Institution of Structural Engineers
South Eastern Counties Branch

Technical Meeting
2 November 2010

Sustainable Concrete Construction
An engineer's views

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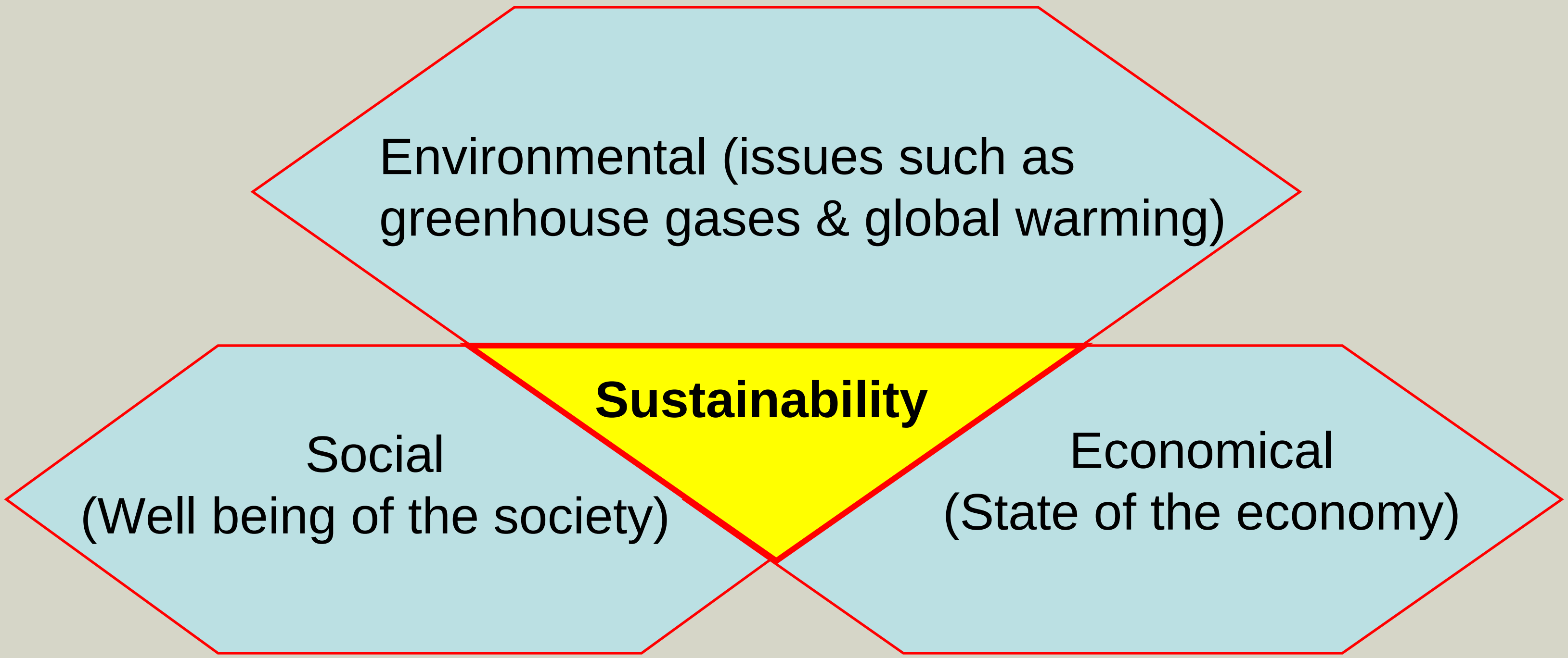
Plan of the Presentation

(Mainly concerning building construction)

1. Introduction
2. Common solutions leading to Sustainable Construction
3. Judicious choice of construction materials
4. Combining Interests of Safety and Sustainability
5. Summary of sustainability solutions

Introduction

Three Facets of Sustainabililty



Our main focus:

Environmental issues concerning concrete construction

Relevance of Building Construction to Energy consumption, CO_2 Emissions and Global Warming

- CO_2 emissions contribute about 70 per cent of the potential global warming effect of emissions of greenhouse gases caused by human activities.
- Approximately 50% of the world's energy is used in buildings, a fifth of which is contributed by energy consumed in building construction.
- The UK contributes about 2 per cent to global man-made emissions of CO_2.
- The UK energy consumption accounts for about 95 per cent of all CO_2 emissions, which is nearly the case in most product manufacturing processes.

CONCRETE – AN IMPORTANT BUILDING CONSTRUCTION MATERIAL

- **Concrete is used only second to water on a volume consumption basis. Globally, concrete is used at a rate of two tonnes per person per year.**
- **Concrete construction is robust and durable, provided that concrete is correctly mixed, placed and cured.**
- **Concrete elements have good insulating properties (energy conservation) and fire resistance.**
- **Members can be cast in required shapes with in-situ or precast concrete, which is important for aesthetics in special buildings designed by architects. (e.g. Santiago Calatrava)**

Santiago Calatrava: Lyon-Satolas TGV Station

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Concrete Construction and Sustainability

- **Since concrete is used in large quantities in construction, it is important to reduce energy consumption and CO_2 emission in its manufacturing process.**
- **Portland Cement (PC) is a vital constituent of concrete and it is often described as an energy-demanding product. The ECO_2 level for PC (embodied CO_2, i.e. CO_2 generated by a product) is quoted as approximately one tonne per tonne.**
- **Normal PC concrete may contain 300 kg PC per m^3 (2.4 tonnes) i.e. 125 kg of PC per tonne, and, therefore, an overall impact of its ECO_2 level is low - even lower when related to building in use for its service life.**
- **ECO_2 level for PC concrete is further reduced with reduction in use of PC and its replacement with industrial byproducts.**

Embodied CO_2 (ECO_2)– A proper perspective

Material	(ECO_2 kg) / (weight in kg)
PC concrete (Grade 40 with 30 kg of steel reinforcement)	0.153 (0.125 for PC + other materials)
Sawn Softwood	0.44
Structural Steel*	1.93

* Recycling steel is more advantageous than other materials.

MPA Website

Wholemeal Bread
800g, 1.3kg CO_2

~1.63

Orange juice
1 Litre, 1.1kg CO_2

~1.10

Bag of crisps
35g, 80g CO_2

~2.29

The Independent, 13–10-10

Sustainable Concrete Construction

Basic Principle

Prudent use of natural resources to meet the needs of the current generation without jeopardising the needs of the future generations

Sustainable Concrete Construction

Topics considered in this presentation

- ***Reduction in use of natural resources***

⇨ ***Replacement of Portland Cement (PC) with Pulverised Fuel Ash (PFA) and / or Ground Granulated Blast-furnace Cement (GGBS)***

- ***Recycling of construction and demolition waste***

⇨ ***Use Recycled Concrete Aggregate (RCA)***

Sustainable Concrete Construction

Other important topics

Reduction of waste on construction sites

Reusing* and *Refurbishing of buildings

Available information in the UK:

www.theconcretecentre.com (The Concrete Centre)

Building Research Establishment (The Green Guide)

Code for Sustainable Homes – Technical Guide (www.communities.gov.uk/publications)

Waste on construction sites

- **The construction industry is responsible for some 33% of all waste arising in the UK, i.e. 120 million tonnes of construction, demolition and excavation waste per year. An estimated 25 million tonnes of this waste ends up in landfill without any form of recovery or reuse.**
  (Halving waste to landfill - Waste & Resources Action Programme (WRAP) website)

- **Eight cubic yard skip costs around £150 to hire for ~10 days, as an average. The average cost of material in that skip is > £1,500.**

- **On average, 13% of all materials delivered to construction sites are not used and go in to the skips.**

- **Typical building projects could produce waste worth £43/m^2.**

Reduction in wastage of materials on site

- UK businesses could save some £6.4 billion by using resources more efficiently.

- Designing out Waste: A design team guide for buildings

  Information on the key principles that designers can use during the design process and how these principles can be applied to projects to maximise opportunities to “Design out Waste”.

(Guide produced by WRAP - Waste & Resources Action Programme)

Progress in the UK

Cement:

CO_2 emission is reduced by 20% compared to 1990 level.

300,000 tonnes of processed waste materials are used as fuel, replacing some 20% of fossil fuel.

Aggregate:

Recycled and secondary aggregate amount to 25% of the total market.

Precast product manufacturing:

Cement replacement using industrial byproducts:

- **34% ground granulated blast-furnace slag (GGBS)**
- **11% Pulverised Fuel ash (PFA)**

Additions to Cement used in the UK (tonnes per annum).

Total Portland Cement (PC) consumption: 12,500,000 tonnes

Source: THE INSTITUTE OF CONCRETE TECHNOLOGY, ANNUAL TECHNICAL SYMPOSIUM , 28 March 2006

	Addition at mixer	Component of blended cement
Ground granulated blast-furnace slag (GGBS)	2,000,000	Very small quantity
Pulverised Fuel Ash (PFA)	500,000	~ 100,000
Silica fume	3,000	Very small quantity
Limestone fines	< 10,000	~50,000

Some issues concerning further promotion of sustainable concrete construction in the UK

- **Structural design concerns only the compressive strength and not usually the influence of constituents of concrete on its structural performance.**
- **Clients may not be willing to bear the additional costs of sustainable construction, especially if there is any question of adverse influence on durability.**
  (Especially in the difficult financial situation at present!)
- **Authoritative guidance on composite cements and usage of industrial byproducts could assist in creating confidence.**
- **Incentives such as taxation on disposal of waste and on aggregate extraction could continue to improve usage of recycled aggregate.**

An Engineer's Responsibilities

- **Safety of construction (statutory responsibility) and awareness of liability.**
  (Unjustifiable risk-taking is not covered by Professional Indemnity Insurance.)

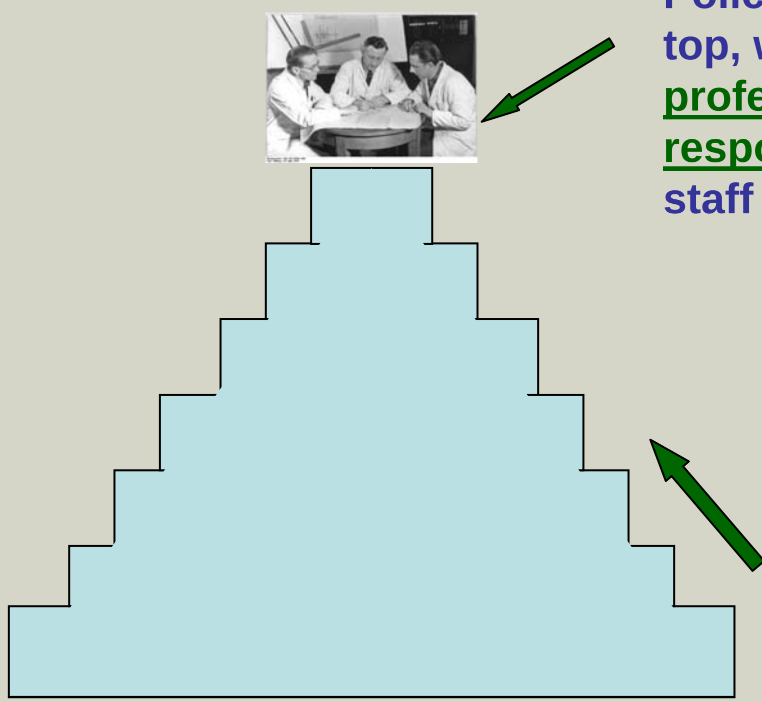
- **Clients' Interests –**
  - **Durability and service life of building**
  - **Economy of Construction**

- **Earning just reward for the work under circumstances influenced by fee competition, downturn in building industry, availability of competent staff at affordable salaries, etc.**

Changing circumstances may present difficulties in adopting sustainable construction solutions.

Changing models of Engineering Firms

A Model - perhaps an old-fashioned one!



Policy made by the engineers at the top, who would understand professional & environmental responsibilities, need for training & staff structure, etc.

A mixed staff structure, old & young, receiving enhanced skills & experience, and aspiring for progressing careers

Present day model of some engineering firms

Routine design and quick invoicing, please!
Training? #!/?>!
Checking? @?#>**!

Businessman, financier for the firm, who understands profit better than engineer's responsibilities, need for training & staff structure, etc.

Sustainable Construction?
Can't afford it at present!

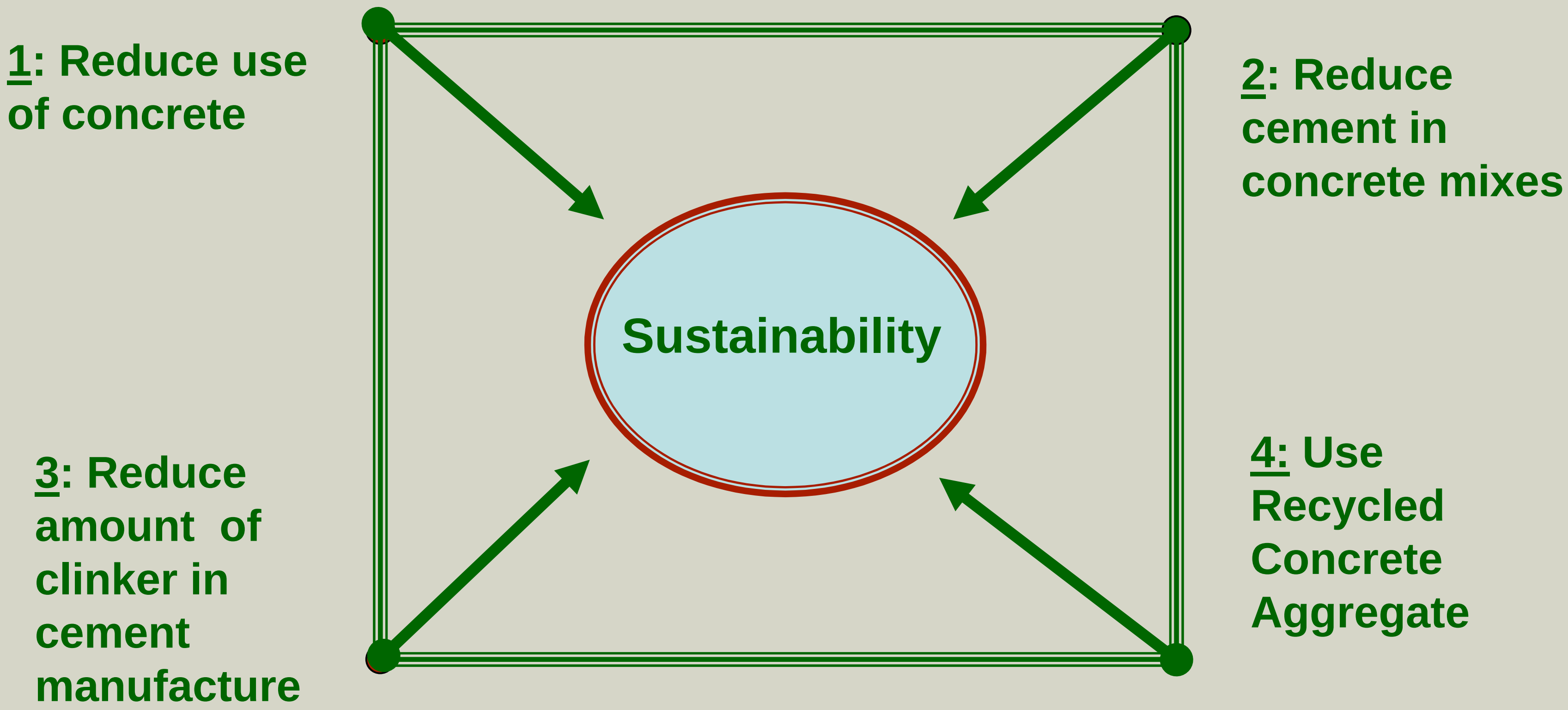
Staff structure with limited chances of reaching even the foot of the precipice and not enough trainees or junior staff to follow them

Common solutions leading to Sustainable Construction

AIM:

To achieve good compromise and optimum solutions with higher level of skills, so that there is no conflict between safety and sustainability of concrete construction.

COMMON SOLUTIONS LEADING TO SUSTAINABLE CONSTRUCTION (Used individually or in combination)



All these solutions may concern costs and they require increased efforts and skills in mix design, structural design and careful specification of materials.

1: Reduce use of concrete

i. **Higher skills of design and rigorous analysis to avoid overdesign and to afford reduction in member sizes, thus reducing wastage of materials.**
   (Avoid routine and "sleep-easy" or over-safe solutions!!)

ii. **Reduction in redundant members, as far as possible.**
   (With due regard to provision against progressive collapse)

iii. **Framing of structures to facilitate reuse of building frames and even permit reuse of structural members, i.e. precast elements, with the help of planned demolition.**

iv. **Improved durability and enhancement in service life of buildings, to avoid premature demolition.**

Sustainable construction and structural framing

i. Use of continuity in structural members and rigid structural joints often lead to robust and economical construction.

ii. However, such structures are difficult to demolish and retrieval of elements for effective reuse is not practicable.

iii. Designers should consider possibilities of using structurally determinate systems and framing, which could lead to simplified fabrication and enable future reuse of components.

2: <u>Reduce cement in concrete mixes</u>

i. **Higher skills of mix design**
   - **Aggregate packing technique**
   - **Water-reducing admixtures to achieve requisite water/cement ratio with less water and less cement.**

ii. **Potential for Codes and Standards to accept 56 days strength in structural elements, if they will not be subjected to substantial loads before 2-3 months of age.**

   (This should help to promote PFA concrete, with slow development of strength.)

3: Reduce amount of clinker in cement manufacture

i. **Blended Cements using industrial byproducts as cementitious materials, e.g. Pulverised Fuel Ash (PFA) and Ground Granulated Blast-furnace Slag (GGBS).**

ii. **Concrete mixes with PFA or GGBS added at the mixers, along with such materials as lime stone filler, silica fume, etc.**

iii. **Important point to note:**

Increased number of cementitious materials should require more careful mix design and consideration of compatibility of constituents, compared with concrete made with PC only, in order to avoid any adverse effect on durability of concrete.

3: Reduce amount of clinker in cement manufacture

Added advantages:

i. **Energy saving and reduction in CO_2 emission related to cement manufacture.**

ii. **Less quarrying of minerals for manufacturing cement.**

iii. **More compact microstructure of PFA concrete compared with that of PC Concrete and improved resistance to chemical attack, e.g. chloride diffusion.**

iv. **Reduction in cost and alleviation of problems associated with storage and disposal of industrial byproducts.**

4: Use recycled concrete aggregate (RCA)

i. **Use of RCA can assist in easing pressures on landfill sites and reduction in number of extraction sites for natural aggregate.

ii. Such sites are often found in locations of natural beauty and scientific interest, and they meet opposition from the environmentalists.

***With due regard to the limitations on use of RCA*

Judicious choice of construction materials

1. Ground Granulated Blast-furnace Slag
2. Pulverised Fuel Ash
3. Other materials used for enhancing durability
4. Recycled Concrete Aggregate

Choice of construction materials

- **An engineer has the responsibility to chose the right construction material to suit the function of a building and its conditions of exposure to the environment.**

- **The products used in construction need to have some accreditation; e.g. CE mark or Agre'mont Certificate. The difficulties arise when using innovative materials that are preferable from sustainability point of view, e.g. industrial byproducts.**

- **Research and development should lead to authoritative guidance on usage of such innovative materials, which should clearly spell out limitations for using such materials.**

Points to consider when choosing construction materials

1. Scope for energy saving and reduction in CO_2 emission.

2. Benefits for durability and structural performance.

3. Potential risks and available means for reduction in risks.

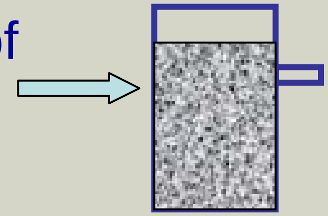
Ground Granulated Blast-furnace Slag

GGBS

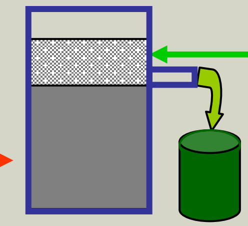
A byproduct from the blast-furnaces used for manufacturing iron

GGBS – THE MATERIAL

Blast-furnaces are fed with carefully controlled mixtures of iron-ore, coke and limestone**,** with temperatures of about 1,500º C.



The iron ore is reduced to iron.



The high temperature process results in molten liquid or slag at the top, which is tapped away.

The slag is rapidly quenched in large volumes of water. This process of quenching **optimises the cementitious properties** and produces **granules** similar to coarse sand particles.

The **'granulated' slag** is dried and **ground** to a fine powder, that is called **GGBS.** It is off-white in colour and has a bulk density of 1200 kg/m^3.

GGBS – THE MATERIAL

Typical Chemical Properties (UK produced)

Calcium oxide (CaO)	40%
Silica (SiO_2)	35%
Alumina (Al_2O_3)	16%
Magnesia (MgO)	6%
Other - Fe_2O_3, etc.	3%

GGBS – THE MATERIAL

1. Economically available in large quantities, requiring storage facility and, therefore, suitable for use in Ready-Mix concrete and production of large quantities of site-batched concrete and in precast product manufacturing.

GGBS has to be handled very carefully. Solution of GGBS and water is highly alkaline, which can severely damage the skin.

2. GGBS has its <u>own reactive components</u>, e.g. Calcium Oxide arising from burning of limestone in the furnace.
3. Activation of the GGBS alkalis and sulfates result in GGBS hydration products.
4. Some of these GGBS hydration products combine with the Portland Cement hydration products to form further hydrates that have <u>pore-blocking effect</u>.

BENEFITS AFFORDED BY PC + GGBS CONCRETE

- **Use of blended cement with 60% GGBS in production of concrete of strength class C25/30 can result in reductions in energy consumption and in CO_2 emissions of the order of 43 % and 50 % respectively.**

- **GGBS Concrete has effective chloride resistance (beneficial for exposed elements, e.g. a bridge across buildings, roof car parks, etc.)**

POINTS TO NOTE WHEN USING PC + GGBS CONCRETE

- **GGBS Concrete could develop early strength but minimum of six days of water- curing is essential for long term strength development.**

(Curing is not easily available in buildings. However, without any water-curing, 91 days strength of in-situ concrete could be only about 60 or 70% of the 28 days standard control strength.)

GGBS Concrete compared with PC Concrete

- **Near-white colour of GGBS cement permits architects to achieve a lighter colour for exposed fair-faced concrete finishes, at no extra cost.**

- **Better workability, making placing and compaction easier.**

- **Lower early-age temperature rise, reducing the risk of thermal cracking in large pours.**

GGBS Concrete compared with PC Concrete

- **Lower heat of hydration. (preferred in most concrete construction projects)**
- **Both the heat of hydration and strength depend on the fineness of GGBS. However, the effect of GGBS fineness on heat of hydration and strength are similar.**
- **Judicious use of GGBS can result in achieving cementitious binder that will conform to the 42.5 strength class within normal, low and very low heat classes.**

Enhanced Durability with GGBS Concrete

- **Defence against damaging internal reactions such as Alkali Silica Reaction.**

- **Higher resistance to chloride ingress, reducing the risk of reinforcement corrosion.**

- **Higher resistance to attack by sulphate and other chemicals.**

Pulverised Fuel Ash (PFA)

A by-product obtained at power stations, where finely powdered (pulverised) coal is used as fuel, mixed with heated air and burned.

It is carried by the exhaust gases and recovered as “fly” ash with fine particles.

ENVIRONMENTAL BENEFITS OF USING PFA

- **Manufacturing one tonne of Portland cement requires about 1.11 Megawatt-hour and it results in emissions of 0.89 to 1.1 tonnes of CO_2 depending on the type of manufacturing process.**

- **Each tonne of PFA used in cementitious products can save 900kg of CO_2 emission on average. For a common PC + PFA concrete, containing 35% PFA, the CO_2 emission can be potentially reduced to 680 kg per tonne of the composite binder compared with ~1000 kg per tonne for PC-only binder.**

  (i.e. the ECO_2 level can come down from 153 to ~110 kg per tonne for commonly used concrete.)

PFA SUITABLE FOR STRUCTURAL CONCRETE

- **Earlier use of PFA as partial replacement of Portland cement (PC) was limited to "fine" PFA, i.e. 12% retention on a 45 µm sieve, and with carbon content measured by loss-on-ignition (LOI) limited to 6%. (BS 3892: Part 1).**

  (A lot of PFA was excluded from its use in construction.)

- **The EN 450 (EU standard for PFA) relaxes the quality of PFA permitted for use in concrete:**
  - **fineness up to 40% retained on a 45 µm sieve**
  - **LOI up to 7%,**

- **Use of EN450 PFA will widen the use of PFA and assist sustainability of concrete construction by reducing the need for PC - with certain precautions.**

ROLE OF FINE PFA IN COMPOSITE BINDER

Typical composition: Silica Dioxide (~50%), Trioxide of Aluminium (~25%) and Trioxides of Iron (~12%), and the rest Oxides of Calcium, Magnesium, etc.

1. **Compounds in PC (Tri-calcium Aluminate and Silicate, Di-calcium Silicate and Tetra-calcium Alumino Ferrite). react with water to give a hydrated paste comprising ~75% Calcium Silicate Hydrate (CHS) and ~25% Calcium Hydroxide (CH).**

2. **Compounds in PFA react with this CH to produce additional type of CHS, which is denser than CHS given by the hydration of PC.**

(Note: This process tends to slow down the initial strength development of PFA concrete.)

PFA concrete (using PC + fine PFA)

- Compared with the common PC concrete, PFA concrete made with good mix design can have more compact microstructure, improved chloride resistance, enhanced durability and better structural performance.

- Slower development of strength of PFA concrete – may not suit the need for rapid reuse of formwork in speedy construction, manufacturing of precast elements, etc.

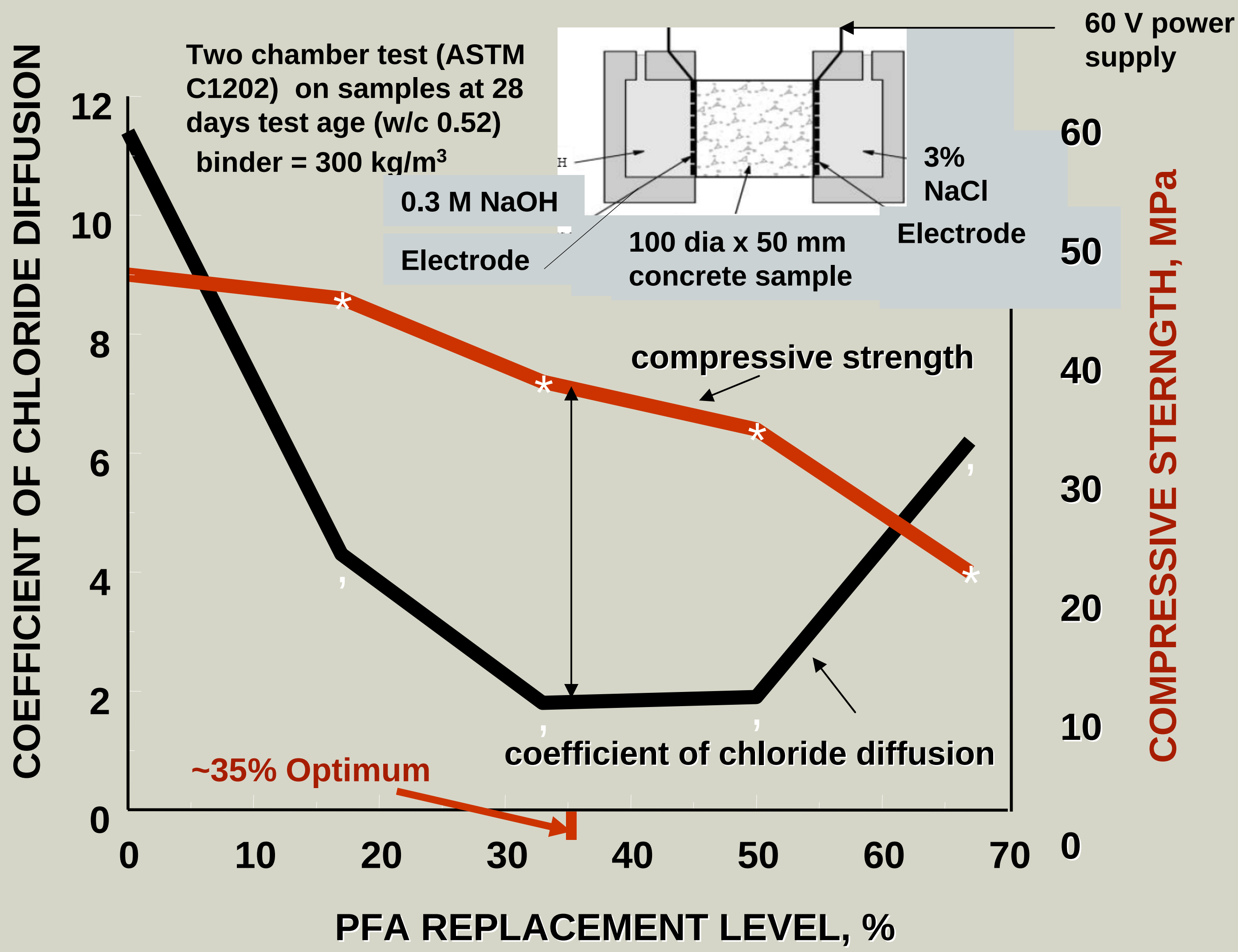
PFA concrete (using PC + fine PFA)

- Level of replacement of PC with PFA should be carefully chosen to achieve optimum performance which depends on chemical properties of PC and PFA.

- **For normally used PC, optimum level of PC replacement is generally 35%, in order to achieve a balance between the strength development and resistance to chloride diffusion of concrete .**

- **For higher levels of PC replacement with PFA, proper choice of reactive PC and special mix design are essential in order to achieve good workability of green concrete, and durability and structural performance of hardened concrete.**

Optimum level of replacement of commonly used PC with fine PFA



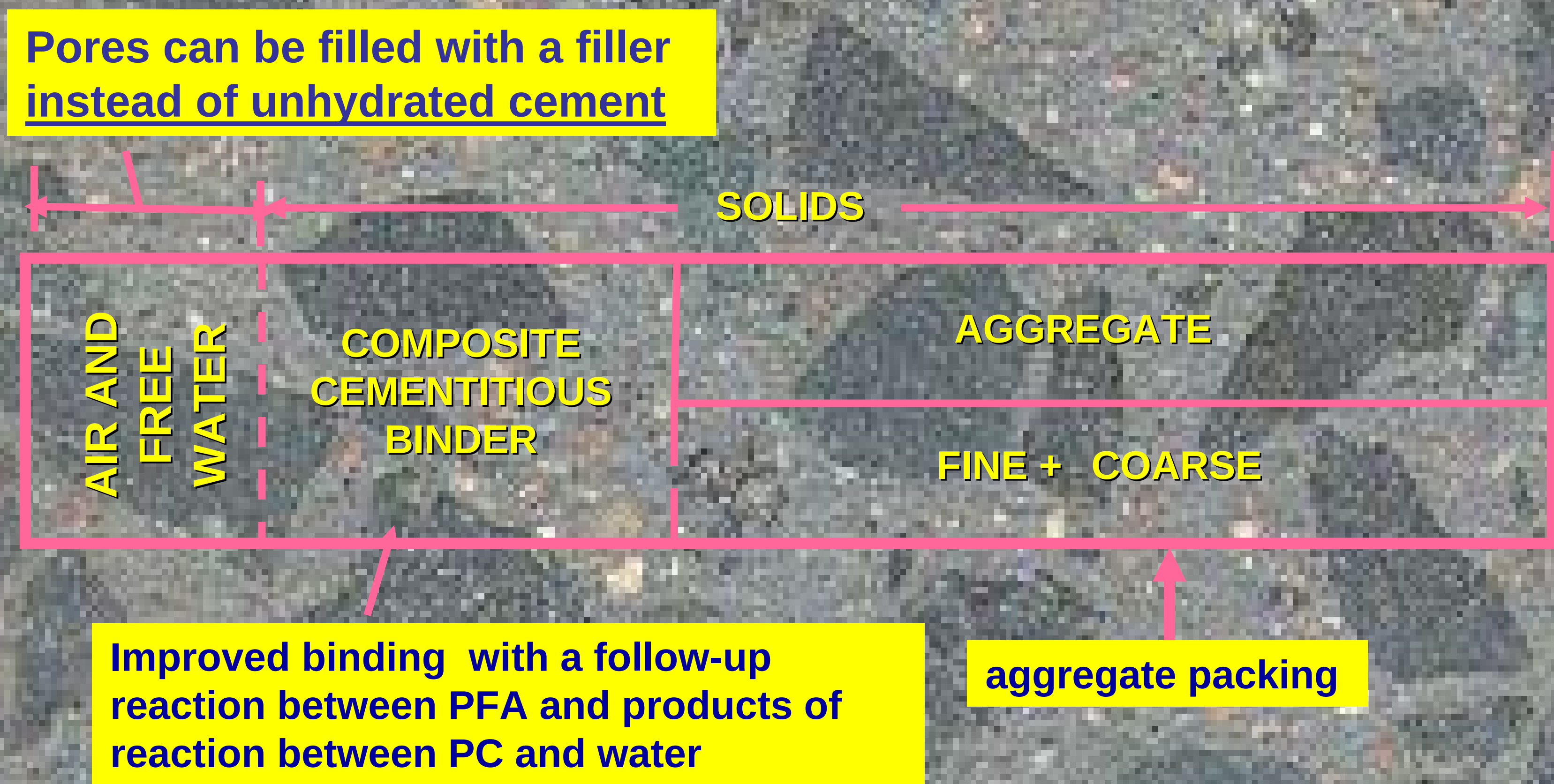
Main points associated with PFA Concrete (Compared with PC Concrete)

Properties	PFA Concrete v PC Concrete
Workability	Increased for the same w/c ratio
Setting Time	Increased
Bleeding	Reduced in most cases
Plastic Shrinkage	Increased (Early curing could prevent cracking.)
Early age Strength	Reduced for equal binder content
Long Term Strength	**30-50% greater than at 28 days**
Formwork striking time	Increased for equal binder content

Main points associated with PFA Concrete (Compared with PC Concrete)

Properties	**PFA Concrete v PC Concrete**
Structural (e.g. f_{cu})	Similar to PC concrete
Carbonation Resistance	Similar to PC concrete
Resistance to Chloride attack	**Much better than PC concrete**
Resistance to Sulfate attack	Somewhat better than PC concrete
Resistance to Freeze-thaw & Abrasion	Little less at early age (depends on strength gained at the time of exposure.)

Enhancement in durability and avoidance of cement wastage in concrete with PC + PFA



PFA concrete (using PC + coarser EN450 PFA)

- **Unless special measures are taken, performance of concrete with coarser PFA can be inferior to that with fine PFA to some extent depending on characteristics of the PC and PFA.**

- **Concrete with EN450 PFA can achieve strength equivalent to that with fine PFA, only through adjustment to either the water content or binder content of the mix, and the use of a water-reducing admixture.**

(Both measures could increase cost and reduce advantages regarding energy saving and CO_2 emission!)

- **Coarse PFA concrete, made with mixes of design strength equivalent to the fine PFA concrete, can have similar durability attributes related to carbonation rate, chloride diffusion, sulfate attack, alkali-silica-reaction, abrasion resistance and freeze/thaw resistance.**

Other materials used for enhancing durability

Silica fume: fine, fluffy, lightweight and non-crystalline powder - greyish white in colour

Silica fume is a byproduct of producing silicon metal or ferrosilicon alloys. It is a highly reactive material, containing higher percentage of Silicon Dioxide (> 85%), compared with PFA (40%) and PC (20%).

Compared with PC concrete, concrete containing silica fume has less $Ca(OH)_2$ crystals in the hydration products and, therefore, its microstructure is dense and homogeneous. Consequentially, it has very high strength and enhanced durability.

Silica fume is very fine and dusty, and it may contain traces of crystalline quartz. Hence, placing, finishing and curing silica-fume concrete requires special attention to safety.

Other materials used for enhancing durability

Metakaolin: A finely-divided material used as 8% - 20% replacement of PC (by weight)

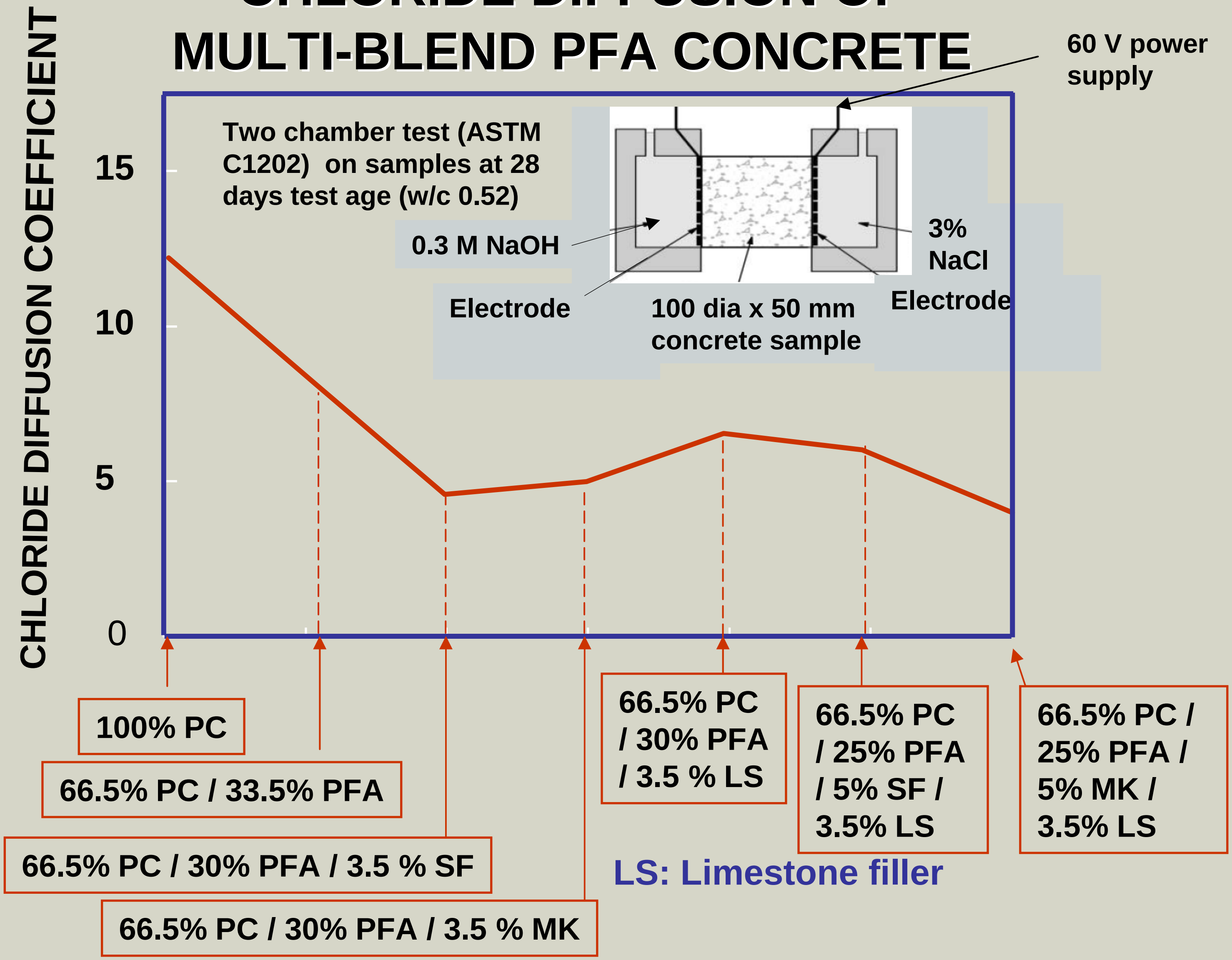
Metakaolin is obtained by heating Kaolin Clay to 500-600^{o} C, a process known as thermal activation of minerals or calcining.

Metakaolin contains aluminosilicate minerals (e.g. Al_2SiO_5), which combine with $Ca(OH)_2$ to produce enhanced cementitious properties.

In addition to increased compressive and flexural strengths, Metakaolin makes concrete more durable (reduced permeability, chloride ingress, effects of alkali-silica reactivity, etc.)

The concrete also becomes and more workable and efflorescence is reduced.

CHLORIDE DIFFUSION OF MULTI-BLEND PFA CONCRETE



RECYCLED CONCRETE AGGREGATE (RCA)

Use of RCA can assist in easing pressures on landfill sites and reduction in number of extraction sites for natural aggregate.

Such sites are often found in locations of natural beauty and scientific interest, and they meet opposition from the environmentalists.

RECYCLING STEEL AND RECYCLING CONCRETE AGGREGATE

1. Compared with recycling of steel, RCA has a lower level of benefits. Recycling of each tonne of steel packaging makes substantial environmental savings, e.g. 1.5 tonnes of iron ore, 0.5 tonnes of coal, 80% of the CO_2 emissions, etc.

   (Production of RCA and natural aggregate would generally result in comparable levels of CO_2 emissions and energy consumption.)

RECYCLING STEEL AND RECYCLING CONCRETE AGGREGATE

2. **While recycling of steel does not damage its structure or downgrade its structural properties, special measures are required to address problems associated with the hygroscopic nature of mortar adhered to the RCA, i.e.**

   - **Adverse influence on workability of green concrete due to harshness of the mix.**

   - **Adverse influence on structural properties and durability of hardened concrete resulting from porosity of RCA concrete.**

RECYCLED CONCRETE AGGREGATE (RCA)

- **Fine RCA**

  Not suitable for structural concrete; Excessive amount of adhered mortar.

- **Coarse RCA**

  Suitable only for structural concrete requiring modest performance and moderate exposure to the environment, unless some special measures are taken.

Fine RCA

- Fine RCA normally contains calcium hydroxide, lime, (from hydrated cement) and siliceous particles (from the aggregates).

- Fine RCA could be used as fill material, as “live sand”, i.e. possessing very nominal cementitious properties.

- Fine RCA can potentially be used in sand-lime bricks. (Research at Kuwait Institute For Scientific Research). Properties of these bricks can be improved by incorporating either additional lime or GGBS.

PRODUCTION AND USE OF RCA IN THE UK

- **Preferred practice of the UK is rapid disposal of waste from demolished concrete structures.**

- **Systematic processing, grading and testing of RCA is essential for ensuring its acceptability in structural concrete. However, costs of such operations are considered to be too high at present.**

- **Depending on the level of cleaning and screening, some RCA can have impurities such as Gypsum, and excessive proportion of dust and fine aggregate, which place considerable limitations on its use.**

Coarse RCA (BS8500 - 2002 Requirements)

Permissible Impurities

	Maximum allowable mass fractions (%)
Masonry	5
Fines	5
Lightweight Material	0.5
Asphalt	5.0
Foreign Material (e.g. glass)	1.0
Acid-soluble sulfate (SO_3)	1.0

RECYCLED CONCRETE AGGREGATE (RCA)

- **30% of coarse RCA can be used in low performance applications (pavements, etc.) or internal RC members.**
  - Provided that the RCA is chemically inert!
  - Use of RCA requires special attention where the design includes consideration of creep and shrinkage.

- **Careful mix design can resolve problem of porosity of hardened concrete, e.g. using PFA.**

- **Green RCA concrete is harsh but careful mix design (using say, coarse PFA) can help.**
  (Adding water and then extra cement to maintain W/C ratio would jeopardise principles of sustainable construction!)

Beneficial Combination of materials is like successful match-making!

RCA – Not so happy as a material

PFA – Not so happy as a material

RCA + PFA or Binder with PFA

An example of ideal way of using RCA

Buro Happold Case Study for the Wessex Water New Operations Centre, Bath

- **Choice of prestressed concrete railway sleepers to obtain RCA from a clean & local source:**
  - To reduce sorting costs and have a reliable product
  - To save transportation costs.
  (The sleepers were munched to remove prestressing wire and the aggregate was suitably cleaned and graded.)

- **Proportion of coarse aggregate replaced by RCA was limited to 40% to minimize any potential difficulties, e.g.**

  - break in continuity of supply and its effect on programme

  - clients' concern about long-term durability problems, etc.

- **The additional initial capital cost of using RCA on this project represented approximately 5–6% of the cost of the placed concrete.**

Combining Interests of Safety and Sustainability

A Re-cap: Safety and sustainability

Structural Safety

- Achieve Safety of construction for people in and around the building.
- Follow statutory guidance advocating robust construction - redundancies and alternative load path.
- Abide by the legislation - liability for specifying products and designing the assembly.

Sustainable concrete construction

- Reduce wastage of materials using rigorous analysis to avoid overdesign and afford reduction in member sizes,
- Reduce redundancies and frame structures to facilitate reuse of building frames and planned demolition to permit reuse of structural members.
- Use specialist mix design to achieve good performance of structural concrete with optimum cement content and cement replacement with industrial byproducts
- Use Recycled concrete Aggregate (RCA), wherever it is possible, combined with judicious mix design to avoid any potential deficiencies in RCA concrete.

Way-forward towards achieving safety and sustainability of construction

(Following relevant principles of CDM regulations)

- **Agree use of construction materials with clients or their professional advisers, wishing to adopt sustainable construction solutions. (as cited in the case study earlier)**
- **Prepare a document for inclusion in the Health and Safety File, containing an account of the agreed construction materials:**
  - **Potentially residual risks presented by the materials and measures to be taken to eliminate or reduce them during construction (slow strength development for PFA concrete, water curing for GGBS concrete, etc.)**
  - **Limitations, if any, on performance of building during its expected life. (e.g. with the use of RCA.)**

Some compromise suggestions towards achieving safety and sustainability of construction

- **Use ready bagged cements containing PFA and GGBS, as they comply with recognised product standards, in preference to separate on-site addition of industrial byproducts at the concrete mixers.**

- **Use precast concrete products, as far as possible, since factory conditions are often better than worksite practices:**
  - **appropriate storage of materials, especially PFA and GGBS**
  - **avoiding wastage of materials**
  - **good quality control on concreting and member sizes**
  - **potential advantages with standardising of member sizes.**
  - **recycling reject precast products to produce reliable RCA.**

General points to note in the interest of achieving safety and sustainability of construction

- **Use statutory and authoritative guidance.**

- **Follow the latest and authoritative information on alternative and environment- friendly products, available from:**

  - Mineral Products Association
  (MPA, http://www.mineralproducts.org)

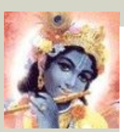
  - WRAP (Waste & Resources Action Programme)
  Guidance for producers, specifiers and purchasers.

- **Keep well informed about research and development but examine carefully the research papers and outputs!**

****A message from a good research output should be**

- **Meaningful**
- **With substance, not shallow**
- **Beneficial**
- **Agreeable**
- **Appropriate**
- **Conclusive**

****A verse from Bhagavadgeeta on a good “message”**



सार्थं तत्थ्यं हितं वाक्यं प्रियं युक्तमनुत्तरं

Points to note when following research outputs on innovative materials

- **A research output should be transparent as regards mix proportions, curing conditions and test procedures.**
- **Laboratory tests should be followed by field trials to bring the research output closer to real life concreting.**
- **Claims made in *industry-sponsored research* projects must be examined carefully. For example:**

"*Uncertainties inherent in any research project often receive inadequate emphasis.*"

"There is always a risk that authors are persuaded towards a greater emphasis on positive findings than is really justified."

- John Le Carre', "The Constant Gardener" (pp 278)

Points to note when following research outputs on innovative materials

- **Concrete technology research may be carried out with commercial sponsorship and it may tend to over-emphasize the merits of concrete made with the new product compared with the PC concrete, e.g.:**
  - **PC concrete test specimens may be made with normal mix design technique.**
  - **Benefits of the commercial product could be enhanced by making the test specimens with advantages of high-tech mix design - such as aggregate packing, reduced water-cement ratio with superplasticizers, etc.**

Examination of research outputs on innovative materials for their clarity and meaningfulness

- **Testing of concrete specimens under laboratory conditions may give substantially better results than works tests on site.**
- **Limitations on usage of materials may not be fully transparent , with regard to the needs of a specific project, e.g.**
  - **PFA concrete: Slow development of strength may not suit the construction.**
  - **GGBS concrete: Requisite curing may not be practical in a general building project.**
- **Composition of RCA mixes may be unclear in respect of cement content, plasticizers, impurities in RCA, etc.**
- **Influence of impurities in RCA on strength and durability may not have been studied.**

Some Gems of Research Reports

RCA concrete had higher strength compared with natural aggregate concrete!

Surprised?

Small print revelation:

The RCA concrete mix had 30% more PC than that for the natural aggregate concrete.

Some Gems of Research Reports

A solution for reducing carbon dioxide in the environment:

Make concrete porous so that it carbonates and absorbs CO_2.

What about corrosion of steel reinforcement and subsequent premature failure?

No problem!

Use stainless steel reinforcement!!

Some Gems of Research Reports

Recycled aggregate can be as good as natural aggregate!!

Microscopy analysis of aggregate recovered from demolition of riverside buildings in Italy showed that the RCA was very similar to the popular gravel aggregate extracted from the river.

A cynical question from an engineer:

Is it any real surprise, Miss? Builders must have taken the aggregate from the river and constructed the concrete buildings with it. You have now found this out the hard way!

SUMMARY OF SUSTAINABILITY SOLUTIONS

- **Reduction in use of concrete using rigorous analysis and improving building life with enhanced durability of concrete.**

- **Energy saving and reduction in CO_2 emission through use of composite binders comprising PFA and GGBS .**

  (Ready-bagged composite cements (combinations of PC with PFA, GGBS and other materials) are more convenient to use, as they comply with accredited product standards.)

- **Enhancement in durability and structural performance of concrete with the use of composite binders, employing higher level of skills in mix design.**

  (Special attention is required in respect of some characteristics of such concretes, e.g. delayed development of strength in PFA concrete and need for water-curing for GGBS concrete.)

<u>SUMMARY OF SUSTAINABILITY SOLUTIONS</u>

- **Minimise wastage of materials on construction sites.**
- **Use RCA that has been produced with quality control procedures, which should lead to consistency of supply, chemical inertness and elimination of impurities.**
- **Fine RCA is not suitable for structural concrete.**
- **Coarse RCA has limited use in structural concrete, on account of <u>hygroscopic nature of the adhered mortar</u>, which requires special measures for achieving some modest performance of concrete.**
- **Exercise engineering judgment in using construction materials to achieve safety and performance of buildings, with an open mind towards potential use of sustainable concrete solutions.**

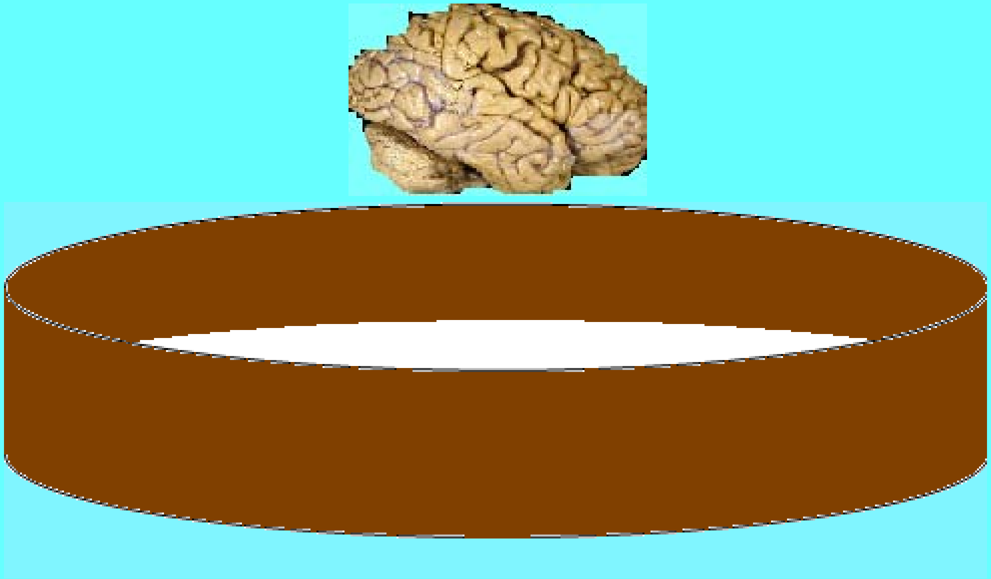
And Finally .....

I wish to leave a thought with you!!!!

An engineer should have an open mind!

But not too open,

To let the brain fall through!!!



Thank you for your kind attention!