Use of Recycled Glass in Concrete
as a cement and fine aggregate replacement

Joshua Flanders

In collaboration with Cairns Regional Council, Pioneer North Queensland, and James Cook University
Second most consumed product in the world after water

Globally, 25 billion tonnes produced annually

<table>
<thead>
<tr>
<th>Material</th>
<th>Percentage</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>14 – 21 %</td>
<td><img src="image" alt="Water" /></td>
</tr>
<tr>
<td>Coarse Aggregates</td>
<td>65 – 80 %</td>
<td><img src="image" alt="Coarse Aggregates" /></td>
</tr>
<tr>
<td>Fine Aggregates</td>
<td>7 – 15 %</td>
<td><img src="image" alt="Fine Aggregates" /></td>
</tr>
<tr>
<td>Cement</td>
<td></td>
<td><img src="image" alt="Cement" /></td>
</tr>
</tbody>
</table>
One tonne of CO\textsubscript{2} per tonne of cement produced

8\% of global CO\textsubscript{2} emissions
Depletion of natural river sands

Costs - collection and transportation
Recycling of Glass

1.5 million tonnes of waste glass per year

60% crushed and sent to landfill
Cement

- $C_3S - 3CaO \cdot SiO_2$
- $C_2S - 2CaO \cdot SiO_2$
- $C_3A - 3CaO \cdot Al_2O_3$
- $C_4AF - 4CaO \cdot Al_2O_3 \cdot Fe_2O_3$

Water

$H_2O$

Hydration

Cement + Water → Hardened Cement Paste

Hardened Cement Paste

$C-S-H - 3CaO \cdot 2SiO_2 \cdot 8H_2O$

Calcium Hydroxide

$Ca(OH)_2$

Water

$H_2O$

Pozzolan

Reactive silica or alumina compound
- Fly ash
- Silica Fume
- Glass powder
crushed & pulverised

Cement Replacement

Recycled Glass Powder - RGP

75μm

Fine Aggregate Replacement

Recycled Glass Sand - RGS

4 mm

crushed

Recycled Glass Sand - RGS

4 mm
### Constituent Mix Proportion (kg/m³)

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Mix Proportion (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GP Portland Cement</td>
<td>336</td>
</tr>
<tr>
<td>20 mm Coarse Aggregate</td>
<td>981</td>
</tr>
<tr>
<td>4 mm Coarse Sand</td>
<td>632</td>
</tr>
<tr>
<td>2 mm Fine Sand</td>
<td>270</td>
</tr>
<tr>
<td>Water Reducer</td>
<td>60 mL</td>
</tr>
<tr>
<td>Water</td>
<td>163 L</td>
</tr>
</tbody>
</table>

- **Glass Powder**: 10%, 20%, 30%
- **Glass Sand**: 20%, 40%, 60%
- **Fly Ash**: 25%
Physical Properties

Particle Size Distribution
Particle Composition and Shape
Specific Gravity

Recycled Glass Powder (RGP)
Recycled Glass Sand (RGS)
GP Portland Cement
Natural Sand
Concrete Properties:

- Fresh:
  - Slump
  - Glass Powder: Workability, Density
  - Glass Sand: Workability, Density

- Bulk Density:
  - Glass Powder
  - Glass Sand
Concrete Properties: Hardened

Compressive Strength
Flexural Strength
Tensile Strength

28 Day Compressive Strength (MPa)
• Strength development cement replacement higher than control – pozzolanic reaction
• Equal developments from RGS – no pozzolanic contribution
“Corrosion of steel reinforcement is the most common problem affecting the durability of reinforced concrete structures”
Concrete Properties: Durability

Chloride Resistance

Chloride Resistance – 28 Day

Chloride Resistance

Control 25% Fly Ash
10% RGP
20% RGP
30% RGP
20% RGS
40% RGS
60% RGS

High
Moderate
Low
Very Low

CHARGE PASSED (COULombs)
Life Cycle Analysis: Environmental Benefit

Recycled waste collected

MRF - glass separated

Glass crushed through series of machines

Electricity usage: 3.1 kWh/tonne

Crushed glass pulverised

Electricity usage: 124 kWh/tonne

Crushed glass stockpiled (ready for use)
Cement Replacement

- Global Warming (kg CO$_2$ eq)
  - Control: 347
  - 10% RGP: 320
  - 20% RGP: 254
  - 30% RGP: 66

- Ozone Depletion (kg CFC-11 eq x 10$^6$)
  - Control: 2.3
  - 10% RGP: 2.3
  - 20% RGP: 2.3
  - 30% RGP: 2.2

- Eutrophication (kg PO$_4$ eq)
  - Control: 0.16
  - 10% RGP: 0.15
  - 20% RGP: 0.14
  - 30% RGP: 0.13

- Water Use (m$^3$ H$_2$O)
  - Control: 8.3
  - 10% RGP: 7.6
  - 20% RGP: 5.7
  - 30% RGP: 5.3

- Fossil Fuels (kg oil eq)
  - Control: 66
  - 10% RGP: 61
  - 20% RGP: 57
  - 30% RGP: 53
Coarse Sand Replacement

<table>
<thead>
<tr>
<th>Environmental Impact</th>
<th>Control</th>
<th>20% RGS</th>
<th>40% RGS</th>
<th>60% RGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Warming (kg CO₂ eq)</td>
<td>347</td>
<td>234</td>
<td>234</td>
<td>234</td>
</tr>
<tr>
<td>Ozone Depletion (kg CFC-11 eq x 10⁶)</td>
<td>346</td>
<td>229</td>
<td>224</td>
<td>218</td>
</tr>
<tr>
<td>Eutrophication (kg PO₄ eq)</td>
<td>0.163</td>
<td>0.162</td>
<td>0.161</td>
<td>0.161</td>
</tr>
<tr>
<td>Water Use (m³ H₂O)</td>
<td>9.53</td>
<td>9.53</td>
<td>9.47</td>
<td>8.99</td>
</tr>
<tr>
<td>Fossil Fuels (kg oil eq)</td>
<td>65.7</td>
<td>65.4</td>
<td>65.1</td>
<td>64.8</td>
</tr>
<tr>
<td>Material</td>
<td>Cost of Materials ($/tonne)</td>
<td></td>
<td></td>
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<tr>
<td>--------------------------</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>GP Portland Cement</td>
<td>267.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GB Portland Cement</td>
<td>216.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recycled Glass Powder (RGP)</td>
<td>20.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recycled Glass Sand (RGS)</td>
<td>0.50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse Sand</td>
<td>38.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine Sand</td>
<td>78.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 mm Aggregate</td>
<td>45.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>25% Fly Ash</td>
<td>10% RGP</td>
<td>20% RGP</td>
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<td>----------------</td>
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</tr>
<tr>
<td>Cost of Concrete Mixes ($/m^3)</td>
<td>180</td>
<td>163</td>
<td>172</td>
<td>163</td>
</tr>
</tbody>
</table>

Life Cycle Analysis: Economic Benefit
INNOVATIVE WASTE MANAGEMENT PROVIDING ECONOMIC, SOCIAL AND ENVIRONMENTAL BENEFITS FOR THE TROPICAL NORTH QUEENSLAND REGION

Provide Education and Awareness
Reduce Waste
Maximise Resource Recovery
Secure our Future Needs
Advocacy and Collaboration

Vision – Cairns Regional Council
## Conclusion

Huge potential of using recycled waste glass in concrete

<table>
<thead>
<tr>
<th>Glass as a Cement Replacement</th>
<th>Glass as a Coarse Sand Replacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Significant reductions in environmental impacts</td>
<td>• Small reductions in environmental impacts</td>
</tr>
<tr>
<td>• Cost saving</td>
<td>• Significant cost saving</td>
</tr>
<tr>
<td>• Strength decreases rapidly as replacement level increases</td>
<td>• Potential to use large amounts of waste glass</td>
</tr>
<tr>
<td>• Feasible for applications where early strength isn’t critical</td>
<td>• Replacement level up to 60% feasible</td>
</tr>
<tr>
<td></td>
<td>• No adverse decrease in strength as replacement level increases</td>
</tr>
</tbody>
</table>
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