The EcoSmart™ Concrete Project

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EXECUTIVE SUMMARY

Concrete, a material synonymous with strength and longevity, is a leading and universal material that is used in all types of construction. However, Portland cement, a key constituent of concrete, has a significant environmental impact: the making of every tonne of clinker, the base for Portland cement, produces a similar amount of carbon dioxide (CO_2), a greenhouse gas, as a by-product, which is released into the atmosphere.

The EcoSmart™ Concrete Project's objective is to minimize the greenhouse gas (GHG) signature of concrete by replacing Portland cement with supplementary cementing materials (SCMs), such as fly ash, to the greatest extent possible while maintaining or improving cost, constructability and performance. The Project is an innovative industry-government partnership that aims to increase awareness of the benefits and challenges of EcoSmart concrete through case studies, applied research and communication to the point where the technology becomes common practice. EcoSmart has demonstrated through a number of case studies that replacement levels of 50% are achievable within the parameters of cost, constructability, and performance, particularly when appropriate design methodologies and construction practices are used.

Adoption of this new technology is one of the biggest challenges for EcoSmart. The LEED™ rating system *potentially* offers an incentive to specifiers to increase the use of SCMs in development projects. However, in order for the LEED™ system to realize this potential, it must first recognize the full environmental benefit of SCMs within its credit system.

ABOUT ECOSMART

Concrete is second only to water as the most consumed substance on earth, and the worldwide demand for concrete continues to increase dramatically. However, the production of Portland cement, an essential constituent of concrete, leads to the release of significant amounts of CO_2, a greenhouse gas (GHG). The expected growth in the use of concrete needs to be made compatible with environmental protection and sustainability.

It has been widely demonstrated in the lab and in the field that reclaimed industrial by-products such as fly ash, ground granulated blast-furnace slag, and silica fume, commonly called "supplementary cementing materials" (SCMs) can reduce the amount of cement needed to make concrete, and hence, reduce its "CO_2 signature". SCMs in concrete not only reduce GHG emissions but also improve long-term strength and durability characteristics, and typically are more economical than ordinary Portland cement (OPC) concrete.

The EcoSmart Concrete Project aims to reduce CO_2 emissions by encouraging the use of high volume of SCMs in concrete. The objective is to minimize the GHG signature of concrete by maximizing the replacement of Portland cement in the concrete mix with SCM within the parameters of cost, performance, and constructability. The expected outcome is to develop EcoSmart concrete to the point where it can be successfully deployed in the building industry—in Canada and worldwide. To this end, EcoSmart has identified and is resolving a number of technical, environmental, and economic issues related to SCMs through case studies.

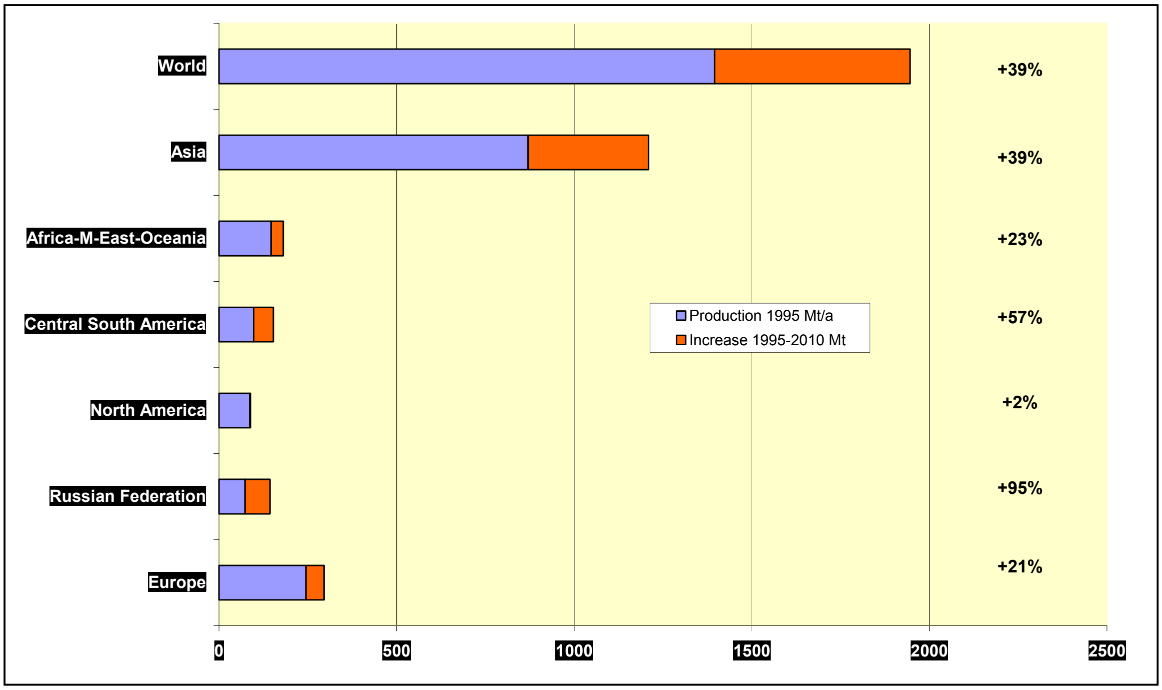
Since 1999, EcoSmart has seized the opportunity to work on numerous case studies demonstrating the replacement of significant amounts of Portland cement – up to 50% - in the concrete mix with SCMs without affecting the performance, cost or constructability.

GHG EMISSIONS RATIONALE

Cement manufacturing is a significant source of greenhouse gas emissions, accounting for about 7% to 8% of CO_2 globally (Mehta, 1998), and slightly less in North America (Neitzert et al., 1999). From 1995 to 2010, the production of cement will have increased by about 40%, releasing an additional 600 million tonnes of CO_2 per year into the atmosphere – an amount greater than the total amount of CO_2 emitted by all of Canada today. The majority of this increase will occur in Asia, as shown in Figure 1, due the enormous demand for concrete in these rapidly developing countries.

Although the cement industry has made some progress in reducing CO_2 emissions through improvements in process and efficiency – especially outside North America- affordable options for further reductions are limited because CO_2 production is an unavoidable consequence of the manufacturing process (i.e., calcination of limestone into lime). The environmental benefits of emission reduction are significant. The production of every tonne of Portland cement contributes about 1 tonne (1.1 ton) of CO_2 into the atmosphere (Malhotra, 1999). Replacing one tonne of cement with one tonne of fly ash, for example, offsets industrial CO_2 emissions by approximately one tonne (Venta, 1999).

Through the reduction of cement use in building construction in Canada, substantial CO_2 emission reductions, up to 3.6 million tonnes by the year 2010, could be achieved, contributing substantially to Canada's efforts to reduce greenhouse gas emissions under the Kyoto protocol.



(based on data from Malhotra, 1999).

Figure 1 World cement production and increase to year 2010.

CASE STUDIES

Case studies are a critical component of the EcoSmart Project. They encourage learning by doing and facilitate an interactive innovation process by allowing experimentation and communication with fellow practitioners. EcoSmart concrete is being used in a wide range of construction projects across Canada, from residential developments to Universities, to rapid transit stations. Because the EcoSmart Project is based in Vancouver, B.C., Canada, the majority of the projects are in the Greater Vancouver area.

Various project partners carried out the case study projects. To identify a project as a case study, the EcoSmart Steering Committee contacted or was contacted by a potential project partner, and discussed the implementation of EcoSmart concrete in the given project. The project team, including the members of the EcoSmart Steering Committee, worked together:

- to learn about using EcoSmart concrete in general and on the given project in particular;
- to implement EcoSmart concrete in the design when the project timeline permitted it, or to adjust the concrete specifications when construction was already underway to reduce the amount of Portland cement and incorporate a larger amount of SCM; and
- to work with the contractor and construction crew on the site to ensure the implementation was successful.

Some of EcoSmart's recent case studies include:

Figure 1 The Lo House under construction.

The Lo House: A unique, architecturally designed structure that utilizes exposed concrete, glass, and a zinc clad, plywood faced, stressed skin roof, as its main design elements. The design for this beautiful home featured EcoSmart concrete primarily because of its aesthetic appeal. EcoSmart concrete was used successfully in both horizontal and vertical applications.

Figure 2 The Technology Enterprise Facility at the University of British Columbia

Technology Enterprise Facility: The University of British Columbia is a leader in sustainable development. One of the newest buildings on campus is the Technology Enterprise Facility (TEF) III, a six-storey facility with laboratories, office space, and two levels of underground parking. The EcoSmart Project identified this project for a case study as it addresses the challenges of lower early strengths and curing of EcoSmart concrete.

Figure 3 Whistler Conference Centre

Whistler Conference Centre: This nine million dollar project incorporates practices and technologies, including EcoSmart concrete, which will lead to the reduced environmental impact of the building during construction and operation. The project is registered with the LEED™ Green Building Rating System and is pursuing gold status. The conference centre will reopen in August 2003.

Figure 4 Artist's rendition of the Computer Science Building, York University

York University Computer Science Building: York University's commitment to environmental sustainability led to the development of the first "green" university building in Ontario. Building materials were carefully selected for low embodied energy and reduced construction waste, which included the specification of high volume fly ash for the majority of the building's concrete elements. Incorporating fly ash in the concrete mix produced a high quality, warm color, smoother and denser finish concrete satisfying the architect's aesthetic expectations at no extra cost. The use of EcoSmart concrete provided a higher strength concrete, excellent workability and did not disrupt the project schedule.

Figure 5 Liu Centre for the Study of Global Issues, University of British Columbia

Liu Centre for the Study of Global Issues: The Liu Centre is a 1,750 m^2 multi-purpose facility containing lecture halls, meeting rooms, classrooms, and common areas. It serves as an important international policy research centre and teaching facility, focusing on the new generation of global issues challenging societies and governments worldwide. Construction followed a sustainable design plan using exposed concrete as the primary architectural finish. The use of pre-cast planks helped minimize the amount of concrete required. With up to 50% (total average 35%) of the cement replaced by fly ash, the Liu Centre became the first building in British Columbia to use EcoSmart concrete throughout.

In carrying out the case studies, it became apparent that each construction sector has its own main interest in the properties of EcoSmart concrete. Based on anecdotal information from members of industry as well as on the results documented in case study reports (all of which are found on the www.ecosmar.ca website), several observations can be made. In general, some building professionals chose EcoSmart concrete for its environmental benefits in order to be able to satisfy the "green" objectives of projects. Otherwise, architects may choose EcoSmart concrete for its smoother, creamier texture, beige tint in the colour, and consistency in appearance. The main concern for these professionals is the look and finish of the concrete (i.e., less patching of "bugholes"), especially of architectural concrete. Contractors prefer to use EcoSmart concrete due to its ease in placing and workability. The main concern of this group is the ability to finish the concrete in a timely manner. EcoSmart concrete is chosen by engineers mainly for its increased strength and durability, and decreased cost. These professionals are mainly concerned with the early strength development and resistance to deterioration of the concrete. Early strength development is also an issue for contractors since this concrete property determines when formwork can be removed, which affects the schedule – and the bottom line for contractors. The increased workability also has substantial benefits in pre-cast elements, in that sharper and more distinct corners and edges are achievable, as well as better surface appearance.

DESIGN, CONSTRUCTION AND INNOVATION

As the case studies have demonstrated, to fully benefit from the unique properties of EcoSmart concrete, it is necessary to develop methodologies that take these properties into account as soon as possible at the design stage. It is equally necessary to implement construction practices that are appropriate for this type of concrete. Both of these could follow current industry "best practices", or preferably, truly innovative approaches could be tried.

EcoSmart concrete, placed, finished and cured under proper construction practices, is stronger in the long-term, more durable, and more resistant to deterioration (such as aggregate sulphate reactivity, chloride penetration, etc.) than ordinary Portland cement (OPC) concrete. But it also has a slower setting time, which could be a major inconvenience. Accordingly, structural designers (both engineers and architects) can try innovative design approaches to design structures that are expected to last longer, have stronger and therefore thinner elements, and require less maintenance / rehabilitation work. EcoSmart concrete together with good design and good construction practice can significantly extend the life of a structure to, for example, a 100-year specification instead of the usual 25-30 years. Extending the time before a structure needs to be rebuilt or repaired provides significant saving cuts in future expenses, resources, energy consumption, and GHG emissions.

The main shortcomings of EcoSmart concrete are slower strength gain, longer setting time, greater sensitivity to cold temperature, and the need to be properly cured. This is another place where the designer and specifier may play a very important role in the quality of the final structure.

EcoSmart is preparing a study on the greenhouse gas emission "signature" of various high-rise building systems and how early design and EcoSmart concrete could reduce this GHG impact. Another study, done by Fast and Epp in 2000 looked at optimizing the amount of fly ash for each type of structural element in a structure, in light of constructability issues and costs.

Obviously, good construction practices are always a key factor in quality concrete. This is even more important with EcoSmart concrete. Here, the warning is: *"fly ash makes good concrete better, but bad concrete worse."* Sufficient moist curing, for at least 7 days, for example, is crucial for developing the properties of EcoSmart concrete and ensuring longevity. EcoSmart concrete typically has a lower water-to-cement ratio than OPC concrete, reducing the bleed water that the finishing crews like so much. Some finishers innovated around this difficulty by adapting a water mister to their tools. Innovative scheduling can also address the longer setting time, for instance, by pouring late in the afternoon and finishing the next day.

SUPPLEMENTARY CEMENTING MATERIALS

Since fly ash is the most readily available and commonly used SCM in Western Canada, where EcoSmart is based, the Project has mainly focused on this material. However, the project is also working with and has investigated other SCMs including slag, silica fume, metakaolin, and natural pozzolans. Of these, fly ash and slag are most readily used in Canada, with silica fume in specialty concretes.

- *Fly ash* is a by-product from coal-fired power plants. Using fly ash in concrete generally decreases permeability, improves sulphate resistance and other durability aspects of concrete, and allows lower water content in the mixture. Fly ash also improves the plasticity and workability of fresh concrete, and produces a warmer coloured concrete.

- Consisting of silicates, aluminosilicates of calcium, and other compounds, blast-furnace slag is a by-product of molten iron production in a blast furnace. The slag is then rapidly quenched to assure a high percentage of glass, and ground to produce a fine powder for use as a SCM. The *ground granulated blast furnace slag* (GGBFS) acts similarly to cement since it possesses hydraulic properties. GGBFS is often used in concrete requiring maximum durability, higher strength, fire-resistance, better insulation, and lighter weight.

- *Metakaolin* is produced by calcination of kaolin (clay mineral) at 650-800°C. Kaolin is usually mined, but EcoSmart found that it could be produced from the by-products of oil sands operations, which can be made into metakaolin-like material, referred to as calcined mature fine tailings. Metakaolin is a highly reactive pozzolan with smaller than cement particles and a high specific surface, which when used as an SCM in concrete, makes it denser and more impervious, and increases its durability (i.e., resistance to chemical attacks, sulphate, ASR expansion, and freezing and thawing). Metakaolin also enhances several mechanical properties (i.e. early-age compressive strength, and flexural strength).

- Pozzolan is a siliceous or aluminosiliceous material that in finely divided form and in the presence of moisture chemically reacts with the calcium hydroxide that is released by the hydration of Portland cement to form compounds possessing cementitious properties. *Natural pozzolans* include diatomaceous earth, kaolin, shale, rice husk ash, volcanic ash, and pumice, all of which are natural materials that may also be calcined and/or processed.

- *Silica fume* is a residue from the manufacturing of silicon and ferrosilicon metals, with particles that have high surface area and are 100 times smaller than cement. Using silica fume increases the density, minimizes permeability, and improves the resistance to freezing and thawing damage of concrete. Silica fume is mainly used to produce special concretes such as high-strength concretes, high-performance concretes, or wash-out resistant concretes.

These materials can be used together, forming so-called ternary or quaternary blends.

Despite the promise of these SCMs, there remain several policy, technical, and economic barriers to their adoption. Technical barriers include longer setting time and slower strength development of concrete containing SCMs (especially fly ash and slag) under cold weather conditions, the quality or percentage of carbon in the fly ash, finishing flatworks, and concern about durability problems for concrete exposed to freezing and thawing cycles and de-icing salts. Economic barriers relate primarily to the cost of transporting and storing the SCMs. As well, the lack of guidelines and standard specifications can present major barriers to the use of SCMs in concrete.

LEED™ CRITERIA

Despite these barriers, there are several incentives for using SCMs in concrete, one of which is that using EcoSmart concrete on a project considerably reduces the GHG signature of the building. Unfortunately, this fact is not well recognized by the current LEED™ version (2.1).

Normally, the use of SCMs should get Materials and Resources (MR) credits 4.1 and 4.2 for recycled content, MR credits 5.1 and 5.2 for regional materials, and presently can get an Innovation and Design Process (ID) credit. However, the contributions to MR credits are negligible (see below). Although the ID credit may recognize the value of using high volumes of SCM in concrete, a system where credits are allocated in proportion to the GHG saving of a particular material would be better related to its environmental benefit.

A material like EcoSmart concrete rates poorly with the current rating system because credits are allocated according to the value of recycled materials, and not their environmental impact. Fly ash is a low cost industrial by-product with very low embedded energy, CO_2 emission, and environmental impact. On the other hand, Portland cement is a high cost, manufactured product, bearing significant environmental impact.

Every tonne of fly ash that replaces a similar amount of Portland cement can save about one tonne of CO_2, the mining and transportation of two tonnes of raw material, and the consumption of 4 GJ of energy (Reid Crowther & Partners, 1998). But the low cost of fly ash does not weigh much in the equation for calculating credits for recycled content. Indeed, if 40% of Portland cement in a building is replaced by fly ash, MR 4.1 would contribute only 0.25% recycled value towards the required 5% for getting one LEED™ point. However, if that building uses 10,000 m^3 of concrete, the fly ash will save 1,400 tonnes of CO_2 – roughly equivalent to 400 cars driving 14,000 km each, 2,800 tonnes of raw materials, and 5,600 GJ of energy (approximately equal to the total annual operating energy of the building if it is designed efficiently) (Personal Communication, Dr. Rosie Hyde, Keen Engineering Ltd., July 25, 2003).

It is recommended that the methodology of monetary value-based credits in LEED™ be re-evaluated for the next version, and that credits be awarded based on the actual environmental benefit of a material rather than its cost.

Currently the GHG benefit of using SCMs in concrete is rewarded by an ID credit if the CO_2 emissions are reduced by 40% from the standard baseline concrete mixtures, according to a credit interpretation ruling made on January 23, 2003. EcoSmart recommends that the criteria for rewarding this environmental benefit be refined in the next version of LEED™. Specifically, a credit for GHG reductions should be created that is independent of the innovation credit, and which rewards the level of GHG reductions achieved by selecting materials accordingly, for example, 10% reduction = 1 point, 20% reduction = 2 points, etc., similar to the aggregated point system for Energy and Atmosphere credit 1 for optimizing energy performance. Under the current LEED™ criteria, reducing GHG emissions by 30% by replacing Portland cement with SCM is not rewarded at all, despite the fact that this is a significant environmental benefit.

It is recommended that the USGBC team consider these concerns and amend the relevant criteria in the LEED™ rating system accordingly.

CONCLUSION

The EcoSmart Project has made considerable progress since its inception in 1999. In British Columbia, in partnership with fly ash marketers and the ready-mixed concrete industry, the EcoSmart Project helped increase the industry standard from 15% fly ash replacement in 1999 to 25% in 2002, with a corresponding reduction in the GHG signature of concrete. EcoSmart case studies have demonstrated that replacement levels of 50% are achievable within the parameters of cost, constructability, and performance. Specifying the use of EcoSmart concrete brings many benefits, including a significant reduction of the CO_2 and other air contaminants emitted during the cement production, and an improvement of the quality and durability of the concrete, allowing for an increase in the service life specification. However, in order for the Project's success to continue, there are some barriers to be overcome. The LEED™ rating system can make a difference, particularly if it is revised to more adequately recognize the environmental benefits of EcoSmart concrete.

REFERENCES

Bouzoubaa, Nabil and Benoit Fournier. 2003. *Current Situations of SCMs in Canada.* Available at http://www.ecosmart.ca/resources/technical/technical_pdf/2003/2003-4-TR-SCMs-In-Canada.pdf.

Fast and Epp Structural Engineers. November 2000. *High Volume Fly ash Concrete Usage for High Rise Construction.* Available at http://www.ecosmart.ca/use/case/other_pdf/HVFAHiRiseReport.pdf.

Hyde, Rosie, Ph.D., Keen Engineering Inc., Vancouver, Canada. (604) 986-5336

INNOVATION & DESIGN PROCESS: Innovation in Design: Specific Title (IDc11) – Project Manager's Ruling, 1/23/2003.

Malhotra, V.M. May 1999. *Making Concrete "Greener" with Fly Ash.* Concrete International, Vol. 21, no. 5, pp. 61-66.

Mehta, P.K. 1998. *Role of Pozzolanic & Cementitious By-Products in Sustainable Development of the Concrete Industry.* Sixth CANMET/ACI/JCI Conference: Fly Ash, Silica Fume, Slag & Natural Pozzolans in Concrete.

Neitzert, F., K. Olsen and P. Collas. 1999. *Canada's Greenhouse Gas Inventory: 1997 Emissions and Removals with Trends*. Environment Canada.

Reid Crowther & Partners Ltd., July 1998. *Environmental Review Tilbury Cement Plant Pollution Prevention Plan, Volume 1.*

Venta, G.J. April 1999. *Potential for Reduction of CO_2 Emissions in Canada through Greater Use of Fly Ash in Concrete.* CANMET/ACI International Symposium on Concrete Technology for Sustainable Development, Vancouver, BC.