Innovative Recycling of Waste Glass as Construction Materials

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Outline

- Hong Kong's Waste Glass Problem
- Recycled Glass Materials in OPC
  - Architectural Mortars
  - Eco-Blocks – Four Generations
  - Eco-glass OPC
  - Applications – From Waste to Construction
- Recycled Glass Materials in AAC
- On-Going Research in PolyU

Waste Glass in Hong Kong

- Daily disposal rate **354 tonnes** in Hong Kong (2016)
- Lack of local glass **manufacturing industry**
- Recycling rate only **7%** (2016)
- Mostly **landfilled**

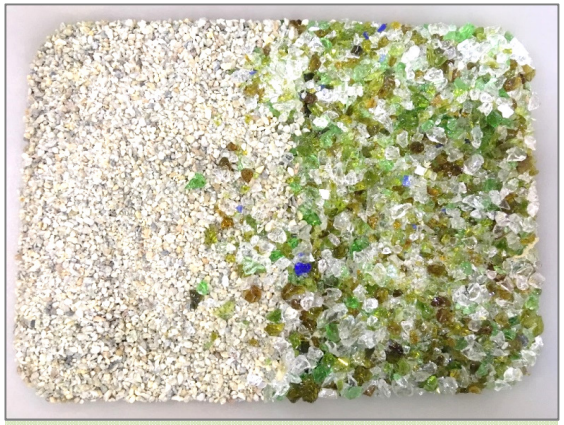
Waste Glass Sources

Mandatory Producer Responsibility Scheme will be launched by Hong Kong Government to encourage waste glass recycling

Residential

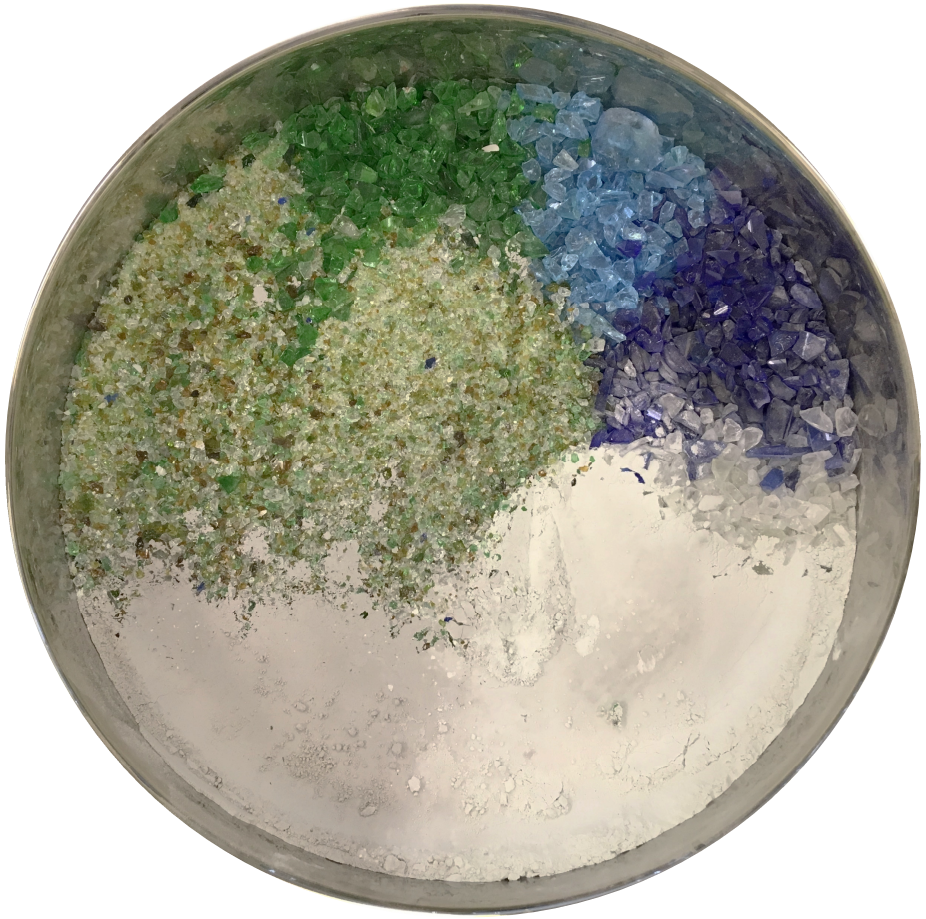
Food & Beverage Industrial

Recycled Glass Materials



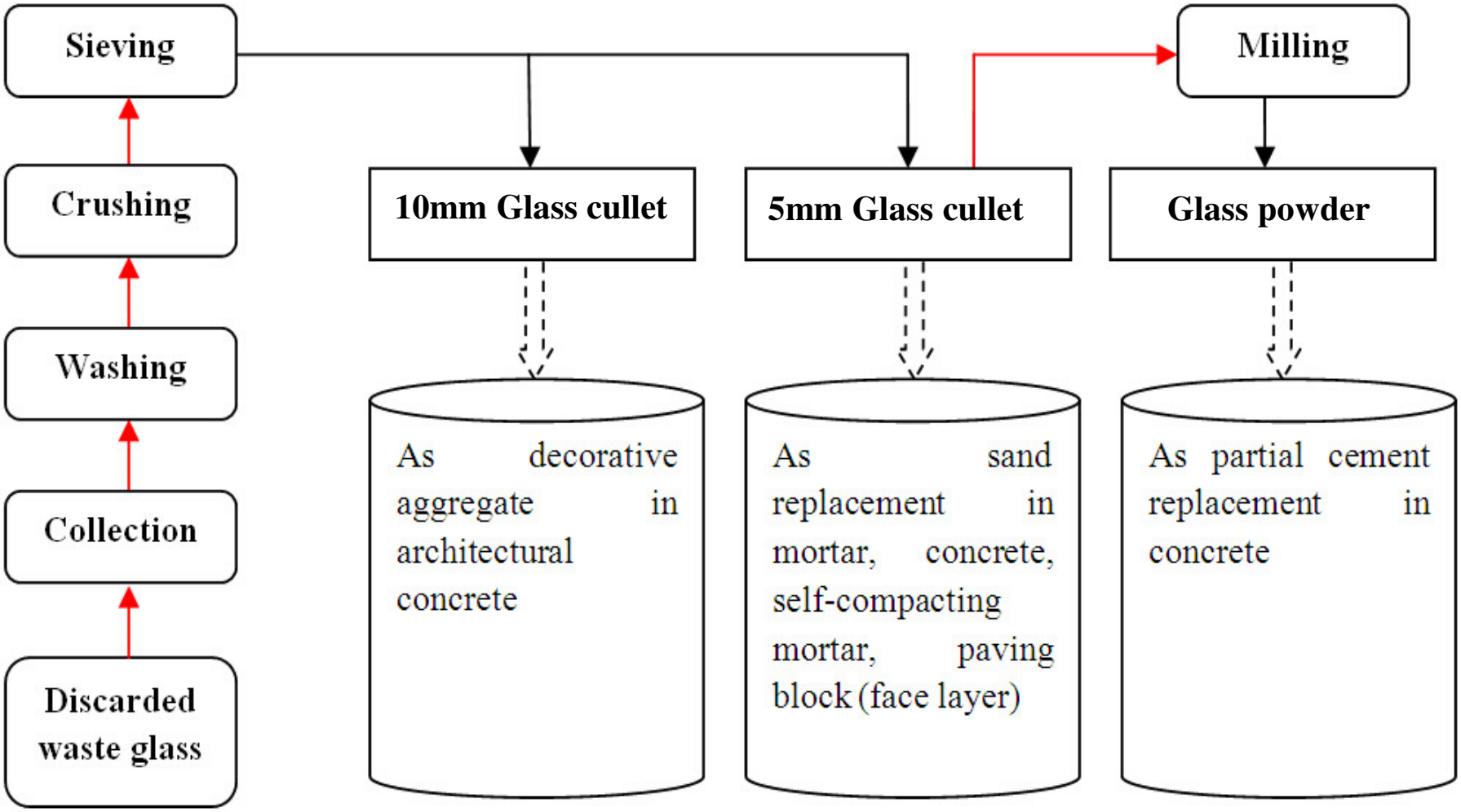
River sand & GC

GP & Cementitious materials



- ✓ Optical transparency
- ✓ High impermeability
- ✓ Chemical inertness
- ✓ High intrinsic strength

Waste Glass in OPC



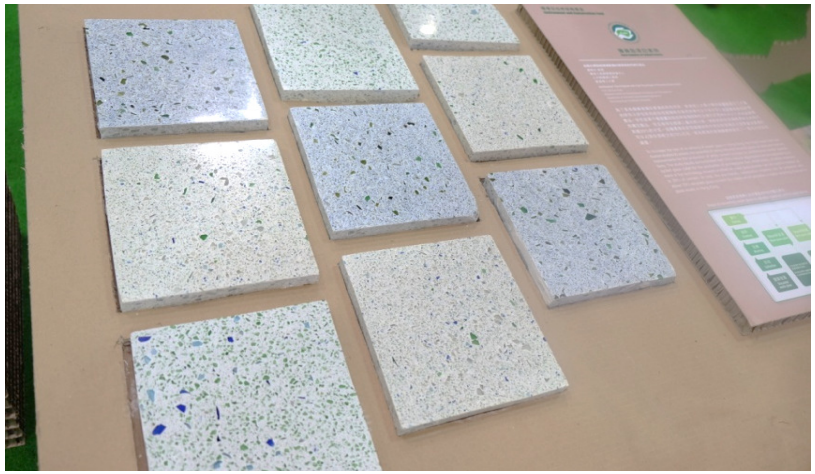
Eco-Blocks Evolution

The Role of Recycled Glass Materials

1st Generation – Recycled Aggregate (RA) incorporation

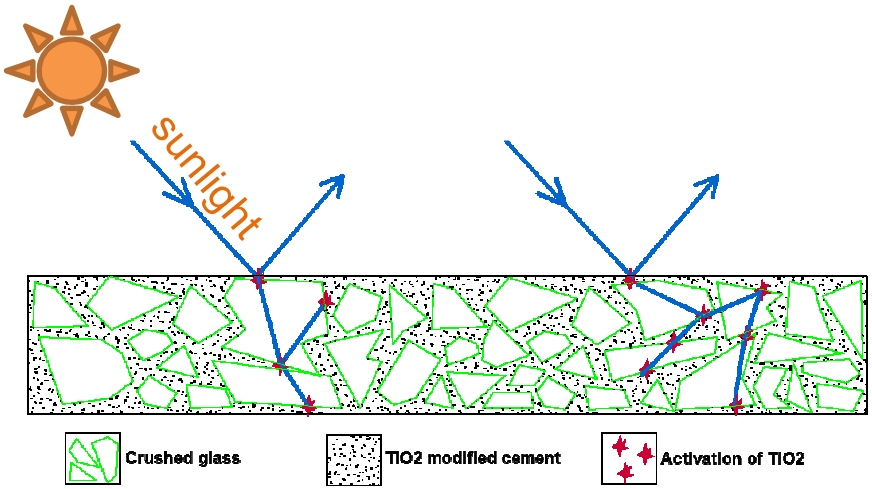
2nd Generation – Recycled Aggregate +Recycled Glass

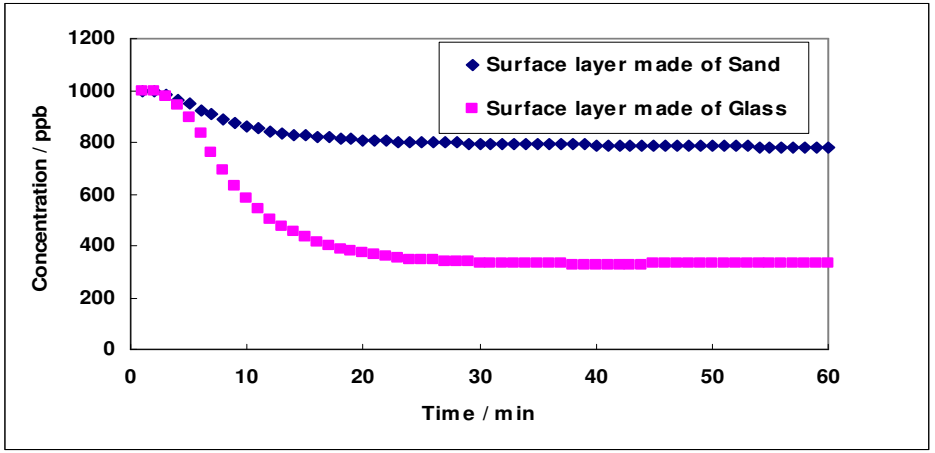
3rd Generation – Developed photo-catalyst function



4th generation Eco-blocks (tiles) for interior decoration

NOx Removal by Use of nano-TiO_2

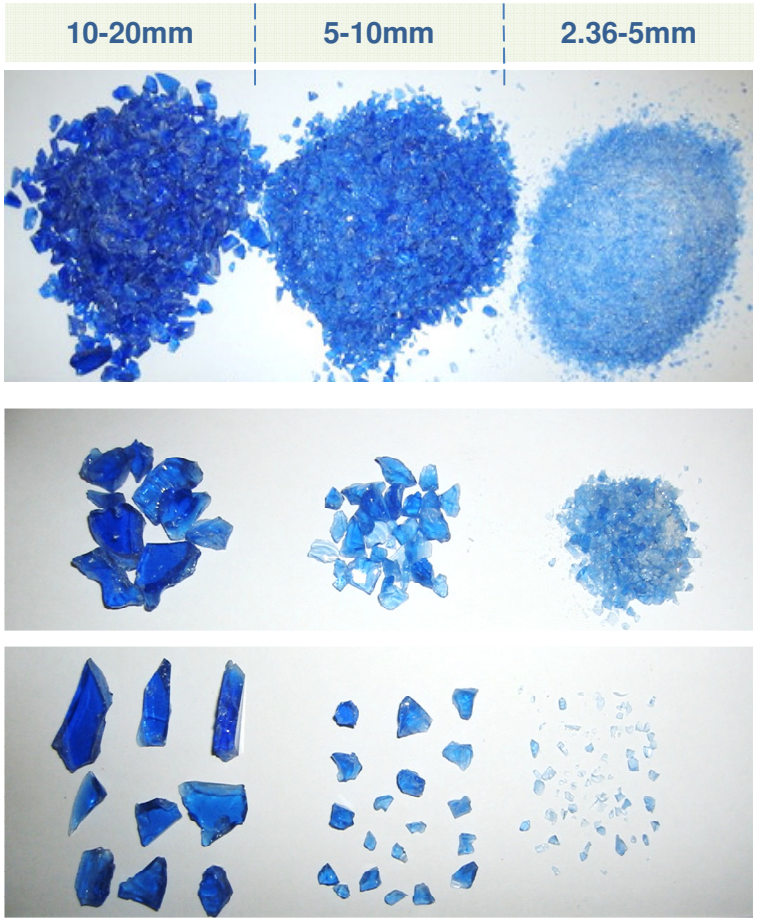




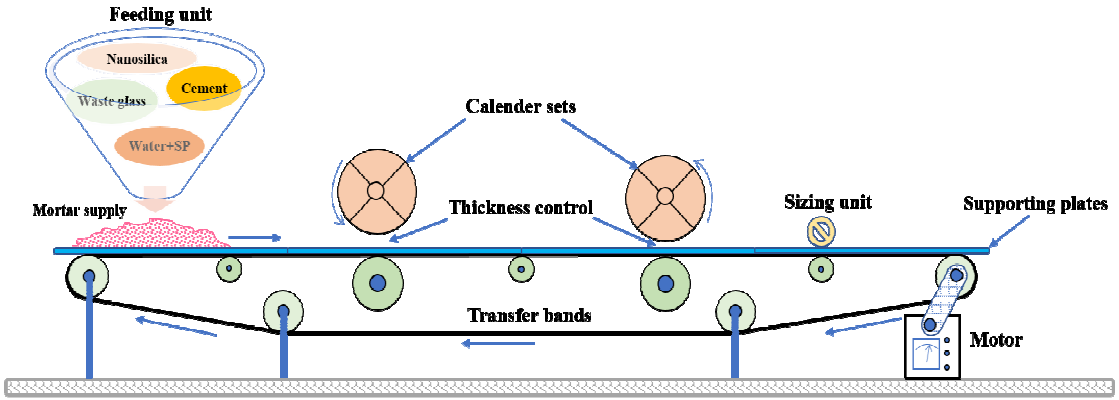
Method of photo-catalyst agent introduction	Amount of TiO_2 (kg/m^3)	28-day NO_x removal rate ($\mu mol\ m^{-2}\ h^{-1}$) Before weathering	NO removal rate ($\mu mol\ m^{-2}\ h^{-1}$) After weathering
Spraying	7.5	210.5	190.0
Dip-coating	-	254.1	166.2
Intermix method	21.8	110.5	122.5

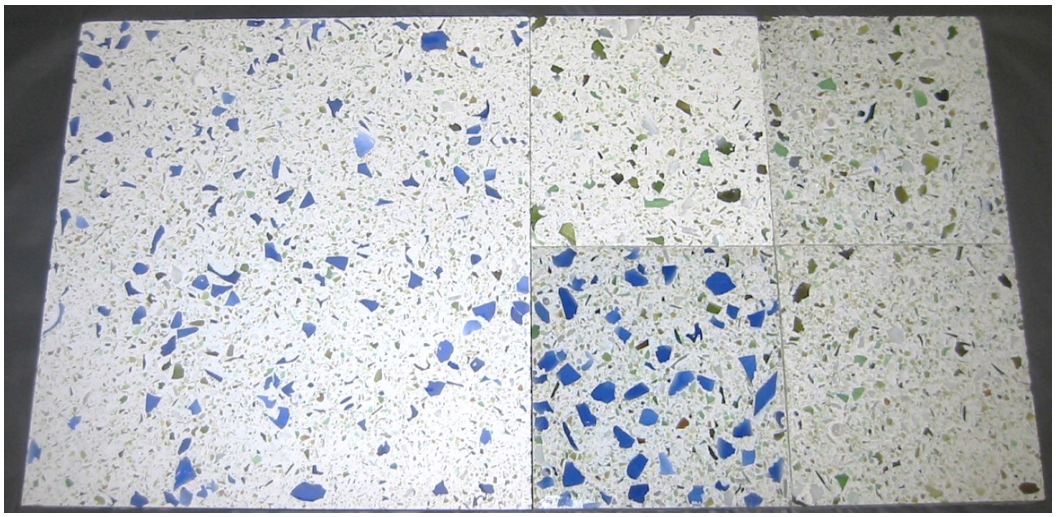
J. Chen and C.S. Poon, Photocatalytic activity of titanium dioxide modified concrete materials – influence of utilizing recycled glass cullet as aggregates, *J Environ Manag* **90** (11) (2009)

Architectural Mortar



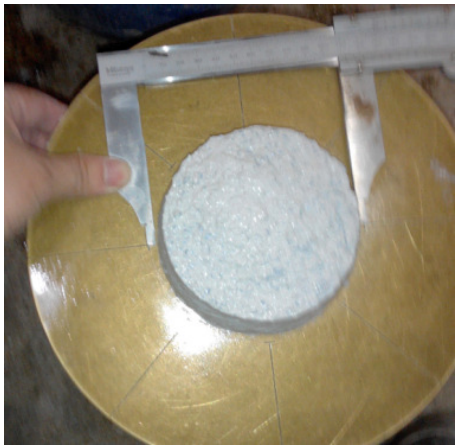
Glass Cullet Selection

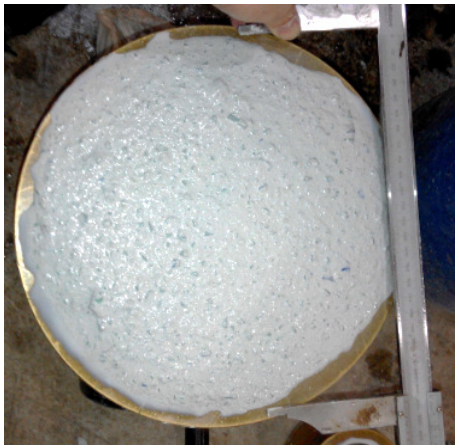




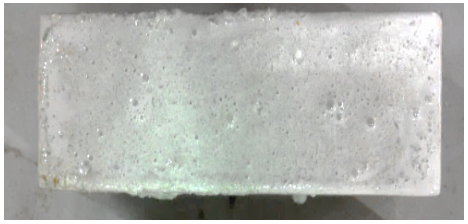
White cement based-recycled glass cullet incorporated architectural mortar

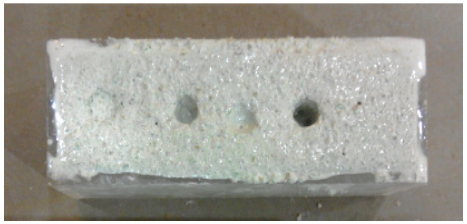
Semi-Flow Architectural Mortar





Flowability

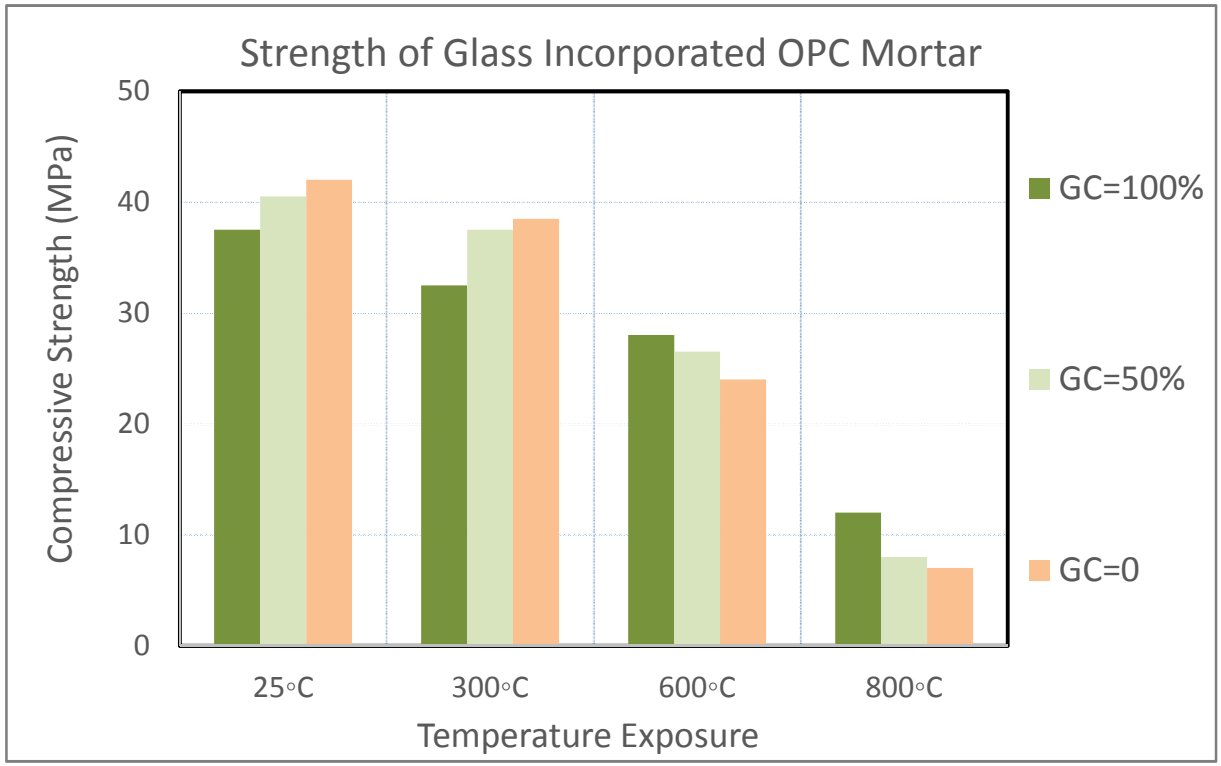


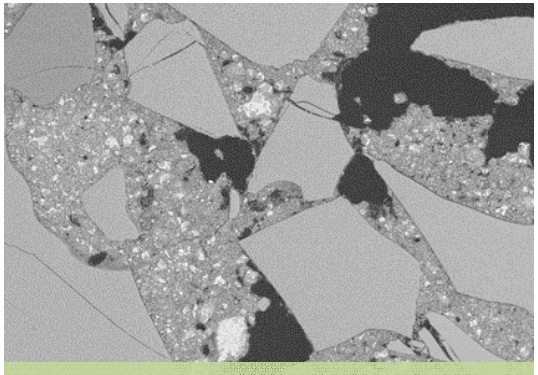


Stiffening

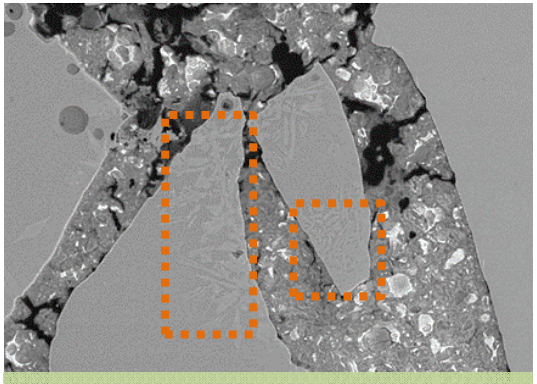
Shape-holding

Recycled GC in OPC





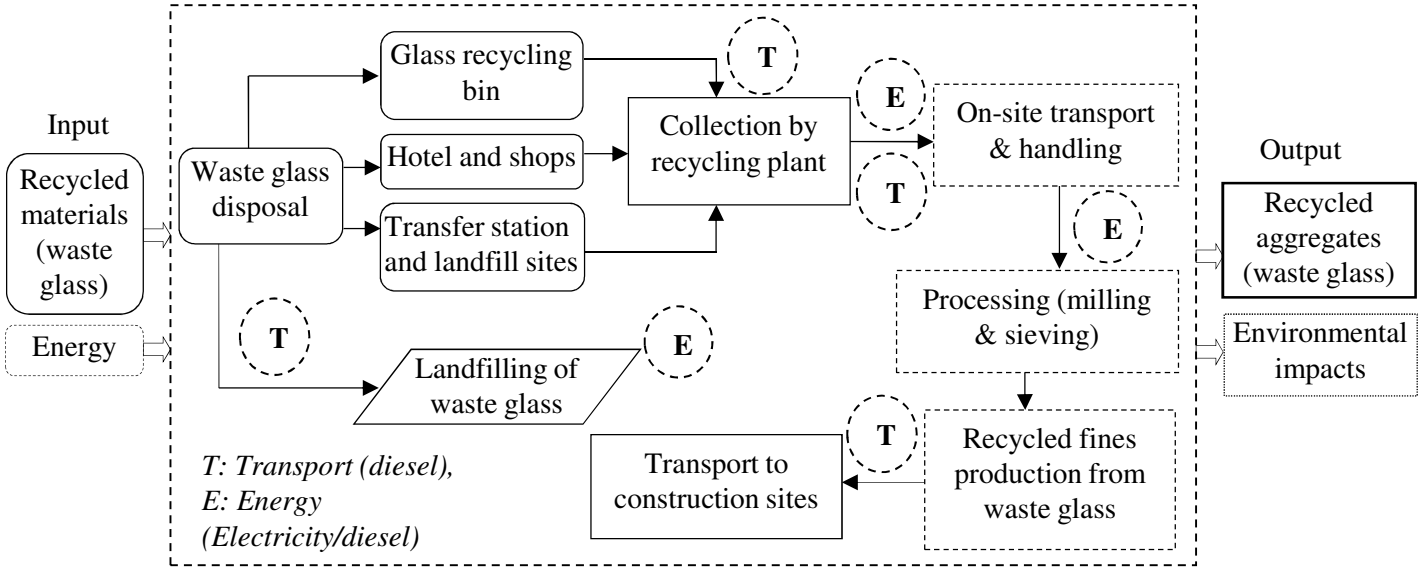
GC-OPC at Ambient Temperature



GC-OPC after 800◦C Melted edges observed

- Recycled glass cullet replacing sand led to **slight strength loss** under **room temperature conditions**;
- Exposure to temperature higher than 400◦C, the decomposition of CH resulted **in drastic strength loss**;
- Recycled glass cullet **partially compensated** high temperature induced strength loss of OPC Mortar.

LCA of Recycled Glass Aggregate



Impact category	Unit	River sand	Crushed fine stone	Recycled C&D waste	Recycled glass
GHG emission	kg CO_2 eq	22.85	32.79	10.17	**9.39**
Non-renewable energy consumption	MJ primary	340.81	518.08	180.98	**156.06**

M.U. Hossain, C.S. Poon, I.M.C. Lo, J.C.P. Cheng (2016). "Comparative environmental evaluation of aggregate production from recycled waste materials and virgin sources by LCA", Resources Conservation & Recycling. Vol. 109, pp. 67-77.

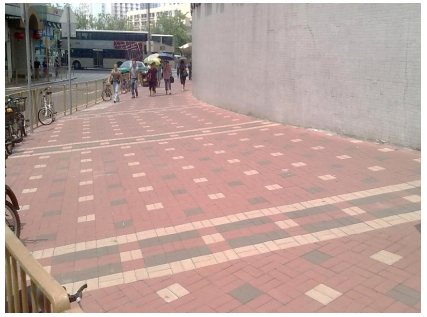
Applications

Recycling and Manufacturing in Factory

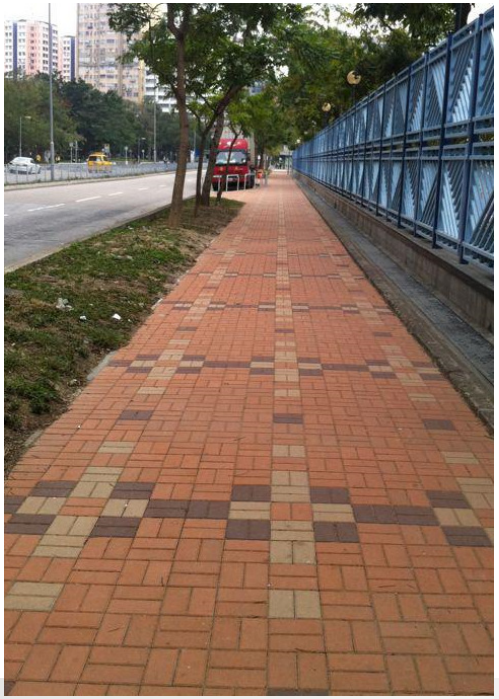
Applications

From Waste to Construction










Testing Standards

- Characteristic compressive strength against GS of Hong Kong (Greater than 30 MPa/ 45 MPa)
- Characteristic water absorption against AS/NZS 4455 (less than 6%)
- Dimensional tolerance against BS 6717:2001 (+/- 2 mm)
- Skid resistance against BS 6717: 2001 (Greater than 45 USRV)
- Abrasion resistance against BS 6717:2001 (Less than 23 mm)

Characteristic Compressive Strength (Cc)

$$Cc = Cm - 1.65 * s$$

- Cm is the average of the compressive strengths (C) of the 8 paving units
- s is the unbiased standard deviation

Compressive Strength (C) Calculation

2006 Edition

Calculation 11.1.4 (1) The compressive strength (C) of each paving block shall be calculated from the equation:

$$C = \frac{W}{A} \times \frac{2.5}{1.5 + \frac{L}{H}} \text{ MPa}$$

Shape Factor = around 0.8

for 200x100x60 mm units

where:

- W is the breaking load (N)
- A is the nominal gross plan area based on the manufacturing dimensions of the paving blocks or the area of the tested portion if the block size is reduced for testing (mm^2)
- L is the lesser of the two plan dimensions (mm)
- H is the thickness of the block (mm)

Characteristic Compressive Strength

	1	2	3	4	5	6	7	8
Breaking Stress (MPa)	45	48	44	53	49	48	74	42
Compressive Stress (C) (MPa)	36	38	35	42	39	38	59	33
Average (Cm)	40 MPa							
Unbiased Standard Deviation (s)	9 MPa							
Characteristic Strength (Cc)	26 MPa < 30 MPa (Fail)							

Recommendations

- Overdesign is also environmentally unfriendly. Review of the existing specification is recommended.

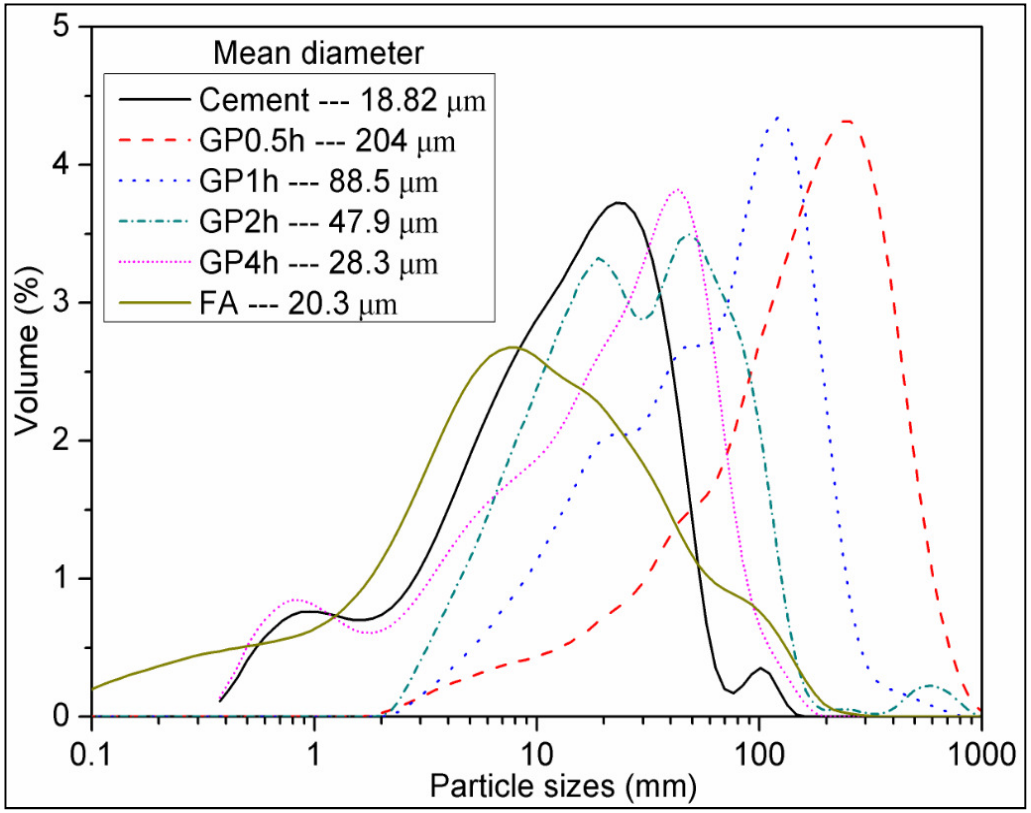
- Use minimum individual value instead of confidence interval of a normal distribution, which cannot be achieved from only 8-10 samples.

e.g.

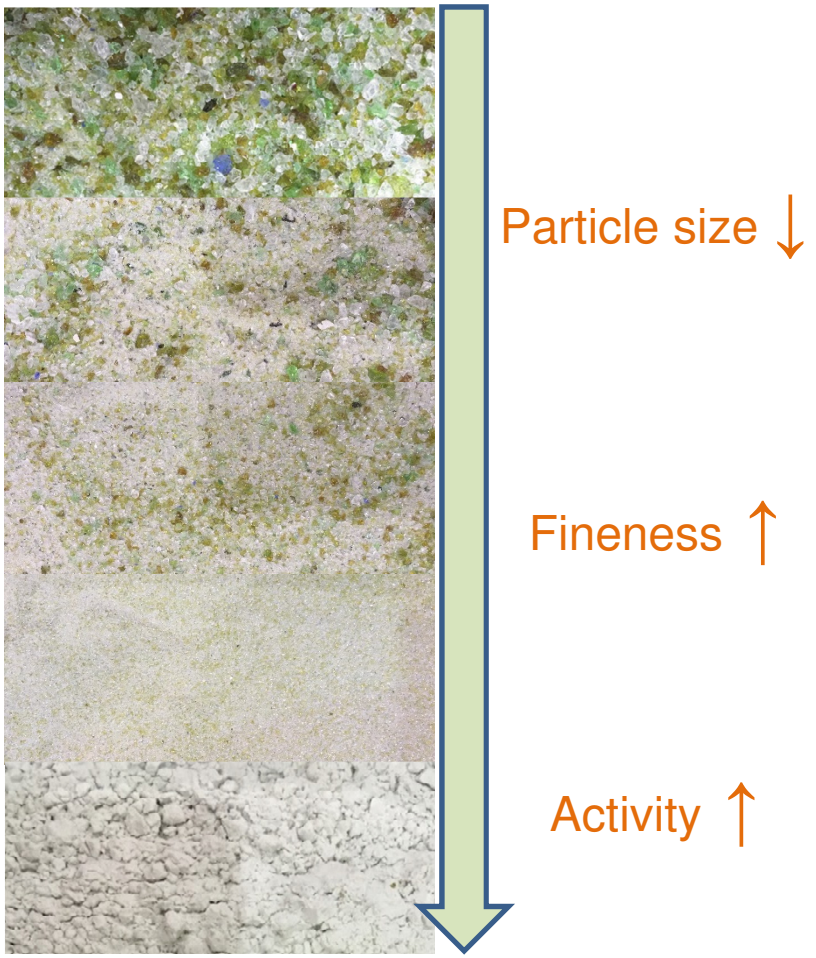
For compressive strength, average compressive strength shall be 30 MPa with no individual value less than 30 MPa

From Glass Cullet to Glass Powder

Effect of Grinding Duration

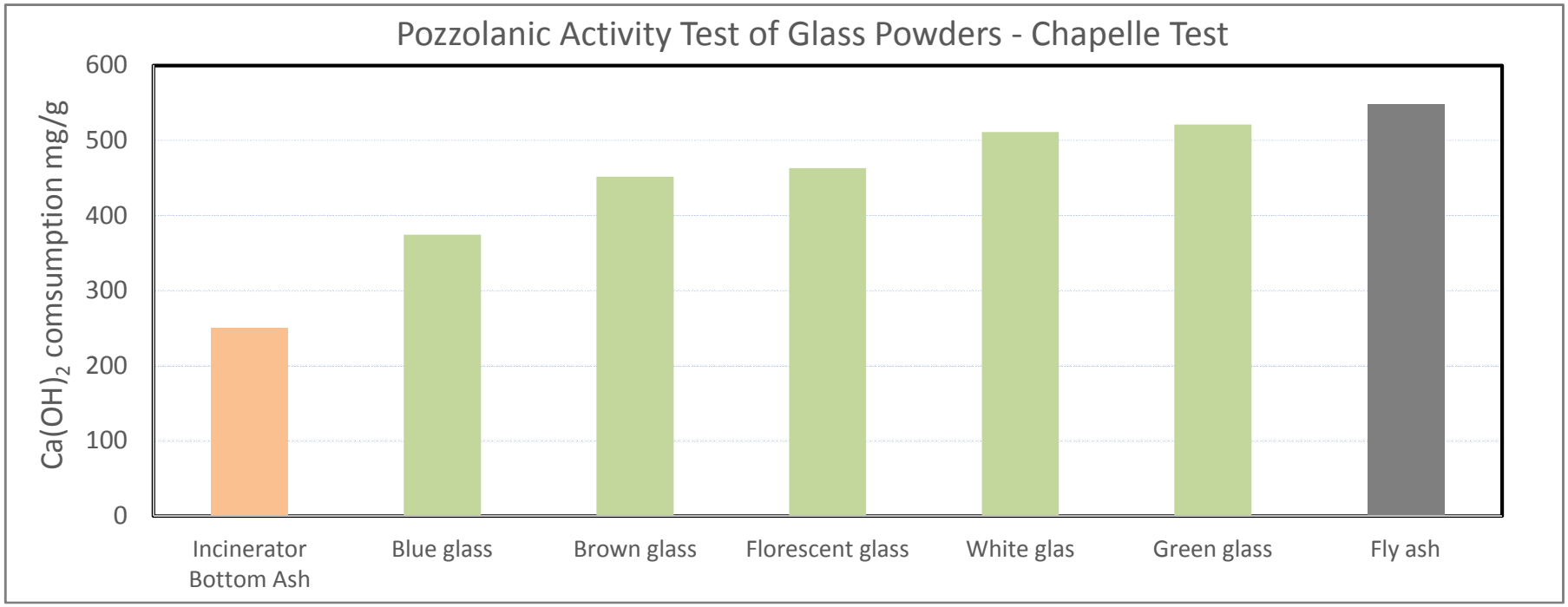


Particle size distribution of recycled glass powder after various duration of grinding



Reactivity of Glass Powder

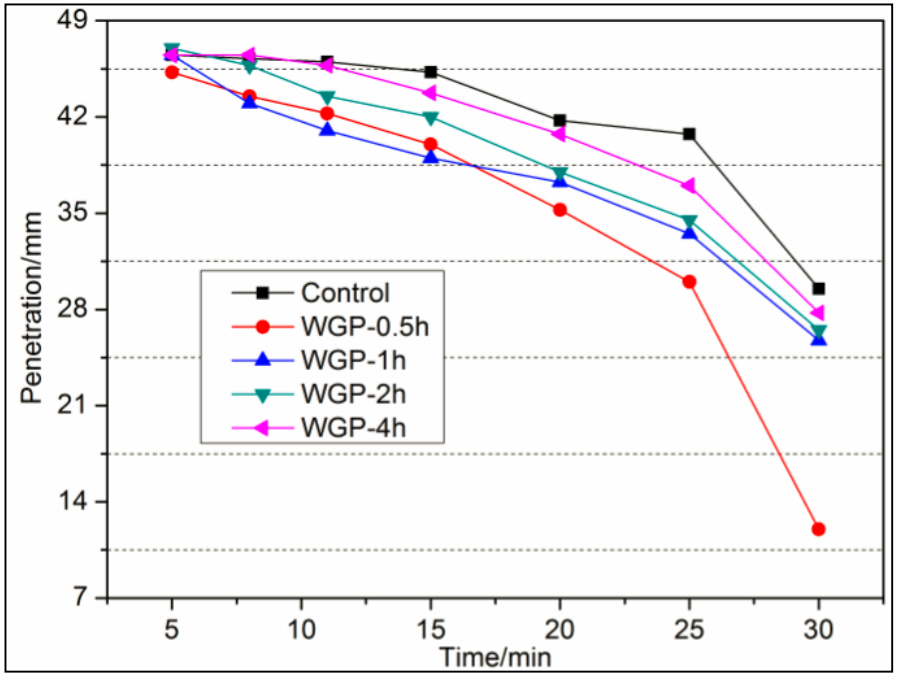
Supplementary Materials Not Only to OPC



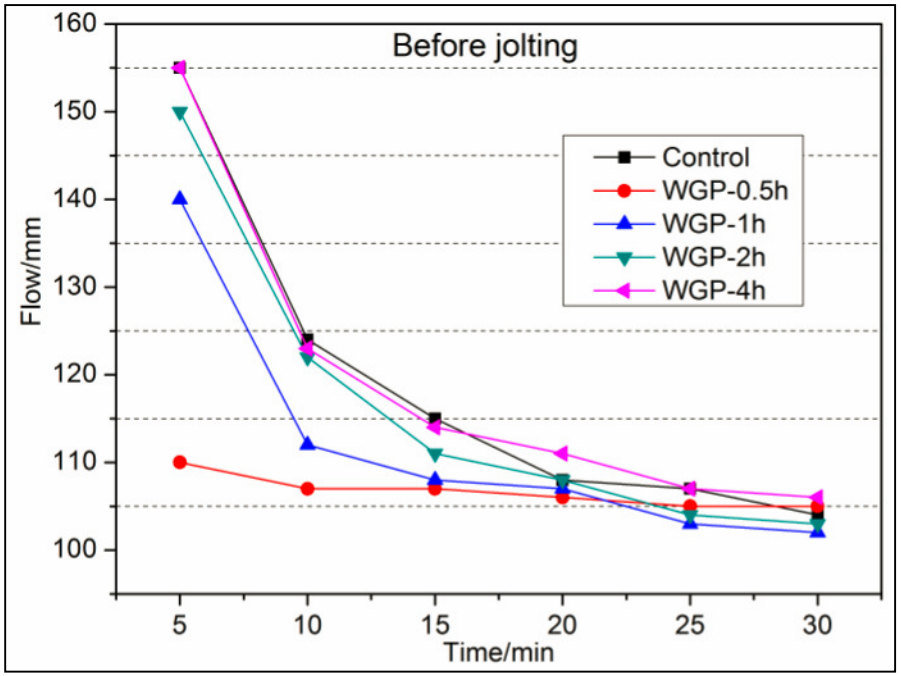
- Glass powder ground from recycled glass cullet with different colors show slightly different activities in the **Chapelle pozzolanic activity** test;
- Various types GP exhibit **comparable activity to fly ash**, which indicates the **feasibility** of using recycled glass powder **not only as a** pozzolanic material in **OPC** concrete but also a **precursor** material in Alkali Activated Cement (**AAC**) based materials.

Glass Powder in OPC Mortar

Fresh Properties



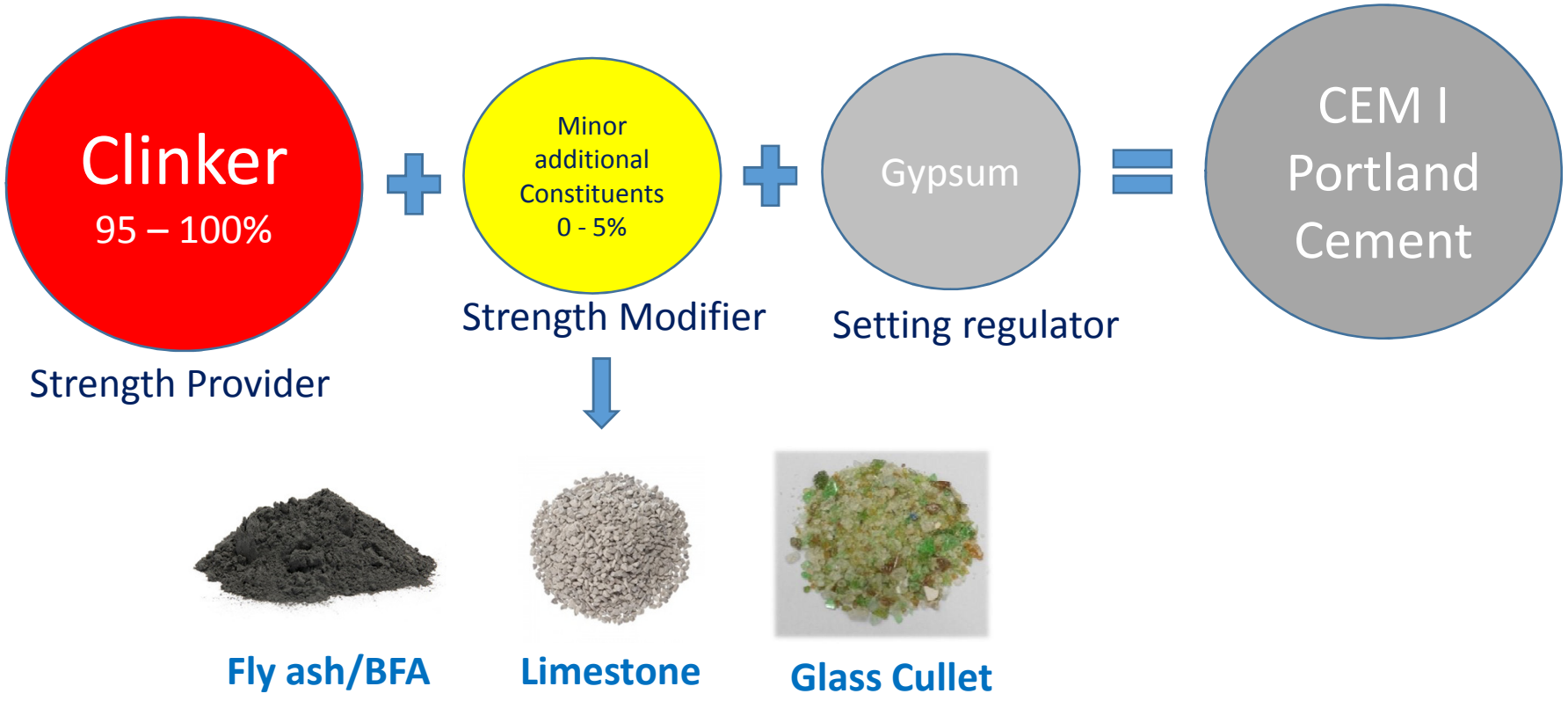
Effect of GP's fineness on stiffening time



Effect of GP's fineness on flowability

- The fineness of recycled glass powder affects both stiffening time and flowability;
- After **4 hour's grinding**, the fineness of recycled glass powder reaches a level that enables **comparable** stiffening time and flowability of the control mix.

Composition of Cement to EN197-1 CEM I



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Cement Manufacturing Process

Sintered at **1,450°C** to form Clinker

Finely grind to become Cement

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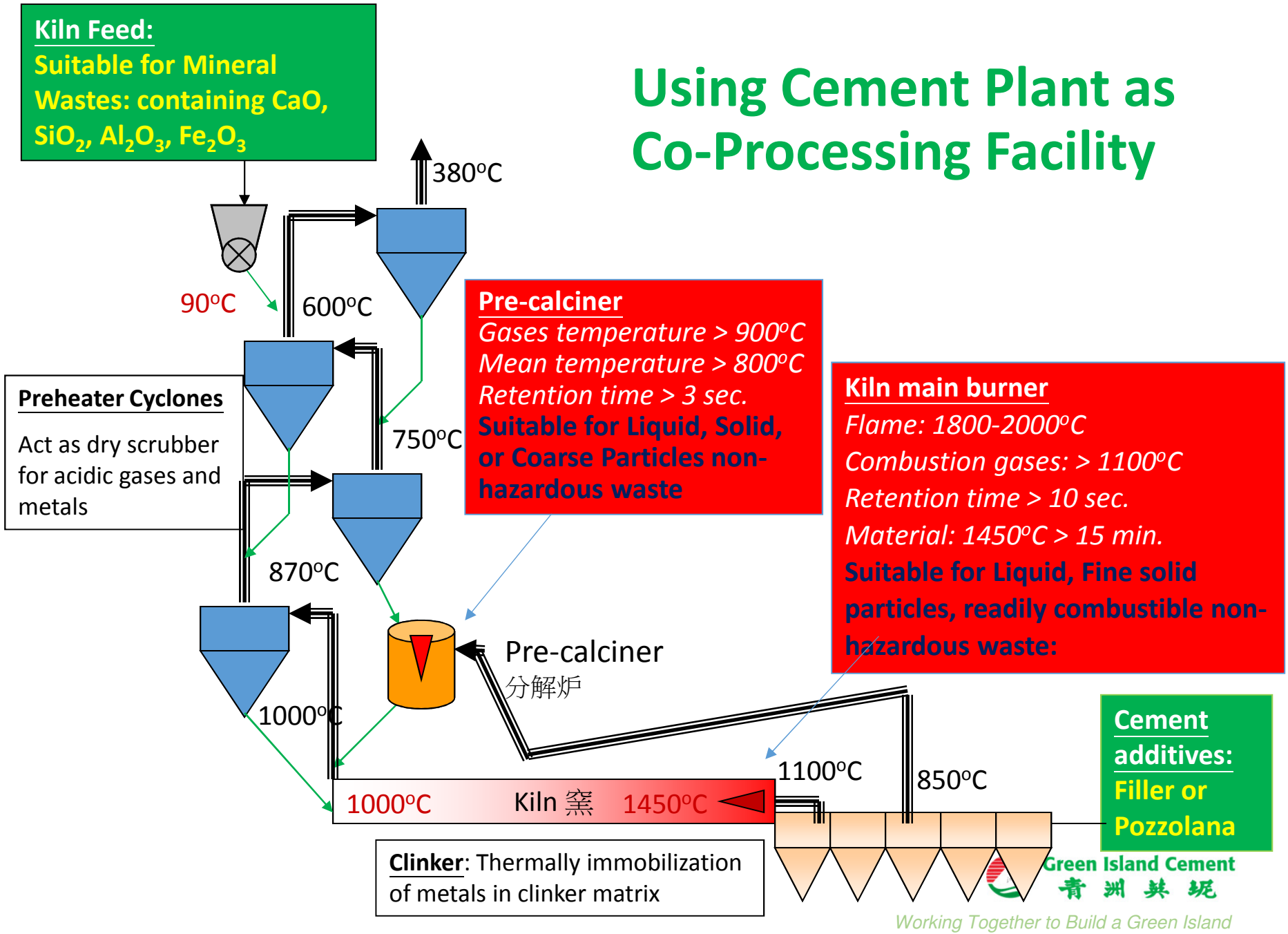
Using Cement Plant as Co-Processing Facility



Concept of Co-Processing

Co-processing is the use of wastes as raw materials, or as a source of energy, or both to replace natural mineral resources and fossil fuels such as coal, petroleum and gas in industrial processes, mainly in **energy intensive industries** such as cement.

Waste		Substitution	Examples
Energy Content (carbon, hydrogen)	Energy recovery	Substitution of fossil energy	Waste plastics Waste Wood Solvents Waste oil
Energy Content Material Content	Energy recovery Material recovery	Substitution of fossil energy Substitution of raw material	Used tires Polyurethane Reside Used paints IndustrialfFba sludge
Material Content (CaO, Fe_2O_3, Al_2O_3, etc)	Material recovery	Substitution of raw material	Fly ash & FBA By-product gypsum Blast furnace slag Glass Cullet

Techno-environmental feasibility of wood waste derived fuel for cement production

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Published in Journal of Cleaner Production, 2019

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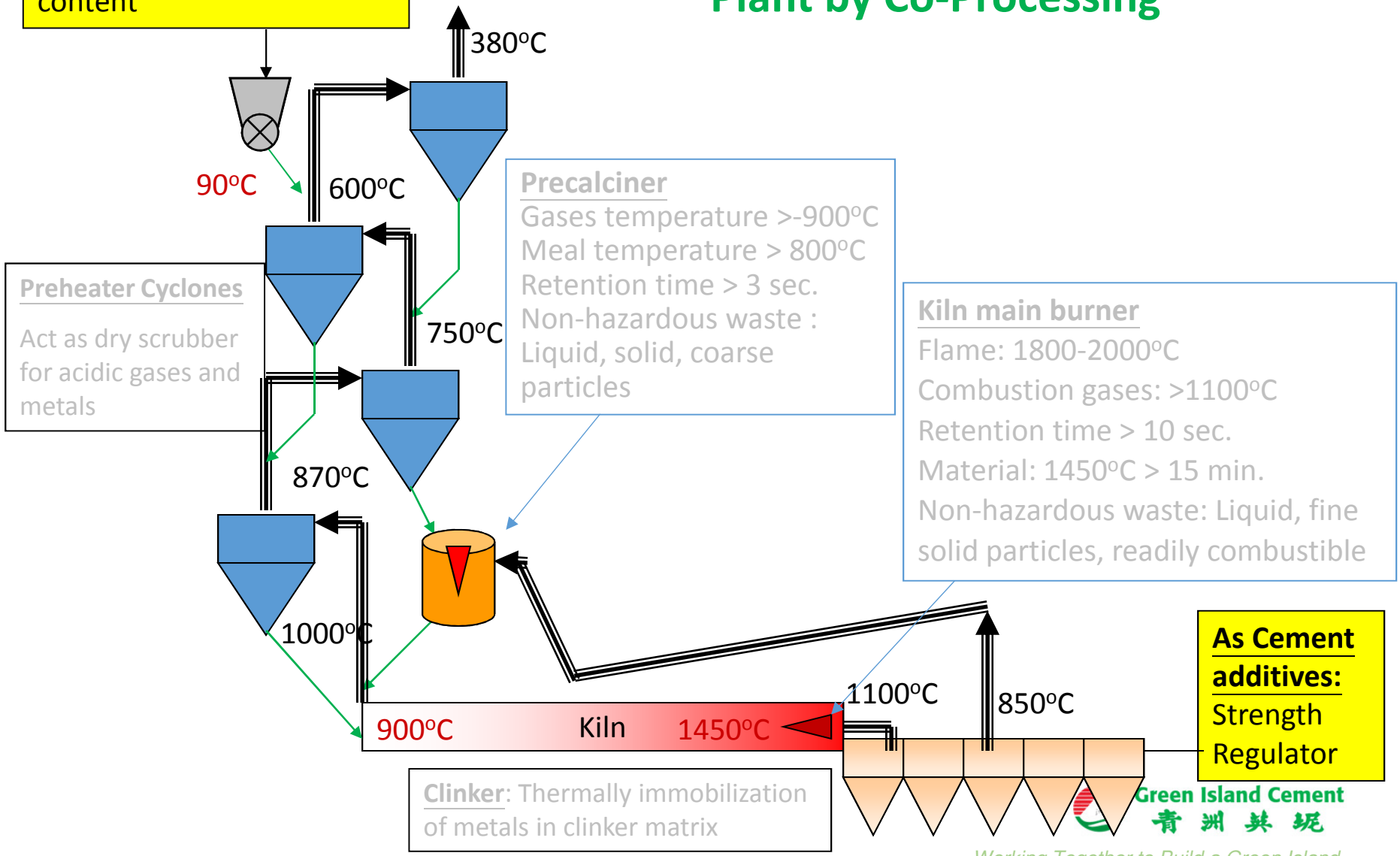
Use of Recycled Glass in Cement Production, TSK

Waste Glass Used in Cement Plant by Co-Processing

As Kiln Feed Raw Material:
Replace Silica for its SiO_2 content



Preheater Cyclones
Act as dry scrubber for acidic gases and metals

Precalciner
Gases temperature >-900°C
Meal temperature > 800°C
Retention time > 3 sec.
Non-hazardous waste : Liquid, solid, coarse particles

Kiln main burner
Flame: 1800-2000°C
Combustion gases: >1100°C
Retention time > 10 sec.
Material: 1450°C > 15 min.
Non-hazardous waste: Liquid, fine solid particles, readily combustible

As Cement additives:
Strength Regulator

Clinker: Thermally immobilization of metals in clinker matrix

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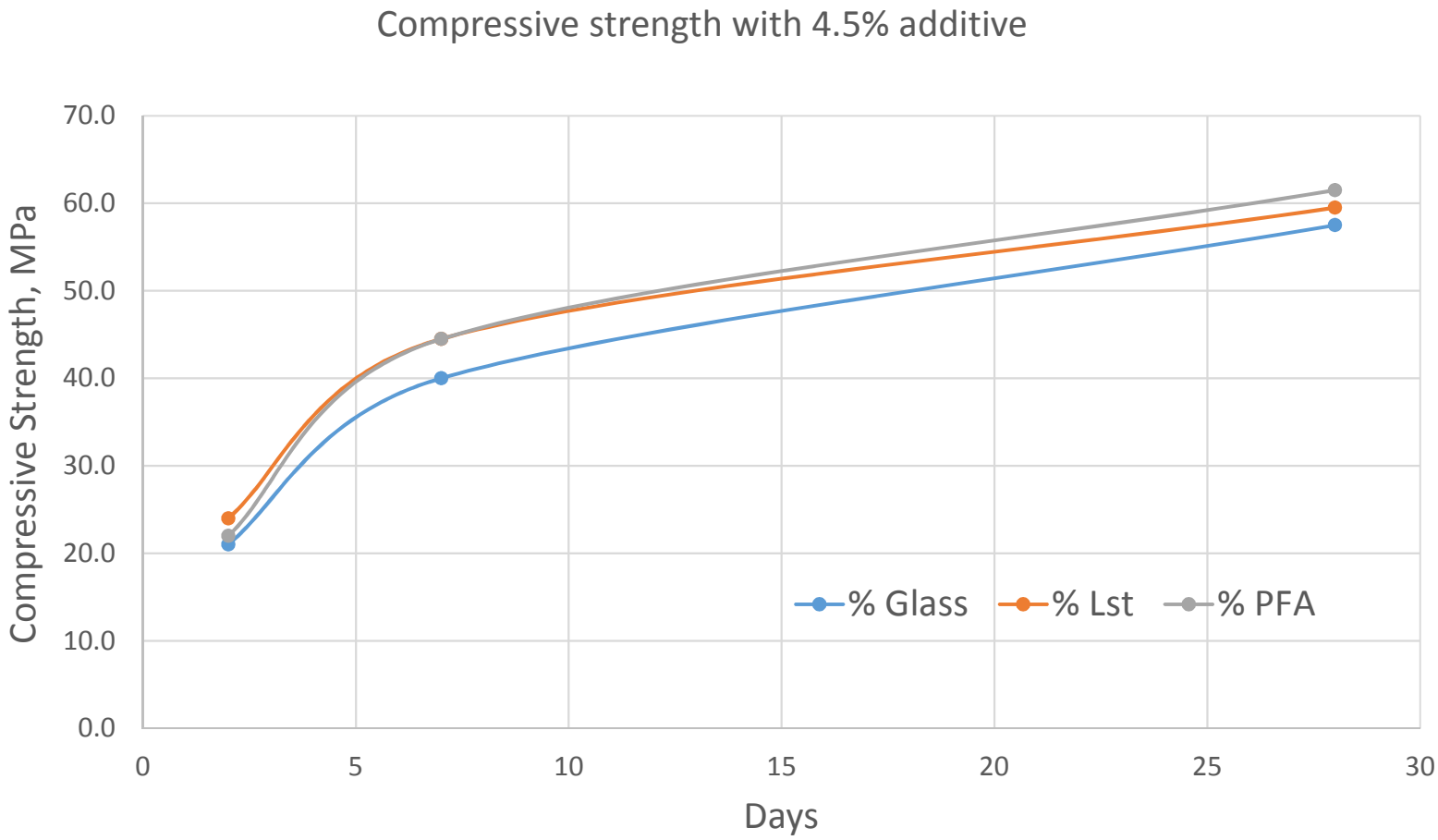
Strength Development Profile of OPC Additives



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Comparison of Minor Constituents Available Locally

Material	Strength Activity	Impact
Fly ash or Bottom Ash	Moderate	Enhance Latent hydraulic property
Limestone	Fast	Enhance early hydration property
Glass	Slow	Contribute to long term properties

Use of Glass in Cement

- Utilize waste glass as cement additive since 2014
- Started to collect from GMC contractor since 20 August 2018*

Year	Recycled Glass received, tonne
2014	7
2015	-
2016	134
2017	459
2018 Jan - Jul	326
2018 Aug - Dec*	3,319
2019 up to Apr*	2,257

Estimated annual consumption of glass in cement process : 25,000 t

Summary of the LCA results

Overall energy consumption and GHGs emission for cement manufacturing

Type of cement	Energy consumption, MJ/t		GHGs emission (CO_2 kg eq/t)	
	Assessed	Compared with OPC (%)	Assessed	Compared with OPC (%)
OPC (90/5/5)	4910.43	---	1016.70	---
Eco-GC (90/5/3/2)	4788.86	2.48 ↓	993.64	2.27 ↓

Hossain M.U., Poon Chi Sun, Lo, I.M.C., Cheng, J.C.P., (2017). Comparative LCA on using waste materials in the cement industry: A Hong Kong case study, Resources Conservation and Recycling, 120, pp. 199-208.

Waste Glass in AAC

Waste Glass

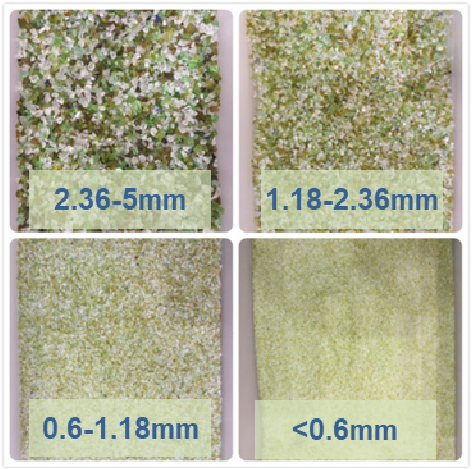
1. Preliminary cleaning & labels removal

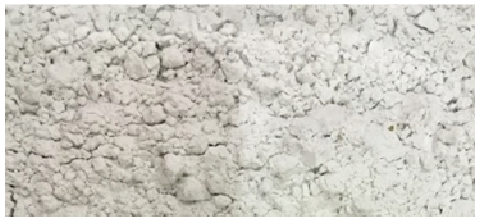
Glass Bottles

2. Crushing

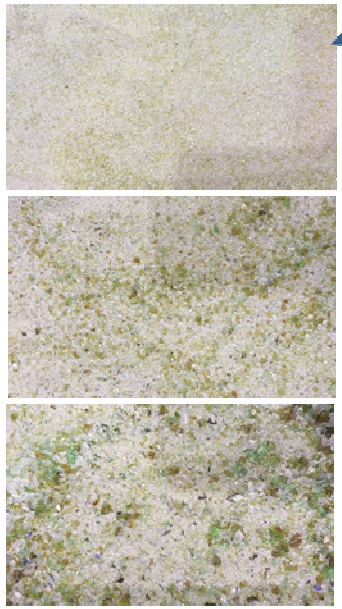
Mixed Glass Cullet (GC)

3a. Sieving



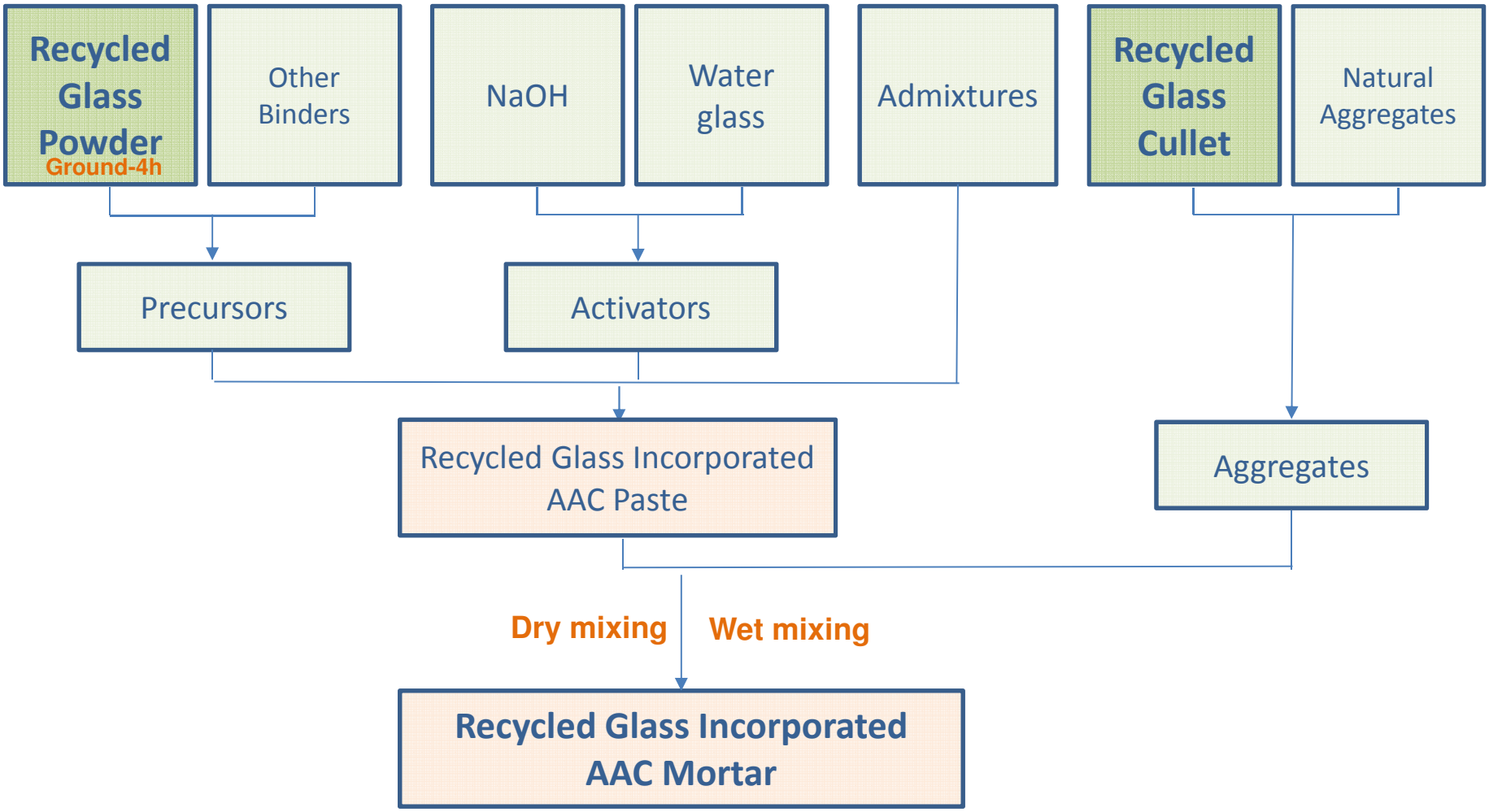


Glass Powder (GP)



3b. grinding

Recycled Glass in AAC

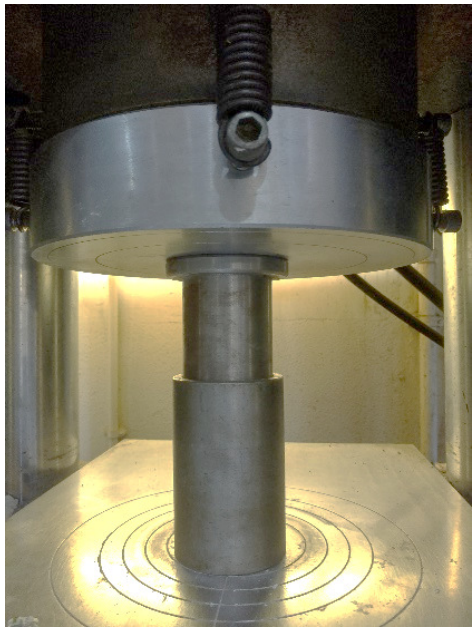


Glass Incorporated AAC Mortar

Two Mixing Schemes

Wet mix scheme

- Flowable
- Casting under vibration



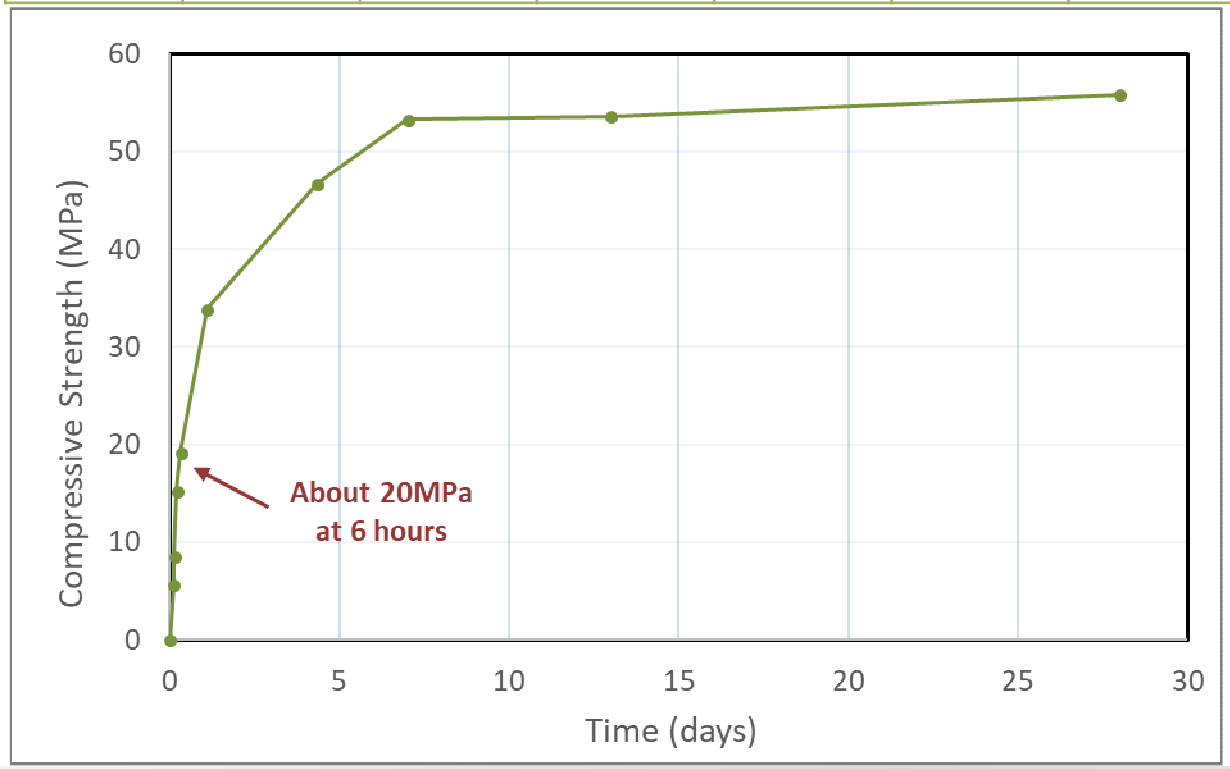
Dry mix scheme

- Non-flowable
- Casting under compression (60kN)

High Early Strength Development

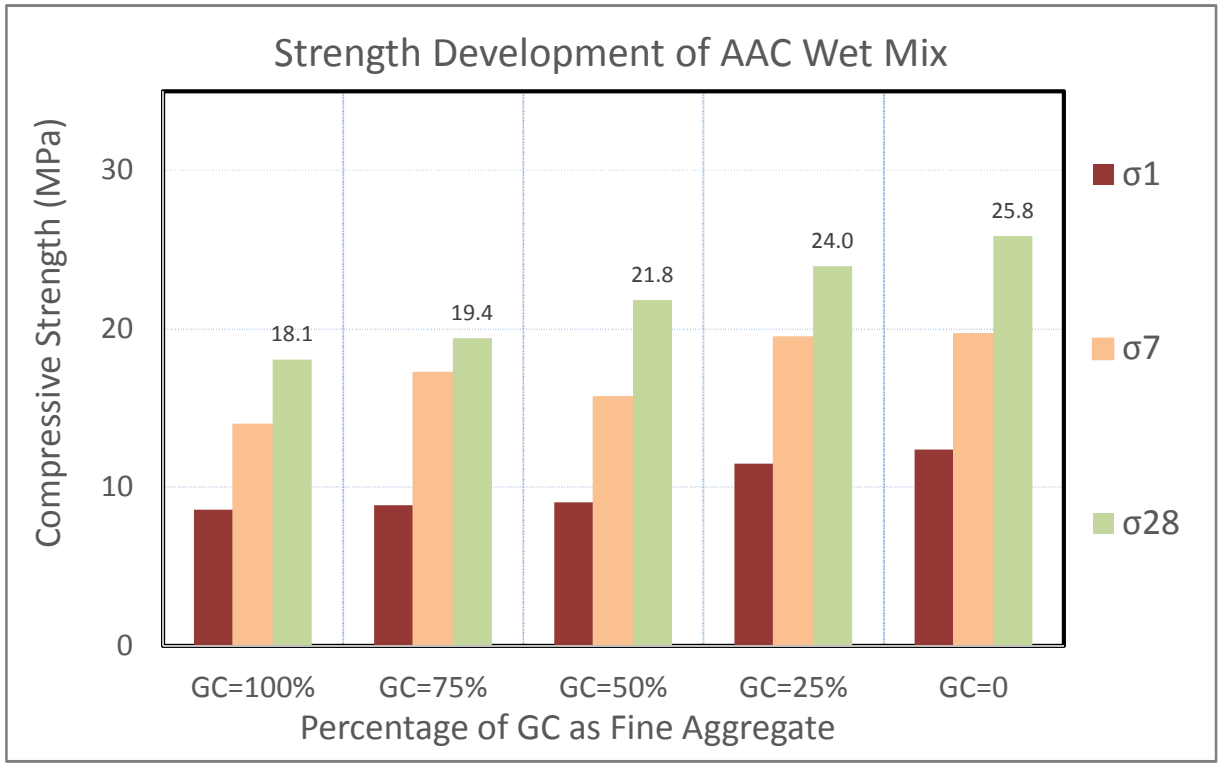
Dry mix – Pre-cast Applications

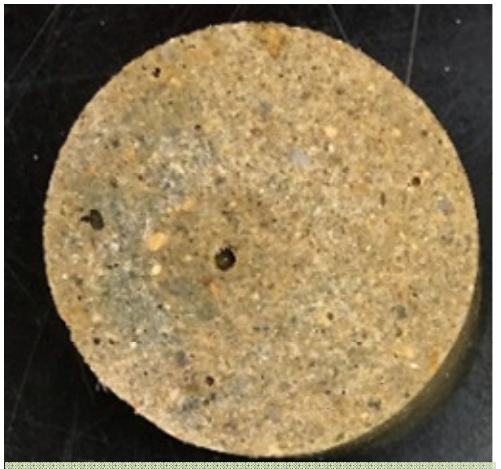
Mix Proportion (wt%)						Strength Development (MPa)			
Glass powder	Glass cullet	**Total Glass content**	Cementitious material	Natural aggregate	Alkali solution	σ-3h	**σ-6h**	σ-1 day	σ-28 day
18.0	51.9	**69.9**	18.0	0	12.1	8.5	**19.2**	33.9	55.8



Strength Development

Wet Mix – Partition Wall Applications



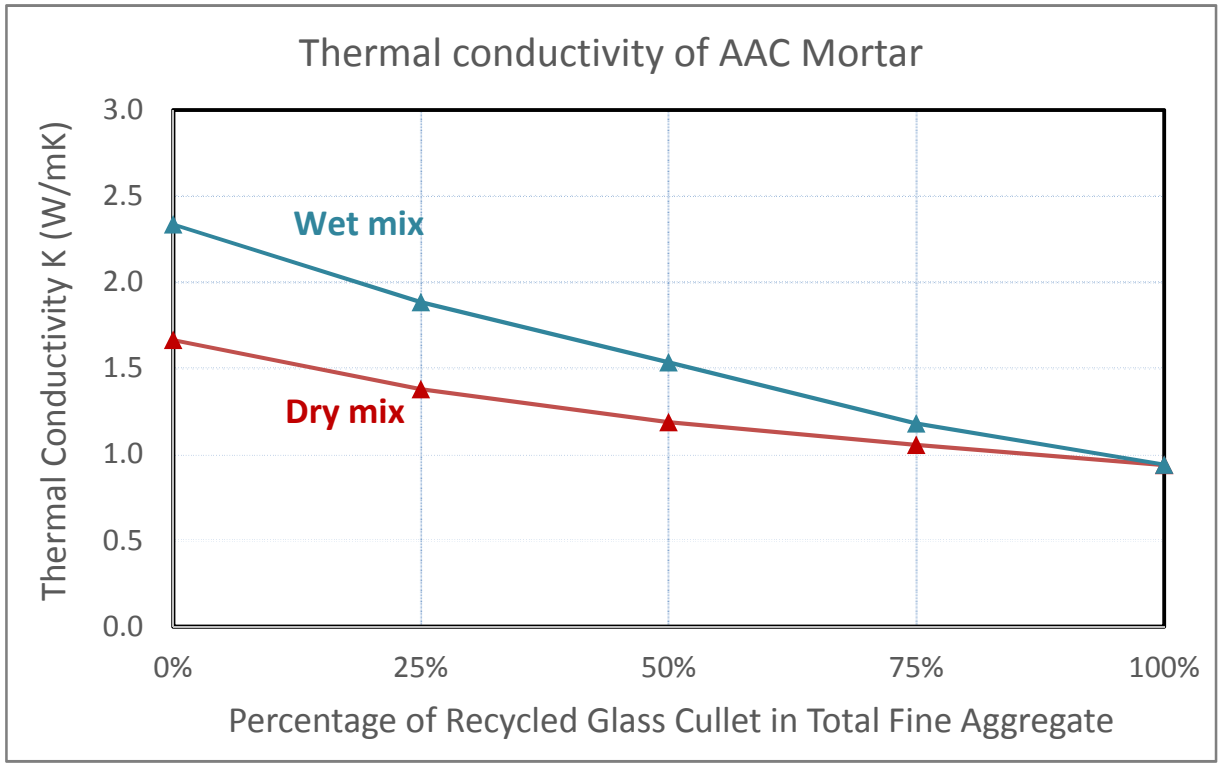


AAC Mortar, GC=0

AAC Mortar, GC=100%

- Cylindrical specimens D50mm*H50mm casted for compressive strength test;
- Slightly strength loss occurred due to recycled glass cullet incorporation;
- Strength of mixture incorporating 100% GC was higher than 10MPa, which can be used as partition wall.

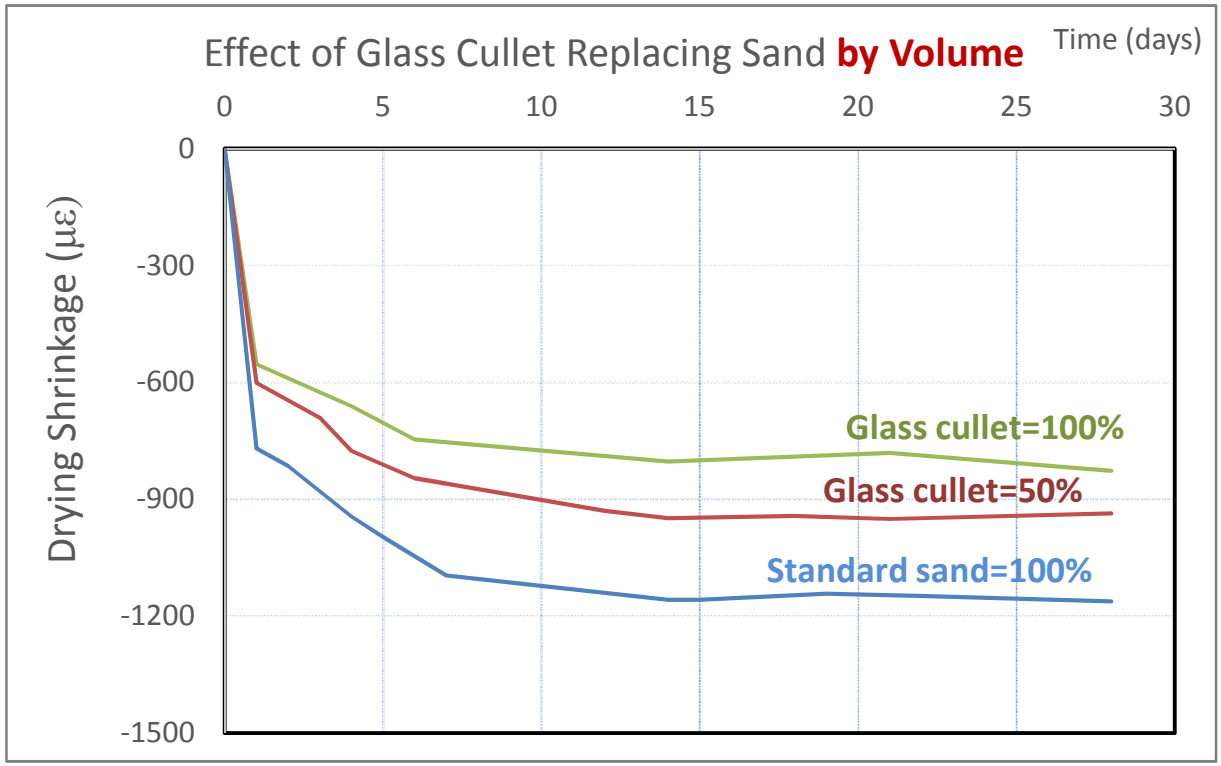
Insulation Properties Enhancement

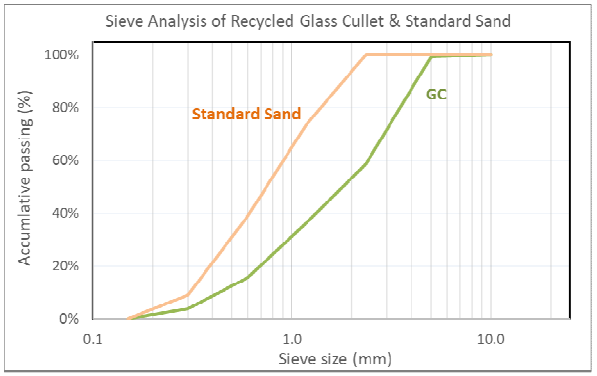


Hot Disk M100 for K-value Test
Applicable range 0.03-40 W/mK

- Dry mix method sample showed lower thermal conductivity due to higher porosity;
- Incorporation of recycled glass cullet as fine aggregate leads to a linearly reduced K-value as the lower thermal conductivity of glass (1.05 W/mK) compared to sand(1.7 W/mK) .

Drying Shrinkage Mitigation

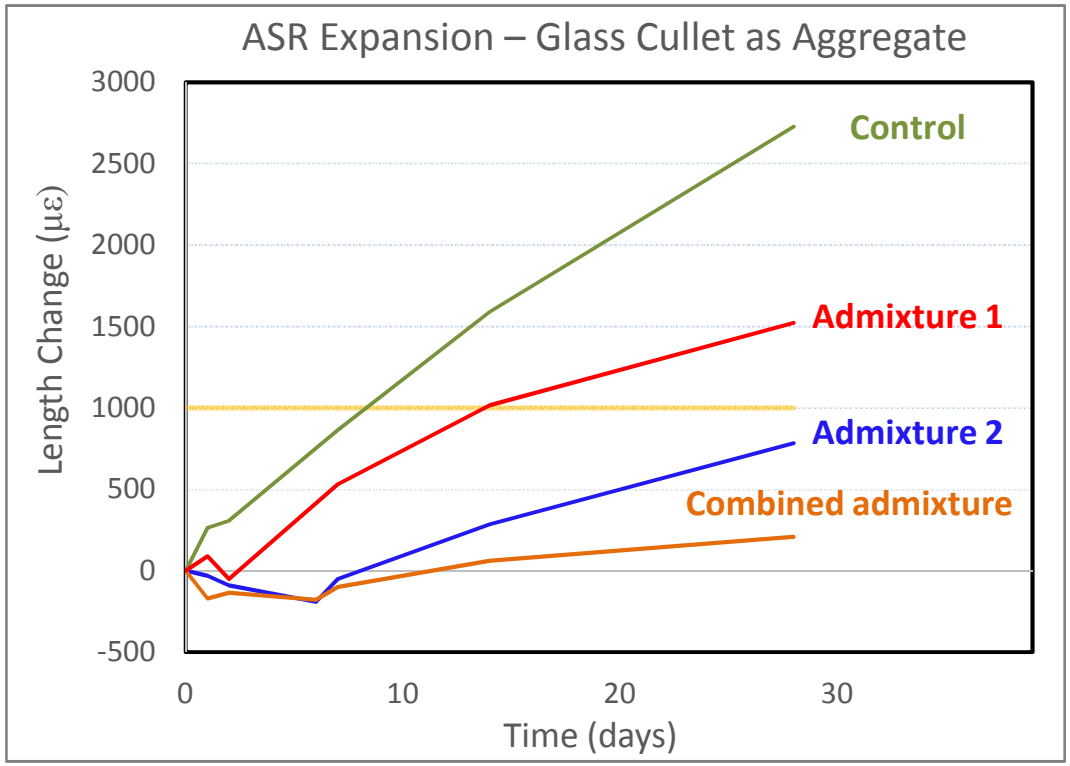


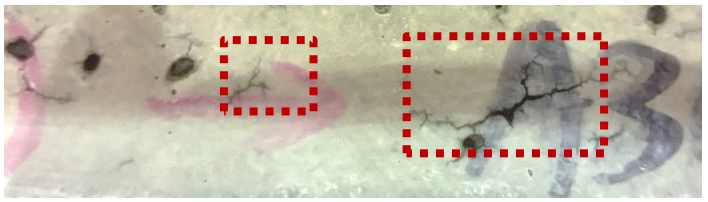


- Replacing standard sand by the recycled glass cullet led to reduced drying shrinkage;
- The reduction is possibly due to the presence of larger particles (>2.36mm) in the glass cullet;
- Shrinkage values comparable to OPC based mortars.

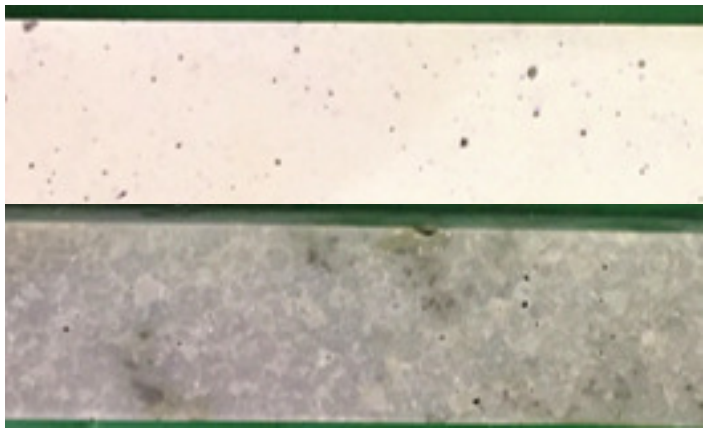
Alkali Silica Reaction

Suppression effect of Admixtures





Without admixture - Obvious cracks only after 2 days immersion

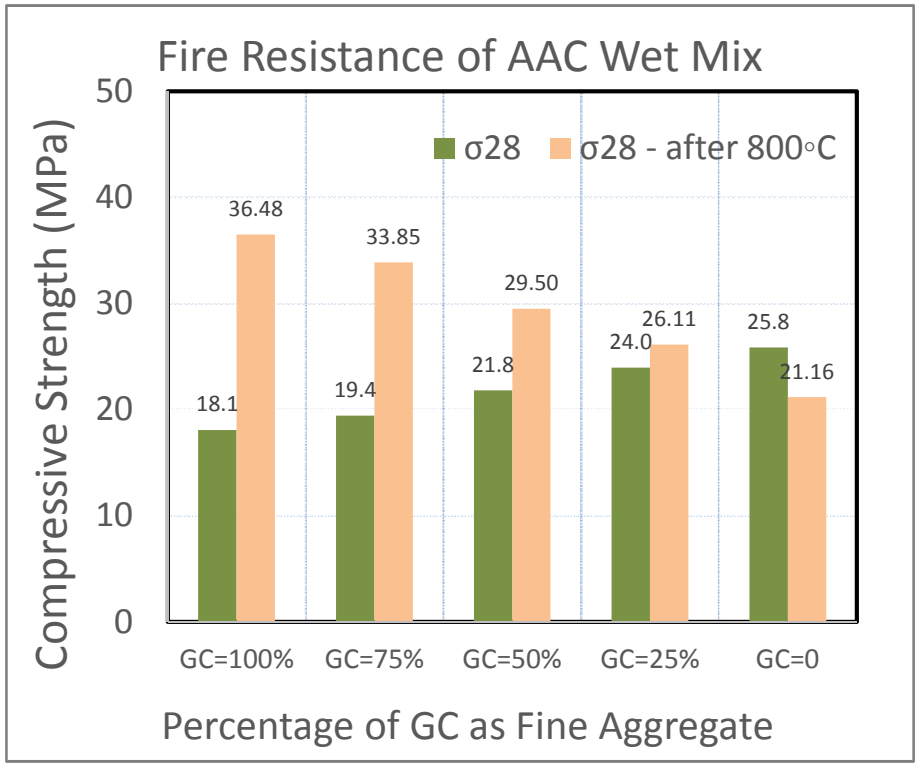


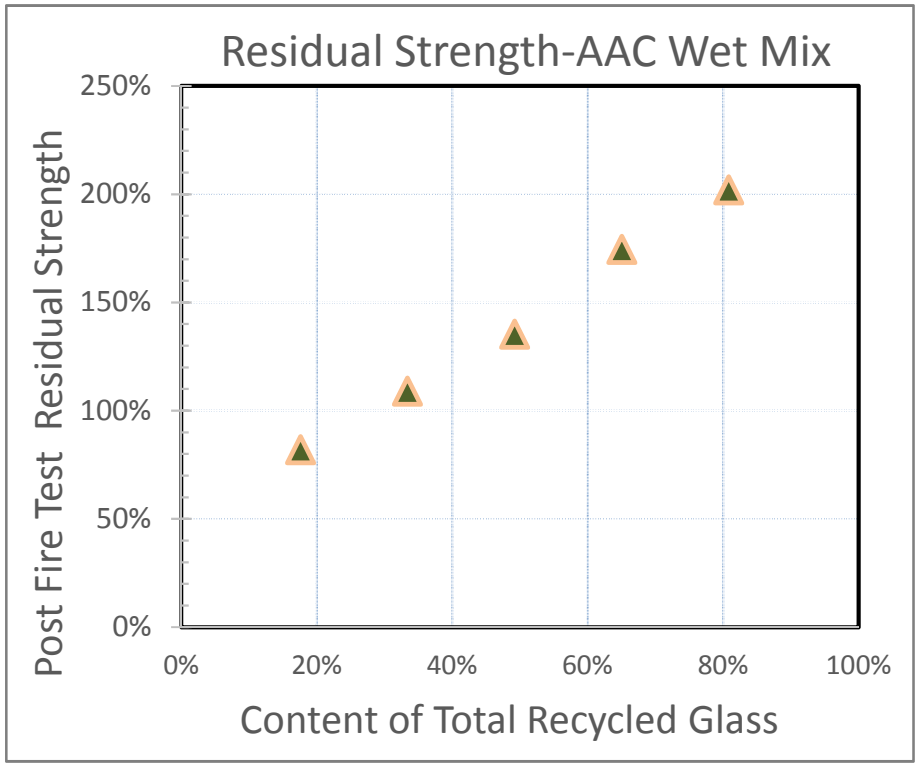
With Admixtures- Slight or negligible cracks after 28 days immersion

- ASR expansion can be effectively suppressed with the use of admixtures.

Fire Resistance

Test at 800◦C for 2 hours – Glass powder 75%

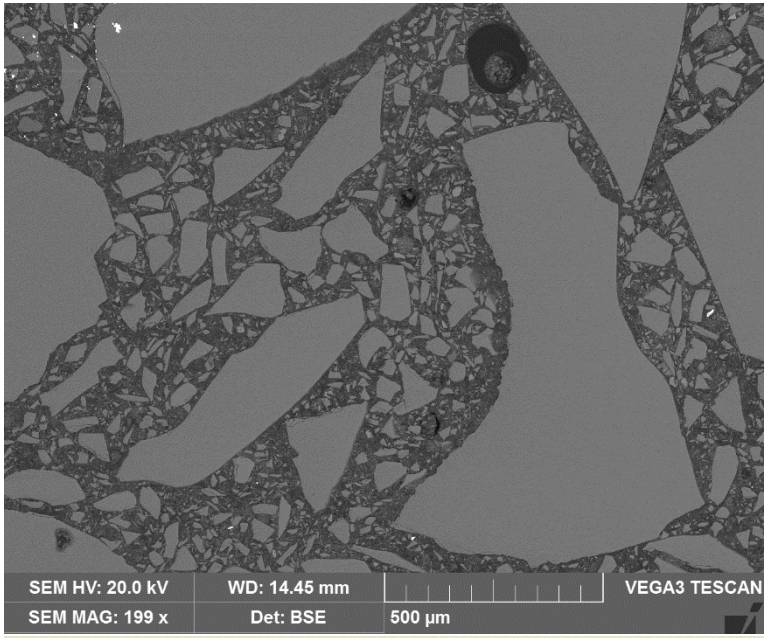




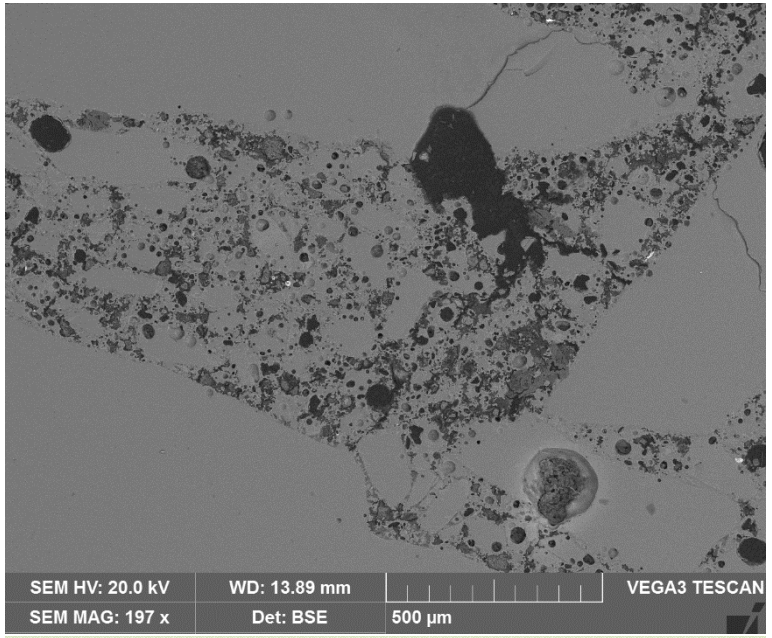
- Strength increment observed for recycled glass incorporated AAC mortars;
- AAC mortars with higher contents of recycled GC attained better residual strength after exposure to 800 C.

Fire Resistance

Take a Closer Look at Recycled Glass Cullet in AAC



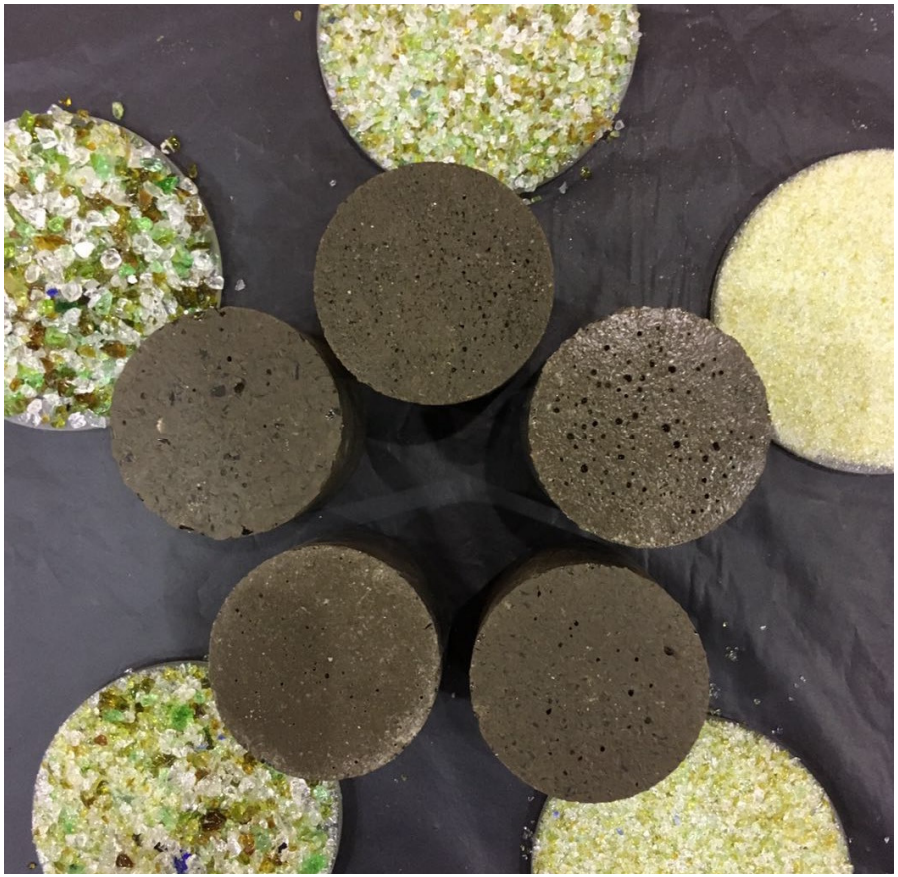
Before Fire Test
Glass cullet distributed in AAC paste

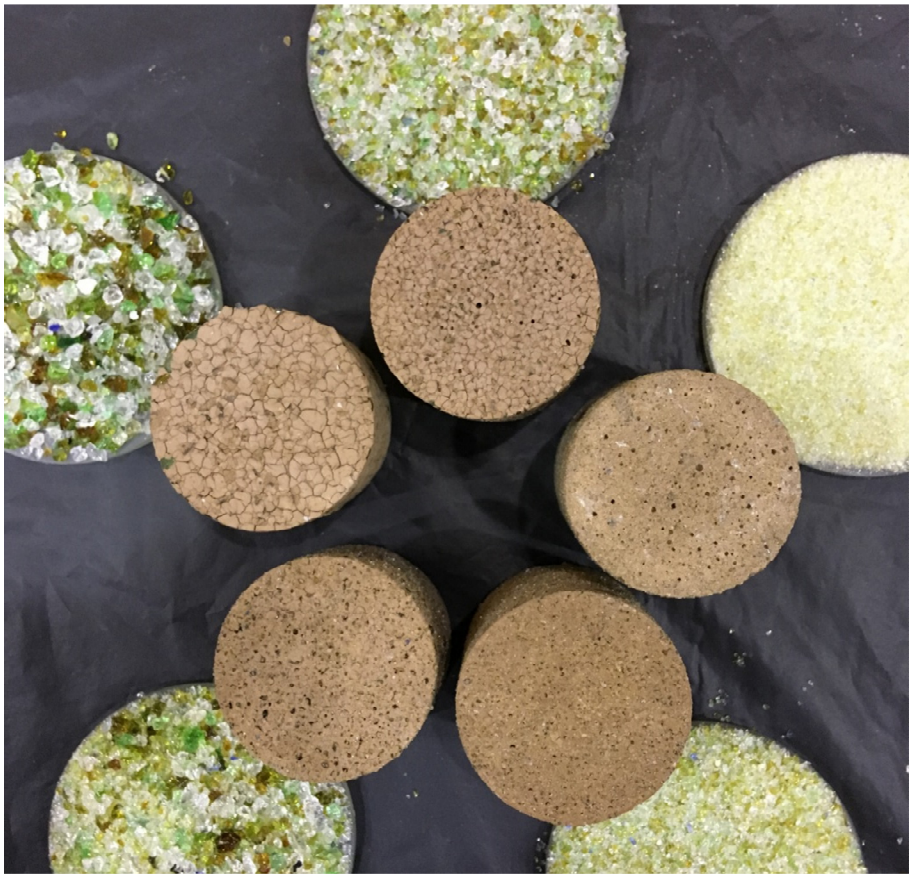


After Fire Test
Glass particles melted together

- Before fire test, distinct weak interfacial transition zone present between glass cullet particles and paste;
- Glass cullet particles partially melted and fused together after exposure to high temperature, thus drastically increased the bonding between aggregate and paste.

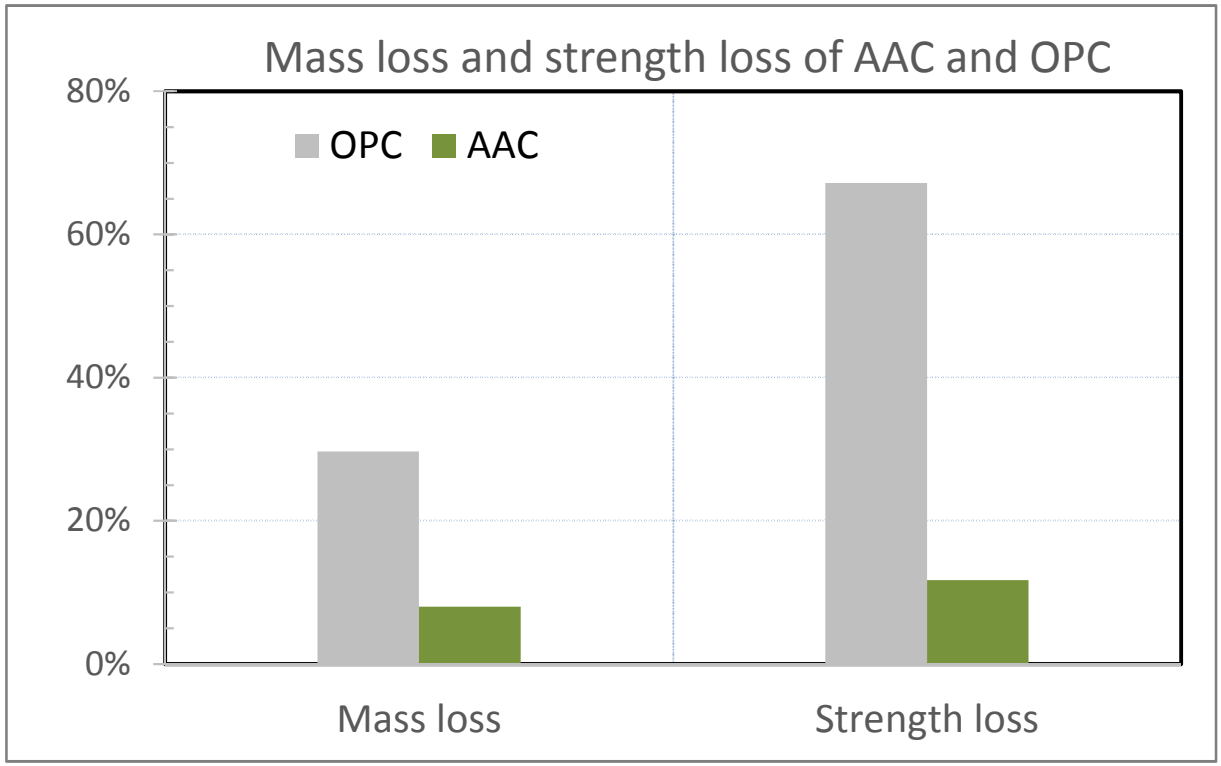
Before & After 800◦C

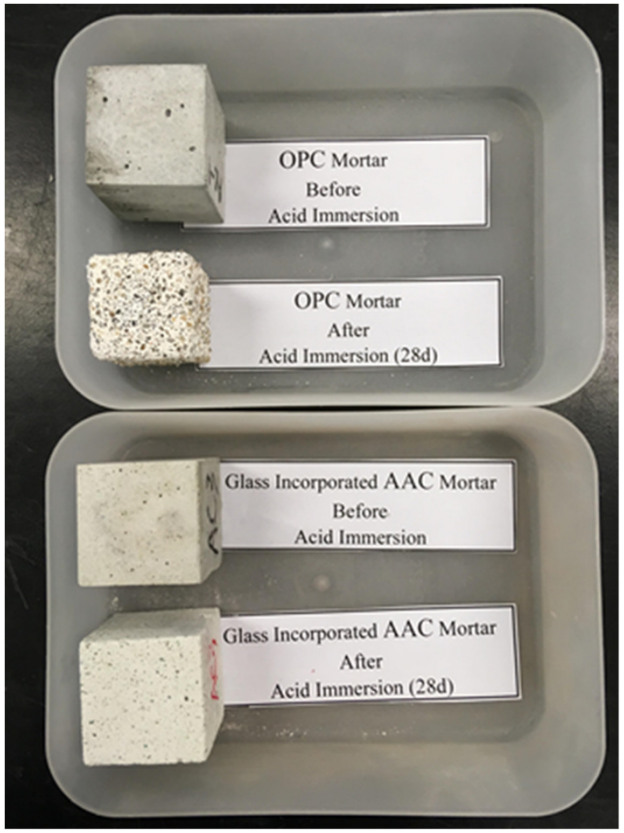




Chemical Attack Resistance

In Comparison with OPC Based Mortar

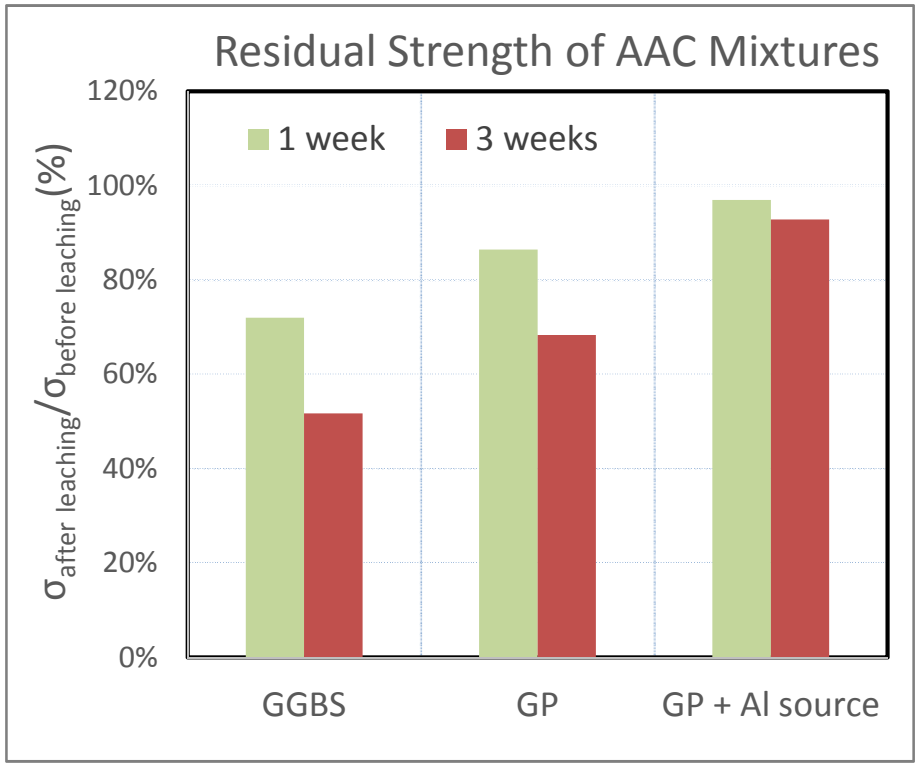




- The recycled glass incorporated AAC showed superior acid resistance (0.5N/L sulphuric acid immersion) compared to OPC based mortar

Efflorescence Mitigation

In Comparison with GGBS Based AAC Mortar/Paste



GGBS Based Paste

GP=75% Paste

- Residual strength test showed that GP dominated AAC mortars had higher residual strength after efflorescence test;
- After 3 weeks of contact with water, GGBS based paste showed significant efflorescence, while 75% GP paste exhibited limited efflorescence.

Highlights – Recycling of Waste Glass as Construction Materials

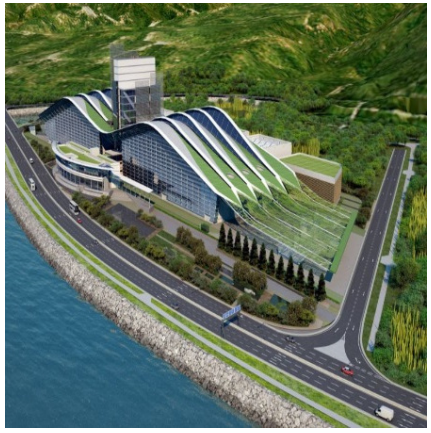
- Recycling & reusing waste glass cullet in **paving blocks and mortars** led to **reduced energy consumption** for aggregate production;
- Longer grinding duration enables higher activity, **4h** grinding enables sufficient fineness and activity of glass powder;
- Waste glass powder can be incorporated **in the production of OPC** without affecting its performance;
- A wider channel of use of **waste glass powder/cullet in AAC;**

More Than Waste Glass

More Than Recycling, More Than Innovation

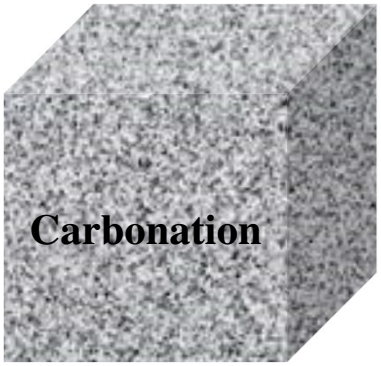
C&D Waste

Incinerator Ash

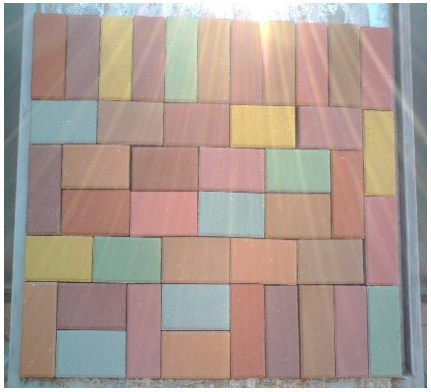


Waste Timber

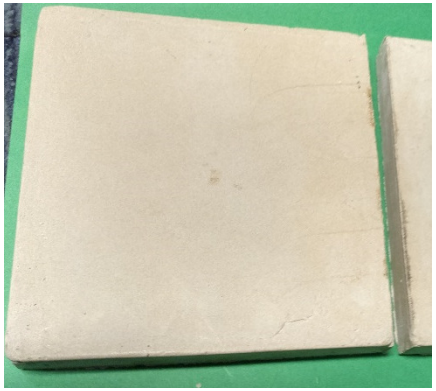
Waste Tyres



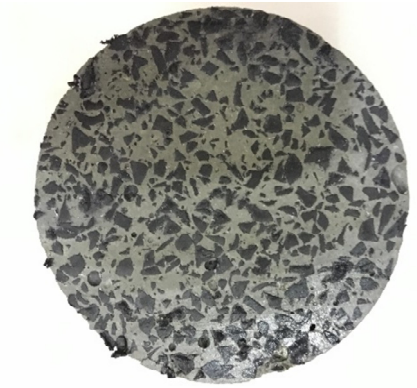
GHGs Sequester



Decorative Tiles



Waste wood-MOC slab



Rubberized AAC


Thank You!
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