


## Research Article

# Mechanical and Durability Characteristics of $\text{TiO}_2$ and $\text{Al}_2\text{O}_3$ Nanoparticles with Sisal Fibers

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Received 27 January 2022; Revised 25 February 2022; Accepted 11 March 2022; Published 4 April 2022

Academic Editor: Arpita Roy

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The use of nanoparticles in concrete increases the material's strength and durability, making it useful in the building sector. Nanomaterials can lower the amount of cement in a building since cement releases carbon dioxide, which contributes to global warming. The mechanical response of concrete is studied in this study by replacing cement with various dosages of nanotitanium dioxide and nanoalumina. Nanotechnology has attracted a lot of attention in recent years because of its potential uses for particles. Cementitious materials at the nano/atomic level are the primary focus of current research. The mechanical characteristics of cementitious materials have been significantly improved by introducing nanotitanium dioxide and nanoalumina into cement. Nanotitanium dioxide and nanoalumina have been added to concrete in this study to examine its sorptivity and water absorption properties. To lower the carbon footprint of concrete, nanotitanium dioxide and nanoalumina can be used in place of cement.

## 1. Introduction

Due to the growing demand for the construction sector in the recent times, it has become a necessity to find alternatives for building materials for various reasons. One being, over exploitation of non renewable resources. Second being, the existing rapid usage of the resources is polluting the environment, which creates a great impact on the human and animal ecosystem [1, 2]. Thus, there has been various researches in modifying the conventional matrix by adding additives to make it more efficient and effective in terms of performance [3–5]. Cement has been one of the very important aspect in the construction sector, which is also very widely used. Reports are shown that, by using a ton of the conventional Ordinary Portland Cement (OPC), the same amount of the carbon dioxide gas is effused in the atmosphere. This ultimately increases the carbon footprint in the environment [6]. And also, it has been reported that the construction sector is responsible for about 7-8% of the carbon dioxide emission worldwide [7]. Thus, all these situations have aggravated the process of using various additives

or modifying the conventional concrete to make it greener and more economical.

The durability and efficiency of the cementitious particles depend upon calcium silicate hydrate (C-S-H) particles present in the cement [8]. The characteristics of these particles are due to the fact that their size is about few nanometers, which gives them the properties like binding, etc. Thus, nanoparticles are widely researched sector as additives to the concrete, which enhances the efficiency and performance of the same [9, 10]. As compared to the conventional concrete particles, nanoparticles are higher when properties like reactivity and specific area are considered. Thus, the nanoparticles which are smaller size, the chemical reaction in the cement is more enhanced [11]. Nanotechnology involves particles which are less than or equal to nanometers (0.1 nm to 100 nm). Researches have shown that the particles which are smaller can react easily and effectively than the same particles which are bigger in size. The nanoscale of the particles can be achieved by, namely, two approaches, one being the top-down approach and second the bottom down approach. Both the approaches have their own advantages and

disadvantages to them. In the top-down approach, the larger particles are made to size down, which may or may not give finer particles. It is also observed that the size distribution is higher in terms of top-down approach. Whereas in the bottom-up approach, the smaller-sized atomic particles are made to size up via self-assembly, which creates difficulty in scaling [12, 13]. There are various methods used in various approaches. For example, in the bottom-up approach, methods like nanolithography, high pressure torsion, accumulative roll bonding, etc. are used. In the top-down approach, methods like spray conversion processing and chemical vapor deposition are used [14]. But either of the methods demands various heavy machinery and toxic chemicals, which take up higher manual labor and energy, which is not environmentally friendly [15]. But, usage of phytochemicals and enzymes present in the plants for the production of the nanoparticles is a greener option, which is environment friendly and economically viable [16].

Concrete as a building material has its demand in the infrastructure sector for a long time. Owing to its attributes such as its versatility, mechanical properties, and availability, concrete has been used at about 20 billion tones as per the per capita consumption globally [17]. Moreover, due to the dynamic nature of the concrete, it is possible for various interventions that can be done to increase the efficiency and performance of the building material. These interventions are required to be environment friendly and economically viable [29,30].

Nanotechnology has been most researched sector for the infrastructure industry to be integrated to increase the efficacy of the same [27,28,34]. Researches have been done by using nanoparticles of  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$ , and  $\text{ZnO}$  as additives for the concrete, and it has been observed that it led to improvement in the packaging [18–20]. The high reactive property of the nanoparticles leads to good efficiency in the pozzolanic reaction. Zinc oxide ( $\text{ZnO}$ ) is a semiconductor which found its way to the solar cells, photocatalysts, chemical sensors, etc. [21]. It has been observed that usage of the  $\text{ZnO}$  nanoparticles in the cement alters and improves the kinetics of the hydration process in its initial stage. Studies conducted by Olmo et al. suggested that by using cement paste consisting of 15% of  $\text{ZnO}$ , the setting time increased, observing that the presence of  $\text{ZnO}$  led to reduction of the compressive strength of the mixture [20]. Arefi and Rezaei-Zarchi observed that by using 5% of  $\text{ZnO}$  in the mixture, the initial stages were more enhanced and improved [22]. It is seen that by using ultramicro  $\text{ZnO}$  nanoparticles, it produces filler effect and also reduces the production of the CH particles by using the  $\text{OH}^-$  ions. Moreover, by using  $\text{ZnO}$  nanoparticles, it slows the process of hydration reaction, and thus, density of the overall structure is improved, and it is more densely packed [20, 23].

Titanium oxide ( $\text{TiO}_2$ ) nanoparticles have also been studied to be used as additives for the concrete. Li et al. observed that by using the  $\text{TiO}_2$  nanoparticles with the concrete, the fatigue performance is increased significantly [24]. When the attribute of abrasion resistance is taken into consideration, it has been seen by Li et al. that the abrasion resistance is directly proportional to the amount of the

nanoparticles added. It has been observed that as the number of nanoparticles used increases, the extent of the abrasion resistance is also increased [25].

Muzenski et al. [30] found that adding a small amount of  $\text{Al}_2\text{O}_3$  nanofibers (0.25 percent by cement weight) increased the strength properties of cement-based composites by about 30%. Yang et al. [31] evaluated the chloride-binding ability of cement specimens after adding a range of nano- $\text{Al}_2\text{O}_3$  concentrations (0.5–5%). The chloride-binding ability of cement increased by 37.2 percent when nano- $\text{Al}_2\text{O}_3$  particles were added at a concentration of 5%, and the researchers concluded that adding the right amount of nanoalumina can enhance the chloride-binding ability of cement. It has also been found that even a 3% incorporation of nanoalumina to mortar can densify the microstructure [32].

This paper is aimed at researching about the usage of alumina and  $\text{TiO}_2$  as additives in the concrete mixture.

*1.1. Mix Proportions.* Various replacements of alumina and  $\text{TiO}_2$  nanoparticles were incorporated in concrete as a partial replacement of cement. Sisal fibers were incorporated in concrete at a constant percentage of 2% as a partial replacement of cement. The usage of nanomaterials beyond 5% minimizes the strength properties of cement; the incorporation of nanoparticles was fixed as 3% and 4%. Table 1 depicts the mix proportions of nanoparticles and sisal fibers incorporated concrete specimens.

## 2. Result and Discussions

*2.1. Experimental Procedure.* Indian standard IS: 516-1959 [24] specifies procedures for examining hardened concrete properties and fresh concrete mix properties. Concrete workability is determined by conducting a slump cone test. In order to determine the hardened concrete properties, split tensile strength and flexural and compressive strength are measured at 7, 28, and 90 days, respectively, after curing in water. A variety of specimen sizes is considered for all tests. An experimental specimen with a size of 150 mm cube sides will undergo compressive strength testing, and another 1-meter long cylindrical specimen with a size of 150 mm and a height of 300 mm will undergo split tensile strength testing.

Specimens measuring 100 mm\*100 mm\*500 mm are used for flexural strength testing. In addition to these tests, the longevity of the concrete is also evaluated. A series of endurance tests is being conducted to test hardened concrete quality to study how it holds up after the hydration process and chemical exposure. These tests include water absorption and sorptivity. In accordance with ASTM C1585-thirteen, a 150 mm dice specimen is tested for sorptivity in order to examine the capillary upward thrust in concrete specimens due to its porous nature. A microwave oven is used to achieve consistent weight after 28 days of wet curing prior to appearance of this check. Furthermore, the concrete aspects are applied with oil to prevent water penetration besides for the lowest surface and are stored in water for 30 min.

The surface of the water bath is dried with an absorbent cloth after 30 minutes and then weighed. Concrete is also

TABLE 1: Mix proportions of concrete specimens.

Mix ID	Cement (kg/m <sup>3</sup> )	Fine aggregate (kg/m <sup>3</sup> )	Coarse aggregate (kg/m <sup>3</sup> )	Water content (kg/m <sup>3</sup> )	TiO <sub>2</sub> nanoparticles (kg/m <sup>3</sup> )	Al <sub>2</sub> O <sub>3</sub> nanoparticles (kg/m <sup>3</sup> )	Sisal fibers (kg/m <sup>3</sup> )
CC	435	672	1179	172	0	0	0
CC-1	413.25	672	1179	172	13.05	0	8.7
CC-2	408.9	672	1179	172	17.4	0	8.7
CC-3	413.25	672	1179	172	0	13.05	8.7
CC-4	408.9	672	1179	172	0	17.4	8.7
CC-5	400.2	672	1179	172	13.05	13.05	8.7
CC-6	391.5	672	1179	172	17.4	17.4	8.7

subjected to a water absorption test to determine its ability to absorb water or other liquids. A 150 mm cube sample after 28 days of curing is stored in a microwave oven until it reaches a constant dry weight before water. The absorption test begins. We weigh the samples every 12 hours until they reach a stable absorbed weight by keeping the cubes in a water bath. By comparing the wet and dry weight of the sample, we can determine the rate of water uptake.

**2.2. Slump Cone Test.** The slump cone test, which is based on the Indian Standard IS: 516-1959 [24], assesses the quality of new concrete.

The workability of all mixtures is determined by a slump cone test. Figure 1 illustrates the slump value based on various mix proportions. We can observe from the test results that a larger proportion of nanoparticles correspond to a higher slump value, indicating a high-quality and practical concrete. Slump was considerably enhanced when sisal fiber, and nanoparticles were added to mixed concrete.

Slump cone results can be viewed as a graphical representation. Slump values gradually grow until CC-6 and conclude that increase in nanoparticles percentage increases the slump value of concrete. Maximum slump values at 4% TiO<sub>2</sub> and 4% Al<sub>2</sub>O<sub>3</sub>, with taking any sisal fibers into consideration. Figure 1 depicts the graphical fluctuation of slump values with and without nanomaterials. Fibrous aggregate performs better than nonfibrous aggregate in concrete mixes. Concrete becomes more workable as the fiber content and nanoparticles rise. The graphical variant illustrates and supports these findings.

**2.3. Compressive Strength.** Using a compression testing machine, cube specimens of 150 mm\*150 mm\*150 mm size are used to measure the compressive strength of concrete. As per the Indian Standard, 250 square specimens were added together to test compressive strength. Tests are conducted after 7, 28, and 90 days of curing. The data shows a significant increase in compressive strength as nanomaterial percentage increases as shown in Figure 2. When 4% Al<sub>2</sub>O<sub>3</sub> is replaced in CC-4 composition of concrete, maximum strength is obtained. Concrete reinforced with fibrous hybrid nanomaterials exhibits similar enhanced strength. Conventional concrete seen a decline in strength. A nanomaterial (TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub>) effectively increases the strength of the material up to a certain percentage. These two examples

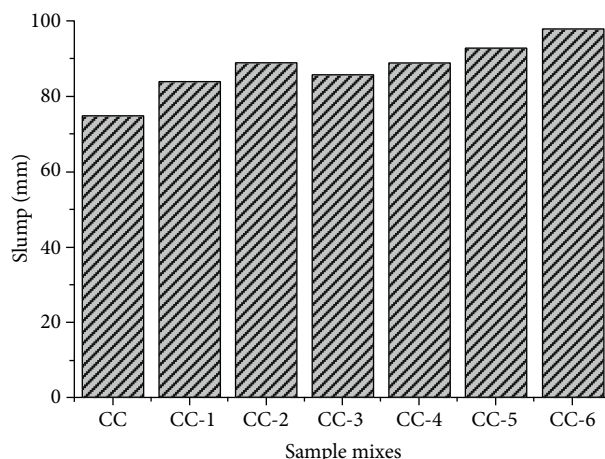


FIGURE 1: Slump values of concrete specimens.

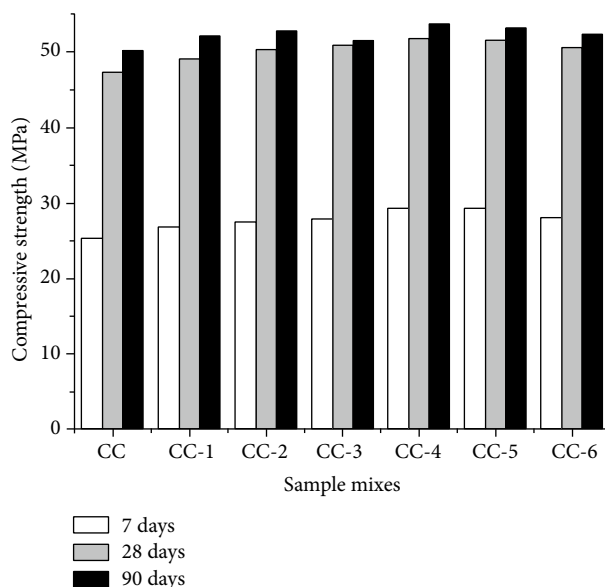


FIGURE 2: Compressive strength of concrete specimens.

compare a variety of mixes to the reference mix of concrete and show the strength variations between them. These nanomaterials have been tested separately and have proven to be as strong as standard concrete when combined by replacing cement with 4%TiO<sub>2</sub> and 4% Al<sub>2</sub>O<sub>3</sub> along with sisal fibers. Our experimental study, however, took into account

different percentages of nanomaterials compared to those that were tested with sisal fibers. Its economic and environmental benefits make it a positive development. A maximum strength of 54.41 MPa can also be achieved.

**2.4. Split Tensile Strength.** Compression testing equipment is used to measure the split tensile strength of concrete using a cylindrical specimen with a length of 300 mm and a diameter of 150 mm.

The tensile strength of cylindrical samples is evaluated according to the Indian Standard. The test is performed after 7, 28, and 90 days of wet curing. The average strength of cylindrical specimens was tested, and the findings are shown in Figure 3. We can see a rise in split tensile strength as the proportion of nanomaterials increases in the data. At all ages, the maximum strength is attained in concrete with a CC-4 composition including 4%  $Al_2O_3$  and sisal fibers.

The rise of nanomaterials over the optimal proportion has resulted in a decrease in strength. The inclusion of nanoparticles ( $TiO_2$  and  $Al_2O_3$ ) enhances the strength of a segment of the material until it reaches a point where it begins to deteriorate. Figure 3 shows the strength differences between various mixtures when compared to a standard concrete mix. According to the graphical fluctuation of test findings, nanomaterials enhance the strength of CC-4 and CC-5 before decreasing somewhat. This reduction in strength is due to a higher proportion of nanomaterial substitution.

CC-4 has a higher strength, reaching 4.94 MPa and 5.11 MPa after 28 and 90 days of curing, respectively. When compared to conventional concrete, CC-4's performance improves due to the addition of sisal fibers to the concrete mix.

**2.5. Flexural Strength.** To evaluate the flexural strength of concrete, a compression machine is utilized to test a specimen of 100 mm\*100 mm\*500 mm. Figure 4 shows that an increase in nanomaterials enhances flexural strength. The greatest strength is attained when 4%  $Al_2O_3$  and sisal fibers are substituted in the CC-4 concrete mix. Sisal fibers and nanomaterial incorporated concrete shows improvement in strength due to microstructure densification. The use of nanomaterials has exceeded the optimal replacement percentage, resulting in a loss of strength. In addition to nanomaterials ( $TiO_2$  and  $Al_2O_3$ ), the strength rises for a short period of time before declining. Figure 4 demonstrates the differences in strength of concrete with and without sisal fibers and nanoparticles. We explored expanding the study to include durability testing after seeing these differences in strength test results.

**2.6. Water Absorption.** Water is absorbed less by nanoparticles as the percentage of nanomaterials rises, according to the results of the experiments. The same tendency may be seen when sisal fiber is included. Water absorption is limited in CC-4 and CC-5 compared to other concrete specimens, indicating that gaps or pores have been minimized, resulting in a more compact concrete. The highest resistance to water absorption is obtained when sisal fibers were coupled with 4%  $Al_2O_3$ . Because of its firm texture, concrete acquires strength and resistance to absorption as it ages. Similar

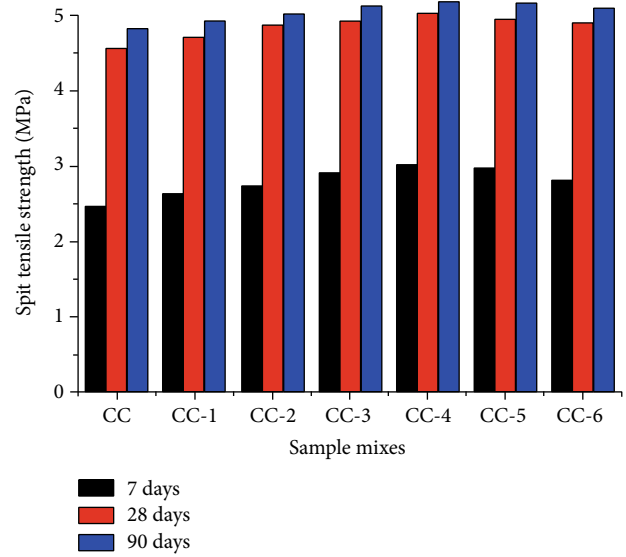


FIGURE 3: Split tensile strength of concrete specimens.

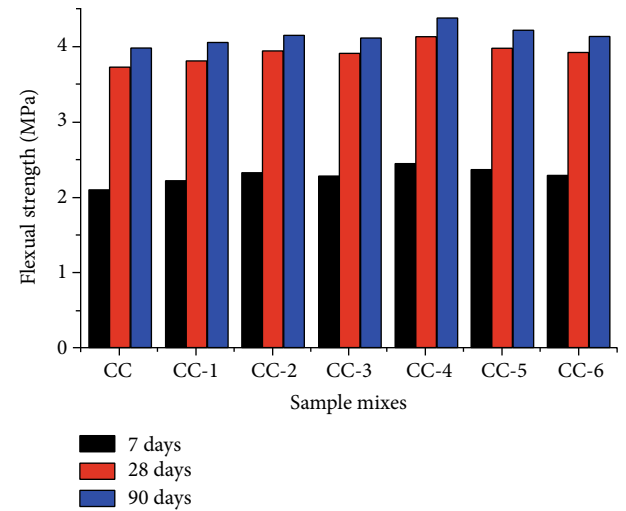


FIGURE 4: Flexural strength of concrete specimens.

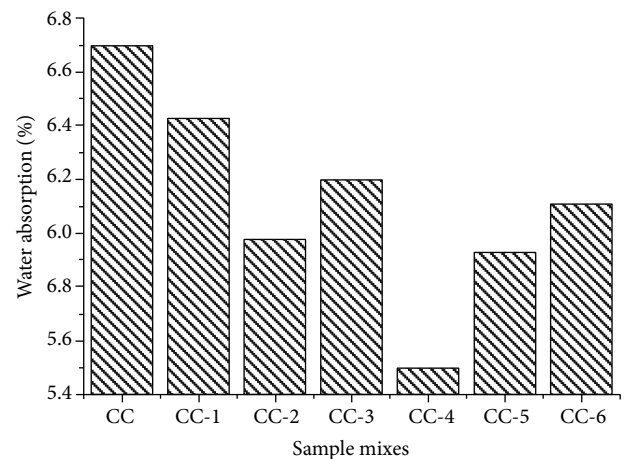


FIGURE 5: Water absorption % of concrete specimens.



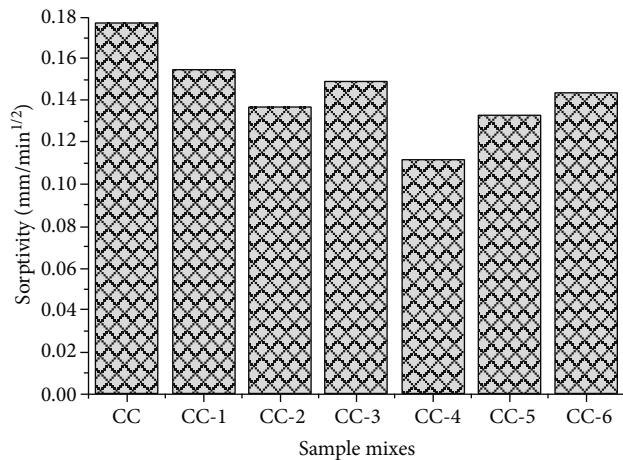


FIGURE 6: Sorptivity of concrete specimens.

resistance characteristics are obtained when sorptivity tests are performed on CC-4 and CC-5.

CC-4, which is composed of 4%  $\text{Al}_2\text{O}_3$  and sisal fibers, exhibits the least movement rate in concrete. The graphical interpretation clearly illustrates these variations. Figures 5 and 6 demonstrate the variation in water absorption and sorptivity, respectively, according to the mix and fiber content.

### 3. Conclusion

The combined influence of alumina oxide, titanium dioxide, and sisal fibers in concrete on fresh, durability, and mechanical qualities is the primary subject of this investigation. Based on the results of the experiment, the following conclusions are formed.

In concrete, nanoparticles such as alumina and titanium dioxide ( $\text{TiO}_2$ ) have increased workability. Slump tests show that the workability of concrete improves up to Mix-4 (4 percent  $\text{Al}_2\text{O}_3$  and 2.5% sisal fibers), which is the highest mix. The incorporation of fibers into concrete also increased its workability, compared to mixes that did not contain fibers. Using  $\text{Al}_2\text{O}_3$ ,  $\text{TiO}_2$ , and fiber decreases internal friction between the various components. As a result, just a slight increase in the fresh concrete qualities can be observed.

In terms of mechanical qualities such as the compressive, split tensile, and flexural strength of concrete, an increase in the use of  $\text{Al}_2\text{O}_3$  and  $\text{TiO}_2$  is noted. CC-4 (4 percent  $\text{Al}_2\text{O}_3$  and sisal fibers) shows an enhancement in the mechanical characteristics of concrete up to that point. To put it another way, the use of  $\text{TiO}_2$  and  $\text{Al}_2\text{O}_3$  in place of cement resulted in a stronger link between the concrete's components. Mechanical qualities of concrete begin to decline after an increase in  $\text{Al}_2\text{O}_3$  and  $\text{TiO}_2$  is observed. Additionally, mixes with fibers (0.6 percent of the cement weight) had higher strengths than mixes without fibers. An improved C-S-H gel formation may result from the addition of nanomaterial fibers to concrete, which makes the concrete denser. According to the findings of mechanical property tests, the optimal use of  $\text{TiO}_2$  and  $\text{Al}_2\text{O}_3$  is found to be 4% and 4% with fibers.

Concrete made with nanoparticles ( $\text{Al}_2\text{O}_3$  and  $\text{TiO}_2$ ) and fibers shows better resistance to degradation in terms of quality when exposed to diverse environmental conditions. Using nanoparticles and fibers in concrete reduces the material's susceptibility to chemical assault and water absorption, according to research. Concrete made with  $\text{Al}_2\text{O}_3$  and tin oxides is more resistant to chemical assault because of the replacement of cement with these materials.

### Data Availability

The data used to support the findings of this study are included within the article.

### Conflicts of Interest

The authors declare that they have no conflicts of interest.

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