Sustainability in Construction:
Using Fly Ash as a Cement Replacement

Phil Seabrook PEng
Kevin Campbell PEng
Levelton Engineering Ltd

Concrete — a material synonymous with strength and longevity — has emerged as the dominant construction material for the infrastructure needs of the 20th century. In addition to being durable, concrete is easily prepared and fabricated from readily available constituents (cement, aggregates and water) and is therefore widely used in all types of structural systems. However, the environmental drawbacks of cement production have come under increased scrutiny as expanding industrialization and urbanization fuel the accelerated growth of infrastructure worldwide.

Cement manufacture is a major source of CO_2, a significant contributor of greenhouse gases: each tonne of cement produced releases about 0.9 tonnes of CO_2 into the environment. Although vehicle emissions are by far the major source of atmospheric CO_2, cement production is another significant contributor, representing about 20% of Canada's metals and minerals industry CO_2 production, or 14% of total industry production. Therefore, a great potential exists to reduce the concrete industry's contributions to greenhouse gases through reductions in cement consumption.

One alternative concrete system that has been applied in BC for over 25 years is the use of fly ash as a supplementary cementing material. Although this is not a new technology, there are numerous opportunities to "raise the bar" by increasing the proportion of fly ash used as a cement replacement. A recent demonstration project, the Liu Centre for the Study of Global Issues at the University of BC, has successfully demonstrated the practical application of high volume fly ash (HVFA) concrete as a sustainable alternative for the construction industry.

Evolution of Fly Ash as an SCM

A stack emission from coal-fired thermal plants, fly ash (FA) is a byproduct that must be used or landfilled. Once collected from stacks and size classified to roughly the fineness of cement, FA can be used as a supplementary cementing material (SCM) to replace cement.

The world production of FA is over 500 M tonnes annually and is projected to increase significantly. Canada produces about 5 M tonnes annually, of which about 10% is currently used as an SCM. Much of this use is in Western Canada, where the properties of available FA are appropriate as a premium SCM.

BC, which produces about 1 M tonnes of cement per year, produces no FA but currently uses about 160,000 tonnes annually sourced from Alberta (where four coal-fired plants produce about 2.7 M tonnes annually, of which about 25% is used in various forms including SCMs) or from Centralia, Washington.

Historically, BC's ready-mix concrete industry has replaced 15 to 18% of cement with FA and it is also used in cement-based dry bag products and masonry cement. It is estimated that an increase to a readily achievable 25 to 30% replacement would reduce CO_2 emissions in the order of 80,000 tonnes annually.

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

Today in the Lower Mainland, the cost of cement is approximately $126 per tonne while FA is approximately $65 per tonne (a typical cubic metre of concrete contains about 270 kg of cementing materials). Given that FA will produce about 90% of the strength of the same unit mass of cement, this represents a small savings in the concrete itself while using an environmentally beneficial alternative.

Fly Ash Advantages and Constraints

In Canada, much of the impetus for SCM development came from work by CANMET (now Natural Resources Canada), which has published extensively on this concept and whose work included the development of up to 65% replacement HVFA concrete. Advantages of using FA as an SCM in concrete are that it:

- 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;
- costs less than cement;
- 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 that have borderline reactivity characteristics; and
- produces higher long-term strength.

Although it would appear that the use of FA should be more extensive, one main deterrent is that FA hydrates more slowly than cement and has correspondingly slower strength gain. This factor, which increases with increasing FA replacement dosages, presents a problem in today's concrete construction where rapid form stripping and turnaround are essential. Other constraints to FA replacement are:

- FA as an SCM is permitted but not specifically mandated by Canadian building codes, nor is it mandatory in most engineering specifications.
- Concrete strength acceptance in North America has historically been based on a 28 day test, which 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 achieve 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 innovations such as HVFA present risks, albeit small.

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

The Liu Centre Project

For the reasons described above, it became necessary to move the HVFA concept from the laboratory to field demonstration projects. The project chosen for this purpose was the University of BC's Liu Centre for the Study of Global Issues, a small structure that uses exposed concrete as the principal architectural finish.

UBC's Liu Centre for the Study of Global Issues opened in September 2000.

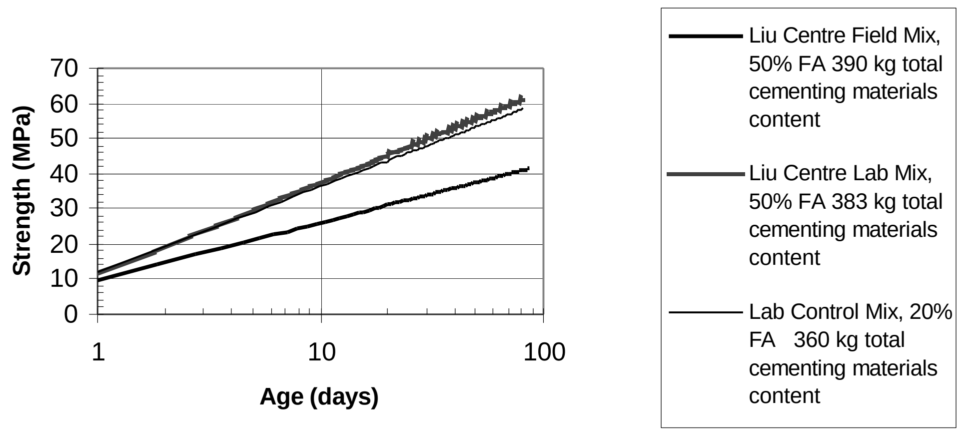
UBC, the owner, has mandated that sustainability be integrated into the design of buildings on campus. The other willing participants on this project were Architectura (architect), Haebler Construction (contractor), Ocean Construction Supplies (concrete supplier), Levelton Engineering (materials engineer) and Bush Bohlman & Partners (structural engineer).

The next step was to conduct laboratory trial mixes using local ready-mix concrete materials to assess the workability of HVFA concrete and the strength performance of the mixes. CANMET sponsored (through a grant from TEAM, a federally funded program and a component of the Climate Change

Action Fund) 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.

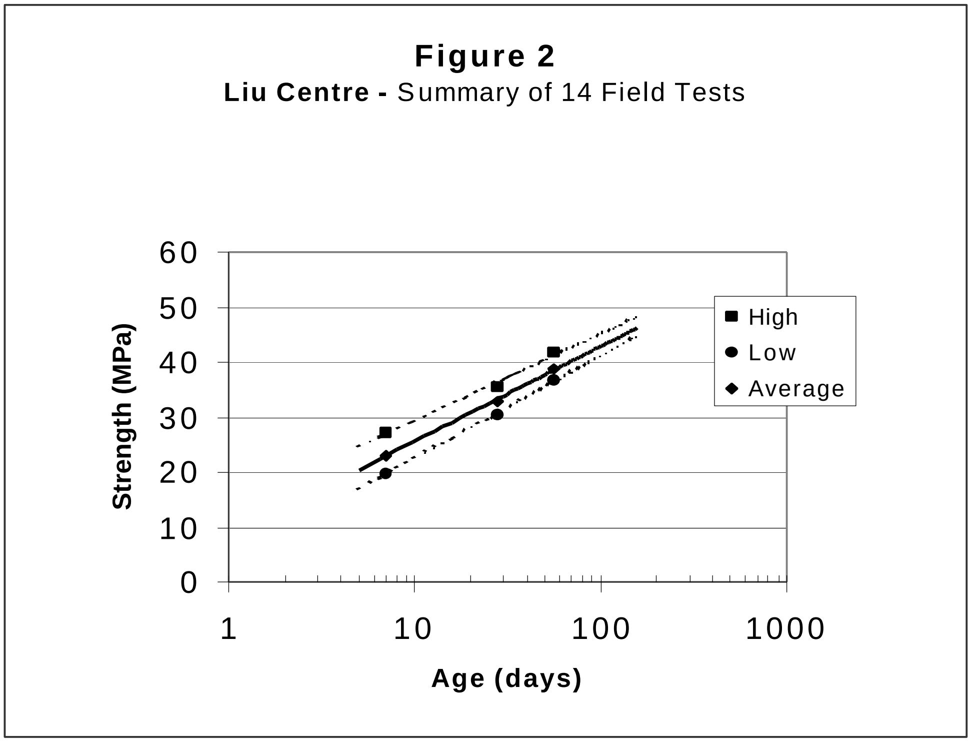
The HVFA trial mixes performed well with surprisingly low water contents, good workability without the use of high-range water reducing admixtures, and excellent strength performance when compared to conventional concrete (see Figure 1). The graph shows about 10 MPa at one day, which was sufficient for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

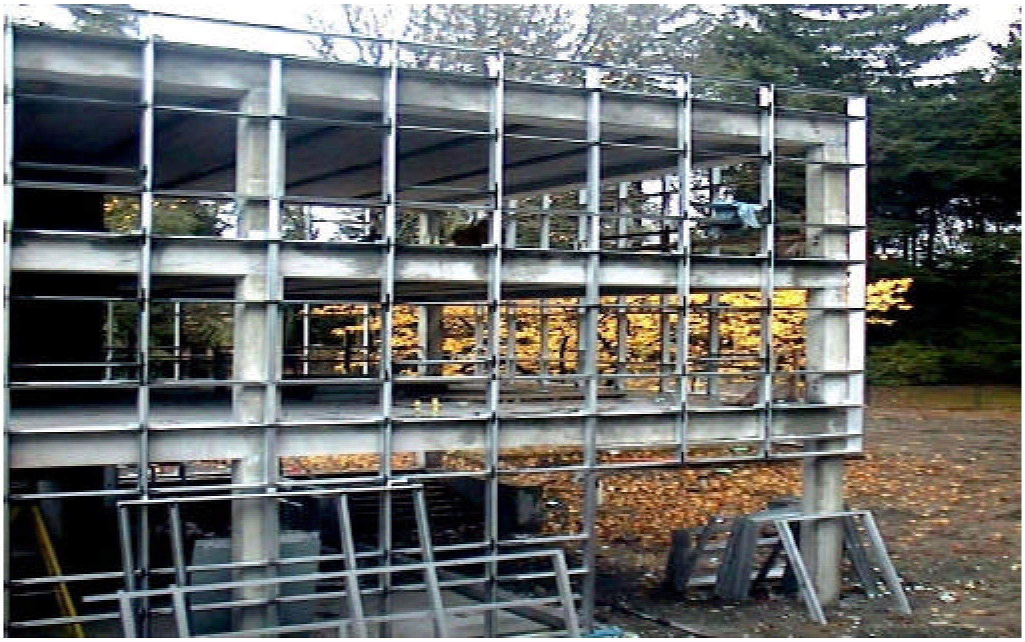
Figure 1
HVFA - Strength History Summary



The 50% replacement mixture selected for initial foundation concrete comprised the following: cement 195 kg, fly ash 195 kg, fine aggregate 760 kg, coarse aggregate 1,080 kg, water 130 L and admixtures (water reducing agent) for one cubic metre. Properties were slump 110 +/- 20 mm and air content 3 $\pm$ 1%. The original intent was to reduce the FA replacement from a 50% mix for the above-grade concrete. However, the mix performed so well that it was maintained for the entire Centre.

Figure 2, a strength summary for the Liu Centre field tests, also shows excellent uniformity. Although strength exceeded the required 25 MPa by a significant amount, it was durability (as determined by a low water to cementing materials ratio), not strength, that controlled the mixture proportioning. (The average strength from Figure 2, which is superimposed on Figure 1, shows a significantly lower and slower strength gain than the trial mixes, the reason for which has yet to be determined.)





The Liu Centre under construction.

Recent Developments

The Liu Centre success and the publicity it received set the stage for further local developments; a number of architects and engineers are now considering “green” concrete structures. The EcoSmart Concrete Project, a partnership between the GVRD, Environment Canada, Industry Canada, CANMET and industry representatives, has encouraged the use of HVFA concrete in the Lower Mainland to help reduce CO_2 emissions associated with concrete. The project is exploring a number of demonstration and technology studies, and there is a strong interest from the Rapid Transit Project Office to use HVFA in the new Sky Train stations.

Some organizations with major building holdings, including BC Gas and some school districts, have developed “green” construction mandates. One major precast concrete supplier has conducted research into the potential for using HVFA. Precast presents unique demands due to the controlling need for early strength; however, initial results are encouraging.

Leadership is also being provided by various levels of government. Prominent among these is Public Works & Government Services Canada, which has issued a guideline stipulating the use of SCM unless it can be shown that the incorporation of these materials is technically and/or economically not feasible.

The Future

Although the viability of HVFA concrete as an easily implemented and cost effective construction element has been well documented, the implementation of this technology on a broader basis remains to be seen. This will require: 1) a commitment by architects and engineers to sustainability in their designs, 2) further successful demonstration projects such as the Liu Centre, and 3) a mandate by building owners to require “green” construction.

As a signatory to the Kyoto Protocol, Canada has committed to reduce its greenhouse gas emissions to 6% below 1990 levels by 2010 — which equates to a 25% reduction below levels currently projected for 2010. Given that the atmosphere knows no political boundaries, perhaps the biggest potential for Canada's contribution to greenhouse gas reduction lies in providing HVFA technology to developing countries to help them reduce their own CO_2 emissions.■

Acknowledgments

The authors recognize the leadership provided by UBC, Architectura and Bush Bohlman in advancing the HVFA concept at the Liu Centre as well as the cooperation of Ocean, as the concrete supplier, and Haebler’s quality concrete construction.

References

Bilodeau, A. “Field Application of High Volume Fly Ash Concrete in Vancouver, BC.” Presentation to Fly Ash in Concrete for Sustainable Development, San Francisco, September 1999.

Cheung, M S and C Foo. “Use of Fly Ash or Slag in Concrete: Proposed PWGSC Guidelines.” CANMET/ACI International Symposium on Concrete Technology for Sustainable Development, Vancouver, BC, April 1999.

Malhotra, M. "Role of SCMs in Reducing Greenhouse Gas Emissions." *Infrastructure Regeneration,* University of Sheffield, Sheffield Academic Press, July 1999.

Phil Seabrook PEng is a Past President of APEGBC and is currently Executive Vice President of Levelton Engineering. He has over 30 years of experience in construction materials consulting and specializes in concrete technology.

Kevin Campbell PEng is a Project Engineer with Levelton Engineering and can be reached at kevinc@levelton.com.

Neil Cumming PEng, President of Levelton Engineering, will present a session on "High Fly Ash Content Concrete" on Friday, October 20 as part of the professional development program at APEGBC's 2000 Annual Conference, to be held October 19-21 in Whistler.

Reprinted from Innovation, journal of the Association of Professional Engineers and Geoscientists of BC, September 2000 issue, with permission.