Photocatalytic Concrete Using ZnO and Al_2O_3 - A Review

Julieta Eka Yudo Putri[1] and *M. Mirza Abdillah* Pratama[2,3*]

[1]Laboratory of Structure, Department of Civil Engineering and Planning, Universitas Negeri Malang, Indonesia
[2]Department of Civil Engineering and Planning, Universitas Negeri Malang, Indonesia
[3]Department of Civil and Structural Engineering, The University of Sheffield, United Kingdom

Abstract. Photocatalytic concrete is one of the innovations in the construction sector that environmentally friendly. Photocatalytic concrete can be decomposing harmful pollutants such as nitrogen oxides (NO_x) and SO_2. In its application, a widely used photocatalyst is TiO_2. In fact, the use of TiO_2 has several disadvantages, which is less efficient because the separation of TiO_2 photocatalysts is very difficult and requires greater energy. In addition, the wide band-gap energy of TiO_2 makes only a fraction of the ultraviolet (UV) fraction of sunlight usable. This study aims to analyse photocatalysts that are more usable in large quantities and easy to apply. Based on research that has been done, the use of ZnO and Al_2O_3 as photocatalysts replaces the use of TiO2 which has been used effectively to do. In addition to its simpler use, and its abundant availability, Al_2O_3 and ZnO can break down pollutants well.

1 Introduction

Currently, air pollution is one of the focuses that is being given attention by the world. Nearly 90% of air pollution-related deaths occur in low- and middle-income countries, with nearly 2 in 3 cases occurring in Southeast Asia and the Western Pacific region [1]. This air pollution mainly affects people living in urban, where industrial and traffic emissions have the largest contribution to air quality degradation, especially NO_x pollutants [2]. The main sources of NOx are transportation at 43%, industrial at 32% and natural processes at 5%. In urban areas there are many uses of motor transport and industrial centres. Nitric oxides (NO_x) are a group of gases present in the atmosphere consisting of nitric gas (NO) and nitrogen dioxide (NO_2). NO_x is also a gas responsible for smog and brown clouds produced by industry and vehicles in big cities and makes air quality in big cities worse [3]. This makes NO_x pollutants as pollutants that play a role in the formation of the O_3 troposphere, Peroxyacetyl Nitrate (PAN), and aerosols [4]. Nitrogen Oxide (NO_x) emissions produced from various human activities affect plants, animal, and human life. Air pollutants, such as NO_x affect the human body, causing premature death especially in the heart and lungs.

* Corresponding author: mirza.abdillah.ft@um.ac.id

One way that can be taken by the construction sector to overcome pollutants is to create self-cleaning concrete or concrete with photocatalyst added [5,6]. One photocatalyst that has been widely used is TiO_2 [7,8]. Both laboratories and fields that have conducted experiments, revealed that the addition of TiO_2 to pavement surfaces and building materials can significantly reduce air pollution and is self-cleaning [9]. However, photocatalytic compounds in the form of TiO_2 have various disadvantages. TiO_2 is considered a less efficient material because the separation of TiO_2 photocatalysts is very difficult and requires more energy. In addition, the band-gap energy of TiO_2 is wide (≈3.2 eV), so that only a small fraction of ultraviolet (UV) sunlight can be used [10]. Therefore, other photocatalytic compounds are needed that are feasible and can be used in photocatalytic concrete for the same purpose and can be used in the long term. One compound that is considered better and feasible for use in *photocatalytic concrete* is zinc oxide (ZnO) and aluminium oxide (Al_2O_3). Zinc oxide has been tested to have high electron mobility, so fabrication will be easier and make production costs cheaper [11]. This study was conducted to analyse the use of ZnO and Al_2O_3 as photocatalysts.

2 Method

This research was conducted using the literature review method using secondary data obtained from previous studies. The stages carried out in this study are data collection, data reduction, data analysis, discussion, and finally is drawing conclusions and finishing. The stages of research are systematically presented in Figure 1.

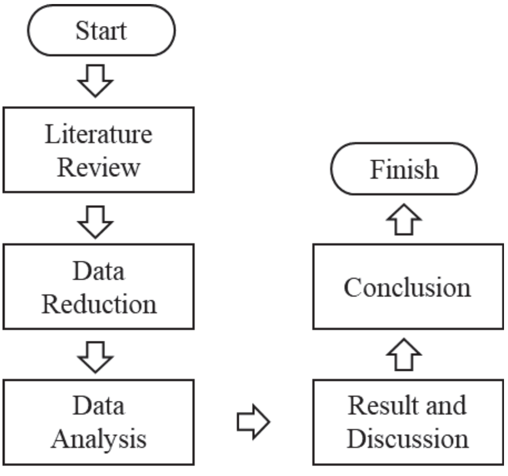

Fig. 1. Research flow chart

a. Data collection is carried out by looking for theoretical bases and research data related to the topics raised with the keywords self-cleaning concrete, photocatalyst concrete, the effect of adding TiO_2 to concrete, the effect of adding ZnO to concrete, the effect of adding Al_2O_3 to concrete in reputable articles and journals.
b. Data reduction by summarizing the data obtained to review the use of ZnO and Al_2O_3 as photocatalysts.
c. Data is presented in the form of tabulations and presentation of quantitative data for further analysis in the form of narrative text, graphs or tables to facilitate understanding.
d. Drawing conclusions is carried out by synthesizing the data obtained and equating with various sources in order to get the best conclusion.

3 Result and Discussion

3.1 Air Pollutants and their impact

Air is the most important substance after water in its contribution to life. Normal air contains 78.1% nitrogen, 20.935 oxygen and 0.03% carbon dioxide. As population and human activities increase, air quality declines and ultimately affects health. Air pollution itself is a condition of entry of other components into the air both by human activities and natural processes that cause air quality to drop and result in a decrease in the quality of the environment and life [12]. Any substance or material not a component of normal air is called a pollutant [13]. Air pollution consists of various components including fine particles (PM2.5), coarse particles (PM10), oxides of nitrogen (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), and tropospheric ozone [13]. Emission patterns will classify pollutants from point sources, line sources and area sources. Viewed chemically, there are many kinds of pollutants but what is usually a concern is the main pollutants (major air pollutants) namely the group of carbon oxides (CO, CO_2), sulfur oxides (SO_2, SO_3) and oxides of nitrogen (N_2O, NO, NO_3) compounds resulting from photochemical reactions, particles (smoke, dust, asbestos, metal, oil), anorganic compounds (HF, H_2S, NH_3, H_2SO_4, HNO_3), hydrocarbons (CH_4, C_4H_{10}) radioactive elements (titanium, radon), thermal energy (temperature, noise).

Humans come into contact with various air pollutants through a very easy way in the form of inhalation and consumption as well as small exposures to the skin. Air polluted with particles in the form of dust, aerosols, lead and gases including CO, NO_x, SO_x, H_2S, can cause health problems of different levels and types, depending on the type, size and chemical composition. These disorders mainly occur in the function of crucial organs such as the lungs and blood vessels or can also cause irritation to the eyes and skin. Air pollution due to dust particles usually causes chronic respiratory diseases such as bronchitis, chronis, emphysema, lung cancer. CO gas poisoning arises due to the formation of carboxyhemoglobin (COHb) in the blood. Reduced oxygen supply to the body will make shortness of breath, and can cause death[14][15].

With the huge risk of air pollution, efforts to reduce the presence of these pollutants continue to be carried out by various sectors, one of which is the construction sector. The construction sector is one of the biggest contributors to air pollution, namely through the use of large fossil fuels in every process. Researchers continue to innovate through low-emission material modification and applying green construction principles to reduce as much as possible the emissions caused by the construction sector. One of these innovations is the use of photocatalysts in construction materials that have photocatalytic capabilities in the hope of being able to break down pollutants and return them to nature as harmless substances.

3.2 Photocatalytic Concrete

Photocatalytic concrete is one of the environmentally friendly concrete innovations that is able to decompose harmful pollutants such as nitrogen oxides (NO_x) and SO_2 into HNO_3, H_2SO_4, and H_2CO_3 which are easily washed away by rainwater. Photocatalytic concrete has the ability to clean itself independently so that it is recognized by concrete with the principle of self-cleaning or self-cleaning concrete. Photocatalytic concrete is made by adding photocatalysts in several ways, including direct addition when mixing concrete constituent materials, using concrete constituent materials that have been added photocatalysts or by spraying photocatalyst liquid on the concrete surface. Several studies have proven that the addition of photocatalysts allows concrete to clean itself and decompose contaminants containing NO_x, SO_2, and others through photocatalyst reactions [5,16–19].

3.3 Photocatalytic Mechanism

Photocatalyst consists of photo which means light and catalyst which means a substance that can accelerate a chemical reaction [20]. Thus, based on this, photocatalytic reactions are chemical reactions that are accelerated by the presence of photocatalyst material with the help of photons. Photocatalytic reactions are also one of the advanced oxidation technologies used in water and air purification. The principle of self-cleaning was originally discovered by Wilhelm Barthlott and his team from the University of Bonn, Germany in 1973 [21].

The photocatalyst mechanism begins with the presence of semiconductor materials which in this case are catalytic substances containing valence bands and conductivity in their atomic structure. If a photon is absorbed from a UV source with energy greater than the band gap of the semiconducting material, then an electron in the valence band is stimulated to move to the conductivity band and an electron void occurs in the valence band. Thus, the reaction will produce a stimulated electron pair (e-) – positive space (h+). This e^- - h+ pair will undergo chemical reduction and oxidation reactions on the surface of the photocatalyst. However, to remove pollutants, physical reactions such as rain and wind are needed. The mechanism of the photocatalytic process is shown in Figure 2.

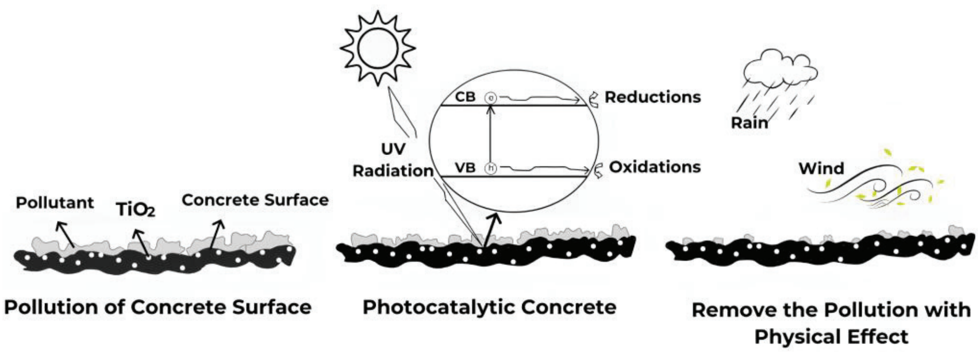

Fig. 2. Photocatalytic process mechanism [12]

3.4 Zinc Oxide (ZnO) and Aluminum Oxide (Al_2O_3) as Photocatalysts

Zinc Oxide is an inorganic compound with the formula ZnO. In most cases, this compound is in the form of a white powder and is almost insoluble in water. The powder is widely used as an additive into various materials and products including plastics, ceramics, glass, cement, rubber and lubricants. The advantages of using ZnO are one of which is relatively low and abundant availability in nature, stable chemical structure and non-toxic. The use of ZnO as a photocatalyst is caused because this substance has *self-cleaning, self-disinfecting* properties, and converts NO_x into NO_3 which is not harmful to the community (depollution) [22] ZnO has a higher biocatalyst efficiency compared to other photocatalyst materials, due to the strong UV light absorption process from the sun's specs [23]. In addition, ZnO is an efficient photocatalyst material to improve manufacturing time. The addition of ZnO increases the processing time and resistance of concrete to water. When the sun hits the concrete surface, some of the organik pollutants will be neutralized. In the presence of light, zinc oxide creates a charge that is scattered on the surface of the photocatalyst and reacts with external substances to decompose organic compounds [24]. Aluminum oxide with the chemical formula Al_2O_3 is a natural compound that has high thermal conductivity and is highly reactive with atmospheric oxygen.

In their research, [25] analyzed the comparison of the use of TiO_2, ZnO and Al_2O_3 on concrete cubes measuring 150 × 150 × 150. The concrete used is M25 grade concrete designed based on IS code-10262: 2009. Furthermore, concrete mixed with photocatalysts in this case used are TiO_2, ZnO and Al_2O_3 with percentages of 0.5%, 1%, and 1.5% of the weight of cement. Based on concrete compressive strength tests conducted after days 7 and 28, an increase in compressive strength occurred in the concrete mixture with the addition of 1% photocatalic nanoparticles. This is in line with research from [24], which tested the compressive strength of concrete in the addition of 0%, 0.5%, 1%, and 1.5% ZnO nanoparticles to the weight of cement. In this study, an increase in compressive strength also occurred at a level of 1% and decreased at a level of 1.5%. The decrease in compressive strength in the increase in nanoparticle levels is caused by the content of nanoparticles that fill the pores of cement too large and interfere with the reaction of cement water so that its strength decreases [25]. Next, to analyze the ability of self-cleaning [25] added 1 ml of Rhodamine dye dripped on each surface of the concrete cube with a nanoparticle content of 1%. Next, the specimen is placed in direct sunlight. Concrete containing photocatalysts is evaluated based on decoloration under sunlight, which is a standard test for self-cleaning cementitious materials. Based on the tests conducted, cube samples with a mixture of TiO_2 nanoparticles showed better cleaning ability compared to cubes with a mixture of ZnO and Al_2O_3 with the order TiO_2 > Al_2O_3 > ZnO. Although the cleaning capability of TiO_2 is greatest, the use of ZnO and Al_2O_3 can be considered for widespread use to replace TiO_2 as photocatalysts. In addition to having chemical stability, high thermal conductivity, large electronic mobility, non-toxic, ZnO also has a cheaper price.

3.5 Implementation of Photocatalytic Concrete

Photocatalytic concrete can decompose organic matter (soot, dirt, and oil), biological material (fungi, algae, and bacteria), and pollutants (volatile organic compounds), so it has great potential to build infrastructure that functions to prevent environmental degradation. Until now photocatalytic concrete has begun to be applied, including its use as paving, exterior wall and roof materials. Based on the presentation of [26], there are several buildings in the world that have applied this photocatalytic concrete, including Cité de la Musique et des Beaux-Arts'Chambery, France; The Hôtel de Police'Bordeaux, France; MSV Arena Football Stadium Germany; Saint John's Court Montecarlo Bay residence, Monaco; Manuel de Gonzalez Hospital, Mexico; and Tüpras Refinery, Kocaeli – Turkey.

3.6 Challenge of developing photocatalytic concrete

The use of photocatalyst reactions in the context of Nox reduction has been carried out for more than 20 years. The use of photocatalytic concrete as part of the use of the photocatalyst effect is being developed for commercialization [27]. Although air quality is currently declining with pollution, photocatalytic concrete is still very rare for use in the construction sector. Its application is only carried out in a few locations with the aim of scientific research and demonstration such as in Italy [28], France [[28]], Japan[[29]Belgium [18,30], England,[31]and China. The obstacles to the application of photocatalic concrete stem from the high costs that must be incurred for its application, but many still question its effectiveness in breaking down pollutant molecules if used on a large scale.

Actually, in its use photocatalyst concrete only requires sunlight, oxygen and water which means the remediation process can be carried out continuously during the day. However, the widespread use of photocatalic concrete needs to consider fundamentals such as light sensitivity and geographical applicability i.e. the influence of latitude, season and time on photocatalytic performance. Furthermore, it is also necessary to consider the presence or absence of side effects caused by catalyst chemicals if used continuously.

4 CONCLUSION

Photocatalytic concrete is one of the environmentally friendly concrete innovations that is able to decompose harmful pollutants so that it has great potential to build infrastructure that functions to prevent environmental degradation. Based on the explanation in subchapter 3, it can be concluded that the use of ZnO and Al_2O_3 as photocatalysts replaces the use of TiO_2 which has been used effectively to do. In addition to its simpler use, and its abundant availability, Al_2O_3 and ZnO can break down pollutants well.

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