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A Non-linear analysis of Wall Putty and ConcreteCubes for Self-Cleaning usingTitanium Dioxide

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Abstract:
Concrete is the most common construction materials for building construction. However, in urban region the surface of concrete is contaminated due to air pollution. Self-cleaning construction materials have the ability to clean themselves by breaking down and removing dirt, pollutants, and other contaminants without the need for human intervention. Photocatalytic materials such as titania (TiO2) and zinc oxide (ZnOgenerally possess self- cleaning properties in it and is introduced in this study. This paper reviews the Non-linear analysis ofTitania and Zinc oxide on concrete and wall putty. The optimum dosage of Titania is investigated and the its periodic absorption is noticed to check the removal of dirt from the surface of concrete. The same principle is applied on wall putty panel. The results of the study showed that TiO2 can be used upto 10%. Increase in dosage decreased the tensile strength of finished putty layer.

Keywords: Wall putty, photocatalysis, Titanium di-oxide, Zinc oxide.

Introduction

Self-Cleaning Concrete is a remarkable building material that not only remains clean but also purifies the air by removing pollutants. This is achieved through the use of photo-catalytic components that utilize UV light energy to oxidize both organic and inorganic substances. This unique feature enables the concrete to eliminate air contaminants that would typically discolor exposed surfaces due to environmental factors, with the remnants being rinse away by rain. This innovative material helps to produce cost-effective concrete and plaster products that require minimal maintenance while being environmentally friendly. The catalysts present in the concrete, typically titanium oxides, use the energy generated by light and heat on its surface to break the dirt into smaller molecules such as oxygen, water, carbon dioxide, nitrates, and sulphates. After which the gaseous pollutants are released into the atmosphere, while any liquid or solid pollutants remaining on the surface are washed away by rain. Additionally, the concrete can also break down the pollutants present in the air around it, reacting with them in the same way as they would on its surface.

It has been observed that in the process of self-cleaning in concrete, the solid and liquid pollutantsthat are not effectively removed are washed away by rainfall, posing a risk of contamination to groundwater, rivers, and lakes if left unaddressed. For instance, nitrates carried into rivers can trigger harmful algae blooms, leading to a decrease in oxygen levels in the water. Clearly, as self-cleaning concrete gains wider acceptance, proactive measures must be taken to prevent runoff from adversely affecting aquatic ecosystems. Nonetheless, considering the numerous advantages of self-cleaning concrete, it warrants thorough investigation for extensive future utilization. The photocatalytic mechanism not only maintains the appearance of the concrete but also contributes to purifying the surrounding air, promoting safety and cleanliness. With innovative solutions to mitigate potential risks, self-cleaning concrete is poised to become a fundamental component in construction projects.

When exposed to UV light, photocatalytic titanium dioxide becomes activated and enhances the breakdown of organic particles and airborne pollutants, such as nitrous oxide (NOx). When incorporated into concrete structures, these photocatalysts facilitate the decomposition of various organic substances that accumulate on surfaces. These substances encompass dirt (like soot, grime, oil, and particulates), biological organisms (such as mold, algae, bacteria, and allergens), airborne pollutants (including VOCs like formaldehyde and benzene, tobacco smoke, as well as nitrous oxides (NOx) and sulfur oxides (SOx) which contribute to smog), and even odor-causing chemicals. The catalytic process breaks down these compounds to benefit the environment or have a relatively harmless impact on it. The resulting products from the catalytic reaction are easily removable from the treated surface because the surface becomes hydrophilic and the surface is eliminated by rinsing or during rainfall.

Literature Review

Jay Sorathiya, Dr. Siddharth Shah, and Mr. Smit Kacha, (2017) in their work replaced cement with0.5 %, 0.75%, 1%, 1.25%, and 1.5% of Titanium Dioxide (TiO_2). The average particle size was considered as 15 nm. The compressive strength increased as the percentage of TiO_2 was increased till 1% and thereafter started to decrease. Also, the workability decreased with increase in the addition of TiO_2.

Nazari et al., (2011) in their research focused on the effect of incorporating limewater for curing concrete added with TiO_2 by partially replacing 0.5, 1.0, 1.5, and 2.0 weight per cent of cement.Results indicated that concrete with nano-TiO2 exhibited higher flexural strength compared to conventional concrete. Notably, the most effective replacement percentage for nano-TiO2 was determined to be 1% over curing periods of 7, 28, and 90 days. Additionally, experimental findings revealed a significant reduction in the rate and overall amount of water absorption in concrete with TiO2 nanoparticles at all stages.

According to Konstantin Sobolev (2016), nanotechnology offers promising avenues for enhancing the performance of cement-based materials. To achieve better slump,Polycarboxylic Ether (PCE) was utilized and it proved higher strengths. Nano silica has demonstrated the ability to enhance workability by resisting segregation within the cement matrix. Moreover, increased density and pore filling contribute to reduced permeability and enhanced durability against environmental degradation factors like acid/sulfate attack or corrosion in reinforced concrete structures. Additionally, the incorporation of nano-TiO2 particles introduces novel characteristics such as self-cleaning properties, attributed to its photocatalytic nature.

Methodology

Natural source of sun is utilized in the self-cleaning process of concrete surface in this study. In the concept of photocatalysis, light energy (from the sun or an electrical light source) is transferred into chemical energy, which is then transferred to water vapour and transformed into active oxygen species at the surface is applied.The presence of light energises a photocatalyst coating. The photocatalyst's excitation initiates a series of reactions on the coated surface.When exposed to light, the photocatalyst coating undergoes a transformation, leading to air purification and self-cleaning properties. These coatings are transparent and specifically engineered for a diverse range of common surfaces encountered in everyday life. The key component, titanium dioxide, remains insoluble in water and is a widely recognized safe substance utilized in various cosmetics and food additives. Self-cleaning concrete uses the process of photocatalysis where energy from sun to vaporize dirt. Also,the air surrounding the photocatalyzed concrete exhibited an 80% reduction in nitrous oxide, indicating that the concrete also functions to purify the air. Figure 1 explains the method adopted in the process of self-cleaning of concrete and wall putty.

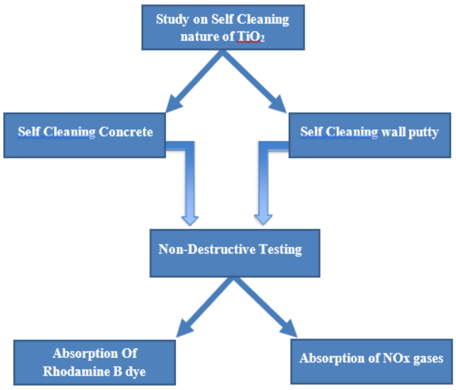
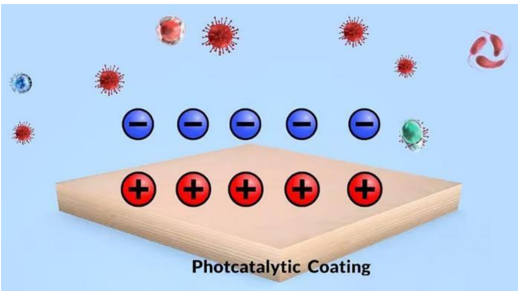


Figure1. Methodology adopted in the development of self-cleaning concrete and wall putty

Experimental Investigation

Mechanism of photocatalysis:

During photocatalysis, titanium dioxide when exposed to light energy from the sun or fluorescent lighting, generates a powerful decomposition effect on its coated surface. Leveraging its properties, microorganisms and viruses undergo continuous decomposition until rendered harmless. The effects of photocatalysis are nearly permanent. Upon light exposure to the surface of titanium dioxide, electrons are released.



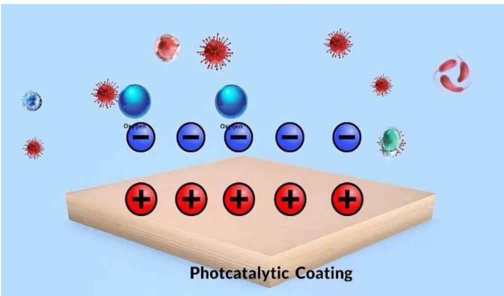
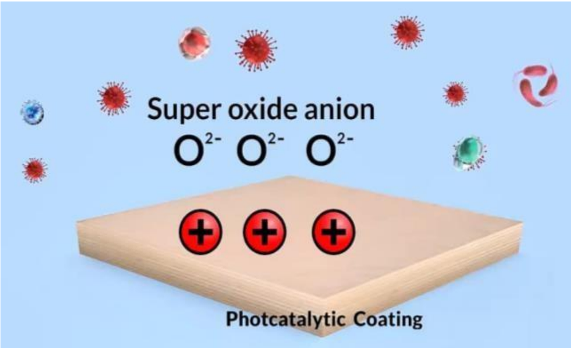


Figure 2. Photocatalysis Step 1 **Figure 3.** Photocatalysis Step 2

The released electrons bind with oxygen to become superoxide and ion as shown in Figure 2 and 3



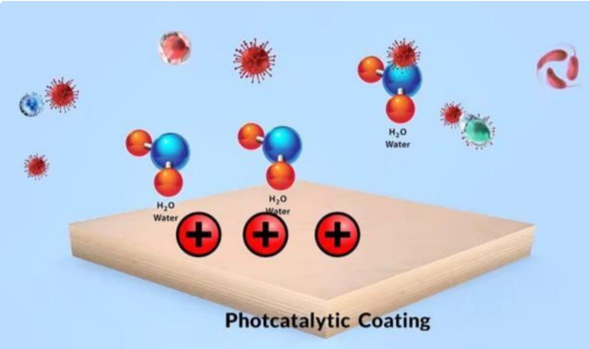
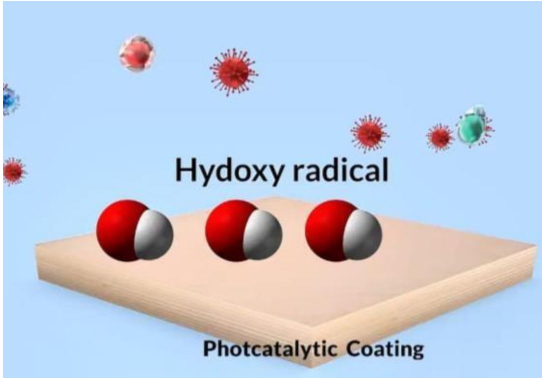


Figure 4. Photocatalysis Step 3

Figure 5. Photocatalysis Step 4

The titanium oxide takes electrons from the moisture in the air and they become positively charged as shown in Figure 4 and Figure 5



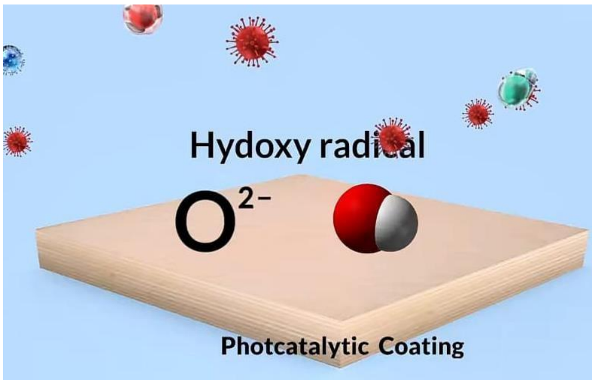


Figure 6. Photocatalysis Step 5

Figure 7. Photocatalysis Step 6

The moisture in the air becomes hydroxyl radical as they lose electrons as shown in Figure 6 and 7

The hydroxyl radical is commonly termed the "detergent of the troposphere" due to its ability to react with numerous pollutants, breaking them down through a process called cracking. It often serves as the initial step in their removal. Both the superoxide anion and hydroxyl radicals possess potent oxidative capabilities, facilitating the decomposition of organic compounds such as Covid-19, bacteria, debris, fungus, salmonella, and unpleasant odors. This breakdown process converts these substances into water or other harmless compounds, dispersing them into the atmosphere.as shown below in Figure 8 and Figure 9

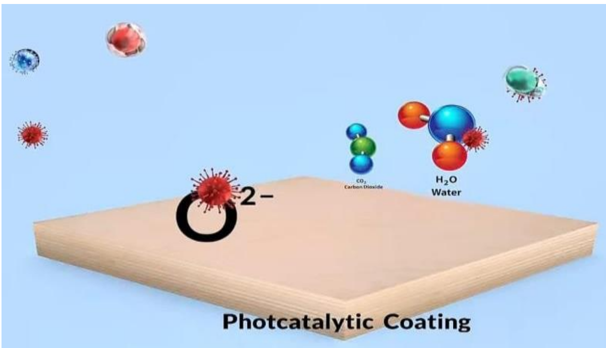


Figure 8. Photocatalysis Step 7

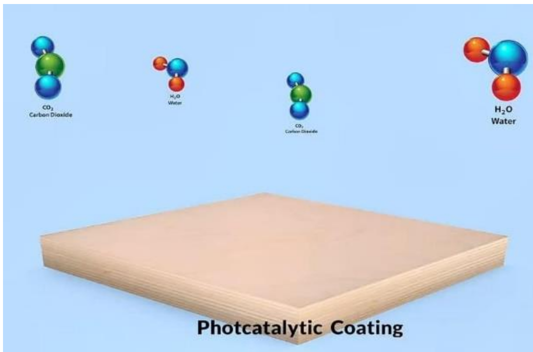


Figure 9. Photocatalysis Step 8

Process of Photo-catalysis in concrete

The process of self-cleaning takes place as follows: when the surface of the concrete is hit by light and heat, the catalysts, titanium di-oxide using the energy breaks the dirt into oxygen, water, carbon dioxide, nitrate and sulfate molecules. The form of gases floats off the surface of concrete and the solid and liquid particles are rinsed off during rain. The same process is deployed to purify the surrounding air around the concrete.

Concrete has evolved significantly in recent decades, introducing innovative features such as self-cleaning abilities, which maintains light colour on the surfaces over time, and the capacity to eliminate airborne toxins, notably nitrogen oxides. These reactions are triggered when the catalytic material within concrete is stimulated by sunlight or artificial light possessing similar properties, such as ultraviolet li

Decomposition of organic materials is enhanced by strong sunlight, but it happens at slower pace, whereas the process gets accelerated by the use of photocatalysts. Also, the chemical transformation is stimulated without being consumed by the reaction. The efficiency of the photocatalyst is increased when it comes in contact with sunlight, so they must be present on the surface of the material.

When incorporated into concrete, these additives break down organic substances such as oil and silt, biological elements like mold, algae, and bacteria, as well as pollutants including volatile organic compounds and tobacco smoke. This decomposition yields molecules such as oxygen, water, carbon dioxide, nitrates, and sulfates, resulting in a notable decrease in pollutant concentrations. The efficacy of self-cleaning in concrete is contingent upon the titanium dioxide (TiO_2) content within the cement. Research findings indicate that higher TiO_2 concentrations in cement enhance the self-cleaning capabilities.

Experimental investigation

Properties of material:

Cement:

Cement of grade 53 grade was used for preparation of concrete specimen. Table 1, provides the properties of cement used in the study.

Table 1. Properties of cement

Sl.No	PropertyValue	Value
1	SpecificGravity	3.15
2	InitialSettingtime	40min
3	FinalSettingTime	450Min
4	StandardConsistency	30%

FineAggregate

The quality of concrete is ensured when sand consisting of rounded grains are used rather than angular grains.In this study, manufactured sand has been used as fine aggregate.The propertiesof M-sand are given in Table 2 below.

Table 2. Properties of M-sand

Sl.No	Properties	M-Sand
1	Specific Gravity	2.84
2	Fineness modulus	2.8
3	Water Absorption	5.4 %

Coarse aggregate:

Coarse aggregates are categorized based on availability such as smooth or rounded if procured as river gravel and angular if bought as crushed stone. The properties of coarse aggregate are given in table 3.

Table 3. Properties of Coarse aggregates

Sl.No.	Properties	Coarse aggregate
1	Specific Gravity	2.88
2	Impact value	26
3	Water Absorption	0.5%

Titanium dioxide

Titanium dioxide, also referred to as titanium oxide or titania, is a chemical compound with the chemical formula TiO2, occurring naturally as the oxide of titanium. Its photocatalytic activity, another characteristic of TiO2, is significantly enhanced due to the high surface-to-volume ratio of nanoparticles compared to micro particles. In this investigation, cement is substituted with 3%, 4%, and 5% of titanium dioxide and subsequently analyzed.

Rhodamine B Dye

Rhodamine is a versatile chemical compound known both for its dye properties and its applications in various fields. Frequently employed as a tracer dye in water, it helps ascertain the speed and path of flow and transport. Rhodamine dyes exhibit fluorescence, allowing for straightforward and cost-effective detection using instruments known as fluorometers.

Preparation of specimen

The ingredients for the self-cleaning concrete specimen are cement, fine aggregates, coarse aggregates, and commercial Titanium dioxide powder. For the preparation of specimen, volumetric batching was found to be unreliable therefore weigh batching method was followed. Each ingredient was accurately weighed and batched. he specimen was designed to a grade of M25. Therefore, it has a ratio of 1:1:2 (Cement: M Sand or fine aggregates: Gravel or coarse aggregates).

The casted specimen had a weight of 7206 grams, so let us assume the overall weight of the specimen to be 7200 g.

The proportion of materials by replacing 4% of cement by titania is given in table 4.

Table 4. Proportioning of materials

Weight of Cement	1728 g (1 part)
Weight of TiO2	72 g (4% of 1800 g)
Weight of Fine Aggregates	1800 g (1 part)
Weight of Coarse Aggregates	3600 g (2 parts)
Total weight of Specimen	7200 g

With the above quantity of materials and water-cement ratio of 0.23, concrete cubes were casted and cured.

Testing of concrete specimen

This study focus on the experimental results based on the tests for compressive strength for the partial replacement of cement by titanium dioxide in M25 grade of concrete. The compressive strength of the cubes after replacing the cement by 3% and 4% and 5% were tested after 28 days. With the increase of concentration of Titanium dioxide in concrete the strength of the concrete decreases. This is because TiO2 replaces the volume of cement in the concentrations of 3%,4% and 5% of the volume of cement from the previous researches. Table 5 gives the results of compressive strength of concrete on 7th, 14th and 28th day and the results have been compared in figure 11.

Table 5. Compressive strength of concrete on 7th, 14th and 28th day

S.NO	% Of TiO2	7 days	14days	28days
1	3	25.04	28.88	32.6
2	4	22.64	26.66	30.1
3	5	19.82	21.93	27

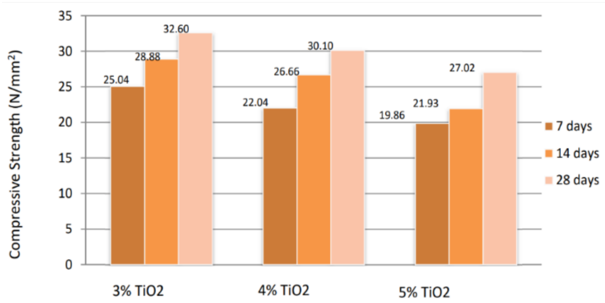


Figure 11. Comparison of compressive strength

RhodamineBDyeDecolourizationTestOnSelf-CleaningConcrete

The process of self-cleaning of concrete was tested by the use of Rhodamine B dye. In this test, concrete cubes prepared with TiO_2 photocatalyst was applied with 5 ml of Rhodamine B dye and placed under sunlight. The decolourization of the cementitious material was observed and iven below for zero hours, two hours and after five hours.

Figure 11. Decolourization of dye at zero hour

Zero hour

One teaspoon or 5 ml of Rhodamine B Dye was applied on the surface of the proposed Self- cleaning concrete to analyse its photocatalytic activity of TiO2

	
 **Figure 12.** Decolourization of dye after two hours	**After two hours** Decolourization of the dye was visually observed after two hours. The titanium di-oxide slowly cleans the surface.
 **Figure 13.** Decolourization of dye after five hours	**Five hours** After 5 hours almost the concrete surface was cleaned and reverting to its natural colour indicating the self-cleaning process taking place on the concrete surface.

Photocatalytic Performance

In the current study, light absorption measurements were acquired by reflecting light off the surface of the cement where the dye was applied. This method yields diffuse reflectance spectra, as demonstrated in Figure 11, Figure 12, and Figure 13.

Photocatalytic activity analysis on wall putty due to TiO2 by RH dye:

Two different samples were made of roughly 1.5 to 2 feet were made on a gypsum board to indicate realistic plain surfaces such as brick work and concrete surfaces. The samples were prepared in such a way that each board represents the percentage of TiO2.

TiO2 was used to replace white wall putty to a percentage of 5% and 10% respectively of the total putty volume / weight. Here higher percentage of titanium dioxide was used in order to increase the efficiency of the photocatalytic self cleaning activity, since the thickness of the finishing putty is minimal also because both TiO2 and wall putty are of same colours and compositions like grain size they would blend easily to form a uniform mixture

1 teaspoon or 5ml of RHODAMINE B DYE was introduced on to the surface of the wall putty boards (5% and 10%) respectively and their photocatalytic discoloration test was observed. The Figure 14 below indicates the nature of the boards at the time of introduction of RH dye.

Figure 14. Application of Rhodomine dye on wall putty specimen

Figure 15. Observation of wall putty specimen after 8 hours.

The above Figure 15 indicates photocatalytic discoloration of RH dye due to the action of TiO2 photocatalysis within a time frame of 8 hours. This test is a quantitative inspection or visual test of TiO2 photocatalytic activity.

Rhodamine B Dye Decolourization Test On Traditional Concrete

To check the process of this study, rhodomine dye was applied on conventional concrete surface and similar observation was made after seven hours.

Figure 16: RH B Dye- Zero Hour-Traditional Concrete

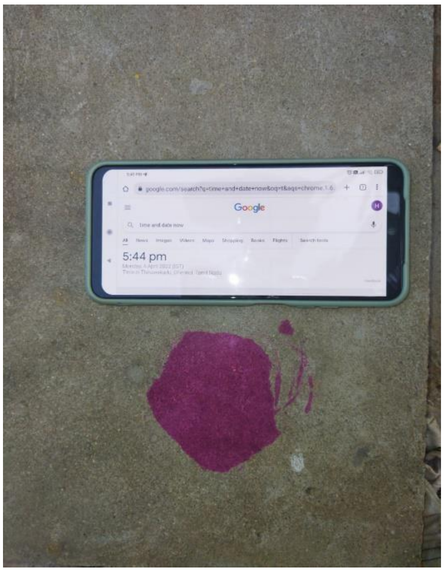


Figure 17: RH B Dye- Seven Hour-Traditional Concrete

When the traditional concrete surface was tested by introducing a texile dye-Rhodamine B. Even after 7 hours of introducing the RH dye no changes were recorded visually. Hence a traditional concrete does not possess a photo catalytic nature. It can be inferred that our specimens both concrete (4% of Ti02) and wall putty (5% and 10% of TiO2). This test is a quantitative test which produces quantitative results that cannot be measured or quantified up to the mark. A quantitative result cannot be expected by doing a RH dye discolouration test.

Out of the two wall putty specimens (5% and 10% of TiO2) the one with 10 percentage TiO2 showed slightly better self-cleaning results from the visual inspection. But using higher percentage of TiO2, that is >10% of mass of wall putty the tensile strength of the finishing putty layer decreases drastically.

Conclusion

- The obtained results from the visual experimentations, like the decolorization of Rhodamine B Dye and NOx gas conversion, give a clear understanding on qualitative understanding of how effective is the self- cleaning activity of TiO2.
- The Rhodamine B Dye discoloration test on self-cleaning concrete showed the vanishing of the dye, 5 hours after application.
- The Rhodamine B Dye discoloration test on self-cleaning wall putty surface showed the vanishing of the dye, 8 hours after application. The proportion of TiO2 used here was 5% and 10% of the weight of wall putty powder. The tile consisting of 10% of TiO2 showed better self-cleaning activity.
- The specimen with 10% of TiO2 showed no loss in cementitious strength, hence that proportion was chosen for the proposed model and test specimen cube (2” cube specimen).

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