# Curing Efficiency of Three Different Curing Compound Applications to Concrete Pavements

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**Abstract:** Premature deterioration is a common concern for all types of concrete structures. To help mitigating this issue, the concrete hardening process is required to take place in a manner which provides optimum hydration development. This can be achieved through proper and adequate curing practices of concrete. The effect of curing on the performance of concrete is essential at controlling its mechanical and durability performance during service. Depending on the adiabatic conditions, type of application and project specifications, the curing approach may vary considerably (e.g. continuous fog spraying for long time, application of a curing compound, etc.). The aim of this research project is to assess the effect of three different curing compound applications (no curing, one coat of curing compound, two coats of curing compound) on the behavior of concrete pavements, and thus projecting their long-term durability. The project involved experiments on cores extracted from a newly (August 2014) constructed pavement sections in Mulvey Avenue, Winnipeg in comparison to corresponding specimens produced from similar concrete under laboratory conditions. Absorption and rapid chloride permeability tests were conducted on specimens to study the effect of the different curing methods, and the results were statistically analyzed by the analysis of variance method. The overall trends indicate that applying curing compounds is critical to ensure moisture retention in concrete for efficient hydration reactions and microstructural development. Even one coat of curing compound thoroughly applied to concrete is sufficient for achieving target strength and durability characteristics.

## 1 INTRODUCTION

Hardened properties of concrete, especially mechanical and durability characteristics are influenced by curing which has a significant effect on the hydration of cement. Curing can be described as maintaining satisfactory level of moisture content (RH above 90%) and temperature in concrete for a period of time (preferably seven days or more) immediately following placing and finishing activities, so that the desired properties (e.g. strength) are achieved. Inadequate curing of concrete can cause incomplete hydration, and subsequently the target strength and durability may not be achieved. For example, continuous pore structure formed within the surface of concrete will facilitate the penetrability of aggressive agents, provoking various damage mechanisms of concrete (e.g. surface scaling). In addition, drying of concrete at early-age leads to the development of a network of cracks which affect its long-term performance. During the hardening process, concrete is vulnerable to moisture loss via evaporation to achieve equilibrium with the surrounding environment, especially for concrete elements with high surface-to-volume ratio (e.g. concrete pavements) (Mehta and Monteiro 2014). This action results in incomplete hydration of the cementitious matrix and plastic and drying shrinkage cracking. Moisture loss to the surrounding environment affects the outer (0 to 50 mm deep) surface of concrete, while the inner core of concrete is barely subjected to moisture movement. This critical depth represents the cover thickness in many reinforced concrete elements. Ho et al. (1989) reported that by reducing the relative humidity during the curing process from 100 to 94%, the water absorption capacity of concrete markedly increased, implicating the alteration of pore structure. If the external relative humidity falls below 80% during the initial curing process of concrete, the proportion of macro-pores in the hydrated paste significantly increases, which can cause higher penetrability of concrete (Patel et al. 1988). In addition to the mixture design of concrete, key factors such as relative humidity, adiabatic and concrete temperatures and wind velocity affect the evaporation rate of moisture form the surface of concrete pavements. Hence, this rate must be maintained at a minimal level to facilitate the hydration process of the cementitious matrix.

Advancements in materials manufacturing have introduced to the construction industry new chemicals such as membrane curing compounds, which are considered a viable option for concrete elements with large surfaces. It is worth mentioning that the curing method of concrete may considerably vary based on adiabatic conditions, project specifications and type of application. Typically, curing of cast-in-place concrete can be done by applying each or a combination of the following methods: maintaining the presence of water during the early hardening period with full immersion or ponding, fog spraying and saturated wet coverings, and reducing/preventing the loss of water from the surface of concrete by covering the concrete with plastic sheets or application of curing compounds (Kosmatka, Kerkhoff, and Panarese 2002). Yet, whether applying multiple coats of curing compounds on concrete pavements can significantly improve its hydration and in turn its resistance to infiltration of fluids remains uncertain. Hence, the main objective of this research study is to investigate the effect of three different curing compound applications (no curing compound, one coat of curing compound and two coats of curing compound) on the behavior of concrete pavements in terms of their resistance to infiltration of fluids, and thus projecting their long-term durability. The project consisted of experiments on cores extracted from a newly (August 2014) constructed pavement in Mulvey Avenue (Winnipeg, MB, Canada) in comparison to corresponding specimens produced from similar concrete under laboratory conditions. The main tests included rapid chloride penetrability test (RCPT) and COW absorption test. This collaborative research study between the City of Winnipeg (COW) and University of Manitoba (U of M) was conducted in order to informatively guide the choice of the most effective application method for curing compounds to be incorporated in the COW specifications for concrete pavements.

## 2 EXPERIMENTAL PROGRAM

### 2.1 Materials

In this pavement project, the COW specified a ready mix concrete with target performance of 35 MPa and meeting a class of exposure C-2 according to CSA A23.1 (2014). The same type of concrete was delivered to the U of M to prepare the laboratory specimens. The binder comprised General Use (GU) portland cement and fly ash (Class F), as a supplementary cementitious material (SCM), meeting the current requirements of CSA A3001 (2009), and the water-to-cementitious materials ratio (w/cm) was in the range of 0.36 to 0.38. A chemical air-entraining admixture complying with ASTM C260 (2010) was used in concrete to achieve a fresh air content of 5 to 8%. Also, a high-range water reducing agent complying with ASTM C494 (2012) was used to obtain a target slump of 30 to 70 mm to facilitate slip forming. Due to a confidentiality agreement between the U of M and the concrete supplier, the specific proportions of the concrete mixture design cannot be disclosed. The curing compound used was made of high-grade hydrocarbon resins in a water-based emulsion conforming to ASTM C309 (2012) Types 1, 2 and 1-D, Class B. The laboratory and field concrete received three different curing compound applications (no curing compound [NC], one coat of curing compound [1CC] and two coats of curing compound [2CC]). Laboratory specimens were kept in the molds for 28 days, and the different curing methods were applied to the top surface to simulate the case of field cores extracted from pavements.

### 2.2 Tests

In this study the properties of hardened concrete were evaluated by RCPT (ASTM C1202 2012) and City of Winnipeg water absorption test (COW 2013-01 2013) after 28 days. In RCPT, the transport of solution takes place by electro-migration of ions through concrete, which expresses the diffusion mode of transport. Comparatively, the water absorption test indicates mass transport of fluids into concrete by capillary action. The tests were done on laboratory specimens and field cores extracted at joints, areas adjacent to joints and from center of slabs to capture the effect of curing variability, if any, in the joint locations relative to the center of slabs.

### 2.2.1 Rapid chloride penetrability test (RCPT)

After being subjected to different curing methods, the interconnectivity of pore system in concrete specimens was assessed by RCPT (ASTM C1202 2012). At 28 days, the surface skin (~3 mm) from the top and bottom of cylindrical specimens was removed to reach a clear surface, and the adjacent 50 mm thick discs were cut as the test specimens. The discs were air-dried in the laboratory for one hour and then their side surfaces were coated with rapid setting epoxy to reduce moisture evaporation and leakage of solution during testing. Subsequently, the concrete discs were placed in a desiccator under vacuum pressure for three hours. Concurrently, the required amount of water was boiled for de-aeration and allowed to cool down to ambient temperature. After three hours of vacuuming, de-aerated water was allowed to enter into the desiccator while the vacuum pump was still running. Subsequently, for additional one hour, the vacuum pump was operated and then the valve was opened to allow air to flow into the desiccator. The specimens were kept in the desiccator and soaked under water for 18 hours before the test. On the following day, the concrete discs were put in the test cells, where one compartment was filled with 3% NaCl solution (cathode) while the other compartment was filled with 0.3 N NaOH solution (anode). During the test period (six hours), 60 V DC was applied to the cell compartments, while the temperature of sodium chloride solution was continuously monitored by a thermocouple. The computer connected to the microprocessor power supply recorded all the data during the entire test in terms of passing charges in Coulombs through concrete to determine the penetrability class according to ASTM C1202 (2012).

Since physical observation provides better representation of the penetration of chloride ions into concrete (Bassuoni et al. 2006), the physical penetration depth of chloride ions was measured immediately after the completion of the test by spraying 0.1 M $AgNo_3$ solution on the surface of equally split discs. The discs were allowed to set under fluorescent light for about 15 minutes to obtain the whitish precipitate of silver chloride. Five penetration depths (every 20 mm) were measured on each half disc (i.e. 10 readings per specimen) to calculate the average penetration depth for each specimen.

### 2.2.2 City of Winnipeg (COW) absorption test

In this study, the COW absorption test (COW 2013-01 2013) was conducted on both laboratory specimens and field cores. After 28 days, specimens were gently brushed with a brass brush to remove the curing compound layer, and 50 mm thick slices were cut from cylindrical specimens. For the laboratory specimens and cores extracted from the center of slab, top and bottom 50 mm (baseline) slices were obtained, whereas only the top 50 mm part was cut from the cores obtained at the joints, as required by the test procedures. The concrete discs were placed in a sealed vacuum desiccator under a vacuum pressure (~85 KPa) for six hours. Subsequently, the specimens were removed from the desiccator and each one dried out with compressed air. Afterwards, the initial mass of the dried specimens to the nearest 0.01 g were recorded. Each specimen was freely immersed in deionized water for 60±3 s, and then excess water was blotted off and the wet weight of the specimen was recorded within 25 s to the nearest 0.01 g. The amount of water absorbed into concrete was determined by subtracting the dry mass from the wet mass and converted to a percent of the wet weight of the specimen. The percentage water absorption (*WA*) is important because the actual volume of specimens may vary due to coring or deterioration of concrete, and it is calculated by:

$$[1] \quad WA=\frac{W_g\text{-}D_g}{W_g}\times 100$$

where $WA$ is the percentage of water absorption of concrete, $W_g$ is wet weight of the concrete test specimen in g, and $D_g$ is dry weight of the concrete test specimen in g. To evaluate the effectiveness of the curing compound on concrete slabs, the absorption of the top part for each location was compared to the absorption of the bottom slices of the center of slab. The bottom slices of the center of slab are considered as the baseline for curing efficiency in the field (COW 2013-01 2013).

## 3 RESULTS AND DISCUSSION

All the results were statistically studied by the Analysis of Variance (ANOVA) method at a significance level (α) of 0.05. ANOVA is a statistical model used to analyze the differences between group means and their variation among and between groups. The variance of a specific variable is separated into components attributed to different sources of variation. ANOVA tests the hypothesis that the means of several groups are comparable via a t-test, and it can generalize the test to more than two groups. According to ANOVA, exceeding the $F_{cr}$ for an F-distribution density function indicates that the variable tested has a statistically significant effect on the average results (Montgomery 2014).

### 3.1 Rapid chloride penetrability test (RCPT)

The penetrability classification (ASTM C1202 2012) and physical penetration depth (Bassuoni et al. 2006) of concrete were determined after operating the RCPT for 6 hours. The whitish color showing the penetration depth of chloride ions was broadly visible, as for example shown in Figure 1. The passing charges and penetration depths of laboratory and field concrete are listed in Table 1. The classification of chloride ions penetrability of concrete was consistent with the penetration depth results. The passing charges in all concrete specimens were in the range of 1000 to 2000 Coulombs; hence, all the specimens were classified as “Low Penetrability” according to ASTM C1202 (2012). This conforms to small penetration depths (below 13 mm), irrespective of the curing method.

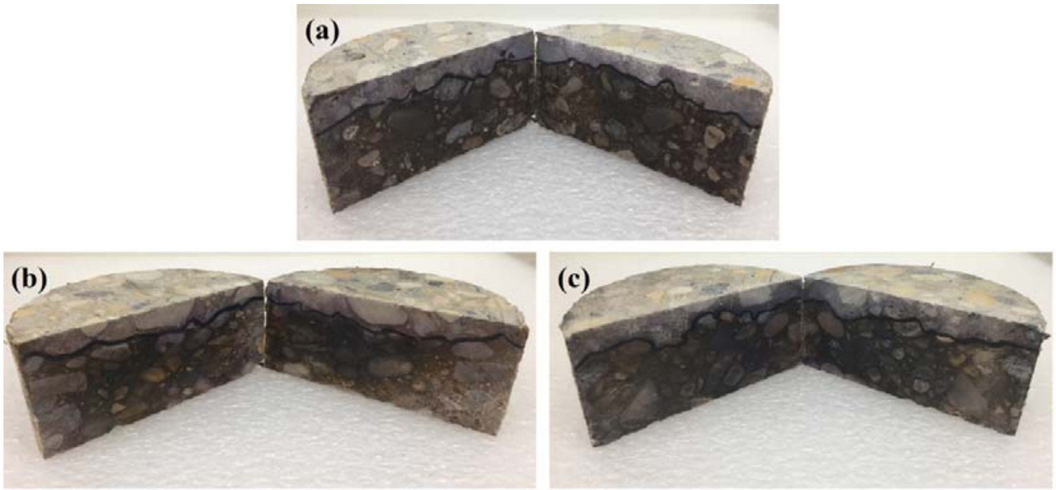

Figure 1: Whitish color showing the chloride front in the top part of laboratory specimens: (a) NC, (b) 1CC, and (c) 2CC

Table 1 and Figure 2 show the average penetration depth for laboratory and field concrete. All the trends were consistent in the sense that there was a slight reduction in the penetrability of concrete with 1CC and 2CC relative to corresponding specimens without curing (NC). For example, specimens taken from cores adjacent to joints with NC, 1CC and 2CC had penetration depths of 11.3 to 10.5 and 10.2 mm, respectively. Nevertheless, ANOVA (Table 2) for the results of penetration depths showed that the change in curing method had an insignificant effect on the results. For instance, for laboratory specimens, changing the curing method had an F value of 5.12 compared to a critical value $F_{cr}$ of 5.14. This trend may be attributed to the high quality of the concrete mixture with low w/b (0.36 to 0.38) which led to a dense and disconnected microstructure that discounted migration of chloride ions into concrete. It should be mentioned that specimens from the pavement section without curing compound (NC) were exposed to periods with high relative humidity (Figure 3) and intermittent rainfall (natural curing), which improved the efficiency of hydration reactions in a comparable manner to corresponding specimens from sections with 1CC and 2CC. Correspondingly, laboratory specimens without curing (NC) were kept in the moulds for 28 days and had a limited evaporative surface, which did not affect the evolution of hydration reactions within 50 mm depth from the surface.

Table1: Passing charges and penetration depth (ASTM C1202) for the laboratory and field specimens

| | **Laboratory Specimens** | | **Cores at Centre** | | **Cores adjacent to Joint** | |
|---|---|---|---|---|---|---|
| **Specimen***| **Passing Charges** | **Average Penetration Depth (mm)** | **Passing Charges (Coulombs)** | **Average Penetration Depth (mm)** | **Passing Charges (Coulombs)** | **Average Penetration Depth (mm)** |
| NC-I | 1878 | 12.6 | 1756 | 12.3 | 1810 | 11.3 |
| NC-II | 1920 | | 1749 | | 1841 | |
| NC-III | 1497 | | 1862 | | 1862 | |
| NC-IV | - | | 1654 | | 1942 | |
| 1CC-I | 1691 | 11.5 | 1623 | 11.6 | 1795 | 10.5 |
| 1CC-II | 1634 | | 1504 | | 1804 | |
| 1CC-III | 1671 | | 1551 | | 1762 | |
| 1CC-IV | - | | 1513 | | 1831 | |
| 2CC-I | 1586 | 11.1 | 1872 | 11.5 | 1961 | 10.2 |
| 2CC-II | 1598 | | 1758 | | 1842 | |
| 2CC-III | 1790 | | 1715 | | 1713 | |
| 2CC-IV | - | | 1878 | | 1736 | |

* All mixtures had a ‘low penetrability’ class (ASTM C1202)

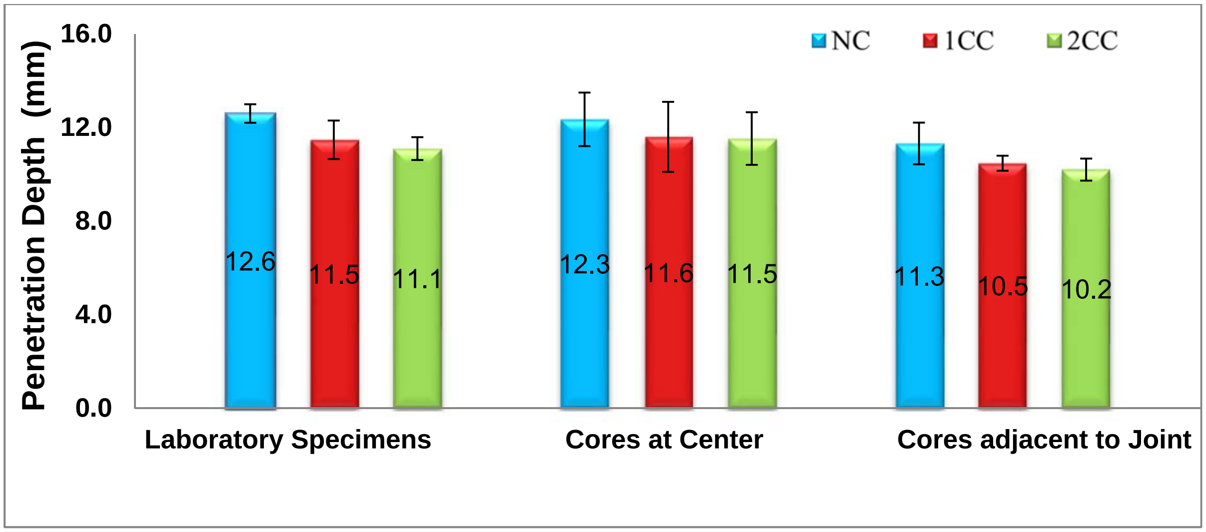

Figure 2: Penetration depths from RCPT (ASTM C1202) of laboratory and field specimens (top portion)

Table 2: ANOVA for RCPT (ASTM C1202) results of laboratory and field specimens

| **Source** | **F** | **P-Value** | **$F_{cr}$** | **Effect** |
|---|---|---|---|---|
| Laboratory Specimens | 5.12 | 0.0504 | 5.14 | Insignificant |
| Cores at Center | 0.51 | 0.6148 | 4.26 | Insignificant |
| Cores adjacent to Joint | 3.61 | 0.0704 | 4.26 | Insignificant |

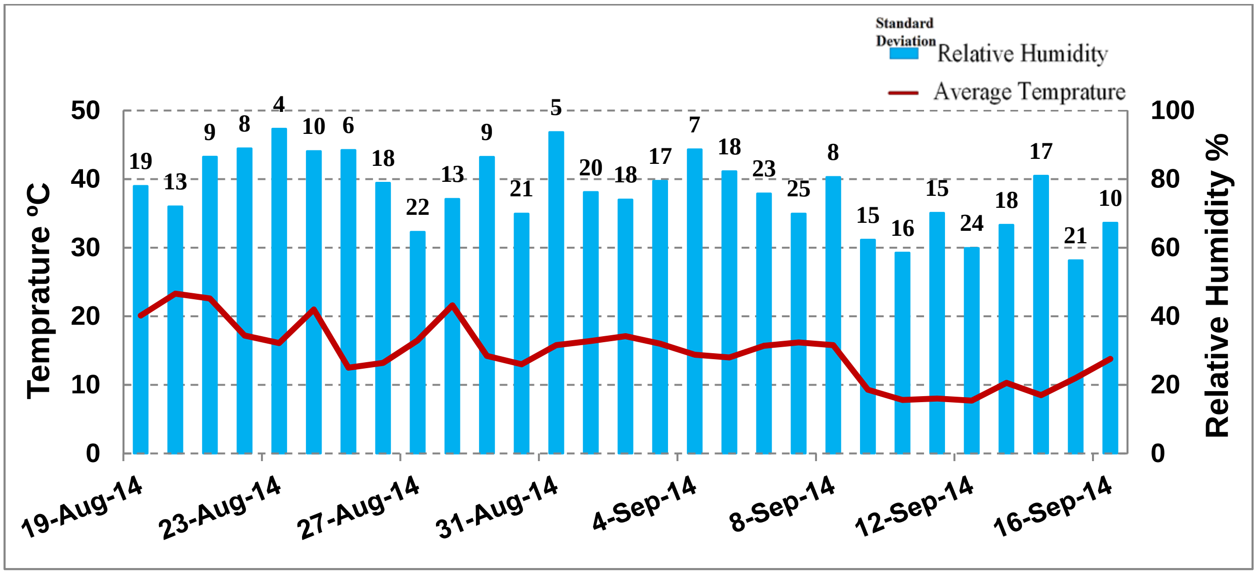

Figure 3: Average daily temperature and relative humidity data for the period of 28 days from the date of casting concrete pavement (data labels represent the standard deviation values)

### 3.2 City of Winnipeg (COW) absorption test

The results of the COW absorption test are given in Table 3, and the absorption ratios (top-to-bottom of the center of slab) are shown in Figure 4. It was noted that the average absorption ratios for the cores from the center of slab were 0.9 and 0.8 for specimens with 1CC and 2CC, respectively. This might be attributed to the difference in the level of consolidation between the top and bottom layers at the center of slab for these sections of the placement. Also, inadequate moistening of the base course in this area under the slab prior to placement of fresh concrete could have led to some moisture loss from the bottom portion of concrete, and thus influenced the evolution of hydration and characteristics of pore structure. Irrespective of the method of curing, it can be observed that the absorption values and ratios for the cores extracted at joints are significantly higher than that of corresponding cores extracted from the center of slab or specimens prepared in the laboratory. The higher absorption values of the cores at the joints can be attributed to increasing the exposed surface area in contact with water due to the existence of a groove in the core. In addition, the saw cutting process at early and later ages generated weakened planes in the concrete at the joint locations, which can increase the absorption of the concrete surface within the groove.

For laboratory concrete, the absorption ratios of specimens with NC, 1CC and 2CC were 1.6, 1.2, 1.1, respectively (Figure 4). This trend is consistent with the results of field concrete obtained from cores at the center of slab, which signifies the importance of curing in reducing the absorption of concrete. ANOVA for the absorption ratios (Table 4) indicates that this trend is statistically significant for specimens prepared in the laboratory and from cores extracted from the center of slab. For example, for laboratory specimens, changing the method of curing had an F value of 30.32 compared to a critical value $F_{cr}$ of 5.14. The reduction of absorption capacity of concrete with 1CC and 2CC is due to the retention of moisture within the surface layer of concrete, which led to efficient hydration and microstructural development and consequently less water absorption relative to concrete with NC. In addition, the results indicated that there was no marked difference between concrete with 1CC and 2CC as specimens from both types of curing had comparable results, which conforms to the RCPT trends. This suggests that applying one coat of curing compound thoroughly is sufficient for maintaining the efficiency of hydration reactions.

The absorption ratios for the cores extracted at the joints with NC, 1CC and 2CC were 1.9, 1.7 and 1.6, respectively (Figure 4). ANOVA of these results yielded an insignificant effect of the curing method on the absorption results at the joints (Table 4). The error bars (standard deviation) of the absorption ratios for the three curing methods at the joints had higher variability, which contributed to this statistical insignificance. This might suggest that the application of the curing compound within the joint space did not evenly cover the vertical surfaces of concrete within the groove (i.e. all joints almost received NC), which adversely affected the efficiency of curing (absorption ratio) as these vertical planes represent a considerable area of the specimens in the COW test.

Table 3: Water absorption (COW method) of laboratory and field specimens

| Specimen | Laboratory Specimens | | | Cores at Center | | | Cores at Joint | |
|---|---|---|---|---|---|---|---|---|
| | Absorp. Top (%) | Absorp. $Bot_{ave.}$ (%) | Top / $Bot_{ave.}$ | Absorp. Top (%) | Absorp. $Bot_{ave.}$ (%) | Top / $Bot_{ave.}$ | Absorp. Top (%) | Top / $Bot_{ave.}$ |
| NC-I | 0.15 | 0.1 | 1.6 | 0.16 | 0.13 | 1.2 | 0.19 | 1.5 |
| NC-II | 0.16 | | 1.6 | 0.16 | | 1.3 | 0.2 | 1.6 |
| NC-III | 0.16 | | 1.6 | 0.14 | | 1.1 | 0.3 | 2.3 |
| NC-IV | - | - | - | 0.18 | | 1.4 | 0.26 | 2.1 |
| 1CC-I | 0.11 | 0.1 | 1.1 | 0.13 | 0.13 | 1 | 0.19 | 1.4 |
| 1CC-II | 0.13 | | 1.3 | 0.11 | | 0.8 | 0.18 | 1.4 |
| 1CC-III | 0.13 | | 1.3 | 0.13 | | 1 | 0.27 | 2.1 |
| 1CC-IV | - | - | - | 0.1 | | 0.8 | 0.26 | 2 |
| 2CC-I | 0.12 | 0.1 | 1.1 | 0.1 | 0.15 | 0.7 | 0.21 | 1.4 |
| 2CC-II | 0.1 | | 0.9 | 0.11 | | 0.8 | 0.18 | 1.2 |
| 2CC-III | 0.11 | | 1.1 | 0.12 | | 0.8 | 0.27 | 1.8 |
| 2CC-IV | - | - | - | 0.12 | | 0.8 | 0.28 | 1.9 |

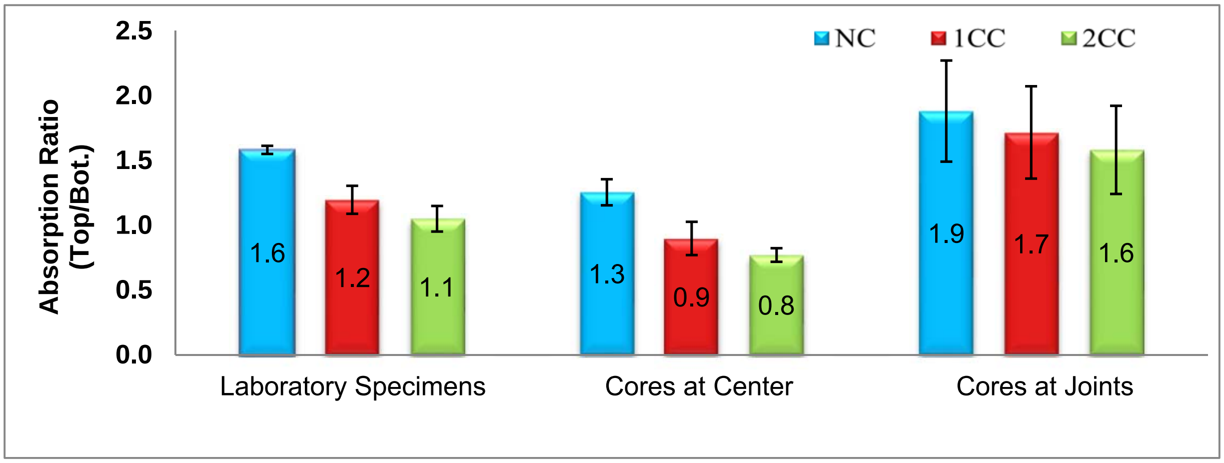

Figure 4: Absorption ratio (COW method) of laboratory and field specimens.

Table 4: ANOVA for absorption ratio (COW method) of laboratory and field specimens

| Source | F | P-Value | $F_{cr}$ | Effect |
|---|---|---|---|---|
| Laboratory Specimens | 30.32 | 0.0007 | 5.14 | Significant |
| Cores at Center | 25.76 | 0.0002 | 4.26 | Significant |
| Cores at Joint | 0.68 | 0.5300 | 4.26 | Insignificant |

## 4 SUMMARY AND CONCLUSIONS

Curing of concrete elements is a key factor to achieve the target strength and durability as it improves the hydration of cement by retaining sufficient moisture for an adequate time period in the matrix. The effect of three different curing compound applications (no curing compound [NC], one coat of curing compound [1CC], two coats of curing compound [2CC]) on the transport properties (absorption and penetrability) of concrete pavements were investigated in this project. Based on the experimental variables and test procedures implemented in the current research, the following conclusions can be drawn:

- The RCPT expresses the diffusivity of chloride ions within saturated concrete, which is a good indication for the interconnectivity of the pore system up to a thickness of 50 mm. The RCPT results for laboratory and field concrete showed that specimens with 1CC and 2CC had slightly lower penetrability than that of corresponding specimens with NC, without statistical significance. This trend may be attributed to the low w/b of the concrete mixture used which led to dense and disconnected microstructure that discounted migration of chloride ions. Also, specimens from the pavement section without curing compound (NC) were exposed to high relative humidity and intermittent rainfall periods (natural curing), which improved the efficiency of hydration in these specimens. This trend was replicated for laboratory specimens due to the limited area exposed to drying.

- In the COW test, the higher absorption values of the cores at the joints can be attributed to increasing the exposed surface area in contact with water and weakened planes from the saw cutting operations. The absorption ratios for the cores extracted at the joints were comparable with an insignificant effect of the curing method on the absorption results. This might suggest that the application of the curing compound within the joint space could not thoroughly cover the vertical surfaces of concrete within the groove, which adversely affected the efficiency of curing as these vertical planes represent a considerable area of the specimens in the COW test.

The overall results indicate that applying curing compounds thoroughly (even one coat) is sufficient to ensure moisture retention in concrete for efficient hydration reactions and microstructural development to achieve target durability characteristics. At the joint locations, saw cutting operations at early and later ages and lack of homogenous curing of vertical surfaces within the joint seem to affect the absorption capacity of concrete. It is recommended that joints be fully saturated with curing compound after saw cutting operations to mitigate this issue.

## 5 ACKNOWLEDGMENTS

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## 6 REFERENCES

ASTM-C1202. 2012. “Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration.” *Annual Book of American Society for Testing Materials*, Philadelphia, Sec. 4, 4.02.

ASTM-C260. 2010. “Standard Specification for Air-Entraining Admixtures for Concrete.” *Annual Book of American Society for Testing Materials*, Philadelphia, Sec. 4, 4.02.

ASTM-C309. 2012. “Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete.” *Annual Book of American Society for Testing Materials*, Philadelphia, Sec. 4, 4.02.

ASTM-C494. 2012. “Standard Specification for Chemical Admixtures for Concrete.” *Annual Book of American Society for Testing Materials*, Philadelphia, Sec. 4, 4.02.

Bassuoni, M.T., Nehdi, M.L. and Greenough, T.R. 2006. “Enhancing the reliability of evaluating chloride ingress in concrete using the ASTM C 1202 rapid chloride penetrability test.” *Journal of ASTM International* 3(3), 13 p.

CAN/CSA A23.1. 2014. “Concrete materials and methods of concrete construction.” *Canadian Standards Association*, CSA, Mississauga, Ontario, Canada.

CAN/CSA-A3001. 2008. “Cementitious materials for use in concrete.” *Canadian Standards Association*, CSA, Mississauga, Ontario, Canada

Ho, D.W.S., Cui, Q.Y. and Ritchie, D.J. 1989. “Influence of humidity and curing time on the quality of concrete.” *Cement and Concrete Research* 19(3):457-464.

Kosmatka, S.H., Kerkhoff, B. and Panarese, W.C. 2002. *Design and Control of Concrete Mixtures*. Portland Cement Association.

Montgomery, D.C. 2014. *Design and Analysis of Experiments*, John Wiley and Sons, Arizona, USA.

Mehta, P.K. and Monteiro, P.J.M. 2014. Concrete: Microstructure, Properties and Materials. McGraw Hill Education, California, USA.

Patel, R.G., Killoh, D.C., Parrott, L. J. and Gutteridge, W.A. 1988. “Influence of curing at different relative humidities upon compound reactions and porosity of Portland cement paste.” *Materials and Structures* 21(3):192-197.

Peters, B. and Holfield, D. 2013. “Standard Test Method for Measuring Absorption to Evaluate the Effectiveness of Curing Compound onConcrete Slabs and Adjoining Joints.” Public Works Department, City of Winnipeg.