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Enhancing the Properties of Concrete by Partial Replacement of Cement with Nano Materials

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ABSTRACT
Nanotechnology has indeed revolutionized various fields of research, including construction and materials science. The incorporation of nanomaterials in concrete has opened new possibilities and brought significant improvements to the properties of traditional concrete. The evaluation of blended cement containing Nano zirconium dioxide, and Nano titanium oxide were carried out. Both the nano materials are replaced with cement in percentage of 0.3% to 2.5 % Nano zirconium dioxide (ZrO_2), and 0.3% to 2.5 % Nano titanium oxide (TiO_2). To find out properties in plastic stage workability test by using compaction factor test, and slump cone test, was carried out on fresh concrete. while to find out properties in hardened stage compressive strength, flexural strength, split tensile strength was carried out on hardened concrete. A concrete mix of grade M 40 was implemented. Result revealed that strength of concrete has been enhanced by replacing 1.8 % nano zirconium dioxide, and Nano titanium oxide.

Keywords - Nano TiO_2, nano ZrO_2, workability, Compressive strength, split tensile strength.

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I. INTRODUCTION

Due to the wide application of Concrete in the various construction industries, concrete has excellence present and future scope [1]. Concrete structure has been used all over the world for construction buildings, docks and harbour, bridges, tunnel, dams, etc [2]. To improve the strength, and the quality of construction proper proportion of ingredient such as fine aggregate, coarse aggregate, cement, water cement ratio, and admixture plays crucial role [3]. Depending upon the size of the aggregate water cement required for the construction work varies due to which strength of the concrete will be hampered [4]. To enhance the quality and durability of structure modern material need to be replaced cement by adding nano materials [5]. Nano material such as Nano Silica, Nano titanium oxide, and Nano zirconium dioxide having the wide application in the construction company [6]. The use of a combination of Nano titanium oxide, and Nano zirconium dioxide as a cement substitute could help to minimize CO2 emissions, which contribute to global warming and climatic changes [7]. When different byproducts from various sectors are used to replace cement in concrete, energy and natural resources are saved [8]. Due to the application of cement on a large-scale carbon dioxide emission will be occurred [9-12]. Hence there is urgent need to partially replace the cement by suitable advance material such as Nano titanium oxide, Nano zirconium dioxide, graphene oxide, nano metakaolin, nano ferric oxide, nano alumina, nano silica, carbon nano tubes, etc [13-15]. Out of this modern construction material Nano titanium oxide, Nano zirconium dioxide has great demand in 21st century. Nanotechnology looks promising approach in improvising the properties of concrete. The introduction of nanotechnology represents a revolution that allowed for the development of high-performance and long-lasting products and processes within an ideal context of sustainable development. Nano titanium oxide, also known as titanium dioxide nanoparticles or nano TiO_2, is a form of titanium dioxide (TiO_2) that has been engineered at the nanoscale. Titanium dioxide is a naturally occurring oxide of titanium and is widely used in various industries due to its unique properties. When reduced to the nanoscale, titanium dioxide exhibits enhanced properties, such as increased surface area and altered reactivity. Nano zirconium dioxide, also known as zirconia nanoparticles or nano ZrO_2, is a nanomaterial composed of zirconium dioxide (ZrO_2) particles. Zirconium dioxide is a crystalline oxide of zirconium and has excellent thermal, mechanical, and electrical properties. Like nano titanium oxide, nano zirconium dioxide exhibits unique characteristics at the nanoscale.

Nanomaterials are incredibly small substances containing nanometre-sized particles [16]. Due to their extremely small size, these materials are exceptionally effective at altering the characteristics of concrete at the ultrafine level. The particles' tiny size also results in a larger surface area. A faster reaction can be accomplished since the pace of a pozzolanic reaction is related to the available surface area. To obtain the required outcomes, just a tiny portion of cement may be changed. By filling in the tiny gaps and pores in the microstructure, these nanoparticles increase the strength, longevity, and permeability of concrete. Because the nanoparticles of silica in the concrete have the property of clogging pores, using nano-concrete also results in a decreased rate of corrosion of the steel reinforcing. There will be many prospects for more study and development of concrete used in the building industry if Portland cement can be produced utilizing nanosized particles. Additionally, the nanoparticles improve the cement's environmental friendliness and lessen the negative environmental effects of the building sector, resulting in a more sustainable future. This process will produce cement that is not only more affordable than conventional cement polymers, but also more fire resistant. Therefore, a structure constructed using nanoparticles will be more robust and long-lasting than one constructed with normal concrete, extending the building's useful life.

This paper insight the application of Nano titanium oxide, and Nano zirconium dioxide. The objective of research paper is to investigate the effect of Nano material partially used as cement replacement on structural properties of concrete and durability performance. This paper also determines the optimum content of Nano Titanium, Nano zirconium dioxide as a substitute for cement in concrete. This paper also gives the brief information about the mechanical properties of concrete containing Nano Zirconium dioxide and Nano Titanium dioxide as cement replacement in concrete.

II. MATERIALS

Titanium Dioxide nanoparticles, and Nano zirconium dioxide were procured from local vendor MIDC, Ahmednagar. The physical properties of both Nano materials are summarized in table 1. For the preparation of concrete material required such as fine aggregate, coarse aggregate, and cement were purchased from local Vendor MIDC Ahmednagar, Maharashtra, India.

Table.1. Physical properties of Nano Titanium dioxide

Physical Properties	Titanium dioxide	Zirconium dioxide
Purity	99.8%	99.9%
Average Particle Size	30-50nm	30-50nm
Specific surface Area	33.3 m^2/g	40-45m^2/g
Appearance	White	White
Crystal	Closed pack hexagonal	Monoclinic
Melting point	1843℃	2715℃

III. METHODOLOGY

As per the literature survey M 40 grade of concrete were considered for the mix design. M40 grade of concrete is prepared as per the IS Code 10262 (2009). In the mix design cement is replaced by Nano titanium oxide, Nano zirconium dioxide in the range of 0.3 % to 2.5 %. The properties of concrete were carried out such as workability, compressive strength, split tensile strength, and flexural strength worked out.

IV. RESULTS

Zirconium oxide is produced through the reduction and fusion of zircon sand. (Zirconium silicate). 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. Nano zirconium shows good aesthetics, superior physical resistance (hardness, flexibility, and durability), and chemical resistance (practically inert) and is a very good insulator. Concrete is the one of the powerful ingredients for construction field this concrete can improved by adding some extra additives like Nano powders which helps to increases the strength in the concrete, 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. Nano titanium dioxide is also called ultra-fine titanium dioxide Particles of titanium dioxide (TiO_2) with diameter less than 100 nm. TiO_2 added to cement impart improvements in hydration and increases strength, durability, and mechanical property of cement. Approximately 50% of titanium dioxide colour is manufactured in Japan, hence it has emerged as the largest exporter of titanium dioxide colour in Asia Pacific. This concrete is used at the place where the high strength and low permeability required. The application of nanotechnology by incorporating nanomaterials in concrete has added a new dimension to improve the mechanical properties of the concrete. This concrete is used at the place where the high strength and low permeability required. Fig. 1a represents the Split tensile test on cylinder, and Fig. 1b insights the Flexural test on beam.


Fig. 1a. Split Tensile Test on Cylinder

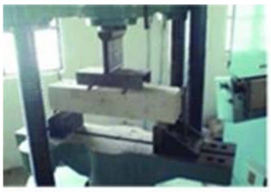
Fig 1b. Flexural Test on Beam

To check properties of concrete in plastic stage slump cone test, and compaction factor test were carried out. Following are the result of workability test by adding Nano titanium oxide, and Nano zirconium dioxide along with conventional concrete. For the experimentation M 40 grade of concrete were used. The results obtained were compared with the conventional concrete. Nano Table 2 represents the workability of Nano materials. Key role of workability test is to check the performance of concrete. Compaction of the concrete is essential, as on the basis of compaction of concrete quality of the concrete has been checked. By using slum cone test, and compaction factor test were implemented to find the workability of the concrete. Maximum workability of the concrete is found to be 0.97 for 1.8 % ZrO_2, and 0.9 % TiO_2.

Table 2 Workability of individual blend of cement

Mix Combination	Slump of concrete	Compaction factor	Workability
Ordinary concrete	89	0.89	Medium workability
0.3 % ZrO_2	90	0.86	Medium workability
0.6 % ZrO_2	95	0.89	Good workability
0.9 % ZrO_2	107	0.92	High workability
1.8 % ZrO_2	121	0.97	High workability
2.5 % ZrO_2	102	0.91	Medium workability
0.3 % TiO_2	90	0.86	Medium workability
0.6 % TiO_2	95	0.89	Good workability
0.9 % TiO_2	107	0.92	High workability
1.8 % TiO_2	100	0.89	Medium workability
2.5 % TiO_2	97	0.85	Medium workability

Compressive Strength

Compressive strength is a fundamental mechanical property used to evaluate the ability of a material to withstand compressive loads without deformation or failure. It measures the maximum resistance of a material to compressive forces and is an important parameter in the design and assessment of various structures and components. In a compressive strength test, a sample specimen of the material is subjected to a compressive force along its axis. The force is gradually applied until the specimen fractures or experiences significant deformation. The maximum force at which this occurs is recorded, and the compressive strength is calculated. Compressive strength is typically expressed in units of force per unit area, such as megapascals (MPa) or pounds per square inch (psi). The compressive strength of a material is influenced by its composition, density, porosity, and internal structure. Different materials have different compressive strengths; for example, concrete, rocks, metals, and ceramics all exhibit varying levels of compressive strength. Compressive strength is a critical property in the construction industry, where it is essential to ensure that materials used in buildings, bridges, roads, and other structures can withstand the loads and forces they will be subjected to during their lifetime. Engineers use compressive strength data to determine the appropriate material selection, design structural components, and assess the overall safety and performance of a structure.

Table. 3. Various replacement level of cement for compressive strength

Replacement Levels (%)	Compressive Strength (N/mm^2)		
	7 days	14 days	28 days
Ordinary concrete	22.45	33.05	42.78
0.3 % ZrO_2	23.56	35.56	43.33
0.6 % ZrO_2	24.89	36.22	45.44
0.9 % ZrO_2	25.78	37.19	45.97
1.8 % ZrO_2	26.89	38.67	47.17
2.5 % ZrO_2	24.14	36.55	45.95
0.3 % TiO_2	25.56	33.33	42.22
0.6 % TiO_2	27.11	35.11	44.89
0.9 % TiO_2	28.22	36.44	47.11
1.8 % TiO_2	27.33	35.56	43.46
2.5 % TiO_2	26.48	34.24	41.39

Split Tensile Strength

Split tensile strength, also known as indirect tensile strength, is a measure of the tensile (pulling) strength of a material in a direction perpendicular to the applied force. It is commonly used for brittle materials like concrete and rock, which may not have well-defined tensile strength in direct tension. In a split tensile strength test, a cylindrical or cylindrical disc specimen is subjected to diametrical compression. The test involves applying a force perpendicular to the axis of the cylinder until it fractures into two halves. The force required to cause the splitting of the specimen is measured, and the split tensile strength is calculated. Split tensile strength is particularly relevant for materials like concrete, which are known to be weak in direct tension but perform better under compressive loads. This property is essential in the design and analysis of concrete structures, such as bridges, buildings, and pavements, where the material is subjected to various loading conditions, including tensile forces. By conducting split tensile strength tests on concrete samples, engineers can assess the material's behavior under tensile stresses and use this information to optimize the mix design and ensure the structural integrity of the concrete elements in real-world applications.

It displays a greater value of split tensile strength with 1.8% addition of zirconium dioxide (ZrO_2), with a value increase of up to 88.22% when compared to Ordinary concrete and the value decreases after 1.8%. It demonstrates a greater value of split tensile strength with 0.9% addition of titanium dioxide (TiO_2), and this value grows up to 84.25% when compared to Ordinary concrete, and the value likewise decreases after 0.9%.

Table 4. Various replacement level of cement for Split Tensile strength

Replacement Levels (%)	Split Tensile Strength (N/mm^2)28 days
Ordinary concrete	4.12
0.3 % ZrO_2	4.21
0.6 % ZrO_2	4.38
0.9 % ZrO_2	4.45
1.8 % ZrO_2	4.67
2.5 % ZrO_2	4.56
0.3 % TiO_2	4.24
0.6 % TiO_2	4.35
0.9 % TiO_2	4.49
1.8 % TiO_2	4.45
2.5 % TiO_2	4.38

Flexural strength

Flexural strength, also known as bending strength or modulus of rupture, is a mechanical property used to measure the ability of a material to resist deformation and fracture under bending loads. It is an important characteristic for materials that will be subjected to bending or flexural stresses, such as beams, plates, and other structural elements. When a material is subjected to a bending force, one side of the material experiences tension (stretching) while the other side undergoes compression (compression). At some point, the material may reach its maximum resistance, leading to failure or fracture. Flexural strength is defined as the maximum stress that a material can withstand at the outermost fiber (farthest from the neutral axis) before breaking. Flexural strength is typically expressed in units of force per unit area, such as megapascals (MPa) or pounds per square inch (psi). The test to determine flexural strength involves applying a three-point or four-point bending load to a sample specimen and measuring the applied force at the moment of fracture. Different materials have different flexural strengths based on their composition and internal structure. For example, concrete, wood, ceramic, and metals all have different flexural strengths. It's important to consider flexural strength when designing and constructing various structures and components to ensure they can handle the bending forces they will be subjected to during their service life. Engineers and material scientists use flexural strength data to make informed decisions about material selection and structural integrity.

It shows a greater value of flexural strength with 1.8% addition of zirconium dioxide (ZrO_2), with a value rise of up to 90.43% when compared to Ordinary concrete, and the value also decreases after 1.8%. It demonstrates a greater value of flexural strength with 0.9% addition of titanium dioxide (TiO_2), with this value increasing up to 94.08% when compared to Ordinary concrete, and the value likewise decreases after 0.9%. As a result, it was discovered that adding 1.8% nano zirconium dioxide (ZrO_2) and 0.9% nano titanium dioxide (TiO_2) improves workability and mechanical characteristics. As a result, it can be used in concrete to enhance its properties.

Table 5. Various replacement level of cement for Flexural Test

Replacement Levels (%)	Flexural Strength (N/mm2) 28 days
Ordinary Concrete	5.57
0.3 % ZrO2	5.69
0.6 % ZrO2	5.88
0.9 % ZrO2	5.97
1.8 % ZrO2	6.16
2.5 % ZrO2	6.02
0.3 % TiO_2	5.65
0.6 % TiO_2	5.78
0.9 % TiO_2	5.92
1.8 % TiO_2	5.88
2.5 % TiO_2	5.75

V. Conclusion

It demonstrates a greater workability value for a 1.8% addition of zirconium dioxide ZrO_2, and this value rises to 73.55% in comparison to Ordinary concrete. The result also demonstrates that the value decreases after 1.8%. The results indicate that the value is decreasing with the addition of 0.9% of titanium dioxide TiO_2, with a value increase up to 83.17% when compared to Ordinary concrete. It displays a higher value of compressive strength for 1.8% addition of zirconium dioxide ZrO_2 and this value grows up to 90.70% when compared to Ordinary concrete. and the value likewise decreases after 1.8%. It displays a greater value of workability for 0.9% addition of titanium dioxide TiO2, and this value increases up to 90.80% when compared to Ordinary concrete.

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An acknowledgement section may be presented after the conclusion, if desired.

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