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Sustainable coatings fabricated from inorganic wastes for indoor humidity control and degradation of formaldehyde

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Abstract: With the development of living standard, people spend more time indoors, and the diversified home decoration will lead to indoor hazardous gas emission. Among them, formaldehyde (HCHO) is one of the most important sources of indoor air pollution, which is commonly found in building materials as a human carcinogen. To address this issue, we developed highly efficient multifunctional green building coatings (GBC) by TiO_2, enhancement silica fume (ESF) and spent fluid catalytic cracking catalysts (sFCCC). Among these prepared GBC, the GBC-0.8 exhibited HCHO removal efficiency of 85.0 % under visible light at ambient temperature, which was much higher than that of commercial coatings (30.8%). In addition, moisture adsorption-desorption carrier tests were executed by different humidity. The humidity control capacity of GBC-0.8 could reach 293.8 g/m^2 and demonstrate superior stability after 3 cycles. Compared with pristine TiO_2, the addition of ESF and sFCCC showed higher specific surface area and pore size distribution, which was beneficial to improve humidity control and photocatalytic degradation performance. This study provides a promising green method for designing multifunctional green building materials coatings to recycle waste into high-value products and remove HCHO at room temperature

Key words: Multifunctional coatings, Formaldehyde photodegradation, Indoor humidity buffering, Inorganic wastes

1. INTRODUCTION

In recent years, indoor air pollution has received more attention than before because people in developed countries spend almost 90% of their life indoor with the development of technology and the ravages of infectious diseases. One of the most widespread indoor air pollution is formaldehyde, a colorless gas with an acrid smell, which has been confirmed related to several types of cancers.

However, there are several potential strategies to treat formaldehyde, can be roughly divided into physical adsorption, chemical catalysis, and bioremediation. Among them, catalytic oxidation can completely decompose formaldehyde into harmless CO_2 and H_2O, considered as the most ideal method under natural atmospheric pressure and at room temperature. Moreover, graphitic carbon nitride (g-C_3N_4) is considered as a superior catalyst for decontamination of organic contaminants with outstanding optical and electronic properties and thermal properties

In addition, there is high humidity and high temperature in Taiwan due to the island-type climate for a long term, which is higher than 75% RH. The high humidity environment is easy to breed mold and bacteria and related to human healthy and energy consumption.

Also, the amount of inorganic sludge increased in recent years, resulting in insufficient space of landfill sites and severely affecting the ecological environment. To reduce the demand of landfill sites in Taiwan with high population density, this study converted two kinds of inorganic sludge into useful material, spent fluid catalytic cracking catalysts (sFCCC) from petroleum refining waste and Enhancement Silica Fume (ESF) from the manufacture process of precipitated silica. So that it could not only decrease the disposal cost by the company but also increase the environmental sustainability.
Consequently, this research expects to develop a photocatalyst from inorganic waste to photodegrade formaldehyde, and then produce a multi-functional coating made from the photocatalyst and waste to control indoor humidity control and photodegrade formaldehyde.

2. METHODS

A schematic diagram of photocatalyst and coating preparation was shown in Fig. 1. In a typical synthesis, the weighed photocatalysts, ESF, sFCCC and bassanite were mixed entirely. The acrylic resins and sodium silicates were liquefied in deionized water and sol-gelled together with the aforementioned components for 30 min. The resulting mixture was denoted as GBC coatings and applied onto a plastic plate, followed by curing at 25 °C for 24 h with 75% relative humidity (RH).

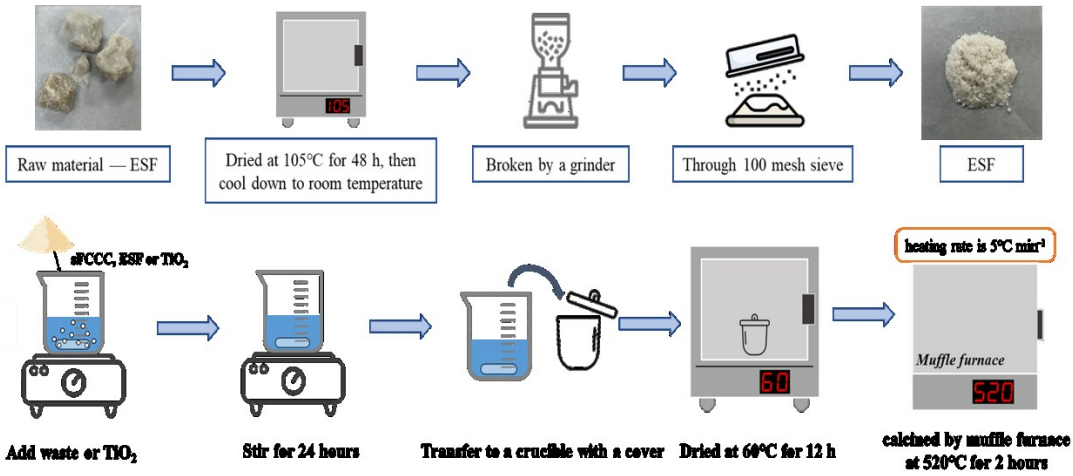
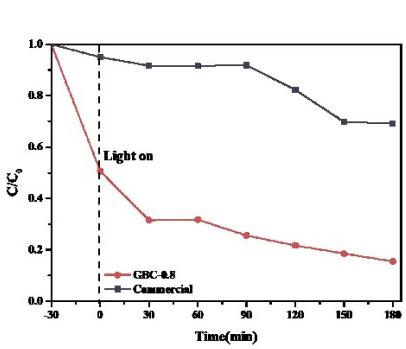
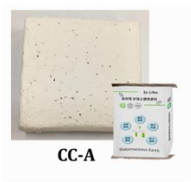


Fig. 1. A schematic diagram of coating preparation.

3. RESULTS AND DISCUSSION

The photocatalytic HCHO degradation activity of coatings was investigated, as shown in Fig. 2. After injecting ca. 3 ppm of formaldehyde to the batch reactor and performing dark adsorption to reach equilibrium (ca. 3 h), the 10 W LED light for photodegradation was turned on. The results showed that the degradation efficiency of GBC-0.8 coatings was superior to the commercial coating. The GBC-0.8 coatings exhibited the highest HCHO removal efficiency of 85.0% with a rate constant of 0.0062 min^{-1}, which was ca. 3.0-fold higher than the commercial coatings. Compared to the results from the dark adsorption experiments, there was a rapid decrease in the HCHO concentration upon turning the light on, indicating the photocatalytic activity of GBC-0.8 coatings. Moreover, the GBC-0.8 coatings with the more evident mesopores (2-50 nm) distribution than the commercial coatings, resulting in the superior moisture absorption and moisture content. It is worthy to note that the visible holes in the commercial coatings (see Fig. 2) were caused by the presence of diatomite in the coatings. To study the moisture control performance of prepared coatings, the moisture adsorbed capacities and contents were measured in the high humidity range of 50–90% RH. As a result, the moisture adsorbed capacities of 293.8 g m^{-2} were observed for GBC-0.8 coatings, which were surpassing the commercial coatings (i.e., 20.9 g m^{-2}) by at least 14.2 times (see Table 1). Likewise, the moisture contents of GBC-0.8 coatings (i.e., 20.9%) were much higher than that of commercial coatings (1.9%). It can be seen that the replacement of diatomite with ESF could remarkably enhance the moisture adsorption performance. In particular, the W/B/S-47/47/6 coatings achieved the optimal moisture adsorption-desorption capability (considerably superior to commercial coating), which was due to the increased surface area and micropore volumes. Also, hygroscopic curves of the GBC coatings are shown in Fig. 3b. No matter in the high RH range (80% RH) or low RH range (40% RH), the moisture adsorbed contents of GBC-0.8 coatings were obviously better than commercial coatings. Note that the moisture adsorbed contents of GBC-0.8 were increased rapidly in the range of 80-90% RH, which was attributed to the appropriate amounts of sFCCC.





	GBC-0.8	Commercial
Removal	**85.0%**	**30.8%**
k (min^{-1})	0.0062	0.0019
R^2	0.976	0.821

Fig. 2 Photodegradation of HCHO and reaction rate constants of GBC-0.8 and commercial coating.

Table 1. Moisture buffering capacities and contents of GBC-0.8 and commercial coating.

JIS-A 6909 (90% RH-45% RH)	Moisture adsorbed values (g/m^2)	Moisture content (%)
GBC-0.8	293.8	20.9
Commercial	28.9	1.9

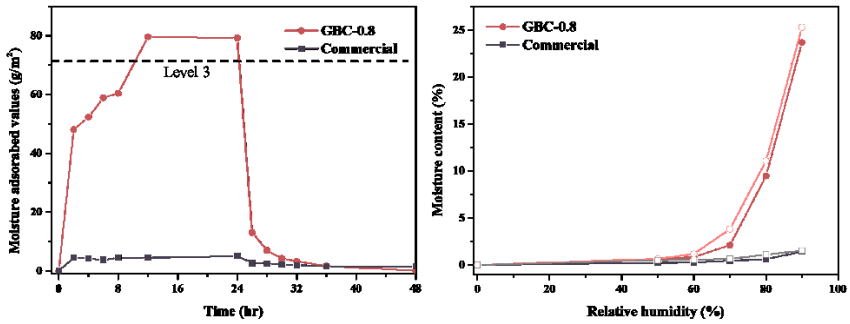


Fig. 3 (a) Moisture adsorption-desorption performance and (b) hygroscopic curves of various GBC-0.8 and commercial coatings.

Moreover, the leaching of heavy metals for GBC-0.8 coatings was measured by the TCLP tests, as displayed in Table 2. Most of heavy metal (Hg, Pb, Cr^{6+} and Ag) cannot be detected. Therefore, the GBC-0.8 coatings prepared from WC and sFCCC could not only obey the regulatory limits but also the criteria for green building materials. Based on the aforementioned results, the fabricated GBC-0.8 coatings possessed superior humidity control ability, photodegradation performance and environmental friendliness.

Table 2. Leaching of heavy metals for GBC-0.8 coatings.

Heavy Metal	Leaching conc. (mg L^{-1})	Regulatory limit (mg L^{-1})	Green building materials criterion value (mg L^{-1})
Mercury (T-Hg)	ND	0.2	0.005
Cadmium (T-Cd)	0.02	1.0	0.3
Lead (T-Pb)	ND	5.0	0.3
Chromium (Cr^{6+})	ND	5.0	1.5

Copper (T-Cu)	0.1	15.0	0.15
Silver (T-Ag)	ND	5.0	0.05

ND: not detected (< 0.01 mg L^{-1})

4. CCONCLUSIONS

ESF and sFCCC possessed large surface area and mesoporous structure according to porous properties. The surface area of GBC-0.8 is much large than that of commercial coating, affecting the humidity control performance. For HCHO removal, the capacity of GBC-0.8 is two times as that of commercial coating. For moisture adsorbed ability in medium (50-75%) and high (45-90%) humidity range, GBC-0.8 is ten times as commercial coating. Comparing with commercial coating, GBC-0.8 adsorbed more moisture, especially for 70-90% RH. The valorization of SiO_2 wastes which could increase the specific surface area with abundance of hydroxyl groups in the high-performance coatings demonstrated the superior formaldehyde removal and humidity regulation. The sustainable multifunctional coatings prepared via a facile route may offer the future practical applications in the indoor space.

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REFERENCES

[1] H.C. Lu, C.H. Kuok, S.H. Liu, “High-performance humidity control coatings prepared from inorganic wastes”, Constr Build Mater., 263, 120169, 2020.

[2] C.H. Kuok, D. Wahid, S.H. Liu, “A simple method to valorize silica sludges into sustainable coatings for indoor humidity buffering”, Sustain. Environ. Res., 32, 8, 2022.