

Assessing the Effect of Accelerated Moist Curing on the Near-Surface Durability Performance of Concrete

Report for

Canadian Precast/Prestressed Concrete Institute

February 2020

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Executive Summary

Curing specifications are often prescriptive, limiting the advantages of using accelerated heat curing. The work presented in this report validates the profiling of the initial rate of absorption of a sodium chloride solution in the concrete cover as a reliable performance assessment test method. The results can be used to optimize the required moist curing period following accelerated heat curing in precast concrete production plants. The validity of the test is assessed using 2 precast concrete mixtures each subjected to 4 different curing regimes. The ASTM C1202 test, also known as “rapid chloride permeability test”, is deemed to be relatively insensitive to differential curing through the depth of the concrete cover. The same observation is made regarding the bulk electrical resistivity test (ASTM C1876). On the other hand, the curing effects can be detected with very high confidence (> 95 %) using the initial rate of absorption test method suggested in this research program.

This work was funded by the Canadian Precast/Prestressed Concrete Institute with support of Mitacs, and the Natural Science and Engineering Research Council.

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Introduction

The type and length of curing (both temperature and moisture) control the evolution of the degree of hydration and microstructural developments of the concrete at early ages, especially in the cover layer over reinforcement. These conditions are not uniform in the near-surface cover layer due to loss of moisture to the exterior (Hooton et al., 2002). In addition, concretes cast at a low water-to-binder ratio, undergo self-desiccation, and require additional moisture to be supplied during curing. The capillary porosity and pore connectivity control the rate of chloride ingress and are affected by the curing treatment at early ages. In addition, due to the resulting partially unsaturated pore network, the ingress of chlorides in the concrete cover involves both capillary absorption and ionic diffusion. The rate of ingress due to capillary absorption is orders of magnitude faster than by ionic diffusion at larger depths, which accentuates the poor performance of imperfectly cured concrete.

There is a lack of reliable and rapid curing performance evaluation tests. Typically curing until attainment of a particular compressive strength is often prescribed, however, strength is not representative of the chloride penetration resistance given that it is only dependent on porosity and not pore structure connectivity. The Canadian Standards Association (CSA) prescribes a minimum 7-day moist curing period at a minimal temperature of 10 °C and until 70 % of the compressive strength is achieved for severe chloride exposures (CSA A23.1, 2019). This specification was originally designed for cast-in-place concrete, and does not consider the increased early-age maturity provided by accelerated temperature curing used by the precast industry. Such a prescriptive approach limits the adoption of potentially more effective curing techniques such as accelerated moist curing, often adopted by the precast concrete industry. Although precast-specific accelerated moist curing is allowed by CSA A23.4-16, some agencies still invoke the same prescriptive curing requirements for cast-in-place concrete in CSA A23.1. While certain performance requirements can be specified for precast concrete elements exposed to chlorides, such as a limit on maximum charge passed in accordance with ASTM C1202, the test results are not representative of the concrete cover quality given that the test specimens are thicker than the curing-affected zone.

Accelerated moist curing (Figure 1) consists of a 4-stage cycle, typically shorter than 20 hours, where both the temperature and relative humidity are increased at early ages. This allows an early-age gain of maturity and strength, enabling early formwork removal and release of prestressing. There have been concerns that accelerated curing of Portland cement concretes can result in a coarser microstructure and a higher rate of chloride ingress, as outlined by Kjellsen et al. (1990), Kjellsen (1996), and Bu et al. (2014).

This effect can be effectively countered by including supplementary cementitious materials, particularly blast furnace slag, which slows down the reaction kinetics. Detwiler et al. (1994), and Hooton and Titherington (2004) demonstrated that the use of silica fume and blast furnace slag offset the deleterious effects of high temperature curing and reduced the chloride diffusion coefficient of the cured concrete.

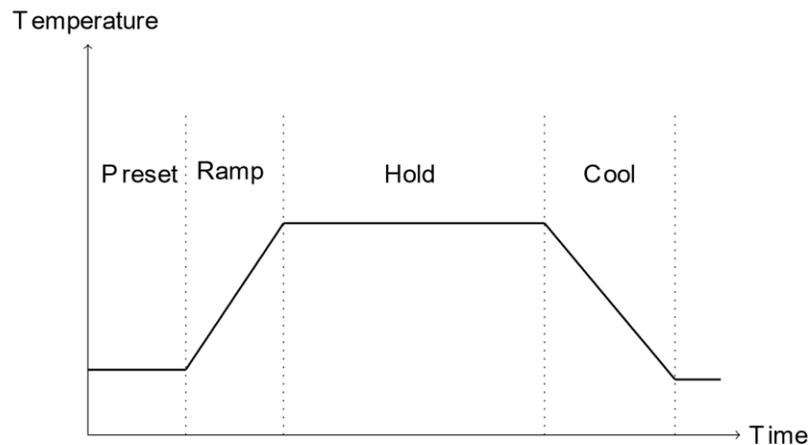


Figure 1 Generic Accelerated Moist Curing Cycle

An interlaboratory test involving different precast concrete producers in Canada was performed by the National Research Council of Canada (NRCC) (Makar, 2014), aimed at assessing the effect of curing on the chloride penetration resistance of a wide range of concrete mixtures. The ASTM C1202 test was used as the durability indicator. Concrete slabs were subjected to accelerated heat curing cycles and subsequently divided into three categories: ambient air cured, and moist cured for 3 and 7 days respectively. Cores were extracted from the slabs and cut into 50 mm thick specimens where one of the surfaces of the test specimen was 10 mm away from the slab cast surface. No significant difference was found between concrete samples subjected to the different curing regimes. The study conducted by NRCC had limitations in part due to the discarding of the 10 mm concrete layer closest to the slab surface, which is more strongly affected by curing. In addition, the rapid chloride permeability test might not be sensitive enough due to the test specimen thickness (50 mm) part of which might be beyond the thickness of the curing-affected zone.

A review of common test methods for predicting resistance to chloride ingress including their limitations can be found in Stanish et al. (2001). In this study a modified version of the ASTM C1585 test method “Standard test method for measurement of rate of absorption of water by hydraulic-cement concrete” (ASTM, 2013) was evaluated in terms of its ability to detect curing effects on fluid penetration resistance of the concrete cover. In addition, the commonly used ASTM C1202 “Standard test method for electrical

indication of concrete's ability to resist chloride ion penetration" (ASTM, 2019), and recently adopted ASTM C1876 "Standard test method for bulk electrical resistivity or bulk conductivity of concrete" (ASTM, 2019) were also evaluated.

Previous work at the University of Toronto funded by the Canadian Precast/Prestressed Concrete Institute evaluated different techniques to assess the effect of different curing regimes on the near-surface durability performance (Hooton, 2015; Dadic, 2018). Measuring the initial rate absorption of a sodium chloride solution from cut faces at different depths from exposed surfaces was retained as the most promising method. A similar method was originally suggested by Hooton et al. (1993) who profiled the initial rate of water absorption of moist cured and air cured concretes up to 75 mm depth from the cast surface of concrete slabs, and successfully quantified the differential curing effects. Numerous studies have shown the efficacy of sorptivity tests at characterizing cementitious systems, such as that of Parrott (1992), Martys and Ferraris (1997), and Dias (2000). Equation 1 allows for the experimental determination of the rate of absorption (S), determined by least-squared error fitting of the relationship between the square root of time and the absorption (I). For a given test specimen, there exist 2 values of S : the initial sorptivity, and secondary sorptivity. The first corresponds to the filling of unsaturated capillary pores, and is thus dependant on the quality of curing, whereas the second corresponds to the slower ingress into the entrained air voids (Li et al., 2012). Given that the goal of this study is to assess the ingress of aggressive fluids into unsaturated concrete, the initial sorptivity (or initial absorption rate) is of interest, since it is related to the rate of chloride ingress into the curing-affected zone.

$$I = S t^{\frac{1}{2}} + A \quad (1)$$

where:

- I the fluid absorption such that $I = \frac{m_t}{a \cdot d}$;
- S the sorptivity, or absorption rate;
- t the elapsed time from initial exposure to absorbed fluid;
- A a residual obtained by linear fitting of I and $t^{1/2}$, corresponding to the filling of open surface porosity on the inflow surface;
- m_t the mass change at time t ;
- a the exposed surface area of the test specimen; and
- d the density of the absorbed fluid.

The main objective of this study was to assess the validity of capillary absorption profiling in the near-surface zone as a rapid pre-qualification test for the effect of concrete curing on chloride penetration resistance. The test method is a modified version of the ASTM C1585, “Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes”. A second objective is to take this draft test method to the appropriate CSA standards committee for consideration as a standard test method. A final objective is to suggest criteria for acceptance that can be considered for adoption in specifications by various agencies.

Since the curing has to satisfy the prescriptive requirements of Clause 7.7 of CSA A23.1-19 (CSA, 2019), quantifying the curing-affected chloride penetration resistance of a concrete mixture obtained with this prescriptive curing would allow the performance of alternative curing regimes to be compared. The test should provide enough information on the quality of the curing. Figure 2 describes this concept. In addition to length and type of curing, CSA A23.1 (2019) prescribes a minimum curing temperature of 10 °C. Since curing is often carried out at higher temperatures than 10 °C, this provides additional challenges in defining the performance baseline for comparative purposes. CSA A23.1-19 standard does allow for the adoption of alternative curing regimes if equivalent performance is demonstrated. In near-surface, curing-affected zones that are partially dry when exposed to chlorides, the dominant (and rapid) mechanism of chloride ingress is by capillary absorption. Therefore, sorptivity (rate of absorption) testing is a reasonable performance approach and acceptance criteria for assessing an alternative curing regime for a given concrete mixture implies assessing the following hypothesis:

$$H_0: S_{d,regime} \leq S_{d,prescribed}$$

$$H_A: S_{d,regime} > S_{d,prescribed}$$

where:

- H_0 the null hypothesis for which the curing regime would be acceptable;
- H_A the alternative hypothesis for which the curing regime would not be acceptable;
- $S_{d,regime}$ the initial rate of absorption at depth d corresponding to the curing regime tested;
and
- $S_{d,prescribed}$ the initial rate of absorption at depth d corresponding to the prescribed curing regime.

These performance metrics can be complemented by others from a variety of test methods. Different frameworks for assessing the curing quality are explored. The significance level of the hypothesis testing can be defined by the decision maker. For example, a transportation agency could accept concrete cured

by alternative regimes if the initial sorptivity, experimentally derived, satisfies H_0 at a confidence level of 90%.

An alternative to the comparative approach would be defining a maximum value of the initial rate of absorption for which the concrete is of acceptable durability performance. This approach would be similar to that adopted when specifying a maximum value of the total charge passed determined by the rapid chloride permeability test as a function of the exposure class and intended service life (CSA A23.1, 2019). This approach is preferred over a comparative approach given that it solely relies on performance metrics and their correlation with service life. However, defining a maximum value of the initial rate of absorption can be challenging.

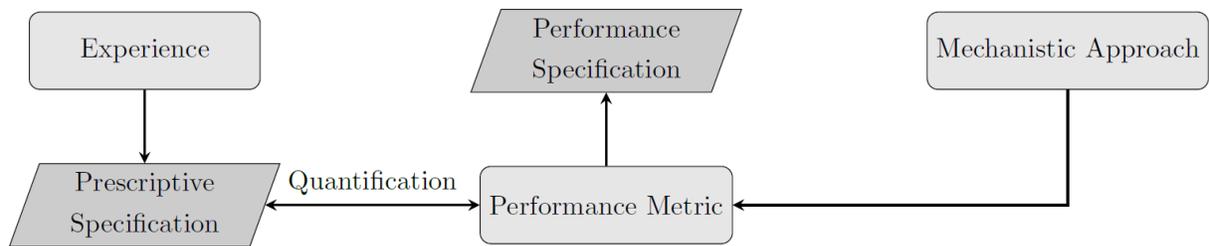


Figure 2 Graphic Representation of the Development Objective

Proposed Test Method

The following modifications were made to the standard ASTM C1585-13:

- Use of a 3.0 % by mass NaCl solution as the absorbed solution instead of water.
- Record the test specimen's mass at time intervals of 0, 1, 5, 10, 20, 30, 60, 120, 180, 240, 300, and 360 minutes of exposure to the solution (reducing the time of test measurements to 6 hours).
- Once the measurements are completed, immediately fracture the specimen along its cylindrical axis and spray the two fracture surfaces with a 0.1 N solution of AgNO_3 to colorimetrically determine the average chloride ion penetration depth.

In addition to these modifications, the conditioning of the test specimens prior to test were modified according to Zhutovsky and Hooton (2019). The rate of capillary absorption and the total mass of water absorbed, are a function of the initial degree of saturation of the test specimen. Zhutovsky and Hooton (2019) compared the effects the conditioning method used in ASTM C1585 consisting of (placing the test specimens for 3 days in a 50 °C and 80% relative humidity chamber, after which the specimens are placed in a sealed container for at least 15 days at room temperature to allow for moisture redistribution). To an

alternative procedure consisting of drying the specimens at 60 °C until constant mass is reached (corresponding to a daily mass change of less than 0.2 %). The first observation noted by the authors was the effect on the rate of absorption. The transition between initial and secondary absorption is sharper with a higher coefficient of determination for the each of the two linear portions for the specimens dried at 60 °C. In addition, a better correlation between sorptivity and water-to-cementing material; level of slag replacement; chloride migration coefficient (as per Nordtest NT 492 (1999)); total charge passed (as per ASTM C1202 (2019)); electrical conductivity (as per ASTM C1760 (2012)); threshold pore diameter; and capillary porosity was observed. Thus, drying at 60 °C until a constant mass was thought to be a more appropriate method and was adopted in this study. Once the constant mass is achieved, the test specimens are placed in sealed containers and allowed to cool at room temperature before test. Containers, 7 L in volume contained 6 specimens each.

The test specimens were 100 mm diameter cores obtained from cast slabs, as described in ASTM C1585 (2013). The experimental setup is shown in Figure 3. The circumferential surfaces, were sealed with vinyl (electric tape), and the non-test surface was covered with a loose plastic sheet to prevent evaporation. The exposed surface was placed on a grid support, allowing exposure to the solution.

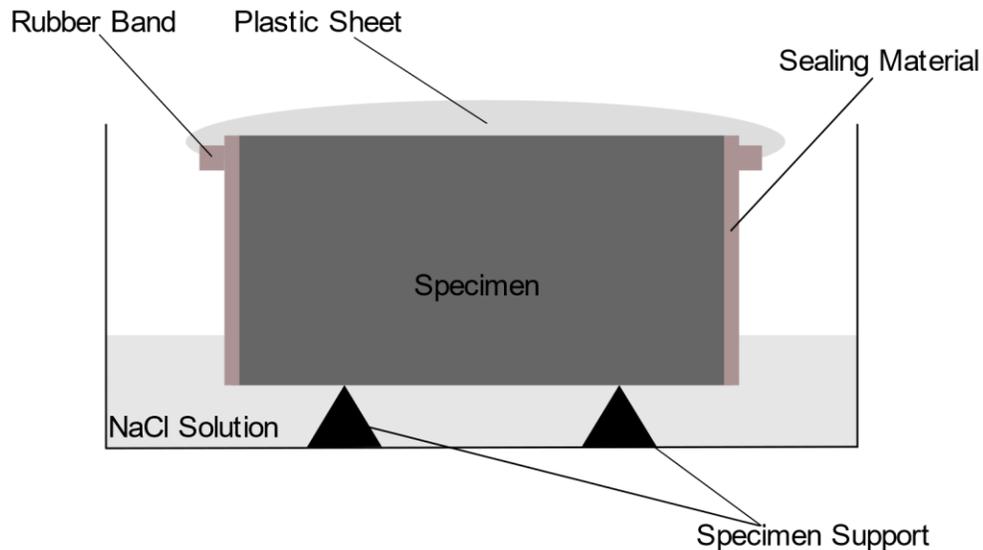


Figure 2 Sorptivity Measurement Setup

The depths of saw-cut exposed test surfaces at which initial rate of absorption is determined can vary based on the goal of the investigation. The effect of curing is variable throughout the depth of the concrete cover, and can be highly variable near the surface (Hooton et al., 1993). The quality of curing affects the

initial sorptivity values but that parameter also varies as a function of depth, as discussed previously. Both the depth of the curing effect and the numerical values of the initial rate of absorption are evaluated.

In order to be implemented as a quality assurance tool, the test method would need to be evaluated over a large set of samples in order to determine its coefficient of variation to provide information on the precision of the test. The ASTM C1585 test method reports a coefficient of variation of 6% for the rate of absorption values recorded by a single operator in a single laboratory (ASTM C1585, 2013). The coefficient of variation of this modified procedure could be larger due to the higher degree of variability in concrete quality near exposed surfaces (whether formed surface or finished surfaces). However, it is believed that the other changes in procedure do not affect the sensitivity of the test, except for the change in the drying procedure, which should provide more precise results.

Experimental program

Two concrete mixtures were evaluated in this study. Mix 1 is a ternary binder blend produced in the lab, whereas Mix 2 is a proprietary binary blend supplied by a precast concrete producer in Ontario. Mix 1 had a 0.40 w/cm with an 8 % silica fume (SF) blended portland cement (300 kg/m³), slag cement (100 kg/m³), crushed 20 mm limestone aggregates (1060 kg/m³), quartz sand (835 kg/m³), an air-entraining agent, and a water-reducing admixture. Mix 2 had a 0.37 w/cm with portland cement and slag, crushed 20 mm limestone aggregate, sand, an air-entraining admixture, and potentially other admixtures.

Sixteen 45 cm x 29 cm x 10 cm thick slabs were cast for each mix. The concrete was finished and covered with plastic sheeting to avoid moisture loss. A 40 mm thick Dow Styrofoam panel was placed on top of the plastic sheeting to minimize thermal losses. The moisture and heat barriers simulated a semi-infinite slab and aimed at isolating any effect to the bottom formed surface. The focus of the study was the formed surface since formed girder surfaces are exposed to chloride spray in-situ.

All slabs were demolded 20 hours after casting. The following curing regimes were used:

- Regime AC (air-cured): The concrete samples were placed in the laboratory at 20 °C and 50 % RH from finishing until 28 days of age.
- Regime MC (moist cured): The concrete samples were placed in a moist chamber at 25 °C and 100 % RH right after demolding and until 7 days of age. Samples were then stored in the laboratory at 20 °C and 50 % RH until 28 days of age.

- Regime HC/AC (heat cured followed by air curing as follows for the two concrete mixtures:
 - o Mix 1: 3 h preset at 30 °C, followed by a linear temperature increase to 60 °C over a 2-hour period. The temperature was held at 60 °C for 12 hours, after which the temperature was linearly decreased to 25 °C during a 3-hour period. The relative humidity of the environmental chamber containing the concrete samples was held at 95 % throughout the temperature cycle.
 - o Mix 2: 3 h preset at 37 °C, after which the temperature is linearly increased at a rate of 3.75 °C/h until it reaches 50 °C. The peak temperature is held for 10 hours and then reduced at a constant rate of 15 °C/h down to 20 °C. The relative humidity is maintained above 95 %.
- Regime HC/MC (heat cured followed by moist curing): Identical to HC/AC for Mixes 1 and 2 respectively, except that after demolding, samples were placed in the moist chamber at 25 °C and 100 % RH until 7 days of age. At the end of the moist curing period, samples were placed in the laboratory at 20 °C and 50 % RH until 28 days of age.

At the end of each temperature cycle, samples were demolded, removed, and placed in the laboratory at 20 °C and 50 % RH until 28 days of age.

Thermocouples were embedded in the center of one slab for each set of slabs to monitor the internal temperature. The temperature profiles can be found in Appendix A. Once demolded, all surfaces – except for the bottom formed surface – were covered with plastic sheeting to limit moisture losses to the surface of interest only. Each slab was cored at 14 ± 1 days of age to obtain eight-100 mm x 100 mm diameter cores. Cores were left in ambient laboratory air for an hour to evaporate the surface moisture resulting from the coring operation. All core surfaces, except for the bottom formed surface were then covered with plastic sheeting until 28 ± 1 days of age when test specimens were obtained by saw cutting the cores. The test specimens are 50 ± 2 mm thick disks, such that the cut depths of the test surfaces are 0, 8, 14, 20, and 53 mm from the formed surface of the core. Additional 2 mm deep test specimens were obtained by end grinding rather than saw cutting. For each mixture, curing regime, and test surface depth, five specimens were obtained with three used for absorption testing and the other two used for ASTM C1202 and ASTM C1876 tests. The test specimens were conditioned for test immediately after cutting. Note that the same specimens were used to perform both ASTM C1202 and ASTM C1876 tests. The bulk electrical impedance was measured first, given its on-destructive nature. Therefore, the test specimen conditioning

procedure was the same – and that of the ASTM C1202-19 (vacuum saturation), differing from procedure given in ASTM C1876.

Results

Test Sensitivity and Reliability

In order to assess the performance of curing regimes using the initial rate of absorption test, one needs to be confident about the sensitivity of the test result to the quality of curing. The reliability of the proposed test method was evaluated by comparing the test results obtained from the air cured concrete (AC) to that of the moist cured concrete (MC). It is assumed that the degree of hydration, and the chloride penetration resistance of the AC and MC concrete will be different due to their early-age treatment. For each of the 2 mixtures tested, and for every test depth, a single-tailed student-t test was performed. The outcome is summarized in Tables 1 and 2, corresponding to Mixes 1 and 2 respectively.

Table 1 Test Reliability - Mix 1

Depth (mm)	Initial rate of absorption	Charge passed	Bulk resistivity
0	99.5 %	55.8 %	90.6 %
2	95.8 %	81.8 %	17.0 %
8	95.8 %	81.4 %	86.9 %
14	97.5 %	75.6 %	43.2 %
20	99.3 %	97.4 %	88.4 %
53	61.2 %	98.4 %	24.9 %

Table 2 Test Reliability - Mix 2

Depth (mm)	Initial rate of absorption	Charge passed	Bulk resistivity
0	99.5 %	79.4 %	87.3 %
2	99.8 %	59.5 %	42.0 %
8	96.3 %	55.9 %	61.3 %
14	99.3 %	67.2 %	92.9 %
20	98.1 %	96.7 %	72.0 %
53	55.0 %	89.2 %	87.6 %

Therefore, due to the consistently high confidence level values (> 95 %), the initial rate of absorption is a reliable test metric for assessing the effect of different curing regimes on the chloride penetration resistance of the concrete cover. The low confidence level at the 53 mm depth for the initial rate of

absorption is due to the lack of difference between AC and MC at that depth, which is beyond the curing-affected zone – this is further explained later. The inability of the electrical-based tests (results shown in Tables 1 and 2) to reliably detect differences between AC and MC specimens is attributed to the fact that the results are influenced by the total thickness of the test specimen, which causes an ‘averaging’ effect that reduces the impact of curing. The rate of solution absorption, on the other hand, is initiated at a single surface at each depth, and is highly dependent on the pore structure at the neighbourhood of that surface.

The average coefficient of variation of the total absorption values was 5.38 %, over all 528 samples tested in triplicate. The coefficient of variation of the calculated initial rate of absorption was 4.91 % on average, over 48 samples of 3 specimens each. Due to the low coefficient of variability of the modified rate of absorption test, testing in triplicate is sufficient to obtain strong conclusions on the quality of the tested curing regimes for future pre-qualification and quality assurance purposes.

Absorption Profiling

Now that the sensitivity of the initial rate of absorption determined using the suggested test procedure has been proven experimentally, comparing the different curing regimes can be done. Figures 4 and 5 show the evolution of the initial rate of absorption as a function of depth from the formed surface for mixes 1 and 2 respectively.

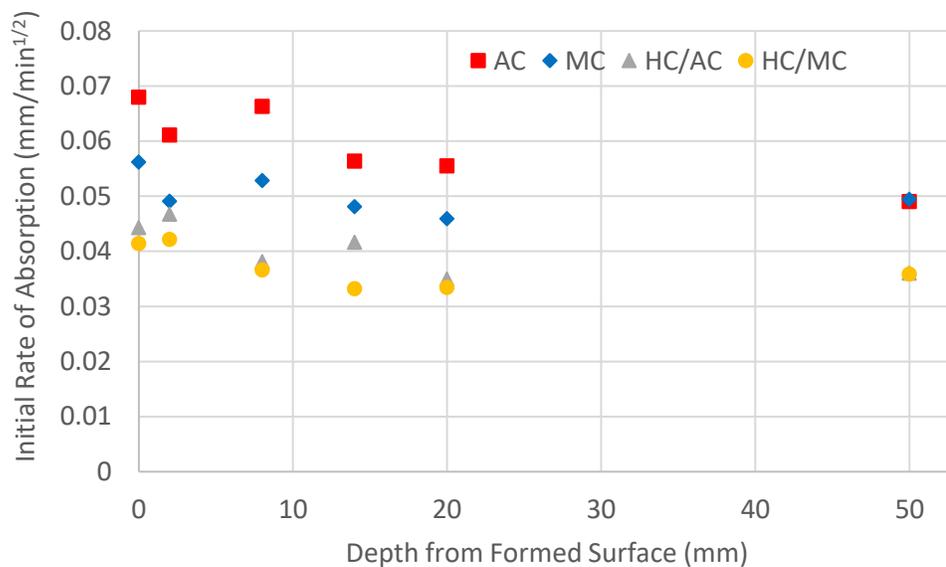


Figure 4 Initial Rate of Absorption as a function of depth from the formed surface – Mix 1

The curing-affected zone can be estimated as the distance from the formed surface after which the sorptivity becomes relatively constant. For the heat cured and moist cured Mix 1 samples, this depth is around 20 mm from the formed surface; whereas for the air cured samples, it is beyond 20 mm but cannot be determined since the last depth of measurement was at 53 mm. However, this value is below 53 mm for the air cured samples since the value of initial rate of absorption for MC and AC is equal at 53 mm from the formed surface.

For Mix 2, the values of initial rate of absorption plateaued at around 8 mm depth, while still exhibiting differences in values until 53 mm. These results validate the range of test depths from 0 mm to 53 mm that included any variation in properties that needed to be detected. The initial rate of absorption values are nearly consistently decreasing with test depth and a clear hierarchy can be defined. As expected, the air cured samples resulted in the highest absorption values, given that desiccation during setting and curing is the most pronounced on these samples.

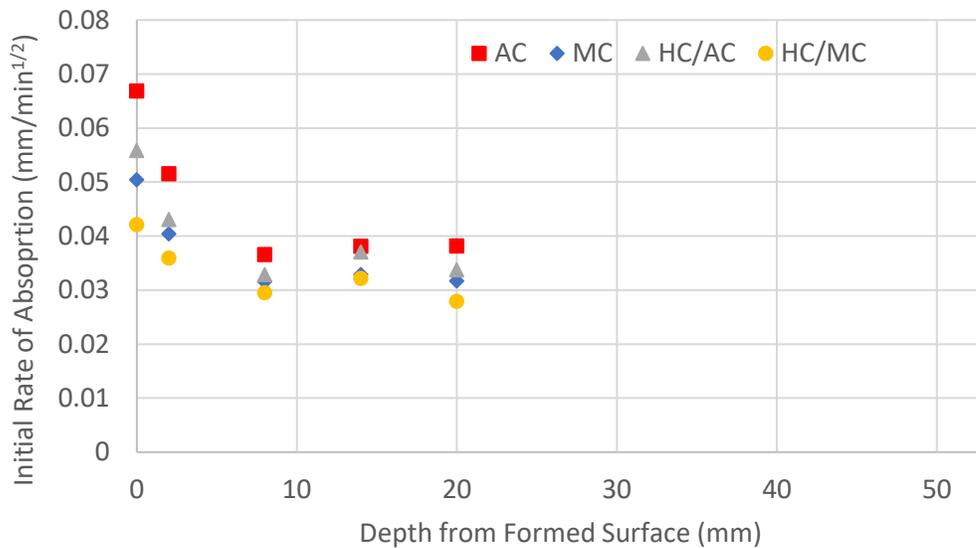


Figure 5 Initial Rate of Absorption as a function of depth from the formed surface – Mix 2

Given that the baseline considered in this set of experiments is the CSA prescribed 7-day moist curing at 23 °C (regime MC), the initial rate of absorption is compared for alternative curing regimes with respect to MC. The ratio of the initial rate of absorption of each alternative regime to that of MC for each test depth is shown in Tables 4 and 5 for Mixes 1 and 2 respectively. A ratio value equal to or smaller than 1 corresponds to a curing quality that is as good as or better than that obtained with the prescribed 7-day moist curing. Table 3 values in parenthesis give the probability that HC/AC is as good as, or better than,

MC (initial rate of absorption equal to or smaller than that of MC). In Table 4, the values in parenthesis correspond to the confidence level of the hypothesis that HC/C is as good as MC. Based on these results, and considering the initial rate of absorption as the only performance metric, one could conclude with a high level of confidence, that the HC/AC curing is as good as or even better than MC for the concrete Mix 1. However, some additional moist curing after the accelerated curing is required for concrete Mix 2 in order to confidently obtain performance equivalent to 7-day moist curing. Given that moist curing up to 7 days after heat curing (HC/MC) considerably outperforms the prescribed moist curing, the prolonged moist curing is deemed to be unnecessary. A shorter moist curing period following heat curing could be adopted. The optimal period can be determined by performing additional tests with shorter moist curing periods.

Table 3 Initial Rate of Absorption Relative to the CSA Prescribed Moist Curing – Mix 1

Depth (mm)	AC	HC/AC	HC/MC
0	1.21	0.79 (99.1 %)	0.74
2	1.24	0.95 (78.2 %)	0.86
8	1.25	0.72 (99.7 %)	0.69
14	1.17	0.87 (95.4 %)	0.69
20	1.21	0.76 (99.1 %)	0.73
53	0.99	0.73 (99.9 %)	0.73

Table 4 Initial Rate of Absorption Relative to the CSA Prescribed Moist Curing – Mix 2

Depth (mm)	AC	HCAC	HCMC
0	1.33	1.11 (16.4 %)	0.83
2	1.28	1.07 (12.2 %)	0.89
8	1.16	1.04 (53.4 %)	0.93
14	1.16	1.13 (15.2 %)	0.98
20	1.20	1.06 (32.4 %)	0.88
53	1.00	1.02 (32.2 %)	0.90

Heat treatment followed by ambient air curing (HC/AC) was sufficient for Mix 1 to achieve the same level of performance achieved by 7-days moist curing at ambient temperature. The high reactivity of the silica fume in the mix, coupled with the heat treatment provided rapid gain in maturity while developing a dense microstructure at early age. The comparison is different, however, for Mix 2. It is attributed to the

slower reactivity of the slag in this mix, which requires additional moist curing. It is worth noting, however, that the value of initial rate of absorption corresponding to moist curing of Mix 2 is lower than that of Mix 1. The improved performance is due to the mixture design and lower w/cm. This highlights the importance of the need of performance specifications and pre-qualification of curing regimes for specific concrete mixtures.

Figure 6 shows the depth-evolution of the uniaxial bulk electrical resistivity for Mix 2. It shows virtually no variation, which confirms the inability of these electrical tests at detecting differences caused by curing. The total charge passed for Mixes 1 and 2 are all below 1000 and 1500 Coulombs respectively – which corresponds to the limits for CSA exposure classes C-XL and C-1 concretes respectively (CSA A23.1-19). Considering the charge limits in the CSA specifications, even the air cured concrete would pass, at any depth from the formed surface.

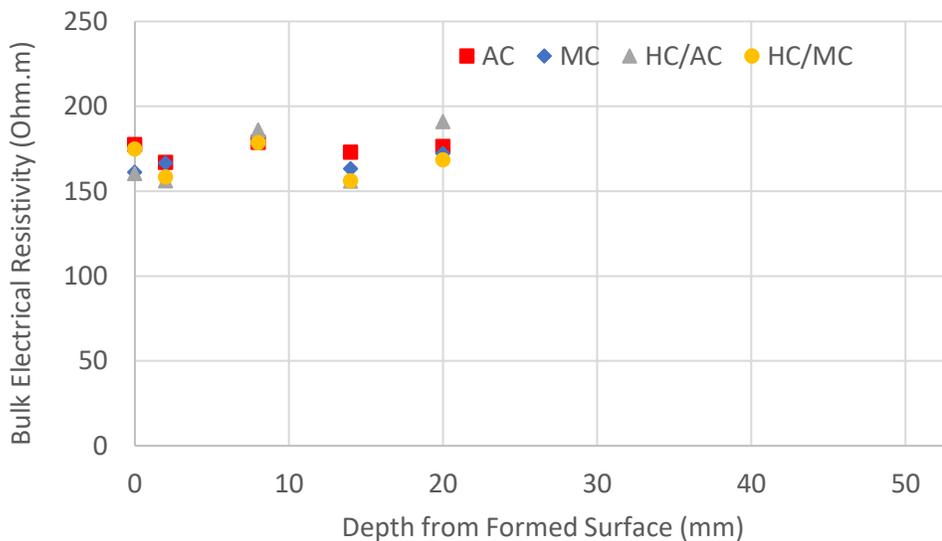


Figure 6 Depth Evolution of the Bulk Electrical Resistivity - Mix 2

The chloride penetration front profiles, Figures 7 and 8, determined colorimetrically (due to the precipitated AgCl_2 turning white, while the AgNO_3 turns dark brown), correlate well with the initial rate of absorption profiles. However, a higher variability in the data is obtained given that aggregates at the fracture surface interfere with the colorimetric front. The determination of the initial rate of absorption is more reliable and practical.

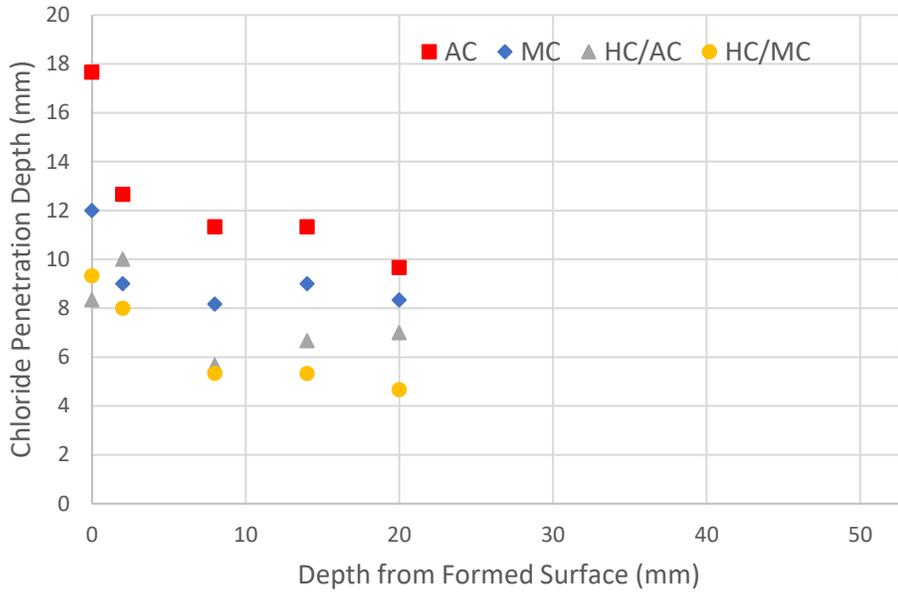


Figure 7 Depth Evolution of the Chloride Penetration Front - Mix 1

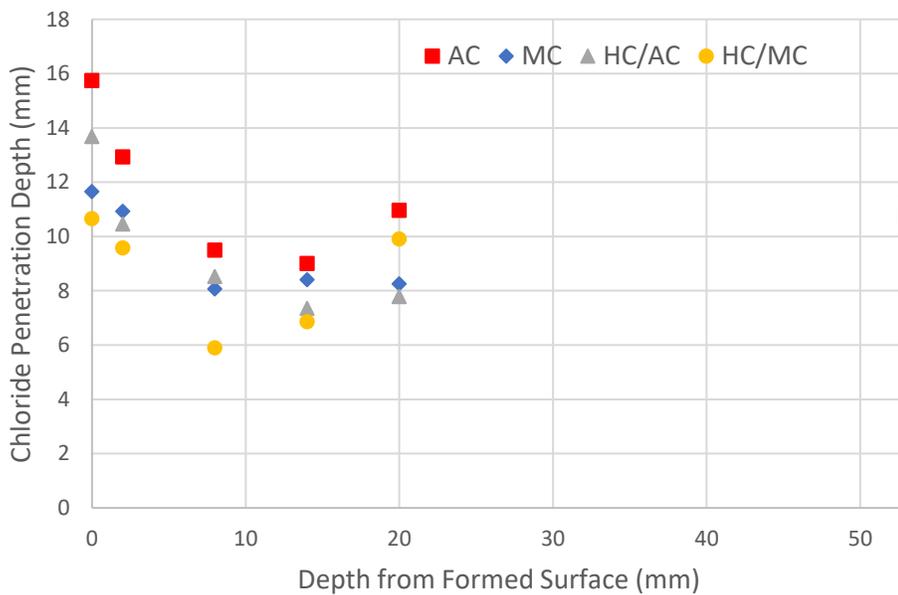


Figure 8 Depth Evolution of the Chloride Penetration Front - Mix 2

The initial rate of absorption test used in this study, when performed on cut surfaces at different depths from the formed or finished face, can be used to determine equivalent performance, in terms of curing-affected chloride penetration resistance, to the prescriptive CSA A23.1 curing requirements.

To make the test more practical, it is desirable to minimize the number of absorption test depths. However, when the test is performed for pre-qualification purposes, it is worth performing the full range of tests in order to best determine the effectiveness of curing techniques such as accelerated moist curing.

In addition, for acceptance purposes, and based on prequalification results, initial rate of absorption values of formed or finished faces could be then measured as a check on production quality.

Conclusions

1. The initial rate of absorption of a 3.0 % by mass sodium chloride solution initiated at different surfaces at a given distance from the formed surface of concrete slabs is highly sensitive to curing. Plotting the absorption profile through the depth of the cover zone provides an estimate of the depth and impact of the curing-affected zone.
2. While suitable for characterizing the performance of the concrete mixture, rapid chloride permeability (ASTM C1202) and uniaxial bulk electrical resistivity (ASTM C1876) test results are not sensitive to differential curing. This conclusion is made based on the inability of the electrical test methods at differentiating between air curing and moist cured concrete.
3. The experimental program demonstrated that equivalent curing performance to the CSA A23.1 prescriptive 7-day moist curing requirements can be demonstrated by profiling the initial rates of absorption through near-surface, curing-affected depths. The equivalence between accelerated moist curing followed by air curing and the prescriptive 7-day moist curing in CSA A23.1-19 would need to be determined on a mixture specific and accelerated curing regime basis. The test can be performed during pre-qualification and the need for any additional post-heat curing measures, if any, can be determined, to meet the equivalent performance level.
4. Combining the well-established RCPT (ASTM C1202), or uniaxial bulk electrical resistivity (ASTM C1876), with the suggested absorption profiling test is a plausible approach for use in performance specifications in concrete production.
5. Specifications could eventually incorporate maximum acceptable values for the initial rate of absorption, similar to what is established incorporating the total charge passed as per ASTM C1202.

Recommendations

1. Adopt the initial rate of absorption test used in this study, to test cut surfaces at different depths from formed or finished faces, to determine equivalent performance, in terms of curing-affected chloride penetration resistance, to the prescriptive CSA A23.1 curing requirements.
2. To make the test more practical, it is desirable to minimize the number of absorption test depths. However, when the test is performed for pre-qualification purposes, it is worth performing the full range of tests in order to best determine the effectiveness of curing techniques such as accelerated moist curing.
3. In addition, for acceptance purposes, and based on prequalification results, perhaps single initial rate of absorption values on formed or finished faces could be then measured as a check on production quality.

Next Steps

1. A Sorptivity test method, based on a modification of ASTM C1585 is being drafted. When completed, it will be brought to the CSA A23.1/A23.2 committee for consideration.
2. A suggested qualification and acceptance criteria/method that could be included in specifications by agencies will be based on using the proposed test method to demonstrate equivalent performance, in terms of fluid penetration resistance, to that provided by the prescriptive curing requirements in CSA A23.1.

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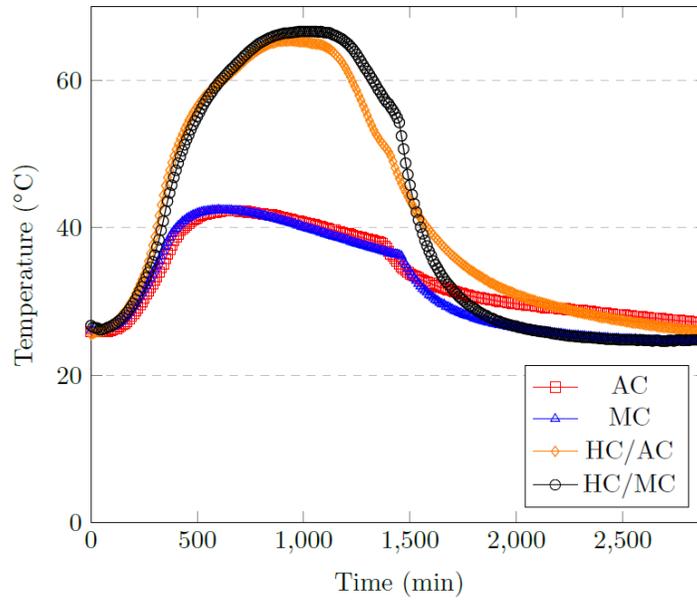
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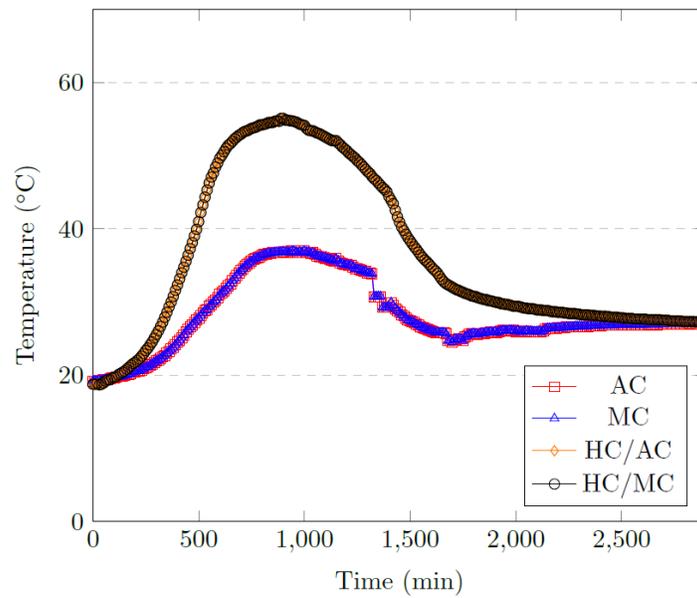
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Appendix A

Internal Temperature Profiles of Slabs



Mix 1 Temperature History

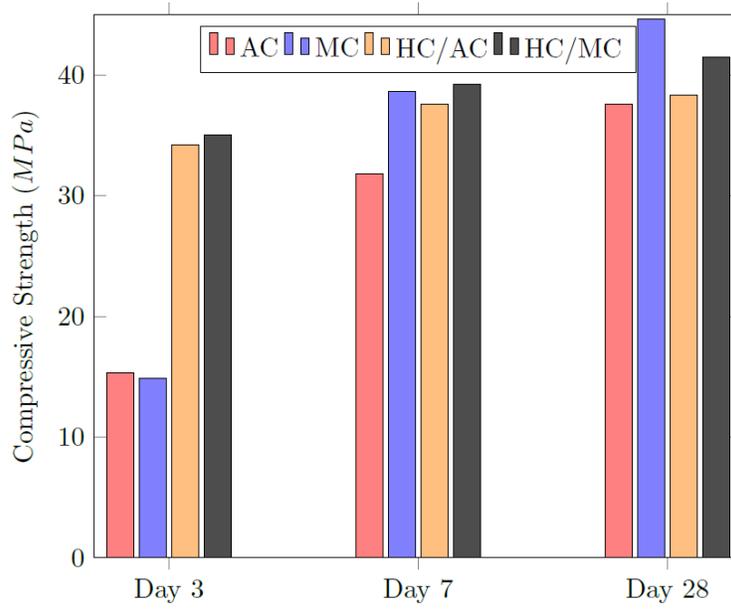


Mix 2 Temperature History

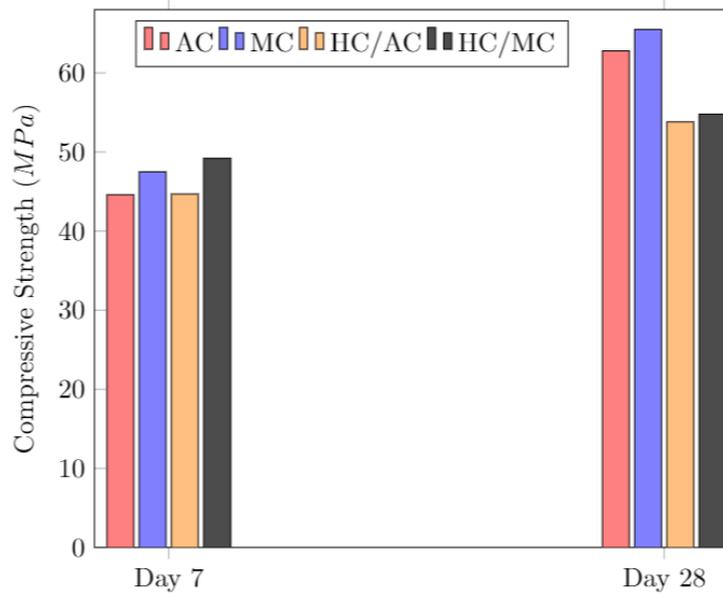
Concrete Fresh Properties

	Mix 1	Mix 2
Slump (mm)	58	120
Fresh Temperature (°C)	28	23
Air Content (%)	9	5

Compressive Strength



Evolution of the Compressive Strength – Mix 1



Evolution of the Compressive Strength – Mix 2

Pictures



Casting Slabs at Precast Concrete Plant



Covered slabs after Casting at Precast Concrete Plant-Mix 1



Conditioning of Slabs Prior to Coring



Coring of Slabs at the Concrete Materials Lab



Absorption Testing at the Concrete Materials Lab



(a) AC



(b) MC



(c) HC/AC



(d) HC/MC

Colorimetric Chloride Penetration Fronts from the Cast (bottom) Faces for Different Curing Regimes – Mix

1



Example of Colorimetric Chloride Front with High Variability