Review on Photocatalysis Applications in Construction

Muhammad Yasir Sadiq
(Graduate student, East Carolina University, Greenville, NC, USA)

Amin K. Akhnoukh
(Associate Professor, East Carolina University, Greenville, North Carolina, USA)
akhnoukha17@ecu.edu

Abstract
Many construction projects are composed of concrete or mortar. After construction of such projects, the material faces challenges which cause aesthetic as well as physical deterioration. This paper discusses the application of Heterogeneous Photocatalysis which is a versatile, cost efficient and environmentally friendly treatment technology. The natural resources that are being used for demonstrating the self-cleaning characteristics of the photocatalytic materials is laudable. The most popularly used photocatalytic material is Titanium dioxide (TiO2).Multiple reasons are discussed for TiO_2 being beneficial for the construction industry. The principal utilization of TiO_2 as a photocatalytic building material is due to its self-cleaning, self-disinfecting and sustainability properties. The basic mechanism of photocatalysis is also analyzed for actual understanding of the project. The photocatalytic application for a greener road environment is worth mentioning. The paper discusses that which type of TiO_2 coating is the most sustainable and best choice for an urban road environment which will efficiently eliminate the harmful nitrogen oxides (NO_X) and volatile organic compounds (VOCs). The effect of particle size on the cost and productivity of the photocatalytic material is mentioned. The variability of the coating mix with the reduction of NO_x and VOCs.

Keyword
Heterogeneous Photocatalysis, Titanium Dioxide, Pollution , Environemnt,self-cleaning concrete

1. Introduction

The research on photocatalytic capability of a material and its applications has started to gain momentum from different aspects. The characteristics and the applications of the materials are undoubtedly a prudent choice for today's world where pollution is added in a proliferated amount because of vehicle and industry emissions. The photochemistry of TiO_2 has become a critical research subject for the future. Different research projects in the world are striving hard for a better, sustainable and green environment for our future generations. This subject gained momentum in research when the photocatalytic splitting of water on TiO_2 and Sr-doped TiO_2 respectively became successful in the 1970's. Two important effects related to nature of photoactive TiO_2 coatings had by this time been discovered a)- self-cleaning effect due to redox reactions promoted by sunlight (or in general weak U.V. light) on the photocatalytic surface and b)- the photo-induced super hydrophilicity of the catalyst surface, which enhances the self-cleaning effect(inorganics causing dirt and stains on surfaces can be easily removed due to rainwater soaking between the adsorbed substance and the TiO_2 surface). For the photocatalysis to initiate U.V. light is fundamental which means that this process will be more productive in the day time than in any other time. The solar energy reaching the earth's surface is about 5 x 10^{24} J per year. This is more than the 10^4 times the annual worldwide consumption of energy. This is the best part that we are using natural resources for this process. This enormous source of energy is utilized with exceptionally engineered construction materials which have the potential to make the environment cleaner and free of pollutants.

1.1 Photocatalysis

Photocatalysis is the photoreaction in the presence of a catalyst. The term "photocatalysis" is in widespread use and is here to stay; it is not meant to, nor should it ever be used to, imply catalysis by light, but rather the "acceleration of a photoreaction by the presence of a catalyst". The term "photoreaction" is sometimes elaborated on as a "photoinduced" or "photoactivated" reaction, all to the same effect (Mills and Hunte, 1997). The process of photocatalysis is very prominent in the presence of light as the photocatalytic efficiency of the building materials is visible. The study of photocatalytic reactions was initiated in 1970's. During the photocatalytic process light is consumed by one or two reacting species and this is the reason that catalyst is added which does not get consumed and accelerates the reaction.

1.2 Types of Photocatalysis

Photocatalysis is the acceleration of a photoreaction in the presence of light. There are two types of photocatalysis which are homogeneous and heterogeneous Homogeneous Photocatalysis the reactants and photocatalyst exist in the same phase

In Heterogenous Photocatalysis, the reactants and the photocatalyst exist in a different phase from the reactants. The hetero generous photocatalysis will be discussed in more detail later

1.3 Heterogeneous Photocatalysis :-

Heterogeneous photocatalysis is based on the irradiation of a semiconductor photocatalyst in contact with a liquid or a gaseous environment. TiO2, ZnO, and CdS are widely used examples (Cassar,2004).

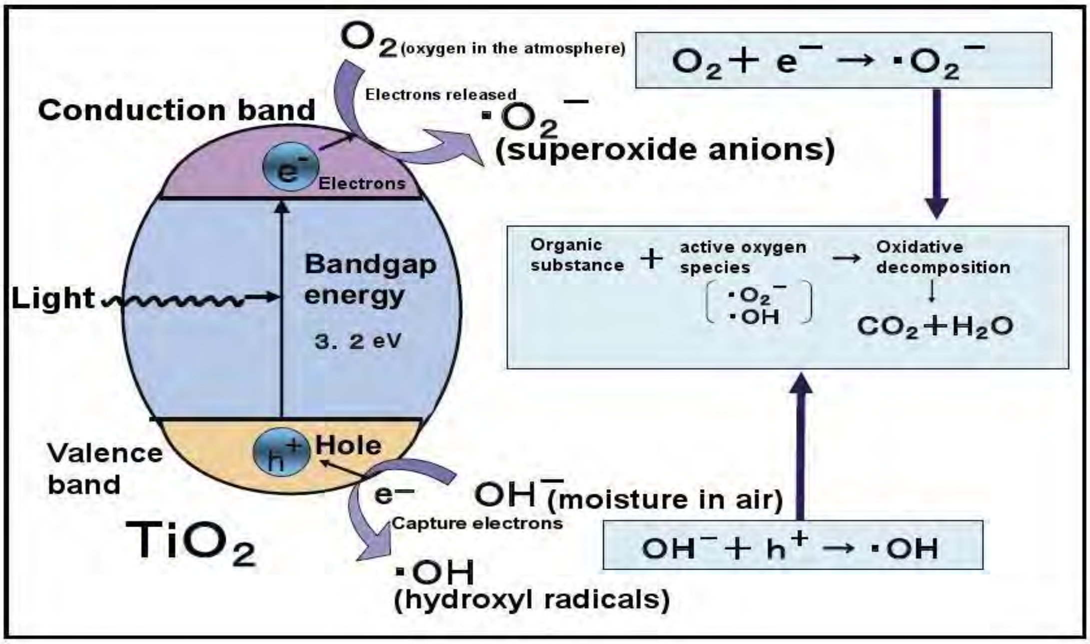

Figure 1 Mechanism of Photocatalysis with TiO_2 (Chen,1970)

A band gap exists between the valence band and conduction band. The electron gets promoted form a valence band to the conduction band in the presence of Ultra violet radiation or fluorescent light. During promotion of electron from a valence band to conduction band a hole is left on the valence band. The holes oxidize the donor molecules. The energy of band gap is 3.2 ev.

$D + h^{+} \rightarrow D^{\bullet +}$

Whereas the conduction band electrons can reduce appropriate electron acceptor molecules.

$A + e^{-} \rightarrow A^{\bullet -}$

The afore-mentioned explanation presents a brief description to the chemistry of the photochemical reaction in which TiO_2 is seen as the photocatalyst.

2. TiO_2 as a Photocatalyst

TiO_2 is used as a photocatalyst. Although, there are several other metal oxides of vanadium, chromium, zinc, tin and cerium. TiO_2 has ample amount of applications such as it is most widely used inorganic pigment for varnishes and plastics. It is used as a white pigment in paints because of its strong resistance to discoloration under UV light. It is also used in foods, pharmaceuticals and cosmetics. The reason of using TiO_2 is that it is very cost efficient and has the capability to go under quick reactions at ambient operating conditions (room temperature, atmospheric pressure). TiO_2 is also used as a photocatalyst because of being chemically stable and compatible with traditional construction materials such as cement. TiO_2 is very effective under weak solar irradiation in various conditions of the environment.

The reasons for using TiO_2 as a photocatalyst are that in addition to the self cleaning characteristics that it shows in the presence of light. It also introduces to its various other characteristics which are the anti-fogging effect, water treatment, air cleaning effect and anti-bacterial effect. Due to these reasons TiO_{2is} considered as a very beneficial oxide in the industry. TiO_2 ceramic tiles are considered to be very effective against organic and inorganic materials and also towards bacteria. Hence when such applications of TiO_2 are seen then there comes no question in using any other metal oxide for photocatalytic process.

2.1 Forms of TiO_2

TiO_2 occurs naturally as rutile, brookite and anatase. Now the question comes that which one is the best for photocatalysis. Compared with rutile and brookite, anatase shows the highest photoactivity (Benedix *et al.*,2000).

Despite the intensive study of TiO_2 there is no generally accepted explanation for the differences of photocatalytic activity of different polymorphs or surface orientations. The general perception that anatase has a higher photocatalytic activity compared to rutile TiO_2 is confirmed by out measurements on extended planar epitaxial thin films . Anatase exhibits an indirect band gap that is smaller than its direct band gap. For rutile, on the other hand, its fundamental band gap is either direct or its indirect band gap is

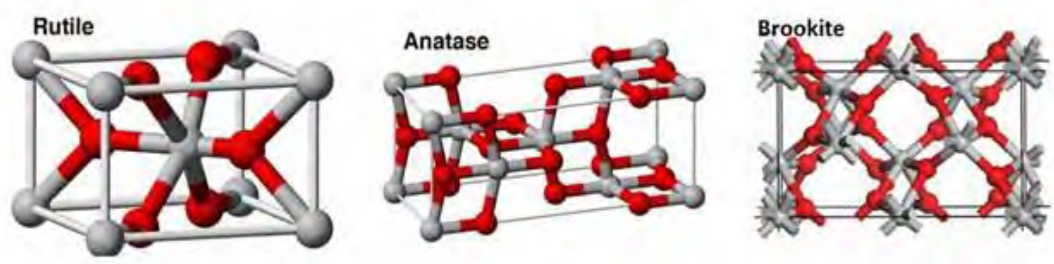

Figure 2 Forms of TiO2 (Naturally Occuring) (Austin and Lim,2008 ; Woodley and Catlow,2009)

very similar to its direct band gap (Luttrell *et al.,* 2014). Anatase, the most commonly used photocatalyst in concrete, is capable, under natural sunlight, of degrading certain atmospheric pollutants, e.g. NO_x, Volatile organic compounds (VOCs) and non-volatile organic residues due to charge transfer (redox) processes on the catalyst surface (Macphee and Folli 2016). The previous researches suggest that anatase has more photocatalytic activity any other of its forms due to which it is used majorly in the environment.

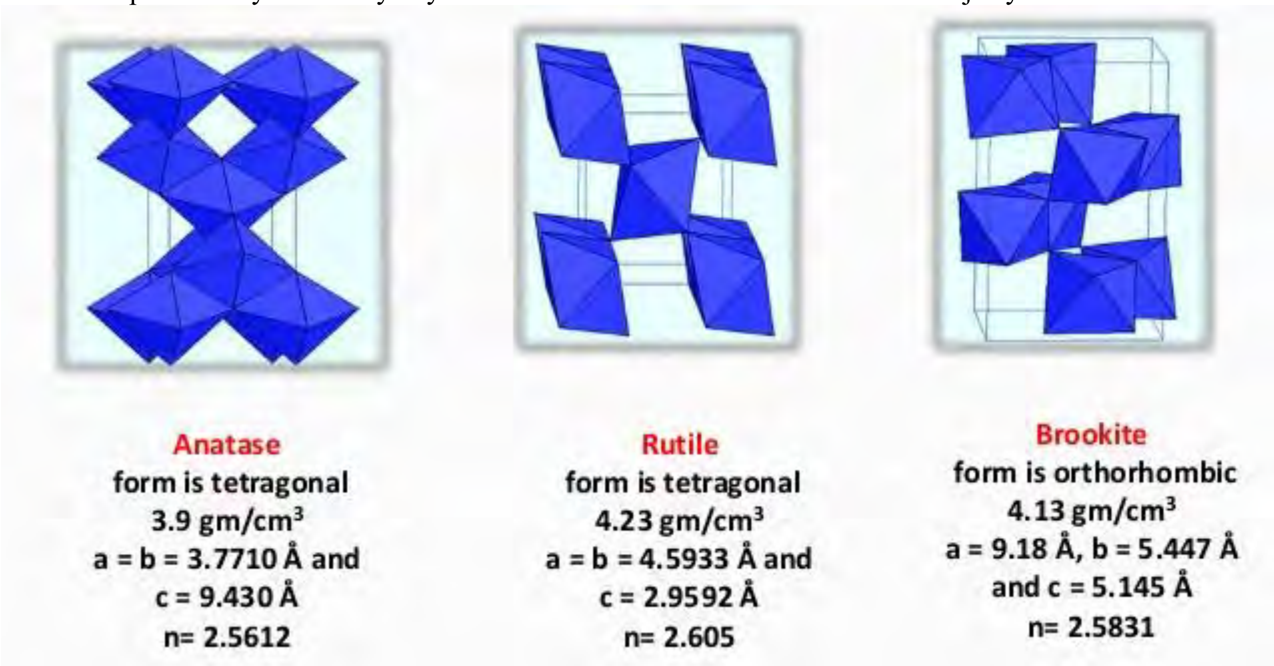

Figure 3 Types of TiO2 (Naturally occurring) and their properties (Al-obaidi, 2012)

2.2 Nano and micro size particles

In relation to size TiO_2 can exist either in micro or nano size. The work done by various researchers suggest that the size has a solid effect on the photocatalytic efficiency of the material. At first nano particles were considered as a favorite choice for better results but latest research opposes this approach. Although TiO_2 is chemically inert, TiO_2 nanoparticles can cause negative health effects, such as respiratory tract cancer in rats (Trouiller B 2009) investigate TiO_2 nano particles- induced genotoxicity, oxidative DNA damage, and inflammation in a mice model. The increased use of nano materials in commercial products has raised a growing public debate on whether the environmental and social costs of nanotechnologies outweigh their numerous benefits (Colvin VL 2003). Up to now, few studies have investigated the toxicological and environment effects of direct and indirect exposure to nano materials and nano particles and no clear guidelines exist to quantify these effects (Hye Won K 2009). This research opens doors for the usage of micro sized TiO_2 powders instead of nanometric ones. They are cost efficient as well as safer for both the environment and the workers on the site which practically apply these materials as a coating on the materials such as concrete blocks or the different parts of the road for a better healthy environment which is more cleaner and free of bacteria. Traditionally it was thought that a decrease in particle size such as nano particle will perform better than micro particle. However the latest research suggests something else as health effects of nano particles cannot be compromised.

3- Applications of TiO_2

TiO_2 due to having various beneficial and prominent characteristics has various practical applications in the construction industry.

3.1 Residential and Commercial Construction

It is a common phenomenon that the aesthetic and luster of the surface of ordinary buildings are gradually lost with time. The building surface could be soiled by greasy and sticky deposits, which results in a strong adherence of ambient dusts. As a result, dirt built up on the surface reduces the visual appearance (Jun Chen 2009). The self-cleaning product having a coating of TiO_2 can save so much money for maintenance of such a dusty building and can be very cost effective. Hence the use of TiO_2 Besides self-cleaning cementitious materials, TiO2-based selfcleaning exterior building products including tiles and glass have been widely commercialized and applied. About 270 patents have been registered in the photocatalytic technology domain by TOTO Ltd (TOTO Ltd 2008). Another important commercial product among the photocatalytic building materials is TiO2 based self-cleaning glass. Its successful application is not only due to the self-cleaning function but also strengthened by the light-induced anti-fogging property. Fogging of the surfaces of mirrors or glass happens when steam is cooled down on the surface to form fine water droplets. As droplets fall or form on a hydrophilic surface, they rapidly coalesce to form a water sheet. The visible view behind the glass can still be observed without blockage or distortion. Moreover, the superhydrophilic layer makes the glass dry without leaving the traditional droplet marks (Sanderson K 2001). Similarly with these advancements, many other researches have been proposed which indicate a new method of cooling buildings by sprinkling water on the surface of buildings which are coated with TiO_2. This new application of photocatalytic building materials can result in significant reduction of electricity consumed for air conditioning (Hashimoto K 2005).

3.2 In an urban road environment

The UK is currently facing a fine of $500 million for London exceeding the PM10 particle pollution limits more than 35 times for the entire year (Olek J *et al*, 2003). This study proves the necessity of photocatalytic coating on a huge scale. Some benefits of photocatalytic concrete are that it decomposes chemicals that contribute to soiling and air pollution, keeps the concrete cleaner, and reflects much of the

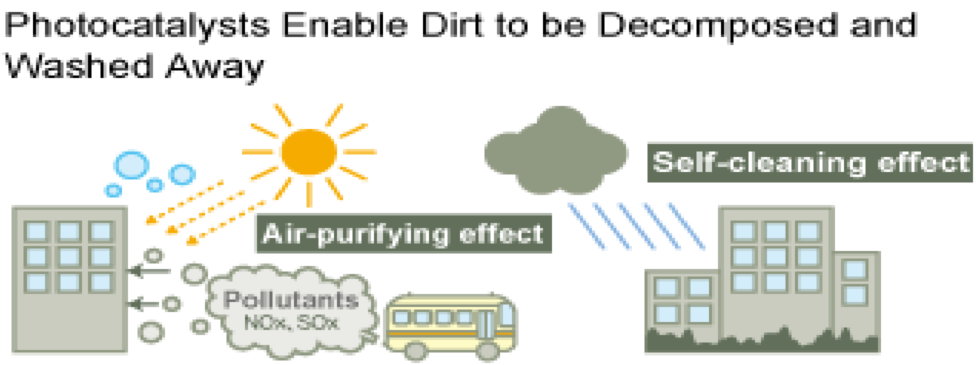

Figure 4 Effects of photocatalysis ("Trends in Japan | Web Japan")

sun's heat and reduces heat gain because of its white color (Chusid M., 2006). However, a lot of work has been done to promote carpooling and better public transportation has been designed but still the vehicle emissions continue to grow in the environment due to which the importance of photocatalytic concrete cannot be neglected. It is to be noted that the contact of TiO_2 with sunlight is very important. Once they stay in contact then the photocatalytic effect becomes very prominent instead of having the TiO_2 mixture within the concrete layer. If the TiO_2 coating is brushed on the top of the surface pavement then they seemed to be more durable in case of light pedestrian traffic whereas in case of high abrasion of vehicles the top coating of the TiO_2 seems to get abraded.

Table 1 Material Cost for each Coating Type (Shen *et al.* 2012)

Coating type	Material cost		Observed pollutant reduction			
	Total material cost ($/ft^2)	Total material cost ($/m^2)	Static chamber (120 min)		Converted Static chamber (29.83 min) total% NO reduction	Decrease in infiltration rate (%)
			Total% toluene reduction	Total% TMB reduction		
Commercial water-Based TiO_2 (CWB)	0.9955	10.70	61.86 ± 14.06	94.64 ± 1.85	97.59	20.60
Cement–water slurry (CWSH)	0.1860	2.00	13.23 ± 1.62	81.65 ± 1.50	85.04	58.29
Driveway protector mix (DPM)	0.3876	4.17	61.65 ± 10.77	93.87 ± 1.09	97.92	30.49
Pureti (PUR)	0.1000	1.08	43.42 ± 1.79	89.50 ± 4.05	95.79	11.92
Cement–water slurry low (CWSL)	0.1655	1.78	78.82 ± 9.22	97.26 ± 0.63	96.94	51.50
Cement/aggregate mix (CAM)	0.3045	3.27	21.62 ± 4.30	68.28 ± 5.99	55.35	3.85
Cement/aggregate mix high (CAMH)	0.3030	3.26	–	–	81.03	3.49

Table 1 shows different coating types which have been mixed together with different concentrations of cement and other substances depending on the coating type. After the study of these different coating types Driveway protector mix was considered the best choice as it is a mixture which consists of a transparent liquid drive way protector (siliconate, water-based concrete sealer) and TiO_2 uniformly mixed together and brushed on to the surface of pervious concrete (Shen *et al.*, 2012). The conclusions of this table suggest that DPM is the best mixture as compared to cost efficiency and performance of its photocatalytic capability. The highest reduction in pollutants and the highest resistance to weathering can be seen with this mixture which is a breakthrough for the photocatalytic research. The white color of the TiO_2 particles seen in the DPM coating could potentially be used as pavement marking materials, at the same time achieving air purification effect (Shen *et al.*, 2012). The other coatings seem not to produce the desired result because of having more concentration of other components in the mixture such as cement than TiO_2. However, more research is required as this is still a nascent research category which still demands substantial amount of concentration to benefit the future generations to come.

4-Conclusions

This paper displays the modern research and development in the construction industry specifically concerning photocatalytic building materials and their carious applications. The scientific, laboratory and on site research avers that photocatalytic building materials are the sustainable future of a smart developing construction industry. Several photocatalytic materials have been used in various projects and the results affirm that photocatalytic materials cannot only retain the aesthetics of the building over time but it can also support well enough in making the environment free of micro-organisms. The paper also exhibits information regarding the approach to applying the photocatalytic materials such as it is discussed it detail in the case of roads which asks to keep the concentration of the mixing material in check with the TiO_2 whereas it also suggests to apply the mixture on the top of the pavement instead of mixing it inside because that would inhibit the direct reaction of TiO_2 with sunlight. Although the efficiency and durability of these materials still needs further investigation in all kinds of weathers and environment but the prospective usage of these photocatalytic building materials display massive and auspicious potential.

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