ECOSMART™ CONCRETE

A Concrete Contribution to the Environment

THE ECOSMART™ CONCRETE PROJECT

Results from the Case Studies

JULY, 2001

Greater Vancouver Regional District

Canada

ACKNOWLEDGEMENTS

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CASE STUDIES LIST

Project	Client / Developer	Architect	Structural Engineer	Materials Engineer	Concrete Supplier	Contractor	Type
Ardencraig	Chesterfield properties	Allan Diamond	Jeff Allester	n/a	Rempel Bros, Rolf Susi and Son Concrete	Timberland Homes	Townhouse renovation
Liu Centre	UBC Facility	Architectura, Erickson	Bush, Bohlman	Levelton	Ocean construction, Con-Force	Haebler	Learning centre
Cranberry Commons	Cranberry Commons	Birmingham & Wood	Chui, Sandys, Wunsch	Levelton	Kask, Lafarge, Gastaldo	Artian	Residential
NVIT - Merritt	University College of the Cariboo	Busby + Associates	Equilibrium	AMEC	Tilbury (Cement), Lafarge (Flyash)	Swagger Construction	Learning centre
Brentwood Skytrain Station	RTPO	Busby + Associates	Fast & Epp	Levelton	Kask, Lafarge	Dominion	Infrastructure
Gilmore Skytrain Station	RTPO	Busby + Associates	Fast & Epp	Levelton	Kask, Lafarge	Dominion	Infrastructure
FineLine Building	FineLine	Busby + Associates	RJC	?	Ocean construction	Ledcor	High Rise condo
York University	York University	Busby, Architecture Alliance	Yolles Partners	Davroc	Italcementi (cement), Lafarge (Flyash only)	Ellis-Don	Learning centre
2nd Ave	Hillside Developments	Erickson, Milkovich	Fast & Epp	AMEC	Ocean construction	Haebler	Condo
BC Gas	BC Gas	MCM	RJC	Levelton	Ocean construction	Dominion	Office
Intergrind	n/a	n/a	n/a	CanMet	Tilbury cement	n/a	n/a
Precast	RTPO	n/a	Fast & Epp	n/a	Tilbury cement	n/a	n/a

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1.0 INTRODUCTION

This report was commissioned by the EcoSmart™ Concrete Project Steering Committee as part of their EcoSmart™ Concrete Project. The EcoSmart™ Concrete Project is a government-industry partnership aimed at reducing CO_2 emissions by encouraging the use of high-volume supplementary cementing materials in concrete. The project goals were: To explore the potential of EcoSmart™ concrete as a cost-effective and practical solution to an environmental challenge and to increase awareness of the benefits and challenges of EcoSmart™ concrete, through case studies, technology innovation, and communication. This report reviews nine case studies throughout the GVRD employing the use of EcoSmart™ concrete. This report supplements the technical data and findings supplied by the individual case studies and verifies the results of numerous technical literature and industry surveys regarding the use of high volume fly ash in the replacement of cement in concrete.

Ecosmart™ Principle - To reduce the environmental impact of a product service or project in such a way that performance and profitability are maintained or enhanced.

Ecosmart™ Concrete Principle - To reduce greenhouse gas (GHG) emissions by replacing Portland cement in concrete with supplementary cementing materials to the greatest extent possible within the parameters or performance, constructability and profitability.

GHG Emission Reduction - Reductions in GHG emissions from a status quo baseline and/or avoided increases in GHG emissions that would have otherwise occurred from an increased demand for concrete.

1.1 THE ISSUE

Cement manufacturing operations are responsible for approximately 8% of the global emissions of CO_2, a significant greenhouse gas. Within the GVRD, cement plants produce approximately 2 million tonnes of CO_2 each year. This represents 12% of the total CO_2 emissions or 50% of the industry CO_2 emissions within the GVRD. CO_2 emissions are a direct function of cement production volume: for every tonne of cement manufactured, roughly one tonne of CO_2 is generated.

Concrete is second only to water as the most consumed substance on earth, and the worldwide demand for concrete continues to increase dramatically. The most promising way to avoid a corresponding increase in global CO_2 emissions is to find ways to replace increasing proportions of the cement in the concrete mix with substitute materials - supplementary cementitious materials or SCMs - which are cost-effective and perform equally well.

1.2 THE OPPORTUNITY

The project began with the idea that EcoSmart™ concrete - concrete produced by replacing roughly half of the Portland cement used in conventional concrete with a supplementary cementing material (or pozzolan) such as the coal fly ash - might be a technically and economically viable solution to a significant environmental problem: the CO_2 generated in the cement manufacturing process.

The technology to create high-volume fly ash concrete was pioneered at CANMET (Canada Centre for Mineral and Energy Technology) over 15 years ago. CANMET has demonstrated that under laboratory conditions, the performance of concrete with up to 60% fly ash can be equal or superior to conventional concrete in almost every aspect.

The first field application of high-volume fly ash concrete was carried out in 1987 in the casting of a concrete block (9mx7mx3m in size) at the David Florida Research Centre near Ottawa. This block, cast indoors in permanent steel forms, is being utilized in vibration testing of components for communication satellites, and was required to have as few microcracks as possible. The values of 91-day strength and modulus of elasticity of this concrete were 46.1 Mpa and 38.8 Gpa, respectively. Another field application took place in Halifax in 1988 in the construction of a 600-car indoor parking garage for the Park Lane Hotel/Office Complex. High-volume fly ash concrete was also used in the construction of drilled caisson piles for a 22-storey office tower in Purdy's Wharf, Halifax. Polypropylene fibre-reinforced high-volume fly ash concrete has been used to stabilize rock outcrop slopes on a highway in Nova Scotia. In 1991-92, the above type of concrete was used to cap rock outcrops and mine tailing sites in British Columbia.

Fly ash has a long history of use in concrete construction in B.C.; however it is normally used to partially replace Portland cement at relatively modest levels of between 15 to 25% (by mass). Use of higher replacement levels (e.g. > 40%) has generally been restricted to special applications such as large monolithic pours requiring temperature control. In addition to the CANMET projects mentioned above, the case studies demonstrated here show that levels between 40 to 60% fly ash can be used in normal structural concrete.

Until recently, the use of fly ash in concrete has been driven primarily by economic and performance considerations. Since fly ash has largely been considered a waste product (90% ends up in landfills) it can be significantly cheaper than cement, lowering the overall cost of the concrete. So if using more fly ash in concrete can also help reduce greenhouse gas emissions and alleviate a fly ash disposal problem, we may achieve a true "win-win" situation.

1.3 THE CHALLENGE

EcoSmart™ concrete is currently not the industry standard. The characteristics and potential benefits of fly ash (or other supplementary cementitious materials) in concrete are not known widely either in the construction industry or among the general public. There is an understandable resistance to adopting a technology many still consider unproven in the field, with the perceived risk of delays or cost overruns. At present, materials standards and building codes do not prohibit the use of fly ash in concrete, but current specification practices effectively discourage it.

There are some practical considerations to be overcome in working with EcoSmart™ concrete at the construction site. The contractors who place and finish the concrete need to become familiar with the somewhat different setting characteristics. The single biggest challenge is the slower initial setting time of higher volume fly ash concrete, which can translate into extra hours before forms can be stripped or surfaces finished, especially in cold weather. In a competitive industry driven by demands for shorter and shorter cycle times, this is often unacceptable. A combination of training, concrete mix optimization, and design innovation is required to overcome these challenges.

1.4 THE PROJECT

The EcoSmart™ Concrete Project was conceived to examine and if possible resolve the major obstacles that are limiting the use of high volume supplementary cementing materials in concrete construction. The following approaches were established:

- **CASE STUDIES** - Facilitating and tracking of EcoSmart™ concrete use in several actual construction projects. The individual case studies document problems encountered and how they were dealt with, as well as overall costs and benefits that resulted from the use of EcoSmart™ concrete.

- **TECHNOLOGY INNOVATION** - Examining the feasibility of several promising technology innovations.

2.0 CASE STUDIES HIGHLIGHTS

EcoSmart ™ Concrete is being used in a wide range of construction projects across Greater Vancouver, from residential developments to rapid transit stations. The next section highlights the case studies goals and results. The findings are intended to - provide a forum for information about the benefits, costs, obstacles and potential solutions to challenges. Refer to individual reports at http://ecosmart.ca for more detailed information.

2.1 RESIDENTIAL

2.1.1 CRANBERRY COMMONS

FIGURE2.1.1
CRANBERRY COMMONS

Cranberry Commons is a 22-unit sustainable co-housing development in Burnaby. EcoSmart™ concrete was to be used in most of the cast-in-place concrete applications. A goal of 50% reduction in cement usage was set which would result in approximately 98 tonnes reduction in CO_2 emissions.

- **Strength** - Strengths above 30MPa were achieved within 28 days, allowing the crew to maintain stripping times for walls, footings and columns. The hardened concrete achieved a 90-day strength of 52 MPa - 70% higher than required by the structural engineering specifications.

- **Workability** - Fresh concrete was found to be easier to pump but more difficult to place, which the workers attributed to the low water content in the concrete making the mix very sticky and therefore difficult to place.

- **Finishing/Setting** - Finishing delays were also encountered from unexpected slow setting time due to the cooler outside temperature encountered during the pour.

- **Economics** - EcoSmart™ concrete increased the project cost due to added accelerants needed to shorten setting times. Added labour for finishing would be charged by the contractor for future high volume fly ash mixtures poured during colder temperatures.

Overall, the goal of 50% cement reduction was not achieved. Although the design mixes included 50% fly ash, the total cementitious material (cement + fly ash) was increased in anticipation of fly ash's effect on slowing the setting time. The cement content was reduced by 32%, which translates into 63 tonnes of CO2 emissions avoided for the project.


FIGURE2.1.2
ARDENCRAIG

2.1.2 ARDENCRAIG

Ardencraig was an existing single family residence converted into four luxurious townhouse units. This project was developed with environmental priorities in mind and targeted the use of 50% less cement in all the concrete applications: footings, foundations, exterior decks and porches, stairs, retaining walls and concrete topping for the radiant floor heating system.

- **Strength** - Strengths above the specified 25MPa were achieved within 28 days.
- **Setting Time** - Despite a slower setting time, there was no negative impact on schedule. The main wood frame house had been raised to allow for the framing of the basement level to be completed. After one week the concrete had cured to sufficient strength for the original house structure to be set down on the hardened concrete foundations.
- **Economics** - EcoSmart™ concrete costed 5% more than the standard concrete mixture. The labour cost charged to the project was no higher than normal. However, the contractor indicated that in hindsight, additional costs should have been charged to compensate for the slightly more difficult finishing of the concrete.

In summary, the EcoSmart™ concrete used at Ardencraig provided a stronger finished concrete, had adequate workability, did not disrupt the project schedule and was close to being cost competitive. Given the potential environmental benefits, the design team, convinced that even a project this small could have an enormous impact when multiplied by the number of housing starts per year, has committed to the continual use of EcoSmart™ concrete in their future projects.


FIGURE2.1.3a
1540 WEST 2nd AVENUE

2.1.3 1540 WEST 2ND AVENUE

This Artist Live/Work studio complex designed by Arthur Erickson and Nick Milkovich Architects demonstrate both the aesthetic appeal and the cost-effectiveness of EcoSmart™ concrete. With a large percentage of the concrete structure exposed, the architects opted to use EcoSmart™ concrete primarily to obtain a lighter colour and higher quality surface finish of the concrete.

- **Design Mix** - The concrete design mix for 30 MPa incorporated 50% fly ash. However, the amount of cementitious material is more similar to that of a normal 40 MPa mix. This increase in paste volume produced a "creamy" concrete with improved workability and better cohesiveness, which was responsible for the enhanced quality of the exposed concrete.
- **Workability** - Although enhanced pumpability was observed, placing was more difficult. The fresh concrete was more sticky and required a longer and more intensive vibrating.

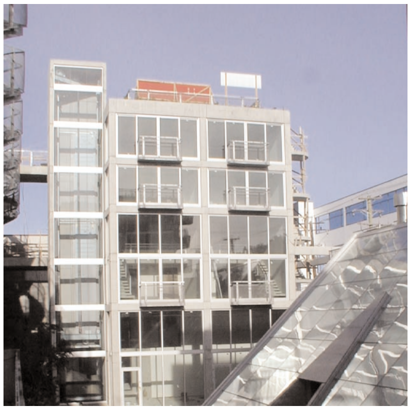


FIGURE 2.1.3b
1540 WEST 2nd AVENUE

- **Strength** - Although the mix was created more for architectural rather than structural demands, strengths above 40 MPa were obtained in 28 days.
- **Setting Time**- With a low water to cementious material ratio in the mix, and summertime pouring conditions, early age strength was achieved avoiding any negative impacts on schedule.
- **Aesthetic Appeal** - The finished concrete surface was found to be even and smooth with less bugholes. Less patching and surface finishing was required.
- **Economics** - Compared to the standard 28-day 30 MPa mixture, the cost of the case study mix was approximately 10 to 15% greater. However, the high volume fly ash concrete used, which gained more than 40MPa after 28 days, would have cost 10% lower than a standard 40 MPa mix. Labour cost was higher for placing but lower for patching and sacking. No special equipment or additional forms were used.

Incorporating high volumes of fly ash into the concrete produced the high quality, warm coloured and attractive finish desired. The scheduled sandblasting was cancelled and a light acid wash performed instead, cutting costs and meeting the owner's expectations. Both the Haebler Group and Arthur Erickson/Nick Milkovich Architects welcome opportunities to use EcoSmart™ concrete in future projects.

2.2 SKYTRAIN STATIONS

2.2.1 BRENTWOOD AND GILMORE STATIONS


FIGURE 2.2.1
BRENTWOOD SKYTRAIN STATION

The EcoSmart™ Concrete Project Steering Committee commissioned Fast + Epp Structural Engineers, working with Levelton Engineers Ltd. and Busby + Associates Architects to investigate the implications of increasing the fly ash volume to a 40-60% content in the concrete works of the Brentwood and Gilmore SkyTrain Stations. For many of the concrete elements used in the station applications, high volume fly ash would be somewhat of a pioneering effort.

The proposed design mix specified a minimum of 50% fly ash in the footings, walls, columns, slabs, and stairways; a minimum of 30% fly ash concrete in precast elements.

Specifications included a clause to disregard fly ash specs under adverse weather conditions.

❖ A follow up report is to be completed for Brentwood and Gilmore Stations.

2.3 HIGH RISE TOWER

2.3.1 THE BAYVIEW, 1529 WEST PENDER


FIGURE2.3.1a
THE BAYVIEW

The goal was to introduce high volume fly ash use to the highrise market in a way that introduced no cost premiums to the existing construction process.

The challenge was to develop a mix that was transparent (e.g. a mix with no differences in strength gain rate compared to normal cement concrete). Given the schedule driven nature of the highrise construction industry, where highly repetitive sequences have been optimized over the years to take full advantage of fast-setting

FIGURE 2.3.1b
THE BAYVIEW

concrete, it was determined that only the podium and parking areas would be promising as candidates for EcoSmart™ concrete use. The slower production rate and less demanding set times in these areas make them more amenable to Ecosmart concrete. A CSA Class CI (i.e. moderate calcium oxide content) fly ash was used for its high pozzolanic properties. Up to 55% fly ash replacement was achieved on all the footings, with 33% replacement on all parking slabs, building shear walls and columns. The tower slabs, representing 35% of the total concrete volume, incorporated only 15% fly ash in the mix. These mixes are designed to provide early-age strength, and higher amounts of fly ash would increase costs, make finishing shifts longer and strength gains slower particularly in colder temperatures. The industry norm for early-age strength mixes is to use no fly ash.

Despite initial caution from the owner and the contractors, the experience with fly ash use in concrete has been a welcome surprise. The concrete placers found the mix to be very workable and the finished result to be smooth and even requiring no patching.

❖ A follow up report The Bayview will be completed by November 2002.

2.4 OTHER PROJECTS

2.4.1 THE LIU CENTRE FOR THE STUDY OF GLOBAL ISSUES, UNIVERSITY OF BRITISH COLUMBIA (UBC)

FIGURE2.4.1
THE LIU CENTRE FOR THE STUDY OF GLOBAL ISSUES

The Liu Centre demonstrates UBC's commitment to leadership in sustainable development. Construction followed a sustainable design plan using exposed concrete as the primary architectural finish. Precast planks and poured-in-place walls and columns helped minimize the amount of concrete required. With 50% of the cement replaced by fly ash, the Liu Centre became the first building in BC to use EcoSmart™ concrete throughout.

- **Mix Design** - A single mix design with 50% fly ash/cement ratio was selected for all cast-in-place applications and exposure classes, except for topping and exterior slab on grade which were a 33% fly ash/cement ratio.

- **Precast Use** - All suspended slabs were made up of precast hollow core planks making efficient use of concrete material. Further cement reduction is achieved by the 33% cement replacement by fly ash incorporated in the hollow core precast planks.

- **Strength** - Early strength of the mix increased to 10 MPa within the first 24 hours; reached its 28 day design strength in 14 days increasing up to 50 MPa in 90 days. Formwork stripping and the removal of shoring were not delayed.

- **Setting Time** - There were no delays in construction associated with the use of EcoSmart™ concrete. Outside temperatures were always well above freezing, so the potential effects of cold weather conditions on setting time were avoided.

- **Appearance** - The finished concrete produced a warmer beige tone. The colour and surface quality of the material satisfied the architect's aesthetic expectations.

The performance of EcoSmart™ concrete exceeded the expectations of the project team, not only in terms of strength, but also in its ability to achieve a high quality finish without a cost premium. Employing a relatively conservative mix design, with a higher cementitious materials content, this first time use of Ecosmart Concrete has nonetheless set a benchmark, fully anticipating the bar to be raised by further advancements in the reduction of cement content.

FIGURE2.4.2a
YORK UNIVERSITY COMPUTER SCIENCE BUILDING

FIGURE2.4.2b
YORK UNIVERSITY COMPUTER SCIENCE BUILDING

2.4.2 YORK UNIVERSITY COMPUTER SCIENCE BUILDING

The York University Computer Science Building was selected as one of 3 buildings to represent Canada in the Green Building Challenge 2000 held in Netherlands and is considered the first cold-climate "green" building in the country. The building materials were carefully selected for low embodied energy and reduced construction waste, which included the specification of EcoSmart™ concrete for the majority of the building's concrete elements. The concrete incorporated 50% cement replacement by fly ash.

- **Quality of Fly Ash** - The higher calcium content in Type C fly ash together with the high Tri Calcium Silicate (C3A) content in the cement, provided primary cementing action resulting in higher early strength concrete.

- **Strength** - The EcoSmart™ concrete mixes developed more than adequate early strength. A one-day strength of 16 MPa was obtained for many mixes. Typically, the specified 28-day strength of 30 MPa was achieved in 7 days.

- **Workability** - Despite lower water content in the wet mix, the concrete placers found the EcoSmart™ concrete mix to be more workable, with better compaction than conventional concrete mixes.

- **Setting Time** - Contrary to the slower setting times predicted for EcoSmart™ concrete use, the EcoSmart™ mix used in York University on average set faster than a typical all cement mix. The concrete was finished and cured successfully at -10°C under normal winter construction practices.

- **Finishing** - Finishers, not being able to rely on bleed water, used a high pressure power washer to mist the air and keep the sheen on the surface. A delay in schedule was avoided due to this adjustment in finishing technique.

- **Appearance** - The architectural concrete finish was lighter and warmer coloured with fewer bug holes and honeycombing, resulting in a denser and smoother surface concrete.

The use of EcoSmart™ concrete provided a stronger finished concrete, excellent workability and did not disrupt the project schedule. The contractors concluded that in another project similar to York University, they would feel confident setting a goal of at least 50% fly ash replacement for the concrete mix.


FIGURE 2.4.3a
NVIT / UCC

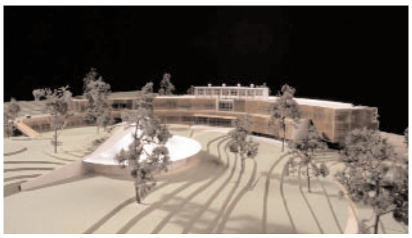


FIGURE 2.4.3b
NVIT / UCC

2.4.3 THE NICOLA VALLEY INSTITUTE OF TECHNOLOGY / UNIVERSITY OF THE CARIBOO

The Nicola Valley Institute of Technology (NVIT) / University of the Cariboo (UCC) is Canada's first post-secondary facility shared by both First Nations and non-native institutes. Poured-in-place concrete with high volumes of fly ash was used for all concrete components of the building.

- **Quality of Fly Ash** - Type F fly ash was used to provide sulfate resistance. Fly ash use is considered an advantage in the Thompson Nicola Region where sulfate ions are found in the soil and ground water.

- **Design Mix** - Although the design mix contained 50% fly ash cement replacement, the water-to-cementitious materials ratio was designed to be exactly the same as in an all Portland cement mix, i.e. between 0.44 and 0.55. The material-testing engineer determined the design mixes to be acceptable for their intended exposure classification and compressive strength requirement.

- **Curing** - NVIT experienced below-freezing temperatures during construction. Temporary hoarding and heating were required to assist in curing thinner elements contributing to an increase in cost for fuel and labor. As expected, large mass elements such as footings were not seen as difficult, compared to pouring flatwork and thinner elements which are subject to chilling as they are exposed at the top and/or bottom during curing.

- **Finishing** - Finishing was a challenge due to less bleed water rising to the surface. As well, slow setting times prevented finishers from accessing the slab as quickly, adding to an increase in labour cost.

The data collected for this project showed that the cold weather concreting done between late December and February did not lend itself easily to larger replacement volumes of fly ash without increased costs and finishing delays. However, the goal of 40% fly ash replacement for the whole project was achieved resulting in the reduction of approximately 180 tonnes of CO_2 emissions.


FIGURE 2.4.4
BC GAS COASTAL FACILITIES OPERATIONS CENTRE

2.4.4 THE BC GAS COASTAL FACILITIES OPERATIONS CENTRE

This reinforced concrete structure was designed to meet a broad range of environmental goals, including the use of recycled materials and EcoSmart™ concrete. The BC Gas building successfully demonstrated the practical application of EcoSmart™ concrete use.

- **Design Mix** - Most of the concrete was designed for a 30MPa strength. The goal was to achieve an overall reduction of 40% cement through the replacement of fly ash. This amount, although arbitrary, was chosen having in mind that while not overly ambitious, it was well above industry norms but within the reach of a market-driven type project.

- **Finishing** - Initially, concrete was poured early in the morning as they do for conventional concrete. Usually, concrete sets up early and finishers are done by the end of the day. With the fly ash concrete mix, the finishers stayed on site until 2:00 a.m. the next morning. Subsequently, they poured late in the day and did the finishing the next morning. The contractor chose to reduce the percentage of fly ash in the mix when ambient temperatures fell below 10°C.

- **Workability** - The contractor found fly ash concrete more workable than conventional mixes. The concrete was easier to place and fill forms.
- **Economics** - Fly ash costs about half the price of cement and is readily available. Additionally, labour costs were lower due to the easier placing and general workability of the mix.

Overall, the experience in this project was very positive. Although the original goal of 40% fly ash was not reached, a large volume of cement was avoided and the project team learned many lessons about working with Ecosmart concrete mixes.

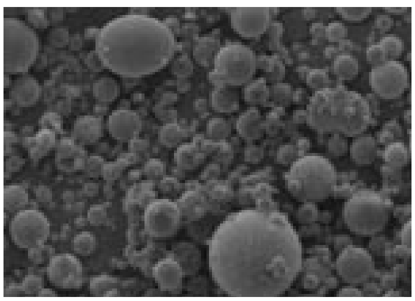


FIGURE 3.0
FLY ASH PARTICLES

3.0 FLY ASH INFRASTRUCTURE AND CASE STUDY FINDINGS

Fly ashes are finely divided residue, a by-product of the combustion of ground or powdered coal in thermal power plants. They are generally finer than cement and consist mainly of glassy-spherical particles formed during cooling. Most fly ash is pozzolanic, which means it is a siliceous or siliceous-and-aluminous material that reacts with calcium hydroxide to form cementitious hydrates. When Portland cement reacts with water it produces a hydrated calcium silicate (CSH), the stronger part of concrete, and Calcium Hydroxide (CH), the weaker part of concrete. Properly selected fly ash reacts with CH to form CSH - the same cementing product as in Portland cement. This reaction of fly ash with lime in concrete improves strength.

3.1 CLASSIFICATIONS AND SPECIFICATIONS

Two major classes of fly ash are specified in ASTM C 618 (CSA-A23.5M86) on the basis of their chemical composition resulting from the type of coal burned: these are designated Class F and Class C. "F" is made from burning anthracite and/or bituminous coal, and "C" is produced from lignite or subbituminous coal. In Canada, there is a further distinction. When the lime content is 8-20 percent, it is classified CI, and when it is higher it is a class CH. Higher calcium fly ashes such as Class C tends to give higher early strength compared to Class F. High calcium fly ashes also contain reactive crystalline minerals such as free-lime, tri-calcium aluminate, tetra-calcium alumino-sulfate, and calcium sulfate.

The two properties of fly ash that are of most concern are carbon content and fineness. Both of these properties will affect the air content and water demand of the concrete. The carbon content, which is indicated by the loss of ignition, also affects the air entrainment and reduces the entrained air for a given amount of air-entraining agent. The carbon content will also affect water demand since the carbon will absorb water. The finer the material the higher the water demand due to the increase in surface area. The finer material requires more air-entraining agent in the mix for a given desired air content.

3.2 FINDINGS

Effects of fly ash, especially Class F, on hardened concrete has been studied extensively by many researchers in different laboratories, including CANMET. The results of the case study investigations focus primarily on effects of fly ash on fresh concrete, appearance and cost implications.

3.2.1 FRESH CONCRETE WORKABILITY

Almost all case study projects reported improved concrete mix responsiveness during pumping, placing and vibration. With some exceptions like NVIT, use of fly ash increases the absolute volume of cementitious materials (cement plus fly ash) compared to non-fly ash concrete; therefore the paste volume is increased, leading to a reduction in aggregate particle interference and enhancement in concrete workability. The spherical particle shape of fly ash also assists in improving workability because of the so-called "ball-bearing" effect. In precast concrete particularly, this can result in sharp and distinctive corners and edges with a better surface appearance. This also makes it easier to fill intricate shapes and patterns.

3.2.2 BLEEDING

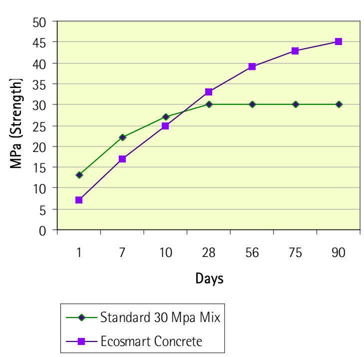
Using fly ash in concrete mixtures usually reduces bleeding by providing greater fines volume and lower water content for a given workability. Concrete with relatively high fly ash content will require less water than non-fly-ash concrete of equal slump. In all case study projects, the bleed water rising to the surface was found to range from low to negligible, generally creating a problem for finishers who are used to more bleed water at the concrete surface during finishing. Proper care was required to prevent plastic shrinkage at the concrete surface immediately after placing. In some cases, finishers not being able to rely on bleed water used a high-pressure washer to mist the air and keep the sheen on the surface.

3.2.3 SETTING TIME

As expected, case study projects using Class F fly ash concrete pouring during cold weather experienced increased setting time of concrete. York University on the contrary, using moderate calcium and high alkali content fly ash (Type C in this case) and a high alumina (i.e. C3A) content cement, finished and cured successfully at -10 C under normal winter construction practices without admixtures or temporary heating. Recent research indicates that slow set and low early strength need not be consequences of using fly ash. Most of the time, the high-fineness and low carbon fly ash will result in high early strength. Field experience has shown the setting time of vertical elements using high volume fly ash is not generally a concern.

3.2.4 COMPRESSIVE STRENGTH AND RATE OF STRENGTH DEVELOPMENT

STRENGTH GAIN COMPARISON



In general, the experience from field mixtures is that high volume fly ash concrete did not show unacceptable retardation in initial setting time, and demonstrated enough strength development to produce adequate strength at one day. Typically, the mixes obtained a one-day strength of 10 MPa. Although some concrete mixes containing fly ash developed lower strength at 3 or 7 days of age, the mixes usually achieved higher ultimate strengths when properly cured. There is a correlation between setting time and strength development (e.g. with all other characteristics being similar, there have been instances in which the concrete with the slower setting time will achieve better strength development over all ages once the hydration process has begun).

3.2.5 USE OF SUPERPLASTICIZERS

The strength of any given concrete is inversely related to the water/cement ratio, (e.g. the lower the water content of the concrete, the stronger it is). Superplasticizers are powerful dispersing agents. When used in concrete incorporating large amounts of fly ash, superplasticizers contribute to a significant increase in compressive strength and enhanced workability, as a result mostly from up to 20% reduction in water content brought by decreasing the water-to-cementitious materials ratio in the range of 0.30 to 0.35. Despite this, to save on cost, most case study projects did not use superplasticisers and some projects such as York University Computer Science Building found little need for superplasticizers to improve concrete workability. Some research indicates that "fly ash is a poor man's superplasticizer" since it has the same ability to reduce water requirements for a given workability while costing much less.

3.2.6 APPEARANCE OF HARDENED CONCRETE

All across the board, the architectural concrete finish was warmer coloured with fewer bug holes and honeycombing, resulting in a denser and smoother surface concrete. The concrete placers in general found the surface to be more predictable and consistent from the forms, requiring less patching and thus avoiding color variations. This advantage resulting from the incorporation of fly ash in the concrete mix was particularly important for the case study projects with large areas of exposed concrete, such as the Liu Centre and 1540 West 2nd Avenue Artist Live/Work Studios.

3.2.7 LIMITATIONS

The main precautions usually associated with the use of high volume fly ash in concrete include somewhat slower early strength development and extended initial setting time during winter months.

It is also worth noting that fly ash in North America can display a very wide range in terms of chemical, mineralogical and physical properties depending on the source. Consequently, every source of fly ash needs to be adequately characterized prior to use in concrete. The high carbon content in certain fly ash products absorbs some air entraining agents, reducing the amount of air-entrained in the concrete, making the concrete susceptible to frost damage. The Type C fly ash used in York University was deemed unacceptable for freeze-thaw durability and was consequently avoided for all air-entrained concrete applications. In areas where sulfate ions are found in the soil and ground water such as the Thompson Nicola Region, the site for the Nicola Valley Institute of Technology, only Type F fly ash is used. Class F fly ash is effective in substantially reducing alkali-silica expansion but Class C fly ash is not as effective unless used in larger proportions. For large pours where there is a risk of thermal cracking, Class F fly ash is generally more effective than Class C in reducing heat of hydration.

The incorporation of high levels of fly ash into a concrete mix is not sufficient to ensure satisfactory performance. Although the water to cementitious material ratio (W/CM) plays an important role in defining pore structure of the concrete, it is the unit water content (W) that sets the total amount of pore space. The combination of low W, low W/CM and a high volume of fly ash (as part of CM) will produce a concrete with very low porosity, thereby producing a low permeability. This was evident from the case study data for laboratory and field trial mixes.

3.2.8 ECONOMICS

Generally, the EcoSmart™ concrete mix used compared in cost to standard concrete mixes. Fly ash is sold for roughly half the price of cement, but in some cases the material savings was offset by the added cost of admixtures and added temporary heating when pouring during cold weather. In most cases, the cost of placing EcoSmart™ concrete was marginally less and slab finishing costs marginally more.

Some contractors using the product for the first time want to apply a premium for future projects based on its newness, but will likely not be successful as EcoSmart™ concrete use becomes more mainstream. Increased cost savings could result from more experience with the use of EcoSmart™ concrete - this entails possible adjustment to schedule and technique to adjust for fly ash concrete's slow setting times.

3.2.9 PERCEPTION

For the most part, contractors and concrete placers had very little or no experience with the use of large volumes of fly ash replacement in concrete. As expected, some of them were very concerned about potential delays associated with setting time and early age development. In some projects, the tradespeople (suppliers, placers, finishers) were prepared in advance for the impacts of high volume fly ash. Discussions were held regarding potential adjustments to handling, placing and finishing of EcoSmart™ concrete mixes. In these cases, with expectations managed properly, the experience of working with EcoSmart™ concrete turned out to be better than what most trades people expected. Overall, the performance of EcoSmart™ concrete exceeded the expectations of the project teams in terms of the simplicity of the technology, low initial cost, high durability and high environmental friendliness of the product.

4.0 TECHNOLOGY INNOVATION

4.1 INTERGRIND

Intergrinding is a process of grinding fly ash together with cement clinker at the cement plant to make a blended cement, instead of the more common practice of blending fly ash with Portland cement at the concrete batch plant. The technology for the grinding of fly ash and cement with interground additives offers high flexibility in the production of a wide range of different cements in one single production unit.

ICON (International Centre for Sustainable Concrete)/CANMET's Advanced Concrete Technology Laboratory in partnership with the Electric Power Research Institute (EPRI) and Tilbury Cement completed the intergrinding test in May 2000 at Tilbury's Bellingham plant. ICON/CANMET tested samples containing 45% and 55% fly ash from the Tilbury Cement's Bellingham plant and the results were satisfactory. See the highlights below:

- The results from ICON/CANMET's investigations showed that the mechanical and durability properties of the blended cement samples were comparable or superior to conventional concrete using cement only. Some of the advantages are: better blending, higher consistency, ability to use lower quality fly ash, no need for an extra silo.

- Although Tilbury's Bellingham facilities are currently being used to produce ASTM Type IP blended fly ash cement (<10%), the system was not optimum for these trials. The various lots of blended cement ranged from 45 to 65% fly ash content. These lots were then blended at the CANMET lab to produce the 55% fly ash blend samples.

- The concrete made with 55% fly ash blended cement developed a one-day strength of 13 MPa, which is high considering the high fly ash content.

- The temperature rise of the blended cement concrete was quite low, suggesting that it would be ideal for concrete structures where high heat of hydration is a concern.

4.2 PRECAST

Using EcoSmart™ concrete in precast (pre-manufactured) concrete structures presents a challenge because of the typical one-day cycle time requirements. Optimization of precast facilities occurs when elements are repeatable and forms can be stripped quickly. Ideally crews should strip forms within 16 hours of completion of placing. This represents a short curing time to achieve a daily cycle. Because fly ash generally increases curing time, most precast plants avoid using significant amounts of fly ash.

Con-Force Structures of Vancouver, B.C., completed a test with up to 50% fly ash incorporated into their precast procedures. As a result of successful testing, their contract with the Rapid Transit Project Office included 30% fly ash in the precast beams for the new SkyTrain stations. Their product Hollowcore containing approximately 33% fly ash was also used as floor slabs for the Liu Centre at UBC. Con-Force Structures is currently working with companies and organizations to find and develop better methods of precast construction, improving efficiency and helping reduce the impacts on the environment.

5.0 CONCLUSIONS & RECOMMENDATIONS

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.

At least in the GVRD, despite sufficient fly ash supply to support a considerably greater level of replacement of cement in concrete, simplicity of the technology and reduced cost of the material, the penetration of fly ash use in the cement market has been slow. Based on interviews conducted during the various case studies employing the first time use of Ecosmart concrete, the market resistance was deemed to be a result of lack of awareness of the product and lack of experience with the technology which undoubtedly leads to concerns regarding technical risk and liability.

The successful use of concrete with high volumes of supplementary cementing materials as shown by York University and the UBC Liu Centre demonstrates that such materials can be used in regular commercial concrete construction without any major changes to normal construction practices or scheduling. Although these demonstration projects will help promote the wider understanding and use of high levels of fly ash in concrete, further initiatives are required if full exploitation of this technology is to be realized.

5.1 NEXT STEPS

- The construction industry, particularly the architects and engineers, needs to be informed about the properties of fly ash and how it may influence a project.
- Design for Ecosmart Concrete - this may involve scheduling construction during warmer seasons, for example.
- Institutional barriers such as national and provincial specifications that place blanket limits on the maximum allowable cement replacement levels need to be removed. Instead, such specifications should continue to control the use of fly ash (and other cementitious materials) through the imposition of appropriate performance criteria.
- There needs to be an incentive for owners, contractors and engineers to experiment with high levels of supplementary cementing materials such as fly ash in concrete.

EcoSmart™ concrete use provides the opportunity to reduce greenhouse gas emissions, alleviate a fly ash disposal problem, save natural resources and produce a high quality product. Despite the challenges, the demonstration projects discussed here show that supplementary cementing materials such as fly ash contribute to tremendous ecological, aesthetic and structural benefits and will continue to gain popularity in the future for use in advanced and sustainable architectural projects.