Environmentally friendly materials and technology in civil engineering

Research progress towards environmentally friendly concrete.

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• Objectives
• Test Methods
• Typical Results
• A vision for the future
Possible routes to Environmentally Friendly Concrete

• Low energy cements such as magnesia cements
• Low impact fuel for cement kilns such as waste tyres.
• Energy saving in cement production with efficient kilns
• Use of waste minerals to replace the cement

We believe that this is the best option
Candidate materials (1)

- Sodium sulphate slag (Britannia Refined Metals Ltd.)
- Spent borax slag (Britannia Refined Metals Ltd.)
- Ferrosilicate slag (lumps from Britannia Refined Metals Ltd. sand size from Britannia Zinc Ltd.)
- Ferrosilicate copper slag (IMI Refiners Ltd.)
- Soda slag (Britannia Refined Metals Ltd.)
- Chrome Alumina slag (London & Scandinavian Metallurgical Co. Ltd.)
- Cement Kiln Dust ,CKD (Rugby Cement)
- Run of station ash (Ash Resources Ltd.)
- Lagoon ash (UK quality Ash Association)
- Steel slag (Tarmac Quarry Products Ltd.)
- “Red” titanogypsum.
Candidate materials (2)

- Waste Gypsum wall board (from the plant or site waste)
- Burnt Oil Shale (Tarmac Quarry Products Ltd.)
- By-product Gypsum (Biffa Waste Services Ltd.)
- Glass cullet (Mercury Recycling Ltd.)
- Limex70 (British Sugar Plc.)
- Shell foundry sand (Bruhl UK Ltd., Hepworth Minerals & Chemicals Ltd.)
- Green foundry sand (Castings Plc. And Bruhl UK Ltd.)
- Fire kettle setting (Britannia Refined Metals Ltd.)
- Fine rotary fascia bricks (Britannia Refined Metals Ltd.)
- Sodium sulphate solution (Britannia Refined Metals Ltd.)
- Air Pollution Control residues: fly ash from domestic waste incinerator
Mixture Liquids

- Water
- Sodium Sulphate Solution from Battery recycling
Typical combinations

• Ash – Alkali mixtures such as run-of-station ash and cement kiln dust.
• Sulphate mixtures such as waste gypsum and steel slag.

“Red” Titanogypsum in a landfill in the UK
Having identified suitable materials it is essential to define the requirements of the proposed application.

Requirements of concrete for landfill barriers

- A cube strength of 5 N/mm²
- The strength requirement is only for emplacement.
- Expansion of the barrier is harmless
- The leachate permeability through the barrier must remain low.
- Cracking is inevitable
- Alkaline buffering is essential
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  – Laboratory Tests
  – Site Trials
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Test Procedures for Cementitious Samples in the Coventry University JL Laboratories

- **Wet Concrete Tests:** Slump, Compaction Index, flow table, VB test, ICAR Rheometer
- **Wet mortar and paste tests:** Grout viscometer, flow trough.
- **Strength Tests:** Cubes (50mm and 100mm), cylinder splitting, beam bending, elastic modulus and Poisson’s ratio with strain gauges, core cutting and testing.
- **Transport Tests:** High Pressure permeability, diffusion cells, Rapid Chloride Permeability, water absorption
- **Corrosion tests:** Rest potential, linear polarisation, concrete resistivity.
Test Procedures for Cementitious Samples in the Coventry University JL Laboratories

• **Chemical tests:** Pore fluid expression

• **Exposure tests:** Freeze-thaw, sulphate attack, expansion

• **Porosity Measurement:** Helium pyconometer

• **Tests available in other departments:** ICP chemical analysis, Scanning electron microscope, Particle sizer, Thermogravimetric balance
Materials Characterisation

• Must be enough analysis to make the work repeatable in other labs.
• An analysis of the variability of the materials is essential.
• Typical tests XRF, XRD
  Particle size
The High Pressure Through Flow Cell

- Water inlet
- Water outlet
- Perforated disc
- Hydraulic oil
- Concrete sample
- Drainage plates
The high-pressure test measures:

• The permeability of the samples to water.
• The change in permeability in the presence of leachate.
• The adsorption of ions from the leachate by measuring eluent chemistry.
• Changes in permeability, strength and eluent chemistry (pH).
• The effect of different residence times in the sample
• The effect of cracking
• The performance of multi-layer systems
• The ability of the clay to seal cracks
• The availability of the buffering capacity of the barrier.
Diffusion Cells
Strength Tests

Corrosion tests - The process is accelerated by applying a positive voltage on 0.1 Volts.
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Why site trials are needed.

• To validate lab results on a large scale
• To demonstrate production methods
• To provide exposure tests for samples which are then returned to the lab
• To provide publicity
• To provide education
# The mixture designs for the trials

<table>
<thead>
<tr>
<th>Trial</th>
<th>Pour</th>
<th>Cementitious component</th>
<th>Strength MPa</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Cell 1 top</td>
<td>Spent borax 100%</td>
<td>4.5</td>
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<tr>
<td>2</td>
<td>Cell 2 top</td>
<td>CKD 60%, Lagoon ash 40%</td>
<td>1.7</td>
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<tr>
<td>3</td>
<td>Cell 3 top</td>
<td>CKD 60%, Lagoon ash 40%</td>
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<tr>
<td>1</td>
<td>Cell 1 base</td>
<td>GGBS 90%, OPC 10%, Sodium sulphate</td>
<td>13</td>
</tr>
<tr>
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<td>Cell 2 base</td>
<td>CKD 60%, PFA 40%, Sodium sulphate</td>
<td>6.9</td>
</tr>
<tr>
<td>3</td>
<td>Cell 3 base</td>
<td>OPC 5%, CKD, 70%, Lagoon ash 25%</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>Trench fill</td>
<td>BOS 60%, Red Gypsum 40%</td>
<td>1.8</td>
</tr>
<tr>
<td>5</td>
<td>Sub-base</td>
<td>BOS 80%, PB 15%, BPD 5%</td>
<td>10.8</td>
</tr>
<tr>
<td>6</td>
<td>Base course</td>
<td>BOS 80%, PB 15%, BPD 5%</td>
<td>30.55</td>
</tr>
</tbody>
</table>
Site Trials

1. Landfill Barrier
2. Trench Fill
3. Road Base
Secondary materials in the mixes
Waste-derived concrete for landfill barrier

Sampling lines below the barrier
Site Trials

1. Landfill Barrier
2. Trench Fill
3. Road Base
Gypsum/Slag mix trial pour

Red Gypsum: 5.3 Tonne
BOS weathered slag: 8 Tonne
Water: 2400 litres
Calculated yield: 7.4 m³
Gypsum/Slag mix trial pour
Site Trials

1. Landfill Barrier
2. Trench Fill
3. Road Base
Trial 5
Car Park
Trial 6
Semi-Dry Paste/grout
Trial 6  Haul Road – Soil Stabilisation
Concrete without Cement (Trials 5 and 6)

Concrete (trial 5)

Semi-dry paste/grout (trial 6)
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Use of Plasterboard Waste in Road Bases
Results for an APC residue (incinerator ash) mix

Strength gain with increase of OPC content, reduction of BPD content and keeping Inc.ash constant at 60% constant
Optimization of BPD, BOS and ROSA mixture

- **BPD10/BOS35/ROSA55**
  - 28 day strength: **14.7 MPa**

- **ROSA48/BOS12/BPD40**
  - 28 day strength: **12.35 MPa**

- **BOS40/ROSA36/BPD24**
  - 28 day strength: **14.6 MPa**

*Use of Plasterboard Waste in Road Bases*
Artificial Neural Networks were not effective because of variability in the materials.

(A and B) - BOS+BPD+RG strength (MPa) after 7 and 28 days
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• **A vision for the future**
  – The problem to be overcome
  – A new type of cement
The Problem

• Almost half the papers in our conference “Sustainable Construction Materials 2” related to the use of secondary materials to replace cement.

• Almost half the papers submitted to the ICE Materials Journal are on the same subject.

• Nowhere near half of the cement used to make concrete is actually being replaced with secondary materials. There is some progress but it is far too slow. The environment will not wait for us.
Some Reasons for the Problem

• New materials cause production problems and increased cost for producers, e.g. the need for more silos.
• Producers are worried about durability.
• Producers are very worried about leaching and other environmental impacts.
• Producers are very very worried about potential impacts on human health.
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A New Type of Cement – defining the requirement

• Large quantities of cement are used for low-strength applications such as road bases, footings and trench and mine backfill.

• These mixes are normally made with the same cement as high-strength mixes (except some hydraulically bound road base materials that use waste minerals which are individually tested before use)

• European Standards have encouraged the use of established cement replacements (such as Pulverised Fuel Ash and Ground Granulated Blastfurnace Slag) but still require high strengths and do not permit many other materials.
A new type of cement “cem-zero”

• For low-strength concrete (up to 20MPa)
• Made entirely with waste minerals
• Continually changing materials and proportions depending on the availability and composition of the wastes.
• A quality assured product so the user can use it like any other cement
• Ideal for LEED and BREAM projects
The “Coventry Blend”

- Basic oxygen slag from steel manufacture (80%)
- Waste plasterboard (15%)
- Kiln by-pass dust from cement manufacture (5%)

100 Tonnes of this blend were made for trials 5 and 6

This blend is not recommended for partial replacement of cement – it is for use without cement
Stage 1 - Blending “cem-zero”

Dryers | Raw material silos | Analysis | Flow control | Mixing | Powder storage
---|---|---|---|---|---
If any of the secondary materials are wet it will be necessary to dry them | The silos should be fitted with agitators to improve uniformity of feed to mixer | In-line sensors | Responding to results of in-line analysis using computer methods established in this project. | Dry powder and small particle blending | The powder will be dry so it may be stored for weeks /months

If any of the secondary materials are wet it will be necessary to dry them.

The silos should be fitted with agitators to improve uniformity of feed to mixer.

In-line sensors.

Responding to results of in-line analysis using computer methods established in this project.

Dry powder and small particle blending.

The powder will be dry so it may be stored for weeks /months.
Stage 2 may be needed depending on choice of product

Transport from stage 1 silo

Mixer
May be a ready-mix plant or a mobile volumetric mixer

Placement as trench fill, mine backfill, road foundation or other application.

Aggregates: Quarry fines, crushed concrete etc.
Thank you

www.claisse.info