DEVELOPMENT OF banahCEM

A GEOPOLYMER BINDER SYSTEM

Andrew McIntosh

Geopolymer Camp 2013
8 – 10 July 2012
St. Quentin
The principle aims of banah UK Limited are to:

- carry out dedicated research and development in the field of geopolymer technology

- erect a production plant to manufacture geopolymer binders for construction

- develop a centre of excellence in Northern Ireland for novel cements through links with local and European universities

- reduce the future impact of the construction industry on the earth
THE STORY

In N. Ireland there is a readily available precursor which has been:

• Deposited by Nature
  Successive volcanic episodes in Co Antrim provide precursor

• Discovered by Industry
  Material associated with precursor exploited in 19th and early 20th Century

• Dreaded by Quarrying
  Precursor found in many quarries and is considered a ‘nuisance’ material

• Developed by banah UK Ltd
  Over the last two years this precursor has been used in the development of geopolymer cement
Geopolymer Cement Development

- Search for local sources of aluminosilicate
  - correct mineralogy
Mineralogy of Geopolymer Precursor
Geopolymer Cement Development

- Search for local sources of aluminosilicate
  - correct mineralogy
  - preferably existing quarry site
  - low environmental impact

- Design of geopolymer cement formulation
  - pre-treatment of raw materials
  - alkali content
  - Si:Al ratios
Amorphous Reacted Geopolymer
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**Geopolymer Cement Development**

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  - correct mineralogy
  - preferably existing quarry site
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- Design of geopolymer cement formulation
  - pre-treatment of raw materials
  - alkali content
  - Si:Al ratios
  - user friendliness

- Increasing sustainability; reducing costs
  - alternative sources of alkali silicate

- Fitness for purpose
  - testing in various applications
  - third party testing
Geopolymer Cement Development

- High Iron Content of Precursor
  - previous work showed lower strengths for this material
  - Ferro-kaolinite Precursor

- Proposal of a New Geopolymer Class
  - (Na, K, Ca) – (ferro-sialate) molecule

- Replicating Natural Silicate Molecules
  - ‘Getting back to nature’
  - Looking at natural mineralogy for future development
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- Two-part cement system
- May be used as a Portland cement replacement
- Ambient temperature setting
- Compressive Strength – 125 MPa +
- Has the following benefits:
  - Low carbon
  - Low environmental impact
  - Acid resistance
  - Sulfate resistance
  - Fire resistance
  - Consistent performance due to quality of raw materials
Compressive Strength of Geopolymer Concrete

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**Compressive Strength**

<table>
<thead>
<tr>
<th>Cement Content - Dry (kg/m³)</th>
<th>GPC Bulk - 28 day</th>
<th>GPC Bulk - 7 day</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>300</td>
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<tr>
<td>400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>600</td>
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</tr>
</tbody>
</table>

**MPa**

**Compressive Strength**

![Graph showing the compressive strength of Geopolymer Concrete vs. cement content.](image)
**Freeze/Thaw Testing**

**Freeze-Thaw Testing of Geopolymer Concrete**

<table>
<thead>
<tr>
<th>Slump Level</th>
<th>50 Cycles</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Slump</td>
<td>30</td>
<td>45</td>
</tr>
<tr>
<td>Low Slump</td>
<td>45</td>
<td>50</td>
</tr>
</tbody>
</table>
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Strength Development

Graph showing the strength development of banahCEM™ compared to typical CEM I over time in hours.
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Isothermal Conduction Calorimetry

Sample 2.5

Rate of Heat Production
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Isothermal Conduction Calorimetry
Sample 2.5

Total Heat Production over first 72 Hours
Accelerated Ageing of Geopolymers


- Ageing at 95°C produced dramatic acceleration of ageing effects
- Strength Loss of 60% of cured value
- Linked to phase changes – development of Zeolites
- Metakaolin based geopolymers unsuitable for construction

From Publication mentioned above
Accelerated Ageing of Geopolymer

- Samples of binder and mortar cast and cured for 28 days
- Stored at 95°C in a sealed container and tested for compressive strength and crystalline structure at intervals
- Slight decrease in compressive strength observed
- NO increase in crystalline structure observed
- NO decrease in compressive strength over 2 years at ambient temperatures.
Figure 1: XRD pattern (8-70° 2theta) showing no difference in XRD trace between two samples.

Blue = banahCEM 1.45 at room temperature

Red = banahCEM 1.45 28 days at 95°C

amorphous 'hump'
Shrinkage

Shrinkage of 35MPa concrete at 200 hours:

Uncovered from casting = -1650 µstrains

Covered for two days = -980 µstrains

With additive, uncovered = -330 µstrains

With additive, covered for three days = -50 µstrains
Initial comparison tests with OPC:

![Acid Resistance Graph]

- OPC 10% H2SO4
- GPC 10% H2SO4
- GPC 5% HCl
- OPC 5% HCl
Further testing began to reveal a trend:
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**Third Party Accreditation**

#### Physical Testing

<table>
<thead>
<tr>
<th>Test</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexural Strengths</td>
<td>Tensile Strengths</td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>Vapour Permeability</td>
</tr>
<tr>
<td>Water Absorption</td>
<td>Initial Surface Absorption (ISAT)</td>
</tr>
<tr>
<td>Freeze Thaw</td>
<td>Capillary Water Absorption</td>
</tr>
<tr>
<td>Slip Resistance</td>
<td>Abrasion Resistance</td>
</tr>
<tr>
<td>Pull-off Tests</td>
<td>Effect of Water/Cement Ratio</td>
</tr>
</tbody>
</table>

#### Chemical Testing of Hardened Cement/Concrete

<table>
<thead>
<tr>
<th>Test</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid Resistance</td>
<td>Sulphate Resistance</td>
</tr>
<tr>
<td>Chloride Diffusion</td>
<td>Protection to Steel Reinforcement</td>
</tr>
<tr>
<td>Alkali Aggregate Reaction</td>
<td>Chloride Ion Penetration</td>
</tr>
<tr>
<td>Leaching / Efflorescence</td>
<td>Coefficient of Thermal Expansion</td>
</tr>
<tr>
<td>Microstructure Observation</td>
<td></td>
</tr>
</tbody>
</table>
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Environmental Impact

CO₂ Emissions
• Portland Cement – typically 880 kg per tonne of product*
  * sales of BCA members in 2007. Supplied by sustainableconcrete.org.uk

• banahCEM – approximately 96 kg per tonne of product

‘Hole-in-the-ground’ Factor
• OPC – 2.05 tonnes raw material for 1 tonne product
  • 1.65 tonnes limestone; 0.4 tonnes clay
  British Geological Survey, Cement Raw Materials, November 2005

• GPC – 1.23 tonnes raw material for 1 tonne product
  • 0.77 tonnes geological precursor
  • 0.46 tonnes for alkali-silicate component
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Production Plant
In summary, banah UK Ltd

• has developed a viable geopolymer binder for use in niche applications

• is finalising plans for a plant capable of 100,000 tonnes/yr

• will be looking to partner with interested parties to see the implementation of geopolymer binders

• will be pressing forward in the design and supply of a revolutionary geopolymer block design

• will continue in the research and development of geopolymer technology in construction