Sustainable concrete

Claisse, P.A.

Sustainable Concrete

Professor Peter Claisse

MA (Oxon) PhD CEng FICE

Coventry University, Coventry UK

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- Introduction
- Current Cement Replacements
- Test Methods
- Typical Results
- A vision for the future

Possible routes to Sustainable 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

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Current Cement Replacements

- Pulverised Fuel Ash
- Ground Granulated Blastfurnace Slag
- Condensed Silica Fume

PFA (PULVERISED FUEL ASH)

- PFA is the ash from the burning of pulverized coal in power stations.
- About 20% of the PFA fused into large particles and drops out of the flue gases to form furnace bottom ash.
- The remaining 80% (fly ash) is extracted with electrostatic precipitators and the material for use with cement is obtained from this.

The Pantheon was built with fly ash ... but from a volcano

Barriers to the use of PFA…

- After some years of discussion the Environment Agency have agreed that PFA is not classified as a waste if it is used in concrete.
- However many environmentalists still don’t like it. This has not been helped by a big spill in the Tennessee Valley in the USA.
- Limited to 35% in CEM II and 55% in CEM IV
- Problems with new sources of imported coal

Emissions to the environment:

- CIA/DETR project showed that using 30% PFA for equal 28 day strength in a concrete mix that:
  - Greenhouse gas emissions are reduced by 17%
  - Acidification reduced by 15%.
  - Winter smog reduced by 15%.
  - Eutrophication reduced by 13% .
  - Primary energy requirements reduced by 14%.

Current Cement Replacements

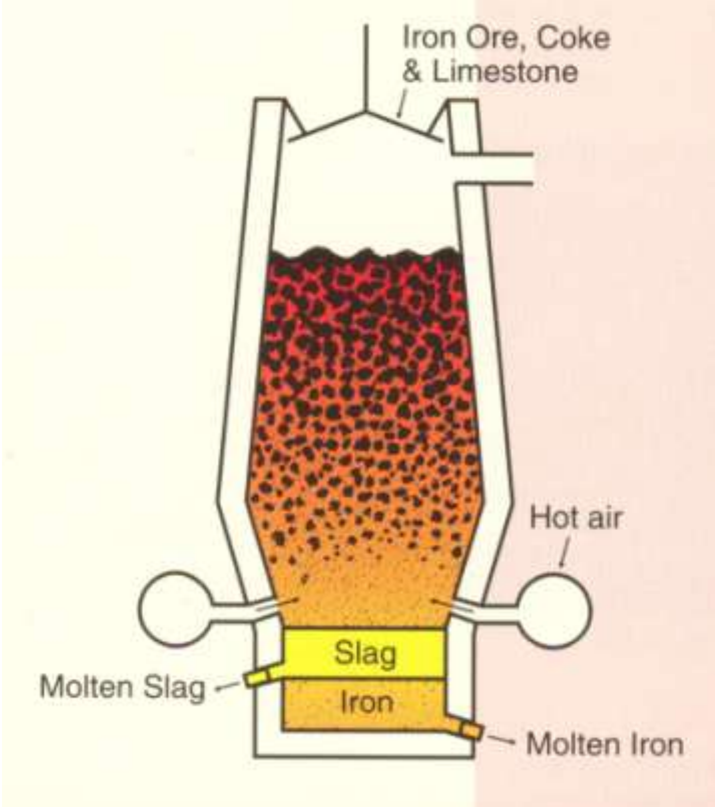
- Pulverised Fuel Ash
- Ground Granulated Blastfurnace Slag
- Condensed Silica Fume

GGBS

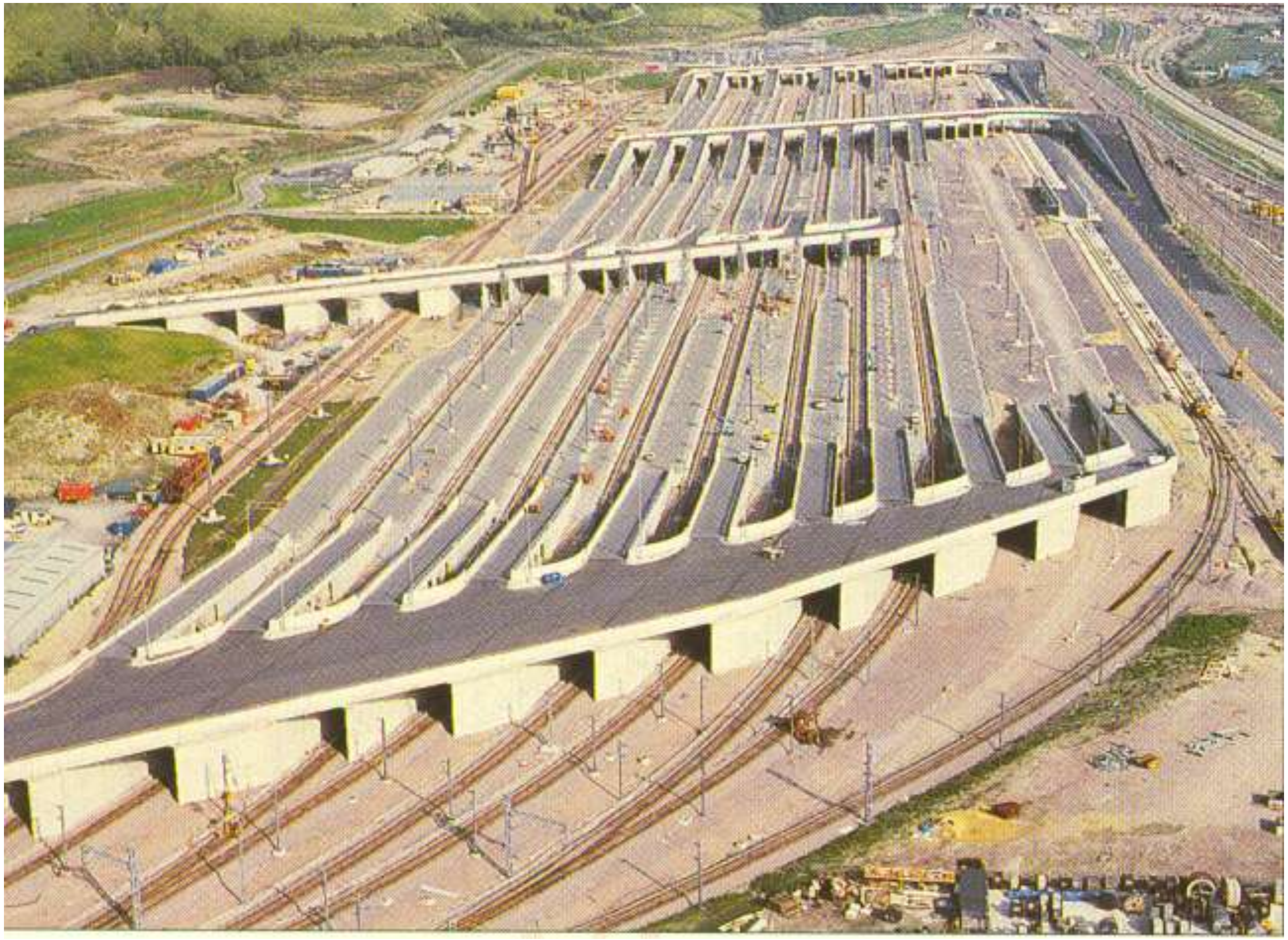
(GROUND GRANULATED BLASTFURNACE SLAG)

- Slag is derived from the production of iron in blastfurnaces.
- The slag contains all of the compounds which would affect the purity of the iron.
- The slag is a hot liquid and may be cooled in air, by mixing with water (foaming) or with high pressure water jets at high water/slag ratios (granulation).
- Only granulation produces non-crystalline slag and only this slag exhibits hydraulic properties and is therefore suitable for use with cement.
- The other types of slag are used as aggregate.

Blastfurnace Slag



GGBS Project



Limits to the use of GGBS

- All the GGBS produced in the UK is now used (depending on activity in the construction and steel industries)
- It costs almost as much as cement
- Some old steel works have insufficient space to install granulators.
- Limited to 35% in CEM II but may be 95% in CEM III.
- Possible problems with new sources of iron ore.

Current Cement Replacements

- Pulverised Fuel Ash
- Ground Granulated Blastfurnace Slag
- Condensed Silica Fume

CSF (Condensed Silica Fume)

- This is a highly reactive pozzolan is also known as microsilica and is derived from the production of silicon steel.
- The production process is highly energy intensive and is carried out in countries like Sweden where hydropower is available.
- The high reactivity can be used to obtain very high strengths but means that great care must be taken with curing etc.
- Various problems have been reported with this material.

CSF Projects

Tsing Ma Bridge, Hong Kong
200m high towers slipformed with microsilica concrete – specified for ease of placement and resistance to an aggressive marine environment.

Tried and Tested on the World's Most Demanding Projects

The benefits of microsilica were first recognised in the 1950s and for more than 20 years microsilica concrete has been specified around the world for the most demanding and prestigious structures.

proven

Canada, Denmark, Germany, Iceland, Norway, Sweden and the USA all have national specifications for the material.

Tarmac Topmix, **the** specialist ready-mixed concrete producer and Elkem, the giant of the silicon alloy industry, have pooled their resources to make Toproc available throughout the UK. Now a growing number of civil engineers are discovering the benefits of Toproc's unparalleled durability, high early build strength, speed, pumpability, long life and ease of use.

There are no uncertainties. All applications have been thoroughly researched, tested and proven in the most demanding and aggressive of environments.

La Grande Arche, Paris.
Constructing a 100m cube, 40 storeys high would not have been possible without microsilica technology.

Gullfaks C Oil Platform.
The innovative construction methods used to build North Sea oil platforms developed around the beneficial pumping properties of microsilica concrete.

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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

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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

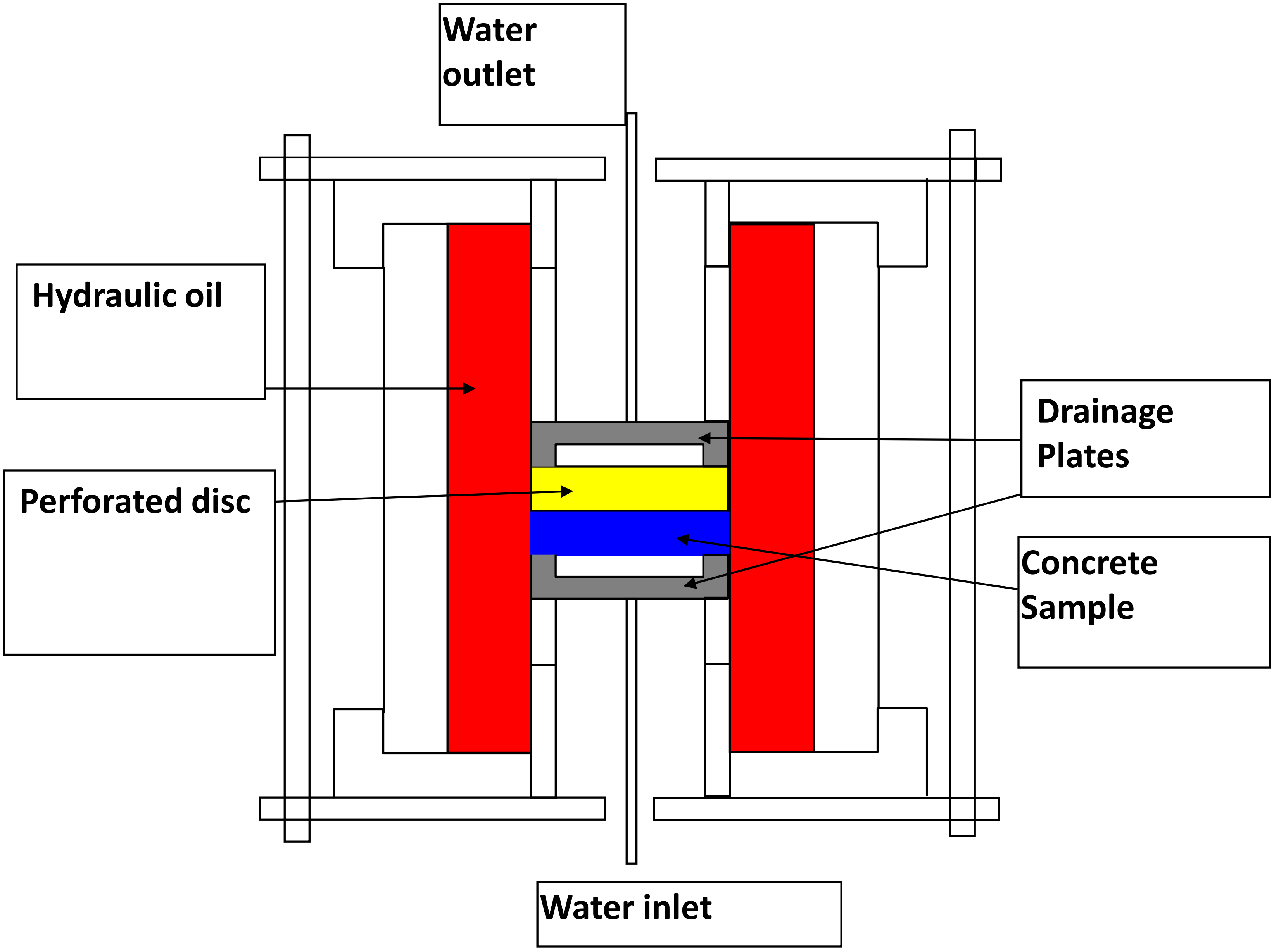
Test Procedures for Cementitious Samples in the Coventry University JL Laboratories

- **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

High Pressure Apparatus



The High Pressure Through Flow Cell

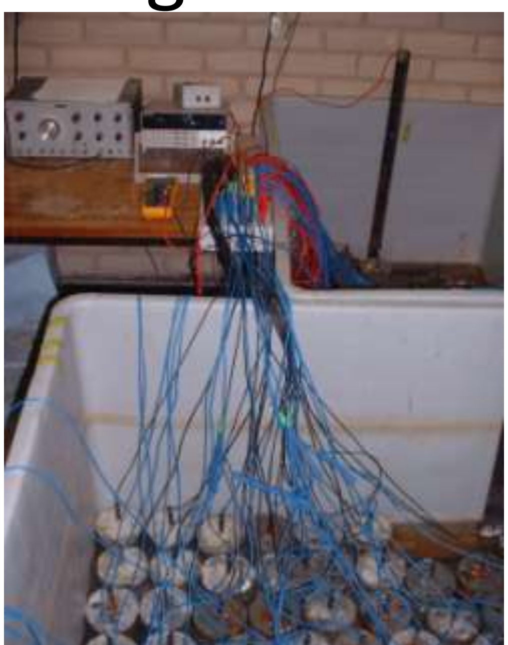
The high-pressure test measures:

- 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 of 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

Trial	Pour	Cementitious component	Strength MPa
1	Cell 1 top	Spent borax 100%	4.5
2	Cell 2 top	CKD 60%, Lagoon ash 40%	1.7
3	Cell 3 top	CKD 60%, Lagoon ash 40%	1.3
1	Cell 1 base	GGBS 90%,OPC 10%, Sodium sulphate	13
2	Cell 2 base	CKD 60%, PFA 40%, Sodium sulphate	6.9
3	Cell 3 base	OPC 5%, CKD, 70%, Lagoon ash 25%	6
4	Trench fill	BOS 60%, Red Gypsum 40%	1.8
5	Sub-base	BOS 80%, PB 15%, BPD 5%	10.8
6	Base course	BOS 80%, PB 15%, BPD 5%	30.55

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 m^3

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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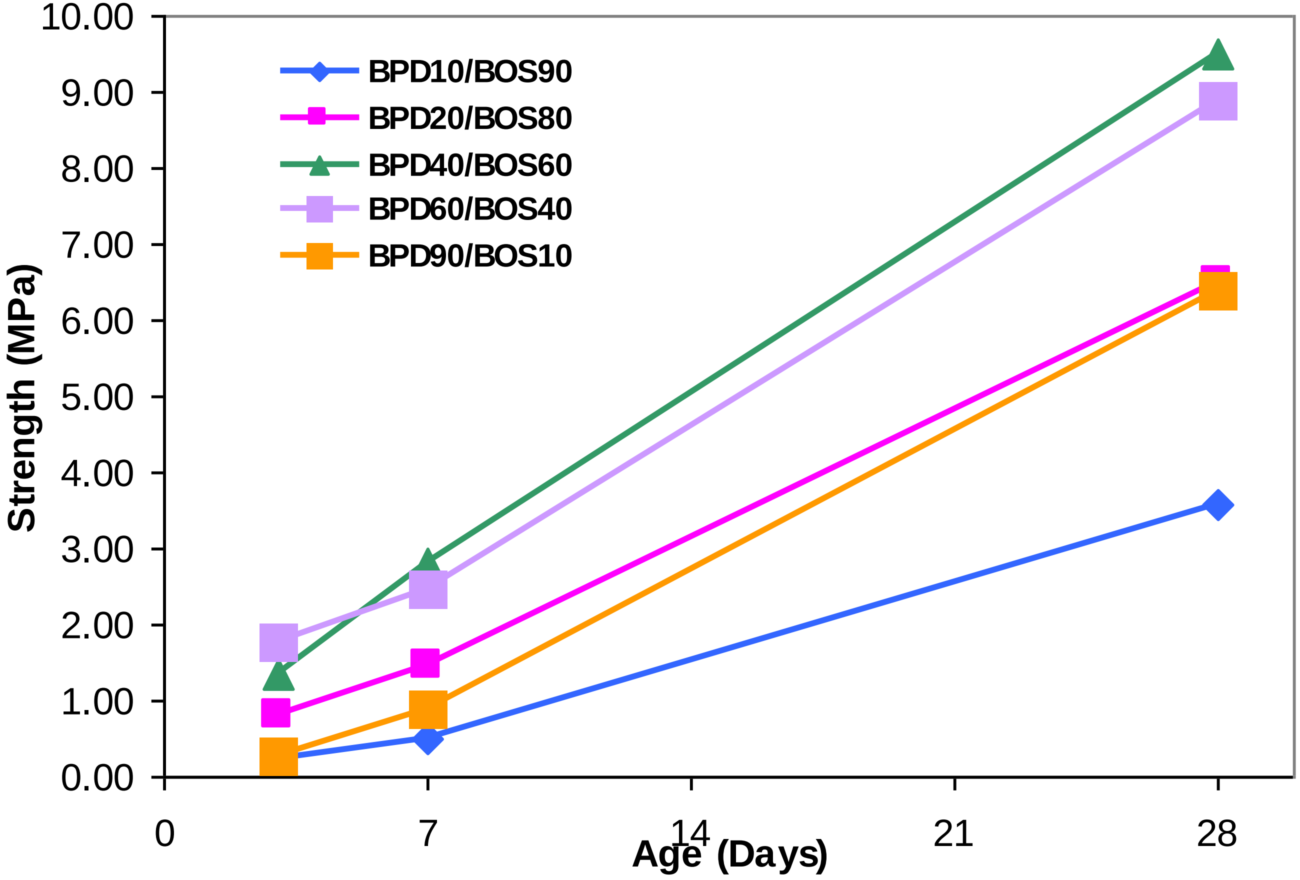
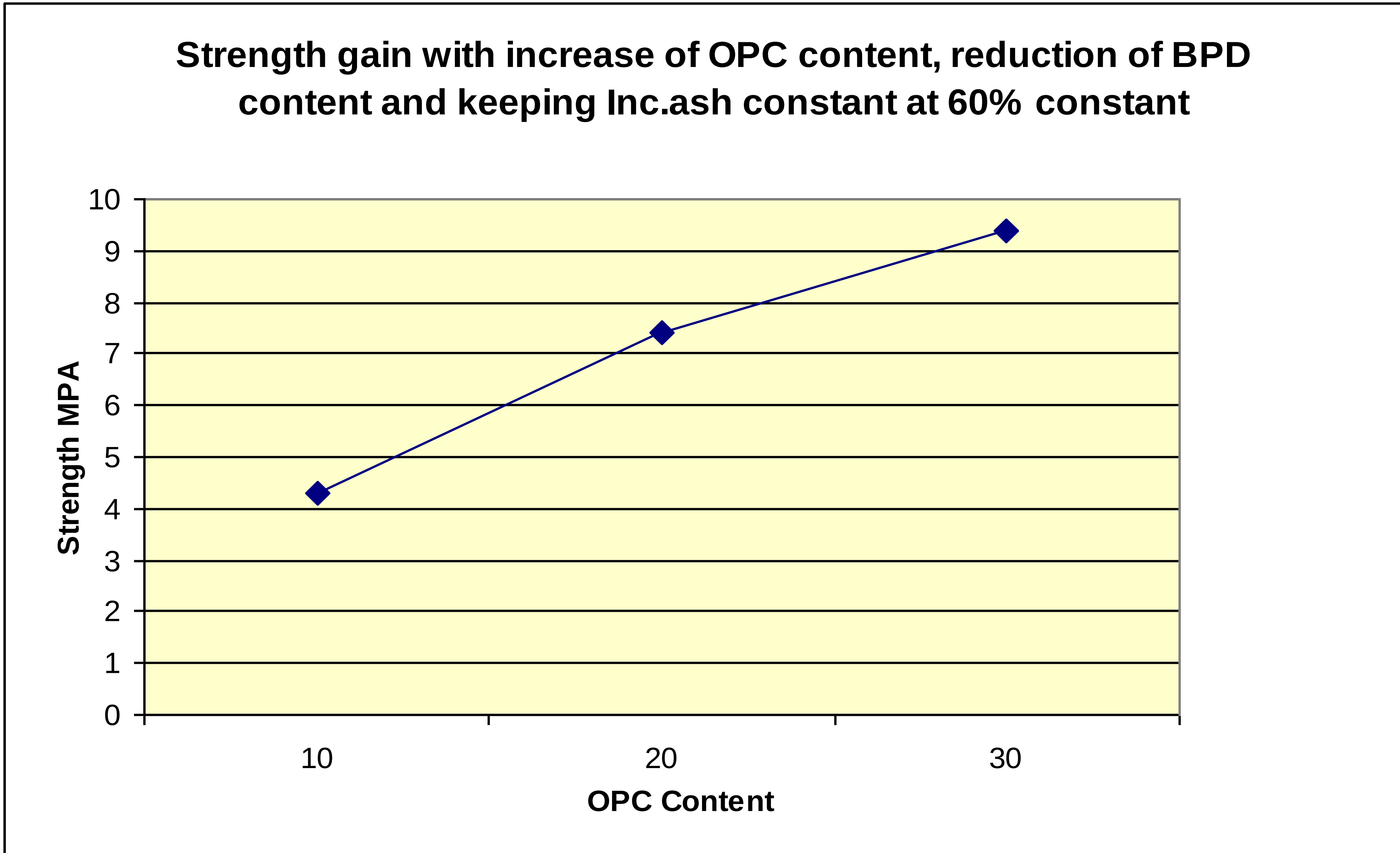
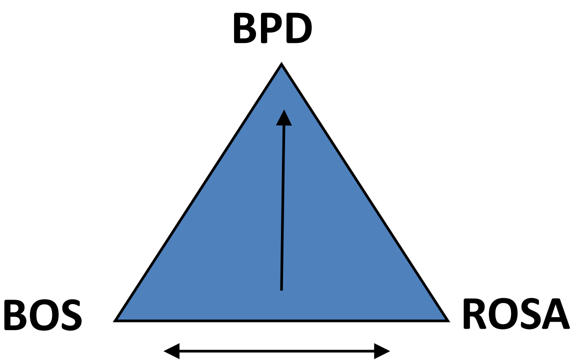
Strength Development (BPD-BOS)



Results for an APC residue (incinerator ash) mix



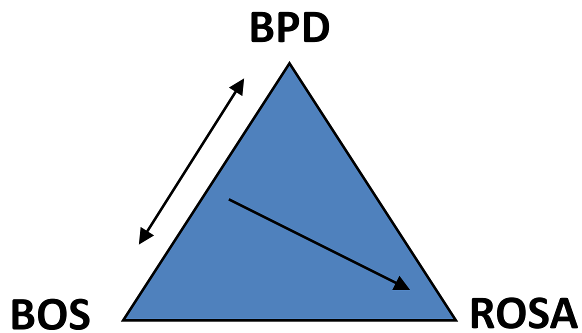
Optimization of BPD, BOS and ROSA mixture



BPD10/BOS35/ROSA55

28 day strength:

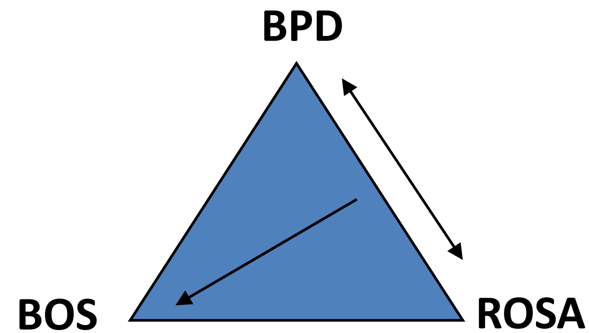
<u>14.7 MPa</u>



ROSA48/BOS12/BPD40

28 day strength:

<u>12.35 MPa</u>



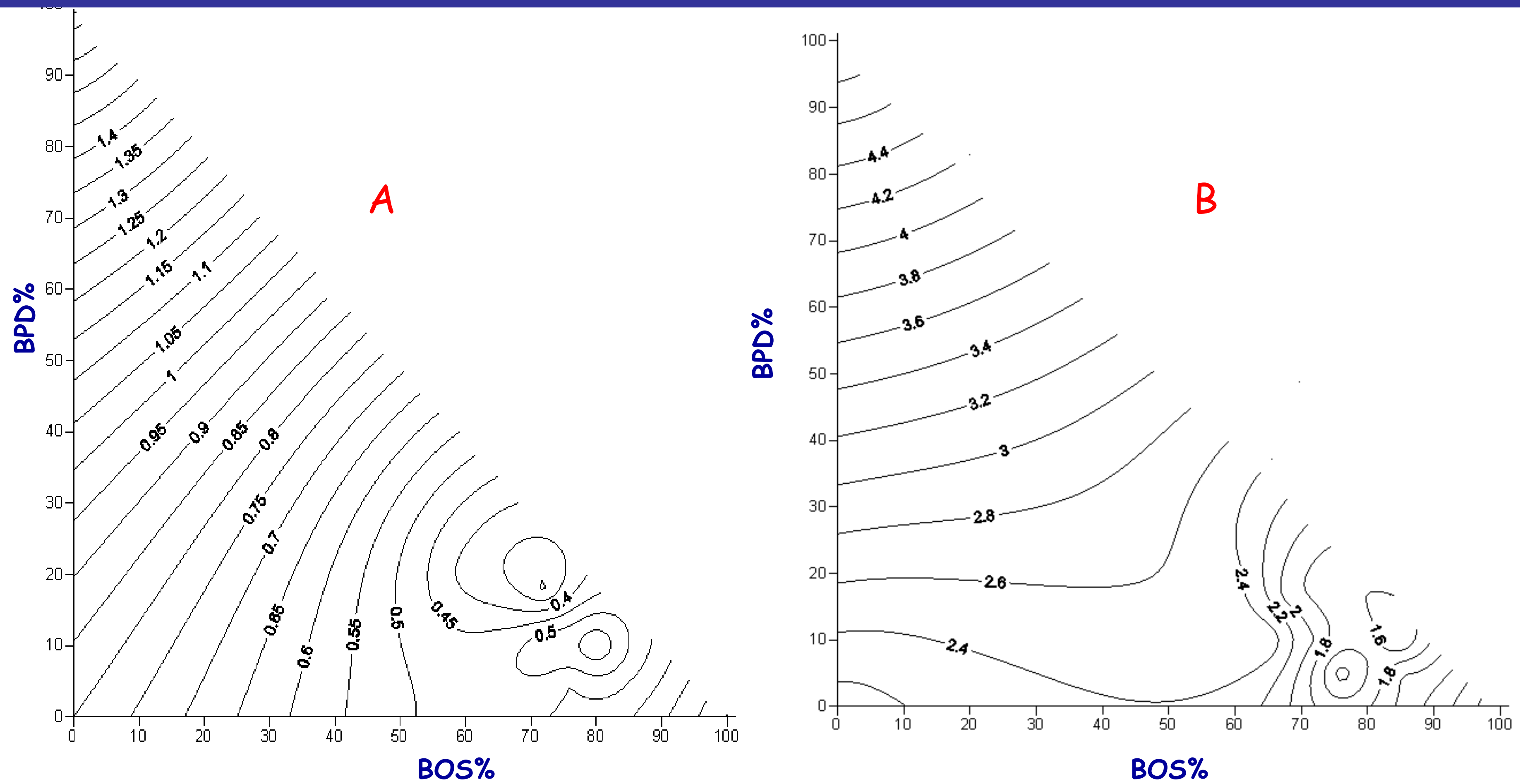
BOS40/ROSA36/BPD24

28 day strength:

<u>14.6 MPa</u>

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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  - 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

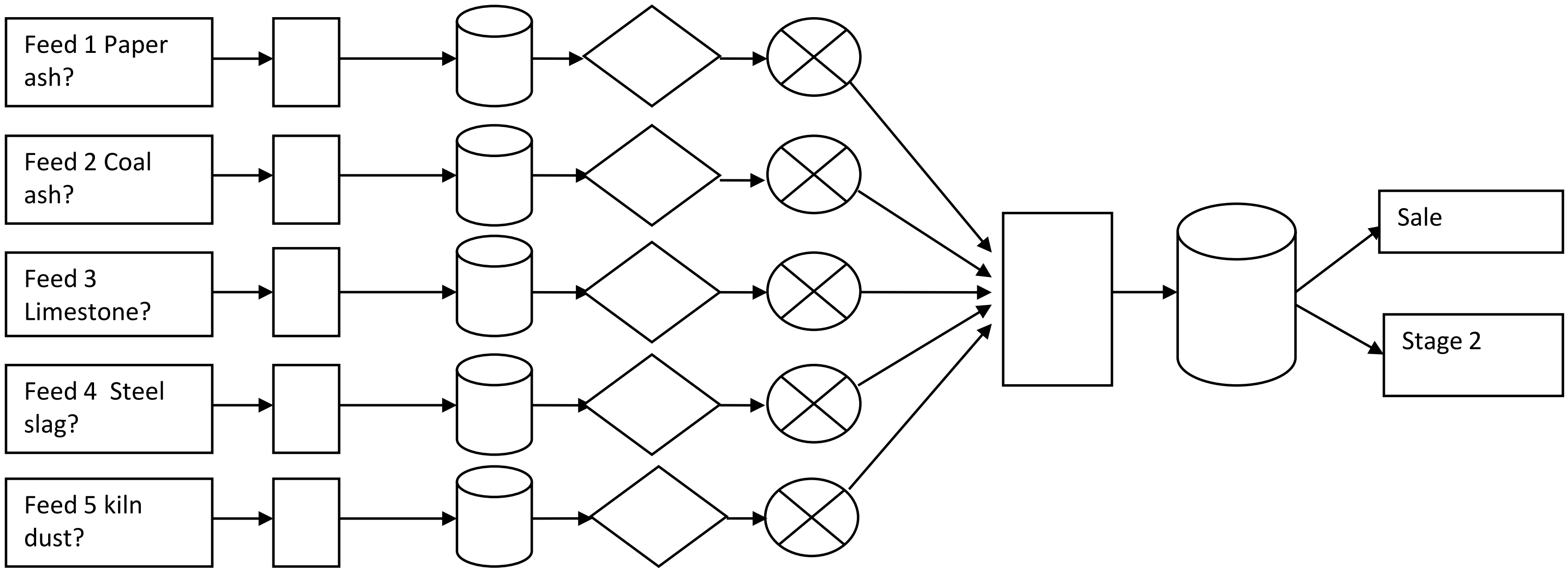
The “Coventry Blend”

- 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

Stage 2 may be needed depending on choice of product

Transport from stage 1 silo

Aggregates: Quarry fines, crushed concrete etc.

Mixer

May be a readymix plant or a mobile volumetric mixer

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

Conclusions

- The easiest way to make sustainable concrete is to use secondary minerals.
- PFA, GGBS and CSF cannot deliver the progress that we need.
- There has been a lot of research on novel materials but little industrial use.
- A major initiative is needed to bring more secondary minerals into use.

Thank you

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