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A Study on the Optimal Utilization Conditions by Verifying the Effectiveness of Fine Dust Reduction of TiO_2

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Abstract - This study recently conducted various experiments using TiO_2 to increase the utilization of economical TiO_2 outer wall coating agents to solve fine dust, which is a major cause of air pollution. By comparing the performance of existing TiO_2-containing application products, it shows how to utilize them for future use of photocatalysts. The experiment is largely divided into two stages. First, the effectiveness was verified by comparing the performance of reducing fine dust according to the mixing concentration of TiO_2. Afterwards, experiments were conducted according to the number of applications, drying time, and surface materials using existing TiO_2-containing products.

***Keywords*:** TiO_2, Fine dust, Cement block, Air purification

1. Introduction

According to the International Air Pollution Research Institute Air Visual's 2019 World Air Quality Report, Korea's ultrafine dust pollution level recorded the highest average PM2.5 among OECD countries, with 61 of the top 100 most polluted cities in Korea. In addition, the maximum gap between regions for fine dust concentrations is only 15 μg/㎥, which is considered a shared problem in both cities and rural areas, and it is urgent to come up with a solution.[1)]

According to data released by the Ministry of Environment in 2019, the primary emission of fine dust is mainly generated when fossil fuels such as coal or oil are burned or gas is emitted from factories and cars, and these harmful substances react with airborne substances to generate secondary generation of fine dust. More than 70% of fine dust in Korea has been found to be secondary-generated fine dust, which consists of substances harmful to the body, such as nitrate, anaerobic sulfate, and ammonium. In order to reduce these substances, reduction of nitrogen oxide, sulfur oxide, ammonia, etc. is necessary.[2)]

While various technologies are emerging to reduce fine dust, technologies that apply photocatalyst are in the spotlight. Photocatalysts are catalysts that accelerate the oxidation and decomposition of fine dust-causing materials when irradiated with light, which can effectively reduce secondary generated fine dust by using the principle of oxidizing and decomposing nitrogen oxides, sulfur oxides, and volatile organic compounds in solar conditions.

Yoon Il-ho (2017) demonstrated significant reduction in levels using photocatalyst Titan dioxide (TiO_2) to reduce nitrogen oxide (NO_X) in the atmosphere, and further studies on reducing nitrogen oxide using photocatalysts have been actively conducted. In particular, TiO_2, which has the advantages of durability, low price, and harmlessness among photocatalysts, is expected to be highly likely to be used.[3)]

Kim Han-im et al. (2019) evaluated the effect and applicability of cement-based construction materials mixed with photocatalysts and confirmed that the NO removal rate also increased as the mixing rate of photocatalysts increased. In addition, efforts to develop photocatalysts in domestic and foreign construction sectors were compared to commercialization at actual construction sites. [4)]

Lee Sang-soo and Lee Won-kyu (2019) analyzed characteristics according to the rate of replacement of cement-based photocatalysts as basic experiments to develop concrete panels for reducing fine dust. As the replacement rate increased, the density, absorption rate, thermal conductivity, and strength of the hardened objects all tended to decrease, and the amount of fine dust reduced increased.[5)]

Song Yong-woo et al. (2019) conducted a Mock-up experiment to change NOx concentration due to UV lamp and photo catalyst paint mixed with TiO_2 to reduce secondary pollutants of fine dust. Through this, it was confirmed that there was a difference in the amount of NOx reduction depending on the presence or absence of ultraviolet rays indoors, but the amount of reduction was not proportional to the amount of UV rays.[6)]

Kim Mi-yeon et al. (2020) quantitatively analyzed the reduction effect of NOx, the cause of fine dust, by applying photocatalyst coating agent, photocatalyst paint, and photocatalyst shotcrete to the outside of the building, which is the actual site. Through preliminary experiments, the effectiveness of each photocatalyst-applied exterior material was verified, and it was suggested that the exterior material should be applied considering surrounding buildings and environmental conditions to maximize NO reduction.[7)]

Kim Min-young (2020) demonstrated the NOx reduction performance of TiO_2 by establishing an environment similar to the actual atmosphere through UV light and NO gas conditions and suggested the possibility of being used as indoor and outdoor finishing materials when applied to buildings affected by ultraviolet rays.[8)]

As a result, research on ways to reduce fine dust using TiO_2 has been actively conducted in the construction industry, but it is limited to be actively applied to industrial sites due to the lack of effective use and application laws. Therefore, in order to improve the efficient and economical utilization of TiO_2 outer wall application, various attempts such as number of applications and surface base materials were made on TiO_2 application methods, and it is intended to be used for actual application development in the future.

2. Method & Material

In this study, we conducted an experiment to check the performance of TiO_2 to improve the atmosphere of fine dust. First, the effectiveness was verified by comparing the performance of reducing fine dust according to the mixing concentration of TiO_2. Afterwards, experiments were conducted according to the number of applications, drying time, and surface base materials using existing TiO_2-containing products.

In this experiment, 5g of solution was applied to $128cm^3$ cement block and compared with the reference body. At this time, a mixed solution of powder-type NP-P400 mixed with colloidal silica was used. In some experiments, white paint from AURO, Germany, containing TiO_2 was applied and used. The TiO_2 powder (NP-P400) has a particle size distribution ranging from 0.1μm to 10μm and its crystal structure is anatase. Colloidal silica YGS-30 (hereinafter referred to as silica sol) is a product of Yeongil Chemicals Co., Ltd. and is used as a high temperature binder, catalyst, and coating agent as solid silica particles are not deposited or agglomerated in liquids such as water and organic solvents.

The experiment was carried out by organizing a ash-type device to identify the change in the concentration of fine dust over time. Cement blocks, fine dust sensors, and fans for internal air circulation were operated in an internal sealed acrylic chamber to measure the amount of fine dust reduction changes for a certain period of time. A UV lamp was installed inside the stainless-steel chamber to activate the catalytic reaction. After configuring the device, gas with high fine dust concentration was injected into the chamber and the fine dust sensor (Sensirion, SPS30) was operated to record the fine dust concentration in the chamber every second. <Fig1> and <Table1> show device configuration, experimental procedures, and device specifications.

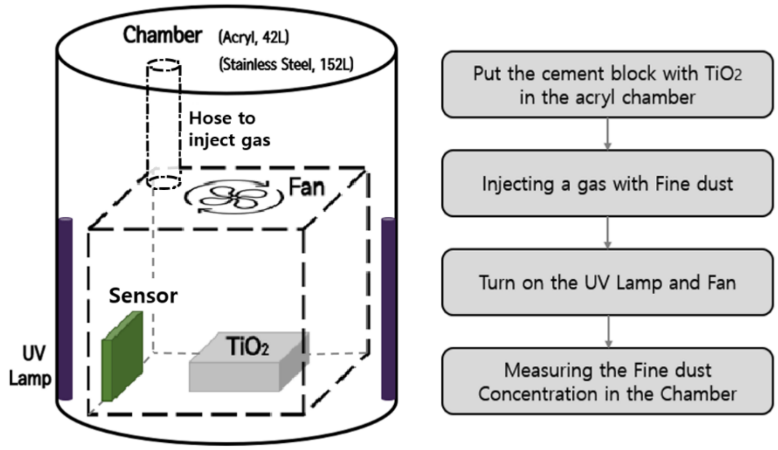

Fig. 1: Schematic diagram of the experimental chamber used in this study

Table. 1: Device Specifications

Equipment	Specification
Chamber	Acryl, 350 mm(D) x 350mm(H) x 5mm(T), 42L
	Stainless Steel, 40GL, 152L
UV Lamp	BLACKLIGHT 352nm, SANKYO DENKI Co., Ltd.
Fine dust Sensor	Sensor SPS30 [range : 1 to 1000 μg/㎥(M1.0, PM2.5, PM4 and PM10)], Sensirion Co., Ltd.

3. Experimental Results

3.1. Comparison of Fine Dust Reduction Performance by TiO_2 Concentration and Applications

In order to minimize the safety of the researchers, a stick type incense was used to collect fine dust. The composition of the fragrance used is herbal and wood powder 20%, 35% of fragrance material, 10% of adhesive powder, and 30% of bamboo stick. When stick incense is burning, it emits fumes containing particulate matter (PM) and other CO_2, NO_2, SO_2. A certain amount of PM2.5 after burning stick incense was injected into the chamber, and the tendency of PM2.5 to decrease according to the internal environment was measured.

Using the chamber described in the previous chapter, the reduction pattern of fine dust(PM2.5) according to the concentration of TiO_2 was measured, and the amount of fine duct initially injected was 260±20μg/$m^3$for concentration mixture test and 600±5μg/$m^3$for number of layers test.

As shown in Fig. 2, it can be seen that the higher the TiO_2 concentration, the larger the reduction over a limited period of time. The test subject with TiO_2 40%, which contains the most TiO_2 showed a fine dust reduction of 262.4μg/m^3, a test subject with TiO_2 20% of 241.7μg/m^3, and a 100% silica sol solution showed a fine dust reduction of 213.8μg/m^3. The higher the mixing ratio of TiO_2, the lower the PM2.5 fine dust within the shorter time required. In addition, when comparing the time reached to the half-density point, it can be observed that the higher the concentration, the less time it takes. The amount of change per hour varies greatly depending on the concentration of TiO_2. This is believed to be due to the application of TiO_2 to the block surface, which is more easily exposed to the outside than the construction materials made by mixing with TiO_2.

After confirming that TiO_2 is effective in reducing fine dust using the chamber used in this study through previous experimental tests, the following experiment was conducted to find out the behaviour of TiO_2 in an environment with various variables. First, TiO_2's behavior was examined by setting the number of applications as variables. The application was carried out using a brush with a rough tip on the cement block, and the drying time for each application is 24 hours. Fig. 3 is a graph that compares fine dust reduction according to the number of TiO_2 applications, showing the largest reduction of 385μg/m^{3}at the 30-minute point in the third times of application. In addition, given the fastest time to reach the half-density reduction point, we found that the 3 coats of application had the best performance. Table 2 also shows the amount of fine dust by elapsed time according to the number of TiO_2 layers This shows that the number of applications and the performance of reduction are not proportional and that there is no significant change in performance above a certain number of applications. The experiment, which finds the number of applications that can achieve efficient performance without overusing TiO_2, is seen as a result that can contribute to the economical and efficient utilization of TiO_2 in a real-world working environment.

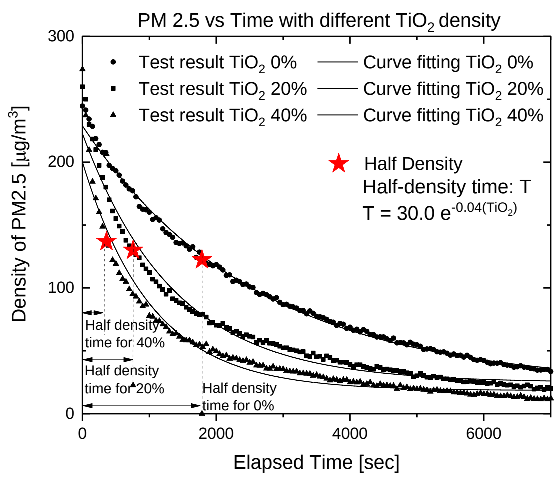

Fig. 2: PM2.5 vs Time with different TiO_2 density

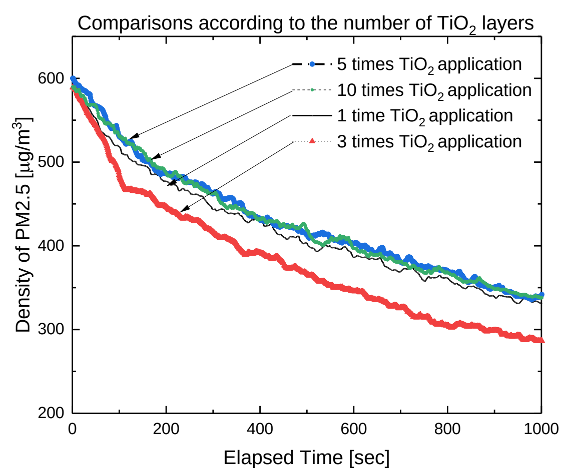

Fig. 3: Comparisons according to the number of TiO_2 layers

Table. 2: Amount of fine dust by time according to the number of applications

Layers \ Density (μg/m^3)	Initial Value	30 minutes	Decreased Amount
1	592	253	339
3	589	204	385
5	599	252	347
10	589	253	336

3.2. Comparison by drying time and surface materials

Afterwards, the experiment was conducted with drying time as a variable for each experiment. Each experiment was dried for 1, 3, 5 and 7 days, and applied using a coarse brush on the cement block as in the previous experiment. Fig. 4 and Table 3 are the results of fine dust reduction by drying time after applying TiO_2-containing paint. Test results showed the best performance at a rate of 62% from day 1 to 54% on day 7, 54% on day 5, and 48% on day 3. To understand this, it is necessary to consider that the nature of the paint used in the experiment requires 48 hours for full drying and 28 days for full resistance., which means that it takes 28days to properly express its own performance. To understand this, it is necessary to take into account that the nature of the paint used in the experiment requires 48 hours for full drying and 28 days for full resistance. Fine dust purification is carried out as TiO_2 is attached to the surface of the cement block. This allows us to expect that the longer the drying time, the more stable the paint will be on the cement block surface. This shows that the longer the drying time, the better the performance is. However, the performance of day 1 is best because the experiment was conducted before the time required for complete drying. The surface must have had some moisture because the surface was not completely dried. This moisture is believed to have fixed fine dust to the surface of the cement block, reducing the concentration of fine dust in the atmosphere. In order to reduce fine dust most effectively through TiO_2, it is important to determine the drying time when the product applied to the exterior material has full resistance.

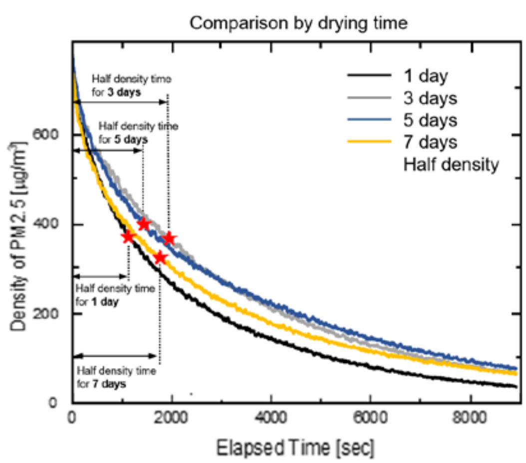

Fig.4: Comparison by drying time

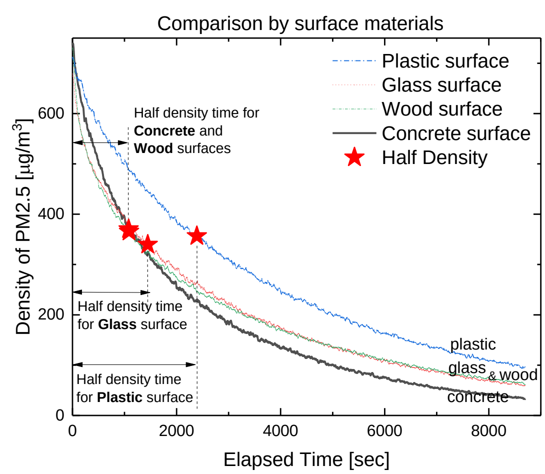

Fig. 5: Comparison by surface materials

Table. 3: Amount of fine dust by time according to the drying time.

Density (μg/m³) / Drying Time(day)	Initial Value	30 minutes	Decreased Amount
1	740	279	461
3	731	375	356
5	777	356	421
7	734	313	421

Fig. 5 is a graph of fine dust reduction based on surface parent material, which showed the highest performance with 62% of concrete, followed by 59% of wood, 55% glass, and 42% of plastic. Due to the characteristics of the paint used in the experiment, it was made for concrete, cement, and mortar, so it was stably fixed to the surface in concrete and showed the best performance. Also, due to the characteristics of paint products that require a little absorption, wood is thought to be better than glass and plastic. Conversely, glass and plastic that are not absorbent showed significantly lower performance than other base materials. However, it can be seen that the reduced performance of glass is relatively fair as it can be seen also in Table 4. This is believed to be more likely to adhere to glass because the base of the product is alcoholic unlike other paints. This shows that the roughness of the surface and the ability to adsorb paint have a significant impact on TiO_2's fine dust reduction performance.

Table. 4 Amount of fine dust by time according to surface materials

Density (μg/m^3) Surface Material	Initial Value	30 minutes	Decreased Amount
Concrete	740	279	461
Glass	679	304	375
Plastic	712	409	303
Wood	730	293	437

4. Conclusion

This study conducted various experiments using TiO_2 to improve the utilization of economical TiO_2 outer wall coating agent to solve fine dust, which is a major cause of air pollution, and summarizes the research results as follows.

First, the TiO_2 coating agent mixed with the silica sol binder applied to the cement block showed a meaningful effect on reducing fine dust and showed the best performance when the TiO_2 mixing ratio was 40% compared to 20% and 0%.

Second, by checking the proportional relationship between the number of TiO_2 layers and the start time of fine dust reduction, it can be seen that the increase the number of applications TiO_2 layers has a positive effect on improving air quality. However, if application is carried out more than a certain number of times (3 coats of application in this study) performance seems to be deteriorating. Through this, it was found that applying more than a certain number of times has no effect on performance improvement. Therefore, it is expected that the economic feasibility and ancillary conditions can be inferred for the possibility of TiO_2 usage in exterior wall.

Third, it was confirmed that the higher the surface roughness and absorbency, the better the effect of reducing fine dust, depending on the characteristics of the base material, and the more stable the adsorption of the outer material coated with TiO_2 depends on the drying time.

Based on the experimental results derived from this study, it is expected that it will be able to contribute to research on the utilization of TiO_2 coatings. It is expected to contribute to the reduction of fine dust in the air by applying the optimal conditions and materials derived from this study.

Acknowledgements

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* MSIT : Ministry of Science and ICT

References

[1] Air Visual. (2020). 2019 World air quality report [Online]. Available: https://www.iqair.com/world-most-polluted-countries

[2] Ministry of Environment. (2019, January). What is 'Fine dust'? (Fine dust! You can ask anything) [Online]. Available: https://www.me.go.kr/home/file/readDownloadFile.do?fileId=168738&fileSeq=4

[3] Il Ho Yoon, Kyoung Bin Lee, Jin Sik Kim, Shin Do Kim. "A Study on the Estimation of NOX Reduction in Ambient by Photocatalyst (TiO2) Block." in Journal of the Korean Society of Urban Environment, 2017, vol. 17, no. 4, pp. 433-443.

[4] Hanim Kim, Jung Jun Park, Jongwon Kwark. "Development of Construction Materials and Application Technologies for Particulate Matter Reduction Using Photocatalytic Materials." In *Journal of The Korean Society of Civil Engineers,* 2019, vol. 67, no. 8, pp. 87-89.

[5] Sang Soo, Lee, Won Gyu, Lee. "Manufacturing Technology of Concrete Panel for Fine dust Reduction Using Photocatalysis(TiO_2)." in *Magazine of the Korea Concrete Institute,* 2019, vol. 31, no. 4, pp. 36-40.

[6] Yong Woo Song, Min Young Kim, Mi Yeon Kim, Jin Chul Park. "Mock-up Test on NOx Concentration of Photocatalytic Paint and UV Lamps." in *Korean Journal of Air-Conditioning and Refrigeration Engineering,* 2019, vol. 31, no. 9, pp. 411-419.
[7] Mi Yeon Kim, Hyung Geun Kim, Jin Chul Park. "Field Experimental Analysis of NOx Removal Efficiency of Photocatalytic Exterior Materials Reducing PM2.5." in Korean Journal of Air-Conditioning and Refrigeration Engineering, 2020, vol. 32, no. 12, pp. 585-592.
[8] Min Young Kim. "A Study on the Reduction of Nitrogen Oxide (NOx) Using Photocatalytic Architectural Coatings." Domestic Master's Thesis, The Graduate School Chung-Ang University, 2020, Seoul.