

**Field and lab assessment for cement-stabilized subgrade in Chatham, Ontario**

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**Abstract:**

Cement stabilized subgrades have been extensively used to improve the engineering performance of pavement structures. Due to the effects of cementitious hydration, pozzolanic reaction, as well as, cation exchange, chemical bonding is generated between fine soil particles. Therefore, the geotechnical characteristics of difficult clay soils will be improved in terms of plasticity, strength, stiffness, and durability. The cement modified soils (CMS) will then function as a new pavement layer which partially or totally replaces the thickness of granular base layer as commonly found in traditional road constructions. This paper first introduced a subgrade stabilization project located in Chatham-Kent, Ontario, followed by the field testing of subgrade stiffness using a light weight deflectometer (LWD) test on the stabilized subgrade surface. Five different low-volume roads were chosen as test sections for LWD stiffness test. The stiffness of the subgrades was measured before the construction, 3 hours after the stabilization followed by testing at 3 days, 7 days, 28 days, and 1 year respectively. Field test results indicated a significant increase of the subgrade stiffness after the cement stabilization and compaction; moreover, the stiffness continued growing along with the curing time. Soil sampled from one of the test sections was tested in lab facilities. Laboratory testing including: unconfined compressive strength (UCS) at 7 days and 28 days, durability test and pH values test for cement stabilized soil. Stabilized soil had 7 days UCS value of 0.83 MPa with 6% cement, and 1.43 MPa with 12% cement. Moreover, 5% to 6% cement stabilized T38 soil specimens had improved durability properties against freezing and thawing and met the weight loss limit requirements. Results also indicated that the cement stabilization changed the soil environment from slightly acidic to alkaline, and reduced the potential for growing of organics. It is also recommended future studies evaluate mixes with supplementary cementing materials to provide a more environmentally friendly stabilized subgrade. The paper finally introduces alternative Hydraulic road binders (HRB) as a more economic, sustainable and environmentally friendly solution to the construction and rehabilitation of Canada's low-volume roads.

**1 Introduction**

The in-situ mixing of soils and chemical stabilizers such as cement and lime have been extensively used to improve the engineering performance of subgrade for decades. Cement has the abilities of hydration, pozzolanic reaction as well as cation exchange, which agglomerate fine soil particles and provide solid chemical bondings (Prusinski and Bhattacharja 1999). Therefore, the geotechnical characteristics of a difficult soil will be improved in terms of plasticity, strength, stiffness, and durability (Petry and Little 2002). The cement modified soils (CMS) will then function as a new pavement layer which could replace the granular base layer as commonly found in

traditional road constructions. Chemical additives such as cement and lime will react with water and existing soils, therefore the cost of transportation and construction of borrowed backfills will be significantly saved. Current research mainly addresses the physical-chemical properties of cement modified soil (CMS), soil-cement remolded specimens and also the soil-cement interactions (Bahar et al. 2004; Wang et al. 2016). Laboratory test manuals had also been built for soil-cement including the cement ratio selection, mix design methods and the criteria (PCA 1992).

However, cement stabilization can also have some disadvantages including rapid setting, drying shrinkage cracking, excessive sulfate content, high cost, and high CO<sub>2</sub> emission (George 1973). In order to achieve the goal of green technology for subgrade stabilization, either the cement ratio shall be controlled, or more environmentally friendly replacement material could be used in lieu of cement.

This paper will first introduce a current subgrade stabilization project located in Chatham-Kent, Ontario. The project was designed to use a cement content of approximately 6% by dry weight of soil. Light weight deflectometer (LWD) stiffness test was conducted to monitor the stiffness of the subgrade and paved road at following time intervals: before the construction on the natural subgrade; 3 hours after the stabilization was completed; and 3 days, 7 days, 28 days, and 1 year after stabilization. In addition, soil from one of the test sections (T38) was sampled for cement modified soil mixing in lab. Laboratory testing included unconfined compressive strength (UCS) of soil-cement at 7 days and 28 days, durability test, as well as, pH values test.

The objectives of the study was first to monitor the stiffness of the 6% cement stabilized subgrade along with the curing period; second, to test the engineering behavior of cement improved soil in laboratory testing at different cement ratios. Both the field and lab test will provide knowledge of the local soil's geotechnical properties, and CMS in local context; therefore, offering reference data for the next research step – HRB-soil stabilization.

## **2 Subgrade stabilization project in Chatham-Kent**

### **2.1 Project description**

The North Kent Wind project was located in Chatham-Kent, Ontario. As part of the project, the constructed roads will provide access from each windfarm tower to the regional road. The soils were originally used for agricultural purposes and contained substantial organic material, the top 100 mm of the soil was removed to clear the grass, roots and other organic material. The procedures of the road construction was summarized below and presented in Figure 1.

**Step 1. Soil breaking and ripping.** Soil clumps were cut into small pieces and were ripped for mixing. The treatment depth of soil was approximately 300 mm (12 in.). In addition, sampling of soil for lab testing was conducted at this stage.

**Step 2. Water adding.** Water was added to the ripped soil. The amount of water was determined to enable the soil to be at its optimum moisture content for mixing. This procedure could be conducted again after the cement spreading process if there is not enough water for hydration process.

**Step 3. Cement spreading.** Cement powder was spread evenly on the soil surface. The amount of cement used in the project was 35.2 kg per m<sup>2</sup> of ground surface area.

**Step 4. Mixing.** Soil, stabilizer, and water were homogeneously mixed to the treatment depth (300 mm).

**Step 5. Compaction.** A sheep's foot roller was first used for compaction and then the surface was graded. A drum roller was used to seal the treated subgrade, additional water can be spread if necessary.

**Step 6. Curing and capping.** A curing time of 7 days was performed after the stabilization. Moisture content of the ground was monitored and maintained during the curing; and no traffic was permitted to be on the treated area. After the curing period, the stabilized layer was capped with a 100 mm thick gravel surface with granular A gravels.



**Figure 1. Pictures showing the stabilization. Cement spreading (left); compaction using sheep's foot roller (right)**

Each site would have a different energy savings as it would depend on trucking distance and availability of the borrowed material. Traditionally, the road construction involved a 300mm soil removal and dumping of virgin Granular B material. The construction of Granular A wearing layer remains the same. Economy is

therefore achieved in this project through the use or reuse of in-place soil. A significant carbon footprint reduction is also realized.

## **2.2 Light weight deflectometer (LWD) test on untreated and stabilized subgrade**

Light weight deflectometer (LWD) had the advantages of non-destructive, portable use, much lower loading capacity and lower cost; therefore making it suitable for measuring the stiffness for subgrade and gravel pavement. The construction sections were named after each tower's name: T38, T41, T49, T15, and T32 respectively. A total of 20 test spots were conducted along with the five test sections.

The stiffness was first measured on untreated subgrade after top soil removal. Then, the stiffness was then tested 3 hours, 3 days, 7 days, 28 days, and 1 year after construction. It should be noted that, after 7 days of curing, the stabilized subgrade was capped with granular Type A aggregates. The wearing gravels could distribute the loading, improve the drainage, prevent reflective cracking, and reduce severe rutting.

Each of the test spots locations were identified by GPS coordinates; so that at each time, the tests were conducted at approximately the same position with a tolerance range of approximately 1 m<sup>2</sup>. The length of the five test sections ranged from 300m to 600m. Additionally, the distance between two adjacent test spots made up approximately 100m. Figure 2 below illustrates the LWD stiffness testing on capped pavement surface on site T32. Photo was taken at August, 2017 when the soil stabilization had been finished for 28 days.



**Figure 2. LWD test on T32, August 2017**

The ground conditions of T38 before and after stabilization are shown in Figure 3. The natural subgrade had loose and soft surface; and the condition became worse when raining and drying occurred. After the stabilization, the stiffness of the subgrade had been significantly improved. The stabilization permanently changed the chemical and physical conditions of the ground and enhanced the workability and durability in terms of freeze-thaw resistance and wet-dry resistance. After 1 year of service, the road conditions of T38, T15, T32, and T49 were observed to be in a fair condition with no obvious potholes, rutting, and cracks appear. However, it was also observed that the capping construction of T41 was not done properly, and had low LWD stiffness values. During the capping of T41, inadequate water was spread; consequently, coarse and fine soil particles were not well compacted. Loose gravel left the water penetrated into the stabilized layer easily, leading to deterioration of pavement due to wetting and drying and traffic conditions. After one year of service, distinct gravel loss was observed and was presented in Figure 5. Such deterioration could be prevented by proper mixing of water and gravel and construction.



Figure 3. Road conditions: T38 before and after and construction, July 2017



Figure 4. Road conditions: T38 (left) and T15 (right) after 1 year of construction, July 2018



**Figure 5. Gravel loss of surface in T41, pictures taken in July, 2018**

Table 1 illustrated the average LWD test results for each section. The LWD stiffness of ground before stabilization accounted for around 20 MPa; and the figure remained consistent along with different test spots and test sections. On the contrary, after stabilization, there were some discrepancies of soil's modulus between different test spots even in one test section. This phenomenon may be due to uniformity of stabilizer spreading, moist variation and compaction (Shafiee 2013). Literature also indicated the field test conducted on sand and clay subgrade may have coefficient of variation (CV) accounted for 23.15% (Shivamanth 2015). During the data analysis, some extreme points were deleted and the average values of LWD stiffness were calculated. And the standard deviations were controlled less than 25% of the average stiffness.

**Table 1. LWD stiffness result (MPa) on natural and stabilized subgrade**

Site No.		Untreated	3 hrs	3 days	7 days	28 days	1 year
T38	Average	20	62.5	216	230	312	440
	Std. Dev.	1	14	2	3	14	63
T41	Average	18	69	71	125	168	102
	Std. Dev.	--	16	11	--	44	3
T49	Average	21		136	135	253	317
	Std. Dev.	1		34	--	43	32
T15	Average	19			173	229	294
	Std. Dev.	0			45	32	56
T32	Average	19			203	250	298
	Std. Dev.	1			48	74	60

\*Note: Values with yellow shade mean the section had been capped while testing. The values with grey shade mean the soil were wet during testing.

3 hours after the construction, the stiffness values had increased significantly by



approximately three times compared to the untreated ones. The immediate improvement of the subgrade strength can be attributed to the stabilization process - pulverizing, moisture addition, compaction, and rapid hydration of cement. During the curing period, the stiffness of stabilized subgrades continued to increase. For each testing spot, a general upward trend was observed for the LWD stiffness value from 3 days to 7 days before aggregate capping. Among all the test sites, subgrade of T38 and T32 had the highest average stiffness of 230 MPa and 203 MPa respectively at 7 days; while the subgrade of T41 had the lowest overall stiffness values- the average stiffness of spots accounted for 74 MPa after 7 days of curing. Field investigation showed that T32 and T49 had relatively better conditions after the stabilization. Moisture content also had a crucial effect on the subgrade's stiffness. Right after the stabilization, the soils were tested to have around 16.3% moisture. Heavy raining, however, occurred on July 10 before the test was conducted. That led to a reduction of stiffness in T41 and T49. Values in Table 1 with grey shade mean the soils were wet while testing.

Stabilized subgrades were capped with an approximately 100 mm thick gravel layer after 7 days curing, the material used for capping was Granular Type A aggregates. Generally, LWD test on the road surface further revealed a gaining of surface stiffness after capping. Due to the cementitious and pozzolanic reactions, the stiffness increase continues even after 1 year of service time. The average stiffness of the 4 sections (T38, T15, T32, and T49) grew from 261 MPa at August 2017 (after capping) to 337 MPa at July 2018.

The LWD and FWD (falling weight deflectometer) stiffness values are frequently adopted as the resilient modulus ( $M_r$ ) of the subgrade which is an important input for AASHTO and MEPDG (Mechanistic-Empirical Pavement Design Guide) pavement design methods. Table 2 presented recommended subgrade resilient moduli values for AASHTOWare pavement design adapted to Ontario conditions. Based on the soil classifications, natural T38 soil was classified as CL, and its  $M_r$  value (20 MPa) was judged to be "Fair" for design. Another LWD field test conducted on Highway 407, Ontario revealed a value of 25 MPa on a silty sand ground at a depth of 0.6 m (D'Amours et al. 2016). The values Table 2 below are for non-stabilized subgrade, once the soils are stabilized, they will be considered as a new pavement layer in pavement design; therefore allows the reduction of the structure number and base thickness.



**Table 2. Recommended subgrade moduli values for the AASHTO–Ontario M-E pavement design model (Tremblay 2002)**

Brief Description	Category No.	MTO Classification (MTO, 1980)	Drainage Characteristics	Susceptibility to Frost Action	Resilient Modulus ( $M_R$ ) for Typical Subgrade Conditions, MPa		
					Good	Fair	Poor
Rock, rock fill, shattered rock, boulders/cobbles	1	Boulders/cobbles	Excellent	None	90	80	70
Well graded gravels and sands suitable as granular borrow	2	GW, SW	Excellent	Negligible	80	70	50
Poorly graded gravels and sands	3	GP, SP	Excellent to fair	Negligible to slight	70	50	35
Silty gravels and sands	4	GM, SM	Fair to semi-impervious	Slight to moderate	50	35	30
Clayey gravels and sands	5	GC, SC	Practically impervious	Negligible to slight	40	30	25
Silts and sandy silts	6	ML, MI	Typically poor	Severe	30	25	18
Low plasticity clays and compressible silts	7	CL, MH	Practically impervious	Slight to severe	35	20	15
Medium to high plasticity clays	8	CI, CH	Semi-impervious to impervious	Negligible to severe	30	20	15

In order to get a comparison between lab and field test results, soil from T38 was sampled and been subjected to laboratory resilient modulus measurements according to AASHTO T 307 - *Standard Method of Test for Determining the Resilient Modulus of Soils and Aggregate Materials*. Laboratory testing indicated a  $M_r$  of 28.3 MPa for remoulded T38 soil, 198.2 MPa for T38 soil with 6% GU after 3 days, 205.4 MPa after 7 days, and 284.9 MPa after 28 days respectively. The  $M_r$  values in lab generally approached the LWD results, but the quantity of test samples was not good enough to determine correlations between lab and field tests. In the next research step, was to take more resilient modulus and modulus of elasticity tests will be conducted for soils from T38 and T49 for lab and field correlations study and pavement design.

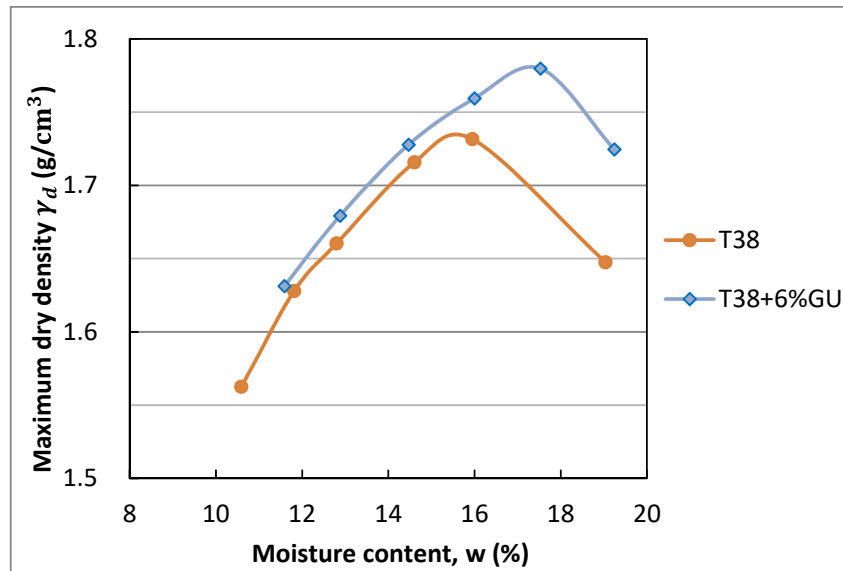
Overall, cement stabilization was tested to efficiently improve the stiffness of subgrade. With the curing time continued, a consistent gaining of stiffness was observed from the field. Capping of the subgrade was observed to have further improvement of the surface stiffness, however, inadequate compaction of gravel will cause a reduction of the stiffness. Additionally, performance of the stabilized subgrade in the longer period of time shall be monitored.

### 3 Lab testing of cement-treated soil

#### 3.1 Characterization of soil and cement

Some geotechnical parameters and the particle size distributions of T38 soil were analyzed in the lab and summarized in Table 3. Since the ground was originally used for agricultural purpose, the soil contained a considerable amount of organic matters (4.54% by dry weight). The soil organic matters (SOM) will affect the cation exchange

capacity (CEC) of the soil, changing alkaline environment; consequently, affecting the soil-cement reactions (Harris et al. 2009).



**Figure 7. Moisture-density relationships of T38 soil and T38 + 6% GU**

The optimum moisture content of T38 soil tested by standard proctor compaction accounted for 15.81%, with the corresponding dry densities of 1.73 g/cm<sup>3</sup>. On the other hand, the cement treated soil had a slightly higher value of maximum dry density (1.77 g/cm<sup>3</sup>), and a roughly 2% of additional moisture in order to completely hydrate the cementitious material (see Figure 7).

The particle size distribution for the T38 Dresden soil is shown in Table 3 below. This soil contained 13.4 % of sand, a high of 66.1% silt-sized particles and 20.5% clay-sized particles, respectively. Based on the particle size distribution analysis, the T38 soil was classified as clayey silt with some plasticity.

**Table 3. Geotechnical characteristics of T38 Soil**

Soil name and location	Dresden
Natural organic matter (%)	4.54
Plasticity index	10
Optimum moisture content (%)	15.81
Maximum dry density (g/cm <sup>3</sup> )	1.73
Sand fraction (4.75~0.075mm) (%)	13.4
Silt fraction (0.075~0.002mm) (%)	66.1
Clay fraction (<0.002mm) (%)	20.5
AASHTO soil group	A-6
USCS soil classification	CL ML

The mix design for the windfarm subgrade stabilization was designed prior to the research. During the construction, the contractor of the windfarm project used the cement amount of 35.2 kg for 1 m<sup>2</sup> of ground surface. Based on the dry density (1.73 g/cm<sup>3</sup>) of T38 soil, the cement ratio was calculated to be approximately 6% by dry weight of soil. In the lab testing, a range of 4% ~ 6% of cement was used for laboratory soil modification. And 9% and 12% of cement was also adopted for creating a strong and stiff cement-soil mixture. Cement used in the field and in the lab was General Use (Type GU) cement which was supplied by Lafarge Canada Inc. Some engineering parameters of GU cement were tested and summarized in Table 4 below.

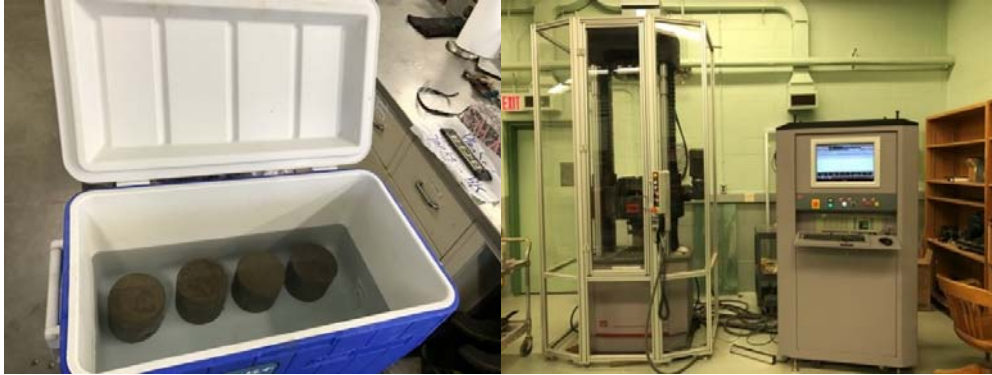
**Table 4. Engineering properties of GU cement**

Parameter	GU cement
w/c ratio by flow test	0.57
25 days of linear drying shrinkage (%)	0.08
Compressive strength 7 days (MPa)	22.1
Compressive strength 28 days (MPa)	28.3
Blaine fineness (m <sup>2</sup> /kg)	383
Vicat initial setting time (min)	133
Loss of ignition (%)	2.3

### 3.2 Unconfined compressive strength

Specimens for UCS and freeze-thaw testing were compacted by standard proctoring effort within  $\pm 1\%$  of their respective optimum moisture content (OMC) and within 95% of the maximum dry density (MDD). The soil was mixed with 4%, 5%, 6%, 9%, 12% of cement by its dry weight respectively. After compaction, the specimens were then cured in a humidity (100%) and temperature (20°C) controlled chamber for a period of time (7 days and 28 days).

All the cylinder specimens had the same diameter of approximately 100 mm and the sample height of 116 mm. Prior to the UCS test, modified and stabilized soil specimens were moved out of humidity room and were transferred into water for a soaking period of 4 hours. The load speed to break the soil sample was set to be 0.05 in. (1.3 mm)/min. Figure 8 below illustrated the soaking period of UCS specimens and the testing frame for performing UCS, respectively.



**Figure 8. Specimen soaking (left) and UCS testing frame (right)**

The cement treated soils normally had rapid strength gain in the early curing age. As was shown in Table 5, remolded T38 soil under its OMC and MDD had the UCS value of 0.17 MPa. Generally there are no restrict guidelines for cement modified soil, one research conducted by University of California Pavement Research Center indicated that a soaked 7-days UCS of approximately 0.4 MPa is sufficient for subgrade improvement (Jones et al. 2010). On the other hand, the AASHTO (2008) and PCA (1992) recommended a high cement ratio (10% to 13% by weight of soil) for silt and clay stabilization, and recommended a minimum strength limits of 1.38MPa of 7 days, and 1.72MPa of 28 days. By adding 4% to 6% cement to the T38 soil, UCS increased by 211% to 388% after 7 days of curing. These values continued to increase with 28 days of curing. Cement ratios higher than 6% lead to a more drastic growth of strength at the curing period of 28 days. In particular, 12% stabilized T38 soil increased the UCS value to a high of 1.78 MPa.

**Table 5. UCS test for cement treated T38 soil**

<b>Specimen name</b>	<b>UCS at 7 days (MPa)</b>	<b>UCS at 28 days (MPa)</b>
T38 soil remolded	0.17	--
T38 soil + 4% GU	0.53	0.69
T38 soil + 5% GU	0.63	0.86
T38 soil + 6% GU	0.83	1.13
T38 soil + 9% GU	1.26	1.56
T38 soil + 12% GU	1.43	1.78

The 12% cement stabilized T38 soil was tested to meet the AASHTO requirement at both 7 days and 28 days of curing. However, this high cement ratio is not frequently adopted for local low-volume road construction as it would not be practical or cost effective to use these higher cement contents. Cement percentage typically vary from 2% to 6% with the majority of cases being between 3% and 5% due to its high cost and environmentally considerations (Halsted 2011). Due to construction

practices and inconsistencies in the subgrade composition 5% to 6% cement by dry weight are normally used for subgrade stabilization jobs in Canada. Additionally, a further research will be conducted to modify the stabilizer type for minimizing the usage of cement. Alternative methodologies include pre-treatment of lime and/or use of Hydraulic Road Binder (HRB).

### 3.3 Freezing and thawing cycles test

The test started with freezing at the end of 7 days curing, and lasted for approximately 24 days. Each freezing and thawing cycle consisted of 24 hours of freezing at a constant temperature of  $-24^{\circ}\text{C}$ , and 24 hours of thawing in a humidity (100%) and temperature ( $20^{\circ}\text{C}$ ) controlled chamber. After each thawing period, the specimens were given 18 to 20 firm vertical brush strokes around the surrounding surface (see Figure 9). At the end of 12 cycles, specimens were oven-dried ( $110^{\circ}\text{C}$ ) until constant mass. The loss of soil specimen was then calculated as follows (ASTM D560):

$$\text{Dry loss of specimen, \%} = \frac{B - \frac{A}{1+a}}{B} \times 100\% \quad (3 - 1)$$

Where,

A = Final dry mass of specimen (g);

B = Calculated initial dry mass of specimen (g);

a = Percentage of water retained in the soil by hydration (%).



**Figure 9. Brush strokes at surface (left), condition of T38 + 6% GU after the test (right)**

Results of weight loss of specimens after 12 cycles of freezing and thawing were analyzed and summarized below in Table 6. According to the requirement of PCA (1992) for durability test, soil-cement specimens should have weight loss not larger than 7% for stabilized T38 soil (A-6).

**Table 6. Weight loss of specimens after freezing and thawing cycles**

<b>Specimen name</b>	<b>Dry weight loss (%)</b>
T38 soil remolded	N/A
T38 soil + 4% GU	9.50
T38 soil + 5% GU	4.41
T38 soil + 6% GU	3.49

The untreated T38 remolded specimen collapsed after the first freezing and thawing cycle, therefore, showing the improvement in durability properties by mixing the soil with cement. During the brush stroke process, loose soil particles were peeled off from the specimen surface, and the size of the specimen had been reduced. Nonetheless, all the soil specimens maintained the overall shape after the test. Among the three, 4% GU cement treated soil had the highest weight loss of 9.5% by dry weight which exceeded the weight limit suggested by PCA. It was observed that 5% and 6% cement stabilized soil specimens had improved durability properties against freezing and thawing and passed the recommended PCA weight loss limit of less than 7%.

### **3.4 pH values test**

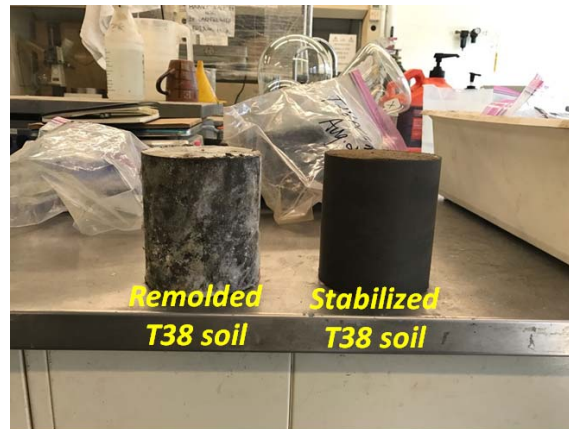
In order to measure the alkaline environment of stabilized soils with different cement contents, pH value test were conducted with a slight modified method of ASTM D6276. The pH value was measured from the soil-water-stabilizer mixture which consisted of 25 g of oven dried soil, 100ml of water, and a certain amount of GU cement. Table 7 below illustrated the pH values of cement-soil-water mixture for cement addition ratios of 0, 3, 6 and 9 percent.

**Table 7. pH values of specimens with different cement contents**

<b>Soil type</b>	<b>Additive type</b>	<b>Additive ratio</b>			
		<b>0%</b>	<b>3%</b>	<b>6%</b>	<b>9%</b>
T38	GU cement	6.51	11.60	11.74	11.86

Figure 10 presented the condition of soil specimens for the remolded T38 soil (untreated) as well as the stabilized soil after 28 days of curing. The organic material in soil including humus, plant, and animal tissues will react with air and water and thus release gas which will loosen the soil structure. Overtime this will cause a deterioration of the above pavement layers. Cement will change the soil's environment from acidic to alkaline with the pH between 11 and 12. Such environment will prevent the reaction and reproduction of organic materials, and thus provide a stable and reliable soil structure. The elimination and prevention of organic reactions of chemically stabilized soil were clearly observed as depicted in

Figure 10 below.



**Figure 10. Condition of remolded untreated Dresden soil (left) and stabilized Dresden soil (right) after 28 days curing**

In general, T38 soil before cement treatment had a slight acidic environment with the pH value accounting for 6.51. Cement changed the chemical environment of soil from acid to alkaline with a pH ranging between 11 and 12. The chemical stabilized soil had a distinct effect of preventing soil organics from growing and developing. It was also observed that the increase of cement ratio from 3% to 9% could lead to a slight growth of pH value but the changes of the values were not substantial.

#### **4. Hydraulic Road Binder (HRB)**

Hydraulic road binder (HRB) are often used to development a more “green” solution while still improving the soil’s behaviorHRB contains considerable amount of Supplementary Cementing Materials (SCMs) such as slag, fly ash and cement kiln dusts. SCMs (i.e., limestone, fly ash, ground granulated blast-furnace slag-GGBS) are industrial by products so there are less energy and CO<sub>2</sub> emission attached to them. Table 8 presented interpret the general energy consumed for material quarrying, transportation, manufacture, and installation (Samad and Shah 2017). In particular, according to UK Quality Ash Association (UKQA 2010, Table 8), an emission of 913kg of CO<sub>2</sub> has to be generated in order to provide the energy for the manufacture of 1tonne of ordinary Portland cement, while the values for SCMs are much less.

**Table 8. Embodied CO<sub>2</sub> of different cement types in UK (retrieved from UKQA 2010)**

<b>Material type</b>	<b>Embodied CO<sub>2</sub> kg/tonne</b>
Portland cement	913
GGBS	67
Fly ash	4
Limestone fine	75



Table 9 presented the strength grade and type of HRBs (data retrieved from EN 13282). Based on the hardening time and clinker content, HRBs in EN standard were basically classified as rapid and normal hardening. They were further classified depend on the compressive strength (MPa) as E2 to E4 for HRB-1 and N2 to N4 for HRB-2 respectively. Generally, both types of HRBs have slower hydration with lower strength on 7 days compared to that of general use Portland cement. However, their strength will grow sustainably and match or exceed that of cement in the period of 28 days and 56 days.

**Table 9. Strength grade of HRBs (data retrieved from EN 13282)**

	<b>HRB-1 rapid hardening</b>	<b>HRB-2 normal hardening</b>
Compressive strength 7 days	E2: $\geq 5$ MPa; E3: $\geq 10$ MPa; E4 and E4-RS: $\geq 16$ MPa	No requirement
Compressive strength 28 days	E2: 12.5 ~ 32.5MPa; E3: 22.5 ~ 42.5MPa; E4: 32.5 ~ 52.5MPa; E4-RS: $\geq 32.5$ MPa	No requirement
Compressive strength 56 days	No requirement	N1: 5 ~ 22.5MPa; N2: 12.5 ~ 32.5MPa; N3: 22.5 ~ 42.5MPa; N4: 32.5 ~ 52.5MPa

Previous studies have indicated that the introduction of SCMs can be used in addition with cement for the treatment of pavement layers. However, there are still a lot of research gaps regarding the HRB formulation and use in Canadian context. The soils obtained from the local test sections will be thereby stabilized with HRB in different percentages. Lab and field results of cement treated soils in this paper are used as a reference for evaluation of HRB-soil stabilization. Proper HRB formulation and stabilizing ratio will further be proposed, therefore giving rise to the first HRB use in Canada in the near future.

## 5. Conclusions and recommendations

Based on the field and laboratory tests and analyses of the data, the following conclusions and discussions can be drawn:

1. Cement stabilization had a significant improvement of subgrade stiffness from 20 MPa to 230 MPa 7 days after construction. A consistent gain of LWD stiffness was observed in the field during the continuing curing time. It was also observed, capping of the subgrade further improved the stiffness of the road surface. However, inadequate compaction of gravel can cause a

reduction of the pavement structure stiffness.

2. Remolded T38 soil under its OMC and MDD had the UCS value of only 0.17 MPa. After cement-stabilization the UCS increased in value to 0.83 MPa after 7 days with 6% cement, and to 1.43 MPa with 12% cement. In addition, 5% to 6% cement stabilized T38 soil specimens had improved durability properties against freezing and thawing and met the PCA weight loss limit requirements.
3. T38 soil before cement treatment had a slight acidic environment with the pH value of 6.51. Addition of cement changed the chemical environment of soil from acid to alkaline with a pH ranging between 11 and 12. An increase of cement ratio could lead to a slight growth of pH value but the changes in values were not substantial.
4. The use of HRB's has the potential to develop an even more sustainable and "green" solution that is more economical, and environmentally friendly solution to the construction and rehabilitation of Canada's low-volume roads.

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