

**SUSTAINABILITY IN CONSTRUCTION**  
**USE OF FLY ASH AS A CEMENT REPLACEMENT**

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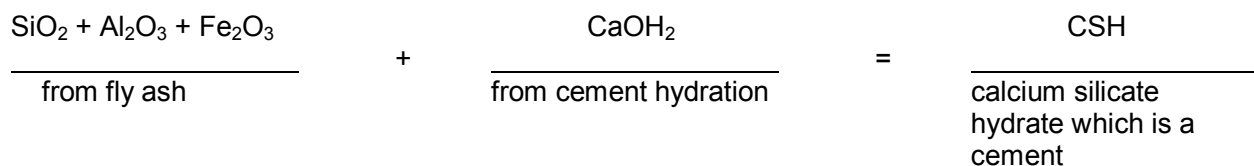
Canada is signatory to the Kyoto Protocol in which there is a commitment on Canada's part to reduce our greenhouse gas emissions to 6% below 1990 levels by 2010. This equates to a 25% reduction below levels currently projected for 2010.

CO<sub>2</sub> is a significant contributor to greenhouse gas. Cement production is a major source of CO<sub>2</sub>, discharging roughly 0.9 Tonnes of CO<sub>2</sub> for each tonne of cement produced. Cement production represents about 20% of Canada's metals and minerals industry production or 14% of total industry production. (The major source of CO<sub>2</sub> is, by far, vehicle emissions). Therefore there is major potential for reduction in industry's contribution through cement reduction - there are big numbers involved.

Given that the atmosphere knows no political boundaries, there is a further potential for Canada's contribution to reduction by providing technology to developing countries so that they might also reduce their CO<sub>2</sub> emissions.

### Use of Fly Ash

Fly ash (FA) is a stack emission from coal-fired thermal plants. It is a by-product which must be used or landfilled. Fly ash can be collected from stacks, size classified in cyclones to roughly the fineness of cement, and used as a supplementary cementing material (SCM) replacing cement. In this use, it forms a cement through this reaction:



There are 5,000,000<sup>T</sup> of FA produced annually in Canada; of this, about 8% is currently used as an SCM. Much of the use is in Western Canada where the properties of available FA are appropriate as a premium SCM.

The world production of FA is currently greater than 400 M tonnes<sup>(1)</sup> and is projected to increase significantly.

### The B.C. Perspective

B.C.'s cement consumption is about 1 M tonnes per year.

B.C. produces no FA but currently uses about 160,000<sup>T</sup> annually sourced from Alberta, (where there are 4 coal-fired plants,) or Centralia, Washington. Alberta currently produces about 2.7M tonnes annually, with about 25% being used in various forms including SCMs. FA has been used as an SCM in B.C. for over 25 years so this is not a new concept. Historically, B.C.'s ready-mix concrete industry has replaced 15 to 18% of cement with FA; but it is also used in cement-based dry-bag products and masonry cement.

<sup>1</sup> Malhotra, "Role of SCMs in Reducing Greenhouse Gas Emissions"; Infrastructure Regeneration, University of Sheffield, July/99, Sheffield Academic Press.

The use of up to 40% cement replacement was pioneered in B.C. about 15 years ago by Levelton and now is commonly used in most mass concrete. Mix designs with 40% replacement are now readily available from most concrete suppliers in the Lower Mainland. The initial use was in large pulp mill foundations, followed by raft foundations for commercial/residential complexes and other forms of mass concrete.

It should be noted below that the challenge here is not to introduce new technology, but to "raise the bar". For example, an increase to a readily achievable 25 to 30% replacement could reduce CO<sub>2</sub> emissions in the order of 80,000<sup>T</sup>.

It is essential that engineers be aware of the basic economies of FA as a SCM. Today, in the Lower Mainland:

cement is approximately \$126/<sup>T</sup>;  
fly ash is approximately \$65/<sup>T</sup>,

so, given that FA will produce about 90% of the strength of the same unit mass of cement, the concept here is not an economic penalty<sup>(2)</sup> but actually a small saving in the cost of the concrete.

The APEGBC has decreed that Engineers should consider sustainability in their designs and materials selections. Their Guidelines for Sustainability require:

- *Take into account the direct and indirect consequences.*
- *Assess reasonable alternative concepts, design and methodologies.*
- *Cooperate with colleagues, clients, employers, decision-makers and the public in the pursuit of sustainability.*

The concept presented here embraces this sustainability directly.

### **The History of Development of FA as an SCM**

In Canada, much of the impetus for SCM development came from work by CANMET (now Natural Resources Canada) who have published extensively on this concept.<sup>(3)(4)</sup>

It is noted above that 15 – 20% FA replacement of cement is now common. However CANMET's work included the development of high-volume fly ash (HVFA) concrete in which up to 65% replacement was possible. The practicality of this HVFA concept will be demonstrated below.

Following are some advantages to the use of FA as an SCM in concrete:

- helps to slow hydration of today's relatively finely ground cements giving improved long-term performance;
- reduces heat in mass sections and therefore reduces the possibility of thermal cracking;
- economy - see cost differential above;

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<sup>2</sup> A typical cubic meter of concrete contains about 270 kg of cementing materials.

<sup>3</sup> Bilodeau, "Field Application of High-Volume Fly Ash Concrete in Vancouver, British Columbia"; Presentation to "Fly Ash in Concrete for Sustainable Development". San Francisco, Sept/99.

<sup>4</sup> Cheung and Foo, "Use of Fly Ash or Slab in Concrete" Proposed PWGSC Guidelines", CANMET/ACI International Symposium on Concrete Technology for Sustainable Development", Vancouver, Apr/99.

- improves resistance to sulphate and other chemicals;
- slightly reduces shrinkage;
- improves workability/pumpability of the fresh concrete;
- controls the disruptive alkali-silica reactions in local aggregates which have borderline reactivity characteristics;
- produces higher long term strength.

It would therefore appear that the use of FA should be more extensive. However, there is one main deterrent to use - FA hydrates more slowly than cement and has correspondingly slower strength gain. In today's concrete construction, where rapid form stripping and turn-around is a driving force, this is a problem which increases with increasing FA replacement dosages.

Other restraints to FA replacement use are:

- Although FA as an SCM is permitted by Canadian Building Codes, it is not specifically mandated there nor in the specifications of most Engineers.
- Concrete strength acceptance in North America has historically been based on a 28 day test. This penalizes the long-term strength gain potential of HVFA mixes. There is little logic today in 28 day acceptance because concrete strength is needed either earlier or later depending on the structural element and construction schedule.
- To get maximum benefit from SCMs, extended curing is required.
- Under most conditions, HVFA mixes set slower and have a richer texture resulting in corresponding delayed finishing and the need for modified finishing techniques.
- The Canadian construction industry bases its cost estimates on risk management concepts and new innovations such as HVFA present risks, albeit small.

So the lower cost of the HVFA concrete itself is balanced by potential increased costs of construction. The hurdle to be overcome is not HVFA technology, because that has been well developed by CANMET and others, but rather the common position of Owners that introduction of HVFA to their project is only acceptable if it has no negative impact on budget or schedule.

Thus it was necessary to move from the concept from laboratory to field demonstration projects as described below.

### **Demonstration of Use of HVFA Concrete**

The process followed was sequentially:

- obtain the support of an Owner and an Architect (now known as "green architects") with a commitment to sustainability;
- identify an appropriate project where the above restraints would be minimum and a willing contractor and ready-mix concrete supplier were in place;
- conduct trial mixes using local materials and with concrete appropriate for that project;

- provide seed funding – this was achieved by a grant from CANMET;
- introduce the concept to the project;
- publicize the results.

The Project chosen was the Liu Centre at UBC. This is a small structure designed, appropriately for purposes here, as a “Centre For the Study of Global Issues”. Exposed concrete was the principal architectural finish. UBC has mandated that sustainability requirements be integrated into the design of their buildings.

In addition to the Owner, the willing participants were:

|                     |   |                                  |
|---------------------|---|----------------------------------|
| Architect           | - | Architectura                     |
| Contractor          | - | Haebler Construction Ltd.        |
| Concrete Supplier   | - | Ocean Construction Supplies Ltd. |
| Materials Engineer  | - | Levelton Engineering Ltd.        |
| Structural Engineer | - | Bush Bohlman + Partners          |

The next step was to conduct laboratory trial mixes; using local ready-mix concrete materials to assess;

- the workability of HVFA concrete;
- the strength performance of the mixes compared to a conventional concrete.

CANMET<sup>(5)</sup> sponsored and directed the trial mix program which was conducted at Levelton’s laboratory. A total of 15 mixes were prepared with variables of entrained air content %, FA replacement and total cementing materials content; comparison was made to a conventional 20% replacement mix.

The HVFA trial mixes performed well with surprisingly low water contents, good workability without the use of high-range water reducing admixtures, and excellent strength performance when compared to the conventional concrete – see Graph 1. The graph shows about 10 MPa at 1 day which was sufficient for the Contractor’s form stripping.

The mixture proportion selected for initial foundation concrete were:

***Proportions, One Cubic Metre***

|                                   |         |
|-----------------------------------|---------|
| Cement                            | 195 kg  |
| Fly Ash                           | 195 kg  |
| Fine Aggregate                    | 760 kg  |
| Coarse Aggregate                  | 1080 kg |
| Water                             | 130 l   |
| Admixtures – water reducing agent |         |

<sup>5</sup> Bilodeau, “Field Application of High-Volume Fly Ash Concrete in Vancouver, British Columbia”; presentation to “Fly Ash in Concrete for Sustainable Development”, San Francisco, Sept/99.

## Properties

|             |   |               |
|-------------|---|---------------|
| Slump       | - | 110 +/- 20 mm |
| Air content | - | 3 ± 1%        |

The HVFA concrete mix was oversized in terms of strength for the foundations, but the intent was to try it in the foundations in the hope that it would prove suitable for the remainder of the structure.

Graph 2 also shows a strength summary for the field tests at the Liu Centre. There is excellent uniformity. The strength exceeded the required 25 MPa by a significant amount but it was durability, as determined by a low water:cementing materials ratio, not strength that controlled the mixture proportioning.

The average strength from Graph 2 is superimposed on Graph 1 and shows a significantly lower and slower strength gain than the trial mixes. The reason for this has not been determined.

Photographs 1 and 2 show the high quality HVFA architectural concrete that the Contractor produced at the Liu Centre.

## Recent Developments

The Liu Centre success, and the publicity that it received, set the stage for further local developments.

A number of Architects/Engineers are now considering “green” concrete structures. Some “seed” research funding has been arranged through the federal departments of Industry, Trade and Commerce, and Natural Resources Canada. The GVRD has formed an industry based Steering Committee to encourage the use of HVFA Concrete as a Lower Mainland air quality improvement initiative.

Some organizations with major building holdings have come forward with “green” construction mandates – B.C. Gas and some school districts are known to the Authors.

One major pre-cast concrete supplier has conducted research into the potential for using HVFA. Due to the controlling need for early strength in pre-cast, this presents unique demands, but initial results are encouraging.

At the project level, HVFA concrete is being considered for a high-rise in downtown Vancouver and for the Rapid Transit Project 2000 Stations.

Leadership is also being provided by various levels of government. Prominent amongst these is PWGSC<sup>6</sup> who have issued this Guideline:

“All concrete shall contain fly ash or ground, granulated blast-furnace slag as partial replacement for cement unless it can be shown that the incorporation of these materials is technically and/or economically not feasible. The amount of cement replacement by fly ash or

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<sup>6</sup> Cheung and Foo, “Use of Fly Ash or Slag in Concrete: Proposed PWGSC Guidelines”, CANMET/ACI International Symposium on Concrete Technology for Sustainable Development”, Vancouver, Apr/99.

ground, granulated blast-furnace slag will depend on the type of application (see attached Guidelines). The concrete so provided shall meet the workability, strength, durability and other performance requirements as specified.”

### **Hurdles to Overcome**

The information presented here, and numerous publications elsewhere, document the viability of HVFA concrete. It remains to implement the technology on a broader base. This will be achieved through these steps:

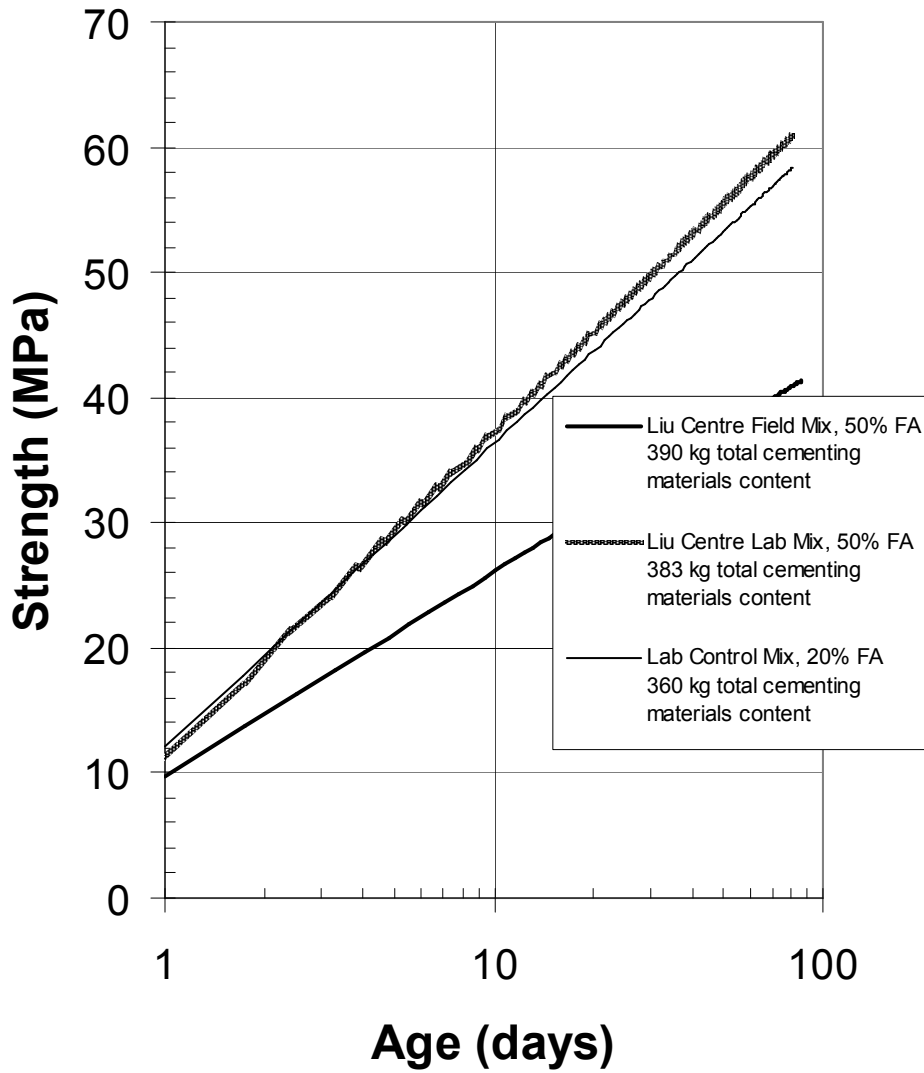
- A commitment by Architects and Engineers to include sustainability in their designs.
- Further successful demonstration projects such as the Liu Centre
- A mandate by building owners to require “green” construction. For these, HVFA concrete is an easily implemented and cost-effective element.

### **Acknowledgement**

The Authors wish to recognize the leadership provided by UBC, Architectura and Bush Bohlman in advancing the HVFA concept at the Liu Centre. They also recognize the co-operation of Ocean, as the concrete supplier, and Haebler’s quality concrete construction.

# HVFA

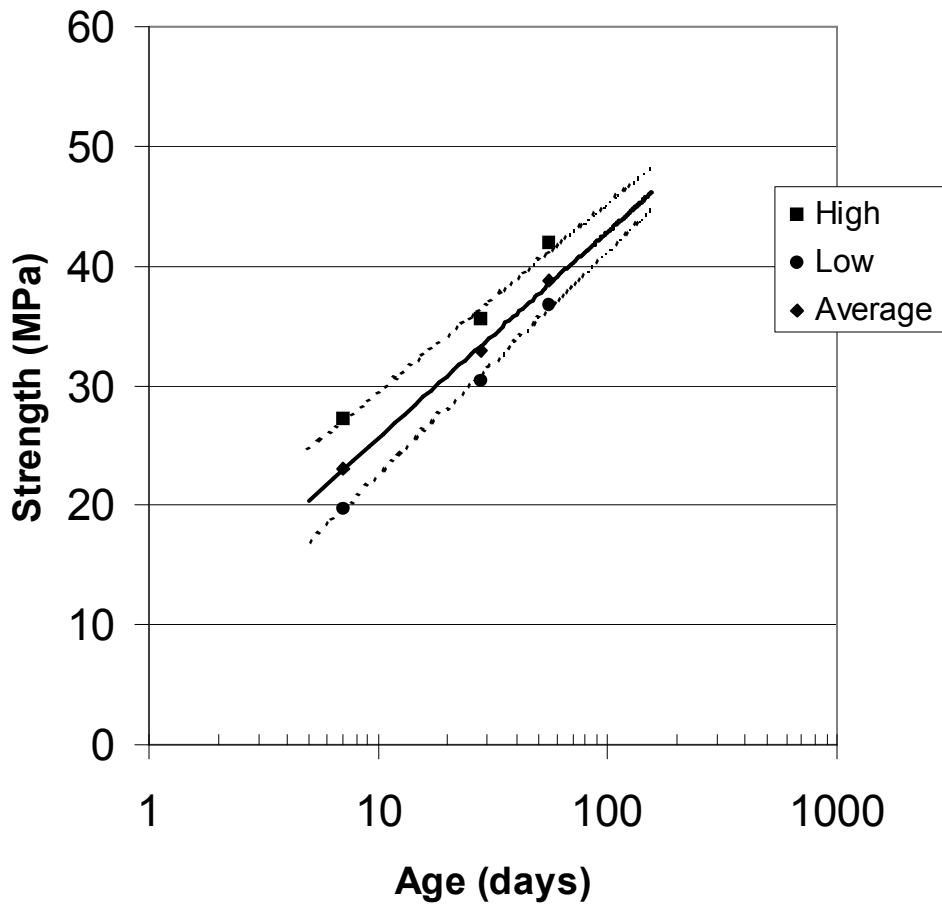
## Strength History Summary



GRAPH 1

# Liu Centre

## Summary of 14 Field Tests



GRAPH 2



Photograph 1 The Liu Centre For the Study of Global Issues. Located in a forested area at the University of British Columbia.



Photograph 2 The HVFA Concrete used in the Liu Centre produced a high quality concrete with a slight “pinkish” tone.

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