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

(Final Report)

By Prof. Chi-Sun Poon
Department of Civil and Environmental Engineering
July 2014
Maximise the use of recycled glass in cement-based construction materials for the Green-Deck (Executive Summary)

Prof. Chi-Sun Poon – Dept of Civil and Environmental Engineering

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.
Maximise the use of recycled glass in cement-based construction materials for the Green-Deck (Final Report)

Prof. Chi-Sun Poon – Dept of Civil and Environmental Engineering

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.

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 TiO₂ catalyst may increase the generation of reactive oxygen species (e.g. ·OH and O₂⁻) 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: metakaolinite: recycled glass: water.

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.

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.

![Experimental calender machine](image)

**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.

![Glass mortar produced from the laboratory molding process](image)

**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>
<thead>
<tr>
<th>Parameter</th>
<th>TiO$_2$ P25 powder</th>
<th>PC-S7 sol</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Degussa-Huls AG)</td>
<td>(Cristal Active)</td>
</tr>
<tr>
<td>Crystal form</td>
<td>75% - anatase / 25% - rutile</td>
<td>100% - anatase</td>
</tr>
<tr>
<td>TiO$_2$ content (weight basis)</td>
<td>99.5%</td>
<td>10%</td>
</tr>
<tr>
<td>Surface area (BET)</td>
<td>50 m$^2$·g$^{-1}$</td>
<td>300 m$^2$·g$^{-1}$</td>
</tr>
<tr>
<td>pH</td>
<td>3.5 - 4.5</td>
<td>8.5</td>
</tr>
</tbody>
</table>

*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%TiO$_2$-P25).
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%TiO$_2$-P25) showed significant NO$_x$ removal under both irradiation sources, the intermixed samples (5%TiO$_2$-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%TiO$_2$-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.
Figures 3 and A4. The color change of self-cleaning architectural mortar samples (PC-S7 coated and 5% TiO2-intermixed) after 26 (R26) 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 A2. Photocatalytic NOx removal of architectural mortar samples (PC-S7-coated and 5% TiO2-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 NOx inlet = 1000 ppb.

Self-cleaning properties

For the evaluation of the self-cleansing ability, Rhodamine B (RhB) removal after 4 (R4) and 26 (R26) 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%TiO2, 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.
Based on the photocatalytic criteria (R₄ > 20% and R₂₆ > 50%), only the architectural mortar samples (PC-S7-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%TiO₂ and reference (no containing TiO₂) 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 × 10⁸ cells·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%TiO₂ and PC-S7 evidenced only ‘slight’ color changes (ΔE<1.5) compared to the reference samples (containing no TiO₂) which evidenced ‘large’ (6 < ΔE < 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.
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%TiO₂ 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 A5. Algal growth on architectural mortar samples (5%TiO₂, PC-S7 and Reference) using a water run-off test set-up. Algae (Chlorella vulgaris) suspension concentration was 6.5 × 10⁸ cells L⁻¹.

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.