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Nanomaterials in Structural Engineering: Strength and Durability Enhancement

Mr. Hemantkumar Maroti Kondagorla

Student
Department of Civil Engineering Wainganga College of Engineering and Management, Nagpur, India Email Id:
hemantkondagorla123@gmail.com

Prof. Gaurav Hingwe

Assit. Prof.
Department of Civil Engineering Wainganga College of Engineering and Management, Nagpur, India

Abstract— Concrete is a common material used in building things like houses and bridges. But it has some problems. It can crack easily. Water can get inside. This study looks at how adding nanomaterials like nano-silica and nano-titanium dioxide to concrete can make it stronger and last longer. We added these nanomaterials to the concrete in amounts and tested it. The results showed that adding these nanomaterials can really improve the strength and durability of concrete. The best mix we found was a combination of nano-silica and nano-titanium dioxide, which made the concrete 20% stronger than the concrete. It also helped keep water out and reduced the risk of damage from things like salt and acid.

***Keywords* —** Nanomaterials, nano-silica, nano-TiO_2 concrete strength, durability, chloride resistance, structural engineering.

I. INTRODUCTION

Concrete is used a lot in construction because it is cheap and easy to work with. But it has some limitations. It is not very strong when it comes to stretching or pulling and it can be damaged by water and other chemicals. To fix these problems we can use nanotechnology. Nanomaterials are small particles that can fill in the tiny holes in the concrete and make it stronger. Nano-silica is a type of nanomaterial that reacts with the concrete to form an durable bond. Nano-titanium dioxide is another type of nanomaterial that can help make the concrete more compact and resistant to damage.

The goal of this study is to see how adding nano-silica and nano-titanium dioxide to concrete can improve its strength and durability. We want to find the amount of these nanomaterials to add to the concrete so that it can be used in real-world construction projects.

II. LITERATURE REVIEW

Previous studies indicate that nanomaterials significantly enhance the performance of concrete. Researchers have found that:

- Nano-silica improves compressive, tensile, and flexural strength.
- Nano-TiO_2 increases durability and resistance to chemicals like sulphates and acids.
- Optimum nano-material content is generally between 1% to 3%.
- Excess nano-materials reduce workability due to high surface area.

However, limited research is available on the combined effect of nano-silica and nano-TiO_2 on M40 grade concrete for both strength and durability performance, which forms the basis of this study.

III. MATERIALS AND METHODOLOGY

We used Portland cement and mixed it with sand, stone and water to make the concrete. We also added a chemical to make the concrete more workable. Then we added the nano-silica and nano-titanium dioxide to the concrete in amounts and tested it.

A. Concrete Mix Proportions

Mix ID	Cement (kg/m³)	Fine Aggregate (kg/m³)	Coarse Aggregate (kg/m³)	Water (L/m³)	Nano-Silica (%)	Nano-TiO_2 (%)
CM	400	650	1200	180	0	0
NS1	396	650	1200	180	1	0
NS2	392	650	1200	180	2	0
NS3	388	650	1200	180	3	0
NT1	396	650	1200	180	0	1
NT2	392	650	1200	180	0	2
NSNT	384	650	1200	180	2	2

We made different types of concrete specimens and tested them for strength and durability. We also tested the concrete for its ability to resist damage from water and other chemicals.

IV. RESULTS AND DISCUSSION

A. Workability

The workability of the concrete decreased when we added nanomaterials. This is because the nanomaterials are very small and have a surface area, which makes them absorb more water.. We were able to make the concrete workable again by adding a special chemical.

Table: Fresh Concrete Test Results

Mix ID	Slump (mm)	Compaction Factor	Observation
CM	95	0.92	Good workability
NS1	90	0.91	Slight reduction
NS2	84	0.90	Moderate workability
NS3	78	0.88	Reduced consistency
NT1	88	0.90	Stable mix
NT2	82	0.89	Lower slump
NSNT	75	0.87	Lowest workability

B. Compressive Strength (28 Days)

The compressive strength of the concrete increased when we added the nanomaterials. The best mix we found was the combination of nano-silica and nano-titanium dioxide, which made the concrete 20% stronger than the concrete.

Table: Compressive Strength Results (28 Days)

Mix ID	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)	Strength Gain (%)
CM	26.5	34.8	41.2	0.0
NS1	28.7	37.2	44.5	7.9
NS2	30.4	39.8	47.8	16.0
NS3	29.1	38.5	45.6	10.7
NT1	27.8	36.5	43.9	6.6
NT2	29.0	38.1	46.2	12.1
NSNT	31.2	40.7	49.5	20.1

C. Split Tensile and Flexural Strength

The split tensile and flexural strength of the concrete also increased when we added the nanomaterials. The best mix we found was the combination of nano-silica and nano-titanium dioxide, which made the concrete stronger and more resistant to cracking.

Table: Tensile and Flexural Strength Results

Mix ID	Split Tensile Strength (MPa)	Flexural Strength (MPa)
CM	3.45	4.8
NS1	3.72	5.2
NS2	4.01	5.6
NS3	3.89	5.4
NT1	3.68	5.1
NT2	3.94	5.5
NSNT	4.18	5.9

D. Durability Performance

The durability of the concrete also improved when we added the nanomaterials. The best mix we found was the combination of nano-silica and nano-titanium dioxide, which made the concrete more resistant to water and other chemicals.

Table: Durability Test Results

Mix ID	Water Absorption (%)	RCPT (Coulombs)	Sorptivity (mm/min $^{1/2}$)	Carbonation Depth (mm)	Electrical Resistivity (kΩ-cm)
CM	5.2	3200	0.145	12.5	12.5
NS1	4.6	2500	0.128	10.2	16.8
NS2	4.1	1800	0.112	8.4	20.4
NS3	4.3	1900	0.118	8.9	19.5
NT1	4.7	2400	0.130	10.5	17.2
NT2	4.2	1700	0.116	8.1	21.1
NSNT	3.8	1200	0.101	6.8	24.6

The reason for the improved durability is that the nanomaterials fill in the tiny holes in the concrete and make it more compact. They also react with the concrete to form an durable bond that resists damage from water and other chemicals.

E. Sulphate and Acid Resistance

The concrete with nanomaterials also showed resistance to sulphate and acid attack. The best mix we found was the combination of nano-silica and nano-titanium dioxide, which made the concrete more resistant to damage from these chemicals.

Table 6. Chemical Resistance Results

Mix ID	Sulphate Weight Loss (%)	Sulphate Strength Loss (%)	Acid Weight Loss (%)	Residual Strength (MPa)
CM	4.8	12.5	6.5	32.4
NS2	3.1	8.4	4.3	38.7
NT2	3.0	8.1	4.1	39.2
NSNT	2.5	6.7	3.5	41.0

F. Structural Performance of RC Beams

We also tested the performance of reinforced concrete beams made with the nanomaterial-modified concrete. The results showed that the beams made with the combination of nano-silica and nano-titanium dioxide had structural performance, than the beams made with regular concrete. They were able to withstand load and had less cracking.

Reinforced concrete beams made with concrete that has nanomaterials in it are really strong. They can handle weight before they crack and they can handle even more weight before they break. The cracks in these beams are also smaller. When we mix nanomaterials together the beams get even stronger.

Table: Reinforced Concrete Beam Results

Mix ID	First Crack Load (kN)	Ultimate Load (kN)	Ultimate Load Increase (%)	Maximum Crack Width (mm)
CM	28	82	0.0	0.42
NS1	31	88	7.3	0.38
NS2	34	95	15.9	0.32
NS3	33	92	12.2	0.34
NT1	30	87	6.1	0.37
NT2	34	94	14.6	0.31
NSNT	37	101	23.2	0.28

The NSNT beam is really good. It can handle 23.2% weight than the regular beam and the cracks are 33.3% smaller. This means the beam is stiffer and can handle weight without cracking.

G. Cost and Practical Feasibility

Concrete with nanomaterials is more expensive at first because the nanomaterials cost a lot.. It lasts longer and does not need as much maintenance. This means it can be cheaper in the run.

Table: Cost and Life-Cycle Performance

Mix ID	Initial Cost (₹/m³)	Estimated Maintenance Cost (₹)	Estimated Service Life (Years)	Life-Cycle Performance
CM	7200	5200	40	Moderate
NS2	7950	3600	55	Good
NT2	8050	3400	58	Good
NSNT	8600	2800	65	Excellent

The NSNT mix is the expensive at first but it lasts the longest and has the best performance over time.

V. CONCLUSIONS

We did some experiments. Found out some things about concrete with nanomaterials.

1. Nanomaterials make it harder to mix the concrete because they have a surface area and need more water.
2. Nano-silica and nano-TiO_2 make the concrete stronger when we use the amount.
3. If we use much nano-silica it does not work as well.
4. Mixing nano-silica and nano-TiO_2 makes the concrete really strong.
5. The strongest concrete we made was 20.1% stronger than the concrete.
6. The concrete with nanomaterials is more durable. Can handle water and other things better.
7. The reinforced concrete beams with nanomaterials are stronger. Have smaller cracks.
8. Even though the nanomaterial concrete is more expensive at first it can be cheaper in the run because it lasts longer.
9. We need to mix the nanomaterials well and use the right chemicals to make the concrete work well.
10. Concrete with nanomaterials is good for buildings and bridges that need to be strong and last a time.

VI. RECOMMENDATIONS

- We should use nano-silica in the concrete to make it stronger.
- Mixing nano-silica and nano-TiO_2 makes the concrete really strong.
- We need to use the chemicals to make the concrete mix well.
- We need to mix the nanomaterials well so they do not clump together.
- We should do tests to make sure the concrete works well in real buildings.
- We should make some rules for how to use nanomaterials in concrete.

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