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Performance Evaluation of Cement Board Mixing Graphite Powder and TiO2

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Abstract

The development of eco-friendly building materials capable of improving indoor air quality is essential. Although studies using photocatalysts have been conducted for this purpose, they have limitations in that their performance in adsorbing and decomposing harmful substances significantly declines in environments without light. To address this issue, this study evaluated the performance of cement board mixing graphite powder, which has physical adsorption performance, along with photocatalysts. Through preliminary testing, the replacement ratio of graphite and photocatalysts (TiO2, Recycled TiO2, and Mixing TiO2) was set at 10% by weight of cement. Comparative experiments were conducted based on the type of photocatalyst mixed with graphite in the cement boards. The test items included flexural failure load, impact resistance, fine dust adsorption, and CO2 adsorption. The experimental results showed that the flexural failure load and impact resistance for all three types met KS standards. For fine dust (PM2.5, PM10), and CO2 adsorption, the best performance was shown by recycled TiO2, Mixing TiO2, and TiO2, respectively, but the differences between them were minimal. Based on these results, it is concluded that the Mixture of graphite increases adsorption performance regardless of the type of photocatalyst used.

Keywords: *Cement board, Graphite, Photocatalysis, Eco-friendly, TiO2.*

Introduction

According to the World Health Organization (WHO), air pollution causes approximately 7 million deaths worldwide each year, with 3.8 million of those attributed to indoor air pollution. Pollutants released indoors are about 1,000 times more likely to reach the human lungs compared to outdoor pollutants, and reducing indoor pollution by just 20% can lower the mortality rate from acute bronchial diseases by approximately 4–8%. Fine dust increases the risk of respiratory diseases such as asthma, allergies, colds, and pneumonia. Elevated CO_2 concentrations can cause drowsiness, headaches, shoulder stiffness, and dizziness. In particular, high CO_2 levels may lead to premature birth or developmental disorders in infants when pregnant women are exposed[1].

Some previous studies have applied adsorbent materials such as photocatalysts (TiO_2 and recycled TiO_2), sepiolite, activated carbon, graphite, and diatomite to materials like cement and paint to remove harmful substances. Among them, TiO_2 is a representative photocatalyst capable of decomposing harmful substances using light energy[2]. However, because TiO_2 exhibits light-activated adsorption properties, its performance in adsorbing and decomposing pollutants significantly decreases in the absence of light. To overcome this limitation and ensure stable removal performance of harmful substances under various conditions, it is considered necessary to combine TiO_2 with adsorbents that are less dependent on light. Additionally, recycled TiO_2 is environmentally friendly, as it is produced by recycling industrial waste. Although studies using recycled TiO_2 have reported its effectiveness in removing harmful substances in cement-based applications, they have not evaluated performance criteria (mechanical and physical properties) required in the construction field.

Therefore, this study examines the performance of cement board mixing a photocatalyst with light-activated adsorption properties and graphite powder with physical adsorption performance. By developing a finishing material using these adsorbents, the study aims to provide foundational data for

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the development of eco-friendly building materials capable of improving indoor air quality.

Theoretical Review

Adsorption refers to the process by which atoms, molecules, or ions in a gaseous, liquid, or dissolved state adhere to the surface of a solid or liquid. A solid on which adsorption occurs is called an adsorbent, and the phenomenon in which gas molecules attach to the surface of a solid adsorbent is commonly referred to as adsorption. Depending on the type of bonding between the adsorbed molecules and the adsorbent surface, adsorption can be classified into physical adsorption and chemical adsorption. In physical adsorption, the electronic structure of the adsorbed molecules remains largely unchanged, and adsorption occurs through weak intermolecular forces, such as van der Waals forces, which act only at very short distances. In contrast, chemical adsorption involves the formation of chemical bonds between the adsorbed molecules or atoms and the surface of the adsorbent.

When exposed to light, electrons (e^-) and holes (h^+) are generated. These electrons and holes react with oxygen and water molecules adsorbed on the surface to produce strong oxidizing agents such as superoxide ($O2^-$) and hydroxyl radicals (·OH). These radicals can oxidize and decompose most organic compounds into CO_2 and water (H_2O), making them applicable for antibacterial purposes, deodorization, and the removal of volatile organic compounds (VOCs), dioxins, soot, and fine dust[3]. Additionally, TiO_2 can adsorb CO_2 through reactions with hydrogen ions or hydroxide ions on its surface[4].

Graphite is a substance in which carbon atoms are bonded in a hexagonal pattern, forming a laminated structure. This continuous layered arrangement gives graphite its physical adsorption performance and affects its electrical conductivity, thermal expansion coefficient, and mechanical strength. In addition, the excellent electrical conductivity of graphite supports electron transfer in TiO_2, thereby improving the efficiency of photocatalytic reactions.

When TiO_2 and graphite are used together, the electron transfer support provided by graphite improves overall adsorption performance while also compensating for the limitation of TiO_2 being dependent on the intensity of ultraviolet light. Graphite physically adsorbs pollutants, and TiO_2 decomposes them through reactive oxygen species (ROS). The combination of TiO_2 and graphite accelerates both the adsorption and decomposition processes, resulting in improved adsorption efficiency. This synergy enables adsorption performance under a wide range of environmental conditions[5,6].

Experimental plan and Methods

Experimental Plan

In this study, the performance of cement board mixing graphite powder and photocatalysts was evaluated. The experiment was conducted in two stages: Series 1 was a preliminary test to determine the optimal replacement ratio of graphite for cement board production, and Series 2 involved producing actual cement board based on the results of Series 1 and evaluating their performance. Based on the results of Series 1, the optimal replacement ratio of graphite was determined to be 10%, considering both mechanical strength and adsorption performance. In Series 2, ordinary portland cement was used as the binder, and the water-to-binder ratio (W/B) was set at 30% to ensure sufficient fluidity for casting. The adsorbents used were graphite and photocatalysts (TiO_2, Recycled TiO_2, and Mixing TiO_2). Among these, Mixing TiO_2 refers to a 1:1 blended of TiO_2 and Recycled TiO_2. Graphite was mixed at the optimal replacement ratio of 10% by weight of cement, as determined in Series 1, and the photocatalysts were also added at 10%, the same as graphite, to ensure equal contribution from both materials. The cement board were fabricated in accordance with KS F 3504, with dimensions of 300 × 400 × 9.5 mm^3, and tested accordingly. The experimental items included flexural failure load, impact resistance, fine dust (PM2.5, PM10) adsorption, and CO_2 adsorption. These tests were conducted at five different experimental levels. The experimental factors and levels are shown in Table 1.

Table 1. Experimental Factors and Levels

Experimental factors	Experimental levels	Remarks
Binder	Ordinary portland cement	1
W/C (%)	30	1

Adsorption materials	Graphite, Photocatalyst	2
Type of photocatalyst	TiO_2, Recycled TiO_2, Mixing TiO_2 (TiO_2 : Recycled TiO_2 = 1:1	3
Mixing ratio (%)	10	1
Curing condition	Humidity 60±5(%), Temperature 20±2 (℃)	1
Experimental items	Flexural failure load, Impact resistance, Fine dust adsorption (PM2.5, PM10), CO_2 adsorption	4

Using Materials

Tio$_2$

The TiO_2 used in this study is a type of photocatalytic material that initiates chemical reactions capable of decomposing nitrogen oxides contained in fine dust when exposed to light. TiO_2, known as titanium dioxide, is composed of one titanium atom, which is a transition metal, and two oxygen atoms. It exists in three main crystalline structures: anatase, rutile, and brookite. In this study, the anatase form, with a density of 4.0 g/cm^3 and a particle size of 20-30 μm, was used.

Recycled TiO$_2$

The recycled TiO_2 used in this study was produced from sludge containing byproducts generated during the wastewater treatment process. It is more economical than conventional TiO_2 and costs approximately KRW 60,000 per kilogram. Its density is 0.45 g/cm^3, and the particle size ranges from 20 to 30 nm.

Graphite

Graphite is a material with a metallic luster in appearance and has a hexagonal crystal structure consisting of many thin graphite layers stacked together in a laminated form. Its laminated structure gives it adsorption capabilities. It is characterized by excellent thermal conductivity and a metallic texture, and it exhibits high resistance to chemical substances, temperature, and shrinkage, along with a low friction coefficient, making it widely used in industrial applications. The graphite used in this study had a density of 2.11 g/cm^3 and a particle size of 10-20 μm.

Experimental Methods

Flexural Failure Load

The flexural failure load test of the fabricated cement board was conducted in accordance with KS F 3504, “Gypsum Board Products.” The test was conducted with a span of 350 mm and an average loading rate of 250 N/min ± 20%.

Impact Resistance

The impact resistance test of the fabricated cement board was conducted after drying the board, in accordance with KS F 2221, “Test Method for Impact Resistance of Building Boards.” A spherical weight (W2-500) was dropped from a height of 500 mm to test the impact resistance.

Adsorption

The adsorption tests for fine dust (PM2.5, PM10) and CO_2 were conducted using a small chamber method proposed by Hanbat National University. For measurement, the fabricated board and the appropriate measuring device, either a fine dust concentration meter or a CO_2 concentration meter (ISR-5000) depending on the test item, were placed inside a small sealed chamber. A fan was operated so that the fine dust (PM2.5, PM10), and CO_2 were evenly distributed within the chamber, and their concentrations were maintained at consistent levels. The fine dust adsorption test was conducted over a total of 120 minutes with measurements taken at 20-minute intervals, and the CO_2 adsorption test was conducted over 18 hours with measurements taken at 2-hour intervals to observe changes in concentration. In addition, ultraviolet (UV) lamps were installed in the chamber based on the principle that photocatalysts remove harmful substances under UV light exposure, and the experiment was conducted accordingly.

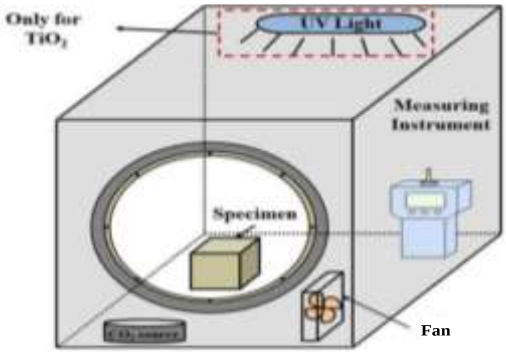


Figure 1. Adsorption chamber

Experimental Result and Analysis

Flexural Failure Load

Figure 2 shows the results of the flexural failure load test of the cement board according to the type of photocatalyst. The flexural failure load was highest in the order of TiO_2, Mixing TiO_2, and Recycled TiO_2. All three types showed performance exceeding the KS F 3504 standard of 140 kN.

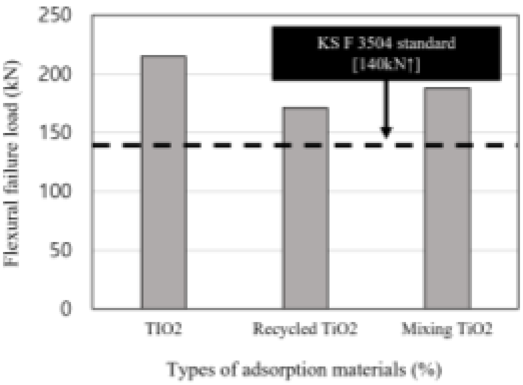


Figure 2. Flexural Failure Load

Impact Resistance

Figure 3 shows the results of the impact resistance test of the cement board according to the type of photocatalyst. The diameter of the indentation caused by the drop of a spherical weight was smallest in the order of TiO_2, Mixing TiO_2, and Recycled TiO_2. All three types showed indentation diameters smaller than the KS F 3504 standard of 25 mm, meeting the KS criteria.

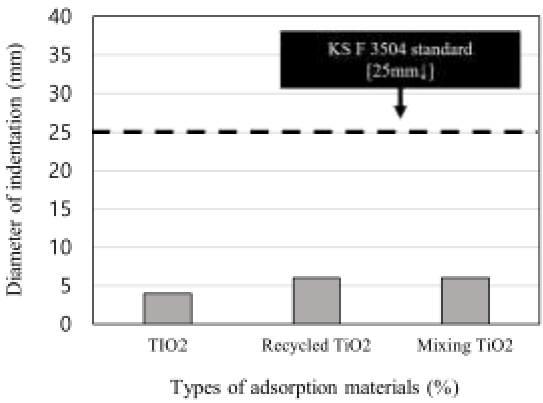
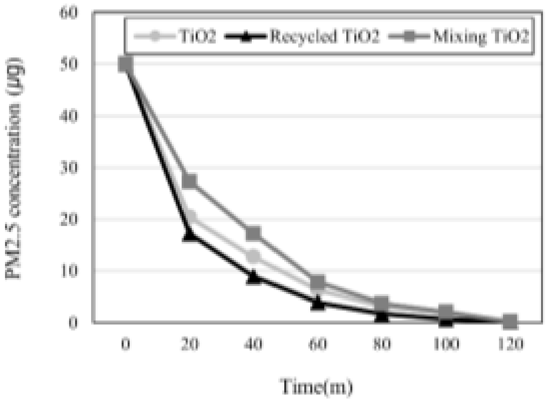


Figure 3. Impact Resistance

Fine Dust Adsorption

Figure 4,5 shows the results of the Fine dust adsorption (PM2.5, PM10) test of the cement board according to the type of photocatalyst. The test results indicated that the adsorption performance for PM2.5 was highest in the order of Recycled TiO_2, TiO_2, and Mixing TiO_2. For PM10, the adsorption performance was highest in the order of TiO_2, Recycled TiO_2, and Mixing TiO_2.



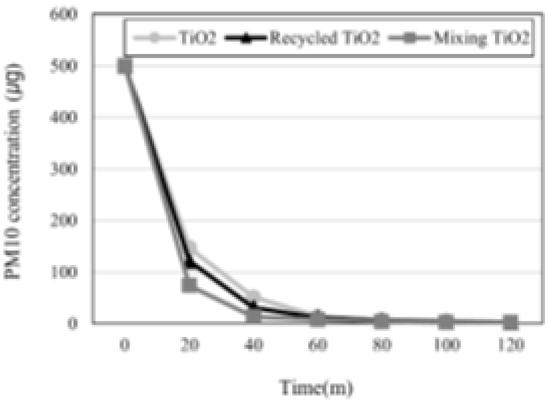


Figure 4. Fine Dust Adsorption(PM 2.5) **Figure 5. Fine Dust Adsorption(PM 10)**

CO_2 Adsorption

Figure 6 shows the results of the CO_2 adsorption test of the cement board according to the type of photocatalyst. The test results indicated that the CO_2 adsorption performance was highest in the order of Recycled TiO_2, Mixing TiO_2, and TiO_2. However, the differences in fine dust adsorption among the types were minimal, with a maximum variation of 165 ppm.

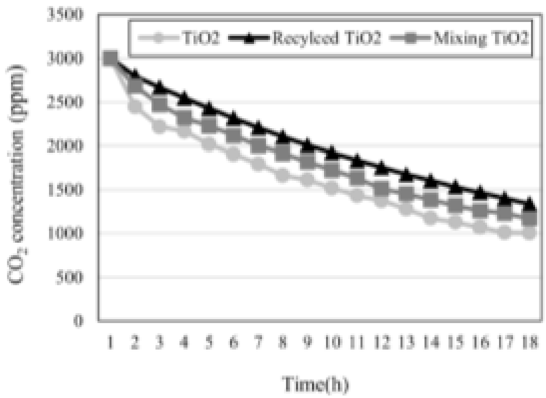


Figure 6. CO_2 Concentration

Conclusion

Using the optimal graphite replacement ratio determined from the Series 1 preliminary experiment, the flexural failure load, impact resistance Fine dust adsorption (PM2.5, PM10), and CO_2 adsorption of cement board mixing graphite and photocatalysts were analyzed in this study. The flexural failure load and impact resistance were found to be highest in the order of TiO_2, Mixing TiO_2, and Recycled TiO_2, and all three types met the KS standards. The maximum flexural failure load reached 44 kN, and the maximum indentation diameter in the impact resistance test was 2 mm, although the differences between photocatalyst types were minimal. For adsorption performance, PM2.5, PM10, and CO_2 were most effectively adsorbed by Recycled TiO_2, Mixing TiO_2, and TiO_2, respectively, although the differences among them were minimal. These adsorption performance are attributed to the catalytic activity of the photocatalysts and the physical adsorption properties of the laminated structure of graphite. Furthermore, the excellent electrical conductivity of graphite is believed to increase photocatalytic reaction efficiency, thereby improving adsorption performance. Based on the experimental results, it is concluded that the mixed of graphite improves adsorption performance regardless of the type of photocatalyst used.

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