Review Article

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Eco-Friendly Concrete Solutions: The Role of Titanium Dioxide Nanoparticles in Enhancing Durability and Reducing Environmental Pollutants - A Review

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ABSTRACT

Concrete is one of the key components of construction, which ensures durability and aesthetics of the building. In recent days, nanoparticles are playing an essential role in civil engineering research. The binding of nanoparticles into concrete significantly improves the mechanical and durable properties due to the nanostructure of the cementitious materials. This review paper represents the existing research data on titanium dioxide nanoparticles, when applied in the different types of concrete. The data influenced by the different research papers are presented in terms of strength and durable parameters. The most important property of titanium dioxide nanoparticle is its self-cleaning effect because of the photocatalytic reaction is also discussed. The inference from the papers shows the effect of titanium dioxide nanoparticles on correct proportion enhances the production of new material with good strength and durable properties in the construction industry. The photocatalytic action of nano titanium dioxide leads to the manufacture of self-cleaning concrete which shields the surface from environmental pollutants.

Keywords: Concrete; Nano titanium dioxide; Photocatalytic effect; Self-cleaning concrete; Durability characteristics.

1. INTRODUCTION

The concrete evolution was started from normal grade and was popular in 1900's for construction process which provides the strength to the buildings (Norhasri *et al.* 2017). However, the emission of CO_2 is having a great impact on the environment. In order to reduce its effect various materials were added as a mineral admixture to cement like silica fume, metakaolin, fly ash and various additional pozzolanic materials in concrete to improve the strength(Oner *et al.* 2005; Güneyisi *et al.* 2012). One such additive which imparts the strength of the concrete is the nanomaterial. Nanotechnology is one of the recent research fields that aid in understanding materials on the order of nanometers, i.e., less than 100nm. There is an excellent opportunity to develop new macro materials and products by utilizing the latest developments in the research and exploitation of materials at the nanoscale (Ganapathy *et al.* 2024; K. Srinivasan *et al.* 2024). However, nanotechnology has seen a variety of advancements and uses in the building and construction material industry(Sanchez *et al.* 2010; Rao *et al.* 2015; Singh *et al.* 2017).

The nanotechnology concept was first presented by Richard Feynman, a Physicist, in 1959, by his talk "There's a plenty of room at the bottom". He explained the idea of employing atoms as a building material to create nanoscale products. This idea leads to the introduction of the word "Nanotechnology" by Norio Taniguchi at the International Conference on Product Engineering. The "top down" approach was introduced by him and it refers to the process of periodically slicing or cutting a bulk material to generate nanoparticles which is shown in Fig. 1. Nowadays, potential opportunities have been created by nanotechnology by its wide applications in various areas including concrete(Raza *et al.* 2023; Samuvel Raj *et al.* 2023).

2. DEVELOPMENT OF NANO CONCRETE

New, marketable products were developed as a result of the commercial application of nanotechnology in concrete. In concrete research, nanotechnology is primarily used in two ways. They are nano engineering and nanoscience. Nanoengineering includes the methods of modifying the nano and micro scale structure of cement-based materials, whereas Nanoscience deals with the examination and evaluation of the structure for the generation of new nanomaterials. It is accomplished by incorporating nano-sized materials (nanoparticles & nanotubes) to add novel properties and govern the characteristics of the substance (Praseeda *et al.* 2022).

Nanoconcrete is a form of concrete that is made of nanoparticles of size not greater than 100 nm. These nanoparticles fill the voids in the concrete which substantially improves the material's strength. The incorporation of these ultrafine particles to cement paste in concrete leads to the potential use of nanotechnology which modifies the properties of materials and performance by minimizing voids. Nanotechnology is also used as a functional coating in buildings and as an architectural application (Pacheco-Torgal *et al.* 2011; Ali *et al.* 2021; Zhu *et al.* 2022).

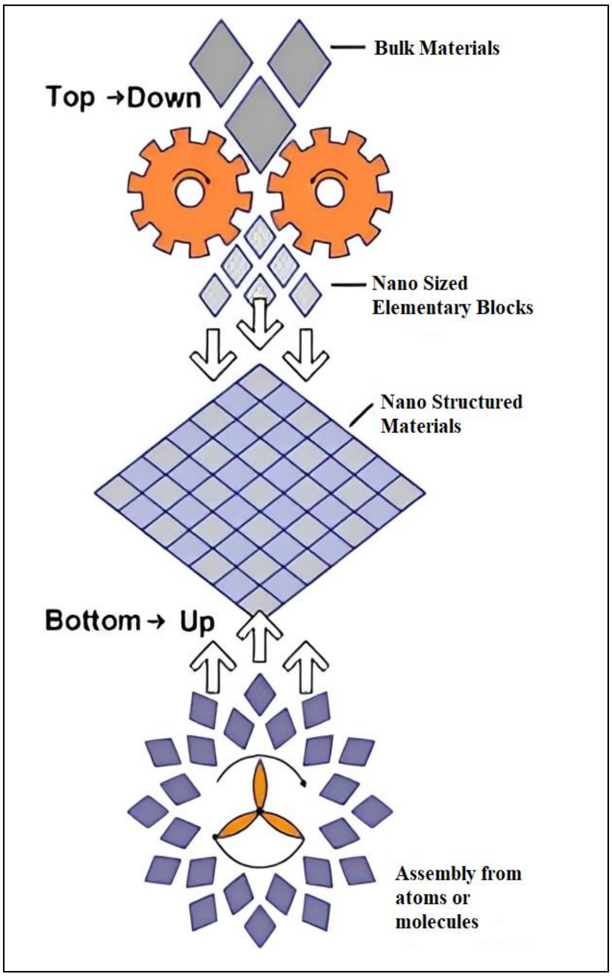

Fig. 1: The Bottom-Up and Top-Down technique in nanotechnology (Sanchez *et al.* 2010)

3. NANOMATERIALS AND CONCRETE

One of the advantages of using nanoparticles is their large volume surface area (P. P. *et al.* 2021), as shown in Fig. 2. In order to provide cement-based materials at the macroscopic level, varieties of nanoparticles have been added to the concrete. These additives lead to the improvement of functions of concrete (Kanagaraj *et al.* 2023).

There were many researches made on the use of various nanomaterials in concrete including nano silica particles (Nano SiO_2), nanoparticles of titanium dioxide (TiO_2), zinc oxide (ZnO), carbon nanotubes, aluminum oxide (Al_2O_3), zirconium oxide (ZrO_2) etc.,(Oltulu et al. 2013). Nano Silica and Carbon Nano Tubes (CNT) helps in increasing the water absorption, sorptivity accelerated corrosion in concrete. The addition of nanomaterial,s helps in the reduction of permeability and porosity characteristics (Ren *et al.* 2018; Thanmanaselvi *et al.* 2023; Kashyap *et al.* 2023; Hwangbo *et al.* 2023). The long-lasting and mechanical properties of the concrete have an adverse impact when modified with nanomaterials (Murad *et al.* 2021).

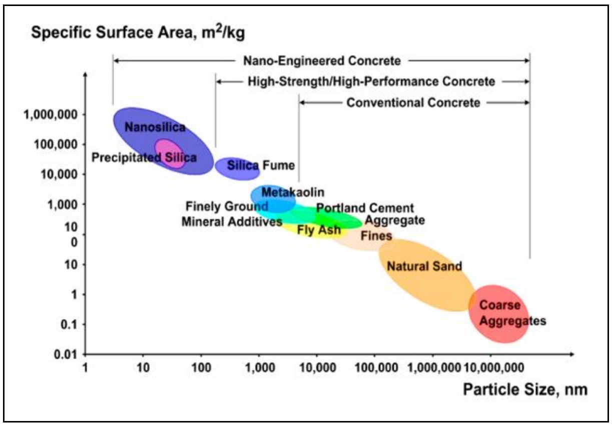

Fig. 2: Specific surface area and particle size related to concrete material (Abhilash *et al.* 2021)

The thermal insulation of the building is effectively increased by the addition of nano materials and thereby the lifetime of the building is also increased (Saleh *et al.* 2021). These nano materials exhibit good mechanical and durable properties under different curing conditions (Pacheco-Torgal *et al.* 2011; Hussien *et al.* 2022). The development of fast crack repairing concrete can be achieved by the application of nanomaterials such as silica, alumina, Fe_2O_3, MgO and $CaCo_3$ at nanoscale (Kumar *et al.* 2018). The wide application of nanomaterial can be done in concrete to study their effects and building elements at different loading conditions.

4. NANO TITANIUM DIOXIDE (TiO_2)

Nano titanium dioxide concrete has attention because of its self-cleaning performance. Titanium dioxide is obtained from the mineral illuminate and it is available in two forms: Rutile (formed at high temperatures of Igneous and Metamorphic rocks) and Anatase (formed at low temperatures and found in minor concentrations of igneous and metamorphic rocks). (Li *et* *al.* 2019). This anatase form of titanium dioxide provides a self-cleaning effect in concrete. Environmental pollutants are removed from the concrete when they are applied on the external surface so that the surface will be cleaned and decrease the air pollution. This photo-catalytic degradation of organic contaminants helps the structure to self-clean itself when exposed to the environment by converting harmful oxides in the air to harmless substances (Li *et al.* 2023). This nanomaterial is not only used in normal conventional concrete but also in other forms of concrete such as geo polymer, fibre reinforced, self-compacting, High Strength and other forms of concrete. (Tufail *et al.* 2022; Kishore *et al.* 2023).

Concrete's mechanical and long-lasting qualities are improved by nano titanium dioxide (TiO_2), also called titanium dioxide nanoparticle. Incorporating nano titanium dioxide makes concrete more cost effective and reduces the emission of CO_2 footprints (Hussien *et al.* 2022). This nanomaterial helps to generate C-S-H gel by hydrating cement at an early age due to its high pozzolanic properties. Fig. 3 illustrates the morphology and SEM image of powdered titanium dioxide nanoparticle.

This review paper covers the reaction of titanium dioxide nanoparticles on fresh and hardened characteristics of concrete as a partial substitution or addition for the cement and also the photo-catalytic effect on the concrete.

5. IMPACT OF NANO TITANIUM DIOXIDE (TiO_2) ON FRESH PROPERTIES OF CONCRETE

The incorporation of titanium dioxide nanoparticles shows different properties in freshly mixed concrete, like setting time, consistency, ease to work etc., (Reshma *et al.* 2021) observed that the workability of concrete rises as nano Titanium dioxide (TiO_2) is added in greater amounts. The combination of ZnO with TiO_2 reduces the internal friction of the material. Many researchers discovered that adding TiO_2 to concrete resulted in a reduction in workability. (Abdalla *et al.* 2022) demonstrated that concrete's workability dropped by 40% with a 1.5 % replacement of TiO_2.

(Nazari *et al.* 2010; Sobhy *et al.* 2022) found that workability decreases with adding nano TiO_2 in optimum percentage. (Hemalatha *et al.* 2021) observed that the workability of concrete in addition of TiO_2 in Self Compacting Geopolymer Concrete increases when the percentage of TiO_2 added rises to 4%. The workability started to decrease for the further addition. The slump value was found to be about 570 mm in diameter with 4% replacement of cement with nano TiO_2 in Self Compacting Geopolymer Concrete. (Chinthakunta *et al.* 2021) found the acceptable range of slump in Self compacting concrete with the influence of nano TiO_2. The 3% replacement of TiO_2 in Self compacting concrete shows a slump value of 610 mm diameter with a combination of 20% and 10% fly ash and silica fume respectively. When 1% nano TiO_2 and 5% poly acrylic acid were added, the slump value was 145mm in comparison with conventional concrete. Nano TiO_2 and nano-silica were added to the concrete to improve its rheological behavior (Senff *et al.* 2012). The initial and final setting time of the concrete was shortened due to the high specific surface area of nano TiO_2 (Daniyal *et al.* 2019). According to (Choi *et al.* 2021a), nano TiO_2 was added to Ultra High Performance Concrete (UHPC) to enhance the material's workability.

Fig. 3: Morphology and SEM image of nano titanium dioxide (He *et al.* 2019)

6. IMPACT OF NANO TITANIUM DIOXIDE (TIO_2) ON HARDENED PROPERTIES OF CONCRETE

6.1 Compressive Strength

The incorporation of nano TiO_2 in concrete has an adverse effect on the hardened properties of concrete. The initial age strength and 28 days strength in compression was found to be high at 1% to 3% replacement of nano Titanium dioxide. (Orakzai *et al.* 2021) reported the combined influence of nano Alumina (Al_2O_3) and titanium dioxide nanoparticles (TiO_2) on concrete's mechanical properties. The findings showed that adding 1% of TiO_2 gave more strength and that adding a mixture of nanoparticles was more advantageous than adding each one separately.(Sun *et al.* 2020) investigated the effect of titanium dioxide nanoparticles of 5 nm and 25 nm of size by 0%, 0.5%, 1%, 1.5%, & 2% by cement's weight. The degree of hydration, hydration products, pore structures and morphologies of cement paste along with compressive strength was researched and it showed that 5nm size of nano titanium dioxide gave more compressive strength when compared to that of 25nm size and also pore refinement was more uniform and dense microstructure was there in cement paste. Thus, the nanoparticle size has an adverse effect on concrete (Li *et al.* 2020).

In comparison to other nanomaterials, the application of nano TiO_2 was primarily focused on enhancing the durability and mechanical qualities of concrete. The compression test was made with concrete replaced by various nanomaterials like ZnO_2, TiO_2, Fe_2O_3 and Al_2O_3 at nanoscale. According to the test results, the 2% replacement of Nano TiO_2 was 22.71% greater than that of regular concrete. The early age rate of hydration and the cement reaction were discussed with the replacement of nano TiO_2. The two different particle size of TiO_2 was replaced with different levels of 5, 7.5 and 10% on cement pastes. There was a change in the rate of cement hydration because of heterogeneous nucleation by the addition of non-reactive nanoscale fillers. Researchers found that the combined effect of nanoparticles shows more strength in concrete than the single nanomaterial. (Reshma *et al.* 2021) influenced the usage of nano ZnO and TiO_2 in concrete along with or without polypropylene fibers. Maximum strength was attained at 4% and 2% of ZnO and TiO_2 respectively when replaced in cement. (Meng *et al.* 2012) highlighted, higher the amount of nano TiO_2, lower the compressive strength of the concrete. (Kumar *et al.* 2018) studied the characteristics of cement using rice husk ash and TiO_2. According to researchers, the concrete with 10% Rice husk ash and 3% titanium dioxide nanoparticles showed higher strength than typical concrete. (Anita Selvasofia *et al.* 2022) observed that adding 2% of TiO_2 to concrete along with nano clay of 3% showed improved performance in concrete's compressive strength. After 60 days, there was about 30% gain in strength.

(Dikkar *et al.* 2021) highlighted that adding 0.5% more cement to the concrete showed higher compressive strength. After 28 days, there was roughly a 30% increase in mechanical strength in comparison with the conventional concrete. (Nazari *et al.* 2010; Ghosal *et al.* 2021) assessed the effect of nano TiO_2 in cement paste and found that adding up to 1% TiO_2 in concrete increased the strength by up to 10% in 90 days. In Geopolymer concrete, (Gopala *et al.* 2021) found that along with the presence of fly ash and 5% nano TiO_2, the compressive strength has increased by almost 54.59%. Researchers concluded that the strength of flyash based geopolymer concrete increases up to 5% when the amount of nano TiO_2 was increased, after then the strength drops (Jumaa *et al.* 2022; Samuvel Raj *et al.* 2023). Nano TiO_2 along with microfibers in geo polymer concrete increased the compressive strength up to 23% with 3% replacement (Raza *et al.* 2023).(Hemalatha *et al.* 2021) observed that the replacement of cement advantageously with 4% nano TiO_2 in Self Compacting Geo polymer concrete comprising wollastonite, fly ash, and Ground Granulated Blast furnace Slag (GGBS) enhances the strength of the concrete up to 8% when compared to Self-compacting Geo polymer concrete. In Pervious concrete, aeration response was enhanced by the addition of titanium dioxide nanoparticles which leads to the improvement in permeability of the concrete (Shen *et al.* 2012). It was found that the drainage facility and control of air pollution can be done during rains by the application of TiO_2 in pervious concrete.

In Fiber Reinforced Concrete (FRC), the implementation of nano titanium dioxide as a new gamma-ray radiation shielding material significantly boosts the strength under compression. According to (Dezhampanah *et al.* 2021) the increase in content of the nano TiO_2 by 0-8% the strength of the concrete was increased due to rapid consumption of calcium hydrate crystals during the hydration process. In the case of Self Consolidating Concrete (Joshaghani *et al.* 2020), incorporation of nanomaterials such as TiO_2, Al2O3 and Fe_2O_3 at nanoscale, the performance of the concrete was increased. High surface area of the nanoparticles develops the hydration process and provides nucleation sites for cement particles. NanoTiO_2 can also be used as viscosity modifying agents along with the fly ash (Ma *et al.* 2016). Rutile based nano TiO_2 improved the compressive strength of the concrete up to 38% in geo polymer concrete with 1.25% replacement (Park *et al.* 2023). The contribution of nano titanium dioxide and nano zinc oxide in High Performance Concrete (HPC) was more according to (Amor *et al.* 2022). The photo catalytic performance of the concrete was improved along with the concrete's strength.

In High Strength Concrete (HSC) 2% replacement of cement with nano TiO_2 showed higher mechanical property and then after with increase in TiO_2 the strength decreased. The comparison of concrete's compressive strength with 1% replacement of TiO_2 is shown in Fig. 4. As the dosage of Titanium dioxide increases in concrete, the compressive strength of the concrete increases. The addition of nano TiO_2 in concrete shows various effects in shielding effect, gamma-ray radiation, impact resistance and ultrasonic pulse velocity. (Dezhampanah *et al.* 2021). The optimization of TiO_2 can be identified based on the size of nano titanium dioxide and the water cement ratio (Li *et al.* 2023). The compressive strength of nano titanium dioxide in various types of concrete is shown in Fig. 5 and its effects are given in Table 1.

6.2 Split Tensile Strength

The application of nanoTiO_2 in concrete exhibits better tensile strength in comparison with ordinary concrete. (Orakzai *et al.* 2021) reported that adding 1% of nano TiO_2 with 0.5% of nano alumina increases the tensile strength up to 34% in comparison with the normal concrete at 28 days. Among different nanomaterials added, the role of nano TiO_2 was good in tensile strength compared to that of other nanomaterials.

The impact of 2% nano TiO_2 in concrete along with the addition of 4% Zinc Oxide and 4% polypropylene fiber exhibited a marked increase in the tensile strength up to 13% and 15%, respectively for 28 and 90 days (Reshma *et al.* 2021).

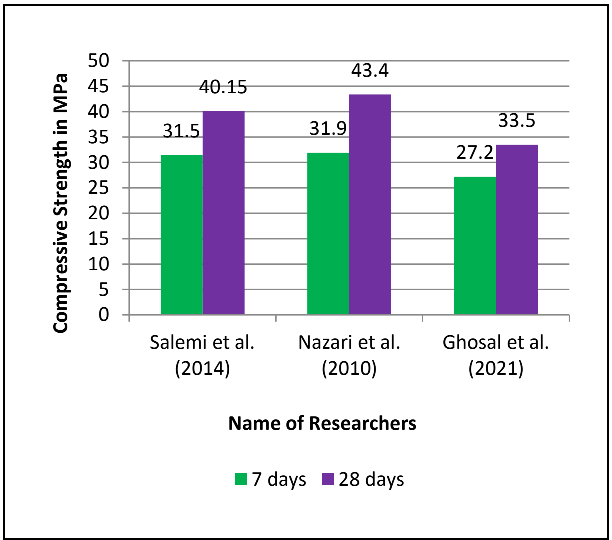

Fig. 4: Compressive Strength with 1% NT in Concrete

Due to the reduction in the voids of concrete by the addition of 3% nano TiO_2 with 10% rice husk ash, the tensile strength increases up to 18% (Praveenkumar *et al.* 2019). According to (Selvasofia *et al.* 2022) the concrete's ultimate tensile strength was improved by 37% at 28 days and 39% at 60 days in comparison with the reference concrete. This strength was obtained by 2% replacement of nano TiO_2 and 3% of nano clay with the cement. In comparison to ordinary concrete, the replacement of 5% nano TiO_2 in geo polymer concrete showed a 22% increase in tensile strength (Gopala *et al.* 2021). The researcher found that adding fly ash, wallanite and 4% nano TiO_2 to the cement in the Self-Compacting Geo polymer Concrete increased its tensile strength by 18% (Hemalatha *et al.* 2021). (Chinthakunta *et al.* 2021) reported that replacing cement with 3% nano TiO_2 and separately adding fly ash and silica fume increased the concrete's splitting tensile strength. However, the strength started to decrease when all the materials (Silica fume, fly ash and nano TiO_2) were added together. The addition of 18nm size nano TiO_2 in self-consolidating concrete produced good tensile strength when compared to regular concrete (Joshaghani *et al.* 2020). The micro-scale analysis of TiO_2 showed an increase in the pore structure of cement mortar which increases the concrete's strength (Shafaei *et al.* 2020). The concrete's tensile strength in the 80:20 aggregate ratio of previous concrete was increased up to 33%. The tensile strength of various concrete comparisons is shown in Fig. 6.

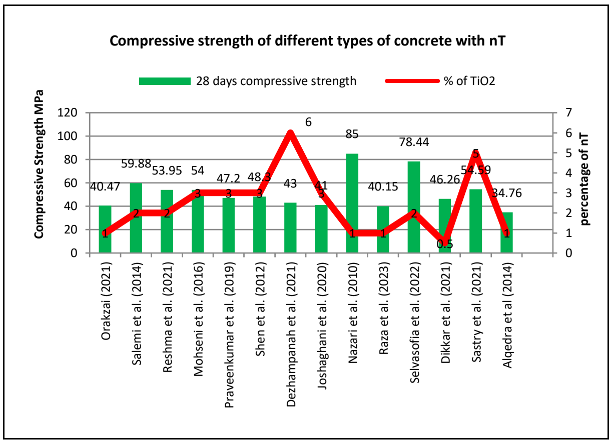

Fig. 5: Compressive Strength with Varying Percentage of NT in Different Forms of Concrete

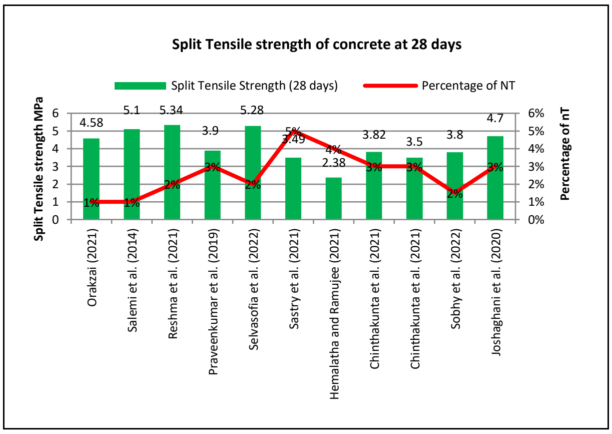

Fig. 6: Splitting tensile strength with varying percentage of NT in different forms of concrete

6.3 Flexural Strength

(Orakzai et al. 2021) highlighted the 1% addition of nano titanium dioxide in concrete along with 0.5% of nano alumina, increased the concrete's flexural strength. In comparison to reference concrete, concrete's flexural strength increased up to 28% after 28 days. According to (Reshma *et al.* 2021) 2% replacement of nano TiO_2 along with 4% Zinc Oxide and polypropylene fiber increased the flexural strength to 3.18, 4.41 and 4.67 MPa at 14, 28 and 90 days respectively. Additionally, they stated that concrete's compressive strength was improved by the nanomaterial's specific surface area. (Kumar *et al.* 2018) observed that concrete's flexural strength in relation to the traditional mix increased by 16% in 14 days and 14% in 28 days. This was done with the incorporation of 3% nano TiO_2 along with 10% RHA (Rice Husk Ash). The addition of RHA in concrete along with nano TiO_2 enhanced the characteristics of concrete that contributed to its increased strength. The concrete's flexural property was studied by (Selvasofia *et al.* 2022) and it was discovered that nano TiO_2 along with the nano clay improved the strength of the concrete. On 2% nano TiO_2 with 3% nano clay in concrete, flexural strength increased by 14% after 60 days of curing.

Table 1. Effect of Nano TiO_2 on compressive strength of various types of concrete

Author	Type of concrete	Remarks
(Orakzai *et al*. 2021)	NT with nano Al_2O_3	Compared to the concrete's M30 grade, the addition of 1% NT with 0.5% Nano Al_2O_3 resulted in a 34% improvement in compressive strength
(Dikkar *et al*. 2021)	NT concrete in pavement	The strength of the concrete on pavement treated with 0.5% NT was 46.26 MPa after 28 days. The strength of the control mix was 35.37 MPa, indicating 30% increase in compressive strength with 0.5% NT
(Selvasofia *et al*. 2022)	NT concrete with nano clay	The concrete's compressive strength measured at 7, 14 and 28 days was 59.53, 78.44 and 81.25 MPa respectively with 2% replacement of Nano TiO_2. However the control mix compressive strength was 46.41, 60.11 and 61.31 MPa at 7 days, 28 days and 60 days respectively. There was an increase of strength up to 31%, with 2% of NT in concrete. Along with 3% of nano clay, there was an increase in the strength of the concrete up to 20% at 60 days.
(Reshma *et al*. 2021)	NT concrete with nano ZnO	Concrete replacement with 4% ZnO and 2% NT along with polypropylene fibers shows an increase in strength of about 14% and 15% at 28 &90 days respectively.
(Abdalla *et al*. 2022)	Geopolymer concrete	The various nanomaterials were used in geopolymer concrete like TiO_2, Fe_2O_3, nano clay and $CaCo_3$ at nanoscale. However, the addition of NT to geopolymer concrete enhances the compressive strength up to 10% when compared to all the other nanomaterials.
(Gopala *et al*. 2021)	Geopolymer concrete	Replacing 5% NT with fly ash in geopolymer concrete increased the compressive strength up to 52% when compared to conventional mix.
(Park *et al*. 2023)	Geopolymer concrete	The concrete strength varies upto 38% when compared with normal concrete with 1.25% replacement.
(Raza *et al*. 2023)	Geopolymer concrete	On 3% replacement of NT, the strength increases upto 23% along with microfibers in concrete
(Hemalatha *et al*. 2021)	Self-compacting concrete	The self-compacting geopolymer concrete exhibited an 8% increase in compressive strength when NT was replaced at 4% with fly ash and either wollastonite or not
(Chinthakunta *et al*. 2021)	Self-compacting concrete	The replacement of 3% NT and 20% fly ash in self-compaction concrete increases the compressive strength up to 19%. The inclusion of 3% TiO_2 and 10% silica fume increase the strength upto 20% at 90 days. The replacement of 3% NT with 10% silica fume and 20 % fly ash in self-compacting concrete increases the concrete compressive strength up to 15% in comparison with conventional concrete.
(Dezhampanah *et al*. 2021)	Fibre Reinforced Concrete	The fiber-reinforced concrete with 6% replacement of NT increased the strength upto 15.5% and then, on further increase in NT the strength decreases.
(Kumar *et al*. 2018)	Pervious concrete	At 2% replacement of NT with an 80:20 aggregate ratio, the concrete's compressive strength raised up to 18% at 28 days.

Table 2. Effect of Nano Titanium dioxide on split tensile strength of concrete

Authors	Type of concrete	Remarks
(Orakzai *et al*. 2021)	NT concrete with nano Al_2O_3	The concrete's splitting tensile strength raised by 34% when nano alumina and NT were substituted at 0.5% and 1%, respectively, compared to the reference mix.
(Reshma *et al*. 2021)	NT concrete with nano ZnO	When 2% NT, 4% ZnO, and 4% Polypropylene Fiber were added, the splitting tensile strength was raised. On 28 days and 90 days, respectively, the strength increases to 13% and 15% more than the reference concrete.
(Kumar *et al*. 2018)	NT concrete with Rice Husk Ash	Incorporating nano titanium dioxide in cement with 3% replacement and Rice Husk Ash with 10% replacement, the tensile strength of the concrete increased to 18% due to the pozzolanic and filler effect of the materials.
(Selvasofia *et al*. 2022)	NT concrete with nanoclay	Adding 2% of NT into concrete increased the tensile strength of 33% at 28 days and up to 41% at 60 days.
(Gopala *et al*. 2021)	NT in Geo polymer concrete	The splitting tensile strength of fly ash-based geopolymer concrete was enhanced by substituting 5% of NT. In comparison to the standard geo polymer concrete, the strength exhibits a 22.2% increase. NT was used in place of fly ash in this concrete.
(Hemalatha *et al*. 2021)	NT in Self-Compacting Geopolymer Concrete	When nano titanium dioxide was added along with fly ash, GGBS, and wollastonite in self-compacting geo polymer concrete, the concrete's tensile strength increased by more than 18% in comparison to the control mix.
(Chinthakunta *et al*. 2021)	NT in Self-Compacting Concrete	The splitting tensile strength of self-compacting concrete rises with the addition of NT. Concrete's strength increased with 3% NT added separately together with fly ash and silica fume. However, the strength dropped when fly ash, silica fume, and 3% NT were mixed together.

Flexural strength in geopolymer concrete was found to be up to 52.3% higher than in the reference mix. (Gopala *et al.* 2021). (Hunashyal *et al.* 2015) found that at 0.5% of nano TiO_2 along with carbon fiber increased the flexural strength. They also suggested that concrete with 0.5% nano TiO_2 shows less deflection than concrete with 0.25% of nano TiO_2. This was because of the crack propagation inhibited by the carbon fiber. (Sobhy *et al.* 2022) suggested that 1.5% replacement of nano TiO_2 in concrete showed an increase in flexural strength when compared to reference concrete. Concrete with 0.75% replacement of nano TiO_2 shows a 15% increase in flexural strength in comparison with reference concrete. However, the flexural strength was more on the addition of nano TiO_2 along with Ground Granulated Blast Furnace Slag (GGBS). The flexural strength of concrete with varying percentages of nano TiO_2 is shown in Fig. 7.

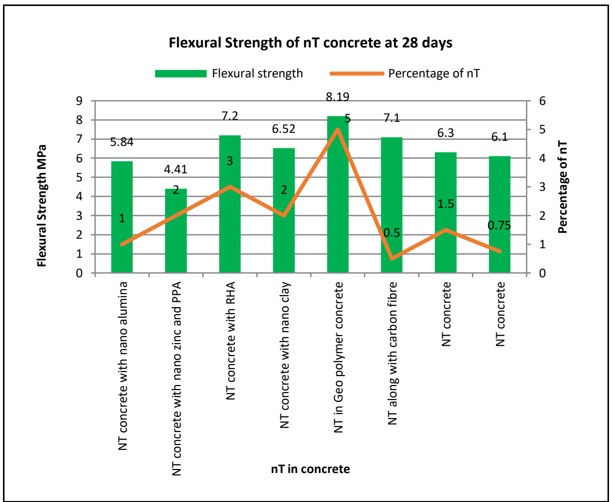

Fig. 7: Flexural strength of different concrete types with varying percentage of NT

7. EFFECT OF NANO TITANIUM DIOXIDE IN DURABLE PARAMETERS

Durability is the ability of the concrete to withstand major deterioration when exposed to the environment. The interaction of nano titanium dioxide in concrete enhances the durable parameters such as infiltration rate, water permeability, water absorption, sorptivity, and penetration of chloride ions, among others. (Orakzai *et al.* 2021) suggested that adding nano TiO_2 to concrete lowers its porosity which improves the materials mechanical properties. Concrete absorbs less water when compared to regular concrete because of the small size of pores due to the nanomaterials. Nano Titanium dioxide on addition with 4% Zinc Oxide and Poly propylene fiber showed good durable performance in water absorbance and sorptivity test. The addition of fibers along with nano TiO_2 increased not only pore structure but also arrested the crack formation which brings long term efficiency of the concrete (Reshma *et al.* 2021). (Kumar *et al.* 2018) discussed the addition of nano TiO_2 in concrete reduced the rate of chloride ion penetration due to pozzolanic actions. They also suggested that when exposed to hydrochloric acid, the concrete with nano TiO_2 showed good resistance to deterioration. (Sun *et al.* 2020) observed that the use of nano TiO_2 improved the concrete's pore structure. The result obtained by (Gopala *et al.* 2021) showed that 5% nano TiO_2 to geopolymer concrete decreased water absorption and sorptivity values in comparison to regular concrete. The reduction in infiltration rate in pervious concrete showed that the influence of nano TiO_2 enhances the durable properties (Shen *et al.* 2012). In Self-Compacting concrete, (Chinthakunta *et al.* 2021) reported that 3% replacement of cement with nano TiO_2 showed more water absorption resistance at 72 hours. Thus, the application of Nano Titanium dioxide showed good durable properties in self-compacting concrete (Nazari *et al.* 2010; Shafaei *et al.* 2020). The water absorption was reduced by 1.5% replacement of cement by nano TiO_2 when compared to the other nanomaterials.

8. PHOTO CATALYTIC EFFECT OF NANO TITANIUM DIOXIDE IN CONCRETE

One of the key characteristics of nano titanium dioxide is its photocatalytic activity. Nano titanium dioxide can be added to concrete to enhance its self-cleaning and air-purifying properties(de Andrade *et al.* 2015). The role of nano TiO_2 provides a sheltering effect because of early age carbonation, which affects the hydration process (Fujishima *et al.* 2008; Satyanarayana *et al.* 2021; Liu *et al.* 2022).

The process of photocatalysis involves the transition of electrons in titanium dioxide crystals from the valence band to the conduction band upon exposure to light radiation. As a result, negative charge (e-) forms in the conduction band while positive charge (h+) forms in the valence band. Thus, the formation of electron-hole pairs, which results in a redox reaction on the surfaces, produces the photocatalytic effect (Kumar *et al.* 2018; Moradi *et al.* 2020). Fig 8. Illustrates the principle of the photocatalysis effect.

8.1 Self-Cleaning Effect

Self-Cleaning's impact on Nano Titanium dioxide is done by these redox reactions triggered on the surfaces by the UV light (Folli *et al.* 2010; Tung *et al.* 2011; Wang *et al.* 2022). The band energy of concrete was raised by the addition of nano titanium dioxide, which also provides a stronger sheltering effect and increases the solid volume. (Lucas *et al.* 2013) reported the use of Fe^{3+} doped TiO_2 powder increased the efficiency of semiconductor photocatalyst. At 4% of nano TiO_2 both in normal and ion doped titanium dioxide the photocatalytic activity was increased. The carbon doped TiO_2 was produced by (Ren *et al.* 2018) also showed good photo catalytic effect. The researchers found that the formation of $CaTiO_3$ based on the dispersion of nano TiO_2 enhanced the photocatalytic effect (Bost *et al.* 2016). Because of its self-cleaning performance nano TiO_2 can be used in pavements which removes the air pollutants and dust on the surface (Shen *et al.* 2012; Liang *et al.* 2019; Wang *et al.* 2020). Nano TiO_2 with 1% replacement along with aerial lime and gypsum binder showed good photocatalytic efficiency (Lucas *et al.* 2013). The photo-induced hydrophilicity is shown in Fig. 9. (Sikora *et al.* 2015; Amor *et al.* 2022) highlighted the photocatalytic activity of nano TiO_2 in High Performance Concrete. This was discovered by observing how the dye that had been placed on the concrete's surface decoloured in the presence of sunshine (Khataee *et al.* 2013). TiO_2 is a prevalent photocatalytic degrader of organic pollutants for post-treatment separation in slurry systems. Thus, Nano titanium dioxide has wide applications in the construction industry (Haider *et al.* 2019).

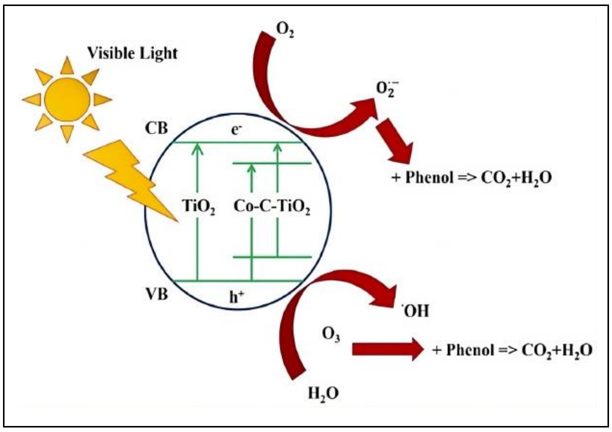

Fig. 8: Photo Catalytic Effect of Tio₂

8.2 Air Purifying Effect

The alteration in air quality is occurring substantially nowadays because of the development of industrial and social activities. (Diamanti *et al.* 2013) found that there was a mutual interaction between carbonation and photo activity. The NOx and COx degradation by TiO2 converts the harmful gases into harmless gases (Hüsken *et al.* 2009; Seo *et al.* 2017). The harmful NOx oxide removal from the air was studied by (Park *et al.* 2023). The researchers highlighted that the addition of nano TiO2 in concrete converts the harmful effect of NOx into harmless. (Ballari *et al.* 2010) found the degradation of Nitric Oxide in concrete pavement by the addition of nano titanium dioxide. In Ultra High Performance Concrete (UPHC) with 75% of Anatase based TiO2 showed good NOx removal rate (Choi *et al.* 2021b). (Chen *et al.* 2021) reported the effect of photocatalytic activity of N-doped TiO2 on the pavement which purifies the vehicle emission. Along with polyethylene fiber, nano TiO2 developed a good photocatalytic effect. The conceptual NOx removal by TiO2 is shown in Fig. 9. A TiO2@CoAl-LDH nanosphere composite was produced by (Li *et al.* 2023), and it was found that not only cement hydration is enhanced but also the photocatalytic property was superior.

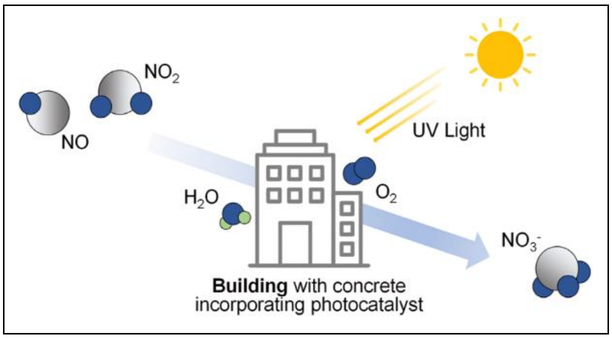

Fig. 9: Conceptual diagram of NO_x removal

8.3 Anti-Microbial Effect

Nano Titanium dioxide (TiO_2) also induces an anti-microbial effect in concrete. The effect of nano titanium dioxide by inhibition of microorganisms was investigated by (Li *et al.* 2019) and it was found that the inhibition and inactivation rates were up to 61% and 80% for 2.32 nano TiO_2 and 37% and 35% for 3.88 nano TiO_2. The influence of TiO_2 on anti-bacterial behavior based on Escherichia coli (E.Coli) was studied by (Hamdany *et al.* 2021; Liu *et al.* 2022) showed that the viable bacteria activated the nano TiO_2 particles induced the photocatalytic effect. Nano TiO_2 generates reactive oxygen species (Folli *et al.* 2010) which alters the metabolism and causes liquid peroxidation reaction. The incorporation of titanium dioxide nanoparticle elevates the bacterial activity, which is responsible for the photo-oxidation (Yeung *et al.* 2009; Zhao *et al.* 2018). Nano TiO_2 was also used as bio-composite reinforcement (Shaili *et al.* 2015) and as nanotubes (Podporska-Carroll *et al.* 2015) for biological investigations.

9. CONCLUSION

The conclusions summarized from the above research papers are listed below

- Nano titanium dioxide has a substantial effect on concrete because of its large specific surface area, which increases the hydration of the cement.

- Studies in the literature have shown that the pozzolanic activity of 1% to 3% nano TiO_2 in concrete results in good mechanical and lasting qualities.

- It was found that more nano TiO_2 lowers the concrete's properties. Nano TiO_2 in concrete showed improvement in microstructure due to their filler effect and uniform dispersion.

- The photocatalytic effect of nano TiO_2 in concrete helps in the removal of air pollutants from the surface, which improves the self-cleaning effect and also purifies the air. The filling effect of the cementitious material is enhanced by Nano Titanium dioxide's antimicrobial properties.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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