Pavement preservation through the use of long-life concrete pavements while also lowering carbon footprint: Quebec Case Study

Guillaume Lemieux, Director of Markets and Technical Affairs, Quebec and Atlantic Region, Cement Association of Canada

Jean-Claude Leduc, Technical Manager, Holcim Canada

Isabelle Dupré, Quality Supervisor, Demix Construction, divison of Holcim Canada

Paper prepared for presentation

at the Pavement Preservation Session

of the 2012 Conference of the

Transportation Association of Canada

Fredericton, New Brunswick

Abstract

Contempra, also known as GUL according to CSA Standards, is manufactured in Canada by intergrinding regular cement clinker with up to 15% limestone. From an environmental point of view, successful implementation of Contempra cement across Canada would decrease CO2 emissions by 10% while still producing concrete with the same level of strength and durability as concrete produced with regular Portland cement (GU). Contempra contributes to lowering the industry's carbon footprint not only during the manufacturing process, but also beyond. While cement typically represents only 11% of a concrete mix, it accounts for more than 80% of all energy required to produce concrete. The environmental benefits are thus exponential. Once it is adopted for all suitable concrete applications, it is expected to reduce Canada's greenhouse gas emissions by up to 900,000 tonnes annually.

Contempra has been widely used across Europe during the last decade. Today, the European cement standard allows for Portland limestone cement made with up to 35% limestone content. These types of cement are the most popular cement sold in Europe today.

The objective of the research presented in this paper was to assess the performance of concrete pavement made with Contempra cement in comparison with typical GU cement. This project, Highway 40 in Quebec near L'Assomption, was constructed on September 2011. 338m^3 of concrete made with Contempra were placed and assessed. Three laboratories were present to perform quality control testing on the fresh and hardened concrete.

It was noticed that the workability of the concrete was improved using Contempra due to its thixotropic behaviour. For given slump and air content values, concrete made with Contempra cement tended to show a better consolidation throughout the slipform paver than concrete made with GU cement. This resulted in faster and easier finishing operations.

Compared to laboratory testing, that showed faster set times and strength development for concrete made with Contempra cement, no significant changes were observed in terms of early age strength development. Saw cuts were made in a similar time frame and one day compressive strength was in the range of the actual standard deviation.

Finally, additional testing that could significantly affect long-term durability of concrete pavement, such as freezing and thawing, salt scaling resistance, air-void spacing factor, as well as chloride permeability were performed on both reference GU and Contempra concrete mixes. Test results for both concretes showed very similar behaviours.

1. Introduction

1.1 History of the Use of Limestone Additions

Limestone cements have been used in many countries since the 1960's. Schmidt [1] states that large quantities of 20% limestone cements were produced by Heidelberg Cement as early as 1965 for specialty applications. In Canada, CSA A5 has allowed up to 5% limestone in Type 10 cement (now Type GU in A3001) since 1983. Adopted in 2008, CSA A3000 allows the use of Portland-Limestone cement (PLC) manufactured by intergrinding portland cement clinker with between 6% and15% limestone. PLC performance specifications are similar to those of regular Portland cement in that PLC must meet the same CSA A3001 physical requirements as regular portland cement. In 2011, the name "Contempra" was chosen to designate PLC produced by cement producers who are members of Cement Association of Canada.

1.2 Characteristics of Contempra cement

Contempra cement is manufactured by intergrinding regular portland cement clinker with up to 15% limestone. The limestone, being a softer material, is ground more finely than the clinker; however, both the clinker and the limestone in Contempra are more finely ground than regular portland cement. Both the size and distribution of the particles in Contempra play a significant role in the strength of the resulting concrete. This process of achieving the proper size and distribution of particles in Contempra is commonly referred to as "optimizing" the cement. The result of the Contempra optimization process is depicted in Fig. 1 below. Chemical and physical compositions of cements used in this study are also presented in Table 1. The figure on the left represents regular Portland cement with a maximum limestone content of 5%. The figure on the right illustrates the finer particle size of Contempra cement with a maximum limestone content of 15%.

On average, the finely ground limestone fraction in Contempra will be approximately half the particle size of the clinker fraction, which in turn is smaller than the clinker particle size in regular Portland (type GU) cement.

The most recent version of CSA A23.1 Standards allowed use of PLC cement in four of its application; general use (GU), moderate heat of hydration (MH), high early strength (HE), and low heat of hydration (LH). However, in light of mixed results in the area of sulphate resistance, the CSA standards do not permit PLC to be used in sulphate exposure environments. Additional testing in this area is ongoing, and while early results are promising, until more complete test data is available on sulphate resistance, PLC will not be permitted for use in these environments.

1.3 Effects of limestone and ultrafine particles on workability of concrete

According to Hooton et al. [2], there are conflicting results in the published literature in regards to the effect of limestone additions on water demand and workability. Much of these effects can be related to the particle size distribution of the limestone in relation to the cement. Generally, fine limestone particles can enhance the overall particle packing of the binder materials resulting in less space for water between the solid grains. Nedhi et al [3] found that decreasing the average particle size of limestone used as a partial replacement for cement gave better early-age rheological properties.

Tregger et al, [4]) also showed that presence of micro- and nanoclay particles help to improve green strength of concrete without sacrificing workability during its placement. On a day-to -day basis, superior workability for a given slump value may result in improved placement and finishability of concrete.

2. Scope of this study

This study was undertaken to assess performance of Contempra cement for concrete pavement application. The use of Contempra cement, in replacement of GU cement, helps to reduce CO2 footprint of concrete pavement. From a national perspective, adoption of Contempra for all suitable concrete applications is expected to reduce Canada's greenhouse gas emissions by up to 900,000 tonnes annually.

3. Experimental program

On September 9th, 2011, 338 m^3 of concrete pavement made with Contempra cement were placed from 9:14 to 14:30. In comparison, 175.5 m^3 of concrete made with type GU cement were also cast from 14:40 to 17:40. The minimum thickness of the slabs was 225 mm. The project was located on Highway 40, near l'Assomption, Québec. All the concrete poured was unbounded concrete overlays of asphalts pavement (also called conventional whitetopping), as shown in Figure 2. This technique consists as a thick concrete layer (100 mm or greater) on top of an existing asphalt pavement. Conventional whitetopping can be used to improve both structural capacity and functional conditions. The major advantage of whitetopping is that minimal amount of preoverlay repair is required.

Table 2 summarizes concrete mixes design that were developed to compare two pavement sections. Concretes were prepared with crushed coarse aggregate with Maximum size aggregate (MSA) of 20 mm, water/cement ratio (*w/c*) of 0.42, binder content of 340 kg/m^3 made using type GU of Contempra cement. Water reducer, set retarder, and air entraining agent were adjusted to achieve slump values ranged from 20 to 60 mm, and air content from 5% to 8%.

Each concrete mixes were tested for workability characteristics, strength development, and durability requirements, as indicated in Table 3. Those testing were assessed by 3 different laboratories: Université de Sherbrooke representing Demix Construction, le Service des Matériaux du Ministère des Transports du Québec and, Solmatec-Qualitas consortium ensuring quality control of the materials for the entire project.

4. Test results and discussions

4.1 Fresh properties

Table 4 summarizes fresh properties for the concretes that were assessed. For a given air content, air entraining agent dosage were approximately 4 times higher for the concrete made with Contempra cement. This is mainly due to the higher Blaine fineness of the cement that tends to increase packing density of the cement paste matrix.

Concrete made with Contempra cement showed lower slump value (20 mm) compared to the one made with GU cement (35 mm). However, workers noticed that concrete made with Contempra was easier to place and tended to achieve more uniform consolidation. Once again, this is mainly due to the higher Blaine fineness of this cement that increases thixotropic behaviour of the concrete.

No significant changes were also noticed at the jobsite in terms of set time. This is mainly due to the fact that external factor such as weather and, asphalt surface temperature had more effect on this behaviour than cement substitution.

4.2 Compressive and flexural strengths

Figure 3 presents test results for flexural and compressive strengths for the trial. Annual average values for the flexural and compressive strengths for concrete made with GU cement are also included in order to be more representative of the results obtained the season.

As expected, early-age strengths (1 and 3 days) were higher for concrete made with Contempra cement. This higher fineness of the cement provided faster hydration of the cement paste. However, this trend tends to decrease with time as 7 and 28 days compressive strengths were very similar for both samples.

Finally, in terms of flexural strengths, no significant variation was noticed between both concrete. This was also expected because this property is generally affected binder content, water/cement ratio, and sand-to-total aggregate ratio. All these parameters were kept constant for this trial. These results were consistent with MTQ requirements for flexural strength, which is 4.5 MPa.

4.3 Durability

An analysis of air-void quality in hardened concrete is a very good indicator of concrete durability over time. As indicated in Table 5, air-void spacing factors of both samples easily meet MTQ requirement. Higher spacing factor was noticed for the concrete made with Contempra cement. It is mainly due to the lower air content analysed in the hardened concrete sample (7% air content compared to 8.3 for the concrete sample made with GU cement).

In terms of freezing and thawing resistance, both samples easily meet MTQ requirements. The sample made with regular GU cement has slightly higher durability factor. Once again, this can be due to the higher hardened air content of this sample compared to the one made with Contempra cement.

Finally, in terms of durability, both concrete easily exceed MTQ durability specification 0.50 kg/m^2 after 56 cycles, according to NQ 2621-900 standards. In both case, low air-void spacing factor, combined with adequate chloride permeability test results showed that air-void system was well-developed and the absence of connections between air voids.

5. Concluding remarks

Based on the results presented in this paper, the following conclusions can be made:

- Concrete made with Contempra cement perform as well as concrete made with GU cement for pavement application. Fresh and hardened properties meet MTQ requirements.
- Concrete made with Contempra cement requires higher dosage of air entraining agent. This is mainly due to higher Blaine fineness of this cement compared to GU cement;

- Presence of finer particles tends to ease placement and finition of concrete made using Contempra cement compared to GU cement. This is mainly due to the thixotropic nature of this concrete.

Acknowledgement

The authors would like to thank Mrs. Marina Beaudoin, Mrs. Julie Roby, and Mr. Denis Thébeau from Service des Chaussées, division of Ministère des transports du Québec (MTQ). Collaboration of Nadia Pouliot, Alain Hovington, Claude Nazaire, Dave Brindle, and Pascale Larouche from Service des matériaux d'infrastructure from MTQ is also acknowledged. Finally, the authors are also grateful to Mr. Jacques Beaulieu from Qualitas as well Mr. Karim BENGOUGAM and Mr. Arezki Tagnit-Hamou for their technical support.

References

[1] Schmidt, M. 1992a. "Cement with interground additives - Capabilities and environmental relief,Part 1." Zement-Kalk-Gips, 45, 2, 64-69 (English part in 45, 4, 87-92.).

[2] Hooton, R. , Nokken,D., and Thomas, M.D.A. 2007. "Portland-Limestone Cement: State-of-the-Art Report and Gap Analysis For CSA A 3000", University of Toronto, Canada, 59 p.

[3] Nehdi, M., Mindess, S. and Aïtcin, P-C. 1998. "Rheology of high-performance concrete: Effect of ultrafine particles", Cement and Concrete Research, 28, 5, 687–697.

[4] Tregger, N., Pakula, M., and Shah, S.P. 2010. "Influence of Micro- and Nanoclays on Fresh State of Concete, Journal of the Transportation Research Board, No. 2141, Volume 1, Washington D.C., 68-74.

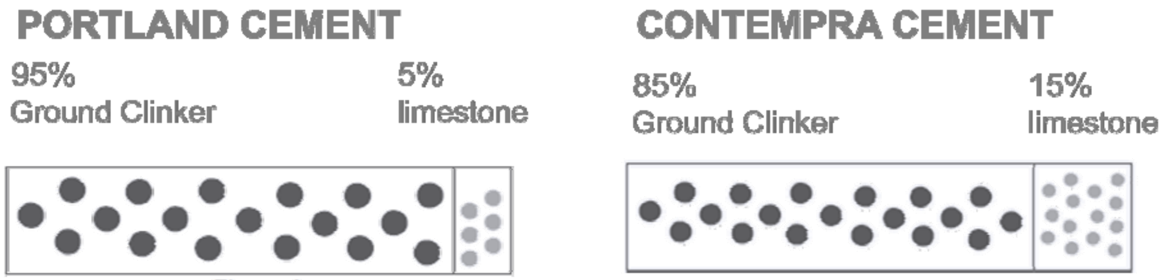


Figure 1: Differences between regular portland cement and Contempra cement

Table 1 – Difference between chemical and physical compositions of tested cements

Cement	Type GU cement	Contempra cement
Physical properties		
Specific gravity	3.15	3.05
Blaine specific surface area, m^2/kg	377	495
Passing No. 325 (45 µm), %	93	97
Chemical composition, %		
Limestone content*	4.5	10.0
SiO_2	20.7	18.7
Al_2O_3	4.3	4.4
Fe_2O_3	2.4	1.7
CaO	62.6	62.0
MgO	2.3	2.2
SO_3	3.5	3.6
Na_2O eq**	0.90	0.76
LOI	2.6	6.0
Fresh and hardened properties		
Initial set time (min.)	155	125
Final set time (min.)	275	205
3-d compressive strength (MPa)	27.5	33.0
7-d compressive strength (MPa)	33.5	39.5
28-d compressive strength (MPa)	42.2	44.9

*Information provided by cement manufacturer (Holcim Canada)

**Na_2O equivalent = $Na_2O + 0.64\ K_2O$

Table 2 - Mixture proportioning and targeted properties of tested concretes

Concrete mix #	1	2
Mixture #	M03213G0	
Cement, kg/m^3	Type GU	Contempra
	340	340
Water, kg/m^3	143	143
w/cm	0.42	0.42
w/cm	0.34	0.40
Sand, kg/m^3	724	724
Coarse aggregate, kg/m^3	1153	1145
Sand/total aggregate, by volume	0.39	0.39
Water reducer, ml/100 kg CM	230	230
Set retarder, ml/100 kg CM	50	50
Air entraining agent, ml/100 kg CM	70	320
Targeted specific gravity, kg/m^3	2358	2349
Targeted Air content, %	5 – 8	
Targeted slump value, mm	20 – 60	
Specified 28-d compressive strength, MPa	35	

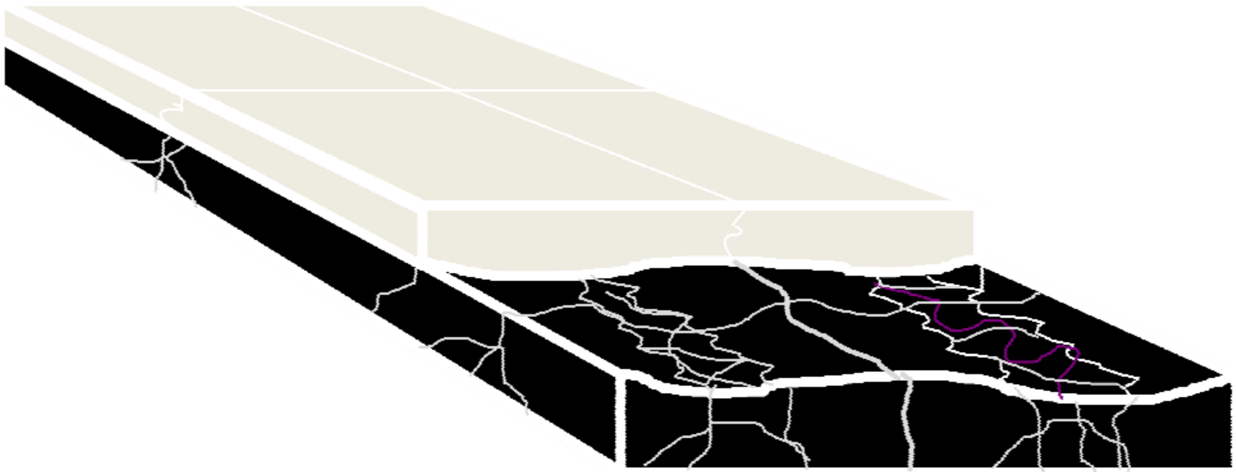


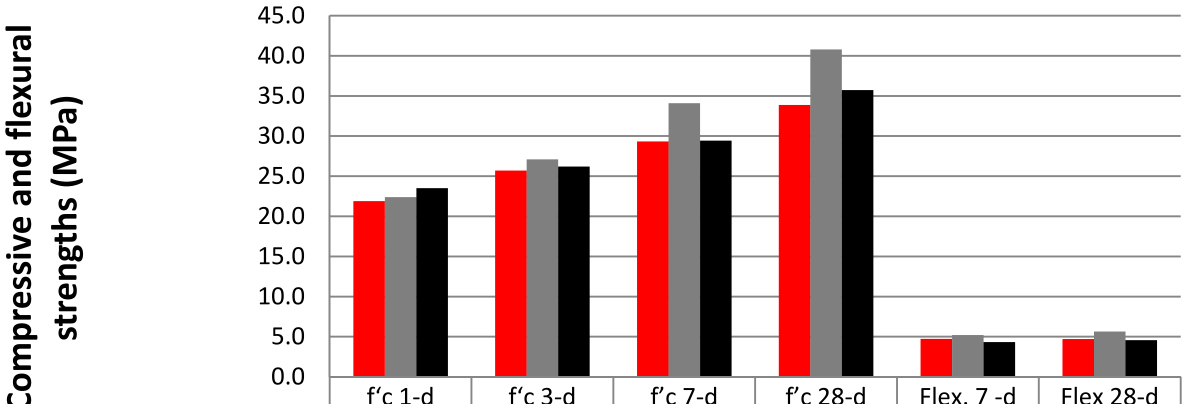
Figure 2: Typical unbonded concrete overlays of asphalt pavement

Table 3 – Summary of testing program

Concrete behaviour	Property	Test Method	Remarks
Workability	Slump, Air content, Temperature	CSA A23.2	Plant & Field
Mechanical properties	Compressive strength	CSA A23.2-9	1,3,7 & 28 days
	Flexural strength	CSA A23.2-8	7 & 28 days
Durability	Air-void spacing factor	ASTM C457	N.A.
	Freezing-thawing	ASTM C666 proc. A	300 cycles
	Salt scaling	NQ 2621-900	56 cycles
	Chloride Ion Penetration	ASTM C1212	28 days

Table 4: Results of fresh properties for concrete tested during the trial

Concrete behaviour \ Cement type	GU Cement	Contempra Cement
Slump at jobsite, mm	35	20
Air content % (AEA dosage ml/100 kg of CM))	6.8 (70)	7.0 (320)
Specific gravity, kg/m^3	N.A.	2297
Concrete temperature, ^oC	26	25.5
Ambient temperature, ^oC	26	26



	f'c 1-d	f'c 3-d	f'c 7-d	f'c 28-d	Flex. 7 -d	Flex 28-d
Average GU Cement (trial)	21.9	25.7	29.3	33.9	4.7	4.7
Average GU (2011)	22.4	27.1	34.1	40.8	5.2	5.7
Average Contempra (trial)	23.5	26.2	29.4	35.7	4.3	4.6

Figure 3: Summary of compressive and flexural strengths

Table 5: Results of durability testing for concrete tested during the trial

Concrete behaviour \ Cement type	GU Cement	Contempra Cement
Air-void spacing factor, µm (MTQ requirement)	137 (≤260)	189 (≤260)
Hardened air content, % (MTQ requirement)	8.3 (≥3)	7.0 (≥3)
Freezing thawing after 300 cycles,% (MTQ requirement)	98 (≥60)	90 (≥60)
Salt scaling after 56 cycles, kg/m^2 (MTQ requirement)	0.035 (≤0.50)	0.095 (≤0.50)
Chloride Ion Penetration, Coulombs	2095	1755