ORAM’S DO-ALL CONTRACTING LIMITED

ENVIRONMENTAL ASSESSMENT REGISTRATION DOCUMENT

GRANT OF LAND FOR EXISTING CONCRETE BATCH PLANT

Prepared By:
Oram’s Do-All Contracting Limited
48 Bayview Heights
Glovertown, NL
A0G 2L0
June 2023

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1 NAME OF THE UNDERTAKING

Land Grant Application

2 PROPONENT

2.1 Name of Corporation

Oram's Do-All Contracting Limited

2.2 Address

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2.3 Executive Officers of the Company

Aubrey Oram, President
Pernell Oram, Vice-President
Pleman Oram, Sect-Treasurer

2.4 Principle Contact Person

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3 THE UNDERTAKING

3.1 *Nature of the Undertaking*

The purpose of the undertaking is to acquire a land grant for an existing portable concrete plant operation located on Bayview Heights, Glovertown, Newfoundland and Labrador. See Figure 1, Figure 2, and Figure 3 for location details.

The portable plant has been in use at the site since 2005. The Town of Glovertown approved and granted a permit on September 15, 2005, for Oram's Do-All Contracting Limited, *"To place and operate a cement batch plant at the quarry site on Bayview Heights, as per letter of application dated August 22, 2005; permit holder must abide by all Municipal Regulations."* An image of the permit is shown in Figure 4.

Oram's Do-All Contracting held yearly quarry permits issued by the Government of Newfoundland and Labrador, Mineral Lands Division for the past 26 years. The Town of Glovertown used this site for storage of old equipment and materials prior to Oram's Do-All Contracting obtaining the permit. The site is located within the boundaries of the Town of Glovertown and located on Bayview Heights. Oram's Do-All Contacting Limited has been using the site since 2005 for the operation of a portable concrete batch plant. The site has already been cleared, and no further construction is considered or proposed, as the business is already established.

3.2 *Purpose/Rationale/Need for the Undertaking*

The purpose of the undertaking is to obtain land for the business, to establish a site for a fixed concrete batch plant operation.

4 DESCRIPTION OF THE UNDERTAKING

4.1 *Geographic Location, Development, and Access*

The area Oram's Do-All Contracting Limited wishes to acquire is located on Bayview Heights, Glovertown. The site is within the boundary of the Town of Glovertown and is approximately 1.7 Hectares. It is bounded by Crown land on the North, South and East, and bounded by Bayview Heights on the West. The attached Figure 2 and Figure 3 show satellite images of the area and its boundaries. Adjacent to the boundary on the North is an additional quarry belonging to Oram's Do-All Contracting Limited, quarry permit # 147815.

The site is cleared, and an existing portable concrete batch plant along with aggregate stockpiles are located on the site. The plant and site were established and approved by a permit from the Town of Glovertown in 2005.

The site is accessed by Bayview Heights road, which runs adjacent to the site.

4.2 *Pollution Control*

Dust control measures, such as bag housing for dust control, have been installed on the silo to prevent/lessen dust during operation and when the silo is being filled. Figure 5 and Figure 6 show the installed bag silo. Dust control by water applications is provided on a regular basis as required and is implemented as a standard operating procedure of the business.

All equipment and vehicles have appropriate emission controls, working exhaust and muffler systems, and are properly maintained to minimize noise. They are regularly inspected and maintained by an off-site approved garage. In addition, all equipment and vehicles are regularly visual inspected to detect and prevent leaks and spills.

Petroleum products are stored and handled as per Storage and Handling of Gasoline and Associated Products Regulations, under the Environmental Protection Act. All wasted hazardous materials are handled according to the Environmental Protection Act and disposed of in accordance with the government laws and regulations at an appropriate off-site hazardous waste disposal facility.

Fuel is stored in a 1500 liter above ground double walled fuel storage tank, which is filled by a licensed and approved agent. Spill kits are located onsite, in all vehicles, and equipment.

Concrete additives are stored in approved, sealed containers and transferred and used in a manner that prevents loss of materials to the environment.

There are no washroom facilities on site, and instead they are located off site, at 48 Bayview Heights. All garbage and hazardous materials are collected and disposed of at the landfill site as required by the Town of Glovertown and Central Newfoundland Waste Management. There is no dumping of garbage or hazardous materials at the site.

All wash water is collected in a wash-out pit to prevent sediment and erosion. The wash water is recycled from the wash-out pit back into the operations for dust suppression when and where feasible. Drawings for the wash-out pit are shown in Figure 7 and Figure 8.

4.3 CO2 Reduction

Oram's Do-All Contracting Limited is one of the few operations that use Portland GU-L cement that has shown to be more environmentally friendly in the production by reduction of CO_2 during manufacturing of making the powder than the production of GU cement [1] [2].

4.4 *Operations*

Oram's Do-All Contracting Limited has been in business for over 40 years, incorporated on May 04, 1984. The batch plant and operations have been in operation since 2005 since the Town of Glovertown issued a permit. The batch plant's typical months of operation are from May to October, and in accordance with demand for the product. The operation is small and consumes approximately 550 MT of Portland GU-L cement per year. Normal batching methods are employed using a plant that is equipped with resources that ensure the lowest impact possible on the environment. Raw materials are washed offsite when required, trucked to site where they are stockpiled to be used in the cement batching operations. Oram's Do-All Contracting Limited regularly employs 8–10 employees.

4.5 *Funding*

There will be no extra funding required, and all expenses associated with acquiring the land will be funded by Oram's Do-All Contracting Limited.

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Pleman Oram
Secretary-Treasurer
Oram's Do-All Contracting Limited

References

[1] Lafarge, "Lafarge Onecem Brochure," 14 June 2021. [Online]. Available: https://www.lafarge.ca/sites/canada/files/documents/lafarge_rebrand_onecem_brochure_en.pdf. [Accessed 13 June 2023].

[2] M. C. K. B. B. D. A. M. P. &. K. K. Thomas, "Use of Low-CO2 Portland Limestone Cement for Pavement Construction in Canada," *International journal of pavement research and technology,* vol. 3, pp. 228-233, 2010.

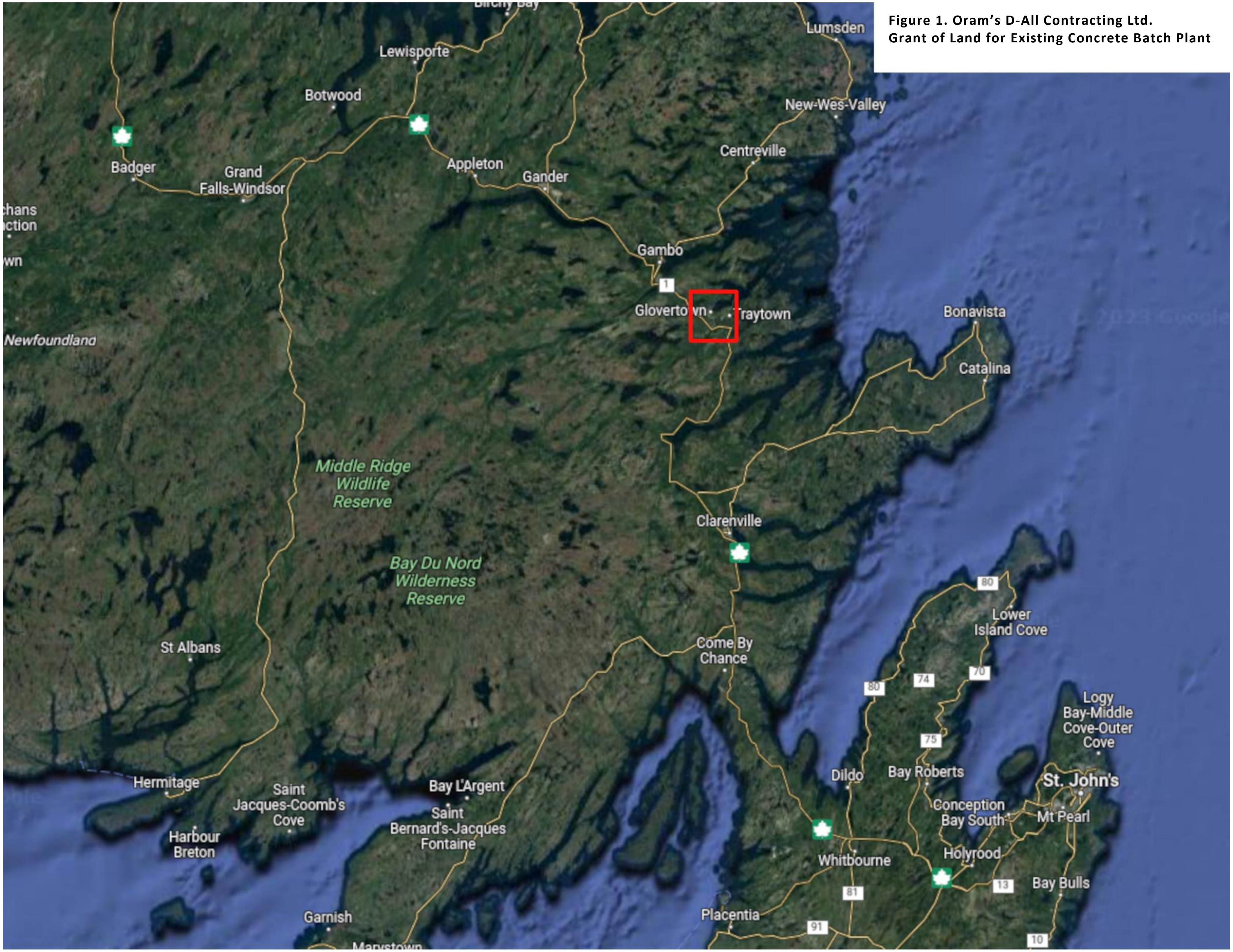


Figure 1. Oram's D-All Contracting Ltd.
Grant of Land for Existing Concrete Batch Plant

Figure 2. Proposed Grant Location
Bayview Heights, Glovertown, NL

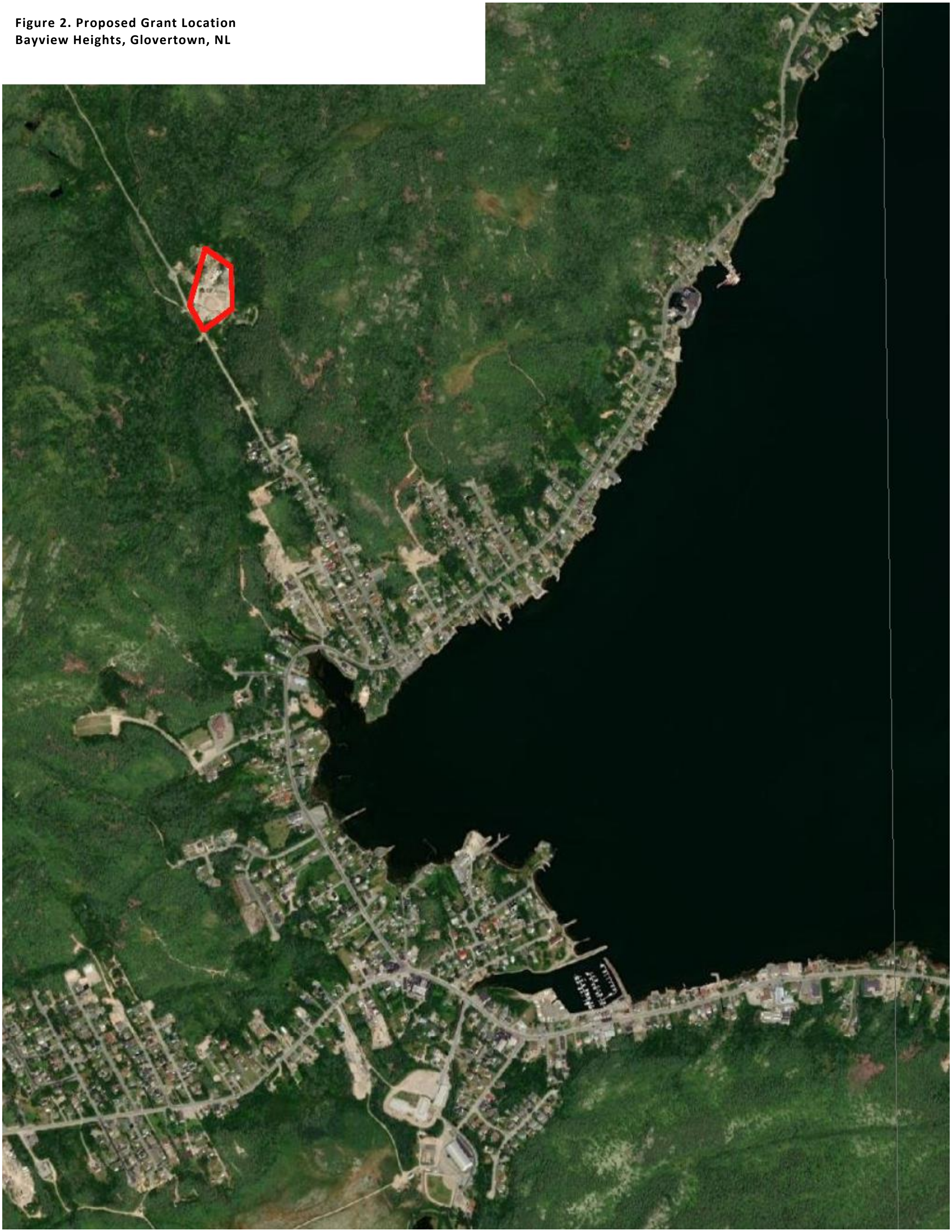


Figure 3. Proposed Grant Location Site View

THE TOWN COUNCIL OF GLOVERTOWN

PERMIT GRANTED

NAME: ORAM'S DO ALL CONTRACTING **NO:** 5977

ADDRESS: GLOVERTOWN, NL **DATE:** Sept. 15, 2005

SPECIFICATIONS:

To place and operate a cement batch plant at the quarry site on Bayview Heights, as per letter of application dated August 22, 2005; permit holder must abide by all Municipal Regulations.

Town of Glovertown

Figure 4. Permit to place and operate a cement batch plant, issued by the town of Glovertown, NL

Figure 5. Concrete Batch Plant Silo with Bag House

Figure 6. Portable Concrete Batch Plant

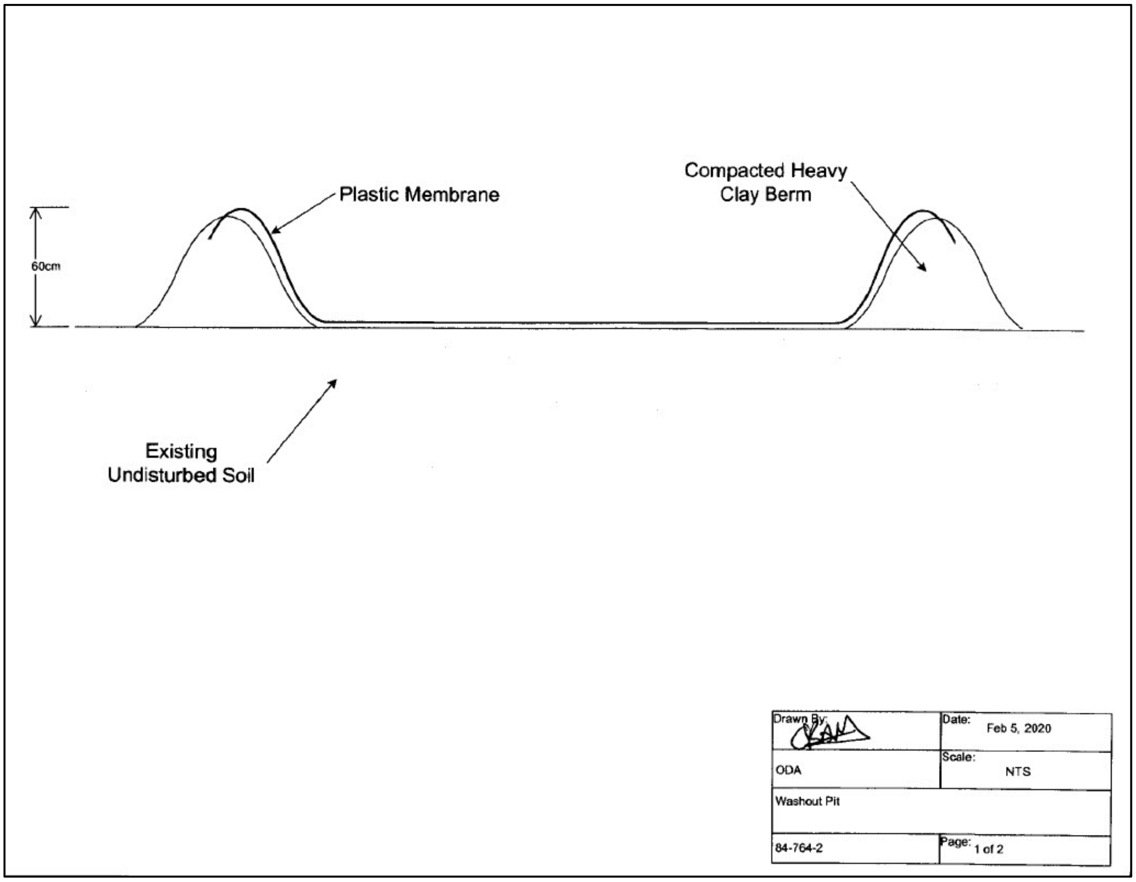


Figure 7. Washout Pit Drawing, side view

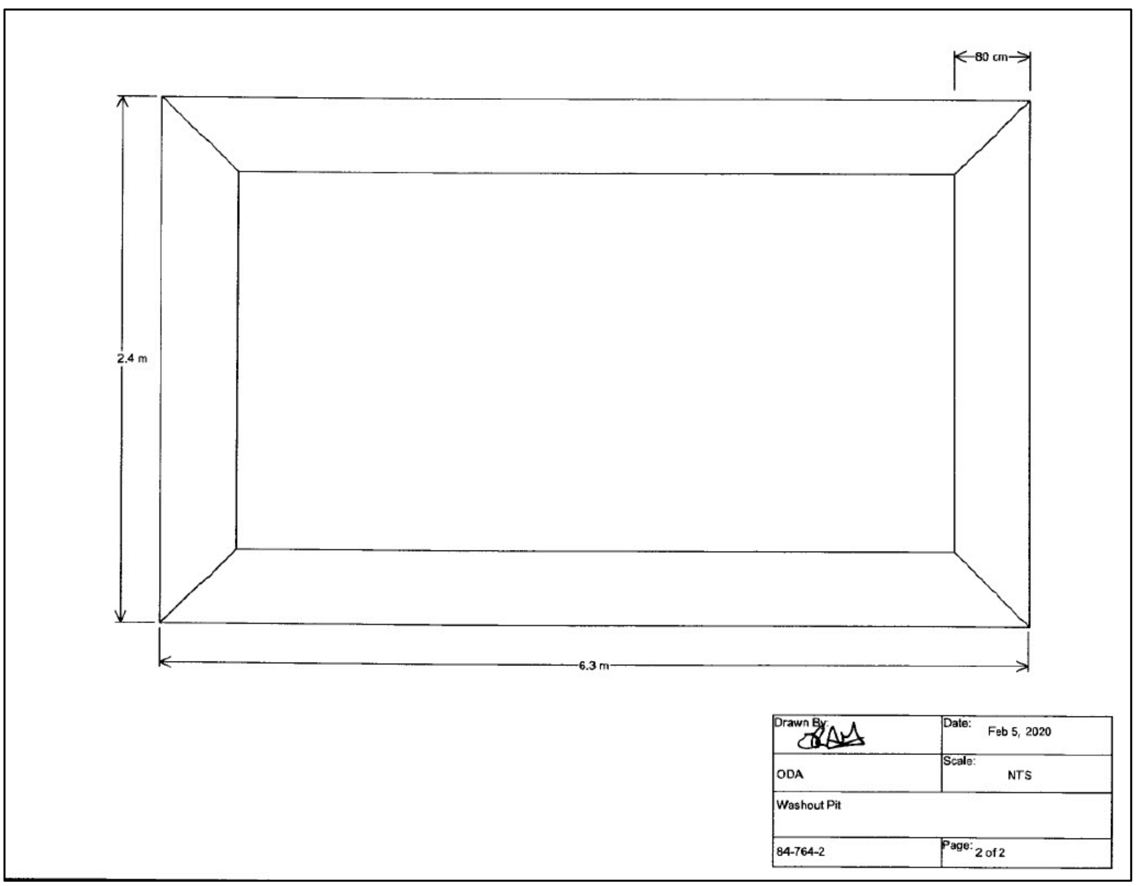


Figure 8. Washout Pit Drawing, top view

References

LAFARGE

www.lafarge.ca

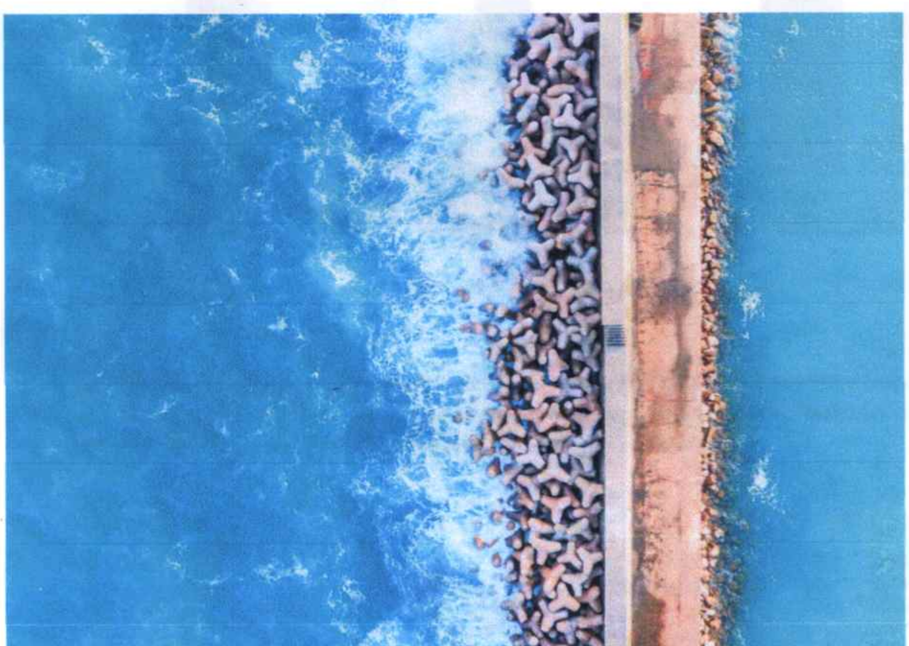
OneCem® Portland Limestone Cement

The One Cement You Need for a Successful Project.

Introducing OneCem portland limestone cement. OneCem is a blended cement in which finely ground limestone (5 to 15%) is an integral component within the cement. OneCem has been designed to perform similarly to existing cements and is rigorously tested to verify its performance. OneCem is currently manufactured according to CSA A3001-18 Cementitious materials for use in concrete.

Sustainability

Growing concerns about climate change and the environmental impact of building materials have been driving forces for the development of sustainable solutions for concrete. GUL cement offers the same level of performance and workability as GU cement. Manufactured with quality limestone, GUL cement uses the same materials as GU cement with less clinker reducing CO_2 emissions by 5 to 10 percent.



Technical Information

OneCem portland limestone cement meets CSA A3000 standard specifications for hydraulic cements Type GUL cement. Type MSL or HSL requirements may also be met. Ask your local sales representative for more information.

Applications

GUL cement is suitable for use in almost all cement and concrete application with minimal or no changes needed when switching from GU to GUL cement for normally proportioned concrete mix designs. It is used in all ready-mixed concrete, architectural and structural precast, concrete blocks and paving, and geotechnical applications. GUL cement does not increase the likelihood of efflorescence in masonry applications.

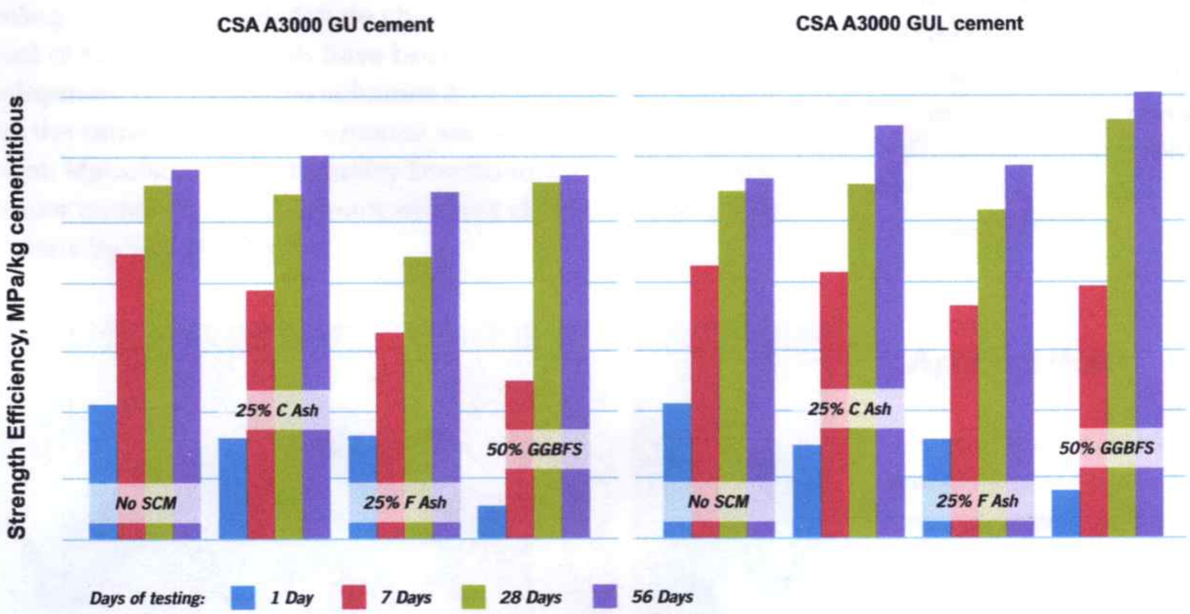
LAFARGE

Performance

Our plants have targeted the performance of OneCem to perform similar to the GU cement produced at the same facility, based on extensive testing and evaluation. The performance targets encompass both fresh and hardened concrete properties. These properties include durability evaluations in addition to the usual strength requirements. It has been found in many studies by Lafarge Canada, third parties and academia that a positive interaction exists between portland limestone cement and supplementary cementitious materials (SCM) such as fly ash and slag cement (ground granulated blast-furnace slag, GGBFS).

Experience

Lafarge has produced over 6 million metric tonnes of GUL cement since 2011, and users can be confident in its performance whilst reducing the carbon footprint in the built environment and community. Lafarge uses GUL cement in ready-mixed concrete applications, without adjustment or impact to admixtures type or dosage. Whether there is a need for sustainable products or a demand for a consistent product, GUL cement meets your needs. With minimal changes, GUL cement is the easiest material switch to reduce impacts whilst driving for consistency and overall performance.



Data from "Shrinkage and Durability Study of Bridge Deck Concrete," MS DOT State Study 216, Burns Cooley Dennis, Inc.; Dec. 2010; concrete strength comparison of RS mixes, agg source #1. The performance of individual material combinations may vary. Testing is recommended to determine their performance characteristics.

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RESPONSE OF PORTLAND LIMESTONE CEMENT CONCRETE TO HIGH CONCENTRATION OF CHLORIDE-BASED SALTS

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Paper prepared for presentation

at the soils & materials Session

at the 2020 TAC Conference & Exhibition

Abstract: General use limestone (GUL) cement is now permitted in the production of all classes of concrete in Canada. Its contribution to reduction in greenhouse gas emissions and sustainable construction is the main driving force for its development globally. However, there has been dearth of information on the effect of GUL on performance of concrete exposed to high concentration of chloride-based salts. Therefore, the aim of this study is to investigate the response, in terms of physico-mechanical properties and microstructural features, of concrete made with GUL without or with fly ash to highly concentrated chloride solutions (NaCl, $MgCl_2$ and $CaCl_2$). A continuous immersion exposure at 5°C was used to promote formation of complex salts (oxychlorides). The results revealed that GUL mixtures exhibited better resistance to de-icing salts due to synergistic physical and chemical actions of limestone in the cementitious matrix. The resistance of concrete exposed to de-icing salts is a function of physical penetrability (magnitude of intruding solution), amount of aluminate in cement and content of portlandite available for chemical reactions in the hydrated paste. The incorporation of high volume fly ash (30%) had a pronounced effect on improving the concrete resistance to damage as reflected by sound mechanical properties and longevity.

Keywords: General use limestone cement; Fly ash; De-icing salts; Physical and chemical resistances; Oxychlorides.

ACKNOWLEDGEMENTS

The authors highly appreciate the financial support from Natural Sciences and Engineering Research Council of Canada, University of Manitoba and City of Winnipeg. The IKO Construction Materials Testing Facility and Manitoba Institute for Materials at the University of Manitoba in which these experiments were conducted have been instrumental to this research.

INTRODUCTION

General use limestone (GUL) cement, containing up to 15% limestone powder, has been introduced in the Canadian market and is now permitted in the production of all classes of concrete in the latest version of CSA 23.1 (CSA 2019). Its contribution to reduction in greenhouse gas emissions and sustainable construction is the main driving force for its development globally. Reducing the clinker content of cement by up to 15% will effectively reduce the CO_2 emissions associated with its production by the same amount. Therefore, it is expected that the future world production and use of GUL will significantly increase due to its ecological benefits.

While there are a number of studies on the hydration and strength characterization of concrete made with GUL cement (e.g. Li et al., 2017; Marzouki et al., 2013; Ramezanianpour and Hooton, 2013) and its response to durability issues such as sulfate attack (e.g. Ramezanianpour and Hooton, 2013), acidic attack (e.g. Amin and Bassuoni, 2018) and chloride ions penetration (e.g. Thomas et al., 2014), there has been dearth of information and field experience regarding the effect of GUL on the performance of concrete exposed to high concentration of de-icing salts. These types and concentrations of de-icing salts are comparable to that applied by different transportation agencies in North America (e.g. Policy on Snow Clearing and Ice Control, 2017; Minnesota Snow-Ice Control-Field Handbook for Snow Plow Operators, 2017) based local availability of the de-icing salt and effective freezing temperature in each region.

Recent studies by the Cementitious Materials research group at the University of Manitoba showed that GUL mixtures exhibited better resistance to freezing/thawing cycles combined with moderate concentration of de-icing salts (Ghazy and Bassuoni 2018). However, the adverse effects of high concentration of de-icing salts on concrete have been a key durability issue and a subject of extensive investigation, especially under continuous immersion at low temperatures (4–10°C) exposures (Ghazy and Bassuoni, 2017; Peterson et al., 2013). Generally, moderate concentration of de-icing salts can aggravate damage by increasing the level of moisture saturation and osmotic pressure in concrete, as well as due to the increased volume of salt crystallization during drying periods (Ghazy and Bassuoni 2018). However, damage can also be aggravated by interaction between concrete and de-icing chemicals, resulting in leaching and decomposition of cement hydration products when high concentration of de-icing salts are used (Ghazy and Bassuoni 2018; Ghazy and Bassuoni, 2017; Peterson et al., 2013).

OBJECTIVES

Given the current stipulations of specifications regarding the limits for GUL cement, the current study focus on substantiating the potential benefits of GUL cement, if any, in mitigating the adverse effects of high concentration of de-icing salts on concrete; hence, improve the current specifications and guidance for concrete exposed to extensive use of de-icing salts and consequently, the wider use of GUL cement in transportation infrastructure in North America.

EXPERIMENTAL PROGRAM

Materials and mixtures

General use limestone (GUL) cement with 11.3% limestone powder content, which meets the requirements of the CAN/CSA-A3001 standard (CSA 2019), was used as the main component of the binder. General Use (GU) cement, which represents typical concrete pavements cement in North America, was also used as a reference. In addition, Type F fly ash (designated as F) conforming to CSA A3001 (CSA, 2018) was used at dosages of 20% and 30% by the total binder content (i.e. 80 and 120 kg/m^3, respectively). The chemical and physical properties for GUL, GU, and fly ash are shown in **Table 1**. Six concrete mixtures were tested in this study; the total binder (GUL or GU cement and fly ash) content in all mixtures and the water-to-binder ratio (*w/b*) were kept constant at 400 kg/m^3 and 0.4, respectively. **Table 2** shows the mixture design proportions of the concrete tested in this study.

The target consistency of fresh concrete was achieved by high-range water reducing admixture (HRWRA) based on polycarboxylic acid and complying with ASTM C494 (ASTM, 2016c), Type F. This HRWRA was added at variable dosages (0 to 475 ml per 100 kg of the binder) to the mixtures in order to maintain a slump range of 50 to 100 mm. In addition, an air-entraining admixture was used to obtain a fresh air content of 6 ± 1%. The coarse aggregate used was mostly natural gravel (max. size of 9.5 mm) with a small proportion of carboniferous aggregate; its specific gravity and absorption were 2.65 and 2%, respectively. The fine aggregate was well-graded river sand with a specific gravity, absorption, and fineness modulus of 2.53, 1.5% and 2.9, respectively.

Constituent materials were mixed in a mechanical mixer and cast in prismatic molds (50×50×285 mm) to prepare triplicates for each mixture. Also, eight replicate cylinders (100×200 mm) were prepared in order to evaluate the compressive strength (**Table 2**) according to ASTM C39 (ASTM, 2016b), and the penetrability of chloride ions into concrete mixtures. The specimens were demoulded after 24 h and then cured for 28 days at standard conditions (22±2 °C and 98% RH) according to ASTM C192 (ASTM, 2016a). The curing period was kept constant to provide a uniform basis of comparison among all mixtures.

Table 1: Chemical composition and physical properties of GU cement, GUL and Fly Ash

	GU	GUL	Fly Ash
SiO_2 %	19.21	18.9	55.20
Al_2O_3 %	5.01	4.4	23.13
Fe_2O_3 %	2.33	3.2	3.62
CaO %	63.22	63.4	10.81
MgO %	3.31	0.7	1.11
SO_3 %	3.01	2.7	0.22
Na_2O_{eq} %	0.12	0.3	3.21
Specific Gravity	3.15	3.11	2.12
Mean Particle Size, µm	13.15	11.81	16.56
Blain Fineness, m^2/kg	390	454	290

Table 2: Proportions of mixtures per cubic meter of concrete

Mixture ID.	Cement (kg/m³)	Fly Ash (kg/m³)	Nanosilica (kg/m³)	Water[a] (kg/m³)	Coarse Aggregate (kg/m³)	Fine Aggregate (kg/m³)	28 day Compressive Strength (MPa)
GU group							
GU	400	--	--	160	1096	590	40 (0.3)[a]
GUF20	320	80	--	160	1077	580	38 (0.7)
GUF30	280	120	--	160	1068	575	35 (1.1)
GUL group							
GUL	400	--	--	160	1096	590	46 (0.4)
GULF20	320	80	--	160	1077	580	43 (1.2)
GULF30	280	120	--	160	1068	575	40 (0.8)

[a] The values between brackets in the last column are the standard errors

Exposures

To evaluate the durability of the tested mixtures to chloride-based de-icing salts, a continuous immersion exposure in which prismatic specimens were fully immersed in high concentration solutions of various de-icing salts at 5 °C up to 540 days was used. Sodium chloride (NaCl), dihydrate form of calcium chloride ($CaCl_2 \cdot 2H_2O$) and hexahydrate form of magnesium chloride ($MgCl_2 \cdot 6H_2O$) with purity of 99, 96 and 96%, respectively were used to prepare the solutions. **Table 3** shows the concentrations of the de-icing solutions used in the present study. Also, for better comparison between the de-icers used, an equal number of chloride ions (~160,000 ppm) among the three solutions was used to maintain similar ionic concentration of chloride ions in each solution. The solutions were renewed every four weeks to keep a continual supply of de-icing salts, thus providing aggravated damage conditions.

Table 3: Concentration of the de-icing salt solutions

Type of Salt	Salt Concentration Mass (%)	Chloride Concentration (mol/l)	Chloride Concentration[a] (ppm)
NaCl	23.3	4.52	160,071
$MgCl_2$	19.1	4.52	160,069
$CaCl_2$	21.9	4.51	160,067

[a] The ionic concentration of Cl^- ions in each solution was verified by ion chromatography (ASTM D 4327, 2011)

Tests

In order to evaluate the physical resistance, the rapid chloride permeability test (RCPT) was performed according to ASTM C 1202 (ASTM, 2012) on four specimens from each mixture. To minimize the effects of electrolysis bias and temperatures on the trends, the penetration depth of chloride ions/front into concrete, which better correlates to the physical characteristics of the pore structure, was determined (Bassuoni et al., 2006). Following the RCPT, the discs were axially split and sprayed with 0.1 M silver nitrate solution which forms a white precipitate of silver chloride, to measure the average physical penetration depth of chloride ions.

Before exposure, the initial physico-mechanical properties of the intact specimens were measured. The initial mass and length (ASTM C 157 (ASTM, 2014a)) were measured before exposure. Specimens were removed from the solutions at specified time intervals (every 2 weeks), and the free expansion of prisms was immediately measured. Subsequently, debris, if any, were removed by a nylon brush, and the specimens were left to dry under 23±2°C and 50% RH for 30 min before visual inspection and measurement of mass. Relative to the initial values, the changes in mass and length versus time of exposure were calculated. The alteration of microstructure in deteriorating specimens was assessed by mineralogical and thermal analyses using X-ray diffraction (XRD, Cu-Kα) with a scanning rate of 0.5°/min and differential scanning calorimetry (DSC) with an incremental heating rate of 10°C/min on powder samples collected from the surface of specimens (within 10 mm). These specimens were first kept in a desiccator containing calcium sulfate for 5 days at 5±2°C. Subsequently, the powder was prepared from selected fracture pieces (not including large coarse aggregate) of specimens, which were pulverized to a fine powder passing through sieve #200 (75 μm).

RESULTS

Visual assessment and mass change

The condition of the specimens was regularly assessed visually (e.g. **Figure 1**). Also, the mass change of specimens with time was measured and summarized in **Table 4**. Up to 540 days of exposure, specimens from all mixtures subjected to continuous immersion in the NaCl solution experienced a steady mass gain (maximum of 2%) with time, without any distinctive visual features of damage. Comparatively, the reference specimens (GU and GUL) and specimens made with binary binders containing 20% fly ash (GUF20 and GULF20) exposed to $MgCl_2$ solution developed blisters at the surface, and the skin of the specimens started to peel off at approximately 90 to 180 days. With time, the deterioration was advancing with visible gel-like compound on/below the surface of the specimens accompanied by high intensity of cracks. Eventually, these specimens were softened, disintegrated, and showed notable swelling and mass loss (**Table 4**); thus, the physico-mechanical measurements were discontinued for these specimens. Similar features of damage were observed for both GU and GUL groups, except that the GUL group (GUL and GULF20) survived longer (**Table 4**) than the GU group (GU and GUF20). Specimens made with binary binders containing 30% fly ash (GUF30 and GULF30) were intact with no evidence of degradation up to the end of the exposure (540 days). $CaCl_2$ solution was the most aggressive solution as the rate of deterioration of specimens was very rapid. Micro-cracks along the edges of all specimens and clear separation of the surface layer from the rest of the specimen were the main features of damage at early stages of exposure. Additional cracks parallel to the edge of prisms progressively appeared and the deterioration of these specimens proceeded until complete disintegration due to macro-cracks with high magnitude of mass loss (**Table 4**), except specimens made with binary binders containing 30% fly ash and GUL cement (GULF30) were intact with no evidence of degradation up to the end of the exposure.

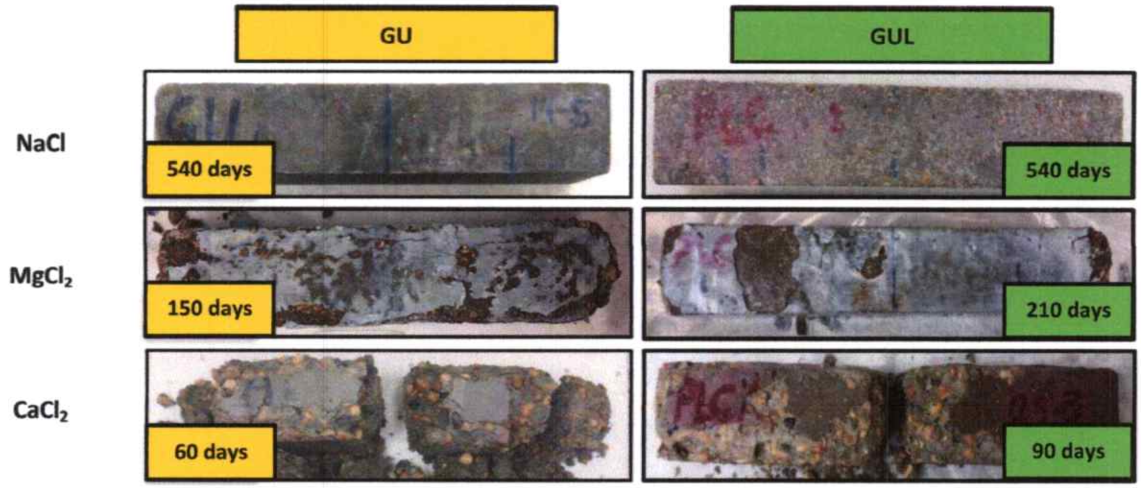

Figure 1: Exemplar visual features of damage for the reference specimens (GU and GUL) exposed to different de-icing salts.

Table 4: Results of mass change, expansion, and time of last measurement

Mixture ID.	NaCl			$MgCl_2$			$CaCl_2$		
	Mass change (%)	Expansion (%)	Time* (days)	Mass change (%)	Expansion (%)	Time* (days)	Mass change (%)	Expansion (%)	Time* (days)
GU group									
GU	1.0	0.02	540	- 20.6	1.56	150†	- 30.6	2.80	60†
GUF20	1.0	0.02	540	- 14.0	0.64	330†	- 25.5	1.07	180†
GUF30	2.0	0.03	540	1.0	0.05	540	- 17.8	0.70	360†
GUL group									
GUL	1.5	0.02	540	-16.3	1.11	210†	-21.4	2.14	90†
GULF20	1.0	0.02	540	-11.1	0.43	490†	-19.3	0.74	265†
GULF30	1.0	0.03	540	0.0	0.03	540	0.0	0.02	540

*Refers to the time of the last measurement.
†Specimens failed after this stage.

Expansion

Table 4 shows the total expansion of all specimens. The expansion was low (maximum of 0.03%) for all specimens immersed in the NaCl solution compared to other solutions. In contrast, the GU and GUL groups immersed in the $MgCl_2$ and $CaCl_2$ solutions showed high expansion before failure (**Table 4**), except binary binders containing 30% fly ash and GUL cement (GULF30). Generally, the GUL group exhibited notably low expansion compared to the GU group. For example, the control GUL specimens immersed in the $MgCl_2$ and $CaCl_2$ solutions yielded an expansion of 1.11% and 2.14% (reduction of 29%

and 24%, respectively) after 210 and 90 days (**Table 4**). Also, incorporating fly ash in the binder notably decreased the magnitude of the expansion irrespective of the type of solution. For example, the binary binders containing 20% fly ash (GUF20) immersed in the $MgCl_2$ and $CaCl_2$ solutions yielded an expansion of 0.64% and 1.07% (reduction of 59% and 63%, respectively) after 330 and 180 days (**Table 4**). The effect of fly ash was more pronounced in the GUF30 and GULF30 specimens. No expansion was recorded for both specimens immersed in the $MgCl_2$ solution and GULF30 specimens immersed in the $CaCl_2$ solution. Also, the GUF30 specimens immersed in the $CaCl_2$ solution yielded an expansion of 0.70% (reduction of 75%) after 360 days (**Table 4**).

RCPT

The physical resistance of all specimens after curing for 28 days was evaluated by the RCPT and the results are listed in **Table 5**. After completing the RCPT, the physical penetration depth of chloride front was measured for concrete specimens as indicated by the whitish precipitate (**Figure 2**). Also, the non-steady-state migration coefficient was calculated based on the penetration depth, geometry of specimen, applied voltage, temperature of the anolyte solution and test duration, according to NT BUILD 492 (2011), to account for the heat (Joule) effect and different testing durations, if any, on ionic mobility within specimens.

The control GUL specimens showed about 26% reduction in penetration depth relative to the control GU specimens. This might be due to the higher fineness of the PLC (460 m^2/kg) in comparison with the GU (390 m^2/kg), due to intergrinding of limestone powder with clinker, which can improve the hydration process and microstructural evolution of concrete (Ramezanianpour and Hooton, 2014). In addition, the filler effect resulting from the continuous particle size distribution of GUL may yield better particle packing in the matrix (Ghiasvand et al., 2015). However, this trend was invalid or diminished for the other mixtures due to the predominant effect of fly ash (e.g. compare mixes GULF20 and GULF30 with, respectively, GUF20 and GUF30). This trend highlights the role of fly ash in refining and densifying the pore structure of the matrix and thus reducing its penetrability.

Table 5: RCPT Results

Mixture ID.	**Charges Passed (coulombs)**	**Chloride Ions Penetrability Class, ASTM C1202**	**Average Penetration Depth (mm)**	**Migration Coefficient, $\times10^{-12}$ (m^2/s)**
GU group				
GU	2248	Moderate	17.6 [0.94][a]	17.67
GUF20	1527	Low	12.8 [0.64]	10.16
GUF30	1253	Low	10.1 [0.57]	8.16
GUL group				
GUL	1867	Low	13.1 [1.07]	12.93
GUL20	1370	Low	11.4 [1.14]	9.81
GULF30	917	Very Low	9.4 [0.96]	8.01

[a] Standard error is shown between brackets

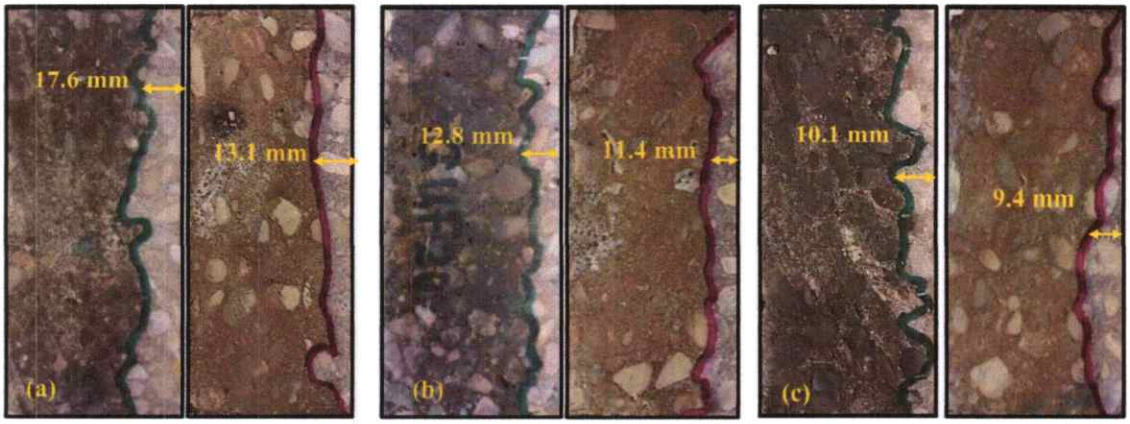

Figure 2: Whitish precipitates showing the average penetration depth of chloride ions in specimens (GU left and GUL right): (a) control mixture, (b) mixtures with 20% fly ash, and (c) mixtures with 30% fly ash.

DISCUSSION

Effect of type of solution

The mechanisms of damage were similar for both GU and GUL group within each salt solution. Thus, in this section, the GUL specimens are presented in order to demonstrate these mechanisms for each salt solution. Subsequently, the effect of type of cement and fly ash on the mechanisms of damage will be discussed.

No signs of deterioration were observed for all specimens immersed in NaCl solution. Portlandite, calcite, quartz and dolomite were shown in the XRD similar for the corresponding specimens immersed in deionized water, except Friedel's salt and ettringite peaks were observed (**Figure 3**). Binding chloride ions by aluminate phases to form chloroaluminate phases such as Friedel's salt may not be detrimental to the integrity of the hydrated cement paste as no marked symptoms of expansion, cracking, spalling and softening were observed for the specimens. The peaks of dolomite and calcite might have occurred because the coarse aggregate contained a fraction (about 10 to 15%) of carboniferous aggregate, while the sources of quartz in the diffractograms originated from the siliceous coarse aggregate and sand in all mixtures.

For $MgCl_2$ solution, the XRD patterns showed dominant phases of magnesium oxychloride (in various forms; 3- and 5-form), brucite, gypsum, quartz, dolomite and calcite (**Figure 3**). This might be attributed to the saturation of the pore fluid with respect to magnesium, calcium, chloride, and hydroxyl ions. The major cause of deterioration by $MgCl_2$ is likely the chemical activity resulting in formation of relatively expansive (magnesium oxychloride) and softening (gypsum) phases.

Calcium oxychloride, Friedel's salt and ettringite were the main reaction phases detected in the XRD patterns (**Figure 3**). Also, portlandite diminished due to its consumption in the formation of calcium oxychloride. Formation of calcium oxychloride was accompanied by significant expansion and cracking, which led to the notable disintegration of specimens, as shown earlier in the Results Section.

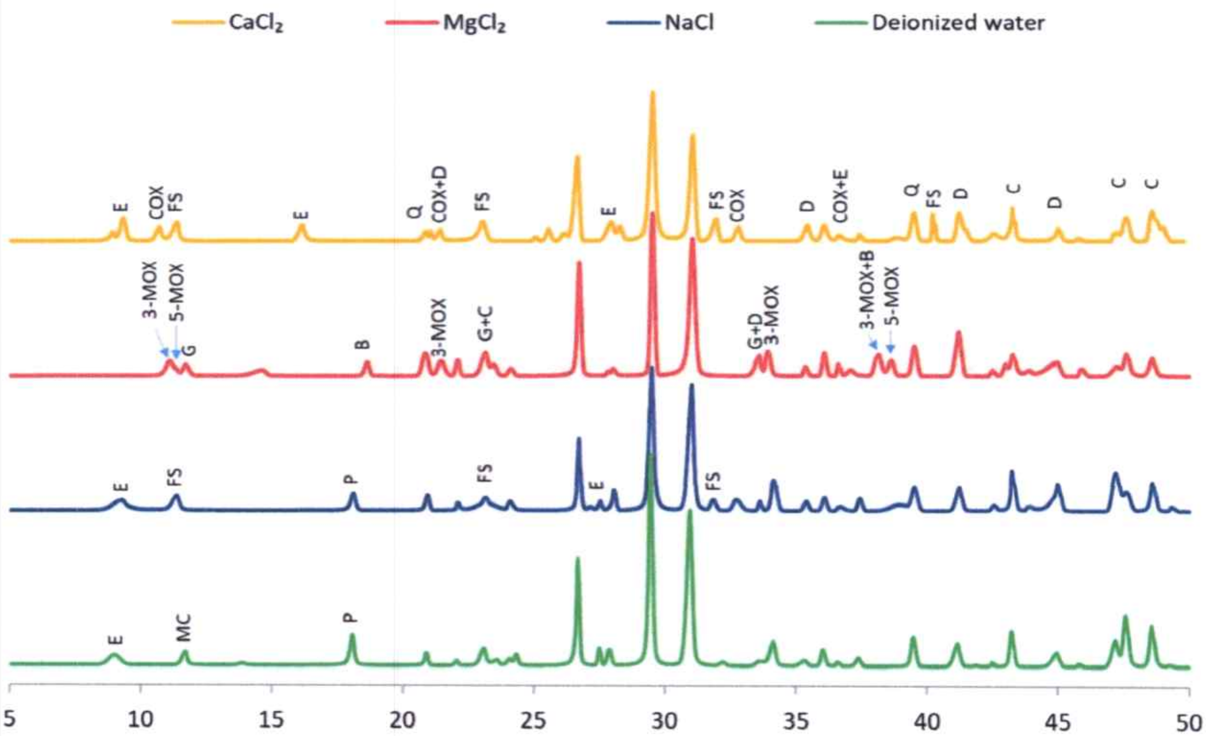

Figure 3: XRD patterns of the GUL specimens continuously immersed in different solutions at the time of failure listed in Table 4. *(Note 2: E = Ettringite, P = Portlandite, FS = Friedel's salt, COX = Calcium oxychloride, 3-MOX = 3-Form Magnesium oxychloride, 5-MOX = 5-Form Magnesium oxychloride, B = Brucite, D = Dolomite, C = Calcite, Q = Quartz, G = Gypsum).*

Effect of type of cement

Generally, the GUL group performed better (less mass loss) and survived longer (high retention of stiffness) than the GU group as shown earlier in the Results Section, irrespective of the type of the solution. This improvement can be ascribed to the synergistic physical and chemical actions of the limestone component in the GUL cement.

Physically, the control GUL specimens showed about 26% reduction in the penetration depth relative to the control GU specimens. Intergrinding limestone powder with clinker during production led to higher fineness of the GUL cement (460 m^2/kg) in comparison to the GU cement (390 m^2/kg), which may improve the hydration process and microstructural evolution of concrete. In addition, the filler effect resulting from the continuous particle size distribution of GUL may yield better particle packing in the matrix (Marzouki et al. 2013). Accordingly, GUL mixtures had reduced ingress of salt solutions and consequently better physical resistance to ingress of de-icing salts.

Chemically, the limestone component in GUL specimens also changed the hydration pattern of the binder as shown by the XRD for the reference sample in **Figure 4**. Carboaluminate appeared as a distinctive reaction product between limestone powder and various aluminate compounds (e.g.

hydroxy-AFm and monosulfate). The formation of carboaluminate-type compounds in portland-limestone cements was also observed in previous studies. The ability of carboaluminate hydrates to bind chloride was also reported to be significantly less than other AFm compounds (e.g. monosulfate) (Ipavec et al. 2013); therefore, lower intensities of Friedel's salt and consequently, formation of the complex salts (oxychlorides). On the other hand, the lower clinker component (due to dilution by 12% interground limestone) in the GUL cement reduced the initial portlandite (at 28 days) in these mixtures; subsequently, the potential for the chemical activity. This was corroborated herein by the lower intensities of portlandite peaks in the XRD pattern. This was also substantiated by the DSC results (17% reduction of the initial portlandite content compared to GU mixture, **Table 5**). Moreover, the GUL mixtures had lower C_3A content relative to the GU mixtures resulting in slower chemical activity (incipient formation of Friedel's salt). These physical and chemical effects of limestone explain the improvement in the resistance of GUL mixtures to degradation.

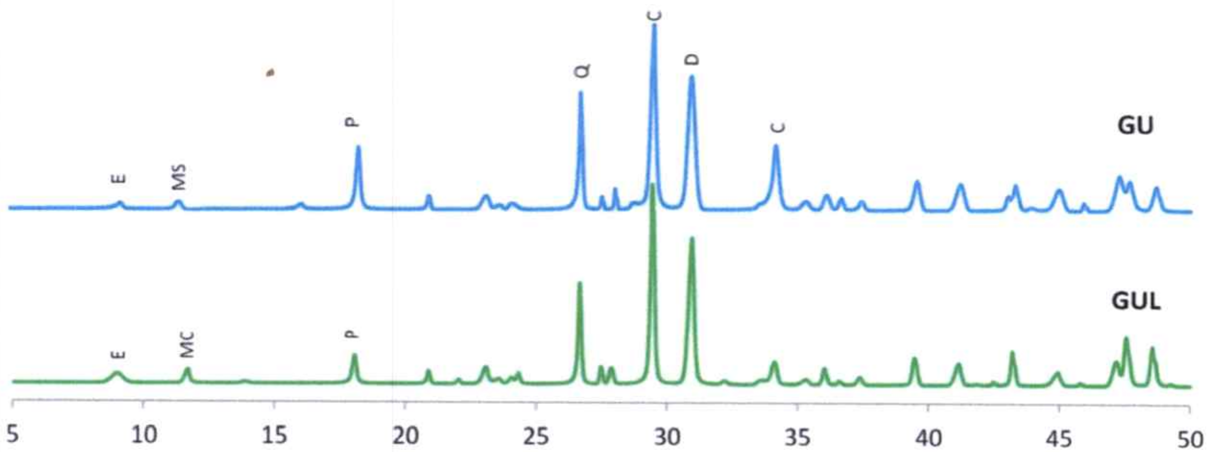

Figure 4: XRD analysis of GU and GUL specimens before exposure. (*Note: E=Ettringite, P=Portlandite, MS=Monosulfate, MC=Monocarboaluminate, Q=Quartz, D=Dolomite, C=Calcite*)

Effects of Fly Ash

Compared to the single binder (GU and GUL) mixtures, the incorporation of fly ash in binary binders reduced the penetrability of concrete. For instance, adding 20 and 30 % fly ash in binary binders (GULF20 and GULF30) led to approximately 13% and 29% reduction in the penetration depth of specimens compared to that of the corresponding specimens prepared with the GUL cement only, which was 12.93 mm (**Table 5**). The reduction of the penetration depth/migration coefficient may be attributed to the reduction of the effective porosity; thus, reducing the penetrability of the matrix (increased physical resistance). In addition, the initial portlandite content in these specimens decreased with increasing the dosage of fly ash in the binders (**Table 5**) owing to the dilution of the cement component, consequently limiting the chemical activity. Hence, fly ash mixtures performed better and/or survived longer than the reference GU or GUL specimens, especially the mixture containing 30% fly ah, as shown earlier in the Results section.

The DSC results showed that there was no efficient later-age pozzolanic activity of Type F fly ash in the binary specimens as indicated by the presence of high portlandite contents at the end of the exposure (maximum consumption of 7% after 540 days, **Table 5**). This implies that the long-term activity of fly ash was hindered at this low temperature (5°C), especially that these specimens were initially cured for 28 days. Hence, the binary fly ash specimens generally failed (but after the GU specimens with higher initial portlandite contents and penetrability) under this exposure before 540 days, especially with the aggressive types of salt solutions (**Table 4**). Perhaps, if the binary specimens comprising 20 and 30% fly ash were initially cured for longer periods (56 days or more) before exposure, the effect of fly ash might have been more improved. The effect of fly ash was magnified in the GUL group owing to the improvement effect of the limestone component in cement, as discussed earlier.

Table 5: Enthalpies (J/g) of portlandite in the cementitious matrix

Mixture ID.	After 28 days in the curing chamber	After 540 days immersed in deionized water	After 540 days or at the failure point* immersed in the de-icing salts		
			NaCl	$MgCl_2$	$CaCl_2$
GU group					
GU	63.6	62.1	42.3	0.0*	0.0*
GUF20	56.8	50.4	38.9	0.0*	0.0*
GUF30	45.8	39.7	31.8	22.9	0.0*
GUL group					
GUL	53.6	48.3	37.4	0.0*	0.0*
GULF20	48.3	42.7	33.9	0.0*	0.0*
GULF30	38.8	32.3	26.1	20.7	21.2

CONCLUSIONS

Based on the exposure procedure, test period, type of salt, and mixture design variables adopted in this study, the following conclusions can be drawn:

- NaCl is not an aggressive salt with respect to degradation of concrete as no signs of deterioration were observed. In contrast, $MgCl_2$, and $CaCl_2$ are aggressive as they enter into chemical reactions with cement-based materials, forming complex salts (oxychloride, Friedel's salt, ettringite, and gypsum, depending on the type of solution).
- GUL mixtures generally had better resistance to degradation by deicing salts due to synergistic physical and chemical actions of the limestone component in the binder.
- The results show that the resistance of concrete exposed to high concentrations of de-icing salts is a function of physical penetrability, amount of C_3A in cement and content of portlandite available for chemical reactions in the hydrated paste.
- Incorporation of 30% fly ash in concrete improved its resistance to degradation by de-icing salts due to reduced solution uptake and amount of portlandite.

The overall results from this study implicate that the restrictive limits on GUL cement and fly ash dosage in concrete exposed to high concentration of de-icing salts, stipulated in most North

American guides and specifications for concrete, may produce concrete less durable than alternative noncompliant mixtures with GUL cement and higher fly ash dosages. Thus, concerted efforts are needed to improve and update current guides and specifications for durability of concrete, especially with the intensive winter maintenance practices adopted by transportation agencies to cope with climatic changes.

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DEDICATION

We would like to pay our gratitude and respects to the late Mr. Rod Hamilton, City of Winnipeg (COW), who helped in initiating and coordinating this project between COW and University of Manitoba. Mr. Hamilton passed away in April 2020. He played an instrumental role in the development of Public Works asset management and pavement research practices. In 2016, Mr. Hamilton was promoted to the Manager of Asset Management, COW where he finished his career.