EcoSmart™ Concrete Project
A Concrete Contribution to the Environment™

COURTYARD ON BEAR & CAVE AVENUE HOUSING – BANFF, AB
CASE STUDY

USING ECOSMART™ CONCRETE
IN COLD WEATHER CONSTRUCTION

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1.0 EXECUTIVE SUMMARY

The goal of this study is to report the challenges encountered using EcoSmart™ concrete during cold weather construction, and to provide possible solutions to these challenges. The *Courtyard on Bear* and the *Cave Avenue Housing* projects in Banff, Alberta were developed with a focus on sustainable design, and are intended to set an example of environmental consciousness for future construction in Banff National Park. EcoSmart concrete requires less cement than standard concrete, which corresponds to a reduction in the greenhouse gasses released into the atmosphere during the cement production process. As such, the decision was made to use EcoSmart concrete to the greatest extent possible on these projects.

Although the original intent of the project was to take advantage of the warmer summer months for concrete placement, an increased design period and delays in the permitting process pushed the construction schedules for both projects to the point that the majority of the concrete was cast in the winter. For this reason, these projects are of particular interest in the use of EcoSmart concrete in cold weather construction.

It is known that EcoSmart concrete generally has slower initial strength gain than standard concrete, which can affect the stripping times of concrete formwork. It is also known that colder ambient temperatures slow the early strength gain of standard concrete as well as EcoSmart concrete. It was uncertain at the outset of the projects the extent of the impact these factors would have on the schedule, considering the uncertainty of the weather the winter would bring, and how significantly the cold temperatures would further slow the early strength gain of the concrete. However, the project team was committed to using EcoSmart concrete. The decision to adjust the concrete pour sequences and experiment with accelerators as required to keep the overall project schedule on track had positive results. Additional concrete testing was undertaken, by means of field-cured cylinders, to closely monitor the strength gain of the EcoSmart concrete. For the remaining pours, particularly the suspended slabs, an in-situ strength tests will be used.

2.0 PROJECT DESCRIPTION

2.1 Project Overview

The larger of the two projects, Courtyard on Bear, is a multi-purpose building containing retail space, several residential units, a restaurant, a bakery, and a hotel/hostel. It contains one level of underground parking and three main buildings, each three stories high above the main floor. The foundations, main floor, second floor, and portions of the third floor are constructed in cast-in-place concrete. The remainder of the building is framed in wood.

Figure 1: Rendering of Courtyard on Bear project

The smaller project, Cave Avenue Housing, is a residential complex. It is built on a steep slope, with the main portion of the building at the low street elevation, and two "wings" of townhouses built up the hill. The main building contains 12 residential units, a common room, and a public plaza, with one level of underground parking and three stories above grade. The parkade, main level, and various retaining walls are cast-in-place concrete, with the remainder of the building framed in wood. Behind the main building the seven townhouse units have cast-in-place concrete foundations and wood framing above. The four-unit wing has basements, while the three unit wing townhouses do not.

Figure 2: Rendering of Cave Avenue Housing project

The contractor, structural consultant, concrete supplier, and formwork supplier met early in the construction phase to discuss the challenges that would be involved to keep the projects on schedule despite the potential formwork stripping delays. The team made a commitment to use the EcoSmart concrete for as much of the projects as possible, and to use standard concrete only as a last measure when no other solutions could be found, such as for the parkade ramp slab where de-icing chemicals and freezing and thawing exposure is expected.

2.2 Project Teams

Courtyard on Bear

Client:	Arctos & Bird Enterprises Ltd.
Primary Architect:	Zeidler Carruthers & Associates Architects
Design Architect:	William McDonough + Partners
Structural Engineer:	Read Jones Christoffersen Ltd.
Mechanical Engineer:	MechWave Engineering Ltd.
Electrical Engineer:	Stebnicki, Robertson & Associates Ltd.
Materials Engineer:	McIntosh Lalani Engineering Ltd.
Contractor:	PCL-Maxam, A Joint Venture
Concrete Supplier:	Lafarge Canada Inc.

Cave Avenue Housing

Client:	Arctos & Bird Enterprises Ltd.
Primary Architect:	IBI Group
Design Architect:	William McDonough + Partners
Structural Engineer:	Read Jones Christoffersen Ltd.
Mechanical Engineer:	MechWave Engineering Ltd.
Electrical Engineer:	Stebnicki, Robertson & Associates Ltd.
Contractor:	Rescom Inc.
Concrete Supplier:	Lafarge Canada Inc.

2.3 Project Details

Courtyard on Bear

Design:	2001 – 2003
Construction:	2003 – 2004
Proposed Completion Date:	January 2005
Building Area:	4500 m^2
Construction Cost:	$11.8 million

Cave Avenue Housing

Design:	2002 – 2003
Construction:	2003 – 2004
Proposed Completion Date:	February 2005
Building Area:	2100 m^2
Construction Cost:	$5.5 million

The Courtyard on Bear project site is located in downtown Banff, and is surrounded by other retail buildings, restaurants, and hotels. The Cave Avenue Housing site is 2 km southwest of downtown Banff in a residential neighbourhood.

In both of the projects, the underground parking level consists of slabs-on-grade, concrete columns, and concrete foundation walls. The main floor structure over the parkades is a slab and slab band system, which best suits the spans between columns. The lateral systems in both buildings consist of concrete elevator shafts and shear walls.

Above the main floors, a combination of wood and concrete structure was used. All areas exposed to the outdoors were designed in concrete for its strength and durability, while the residential units were framed in wood, the typical construction used for low-rise residential buildings.

Figure 3: Courtyard on Bear site as of January 2004

3.0 USE OF ECOSMART™ CONCRETE

3.1 Goals

The owner of the two projects had expressed a keen interest in environmentally responsible design from the outset of the projects. To support this goal, it was decided to use EcoSmart concrete, since cement production is an energy intensive process and results in significant greenhouse gas (GHG) emissions. EcoSmart concrete replaces a portion of the cement in concrete with fly ash, a waste product of coal fired power generation. Replacing a portion of cement with fly ash reduces the embodied energy of the concrete, diverts the fly ash from landfills, and decreases the greenhouse gas emissions generated by cement production.

Due to delays in the design and permitting processes, the projects broke ground in October 2003. As a result, a large portion of the concrete was scheduled to be poured during the winter months. The goals for the project therefore became as follows:

1. Determine the percentage of fly ash that could be used in concrete poured in colder temperatures.

2. Obtain information on the use of accelerators in EcoSmart concrete.

3. Review the energy consumption implications of heating the ground, forms, rebar and concrete prior to and immediately following the pour for EcoSmart concrete relative to standard concrete.

Figure 4: Insulated tarps and heaters enclosing recent wall pours

3.2 Project Chronology

Concrete construction for the Cave Avenue Housing project began in October 2003, while Courtyard on Bear began in December. At the time of submitting this report, the projects have footings, foundation walls, columns, and slabs-on-grade poured. The first suspended slab pour is scheduled for late March, and as such the related experiences and concrete performance results cannot be included in this report.

The temperatures in Banff over this time period ranged from -35°C to +10°C, and concrete was poured when the ambient temperature was as low as -25°C. However, all areas to be poured were first enclosed with insulated tarps and heated with propane heaters to bring the ambient temperature to between 10°C and 25°C. This temperature was maintained for three days or until the concrete reached 40% of its design strength, as per the CSA-A23.1 Standard.

The concrete construction for both projects is scheduled to be complete in the fall of 2004, allowing some of the concrete to be poured in warmer months. The intention is to increase the amount of fly ash in the concrete mix designs as the ambient temperature increases.

3.3 Concrete Use in Structure

The following tables show the volume of concrete for each element in the buildings.

Courtyard on Bear		
Element	**Volume (m^3)**	**% Total Volume**
Footings	530	20%
Exterior Walls & Columns	200	7%
Interior Walls & Columns	240	9%
Suspended Slabs	1470	54%
Slab-on-grade	280	10%
Total	**2720**	

Table 1: Volume of Concrete at Courtyard on Bear

Cave Avenue Housing		
Element	**Volume (m^3)**	**% Total Volume**
Footings	230	16%
Exterior Walls	570	39%
Interior Walls & Columns	60	4%
Suspended Slabs	400	27%
Slab-on-grade	210	14%
Total	**1470**	

Table 2: Volume of Concrete at Cave Avenue Housing

The parking level slabs-on-grade and parkade ramp slab did not use EcoSmart concrete, as there was concern that the cement content should not be reduced where the concrete is exposed to de-icing chemicals. It was believed that this would affect the durability of the concrete. However, it was later determined that research has shown both de-icing chemicals and freezing and thawing cycles present in combination will affect the durability of EcoSmart concrete, while no research has found de-icing chemicals alone create issues if the slab is finished and cured properly. Therefore, the interior slab-on-grade could have used EcoSmart concrete, although the slab-on-grade was completed prior to this discovery.

It should be noted that the standard concrete mix for slabs-on-grade used 25% fly ash as a minimum, which, although a higher percentage could have been sought, is more than would be found in other areas across Canada.

3.4 Concrete Requirements

The cast in place concrete specification requested the concrete supplier submit three mix designs. Figure 5 is an excerpt from the specifications that describes the requirement. Note that three mix designs were requested – Mix A, B, and C.

The mix design shall take full advantage of the use of fly ash or blast furnace slag to reduce the cement content of the concrete.

.1 Coal fly ash shall conform to the standard. Contractor to provide pricing for the following mixes:

- .i Mix A: Current industry standard mix.
- .ii Mix B: Mix maximizing the amount of fly ash to replace the cement content (minimum values shown below).
- .iii Mix C: Mix maximizing the amount of fly ash but suitable for cold weather placing (less than 10℃ ambient temperature) without additional heating during the pour.

.2 Mix B shall contain the following minimum percentages of fly ash (but not be limited to):

.i	Slab and Slab Bands (including parking)	30%
.ii	Slab-on-Grade (interior parking)	25%
.iii	Slab-on-Grade (no parking)	30%
.iv	Slab-on-Grade (exterior)	15%
.v	Footings	50%
.vi	Walls	40%
.vii	Columns	40%

The intent of adding these percentages of fly ash is to see the current cement content proportionally reduced.

.3 The concrete strengths noted on the structural drawings may be obtained in 56 days for mixes B and C.

Figure 5: Partial Structural Cast-in-Place Concrete Specification

The Mix A was requested as a basis of comparison, to ensure that the total amount of cementitious materials was not increased to compensate for the increase in fly ash content. Mixes B and C contain high volumes of fly ash, Mix B for warm summer temperatures, and Mix C for winter weather. Mix C noted the fly ash content should be reduced to the point that no additional winter heating would be required. Winter construction in Alberta requires that heating and hoarding be used to conform to the minimum curing temperatures stated in CSA-A23.1. The intention of the mix design was to ensure extra days of heat would not be required while waiting for the concrete to reach 40% of its design strength.

Figure 6 summarizes the structural concrete requirements of the elements used between the two projects, as well as additional requirements shown on the structural drawings.

1. CEMENT SHALL BE PORTLAND CEMENT TYPE 10 – U.N.O. CONCRETE SHALL BE STONE CONCRETE WITH A UNIT WEIGHT OF 23.6 kN/m^3.
2. CONCRETE PROPERTIES:

Element	Min. 28 Day Strength* (MPa)	Slump (mm)	Max Agg. (mm)	Exposure Class	Court-yard on Bear	Cave Ave. Housing
Slabs, Slab Bands, & Beams	30*	70	20	N	✓	✓
Interior Walls	25*	80	20	N	✓	✓
Interior Columns	30*	80	20	N	✓	✓
Slab-on-grade (Interior Parking)	32	70	20	C-4	✓	✓
Exterior S.O.G, Sidewalks	32	70	20	C-2	✓	✓
Footings	30*	80	40	N	✓	
Foundation Walls	30*	80	20	F-2	✓	
Exterior Columns	30*	80	20	F-2	✓	
Parkade Ramp	35	70	20	C-1	✓	
Footings	25*	80	40	N		✓
Foundation Walls	25*	80	20	N		✓
Slab-on-grade (Interior No Parking)	25*	70	20	N		✓

* May be based on 56 day strength where noted in the C.I.P. concrete specification.

Figure 6: Structural Concrete Requirements

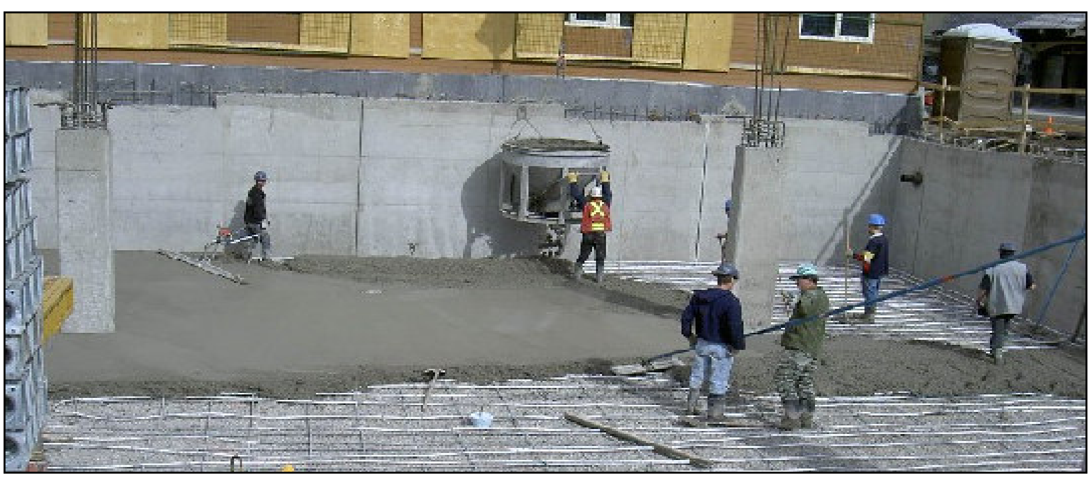

Figure 7: 25% fly ash slab-on-grade pour at Courtyard on Bear

3.5 Concrete Mix Design

The mix designs submitted by Lafarge followed the format set out in the concrete specification. The intention was to use the cold weather Mix C's for the winter construction, and transition into Mix B's once the summer months arrived. The fly ash used on this project was Type CI from the Sundance plant near Edmonton.

As previously mentioned, it was decided that any concrete exposed to de-icing chemicals would use Mix A, therefore alternate mix designs for these elements were not submitted. As such, the slabs-on-grade in parking areas and the parkade ramp are not included for discussion.

The mix designs are summarized in the following table. Note that Mix A is based on 28 day compressive strengths, while Mixes B and C are based on 56 day compressive strengths, as requested in the cast-in-place concrete specification (see Figure 5).

Element	Strength at 28/56 days (MPa)	%Fly ash/Total Cementitious Material and Total Cementitious Material (kg/m^3)			W/CM and Exposure Class
		Mix A Standard	Mix B Summer	Mix C Winter	
Slabs, Slab Bands, & Beams	30	25% 285 kg/m^3	35% 271 kg/m^3	30% 271 kg/m^3	0.60
Interior Walls	25	25% 260 kg/m^3	45% 247 kg/m^3	35% 247 kg/m^3	0.65
Interior Columns	30	25% 285 kg/m^3	45% 271 kg/m^3	35% 271 kg/m^3	0.60
Slab-on-grade (Interior Parking)	25	25% 317 kg/m^3	–	–	0.50 (C-4)
Exterior S.O.G, Sidewalks	32	25% 397 kg/m^3	30% 377 kg/m^3	25% 377 kg/m^3	0.38 (C-2)
Footings (Bear only)	30	25% 285 kg/m^3	50% 270 kg/m^3	40% 270 kg/m^3	0.60
Foundation Walls and Exterior Columns (Bear only)	30	25% 328 kg/m^3	45% 311 kg/m^3	40% 311 kg/m^3	0.48 (F-2)
Parkade Ramp (Bear only)	35	25% 340 kg/m^3	–	–	0.45 (C-1)
Footings (Cave only)	25	25% 260 kg/m^3	50% 248 kg/m^3	40% 247 kg/m^3	0.65
Foundation Walls (Cave only)	25	25% 260 kg/m^3	45% 247 kg/m^3	35% 247 kg/m^3	0.65
Slab-on-grade (Interior No Parking)	25	25% 260 kg/m^3	35% 247 kg/m^3	30% 247 kg/m^3	0.65

Table 3: Concrete Mix Designs

It is important to note the standard mixes provided by Lafarge all contain 25% fly ash. This percentage was higher than had been expected, but the competitive market and availability of fly ash in Alberta have already created a demand increasing the fly ash volumes in standard concrete. Across the rest of Canada, it is more common to use 5% to 15% fly ash in standard concrete mixes.

Although past experience suggested the water to cementing material ratio (W/CM) should be in the order of 0.45 for EcoSmart concrete, the concrete mixes not bound by CSA exposure classes maintain relatively high ratios. The impact is that setting times can be expected to be slower with higher W/CM. This point was discussed extensively, however Lafarge was confident in the quality of the mixes, and it was decided to use the mixes as submitted and keep a close watch on the strength gain of the concrete and the resulting schedule implications.

3.6 Findings

Initial Strength Gain

The initial strength gain of the concrete was measured by field cured cylinders, which were cast and left inside the hoarding until the time of testing. As expected, the initial strengths of the EcoSmart concrete field cure cylinders (10°C ambient curing temperature) were significantly lower than the corresponding lab cure cylinders (20°C ambient curing temperature). This general trend may be seen in data collected for the Courtyard on Bear footing Mix C, shown in Figure 8.

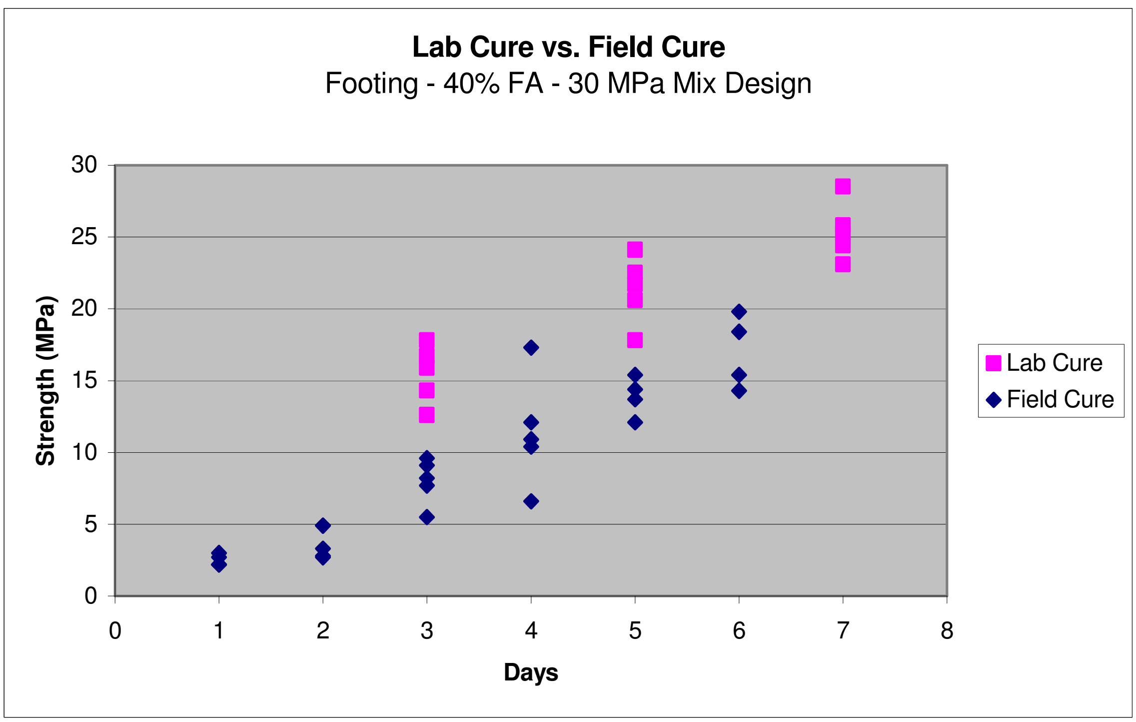

Figure 8: Lab Cure versus Field Cure Cylinder Strengths

Three main factors appeared to affect the strength gain of the concrete. The first was the internal temperature of the concrete when it arrived on site. In cold weather construction, the water added at the batch plant is heated in order to create a higher internal concrete temperature, generally in the range of 20°C to 25°C. However, this temperature drops continuously during transportation, during placement, and after placement. In one case, the concrete destined for a footing pour arrived on site with an internal temperature of 15.7°C. Although only one field cure cylinder was tested for that batch of concrete, the contractor confirmed he noticed a generally slower set time for batches arriving with cooler initial temperatures. The result of this test is charted against a batch that arrived on site with an internal temperature of 22.5°C in Figure 9.

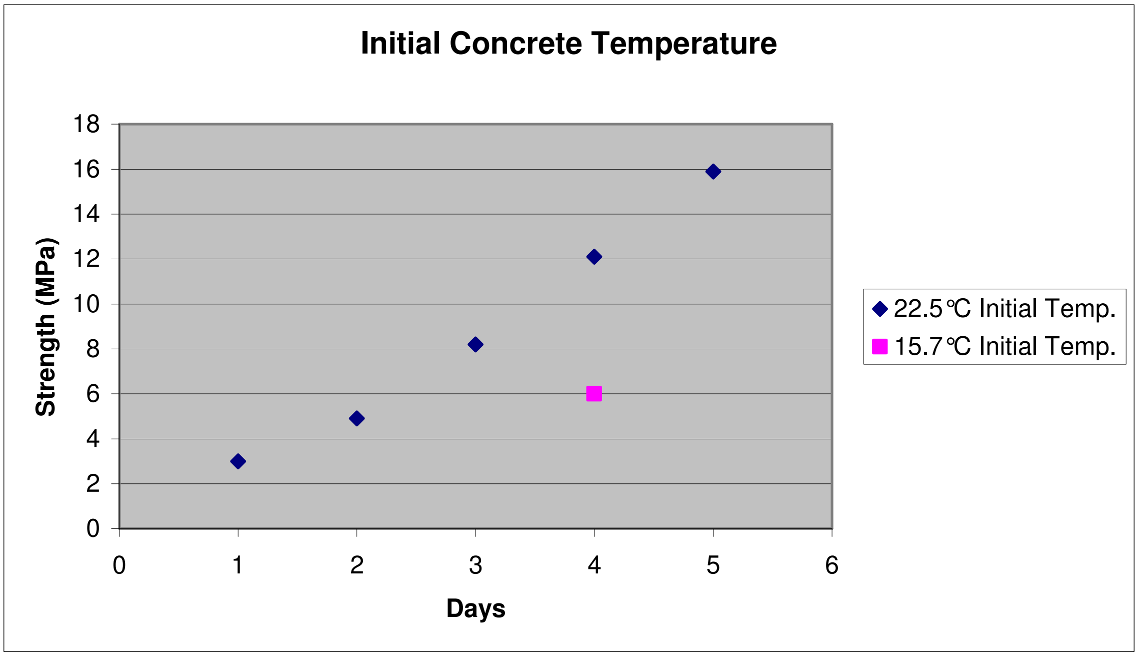

Figure 9: Initial Concrete Temperature Effect on Strength Gain

The second major factor in the strength gain of the concrete appeared to be the internal temperature of the concrete maintained over the curing period. This temperature was measured using metal wire thermometers, which were cast into various concrete elements and later cut off. While higher initial temperatures lent themselves to higher temperatures over the curing period, the heat retention of the concrete was affected by the ability of the outside temperature to permeate the hoarding. Although the hoarding aimed to bring the ambient temperature around the forms to 20°C, the insulated tarps and propane heaters were not a perfectly efficient system, and as such the outside temperature affected the heat loss of the concrete. In addition, the insulated tarps and heaters had to be temporarily removed during concrete placement, which allowed the forms, rebar, and concrete to lose heat during placement.

To illustrate the effect of lowered internal temperatures on strength gain, the lab-cured cylinders may be compared to the field-cured cylinders. Figure 10 illustrates the strength variation between the lab cure cylinders and field cure cylinders for a particular pad footing pour. The initial internal temperature of the concrete when it arrived on site was recorded at 22.5°C. The lab cylinders, cured in a warm bath, maintained an internal temperature between 19°C and 22°C, while the field cylinders experience steadily dropping interior temperatures to between 17°C and 14°C. This more than 5°C difference produced a significant difference in the rate of strength gain between the two scenarios.

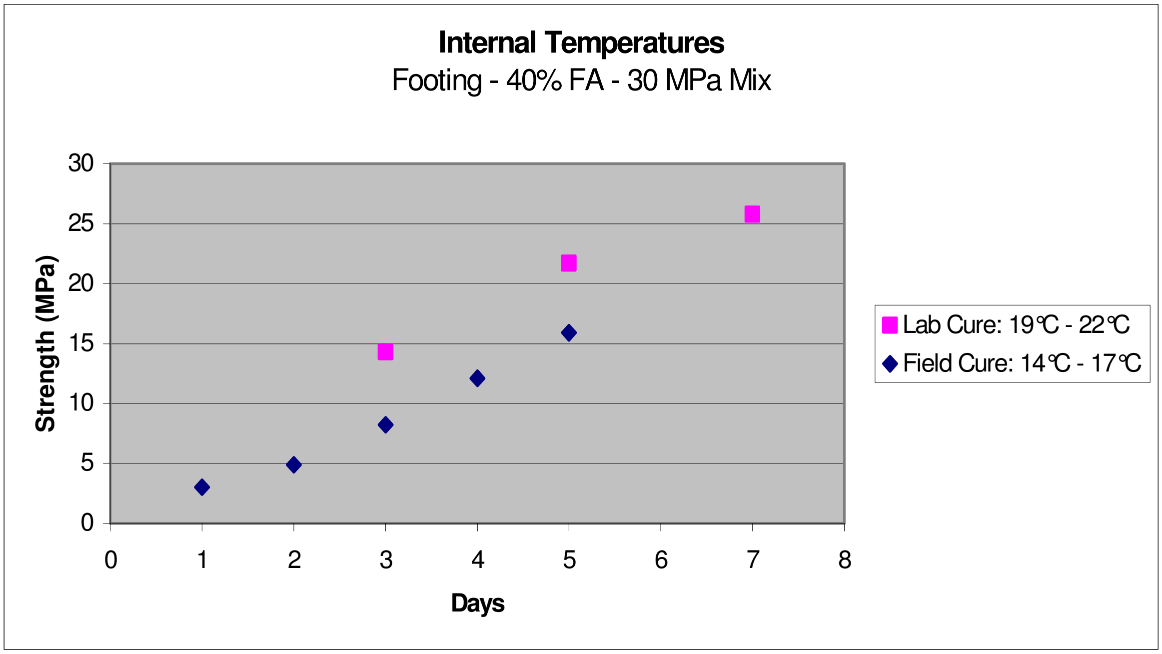

Figure 10: Internal Temperature Effect on Strength Gain

The third major factor in the strength gain is believed to be the W/CM of the concrete mix. However, this aspect of the mixes will be further studied with the suspended slabs, and therefore data is not available at this time to support this theory.

<u>Impact of Strength Gain on Construction</u>

Although initial set time is generally not critical for footings, some of the footings for the Courtyard on Bear project, as well as the walls and columns, encountered initial strength gain issues. The strip footings around the perimeter of the building had raker-tie anchors cast in for the one-sided steel forms. The one-sided forms were necessary because the walls were cast against shoring. For proper anchorage, a footing strength of 18 MPa was required before the walls could be poured. Early strength gain of the concrete was therefore an issue. The schedule was adjusted by pouring the critical footings earlier than originally intended, to allow the greatest amount of time possible between pouring a strip footing and pouring the foundation wall it supported.

Figure 11: Pad Footing Pour in January at Courtyard on Bear

The one-sided foundation wall forms also created problems with the wall pour sequence. One-sided wall forms must contend with greater form pressures, since the form must be anchored at the base to resist the lateral pressure of wet concrete, rather than tied off to a second form at regular intervals. The slower set time of the EcoSmart concrete, in combination with the height of the foundation walls and the concrete temperature, created form pressures in excess of the design pressures allowed by the formwork. Specifically, the slower set time caused by the fly ash and aggravated by the cold weather would create unacceptable head pressures if the wall was poured to quickly. The formwork shop drawings suggested the walls should be poured at a rate of 300 mm per hour. This would require the 3.0 m high walls be poured over 10 hours, which was unacceptable to the contractor.

The concrete columns also required faster set times to allow the concrete to reach stripping strength (8 MPa, as specified on the structural drawings) in 24 hours in order to suit the construction schedule.

<u>Use of Accelerators</u>

To deal with schedule sensitive pours, it was decided to try an accelerator. A non-chloride accelerator was specified for the project, and the contractor chose to use a product from Grace Construction Products called PolarSet®. Although accelerators speed up the initial cure in standard concrete, they are not as effective on fly ash as they are on cement, and therefore their usefulness on the EcoSmart concrete was uncertain.

Accelerator was used at a rate of either 1% or 2%. These percentages imply the liters of admixture used per kilogram of cementitious material (cement plus fly ash) in a cubic meter of concrete. For example, a mix with 270 kg of cementitious material per cubic meter of concrete would require 2.7L of admixture when 1% accelerator was specified.[1]

[1] 270 kg of cementitious materials * (0.01 accelerator / 1 kg of cementitious) = 2.7 L of accelerator

Although the typical footing pours did not have schedule implications, two critical footing pours used 2% accelerator to speed up the set as required by the construction schedule. The strength gain of these footings compared to non-accelerated footings is shown in Figure 12.

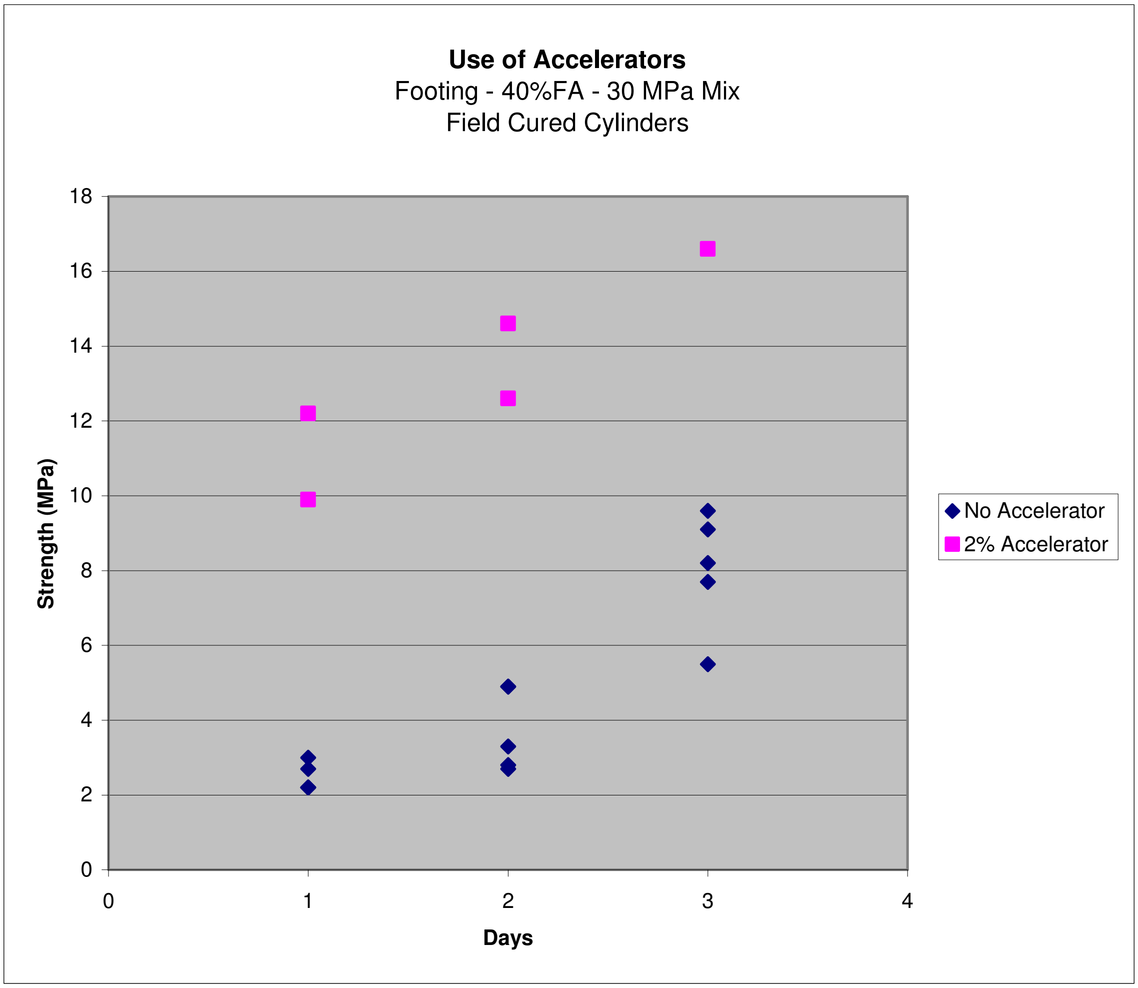

Figure 12: Effect of Accelerators on Strength Gain in Footings

The accelerator made it possible to reach 18 MPa in less than four days, providing the strength required by the raker-tie anchors to resist the one-sided form pressures.

The column form stripping was a critical issue to the schedule, as only four column forms had been provided to the site. As the steel forms were shipped from out of town, it was decided to use an accelerator to enable earlier stripping of the forms rather than incur the cost of additional steel forms. The structural specifications required a minimum concrete strength of 8 MPa prior to stripping forms, and the contractor needed to strip forms 24 hours after pouring. A minimum of 1% accelerator was used for all columns, however when the ambient temperature dropped below -15°C, the contractor found he needed to add 2% accelerator. Figure 13 illustrates the field cured strength gain of the column concrete mix with 1% accelerator, and also demonstrates the concrete gaining strength faster with a warmer ambient temperature. In this case, the accelerator was able to generate the strengths required to strip forms one day after pouring.

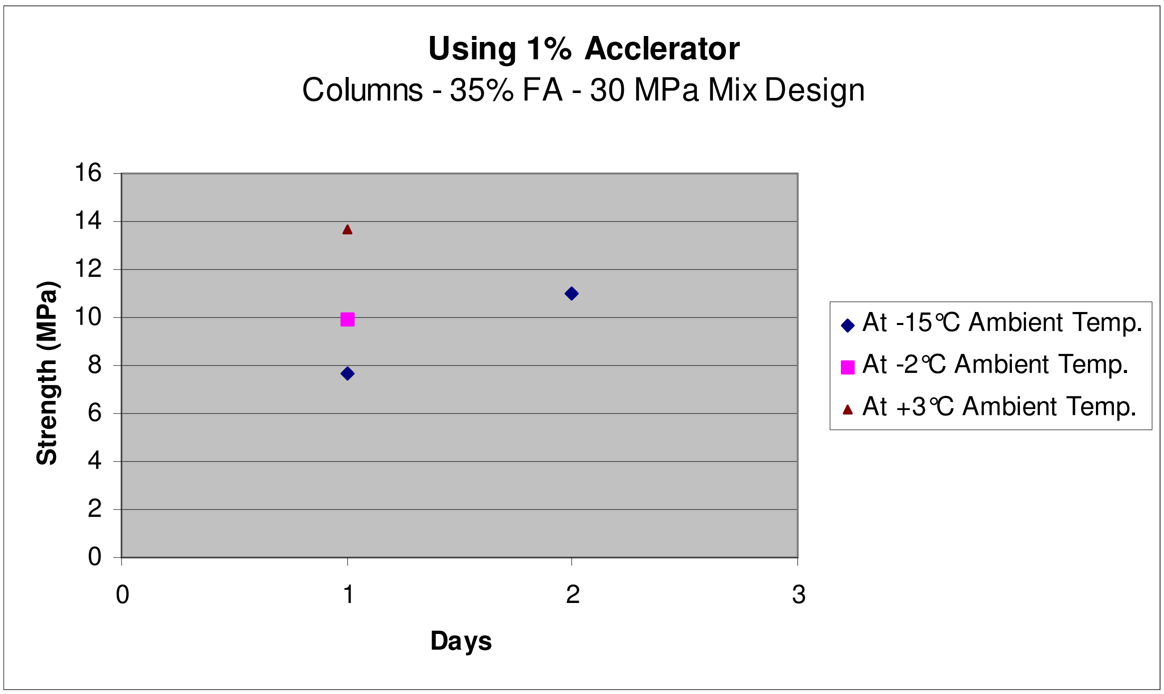

Figure 13: Effect of Accelerators on Strength Gain in Columns

The one-sided foundation walls also took advantage of an accelerator. The contractor chose to use no accelerator when the ambient temperature was above -10°C, a 1% accelerator when the temperature was between -15°C and -10°C, and 2% accelerator for temperatures below -15°C.

Figure 14 shows the wall strength gain for the field cure cylinders at Courtyard on Bear using 2% accelerator compared with no accelerator. The quicker set provided by the accelerator allowed the contractor to pour the walls in two lifts of 1.5 meters each, rather than ten lifts of 0.3 meters as otherwise required by the formwork specifications. Although this method was not covered by the steel formwork shop drawings, the formwork supplier and the contractor agreed this method was acceptable to both parties.

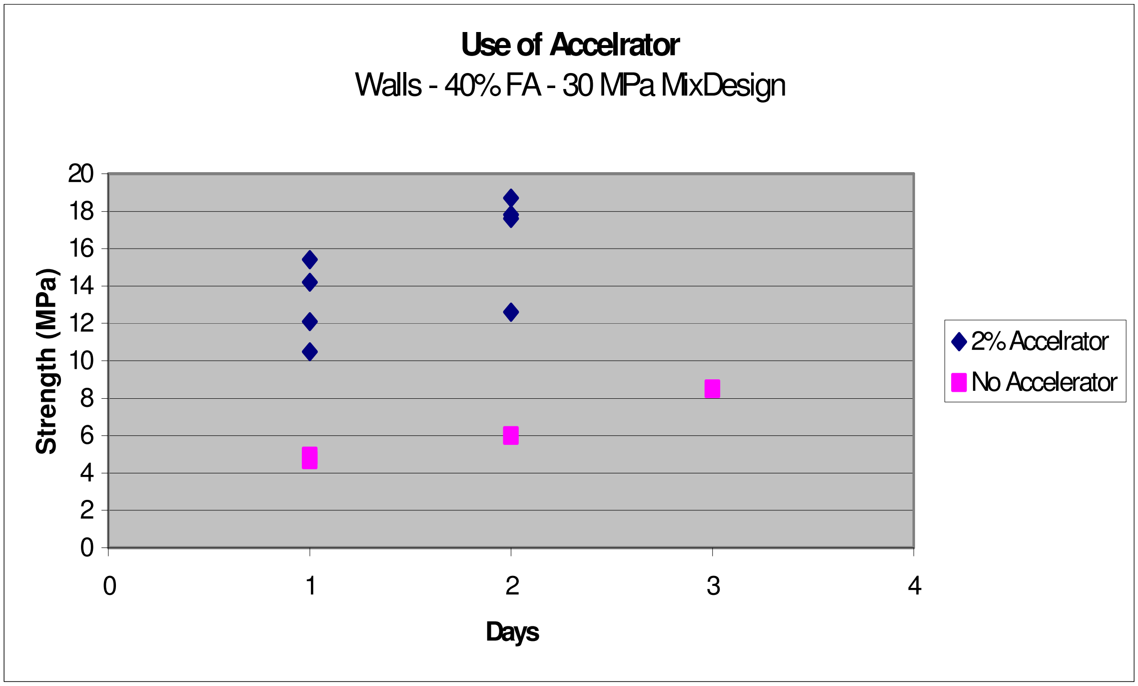

Figure 14: Effect of Accelerators on Strength Gain in Walls

While accelerators are effective in increasing the rate of strength gain of EcoSmart concrete, they do come at a premium in cost. The following table summarizes the base cost of several mixes with and without the addition of accelerators.

Mix	Base Cost of Mix A ($/m3)	Base Cost of Mix C ($/m^3)	Cost with 1% Accelerator ($/m^3)	Cost With 2% Accelerator ($/m^3)
Footings	$140.00	$139.00	$148.50	$158.00
Columns	$140.00	$139.00	$148.50	$158.00
Foundation Walls	$128.50	$127.50	$137.00	$146.50

Table 4: Concrete Cost Comparison

On average, the 1% accelerator mixes cost 6% more that the standard Mix A, while the 2% accelerator mix was a premium of 13%. For these projects, the additional cost of accelerator was determined to be the best solution in order to meet schedule demands.

Permanent Formwork

At Cave Avenue Housing, no shoring was required, and insulated concrete forms were used for the townhouse basements. This method was preferable, since the insulated formwork was left in place and stripping times were not an issue. However, as an oversight, the first wall pour did not have any superplasticizer added on site. Although the concrete was vibrated, voids were found in the concrete walls. Subsequent wall pours using the recommended amount of superplasticizer had no further problems with voids.

Figure 15: ICF Foundation Walls at Cave Avenue Housing

Future pours all included superplasticizer to attain a more workable slump, and no further problems with voids were encountered.

56 Day Concrete Strengths

At the time of writing this report, 56 day lab cure compressive strengths for some of the footing pours are available. The initial results show that the 30 MPa footing mix is consistently achieving 56 day strengths much greater than the specified 30 MPa. Figure 16 charts the results of several cylinder tests.

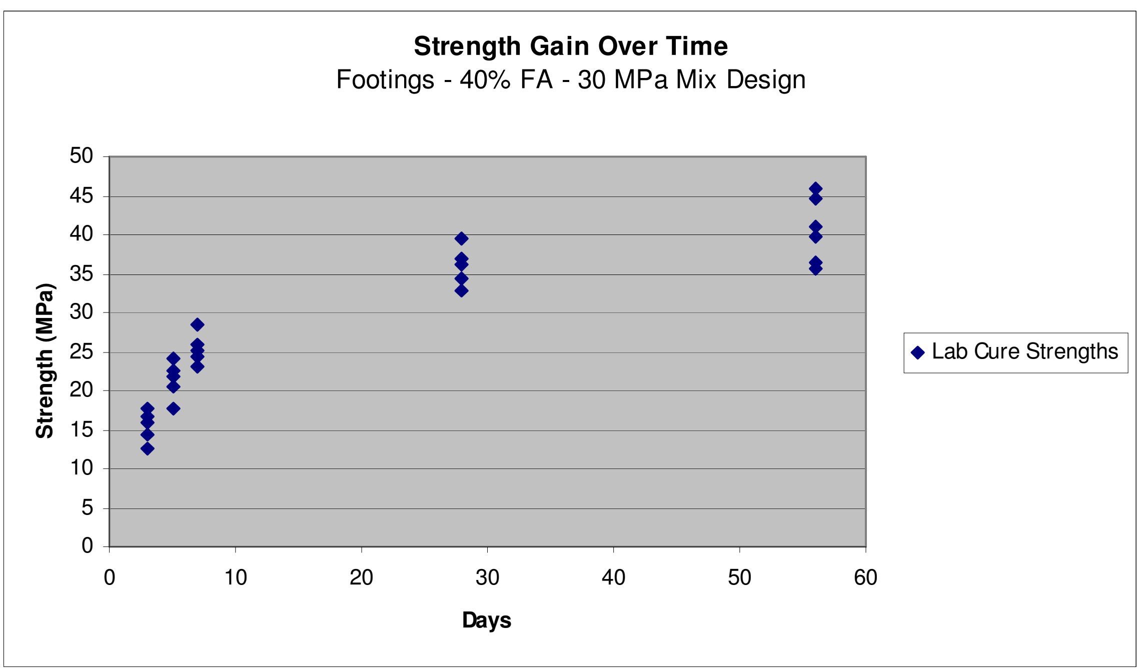

Figure 16: Strength Gain of Lab-Cured Cylinders

Environmental Cost of Winter Construction

The projects used a combination of insulated tarps, 400 000 BTU natural gas heaters, and glycol lines heated by a 1.2 million BTU natural gas fired boiler to thaw the ground, prevent frost from returning to the ground, to pre-heat forms and rebar, and to maintain an ambient temperature above freezing during the initial set of the concrete.

Figure 17: Pouring a slab at Cave Avenue at -25°C

As an estimate of the energy consumption of these units for the Courtyard on Bear site, it could be assumed that on an average day three of the 400 000 BTU heaters would be running constantly, and the 1.2 million BTU glycol heater would be running 50% of the time (as estimated by the contractor). The energy consumption of each 400 000 BTU heater in a 24 hour period is 10 GJ/day[2], and the glycol heater would be 19 GJ/day[3], for a total daily energy consumption of approximately 50 GJ/day. Over a five month period from December to April, the estimated energy consumption of heating the site would be in the range of 5500 GJ of energy[4].

The contractor stated that all of these measures would have been required with standard concrete, and that, with the use of accelerators to speed up the initial set, the heat was not left on any longer than it would have been with standard concrete. However, had the accelerator not been used, the heaters would likely have run at least an extra day after each pour to ensure the EcoSmart concrete was adequately set, resulting in an additional energy consumption over the duration of the project of approximately 1330 GJ[5].

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2 400 000 BTU * 24 hours * (1.05 GJ / 1 million BTU) * 100% efficiency = 10.08 GJ/day for each of 3 units

3 1 200 000 BTU * 24 hours * (1.05 GJ / 1 million BTU) * 80% efficiency * 50% run time = 18.9 GJ/day

4 50 GJ/day * 5 days/week * 22 weeks in 5 months = 5500 GJ over the construction period, assuming that heaters would be turned off during concrete pours, and there would be minimal site activity on the weekends.

5 10.08 GJ/day * 3 units * 2 pours per week requiring one extra day of heating * 22 weeks in 5 months = 1330 GJ

Contractor Comments

Responses from the contractor and his subcontractors have been generally positive, including the following:

- Strength – The strength gain could be managed with proper scheduling and use of accelerators.
- Workability – The workability of the concrete was generally reported to be better than standard concrete. It was described as a "creamier, more flowable concrete," and was easier to finish. The "flowable" characteristic may have been in part due to the addition of superplasticizer.
- Appearance – The finished concrete appearance was not markedly different than standard concrete.

Assessment of Cement "Savings" on the Projects

Although the projects are not yet complete, the following table shows the cement savings anticipated at the time of completion. It is assumed that half of the suspended slabs will be poured with Mix B, as the schedules for the two projects would suggest. Two baselines are used for comparison. The first baseline assumes that if the project did not use EcoSmart concrete, all mixes would have contained 25% fly ash as per the Mix A's. The second baseline is provided to better compare the buildings to other buildings across Canada, where the industry standard for fly ash tends to be in the order of 10% cement replacement.

Project	Cement Use Based on Mix A (25% Fly ash)	Cement Use Based on 10% Fly ash	Actual Cement Use
Courtyard on Bear	599 tonnes	718 tonnes	502 tonnes
Cave Avenue Housing	300 tonnes	360 tonnes	253 tonnes

Table 5: Cement "Savings" on the Projects

For the two projects combined, this means a total cement savings of 323 tonnes of cement over the 10% fly ash baseline, or a 30.0% reduction[6]. It is estimated that each tonne of cement releases 0.9 tonnes of CO_2 into the atmosphere[7]. Therefore, the use of EcoSmart concrete on these projects released 291 tonnes less CO_2 into the atmosphere than it would have if the project had been constructed with standard concrete used across Canada.

[6] 323 tonnes / (718 tonnes + 360 tonnes) * 100 = 30.0%
[7] Neil Cumming and Phillip Seabrooke, "The Role of Concrete in Sustainability", High Volume Fly Ash Concrete. Presentation – AGM APEGBC 2000

4.0 CONCLUSIONS

4.1 Current Practice

The concrete industry in Alberta is currently taking advantage of the use of fly ash in concrete. Although the standard concrete mixes appear to use more fly ash than other areas of Canada, the use of high volume fly ash (30% cement replacement or more) is relatively new.

4.2 Benefits and Impacts

There are many benefits associated with using fly ash in concrete, including increased strength and durability, as well as environmental benefits. The main benefit of using EcoSmart concrete on these projects was the reduction in greenhouse gasses resulting from the reduced cement requirement. The projects were also able to collect valuable data on the use of accelerators and strength gain at lower temperatures, which could be used on future projects in Alberta, and can help promote the use of fly ash with future developers.

Winter construction in general results in increased costs and increased energy consumption. This is true however for construction with both EcoSmart concrete and standard concrete.

The total cost of the concrete on the projects was slightly increased, due to the increased cost of the accelerator used on some pours. Although fly ash is less expensive than cement, the superplasticizer required by the EcoSmart concrete balanced the cost savings incurred by the increased fly ash content. As a result, the cost of the standard concrete was essentially the same as that of EcoSmart concrete. However, as previously noted, the use of accelerator increased the concrete cost up to 13% on those pours that required use of the admixture. As such, the construction schedule was adjusted (at little or no cost to the projects) whenever possible, to avoid the need for accelerator.

4.3 Future Acceptance

There is a fast-growing interest in sustainable design in Alberta. Recent municipal legislation requires all major city-owned projects in Calgary to attain a LEED™ Silver rating or better, and the new LEED Canada credit system has proposed to give the use of fly ash in concrete stronger weight than it currently sees in the US version of LEED. The research and use of high volume fly ash concrete is one means of helping attain the goal of designing more environmentally responsible structures, and its support in the LEED Canada system will help create an awareness and incentive to use EcoSmart concrete more extensively in future construction.

Although the initial strength gain of the EcoSmart concrete remains a challenge, it can be overcome with longer construction schedules or the use of accelerators. In today's market, the costs associated with these solutions may create some resistance, and therefore slow down the incorporation of EcoSmart concrete into general construction.

Overall, the Courtyard on Bear and Cave Avenue Housing projects are on track to reach their common goal to significantly reduce the embodied GHG emissions in the concrete compared to other projects.

5.0 RECOMMENDATIONS

Future projects intending to use EcoSmart concrete should consider creating a schedule that allows for the greatest amount of concrete possible to be poured in the summer months. For cold weather pours (ambient temperatures less than +10°C), accelerators can help speed up initial strength gain, but, whenever possible, the pour sequence could be arranged to allow forms to stay in place as long as possible. This is more realistic for low-rise, large footprint structures than for high-rise structures that reuse forms from floor to floor.

The amount of fly ash used should be reduced for cold weather pours in order to increase initial strength gain, so that the environmental cost of additional heating and hoarding required until initial set is balanced with the cement savings. On these projects, the use of accelerators helped reduce the amount of heating required after pouring the concrete, although the accelerators came at a premium in cost.

Accurate measurements of strength gain are critical when deciding to strip formwork. The field cure cylinders should be carefully monitored to ensure that they are not disturbed, and that they are located to best simulate the temperatures experience by the actual concrete elements. CIPPOC tests (cast-in-place-punch-out cylinder tests), which will be used for the suspended slabs on both projects, have very accurate results. The cylinders are cast into the slab where mechanical sleeves will be required, and are subsequently removed for testing. Therefore the cylinder experiences identical temperatures and curing conditions as the slab itself. Lok test may also be used, however Lok tests may not be as accurate as the CIPPOC tests, as Lok tests generally test the strength of the concrete on the surface, rather than over the depth of the slab.

For the remainder of these projects, further study will be undertaken during the suspended slab pours. It is intended to adjust the W/CM to gauge its effect on strength gain, as stripping time will become more prominent an issue. In addition, since the 56 day strengths are reaching levels considerably higher than the design strengths, some manipulation of the mix designs may be done on non-schedule driven elements to determine if the total cementitious material content could be further reduced.

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