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EXPERIMENTAL STUDIES ON SELF-CLEANING CONCRETE BY PHOTOCATALYTIC ACTIVITY FOR RIGID PAVEMENTS

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ABSTRACT

The environmental sustainability and sustainability of materials worldwide is the most concerning topic in the selection process of materials for construction. Self-Cleaning Concrete (SCC) consists of self-cleaning qualities and it is an environmentally friendly material. The main advantage of this new, modern composite helps in reducing maintenance costs along with a clean environment. This modern concrete removes dust and pollutants under UV rays of sunlight by photocatalytic action. In this study, M_{40} grade concrete was prepared conventionally and by the addition of Titanium dioxide (TiO_2). TiO_2 is added to concrete in amounts ranging from 0.5%, 1.0%, and 1.5% of the weight of cement. The compressive strength and flexural strength of concrete specimens of size 150mm X150mm X 150mm and 100mm X 100mm X 500mm respectively. Then the specimens were cured and tested for 7 and 28 days. The self-cleaning ability of SCC is investigated using methyl orange, methylene blue, and Spectrophotometer under UV light or sunlight.

Keywords: compressive strength, flexural strength, titanium dioxide, conventional concrete, self-cleaning concrete.

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1. INTRODUCTION

Urbanization of countries demands materials for the development of cities and causes lots of environmental disturbance. It causes many health issues and affects the ecosystem. Because of dust in the environment, there is a decline in the air quality and people suffer from a variety of respiratory problems.

Self-cleaning concrete is able to clean its surface and it removes the pollutants coming from the air which results from the photocatalytic action of the concrete. It is a recent invention in civil and environmental engineering, is also called as smog-eating concrete. Unlike conventional concrete, self-cleaning concrete is differed by technology using titanium dioxide (TiO_2) particles. To implement this technique, TiO_2 is either added to the concrete directly or can be painted on the surface of the concrete to achieve photocatalytic action. This technique can be used in any type of concrete; however, it breaks down the smog or other pollutants.

It may be utilized in any type of concrete, with the exception that it can break down smog or other pollutants that have adhered to the concrete through a process called photocatalysis. When the rays of sunlight touch the surface of the concrete, most of the contaminants of organic and inorganic pollutants are neutralized. The absence of this action, the pollution makes the concrete surfaces, discolour. Normally, the rain cleans the surface of the concrete, but air cleans the environment more effectively.

2. LITERATURE SURVEY

The main principle of self-cleaning concrete is the photocatalytic action of TiO_2. This TiO_2 additive concrete structure will act similarly to trees which absorb CO_2 from the atmosphere and release O_2 in to the environment. When the SCC is exposed to light, TiO_2 reacts with light and the surfaces of the concrete get heated. Then, the photocatalytic efficiency of SCC may be enhanced, and dirt can be broken down into basic oxygen, water, CO_2, nitrate, and sulphate molecules. Photocatalysts assist to transform hazardous air pollutants to less dangerous levels in the presence of UV light.

As a result, pollutants and impurities are eliminated from the environment.

İlker Bekir TOPÇU *et al.*[1] stated that anatase is the tetragonal forms of titanium dioxide also used as heterogenic photocatalysis in which wavelength of UV light should be less than 387mm. Intensity of light is also one of the parameters to optimize photocatalytic activity. Recently, research has been done on, the photocatalytic activity when the addition of nanoparticles of TiO_2 to the concrete in the incidence of active visible light range. Photocatalytic anti-bacterial effect, reduction of organic pollutants in water are the few applications of self-cleaning of building materials.

Surface finish and quantity of photocatalyst are some other parameters to measure the efficiency of photocatalytic action of self-cleaning concrete. The degradation of surface finish affects the photocatalytic action. The quantity of Photo catalyst changes the speed of chemical reaction in the presence of sunlight [1].

Serdal Ünal and Mehmet Canbaz, 2022, mentioned that TiO_2 consists of different properties like best oxidation ability, hydrophobicity, inert structure, chemical stability, durability against corrosion and permeability, good dispersion, cheapness and non-toxicity which promote photocatalysis chemical reactions. It is a material which is used in different applications and is an active research topic [2].

Kadir Berkhan Akalın *et al.* (2015) stated that organic and inorganic pollutants are resolved by mixing titanium dioxide (TiO_2) to the concrete mix. So, paving stones with TiO_2 were used to construct street roads in city centers and pedestrian pavements. Concrete pavement requires proper materials which are environment friendly, design mix to construct properly and this results in a good environment. In his study experiments were aimed at investigating the TiO_2 photocatalytic properties which is added concrete pavements. Photocatalytic activities are performed by applying Rhodamine-B in the removal of some pollutants on the concrete specimens [3].

C. Visali reported that the air quality near the urban areas have been improved by using of zinc oxide which got a quite considerable attention in recent years. This concrete having many benefits like purifying the environment without compromising its strength properties. The compressive strength of the concrete increasing up to the quantity of 0.5% of polypropylene fiber and 7% of zinc oxide. The strength of the concrete increase with the fiber content, but it reduces the workability. The reactive nature of the supplementary cementitious materials in the concrete by the addition of ZnO which promote the rate of hydration and the released heat of hydration of the cement [4].

Lu Yang stated that using photonic efficiency as indicator, the investigations had been done on the influences of environmental condition like relative humidity, UVA intensity of light, NO concentration and its flow rate. The TiO_2 supported in higher degradation of NO_x [5].

S. Khannyra stated that from his experimental investigations on Cu-TiO_2 photocatalysts which integrated into silica sol-gel synthesis to produce a new type durable coatings with air purification and cement- based materials having self-cleaning properties. It is also demonstrated that by adding Cu into its network, photoactivity of TiO_2 was enhanced. The efficiency was proved by conducting tests like methylene blue, NO and soot. It is also indicating that photoactivity of TiO_2 increases with increasing copper loading for low doping levels. The optimum dosage of Cu is 5% where the highest photocatalytic action occurs. [6].

C.S. Poon, 2007 stated that the reduction of NO decreases based on mix design, type of materials used and their properties, porosity and content of TiO_2. It also depends on the type of aggregate and the properties like size amount of aggregate used in the blocks. The removal of NO increases with porosity. In addition to this, some parts of aggregate are replaced with crushed recycled glass cullet. The photocatalytic activity of the block was increased because of its light transmitting characteristic. And thereby NO removal ability also increased. [7].

Chunying Wu stated that two reactions were observed for clear picture of synergetic effect between two phases are the anatase and rutile phases. Also, to investigate synergetic effect, two mechanical mixtures were prepared of titania phases. The synergetic effect is identified when the rutile and anatase particles are in closer and in contact. The activity of the synthesized bi-phase was observed as very stable from the result of long duration experiment. The activity and stability of the sulfation of those bi-phase catalysts does not increase compared to anatase single-phase TiO_2 catalyst [8].

Diana-Maria Mircea 2019 mentioned that decomposing of pollutants, organic materials and biological materials is converted into molecules such as carbon dioxide, water, oxygen sulphates, nitrates etc. due to photocatalytic activity/self-cleaning activity materials/substances used in concrete. The photocatalytic substances allow the reduction of pollutants close to their source. Sun light or artificial light activate the catalytic material, then, self-cleaning of concrete starts. The innovative self-cleaning concrete or building materials keep their colour for a longer duration compared to traditional building materials which is the required property for landscaping applications [9].

Heather Dylla 2014 experimented on photocatalytic control on two areas consists of two similar traffic conditions. The areas characterized the traffic classification and the activities. The photocatalytic study was performed to identify the variability pollutants like NO_x reduction. From the results, it was predicted that the NO_x emitted in from traffic sources is not more than amount of 5 grams per hour. A small quantity of pollution emitted due to photocatalytic action and control action in one area compared with other area not used the photo catalytic materials though the small difference in their traffic. However, a significant pollution was observed in non-photocatalytic areas.

Furthermore, a linear correlation was developed between vehicle class and speed and NO_x reduction [10]. Somayeh Asadi *et al*., 2014 developed models like neuro-fuzzy (NF) and artificial neural network (ANN) models to estimate NO_x concentration in air. The quantity of NO_x before applying TiO_2 and after the applying TiO_2 on the surface the pavement was expressed as a function of traffic count and climatic conditions like temperature, humidity, wind speed, and solar radiation. Since, their capability for modelling, extremely non-linear relationships and their ability to be trained using historical data, these models are useful for modelling. The field is prepared by spraying TiO_2 solution on 0.2 mile of asphalt pavement in Baton Rouge. Then, the data of NO_x was identified then the ANN and NF models were developed. From the results of the study, it was found that the NF model exhibited a better fitting to the ANN model for NO_x in the training, validation, and test steps. Parameters like traffic level, solar radiation and relative humidity had the most influence on photocatalytic efficiency [11].

In addition, while decomposing calcium carbonate ($CaCO_3$) rock into carbon dioxide (CO_2) and calcium oxide (CaO). Around half of the amount of carbon dioxide is generating from the source of the process. So, the manufacturers are required to make the processes of production more energy efficient. (Van Dam and Taylor 2009). [12].

Magdalena Janus 2015 stated a model developed for the cement pastes consisting of nitrogen and carbon co-modified TiO_2 (TiO2-N, C) as photocatalysts were exposed to contaminated water under UV light. It is exhibiting more photocatalytic activity than those containing unmodified TiO_2 [13].

Magdalena Janus 2019 studied on photocatalytic activity and mechanical properties of the modified cement mortars using photoactive materials. The modified materials for the building construction were prepared by adding of 1%, 3% and 5 % of nitrogen-modified titanium dioxide (TiO_2/N) based on the wt. of cement content to the cement matrix. Photocatalytic active cement mortars were tested to measure the compressive and flexural strengths, hydration heat and the zeta setting time. NO_x was measured before and after decomposition which resembles their photocatalytic activity on cement mortars in fresh state. The cement mortars with TiO_2/N were also tested for the mechanical properties of hardened cement mortars. The cement mortar with TiO_2/N of 5% wt. to the cement shortened the setting times [14].

3. MATERIALS

The following materials are used for the present investigations.

Cement: 53-grade Ordinary Portland Cement was used and the cement was tested as per Indian standards.

Fine Aggregate: River sand is used for this experiment. The sand is tested according to Indian Standards.

Coarse Aggregate: Locally available 20 mm crushed granite is used as coarse aggregate.

Super plasticizer: Polycarboxylate ether (PCE) chemical admixtures is used in this project.

The physical properties of ingredients like specific gravity are given below Table-1.

Table-1. The specific gravity of ingredients of CC and SCC.

S. No.	Materials	Specific gravity
1	Cement	3.15
2	Fine Aggregate	2.65
3	Coarse Aggregate	2.74
4	Water	1
5	Titanium dioxide	4.26
6	Super Plasticizer	1.15

TiO_2: BFC TITANIUM DIOXIDE LR - 250gm (TITANIUM IV OXIDE) (TiO2) CAS No. 13463-67-7 is used in the present investigations given in Figure-1. The TiO_2 properties are shown in Table-2.

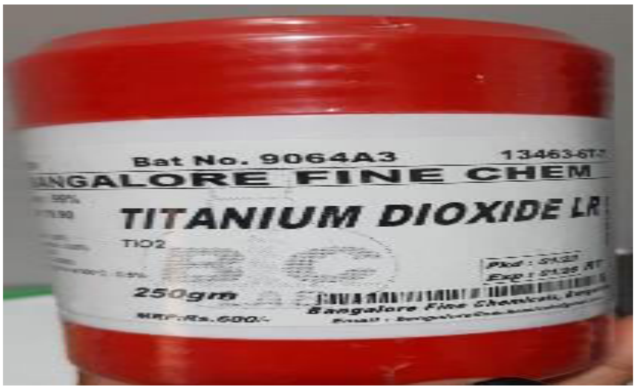

Figure-1. Titanium dioxide.

Table-2. Properties of titanium dioxide.

Titanium dioxide structure

CAS No.	13463-67-7
Chemical Name:	Titanium dioxide
Synonyms	TIO2;p25;Rutile TitaniuM Dioxide;ci77891;TITANIA;TITANIUM(IV) OXIDE;nano titanium dioxide;ANATASE;Ti02;hombitan
CBNumber:	CB0461627
Molecular Formula:	O2Ti
Molecular Weight:	79.8658
MDL Number:	MFCD00011269
MOL File:	13463-67-7.mol
MSDS File:	SDS
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Titanium dioxide Properties

Melting point	1840 °C
Boiling point	2900 °C
Density	4.26 g/mL at 25 °C(lit.)
refractive index	2.61
Flash point	2500-3000°C
storage temp.	Store at +5°C to +30°C.
solubility	Practically insoluble in water. It does not dissolve in dilute mineral acids but dissolves slowly in hot concentrated sulfuric acid.
form	powder
Specific Gravity	4.26
color	White to slightly yellow
PH	7-8 (100g/l, H2O, 20°C)(slurry)
Odor	at 100.00?%. odorless
Crystal Structure	Orthorhombic, Pcab
Merck	14,9472
Exposure limits	ACGIH: TWA 10 mg/m3 OSHA: TWA 15 mg/m3 NIOSH: IDLH 5000 mg/m3; TWA 2.4 mg/m3; TWA 0.3 mg/m3
CAS DataBase Reference	13463-67-7(CAS DataBase Reference)
Substances Added to Food (formerly EAFUS)	TITANIUM DIOXIDE
FDA 21 CFR	175.105; 175.210; 176.170; 177.1200; 177.1650; 177.2600; 177.2800; 178.3297; 181.30
EWG's Food Scores	1-3
FDA UNII	15FIX9V2JP
Proposition 65 List	Titanium dioxide (airborne, unbound particles of respirable size)
IARC	2B (Vol. 47, 93) 2010
NIST Chemistry Reference	Titanium dioxide(13463-67-7)
EPA Substance Registry System	Titanium dioxide (13463-67-7)
Cosmetics Info	Titanium Dioxide

Titanium dioxide Properties

Hardness, Mohs	5.5 - 6.0

4. MIX PROPORTIONS

In this project, M_{40} grade concrete is designed according to IS 10262-2009 and TiO_2 is added to CC 0.5%, 1.0% and 1.5% to prepare SCC to determine the behavior of concrete in the point of view of strength and self-cleaning. The mix proportions and slumps of CC and SCC are given in the Table-3. The CC and SCC exhibit

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low slump values. The sample size is taken as 3 for these experiments.

Table-3. Mix proportions of CC and SCC for one cubic meter.

S. No.	Mix description	Cement (Kgs)	Water (Kgs)	FA (Kgs)	CA (Kgs)	TiO2 (Kgs)	Super Plasticizer (Kgs)	Slump value (mm)
1	Conventional concrete	431	155	765	1139	0	4.31	55
2	SSC- 0.5%	431	155	765	1139	2.16	4.31	43
3	SSC- 1.0%	431	155	765	1139	4.31	4.31	42
4	SSC- 1.5%	431	155	765	1139	6.47	4.31	40

4.1 Preparation, Casting and Testing of specimens

The specimens of size 150 mm cubes and 100 mm x 100 mm x 500 mm prisms are casted and cured for 7 days and 28 days as per IS: 516-1959 to conduct the different tests like compressive strength and flexural strength. These specimens have undergone tests like the spectrometer, methyl orange test and methylene blue test. Casting and curing of self-cleaning concrete are shown in Figure-2 and Figure-3 respectively.

Figure-2. Casting of self-cleaning concrete.

Figure-3. Curing of self-cleaning concrete.

5. RESULTS AND DISCUSSIONS

The specimens of conventional concrete and self-cleaning concrete undergone different tests like compressive strength, spectrometer, flexural strength, methyl orange and methylene blue.

5.1 Compressive Strength Test

150 mm cubes of CC and SCC are casted and cured for 7 days and 28 days and tested in compressive strength testing machine of 2000KN capacity and testing was conducted according to IS 516 (2019). Testing of specimens are shown in Figure-4. The loading rate is 140 Kg/sq. cm/min applied on the specimens.

Figure-4. Compressive test on SCC.

Table-4. Compression strengths of CC and SCC for 7 days and 28 days.

Mix	Compressive Strengths of CC and SCC in MPa			
	CC	SCC with 0.5% TiO2	SCC with 1.0 % TiO2	SCC with 1.5% TiO2
7 Days	33.6	37.2	24.3	20.0
28 Days	47.2	49.5	40.1	27.2

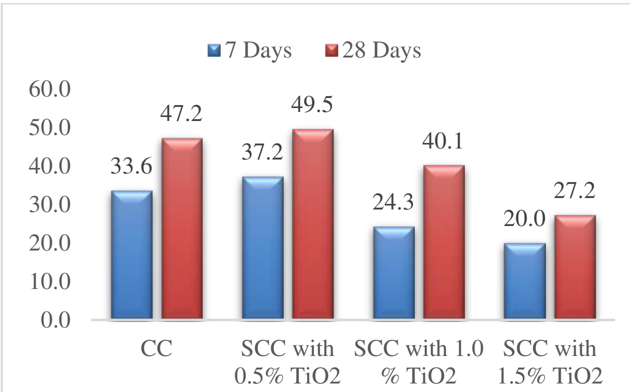

Figure-5. Compressive strengths of CC and SCC for 7 days and 28 days.

Table-4 and Figure-5 show the compressive strengths of CC, SCC with 0.5%, TiO2, SCC with 1.0% TiO_2 and SCC with 1.5% TiO_2 are ranging from 20.0 MPa to 37.2MPa and 27.2 MPa to 49.5 MPa for 7 days and 28 days respectively. After comparing the results with CC, SCC with 0.5% TiO_2 exhibiting more strength for both 7 days and 28 days.

5.2 Flexural Strength

The specimens of the size 100 mm X 100 mm X 500 mm are used to find the flexural strength of CC and SCC. The test was conducted as per IS 516-1959. The rate of loading applied 180Kg/min on the specimen. Flexure testing of SCC are shown in Figure-6.

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Figure-6. Flexural strength test on SCC.

Table-5. Flexural Strengths of CC and SCC for 7 Days and 28 Days.

Mix	Flexural Strength of CC and SCC in MPa			
	CC	SCC with 0.5% TiO2	SCC with 1.0 % TiO2	SCC with 1.5% TiO2
7 Days	4.8	6	5.6	4.3
28 Days	5.2	6.8	6.4	4.8

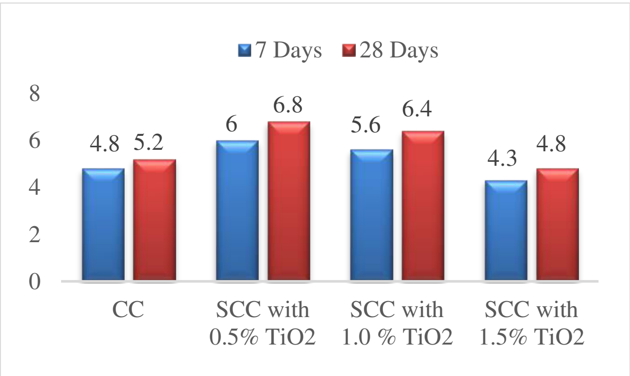

Figure-7. Flexural strengths of CC and SCC for 7 days and 28 days.

Table-5 and Figure-7 show the flexural strengths of CC, SCC with 0.5% TiO_2, SCC with 1.0% TiO_2 and SCC with 1.5% TiO_2 are ranging from 4.3 MPa to 6.0 MPa and 4.8MPa to 6.8 MPa for 7 days and 28 days respectively. After comparing the results with CC, SCC with 0.5% TiO_2 exhibiting more flexural strength. However, SCC with 1.5% TiO_2 has exhibited a minimum for both 7 days and 28 days.

5.3 Spectrophotometer

The spectrophotometer test was conducted on crushed samples of CC and SCC specimens of 28 days to check the light scattering effect.

Figure-8. Spectrophotometer.

Table-6. Absorbance values of CC and SCC for 28 days.

Mix	Absorbance values of CC and SCC for 28 days			
	CC	SCC with 0.5% TiO2	SCC with 1.0 % TiO2	SCC with 1.5% TiO2
Max.	0.6552	0.6856	0.6318	0.6824
Min.	0.3726	0.4570	0.4120	0.4431

The absorbance values of CC and SCC with 0.5% TiO_2, SCC with 1.0% and SCC with 1.5% TiO_2 range from 0.3726 to 0.6552 and 0.4120 to 0.6856 for 28 days respectively. The absorbance values increase in the case of SCC with TiO_2. The maximum value of absorbance was observed in the case of SCC with 0.5% TiO_2.

5.4 Methyl Orange Test

Methyl orange test is one of the commonly used tests to identify the photocatalytic action on self-cleaning concrete. A little amount of methyl orange was applied on the surfaces of CC and SCC of samples. Then the samples of CC and SCC is exposed to UV light for a specified time. More intensity of reduction in orange colour indicates more amount of methyl orange broke down and participated in photocatalytic activity.

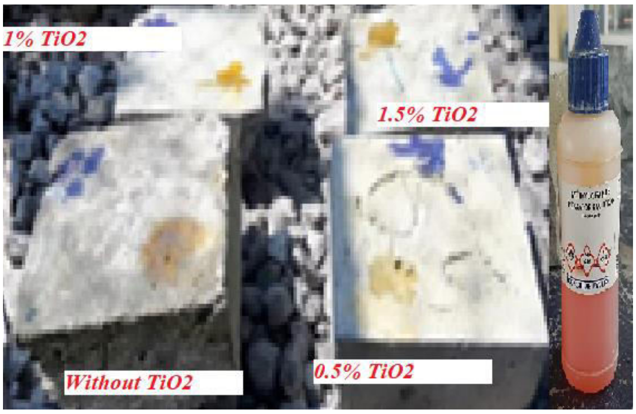

Figure-9. Methyl orange test on CC and SCC at time of application.

Figure-10. Methyl orange test on CC and SCC after 6 hours.

From the test results, there is evidence to show that more is the amount of methyl orange absorbed by SCC with 1.5% TiO_2 compared with the other mixes. However, the specimens of SCC with 0.5% and 1% also showed good performance.

5.5 Methylene Blue Test

This test is also used to identify oxidization and removal of dust, pollutants by photocatalytic action which is similar to methyl orange test. The reduction in methylene blue indicates more photocatalytic action which indicates that photocatalytic action reduces the dye. This test is conducted and observed that the reduction of blue colour is more in case of SCC with 1.5% TiO_2 compared to other combinations of mixes.

Figure-11. The reduction in methylene blue on CC and SCC.

6. CONCLUSIONS

It is known that the pavements subjected to lots of dirt, pollutants, organic matter regularly. This will cause unesthetic appearance, polluted environment and also degradation of quality of pavement surface. Apart from that the workforce is required to clean the pavement. The photocatalytic activity by TiO_2 will be the best solution for the mentioned problems.

From the experimental investigations on conventional concrete and self-cleaning concrete the following conclusions are made:

- Different tests were conducted on conventional concrete and self-cleaning concrete are compressive strength, flexural strength, spectrometer, methyl orange and methylene blue.
- The tests are conducted on CC, SCC with 0.5% TiO_2, SCC with 1.0% TiO_2 and SCC with 1.5% TiO_2.
- SCC with 0.5% TiO_2 showed higher strength compared to CC and remaining SCC mixes.
- SCC with 1.5% TiO_2 absorbed more methyl orange and methylene blue compared to other combinations of mixes. However, SCC with 0.5% TiO_2 also exhibited good performance.
- As per IRC: 58-2011, in no case should the 28 days flexural strength of pavement quality concrete be less than 4.5 MPa. From all the test results, SCC with 0.5% TiO_2 exhibiting better performance in strength wise and pollution cleaning wise among all other mixes and satisfied above clause.

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