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Fly Ash for a 'greener' construction material

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Overview

- Introduction
- Portland cement production & environmental issue
- Fly ash availability, problem and potential
- High volume fly ash concrete
- Fly ash-based geopolymer concrete
- Concluding remarks

What's wrong with cement concrete ?

- **Many concrete structures start to deteriorate after 20 years, especially concrete in severe environment**
- **Cement production releases high amounts of CO_2 to the atmosphere (production of 1 ton of cement releases ~ 1 ton of CO_2). Cement production contributes 7% of the total world CO_2 emissions.**
- **Cement is one of the most energy-intensive materials of construction (after aluminium and steel). Production of 1 ton Portland cement requires ~ 4 GJ energy.**

Regional and World Cement Production to Year 2010

(Source: World Cement Annual Review 1997, in million tonnes)

Region	1995	2000	2010	% (2010)
European Union	168.1	187.9	189.3	9.7
Other Europe	65.8	80.0	94.7	4.9
Former Soviet Union	58.1	80.3	128.2	6.6
North America	92.9	94.9	94.7	4.9
C/S America	89.4	106.6	145.0	7.5
Africa	64.8	74.3	85.5	4.4
Middle East	63.5	75.6	73.4	3.8
East Asia	623.4	732.7	844.3	43.4
S/SE Asia	161.2	219.1	279.2	14.4
Oceania	8.0	10.6	11.8	0.6
World Total	**1396.1**	**1662.1**	**1946.1**	**100.0**

Vision 2030: A vision for the concrete industry **(CI, March 2001)**

Concrete technologists are faced with the challenge of leading future development in a way that protects environmental quality while projecting concrete as a construction material of choice. Public concern will be responsibly addressed regarding climate change resulting from the increased concentration of global warming gases.

We need ‘green’ construction materials

- Durable (Roman concrete is still in good condition after 2000 years)
- Environmentally friendly (use less natural resources, need less energy to produce, minimise CO_2 emissions)
- Satisfy the necessary technical and economical considerations

Approach to lower the environmental impact

- Long Term: to reduce its rate of consumption → produce more durable, resource efficient, more energy efficient product !
- Short Term: practice the industrial ecology, i.e. recycling the waste or by-product
- 3R → Reduce, Reuse, Recycle

How to reduce the use of Cement

- **Partially replace the use of cement in concrete**

  Example: high volume fly ash concrete

- **Develop alternative binder materials**

  Example: fly ash-based Geopolymer concrete

Fly Ash

- Fly ash: ‘the finely divided residue that results from the combustion of ground or powdered coal …’
- In the near future, fly ash production is steadily increasing → power produced by burning coal is remain the cheaper alternative & high quality coal is available abundantly worldwide
- Total yearly production 600 million tons + the amount that has been stockpiled over years
- So far, only disposed in landfills → may cause threat to the environment

Estimated Coal Ash Production and Utilization in 2000

(Source: VM Malhotra, 2004)

Country	Production, Million tonnes	Utilization, Million tonnes
China	>200	>15
India	>80	5%
USA	>60	10%
Russia	60	5
Germany	30	12
UK	10	10

High volume fly ash concrete

- Use 50-60% by mass of fly ash of cementitious materials
- Use low water content, generally less than 130 kg/m^3
- Cement content ~ 200 kg/m^3
- Low water to cementitious ratio

Typical Composition HVFA concrete pavement in India

Particulars	
Portland Cement	225 kg/m^3
Fly Ash	225 kg/m^3
Coarse Aggregate	1283 kg/m^3
Fine Aggregate	547 kg/m^3
Plasticiser	2.25 L/m^3
W/cem	0.32

Source: J.P. Desai, 'Construction and Performance of High Volume Fly Ash Concrete Roads in India', American Concrete Special Publication 221-36, 2004.

The first road pavement in India using *High Volume Fly Ash Concrete* *(Courtesy of JP Desai, Gujarat Ambuja Cement Ltd, India, 2004)*

Typical Performance of HVFA concrete pavement in India

Compressive Strength, MPa	
1-day	9.2
2-days	19.5
7-days	25.5
28-days	40.0
Flexural Strength, MPa	6.8
28-days	
Permeability	563
Rapid Chloride Permeability Test (ASTM C 1202), coulombs	

Source: J.P. Desai, 'Construction and Performance of High Volume Fly Ash Concrete Roads in India', American Concrete Special Publication 221-36, 2004.

Fly ash-based Geopolymer concrete

- Source material containing high Silicon (Si) and Aluminium (Al), for example low calcium fly ash, is reacted with high alkaline liquid (for example: combination of potassium/sodium hydroxide & potassium/sodium silicate solutions).
- Heat (steam curing) may assist as reaction accelerator.

Fly Ash-based Geopolymer Concrete: Process

- Alkaline solutions induce the Si and Al atoms in the source materials (for example, low calcium fly ash) to dissolve
- Gel formation (or polymerisation) assisted by applied heat
- Gel binds the loose coarse aggregate, fine aggregate, and un-reacted source material → **Geopolymer concrete**

Fly Ash-based Geopolymer Concrete: Properties

- Excellent short and long term properties
- Low shrinkage and low creep
- Excellent resistance to sulfate exposure
- Structural members behave as those of Portland cement concrete
- Possible to manufacture using the common technology

Application of Geopolymer Concrete in Structural Elements

Concluding remarks

- One most possible way to make concrete ‘greener’ construction material → to reduce the use of Portland cement.
- Fly ash has potential to substantially replace (partly or totally) the amount of Portland cement needed for making concrete
- HVFA and Geopolymer concrete are among the examples
- Thus, fly ash may play important role to make concrete ‘greener’.

Thank you very much for your attention !