Behaviour of Self Cleaning Concrete using Photocatalytic Material

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Abstract—Air pollution is a significant risk factor for a number of pollution related disease and health conditions. Self-cleaning concrete having a technique to reduce the air contaminants such as NOX, SO2, CO2 and VOC’S from vehicular traffic on streets, any industrial activity and the urban environment. Photocatalytic materials are used in conventional concrete for urban buildings and road pavements to reduce air pollution. The primary photocatalytic material is Titanium dioxide (TiO2), a white coloured powder. TiO2 is activated by the energy from the sun light or UV lamps and it decompose the external pollutants on the surface of the concrete, which is removed by wind and rain action. The presence or removals of pollutants are monitored by the laboratory tests. The workability, compressive strength and durability of the self-cleaning concrete is also tested. As a result it reduces the air pollution (also smog) and causes to self-cleaning activity.

Key words: Self-Cleaning, Photocatalysis, TiO2, EDAX, Durability

I. INTRODUCTION

Photocatalysis process is discovered 40 years ago, which is renewed now as a process which allows to work together effectively against the atmospheric pollution problem. A photocatalytic material (Titanium dioxide TiO2), has been investigated for the self-cleaning process and known as an effective material by reducing harmful gases such as (SOx) sulphur oxide, VOCs (volatile organic compounds) and NOx. Photocatalytic materials (TiO2) are a technology that could help mitigate ultraviolet rays. Photo catalytic mechanisms use energy from sunlight (or ultraviolet light sources) and convert the harmful gases into harmless elements. Photocatalytic materials are helpful to mitigate air pollution directly. When photocatalytic materials absorb UV radiation from the sun light the process of photocatalysis done through the Titanium dioxide (TiO2).

A. Innovation

We are adding the Titanium Dioxide (TiO2) in the percentage of 0-3% (increasing of 0.5%) to find the maximum workability, compressive strength and durability of photocatalytic and self-cleaning concrete.

B. Objective

The main objective of this project is to use of Titanium dioxide (0-3%, increase of 0.5%) in cement content. Characterization of all ingredients of self-cleaning concrete has been performed. Workability, compressive strength and durability properties have been evaluated.

II. LITERATURE REVIEW

Andrea Folli. (2010) NOx oxidation experiments have been carried out in a continuous fixed bed flow reactor according to the Italian Standard UNI 11247. The photocatalytic reactor consists of a Pyrex glass chamber having a total volume of 3.58 l where the specimen under testing can be located on the bottom part supported by a proper sample holder. The gas inlet tube allows the air/NOx mixture to flow directly onto the specimen upper surface whilst the gas outlet tube is positioned underneath the sample holder. The system was kept at room temperature: 25 ± 1°C. U.V. light was provided by an OSRAM ULTRAVITALUX lamp having a main emission in the U.V.-A field distributed around a maximum intensity wavelength of about 365 nm. The lamp – sample distance was set to achieve on the upper sample surface an average irradiance of 20 ± 1 W/m2.

Elia Boonen and Anne Beeldens. (2014) Photocatalytic (TiO2 containing) paving materials with the potential of reducing air pollution by traffic are being used more frequently on site in horizontal as well as in vertical applications, also in Belgium. Laboratory results indicate a good efficiency towards the abatement of NOx in the air by using these innovative materials. The durability of the photocatalytic action also remains mostly intact, though regular cleaning (by rain) of the surface is necessary. The relative humidity (RH) is an important parameter, which may reduce the efficiency on site. If the RH is too high, the water will be adsorbed at the surface and prevent the reaction with the pollutants.

Jay Sorathiya. (2017) M30 grade of concrete designed as IS 10262:2009. Concrete mixtures with different proportions of Nano TiO2 0.5% to 1.5% were cast. The results show that the nano-TiO2 particles added concrete had appreciably higher compressive strength comparable to that of the normal concrete. The increase in nano TiO2 content there is gradual increase in strength as the pores has been filled with TiO2 because of that strength is increased. It is found that the cement could be gainfully added with nano-TiO2 particle up to maximum limit of 1.0% with average particle sizes of 15 nm. Although, the optimal level of nano-TiO2 particle content was achieved with 1.0% added. Nano-TiO2 particles added in concrete by weight of cement decreased workability of fresh concrete with respect to increase the content of titanium dioxide in concrete.

Ranjit K. Odedra. (2014) The TiO2 and white PPC were dry mixed in the mass ratio 3.5:96.5. 20g of the mixture was subsequently hydrated with 8g of distilled water (water: solid mixture ratio, w/s = 0.4). A third set (control) was prepared without photocatalyst. After mixing, pastes were cast in 42 mm diameter x 5 mm height moulds and let harden (with no cover) for one day at room temperature and 80.5% relative humidity. Remove moisture from fine and coarse aggregate and mix it for 1min in concrete mixture, then add 1/3 part of water and mix for 30sec. Further add Mix of TiO2 and cement then mix for 30sec then add remaining water again and mix for 3min.

Wei Li, SMin-Hong Zhang. (2010) The rate of cement hydration was increased with the increase in TiO2...
dosage from 1 to 6 % by mass of cementitious materials in both pastes with or without slag. Workability of the fresh mortars was not affected significantly by 1% TiO₂. However, the workability was decreased with further increase in TiO₂ dosage. Compressive strength of the mortars at 28 days was decreased with the increased in TiO₂ dosage up to 6%. The decrease was more pronounced for the Portland cement mortars than the mortars with slag. With a further increase in TiO₂ dosage to 2%, the rate of colour recovery was further increased. However, the percentage of improvement was less significant compared with 1% TiO₂. There was no obvious improvement in self-cleaning when the dosage of TiO2 is further increased beyond 2%. Self-cleaning efficiency of the mortars tended to decrease with increasing irradiation time. Further study is need for long-term performance and performance in tropical environment.

III. SELF-CLEANING CONCRETE

Self-cleaning concrete is generally also called as photocatalytic concrete, because it used by photocatalytic material. Self-cleaning concrete is being made with photocatalytic materials. It is also air depolluting concrete. When used in concrete, photocatalysts decompose organic materials, biological materials and pollutants. The catalysed compounds break down into molecules that are either beneficial to or have a benign impact on the environment. The primary catalytic ingredient is Titanium oxide (TiO₂). The energy in light causes the TiO₂ to create a charge separation of electrons, which disperse on the surface of the TiO₂ and react with external substances, decomposing compounds.

IV. PHOTOCATALYTIC MATERIALS

A. Types
   - Titanium Dioxide (TiO₂).
   - Zinc Oxide (ZnO).
   - Tin Dioxide (SnO₂).
   - Zirconium Dioxide (ZrO₂).

1) Titanium Dioxide

Titanium dioxide exists in three mineral forms Anatase, Rutile and Brookite, Anatase type TiO₂ has a crystalline structure that corresponds to the tetragonal system, Rutile type TiO₂ also has a tetragonal crystal structure, Brookite type TiO₂ has a crystalline structure that corresponds to the orthorhombic crystalline structure. Titanium Dioxide is a versatile material that has applications in various products such as paint pigments, sunscreen lotions, electrochemical electrodes, capacitors, solar cells and even as a food colouring agent and in toothpastes.

B. Working Principle

Fig. 1: Working Principle

The above figure lonely shows the working principle that is, when the concrete gets pollutants like nitrogen dioxide, carbon dioxide and sulphur dioxide from the vehicle emission by human activity at that same time the UV radiation is on the surface of the concrete the process of the photocatalytic activity (1) can be done. Photocatalytic activity (1) is to reduce the harmful gases into the harmless products using the natural sunlight UV radiation. By the raining activity the harmless products are gets removed and decomposed is the principle of self-cleaning activity (2). Again the concrete get ready for undergo the process of (1) & (2).

NOTE:
1) Photocatalytic activity
   \[ \text{NO} + \text{OH} \rightarrow \text{NO}_2 + \text{H}^+ \ (\text{UV, TiO}_2) \]
   \[ \text{NO}_2 + \text{OH} \rightarrow \text{NO}_3^- + \text{H}^+ \ (\text{UV, TiO}_2) \]

C. Application Areas
   - Roads.
   - Residential buildings.
   - Commercial buildings.
   - Brickwork plastering.

D. Examples for Application

1) Life + Project Photopaq

The European Life+ funded project PhotoPAQ was aimed at demonstrating the usefulness of photocatalytic construction materials for air purification purposes in an urban environment. Eight partners from five different European countries participated in the project. In this framework, an extensive three-step field campaign was organized.

2) Interreg Project

The broad environmental sustainability project ECO2PROFIT dealt with the reduction of the emission of greenhouse gases and sustainable production of energy on industrial estates in the frontier area between Flanders and Holland. To reach these goals, several tangible demonstration
projects were carried out on industrial sites in Belgium and the Netherlands. BRRC was involved in two such projects: “Den Hoek 3” in Wijnegem and “Duwijckpark” in Lier (both near Antwerp).

V. EXPERIMENTAL WORK
The concrete specimens were tested for workability, compressive strength and durability. The mortar specimen was tested using EDAX test.

A. Materials Used
1) For Concrete
Normal Portland cement, natural sand, coarse aggregate and water was used for concrete. Titanium dioxide (TiO$_2$)

2) For Mortar
Normal Portland cement, natural sand and water was used for concrete. Titanium dioxide (TiO$_2$)

B. Mixing & Casting
1) General
All the specimens were mixed using hand mixing under desirable conditions and they are allowed for casting in the pre-fabricated moulds.

2) For Concrete
The size of 150X150X150 mm mould was taken to find the compressive strength and durability. The specimens are allowed 7 days for curing. As per IS 456:2000, 7 days curing is enough to find the strengths.

3) For Mortar
1cm thickness of mortar was prepared to determine the photocatalytic and self-cleaning activity using EDAX. 1 day curing is allowed for mortar as per literature review.

C. Testing Methods
1) Workability
Slump cone and flow table tests were conducted as per IS 7320 to evaluate the effect of TiO$_2$ dosage on concrete flow ability.

a) Slump Cone Test
TiO$_2$ dosage was applied on the rate of 0.5% increasing upto 3% in M20 grade of concrete. The slump values are given as below
The results of slump flow table test is indicated the flow ability of the fresh concrete was not affected by 1.5%.

2) **Compressive Strength Test**

TiO\textsubscript{2} dosage was applied on the rate of 0.5% increasing upto 3% in M\textsubscript{20} grade of concrete. Compressive tests were conducted IS 516-1959 on a 150X150X150 mm cube sample of concrete. For every 0.5%, three cubes were cast then remove mould after 24 hours. Put 7 days curing in water at room temperature. After 7 days curing cubes tested under Compression testing machine of 2000 KN capacity.

The results of compressive strength test is indicated the strength of the hardened concrete was not affected by 1.5%. TiO\textsubscript{2} in the concrete. The Maximum increase in compressive strength of concrete was observed.

3) **Edax Test**

Energy Dispersive Analysis of X-rays. Self-cleaning capability of the mortars with 1.5% dosage of TiO\textsubscript{2} was evaluated by monitoring the Nitrogen, Carbon, Sulphur and Oxygen content present in the concrete specimens by conducting EDAX (Energy Dispersive Analysis of X-rays) test. Samples are casted as mortars for the EDAX test. The four samples were casted namely as sample A, sample B, sample C, sample D. All the specimens are undergoes one day curing and undergoes the process of pollution, photocatalysis and washing on samples A, B, C, D.

EDAX test is an elemental analysis test to determine the pollutants to check the photocatalytic activity and also self-cleaning activity. Initially sample A was tested for the presence of titanium content in sample and pollution factor. The further samples B, C, D are allowed to get pollution. Then sample B was kept inside the laboratory for testing. C & D are exposed to UV radiation from sunlight or artificially. At this stage we have taken the sunlight for 4 hours. After 4 hours of irradiation sample C was kept in laboratory and sample D gets washed then allowed to monitor the elements present in the sample. Comparison was made before pollution, after pollution, under UV radiation and after washing can be done. The samples are tested using EDAX under 4 days laboratorial air temperature and they are not exposing under sunlight. The percentages of elements are shown in as graphical representation.

![Fig. 10: EDAX Testing Machine](image1)

![Fig. 11: Samples for EDAX Test](image2)

<table>
<thead>
<tr>
<th>ELEMENTS</th>
<th>SAMPLE A</th>
<th>SAMPLE B</th>
<th>SAMPLE C</th>
<th>SAMPLE D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti K</td>
<td>1.94</td>
<td>1.72</td>
<td>1.68</td>
<td>1.44</td>
</tr>
<tr>
<td>C K</td>
<td>9.76</td>
<td>16.33</td>
<td>15.04</td>
<td>10.12</td>
</tr>
<tr>
<td>N K</td>
<td>0.06</td>
<td>0.39</td>
<td>0.3</td>
<td>0.04</td>
</tr>
<tr>
<td>O K</td>
<td>46.06</td>
<td>42.8</td>
<td>38.78</td>
<td>49.08</td>
</tr>
<tr>
<td>Si K</td>
<td>2.56</td>
<td>7.96</td>
<td>3.26</td>
<td>2.31</td>
</tr>
<tr>
<td>S K</td>
<td>0.06</td>
<td>2.61</td>
<td>0.07</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Table 1: EDAX Test Values

Based on the test results, initially the titanium dioxide content was present in the sample A is proved and the remaining samples also the values of the titanium content present in the respective samples B, C & D. For this test we had taken the polluted samples by means of vehicles emission. In this emission has Carbon dioxide and shulpur dioxide as a major part and the nitrogen dioxide has takes place as minor part. By this
test shows the good behaviours of this self cleaning concrete by means of photocatalytic activity and self cleaning activity based on the tested values. Presence of pollutants like Nitrogen, Carbon and Sulphur are having higher values in sample B than sample A. After the process of photocatalytic activity and self cleaning activity the sample B & C values are gets reduced than sample B. Finally the sample A & D having the almost same level values.

Fig. 12: Sample A

Fig. 13: Sample B

Fig. 14: Sample C

Fig. 15: Sample D

4) Durability Test

Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. It normally refers to the duration or life span of trouble-free performance.

a) Chloride Attack

The concrete specimens which were dipped into the calcium chloride solutions was evaluated. The weight of the every concrete specimens with TiO₂ was monitored. The compressive strength of three samples was calculated and the average value was noted.

Fig. 16: Specimen Dissolved in Chloride solution

Fig. 17: Result of Chloride Attack Graph
The concrete specimens which were dipped into the zinc sulphate solutions was evaluated. The weight of the every concrete

![Graph](image)

**Fig. 18: Specimen Dissolved In Sulphate Solution**

Specimens with TiO\(_2\) was monitored. The compressive strength of three samples was calculated and the average value was noted.

**Fig. 19: Result Of Sulphate Attack Graph**

VI. CONCLUSION

- Workability of the fresh concrete was not affected significantly by 1\% TiO\(_2\). However, the workability was decreased with further increase in TiO\(_2\) dosage.
- The result shows that the compressive strength of concrete gets increased up to 1.5\% of TiO\(_2\) in the mass of the cement. This maximum strength was attained by the concrete is filling the pores by titanium dioxide, because TiO\(_2\) has smaller in dimensions.
- Prepared mortars using 1.5\% of TiO\(_2\) will shows the good behaviours likely to be photocatalytic activity and self cleaning activity. The percentage of pollutants are gets reduced under UV radiation of sunlight and washing activity to the samples C & D.
- The durability of self-cleaning concrete containing 1.5\% of ti\(_2\) exhibits better resistance against acid attack, sulphaate attack and chloride attack.
- Baesed upon the test results we would like to conclude the atmoispheric pollutions are gets reduced and they are converted into harmless gases, manure for plants and converted into oxygen to inhale by the human.
- Self cleaning concrete helps to make pollution free environment and helps to reduce global warming by its huge amount of application.

REFERENCE