not only fill the micro pore and micro crack of aggregate itself, improve the contact surface of new and old mortar, but also fill the micro pores inside the new mortar, so that the compressive strength of concrete exceeded that of ordinary concrete. The workability and mechanical properties will also study for the conventional and Nano replaced Concrete.

***Keywords* -** Nano Metakaolin, Nano Zirconium Oxide, Nano Ferric Oxide, Nano Materials

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I. INTRODUCTION

Modern construction materials for infrastructure and civil structures include concrete, steel, brick, and timber. The use of nanotechnology in the construction industry can solve many of these complications and can change the organization and condition of certain construction processes.

By combining nanoparticles and traditional building materials, exceptional properties can be achieved for the construction of long span and super high-rise systems. The lower density and higher strength properties of nanomaterial's provide a new impulse to the market growth of green high-tech. Nanoparticles can assist in reducing the use of natural materials by improving the performance of construction materials and decreasing the consumption of energy. The use of nanoparticles in construction offers a cheaper, faster, and safer approach to the production of construction materials. In improving the technical properties of materials, the costs incurred during the life cycle of the nanomaterial's can be reduced and a more rational approach to the use of raw materials in construction can be achieved. Product durability and efficiency can be enhanced and higher performance levels in the production of raw materials can be achieved.

Nanotechnology is a smart concept of using smart technologies. It has been established by study, nanotechnology in construction ranked 8 of 10 applications that most likely have impact in the developing world. The usage of Nanotechnology materials while being incorporated in constructional structures would not only help in prolonging their lifetime, but would also keep a check on the energy spent by them and at the same time gauging their reactions and reacting to different agents like fire, corrosion, water penetration, fractures, cracks, etc. Concrete is stronger, more durable and more easily placed, steel tougher and glass self-cleaning. Increased strength and durability are also a part of the drive to reduce the environmental footprint of the built environment by the efficient use of resources.

1.1 Scope

This aimed to study the effect of Nano metakaolin (NMK), Nano- Fe_2O_3 (NF) & Zirconium oxide (ZrO_2) on some properties (compressive strength, splitting tensile strength & water absorption, flexural strength etc.) of concrete. The strength of concrete with different substitution rates could be increased due to the incorporation of Nano materials. Nano materials could not only fill the micro pore and micro crack of aggregate itself, improve the contact surface of new and old mortar, but also fill the micro pores inside the new mortar, so that the compressive strength of concrete exceeded that of ordinary concrete. The workability and mechanical properties will also study for the conventional and Nano replaced Concrete.

1.2 Research objective

The general objective of this project is to investigate the effect of Nano material partially used as cement replacement on structural properties of concrete and durability performance.

1. To determine the optimum content of Nano metakaolin, Nano zirconium oxide and Nano ferric oxide as a substitute for cement in concrete.
2. To evaluate the mechanical properties of concrete containing Nano metakaolin, Nano zirconium oxide and Nano ferric oxide as cement replacement in concrete.
3. To study the physical properties of concrete material.
4. To arrive a mix design summary for concrete using IS code methods.
5. To compare the strength for different percentage of partial replacement of Nano metakaolin, Nano zirconium oxide and Nano ferric oxide with ordinary concrete.

II. MATERIALS & METHODOLOGY

In this research work Nano metakaolin (NMK), Nano- Fe_2O_3 (NF) & Zirconium oxide (ZrO_2) is added into the concrete with different percentage. Compaction factor test to check the workability while compressive strength, flexural strength, split tensile strength, impact strength was carried out on hardened concrete. A concrete mix of grade M45 will designed by keeping water-binder ratio as 0.4.

2.1 Cement

The compressive strength of the mortar cube after 28 days is specified by the cement grade at 33 N/mm2. Cement of the PPC grade is utilized in this experiment.

2.2 Aggregates

Aggregates are larger than 4.75mm or that has been retrained using a 4.75 mm IS sieve is referred to as coarse aggregate. Tests will be performed in accordance with IS 383 – 1970 to identify the various physical properties of a coarse aggregate with a nominal size of 20mm. This experiment makes use of 20mm coarse aggregate.

2.3 Water

Portable water was used throughout the experiment in compliance with IS 456: 2000 criteria.

2.4 Nano metakaolin

Table I
Physical properties of nano metakaolin

Sr. no.	Physical Properties	metakaolin
1	Specific gravity	2.60
2	Bulk Density (g/cm3)	0.3 to 0.4
3	Physical form	Powder
4	Particle size	20nm
5	Appearance	Off- White

2.5 Nano Zirconium oxide:

Table II
Physical properties of Nano Zirconium

Sr. no.	Physical Properties	zirconium oxide
1	Purity	99.9%
2	Average Particle Size	30-50nm

3	Specific surface Area	40-45 m2/g
4	Appearance	White
5	True density	5.68 g/cm3
6	Crystal	Monoclinic
7	Melting point	2715°C

2.6 Nano Ferric oxide

Table III
Physical properties of Nano Ferric oxide

Sr. no.	Physical Properties	ferric oxide
1	Average Particle Size	10-100nm
2	Specific surface Area	30 m2/g
3	Appearance	Red brown
4	True density	3.21 g/cm3
5	Melting point	1570° C

2.7 Mix Design

Grade designation = M45
Type of cement = PPC
Maximum nominal size of aggregate = 20 mm
Minimum cement content = 370 kg/m3
Maximum water cement ratio = 0.4
Workability = 75-100 mm
Expose condition = Extreme (RC)
Degree of supervision = good
Type of aggregate = crushed angular aggregate
Maximum cement content = 450-500 kg/m3
Chemical admixture type = super plasticizer

Table IV
Quantity of materials for 1 m3 of concrete

Sr. No	Materials	Quantity in Kg/m3
1	Cement	410
2	Water	147
3	Chemical Admixtures	7
4	Fine Aggregates	850
5	Coarse Aggregates	1118.57

III. RESULTS

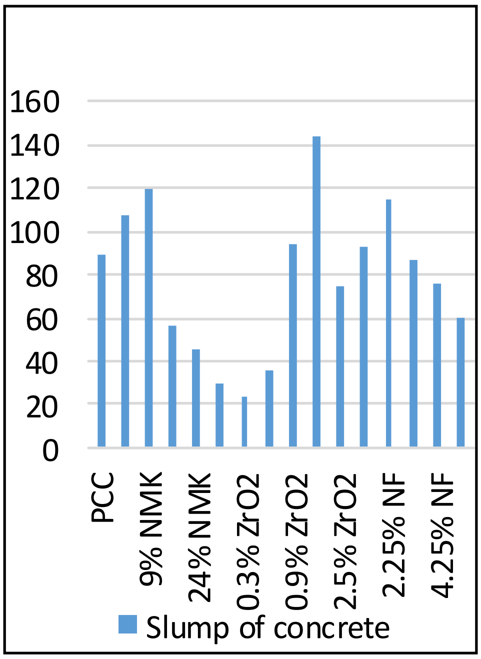
Results of fresh and hardened concrete with partial replacement of Nano Ferric Oxide, Nano Metakaolin and Zirconium Oxide in combination are discussed in comparison with those of normal concrete.

For the combinations of concrete mixes three cubes were being casted each for varying curing days 21, 56 days & three cylinders and three beams were being casted for curing period of 28 days and 56 days. Test for the same being conducted under compressive testing machine of capacity 2000KN.

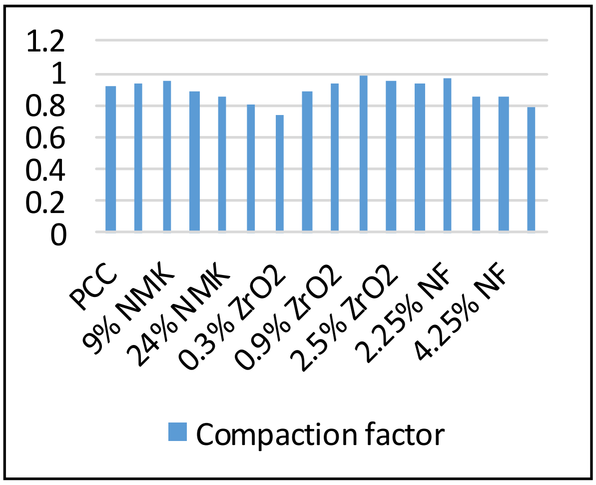
3.1 Workability for concrete mix for blended cements

Table V
Workability of blended cements

Sr. No.	Mix Combination	Slump of concrete	Compaction factor	Workability
1.	Conv. Concrete	89	0.92	Medium
2	3% NMK	107	0.94	Medium
3	9% NMK	120	0.95	High
4	18% NMK	56	0.89	Low
5	24% NMK	45	0.85	Low
6	35% NMK	30	0.80	Low
8	0.3% ZrO_2	23	0.74	Very low
9	0.6% ZrO_2	36	0.89	Low
10	0.9% ZrO_2	94	0.93	Medium
11	1.8% ZrO_2	144	0.98	High
12	2.5% ZrO_2	75	0.95	medium
13	1.25% NF	93	0.93	Medium
14	2.25% NF	115	0.97	High
15	3.25% NF	87	0.86	Medium
16	4.25% NF	76	0.85	Medium
17	5.5% NF	60	0.79	low



Graph 1. Graph of slump showing various replacement

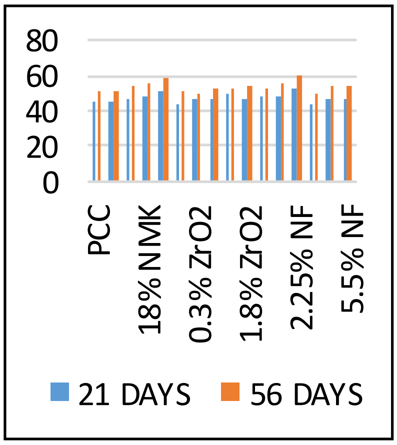


Graph 2. Graph of compaction factor showing various replacement

3.2 Strength behavior of conventional concrete

Table VI
Various replacement level of cement for compressive strength

Sr No.	Replacement Levels (%)	Compressive Strength (MPa)	
		28 days	56 days
1	PCC	44.80	51.52
2	3% NMK	45.33	52.1295
3	9% NMK	47.14	54.211
4	18% NMK	48.97	56.31
5	24% NMK	51.78	59.547
6	35% NMK	44.22	50.853
7	0.3% ZrO_2	43.33	49.829
8	0.6% ZrO_2	45.44	52.256
9	0.9% ZrO_2	45.97	52.865
10	1.8% ZrO_2	47.17	54.245
11	2.5% ZrO_2	45.95	52.842
12	1.25% NF	48.95	56.292
13	2.25% NF	52.78	60.697
14	3.25% NF	43.23	49.714
15	4.25% NF	46.87	53.900
16	5.5% NF	47.15	54.222

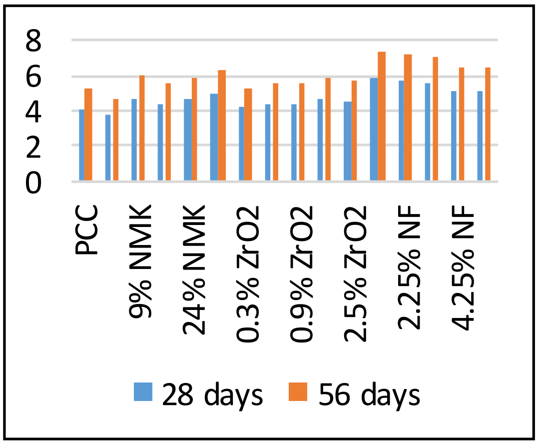


Graph 3. Graph of compressive strength for replacement

Table VII
Split tensile strength of various replacements

Sr. No	Replacement levels (%)	Split Tensile Strength 28 days (N/mm^2)	Split Tensile Strength 56 days (N/mm^2)
1.	PCC	4.12	5.23
2.	3% NMK	3.75	4.76

3.	9% NMK	4.74	6.01
4.	18% NMK	4.46	5.66
5.	24% NMK	4.65	5.90
6.	35% NMK	4.96	6.29
7.	0.3% ZrO_2	4.21	5.34
8.	0.6% ZrO_2	4.38	5.56
9.	0.9% ZrO_2	4.45	5.65
10.	1.8% ZrO_2	4.67	5.93
11.	2.5% ZrO_2	4.56	5.79
12.	1.25% NF	5.84	7.41
13.	2.25% NF	5.73	7.277
14.	3.25% NF	5.56	7.06
15.	4.25% NF	5.10	6.47
16.	5.5% NF	5.15	6.54

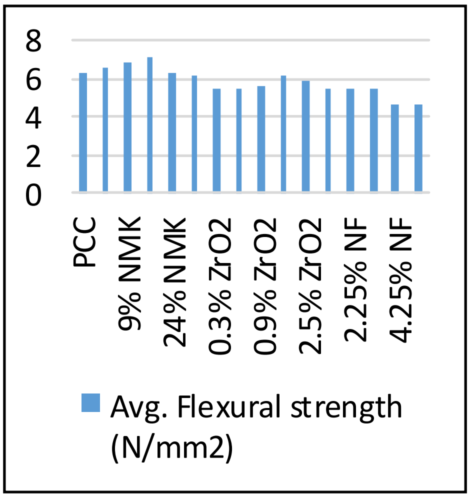


Graph 4. Graph showing results of split tensile strength

Table VIII
28 Days Flexural Strength for various replacements

Sr. No.	**Identification Mark**	**Crushing load (x10^3N)**	**flexural Strength (N/mm^2)**	**Avg. Flexural Strength (N/mm^2)**
1	PCC	32.30	6.46	6.39
	PCC	32.15	6.43	
	PCC	31.33	6.27	
2	3% NMK	31.33	6.27	6.59
	3% NMK	33.15	6.63	
	3% NMK	34.36	6.87	
3	0.6% NMK	34.77	6.95	6.93
	0.6% NMK	33.96	6.79	
	0.6% NMK	35.20	7.04	
4	18% NMK	36.18	7.24	7.20
	18% NMK	37.12	7.42	
	18% NMK	34.66	6.93	
5	24% NMK	37.78	6.46	6.39
	24% NMK	39.12	6.43	
	24% NMK	39.29	6.27	
6	35% NMK	36.87	6.34	6.21
	35% NMK	38.21	6.20	
	35% NMK	38.65	6.09	
7	0.3% ZrO2	25.67	5.30	5.51
	0.3% ZrO2	24.14	5.46	
	0.3% ZrO2	23.20	5.78	
8	0.6% ZrO2	26.04	5.23	5.56
	0.6% ZrO2	29.42	5.59	
	0.6% ZrO2	26.57	5.87	
9	0.9% ZrO2	26.78	5.44	5.67
	0.9% ZrO2	28.52	5.63	
	0.9% ZrO2	28.03	5.94	
10	1.8% ZrO_2	36.34	6.02	6.16
	1.8% ZrO_2	38.10	6.15	
	1.8% ZrO_2	38.88	6.33	
11	2.5% ZrO_2	26.83	5.89	5.97
	2.5% ZrO_2	29.02	5.90	
	2.5% ZrO_2	26.16	6.13	
12	1.25% NF	26.70	5.34	5.49
	1.25% NF	28.50	5.7	
	1.25% NF	27.17	5.43	
13	2.25% NF	26.00	5.2	5.46
	2.25% NF	29.50	5.9	
	2.25% NF	26.33	5.27	
14	3.25% NF	27.20	5.44	5.44
	3.25% NF	28.29	5.66	
	3.25% NF	26.14	5.23	
15	4.25% NF	25.15	5.03	4.7

	4.25% NF	23.14	4.63	
	4.25% NF	22.20	4.44	
16	5.5% NF	26.12	5.06	4.74
	5.5% NF	24.14	4.52	
	5.5% NF	22.30	4.65	



Graph 5. Graph of Flexural strength for various replacement

3.3 Rapid Chloride Permeability Test Results

Table IX
Rapid chloride permeability test results for various replacements

Grade of concrete	Percentage of replacement	RCPT values in Columbs					
		NMK		ZrO_2		NF	
		28 days	56 days	28 days	56 days	28 days	56 days
45	1	778	664	1059	990	1040	945
	2	443	332	825	770	796	725
	3	253	165	915	856	608	552
	4	146	85	1017	950	697	634
	5	85	75	1130	1055	795	723

IV. SUMMARY

From the experiment it is concluded that how the usage of Nano metakaolin (NMK), Nano-Fe_2O_3 (NF) & Zirconium oxide (ZrO_2) helps in improving the strength of the concrete. Nano silica is the important replacement in this project. The Nano metakaolin (NMK), are replaced by 3%, 9%, 18%, 24% and 35% to the weight of cement content. The Zirconium oxide (ZrO_2), are replaced by 0.3%, 0.6%, 0.9%, 1.8% and 2.5% to the weight of cement content. The Nano- Fe_2O_3 (NF), are replaced by 1.25%, 2.25%, 3.25%, 4.25% and 5.5% to the weight of cement content. Collection of the literatures are done and are studied carefully. The design mix and the tests were done as per IS 456 and IS 10262- 2019 code books. The curing & testing were done at an interval of 28 days and 56 days. After the specified curing period, the mechanical property of the specimens is tested.
The addition of Nano metakaolin as additive will delayed in setting time initially and final set due to finer particles size and increase in surface area. 9% of Nano metakaolin gives the highest the strength.
The results of the experimental work for compressive strength and flexural strength it is found that ZrO_2Nano-particles addition up to 1.8% by the weight of cement could strengthen the cement by acting as filler.
The percentage of chemical admixtures increases so the compressive strength of concrete decreases maximum compressive strength was observed 2.25% Fe_2O_3 of 28 days.

V. CONCLUSION

This aimed to study the effect of Nano metakaolin (NMK), Nano- Fe_2O_3 (NF) & Zirconium oxide (ZrO_2) on some properties (compressive strength, splitting tensile strength & water absorption, flexural strength etc.) of concrete. And the results are as follows.

1. The addition of Nano metakaolin as additive will delayed in setting time initially and final set due to finer particles size and increase in surface area. 9% of Nano metakaolin gives the highest the strength.
2. Nano metakaolin is relatively finer and highly pozzolonic as a partial replacement of cement produce pore structure modification reduce porosity.
3. Early compressive strength of mortar is achieved by replacing cement with small percentage of Nano ZrO_2 material.
4. The number of pores are reduced by good compaction and addition of ZrO_2 at 0.3% in the specimen.
5. The results of the experimental work for compressive strength and flexural strength it is found that ZrO_2Nano-particles addition up to 1.8% by the weight of cement could strengthen the cement by acting as filler.
6. Fe_2O_3 nanoparticles can be successfully

applied as an admixture for cementitious materials and its presence does not affect the rate of the cement hydration and the nature of the phases in hydrated cement paste.

7. The percentage of chemical admixtures increases so the compressive strength of concrete decreases maximum compressive strength was observed 2.25% Fe_2O_3 of 28 days.

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