THE HONG KONG
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Maximise the Use of Recycled Glass in Cement-based Construction Materials for the Green-Deck

(Final Report)

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Maximise the use of recycled glass in cement-based construction materials for the Green-Deck (Executive Summary)

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To increase the rate of re-utilizing of waste glass in Hong Kong, the PolyU team had conducted studies to assess the potential of using coloured recycled glass as a sand replacement for the production of self-compacting white cement mortars for architectural mortar applications. The eco-friendly construction material not only provides a viable recycling channel for glass waste in Hong Kong, it also has self cleaning and anti-pollution effect for the removal of air pollutants such as nitrogen oxides. The architectural glass mortar may be suitably adopted in the proposed Green-Deck project.

The objective of the small scale project is to demonstrate PolyU's developed eco-glass block and architectural mortar technologies through the Green-Deck project.

Assuming the cementitious part of the Green Deck is paved with an architectural glass screed (mortar), coated with a thin layer of photo-catalyst, and the area of the cementitious part of the Green Deck is about 5,000 m2, and the thickness of the screed is 35 mm. it is estimated that approximately 143 tonnes of waste glass can be recycled by the construction of the Green Deck.

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Estimation of utilization rate of waste glass by the Green-Deck Project

For enhancing the photocatalytic performance of the architectural mortars, river sand traditionally used as fine aggregate in mortars was completely replaced by recycled glass. Recycled glass which was obtained from crushed post-consumer beverage glass bottles has the potential of facilitating light access to the catalyst particles. Increased light irradiation on the TiO_2 catalyst may increase the generation of reactive oxygen species (e.g. $\cdot OH$ and $O_2\cdot^-$) which are responsible for the oxidation of different pollutants. After a series of laboratory studies, the mix proportion of the architectural mortar developed is 0.8:0.2:2.0:0.4 - white cement: metakaoline: recycled glass: water.

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Development of new molding method

In the course of our study, a new molding method has been identified to allow the forming of the glass architectural mortar without the use of steel molds to enhance the production efficiency. If successfully applied to recycled glass, this would allow more efficient production of the architectural glass mortar in an industrial process without the need for casting in molds and demolding. The trial at PolyU used a laboratory calender extrusion equipment (Fig. 1) to prepare the glass architectural mortar panels and blocks.

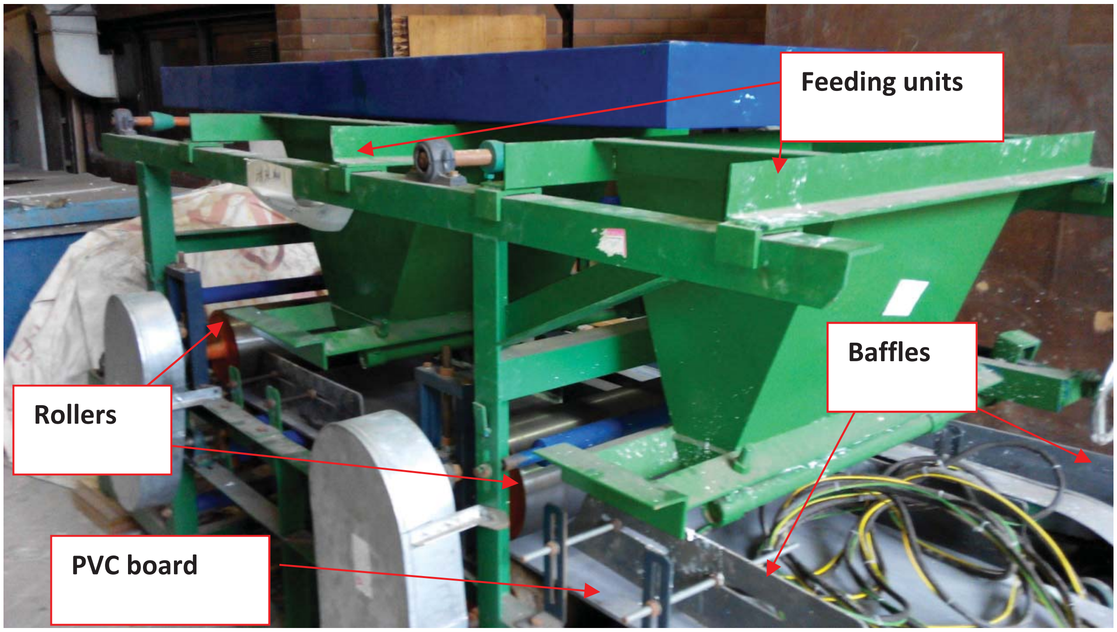

Figure 1 - Experimental calender machine

Through a large number of laboratory trials, the optimal mix design was identified as follows :

0.4 water to cement ratio, 2.5% (by weight of cement) superplasticizer. MK was used to replace 20% of cement by weight. Washed recycled glass, twice the weight of cement, was used as aggregate. PVA fiber with a weight of about 0.3 times of cement was added for cohesion enhancement. Figs 2 – 5 show the laboratory trial production process.


Figure 2 Glass mortar produced from the laboratory molding process

Figure 3 Compacted glass mortar sample

Figure 4 Hardened glass mortar

The hardened glass mortar is shown in Figure 4. A good smooth surface with very little porosity can be noticed. Once polished, the appearance is quite aesthetic pleasing (Fig. 5).

Figure 5 Aesthetically pleasing polished hardened glass mortar

Photo-catalytic activity

Furthermore, previous studies by the PolyU's team demonstrated that the photo-catalytic layer of the eco-glass mortars has the potential to remove NO from air at the vicinity of the layer. It has been estimated that the photocatalytic materials applied in the "Green Deck" project has the potential to reduce air pollutant concentrations at the breathing zone within the Green Deck area (indicated by NO removal of 0 to 80% depending on wind conditions, but, the estimates should be interpreted with care considering the conditions and assumptions taken for making the calculations).

In order to further enhance the photo-catalytic activity and long term performance of the eco-glass architectural mortar, two different TiO_2 incorporation approaches (i.e. TiO_2 intermixed and TiO_2 coating) were further tested. A TiO_2 coating (PC-S7, Cristal Active) was obtained through an aqueous dispersion (sol) of ultrafine anatase particles while the TiO_2 for the intermixed samples (5%TiO_2) was a nanopowder composed of rutile and anatase (P25, Degussa). The characteristics of the catalyst particles used are given in Table 1.

Table 1. Properties of TiO_2 catalysts

Parameter	TiO_2 P25 powder (Degussa-Huls AG)	PC-S7 sol (Cristal Active)
Crystal form	75% - anatase / 25% - rutile	100% - anatase
TiO_2 content (weight basis)	99.5%	10%
Surface area (BET)	50 $m^2 \cdot g^{-1}$	300 $m^2 \cdot g^{-1}$
pH	3.5 - 4.5	8.5

*Information provided by manufacturers

This study conducted included the evaluation of the air-purifying, self-cleaning and antimicrobial properties of the architectural mortars at simulated laboratory conditions. Moreover, in order to have a better assessment of the long-term photocatalytic performance of the architectural mortars containing TiO_2 (coating or intermixed), the evaluation of the self-cleaning and air-purifying properties of the architectural mortar samples was performed before and after the application of a lab-simulated façade weathering process (building material for outdoor vertical application) which represents approximately 20 years of use at Hong Kong weather conditions. Operating in a different mode, this test set-up was also used to evaluate the abilities of resisting algal fouling of the investigated architectural mortars.

The results of the study are summarized in Table 2. More details of the results can be found in the Appendix.

Based on the results, it is clear that the architectural mortar samples (PCS7-coating) have more promising application potentials for the Green Deck Project compared to the intermixed samples (5%TiO2-P25).

Table 2. Photocatalytic performance indicated by the antimicrobial, self-cleaning and air-purifying properties of architectural mortar samples (5%TiO2-P25 and PCS7-coating)

Photocatalytic Performance at laboratory conditions - Summary				
Property & Test Method	UV-A light		Visible Light	
	5%TiO_2-P25	PCS7-coating	5%TiO_2-P25	PCS7-coating
Air Purification: NO_x removal	🟡	🟢	🔴	🟢
Self-Cleanse: RhB removal	🔴	🟢	🔴	🟢
Self-Cleanse: Algae fouling	🟢	🟢	🟢	🟢
Antimicrobial: *E.Coli* removal	🔴	🟢	🔴	🔴

🟢 Good performance
🟡 Good performance only before weathering
🔴 No significant photocatalytic activity

Conclusion

1. The proposed Green Deck project is able to utilize an eco-friendly construction materials based on the eco-glass architectural mortar technology developed by PolyU. Approximately, 143 tonnes of waste glass can be recycled by the construction of the Green Deck.

2. A new industrial production method has been demonstrated to be able to produce the green architectural construction materials efficiently.

3. With the incorporation of appropriate type and amount of photo-catalytic materials, the eco-glass architectural construction material used in the Green Deck has air-purifying, self-cleaning and antimicrobial properties.

Appendix

Results on photo-catalytic study

NO removal ability

For the evaluation of the air-purifying potential of the architectural mortars, photocatalytic conversion of gaseous NO_x under UV-A (2 × F8T5 BLB, HRK) and visible (2 × YZ08T5, NVC) light irradiation was monitored using a chemiluminesce NO_x analyzer (Thermo Environmental Instruments Model 42c). To achieve this, a flow-through operated photoreactor at ambient conditions was used. NO_x removal rates can be seen in Figure A1 and A2. Although non-weathered architectural mortar samples (PC-S7-coating and 5%TiO2-P25) showed significant NO_x removal under both irradiation sources, the intermixed samples (5%TiO2-P25) showed significant reductions after the application of the façade weathering process. Contrary to the coated samples (PC-S7-coating) where TiO_2 was more exposed to the pollutant and light, the accumulation of the removed material in the porous of intermixed samples (5%TiO2-P25) might have blocked the access of both light and pollutant to the TiO_2 particles.

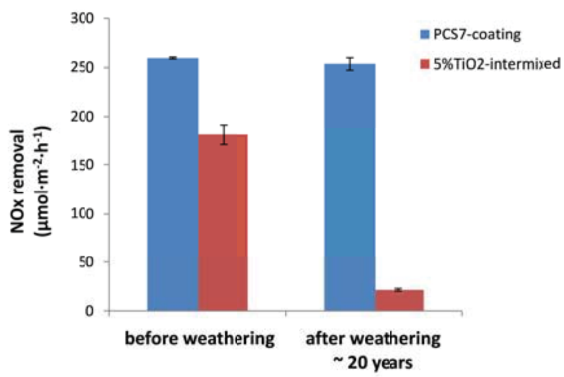

Figure A1. NO_x removal rates from architectural mortar samples before and after application of a façade weathering process (20 years of use at Hong Kong weather conditions) under UV-A irradiation (310-350 μW· cm^{-2}) at ambient conditions (RH = 50% and T = 25 °C) and NO_{inlet} = 1000 ppb.

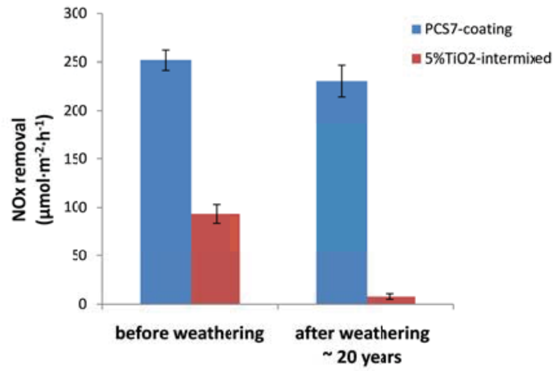

Figure A2. Photocatalytic NO_x removal of architectural mortar samples (PC-S7-coated and 5% TiO_2-intermixed) before and after application of a façade weathering process (~20 years) under visible light irradiation (50-60 µW· cm^{-2}) at ambient conditions (RH = 50% and T = 25 °C) and NO_{inlet} = 1000 ppb.

Self-cleaning properties

For the evaluation of the self-cleansing ability, Rhodamine B (RhB) removal after 4 (R_4) and 26 (R_{26}) hours of both UV-A (2 × F8T5 BLB, HRK) and visible (2 × YZ08T5, NVC) light irradiation, respectively, was monitored on the architectural mortars before and after the application of the same façade weathering process (approximately 20 years of use at Hong Kong weather conditions). Rhodamine B ([9-(2-carboxyphenyl)-6-diethylamino-3-xanthenylidene]-diethylammonium chloride) was selected as the organic dye model to simulate particulate pollutants because its molecule is similar to some airborne particulate compounds such as the polycyclic aromatic hydrocarbons (PAHs). Therefore, the test results of the degradation of RhB, which is also a water soluble and stable dye in alkaline environments, are very suitable for the laboratory evaluation of self-cleaning materials. Monitoring of RhB degradation was done by means of the color changes measured by a SP60 colorimeter (X-Rite). The results can be seen in Figures A3 and A4.

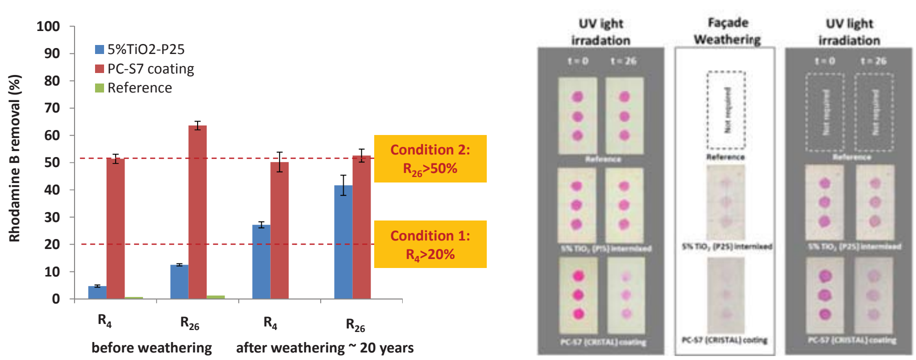

Figure A3. Rhodamine B removal efficiencies of architectural mortar samples (5%TiO_2, PC-S7 and Reference) before and after application of a façade weathering process (20 years of use at Hong Kong weather conditions) under UV-A irradiation (310-350 µW· cm^{-2}). RhB concentration was 5×10^{-4} g·ml^{-1}.

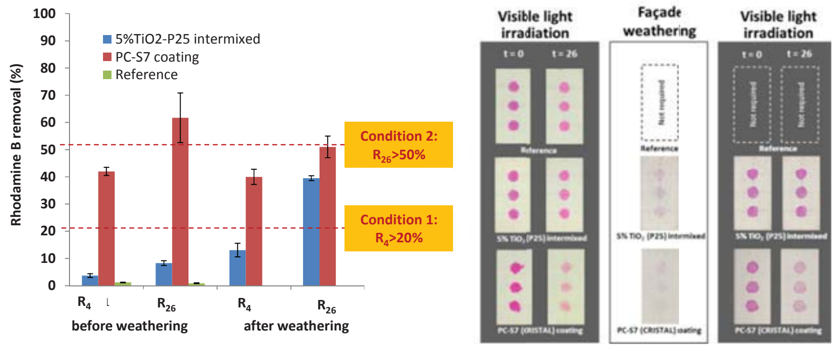

Figure A4. Rhodamine B removal efficiencies of architectural mortar samples (5%TiO_2, PC-S7 and Reference) before and after application of a façade weathering process (20 years of use at Hong Kong weather conditions) under visible light (50-60 µW· cm^{-2}). RhB concentration was 5×10^{-4} $g \cdot ml^{-1}$.

Based on the photocatalytic criteria ($R_4 > 20\%$ and $R_{26} > 50\%$), only the architectural mortar samples (PCS7-coating) showed significant photocatalytic activities before and after weathering and can be considered as a self-cleaning material.

Antibacterial & Anti-fouling Properties

Moreover, as fouling of building materials at outdoor conditions is commonly produced by microorganisms such as algae. Algaecidal activity was monitored by comparing the algal fouling (*Chlorella vulgaris*) on the PC-S7, 5%TiO_2 and reference (no containing TiO_2) samples by means of a water run-off test. This modular test set-up consists of inclined (45°) and independent PVC compartments where the test materials are subjected to two daily alternate wet cycles (algae suspension 6.5×10^8 $cells \cdot L^{-1}$) lasting 1.5 hours each. After 8 weeks of accelerated algal fouling, color changes (indicated by ΔE from CIE lab color space) showed that both 5%TiO_2 and PC-S7 evidenced only 'slight' color changes ($\Delta E < 1.5$) compared to the reference samples (containing no TiO_2) which evidenced 'large' ($6 < \Delta E < 12$) color changes. However, compared to the other materials, all the samples showed a low fouling tendency due to the low bioreceptivity indicated by their relatively low porosity (17.6 ± 2%) and roughness (6.7 ± 0.5 µm). The samples are shown in Figure A5.

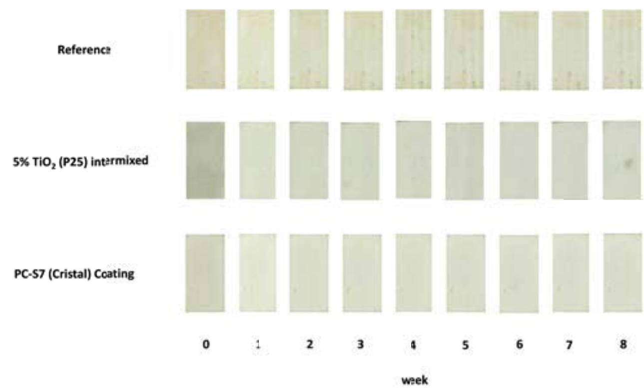

Figure A5. Algal growth on architectural mortar samples (5%TiO_2, PC-S7 and Reference) using a water run-off test set-up. Algae (*Chlorella vulgaris*) suspension concentration was 6.5×10^{8} cells·L^{-1}.

For the evaluation of the antimicrobial properties on the architectural mortars, the antibacterial activity was indicated by the photocatalytic removal of a gram-negative bacterium (*E. Coli*). After 120 minutes of UV-A light (2 × F8T5 BLB, HRK) and visible light irradiation (2 × YZ08T5, NVC) of a pipetted cell culture (5 logCFU·ml^{-1}) on top of the 5%TiO_2 and PC-S7 architectural mortar samples, the results indicated that complete elimination of the culture can be obtained only under UV-A irradiation with the coated architectural mortar samples (PC-S7). The results can be seen in Figure A6.

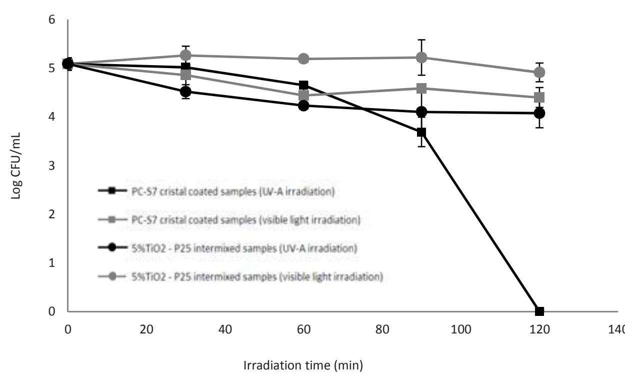

Figure A6. Photocatalytic inactivation of *E. Coli* on mortar samples under visible light (50-60 μW·cm^{-2}) and UV-A (310-350 μW·cm^{-2} irradiation), respectively.