Blast Furnace Slag: Concrete Benefits

Sponsored By
K Wah Construction Materials
(Hong Kong) Ltd
Key Objectives

- Introduce GGBFS
- Discuss Research Framework
- Present Key Results
Slag - GGBFS

- By product of steel industry
- Typical Composition
  - Silica (S 30-40%)
  - Lime (C 35-45%),
  - Alumina (A 10-20%)

- Benefits:
  - Environmentally friendly energy by-product
  - Enhances concrete durability
  - Continued strength gain
  - Reduces heat in concrete
  - Typically replaces 60-70% of cement (compared to 25-40% PFA) and can replace up to 90%.
GGBFS Production Facility

- State of the Art German Polysius AG Plant, Shaoguan, China
- 1.2 Million T PA (a new plant is under construction)
- Significant financial investment
- Recycling of Coarse Screen Material and Closed-System Efficiency
Processing
Plant Management
QA/QC and Testing
The Raw Product

- Consistency of medium to fine sand, gritty texture, pale brown colour.
The Final Product

- Consistency of fine talcum powder, off-white colour, very fine GGBFS.
Typical Chemistry Comparisons

<table>
<thead>
<tr>
<th>Material</th>
<th>C%</th>
<th>S%</th>
<th>A%</th>
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<tbody>
<tr>
<td>OPC</td>
<td>65</td>
<td>22</td>
<td>5</td>
</tr>
<tr>
<td>PFA</td>
<td>2-10</td>
<td>35-50</td>
<td>18-25</td>
</tr>
<tr>
<td>Slag</td>
<td>35-45</td>
<td>30-40</td>
<td>10-20</td>
</tr>
</tbody>
</table>

- Complies with BS 6699: 1992 Requirements C1.9 to 9.7
- Calcium Oxide Content (CaO): 36.1%
- Silica Content: (SiO₂) 34.1%
- Alumina (Al₂O₃): 15.9%
- Magnesia Content (MgO): 12.3% (<14%)
- Insoluble Residue 0.76% (<1.5%)
- Chemical Moduli: (CaO+Mg)/SiO₂ 1.5 (>1)
- & CaO/ SiO₂ 1.1% <1.4%
- Acid Soluble Alkali Content (Eq. Na₂O) 0.69%
GGBFS in HK 1992

- 120 Year Design Life
- Triple Blend: OPC, GGBFS, CSF for harsh marine exposure conditions
- Over 100 intrinsic and inferred performance criteria for concrete.
- Lower heat than OPC triple blend
- Better chloride diffusion resistance
- In 100 years this will be a Historical Structure
How Does Slag Work?

Normal Concrete
- Aggregate
- Cement
- Water
- Concrete

PFA Concrete
- Aggregate
- Cement
- Water
- PFA Concrete
  - R1
  - R2
- PFA

Slag Concrete
- Aggregate
- Cement
- Slag
- Water
- Slag Concrete
  - R1
  - R2
- R1 Gives of Lime CaOH
GGBFS Trials: Key Objectives

- Quality and Consistency
- Strength Development
- Thermal Properties
- Durability
### 3 Main Groups:

**Group 1:** Normal 30MPa Concrete (0.58 W/B Ratio)

**Group 2:** Marine Concrete (0.38 W/B Ratio)

**Group 3:** High Performance Concrete (0.3 and 0.34 W/B Ratio)
Laboratory Trial Procedure

- Group 3 MIX 11
  - Conditions: 480 kg + 5% CSF
  - 60% Slag 200 mm Slump
  - 5.10.2005
TRET Box Samples

- Temperature Monitoring (thermocouples)
- Core Strength
- Water Absorption
- Chloride Diffusion
Colour Differences & Benefits

1. 70% Slag/30% OPC
2. 100% OPC
3. 25% PFA/75% OPC
4. 35% PFA/65% OPC
## Group 1 and Group 2 Mixes

<table>
<thead>
<tr>
<th>GROUP 1 MIX NO.</th>
<th>CEMENT (Kg)</th>
<th>W/B</th>
<th>ADMIX (Lt)</th>
<th>WRD A889</th>
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</thead>
<tbody>
<tr>
<td>1 (25% PFA)</td>
<td>360</td>
<td>0.58</td>
<td>2.16</td>
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<tr>
<td>2 (35% PFA)</td>
<td>360</td>
<td>0.58</td>
<td>2.16</td>
<td></td>
</tr>
<tr>
<td>3 (60% GGBFS)</td>
<td>360</td>
<td>0.58</td>
<td>2.16</td>
<td></td>
</tr>
<tr>
<td>4 (70% GGBFS)</td>
<td>360</td>
<td>0.58</td>
<td>2.16</td>
<td></td>
</tr>
<tr>
<td>5 (100% OPC)</td>
<td>360</td>
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<td>2.16</td>
<td></td>
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<tr>
<td>16 (30% GGBFS)</td>
<td>360</td>
<td>0.58</td>
<td>2.16</td>
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<tr>
<td>18 (100% GGBFS)</td>
<td>360</td>
<td>0.58</td>
<td>2.16</td>
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</tr>
<tr>
<td>15b (90% GGBFS Grade 30 Concrete)</td>
<td>380</td>
<td>0.55</td>
<td>2.28</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GROUP 2 MIX NO.</th>
<th>CEMENT (Kg)</th>
<th>W/B</th>
<th>ADMIXTURE (Lt)</th>
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<tbody>
<tr>
<td>6 (25% PFA)</td>
<td>450</td>
<td>0.38</td>
<td>4.0</td>
</tr>
<tr>
<td>7 (35% PFA)</td>
<td>450</td>
<td>0.38</td>
<td>4.0</td>
</tr>
<tr>
<td>8c (60% GGBFS)</td>
<td>450</td>
<td>0.38</td>
<td>4.0</td>
</tr>
<tr>
<td>9b (70% GGBFS)</td>
<td>450</td>
<td>0.38</td>
<td>4.0</td>
</tr>
<tr>
<td>10 (100% OPC)</td>
<td>450</td>
<td>0.38</td>
<td>4.0</td>
</tr>
<tr>
<td>17 (40% GGBFS)</td>
<td>450</td>
<td>0.38</td>
<td>4.0</td>
</tr>
<tr>
<td>19 (100% GGBFS)</td>
<td>450</td>
<td>0.38</td>
<td>4.0</td>
</tr>
<tr>
<td>20 (80% GGBFS)</td>
<td>450</td>
<td>0.38</td>
<td>4.0</td>
</tr>
<tr>
<td>21 (90% GGBFS)</td>
<td>450</td>
<td>0.38</td>
<td>4.0</td>
</tr>
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</table>

**Group 2 Mixes: Super 20**

<table>
<thead>
<tr>
<th>GROUP 2 MIX NO.</th>
<th>CEMENT (Kg)</th>
<th>W/B</th>
<th>Init</th>
<th>Add</th>
<th>Tot</th>
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<tbody>
<tr>
<td>6 (25% PFA)</td>
<td>450</td>
<td>0.38</td>
<td>4.0</td>
<td>2.25</td>
<td>6.3</td>
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<tr>
<td>7 (35% PFA)</td>
<td>450</td>
<td>0.38</td>
<td>4.0</td>
<td>2.00</td>
<td>6.0</td>
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<tr>
<td>8c (60% GGBFS)</td>
<td>450</td>
<td>0.38</td>
<td>4.0</td>
<td>2.00</td>
<td>6.0</td>
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<tr>
<td>9b (70% GGBFS)</td>
<td>450</td>
<td>0.38</td>
<td>4.0</td>
<td>1.88</td>
<td>5.9</td>
</tr>
<tr>
<td>10 (100% OPC)</td>
<td>450</td>
<td>0.38</td>
<td>4.0</td>
<td>3.50</td>
<td>7.5</td>
</tr>
<tr>
<td>17 (40% GGBFS)</td>
<td>450</td>
<td>0.38</td>
<td>4.0</td>
<td>2.00</td>
<td>6.0</td>
</tr>
<tr>
<td>19 (100% GGBFS)</td>
<td>450</td>
<td>0.38</td>
<td>4.0</td>
<td>3.50</td>
<td>7.5</td>
</tr>
<tr>
<td>20 (80% GGBFS)</td>
<td>450</td>
<td>0.38</td>
<td>4.0</td>
<td>1.60</td>
<td>5.6</td>
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<tr>
<td>21 (90% GGBFS)</td>
<td>450</td>
<td>0.38</td>
<td>4.0</td>
<td>1.40</td>
<td>5.4</td>
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# Group 3 Mixes

<table>
<thead>
<tr>
<th>MIX NO.</th>
<th>CEMENT (Kg)</th>
<th>WATER (Kg)</th>
<th>W/B</th>
<th>Slump</th>
<th>OPC</th>
<th>PFA</th>
<th>SLAG</th>
<th>SF</th>
<th>ADMIXTURE (Lt)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 (60% GGBFS &amp; 5% SF)</td>
<td>480</td>
<td>113 (Plus 24 Lt from SF Slurry)</td>
<td>0.30</td>
<td>200</td>
<td>168</td>
<td>0</td>
<td>288</td>
<td>24</td>
<td>7.00</td>
</tr>
<tr>
<td>12 (70% GGBFS &amp; 5% SF)</td>
<td>480</td>
<td>113 (Plus 24 Lt from SF Slurry)</td>
<td>0.30</td>
<td>200</td>
<td>120</td>
<td>0</td>
<td>336</td>
<td>24</td>
<td>7.00</td>
</tr>
<tr>
<td>13 (60% GGBFS)</td>
<td>450</td>
<td>148</td>
<td>0.34</td>
<td>200</td>
<td>180</td>
<td>0</td>
<td>270</td>
<td>0</td>
<td>5.00</td>
</tr>
<tr>
<td>14 (70% GGBFS)</td>
<td>450</td>
<td>148</td>
<td>0.34</td>
<td>200</td>
<td>135</td>
<td>0</td>
<td>315</td>
<td>0</td>
<td>5.00</td>
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</tbody>
</table>
Cement-Free Concrete?

100% Slag
Compressive Strength Development
Group 1 and Group 2 Mixes

FINAL WORKS CUBES
COMPRESSION STRENGTH DEVELOPMENT
GROUP 1 W/B 0.58 MIXES

STRENGTH N/mm²
0 20 40 60 80 120
DAYS 0 30 60 90 120

FINAL WORKS CUBES
COMPRESSION STRENGTH DEVELOPMENT
GROUP 2 W/B 0.38 MIXES

STRENGTH N/mm²
0 20 40 60 80 120
DAYS 0 30 60 90 120

- 25% PFA
- 35% PFA
- 60% GGBS
- 70% GGBS
- 100% OPC

Graphs showing the compressive strength development for Group 1 and Group 2 mixes with various PFA and GGBS content.
Relative Strength Development
Group 1 & 2 Mixes for 28 Days

Strength Development Relative to 28 Day Strength
Group 1 Mixes

Strength Development Relative to 28 Day Strength
Group 2 Mixes

Percentage of 28 Day Strength

Days

Percentage of 28 Day Strength

Days
Early Age Strength Development
Group 1 & 2 Mixes

Early Age Strength Development: Group 1 Mixes

Early Age Strength Development: Group 2 Mixes
Compressive Strength Development

FINAL WORKS CUBES
COMPRESSIVE STRENGTH DEVELOPMENT
GROUP 3 MIXES

STRENGTH N/mm²

DAYS

- 60% GGBFS & 5% SF
- 70% GGBFS & 5% SF
- 60% GGBFS
- 70% GGBFS
Compressive Strength & W/B Ratio Relationship

- 60% GGBFS (28 Day)
- 70% GGBFS (28 Day)
- 60% GGBFS (90 Day)
- 70% GGBFS (90 Day)
Early Age Strength Development
Group 3 Mixes

Early Age Strength Development Relative to 28 Day Strength for Group 3 Mixes

- 60% GGBFS & 5% SF
- 70% GGBFS & 5% SF
- 60% GGBFS
- 70% GGBFS

Strength Development Relative to 28 Day Strength for Group 3 Mixes

- 60% GGBFS & 5% SF
- 70% GGBFS & 5% SF
- 60% GGBFS
- 70% GGBFS
Initial and Final Set
Group 2 and Group 3 Mixes

Initial and Final Setting Times

- **Group 3**
  - 14 (70% GGBFS)
  - 13 (60% GGBFS)
  - 12 (70% GGBFS & 5% SF)
  - 11 (60% GGBFS & 5% SF)

- **Group 2**
  - 10 (100% OPC)
  - 9b (70% GGBFS)
  - 8c (60% GGBFS)
  - 7 (35% PFA)
  - 6 (25% PFA)

Minutes
Thermal Properties

- Temperature Monitoring (thermocouples)
- Placing Temperature
- Room Temperature
- Peak Temperature & Time
Thermal Properties
GGBFS Content & Temperature Reduction

TEMPERATURE AND GGBFS CONTENT RELATIONSHIP
FOR GROUP 2 MIXES

Peak Temperature
Time (Hours)

0% 40% 60% 70% 80% 90%

0 10 20 30 40 50 60 70 80

% GGBFS CONTENT

Peak Temperature and Time
Thermal Properties
Group 2 and 3 Mixes

PEAK TEMPERATURE AND TIME (Group 2 and 3 Mixes)

Mix Category
Mix 6 Mix 7 Mix 8 Mix 9 Mix 10 Mix 11 Mix 12 Mix 13 Mix 14 Mix 15

Temperature (Centigrade)  
Time (Hours)

GGBFS/SF Mixes
PFA Mixes
GGBFS Mixes
Plain OPC Mixes
90% GGBFS Mix
RAPID CHLORIDE DIFFUSION TEST RESULTS FOR GROUP 2 & GROUP 3 MIXES

Group 2 Mixes

Group 3 High Performance Mixes

Mix Category

- 6 (25% PFA)
- 7 (35% PFA)
- 8c (60% GGBFS)
- 9b (70% GGBFS)
- 10 (100% OPC)
- 11 (60% GGBFS & 5% SF)
- 12 (70% GGBFS & 5% SF)
- 13 (60% GGBFS)
- 14 (70% GGBFS)

Coulombs

- 28 Days
- 90 Days

Durability: Chloride Diffusion
Durability: Sorptivity

SORPTIVITY TEST RESULTS FOR GROUP 2 & GROUP 3 MIXES

- Group 2 Mixes
  - 6 (25% FA)
  - 7 (35% PFA)
  - 8C (60% GGBFS)
  - 9b (70% GGBFS)
  - 10 (100% PC)
  - 11 (60% GGBFS & 5% SF)
  - 12 (70% GGBFS & 5% SF)
  - 13 (60% GGBFS)
  - 14 (70% GGBFS)

- Group 3 High Performance Mixes
  - 11 (60% GGBFS & 5% SF)
  - 12 (70% GGBFS & 5% SF)
  - 13 (60% GGBFS)
  - 14 (70% GGBFS)

Mix Category

28 Days
90 Days
Experience CSPC Project

- US$4.3 Billion CSPC Project in Shenzhen (CNOOC, Shell Petroleum Corporation)
- > 800,000 Cubic Metres of Concrete (All Slag Concrete)
- 65% Slag Content
- Slag all from Shaoguan Plant
- Beijing and Shanghai
Environmental Credit

- Greatly Reduced Cement Content.
- 1 Tonne Cement = 0.8 Tonne CO₂.
- In 2005 China Cement trade released 0.867 billion Tonnes of CO₂. This accounted for 22.8% of total CO₂ emission in China.
- GGBFS is produced anyway. Additional energy input is only for grinding and processing.
- Use of this valuable construction material is an environmental credit for HK and the Mainland as a whole.
- Provides alternative to PFA and is more compatible with renewable energy source objectives.
Key Benefits of GGBFS

- **Very Cost Effective**: Similar market price to PFA per tonne, but twice as much GGBFS is used.
- **Green Perspective**: Significantly Reduces Cement (OPC) and CO₂
- **Properties comparable to PFA**: Thermal, Durability, Strength.
- **Colour**
- **Introduces a Broader Range of Materials & Greater Flexibility**
- **Extensive Experience on Prestigious Projects Exist**
Thank You

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(Hong Kong) Ltd
ALL OF THE SLIDES THAT FOLLOW SHOW ADDITIONAL DATA
## Group 1 Mix Trials
### W/B Ratio 0.58: Grade 30 Concrete

<table>
<thead>
<tr>
<th>MIX NO.</th>
<th>CEM (Kg)</th>
<th>WAT (Kg)</th>
<th>W/B</th>
<th>Slump</th>
<th>OPC (Kg)</th>
<th>PFA (Kg)</th>
<th>SLAG (Kg)</th>
<th>SF</th>
<th>AGG (Kg)</th>
<th>ADMIX (Lt)</th>
<th>WRDA88</th>
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</thead>
<tbody>
<tr>
<td>1 (25% PFA)</td>
<td>360</td>
<td>207</td>
<td>0.58</td>
<td>100</td>
<td>270</td>
<td>90</td>
<td>0</td>
<td>0</td>
<td>690</td>
<td>295</td>
<td>780</td>
</tr>
<tr>
<td>2 (35% PFA)</td>
<td>360</td>
<td>207</td>
<td>0.58</td>
<td>100</td>
<td>234</td>
<td>126</td>
<td>0</td>
<td>0</td>
<td>690</td>
<td>295</td>
<td>780</td>
</tr>
<tr>
<td>3 (60% GGBFS)</td>
<td>360</td>
<td>207</td>
<td>0.58</td>
<td>100</td>
<td>144</td>
<td>0</td>
<td>216</td>
<td>0</td>
<td>690</td>
<td>295</td>
<td>780</td>
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<tr>
<td>4 (70% GGBFS)</td>
<td>360</td>
<td>207</td>
<td>0.58</td>
<td>100</td>
<td>108</td>
<td>0</td>
<td>252</td>
<td>0</td>
<td>690</td>
<td>295</td>
<td>780</td>
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<tr>
<td>5 (OPC 100%)</td>
<td>360</td>
<td>207</td>
<td>0.58</td>
<td>100</td>
<td>360</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>690</td>
<td>295</td>
<td>780</td>
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<tr>
<td>16 (30% GGBFS)</td>
<td>360</td>
<td>209</td>
<td>0.58</td>
<td>100</td>
<td>252</td>
<td>0</td>
<td>108</td>
<td>0</td>
<td>690</td>
<td>295</td>
<td>780</td>
</tr>
<tr>
<td>18 (100% GGBFS)</td>
<td>360</td>
<td>207</td>
<td>0.58</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>360</td>
<td>0</td>
<td>690</td>
<td>295</td>
<td>780</td>
</tr>
<tr>
<td>15b (90% GGBFS)</td>
<td>380</td>
<td>208</td>
<td>0.55</td>
<td>100</td>
<td>38</td>
<td>0</td>
<td>342</td>
<td>0</td>
<td>650</td>
<td>275</td>
<td>760</td>
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# Group 2 Mix Trials

**Marine Concrete (0.38 W/B Ratio)**

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<th>MIX NO.</th>
<th>CEM (Kg)</th>
<th>WAT (Kg)</th>
<th>W/B</th>
<th>CEMENT (Kg)</th>
<th>AGG (Kg)</th>
<th>Admix (Lt)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Slump</td>
<td>OPC</td>
<td>PFA</td>
</tr>
<tr>
<td>6 (25% PFA)</td>
<td>450</td>
<td>167</td>
<td>0.38</td>
<td>175</td>
<td>338</td>
<td>112</td>
</tr>
<tr>
<td>7 (35% PFA)</td>
<td>450</td>
<td>167</td>
<td>0.38</td>
<td>175</td>
<td>293</td>
<td>157</td>
</tr>
<tr>
<td>8c (60% GGBFS)</td>
<td>450</td>
<td>167</td>
<td>0.38</td>
<td>175</td>
<td>180</td>
<td>0</td>
</tr>
<tr>
<td>9b (70% GGBFS)</td>
<td>450</td>
<td>167</td>
<td>0.38</td>
<td>175</td>
<td>135</td>
<td>0</td>
</tr>
<tr>
<td>10 (100% OPC)</td>
<td>450</td>
<td>167</td>
<td>0.38</td>
<td>175</td>
<td>450</td>
<td>0</td>
</tr>
<tr>
<td>17 (40% GGBFS)</td>
<td>450</td>
<td>167</td>
<td>0.38</td>
<td>175</td>
<td>270</td>
<td>0</td>
</tr>
<tr>
<td>19 (100% GGBFS)</td>
<td>450</td>
<td>167</td>
<td>0.38</td>
<td>175</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20 (80% GGBFS)</td>
<td>450</td>
<td>167</td>
<td>0.38</td>
<td>175</td>
<td>90</td>
<td>0</td>
</tr>
<tr>
<td>21 (90% GGBFS)</td>
<td>450</td>
<td>167</td>
<td>0.38</td>
<td>175</td>
<td>45</td>
<td>0</td>
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# Group 3
## High Performance Mixes

<table>
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<tr>
<th>MIX NO.</th>
<th>CEM (Kg)</th>
<th>WAT (Kg)</th>
<th>W/B</th>
<th>OPC</th>
<th>PFA</th>
<th>Slag</th>
<th>SF</th>
<th>AGG (Kg)</th>
<th>ADMIX (Lt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 (60% GGBFS &amp; 5% SF)</td>
<td>480</td>
<td>113</td>
<td>0.30</td>
<td>200</td>
<td>168</td>
<td>0</td>
<td>288</td>
<td>24</td>
<td>600</td>
</tr>
<tr>
<td>12 (70% GGBFS &amp; 5% SF)</td>
<td>480</td>
<td>113</td>
<td>0.30</td>
<td>200</td>
<td>120</td>
<td>0</td>
<td>336</td>
<td>24</td>
<td>600</td>
</tr>
<tr>
<td>13 (60% GGBFS)</td>
<td>450</td>
<td>148</td>
<td>0.34</td>
<td>200</td>
<td>180</td>
<td>0</td>
<td>270</td>
<td>0</td>
<td>620</td>
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<tr>
<td>14 (70% GGBFS)</td>
<td>450</td>
<td>148</td>
<td>0.34</td>
<td>200</td>
<td>135</td>
<td>0</td>
<td>315</td>
<td>0</td>
<td>620</td>
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</table>
## Final Works Cubes: Strength

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Stump Flow (mm)</th>
<th>Mean Cube Compressive strength (N/mm²)</th>
<th>1d</th>
<th>3d</th>
<th>7d</th>
<th>14d</th>
<th>28d</th>
<th>90d</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (25% PFA)</td>
<td>110 - -</td>
<td>8.5 22.5 31.0 39.5 48.0 60.5</td>
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<tr>
<td>2 (35% PFA)</td>
<td>110 - -</td>
<td>6.5 18.0 25.5 33.0 44.0 57.0</td>
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</tr>
<tr>
<td>3 (60% GGBFS)</td>
<td>95 - -</td>
<td>4.0 14.5 33.5 45.0 53.0 64.0</td>
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</tr>
<tr>
<td>4 (70% GGBFS)</td>
<td>95 - -</td>
<td>3.0 14.0 32.5 45.0 54.0 63.0</td>
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</tr>
<tr>
<td>5 (OPC 100%)</td>
<td>95 - -</td>
<td>11.5 29.5 42.0 48.0 53.5 56.0</td>
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<tr>
<td>6 (25% PFA)</td>
<td>160 470 480</td>
<td>20.0 49.0 62.5 73.5 84.5 99.0</td>
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<tr>
<td>7 (35% PFA)</td>
<td>150 450 450</td>
<td>15.5 41.0 55.0 66.0 77.0 92.5</td>
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<tr>
<td>8c (60% GGBFS)</td>
<td>165 480 490</td>
<td>11.0 38.0 60.5 74.5 84.5 88.0</td>
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<tr>
<td>9b (70% GGBFS)</td>
<td>210 570 575</td>
<td>9.5 39.0 56.0 66.5 78.0 83.0</td>
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<tr>
<td>10 (100% OPC)</td>
<td>180 550 570</td>
<td>30.5 67.0 77.0 83.5 91.0 98.0</td>
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<tr>
<td>11 (60% GGBFS &amp; 5% SF)</td>
<td>195 460 445</td>
<td>16.0 50.5 75.0 87.5 97.0 106.5</td>
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<tr>
<td>12 (70% GGBFS &amp; 5% SF)</td>
<td>210 500 490</td>
<td>13.0 42.0 68.5 83.5 92.5 103.5</td>
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<tr>
<td>13 (60% GGBFS)</td>
<td>205 510 520</td>
<td>15.0 47.0 67.0 81.5 90.0 102.5</td>
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<tr>
<td>14 (70% GGBFS)</td>
<td>210 500 530</td>
<td>11.5 41.0 61.5 74.5 86.5 94.0</td>
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</tr>
<tr>
<td>15b (90% GGBFS Grade 30 Concrete)</td>
<td>110 - -</td>
<td>1.5 10.0 23.5 34.0 37.0 43.5</td>
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<tr>
<td>16 (30% GGBFS)</td>
<td>100 - -</td>
<td>8.0 22.0 35.5 47.5 55.0 59.5</td>
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</tr>
<tr>
<td>17 (40% GGBFS)</td>
<td>190 510 520</td>
<td>16.0 42.5 63.5 78.0 86.5 92.0</td>
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</table>
## Durability Performance

### Group 2 and Group 3 Mixes

<table>
<thead>
<tr>
<th>Mix</th>
<th>Mean Rapid Chloride Diffusion (Coulombs)</th>
<th>Sorptivity (mm/min0.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>28d</td>
<td>90d</td>
</tr>
<tr>
<td>6 (25% PFA)</td>
<td>1171/1161</td>
<td>Low</td>
</tr>
<tr>
<td>7 (35% PFA)</td>
<td>505/470</td>
<td>Very Low</td>
</tr>
<tr>
<td>8c (60% GGBFS)</td>
<td>898/987</td>
<td>Very Low</td>
</tr>
<tr>
<td>9b (70% GGBFS)</td>
<td>995/1034</td>
<td>Very Low</td>
</tr>
<tr>
<td>10 (100% OPC)</td>
<td>6035/6023</td>
<td>High</td>
</tr>
<tr>
<td>11 (60% GGBFS &amp; 5% SF)</td>
<td>60/56</td>
<td>Negligible</td>
</tr>
<tr>
<td>12 (70% GGBFS &amp; 5% SF)</td>
<td>156/162</td>
<td>Very Low</td>
</tr>
<tr>
<td>13 (60% GGBFS)</td>
<td>650/623</td>
<td>Very Low</td>
</tr>
<tr>
<td>14 (70% GGBFS)</td>
<td>402/406</td>
<td>Very Low</td>
</tr>
</tbody>
</table>
Madagascar
Power Station: Francoise the Gladiator
Mobile Crushers: Lalatiana, Ruth and Rija
Dredge Units: Madame Rasoazanany and Claude
Rice & Wood = Petrol & Electricity

90% Deforestation
Slash and Burn (Wood Fuel and Rice Plantation).
Mud: Laterite & Saprololite for Building
Natural Construction
Materials: Mud, Straw and Wood
Mud Bricks: 100% Recycled Material
Brick Works at Mud Source
Madagascar’s Capital: Antananarivo
Education: 2008
Education & Social Cement

The Best Concrete Ever Made
Global Citizens & Engineers
Construction Sustainability

- Re: Reuse, Recycling, Regeneration, Rehabilitation: Efficiency. E.g 75% can be reused.
- L: Lifespan. 1 year, 10 years, 50 Years, 100 Years.
- O: Optimal Balance (Consumption, Risk, Safety, Technology). E.g can we produce 40MPa concrete with 30% of the standard cement content we use now. Yes, easily. Solution: time and materials. Do we really need 40 Mpa at 28 days: why not 90 days?
- Social Context, Value and Usage. Is a bridge more valuable than a wall or a school or building or a nuclear power station. Material resources are limited. We should use them wisely.

- Concrete lost technology for 1200 years or so.
- Scottish buildings stones taken from old churches etc over the centuries and re-used.