EVALUATING THE DURABILITY OF CRITICAL INFRASTRUCTURE: DEVELOPMENT OF A NEW TEST METHOD TO EVALUATE THE IMPACT OF CURING ON THE NEAR-SURFACE CHLORIDE PENETRATION RESISTANCE OF CONCRETE

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Introduction

- None of the current CSA A23.2 test methods are designed to evaluate the impact of curing on surface durability.
- The current CSA A23.2-22A (the same as ASTM C1202) “coulomb” test method is not sensitive to curing since the electrical conductivity is averaged over the 50 mm thickness of the test specimen (thicker than the depth of the average curing-affected zone) and from a section that is sliced below the surface of the specimen.
- The CSA A23.4-16 standard does not mandate additional curing after 16 hours of accelerated curing.
- For Class C-1 and C-XL Concretes the concrete must only meet 70% of the design strength, which is typically at 16 hours for accelerated cured concretes.

Introduction

- Two test methods were investigated that have the potential to evaluate impacts of different curing regimes on the surface durability of precast (and potentially cast-in-place) concrete elements with regard to chloride penetration resistance.
- These test methods are modifications of the ASTM C1585 rate of absorption test and the Nordtest NT Build 492 rapid migration test.

Scope of Research

- To suggest a test method to evaluate the near surface durability of accelerated cured precast concrete.
- Two potential test methods are investigated.
- To corroborate previous research that suggests there is no need for additional moist curing of precast concrete elements after the initial 16 hours accelerated curing cycle.

Precast Concretes Tested

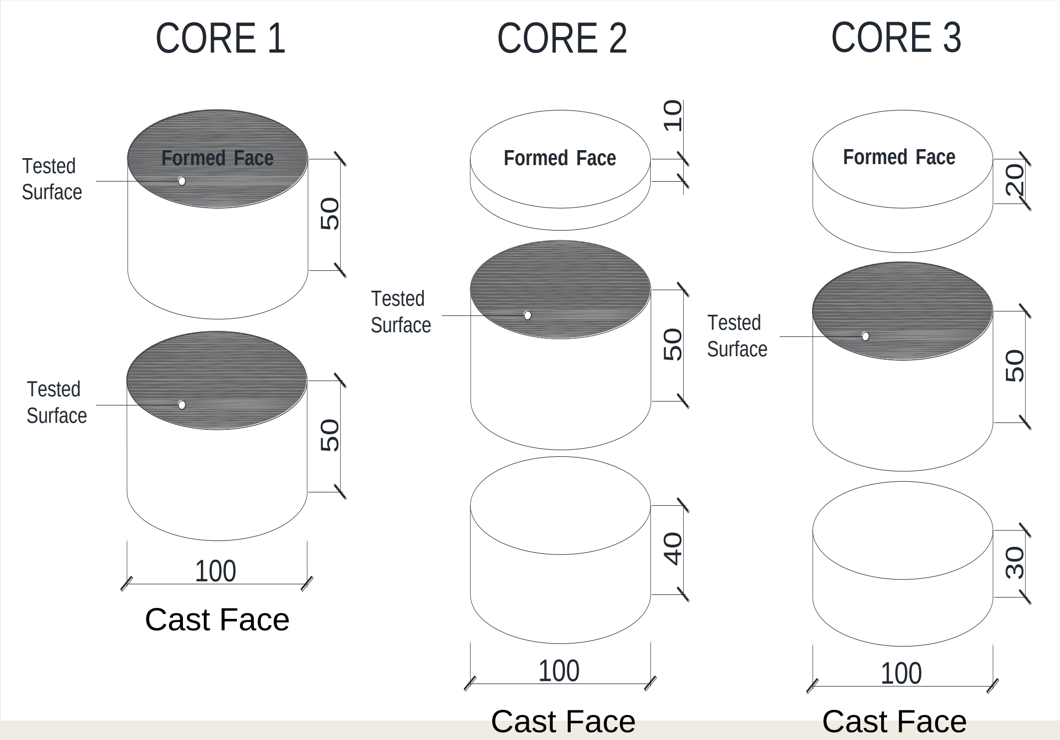
- **CSA C-1** - maximum water-to-cement ratio of 0.40, minimum specified compressive strength of 35 MPa at 28 days and have less than 1500 coulombs at 56 days.
- **CSA C-XL** - maximum water-to-cement ratio of 0.40, minimum specified compressive strength of 50 MPa within 56 days and less than 1000 coulombs at 56 days age.
- C-1 mix was cast at CPCI member plant - Armtec, Woodstock, ON precast plant on June 13th, 2017, w/c=0.30.
- C-XL mix was cast at CPCI member plant - Strescon, Bedford, NS precast plant on September 26th, 2017, w/c=0.32.

Curing regimes

	CSA C-1	CSA C-XL
7-day moist curing followed by ambient air	7MC	7MC
Accelerated cured followed by ambient air storage	A+0D	A+0D
Accelerated cured followed by 3 day moist curing – then placed outdoors	A+3D/OS	/
Accelerated cured followed by 3 day moist curing – then ambient air storage	A+3D/IS	A+3D
Accelerated cured followed by 7 day moist curing – then ambient air storage	A+7D	A+7D
Accelerated cured then frozen to 7 days followed by storage at 50% relative humidity and 25 ℃ temperature	A-FR	/

Modified ASTM C1585 Test

- Comparing the initial rate of absorption of cores at different depths from the formed surfaces.
- For each curing regime, four 100x50 mm discs were tested (at formed face, 10 mm, 20 mm and 50 mm from the formed face).
- Main modification of this test is that instead of water, 2.8M NaCl solution was used.
- Discs were then split and sprayed with $AgNO_3$ to get depth of Cl penetration.

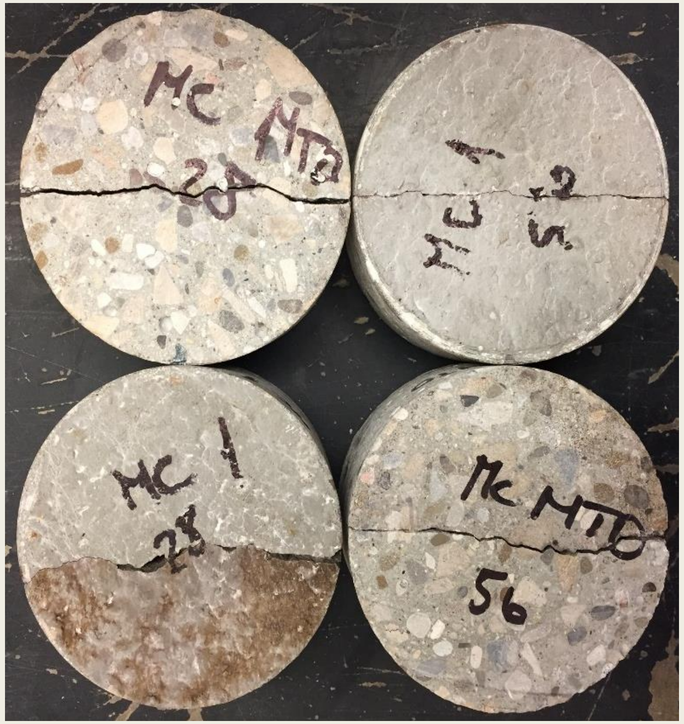


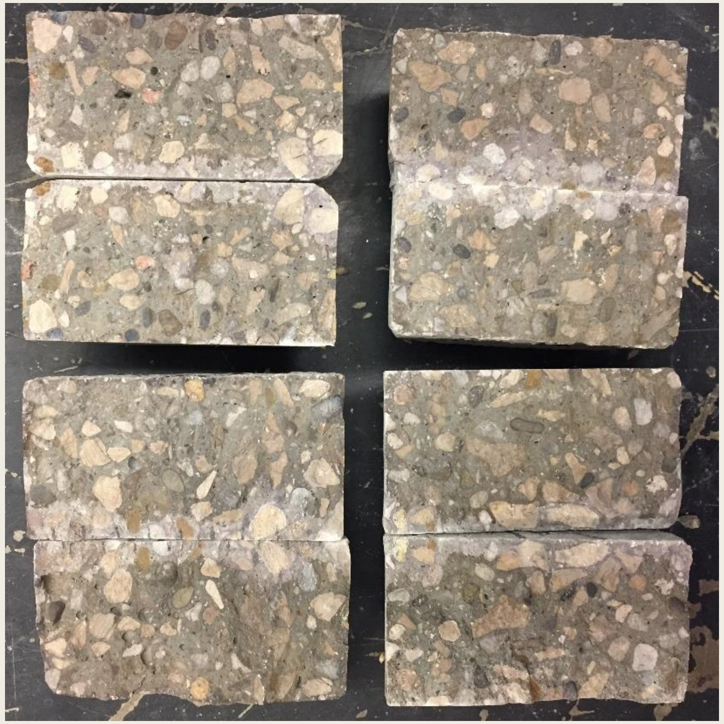
Modified ASTM C1585

- Before testing, discs were dried in 50°C oven for three days on open rack followed by four days in sealed container at 50°C, then cooled to 23°C for one day before testing
- Instead of using water for absorption, 2.8M NaCl solution was used (this is the same solution that is used in NT 443, Bulk Diffusion Test)

Modified ASTM C1585

- After the absorption test, discs were split open, sprayed with 0.1N silver nitrate solution and the depth of chloride penetration measured by the color change





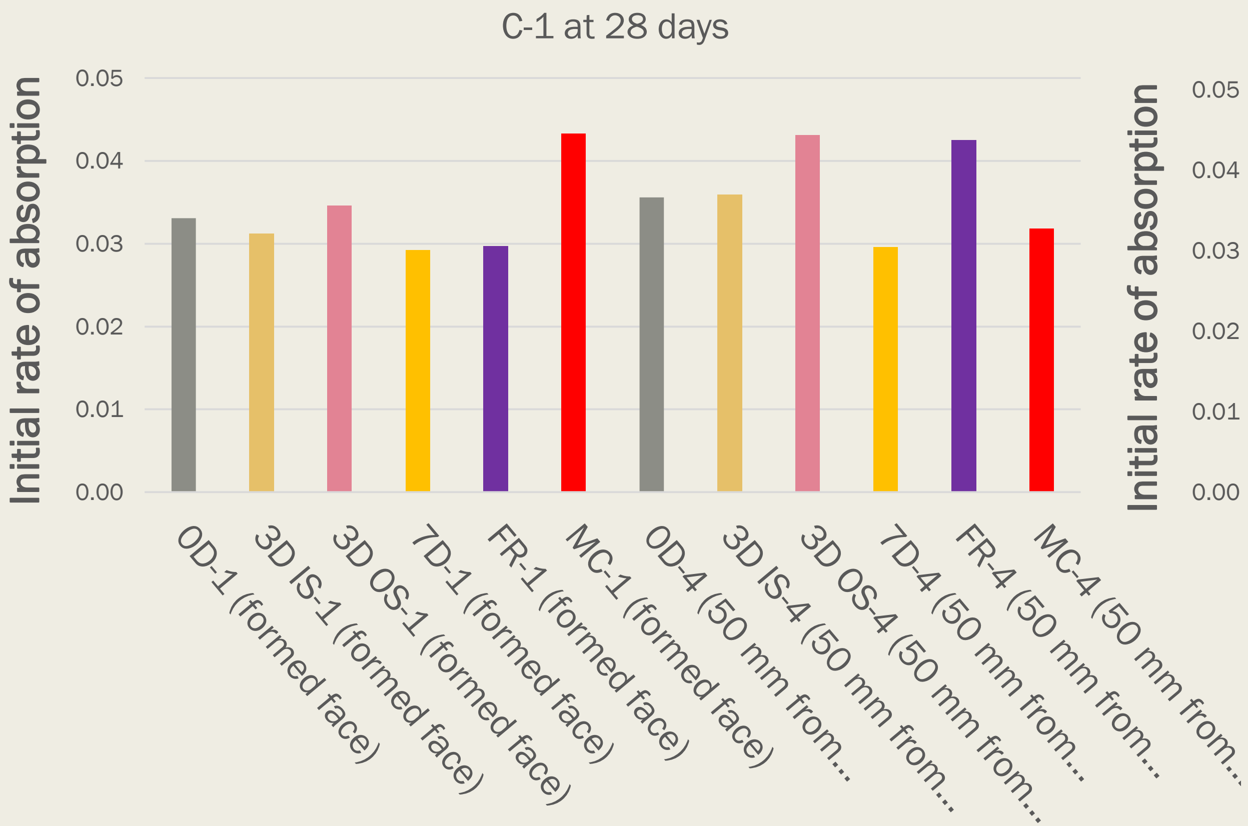
Modified ASTM C1585 Test

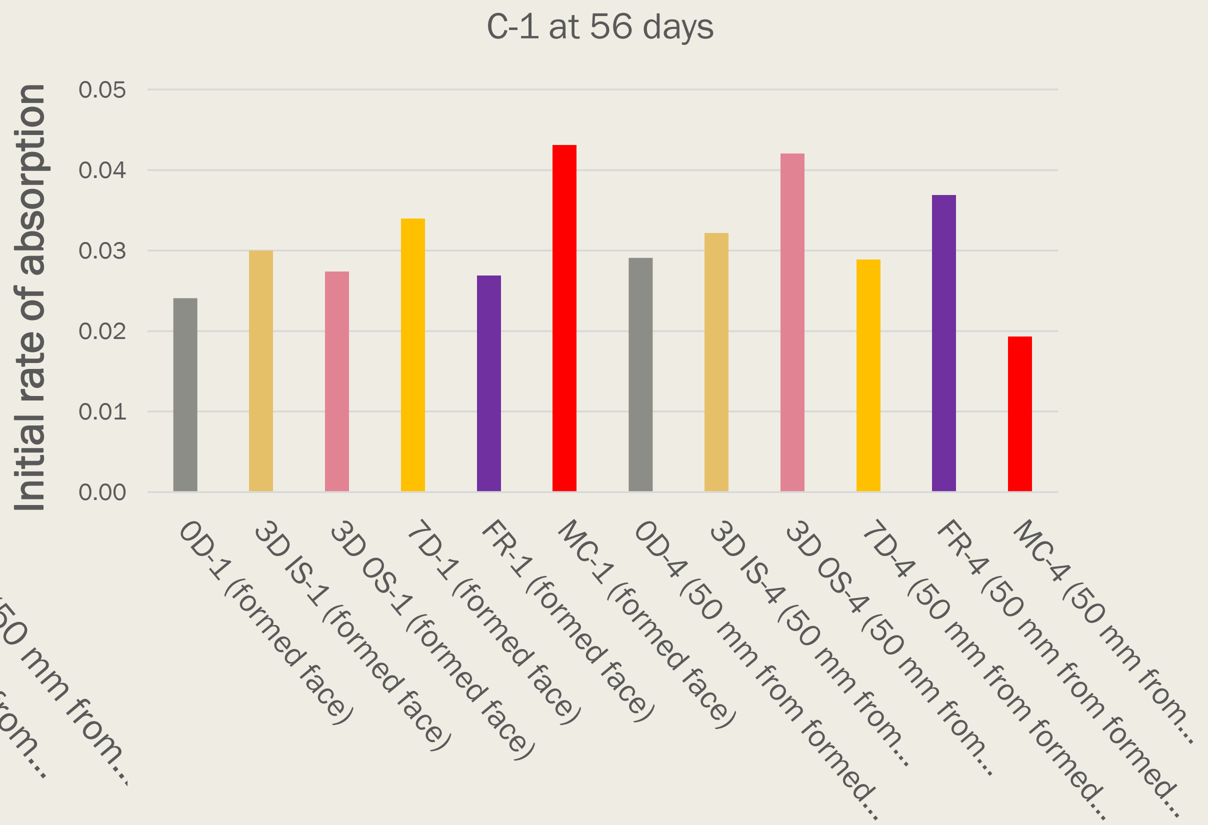
- Initial rate of absorption was measured at 1, 4, 9, 16, 25, 36, 49, 64, 81, 100, 121 and 144 minutes, these numbers were chosen so that square root of each time is a round number.
- When calculating initial absorption, density of 2.8M NaCl solution was taken into account.
- Depth of chloride penetration was determined by splitting core after test and spraying surface with silver nitrate ($AgNO_3$). When it contacts chloride (Cl) ions, it turns white.
- Depth of penetration was measured colorimetrically every 10 mm across surface.

$$AgNO_3 + Cl^- \rightarrow AgCl_2 \rightarrow \text{white}$$

ASTM C1585 results

Initial rates of absorption for C-1 mix at 28 and 56 days (at formed faces and 50 mm below)





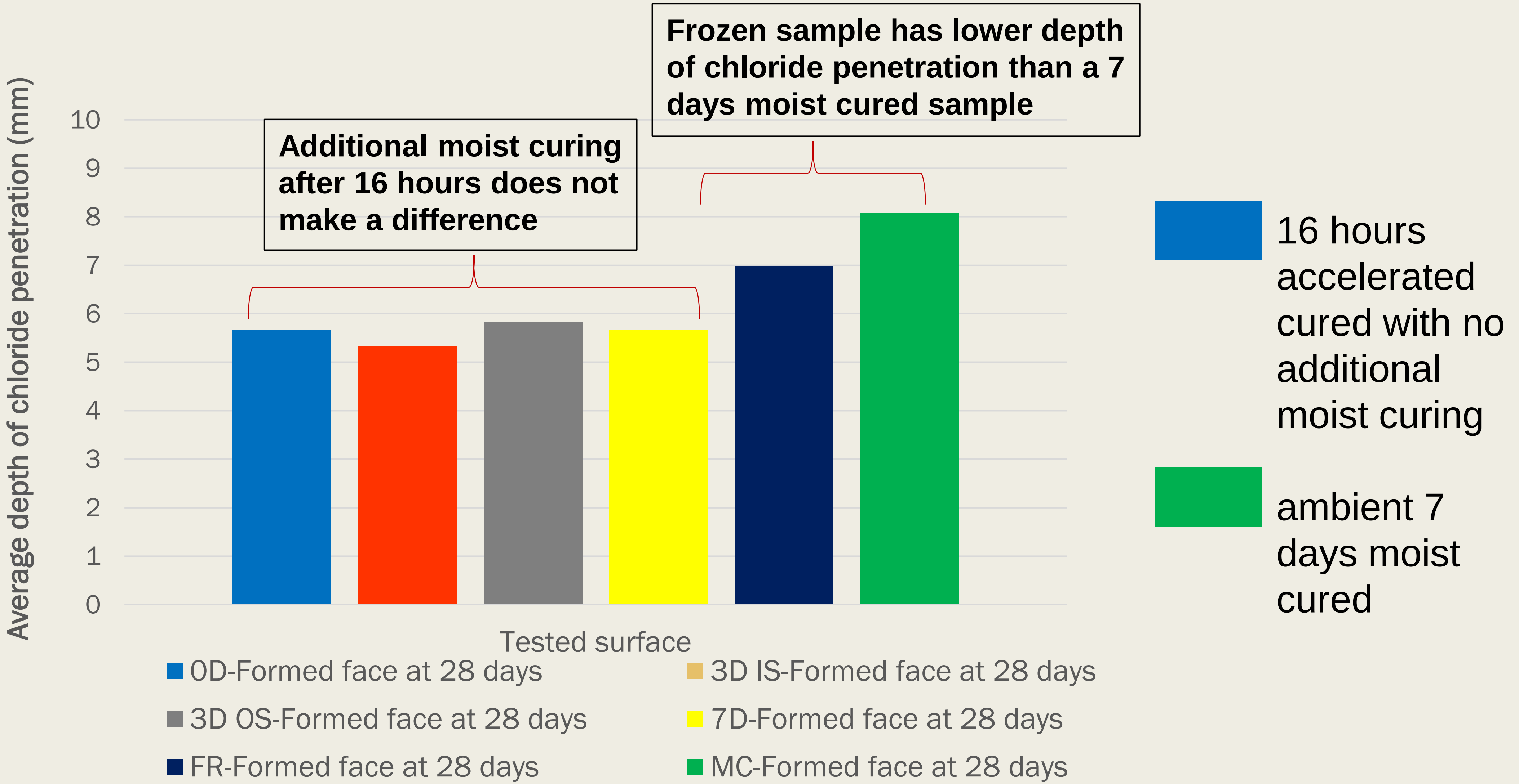
16 hour accelerated curing with no additional moist curing

Ambient 7 days moist cured

ASTM C1585 results

Average depths of chloride penetration for **C-1** mix at 28 days

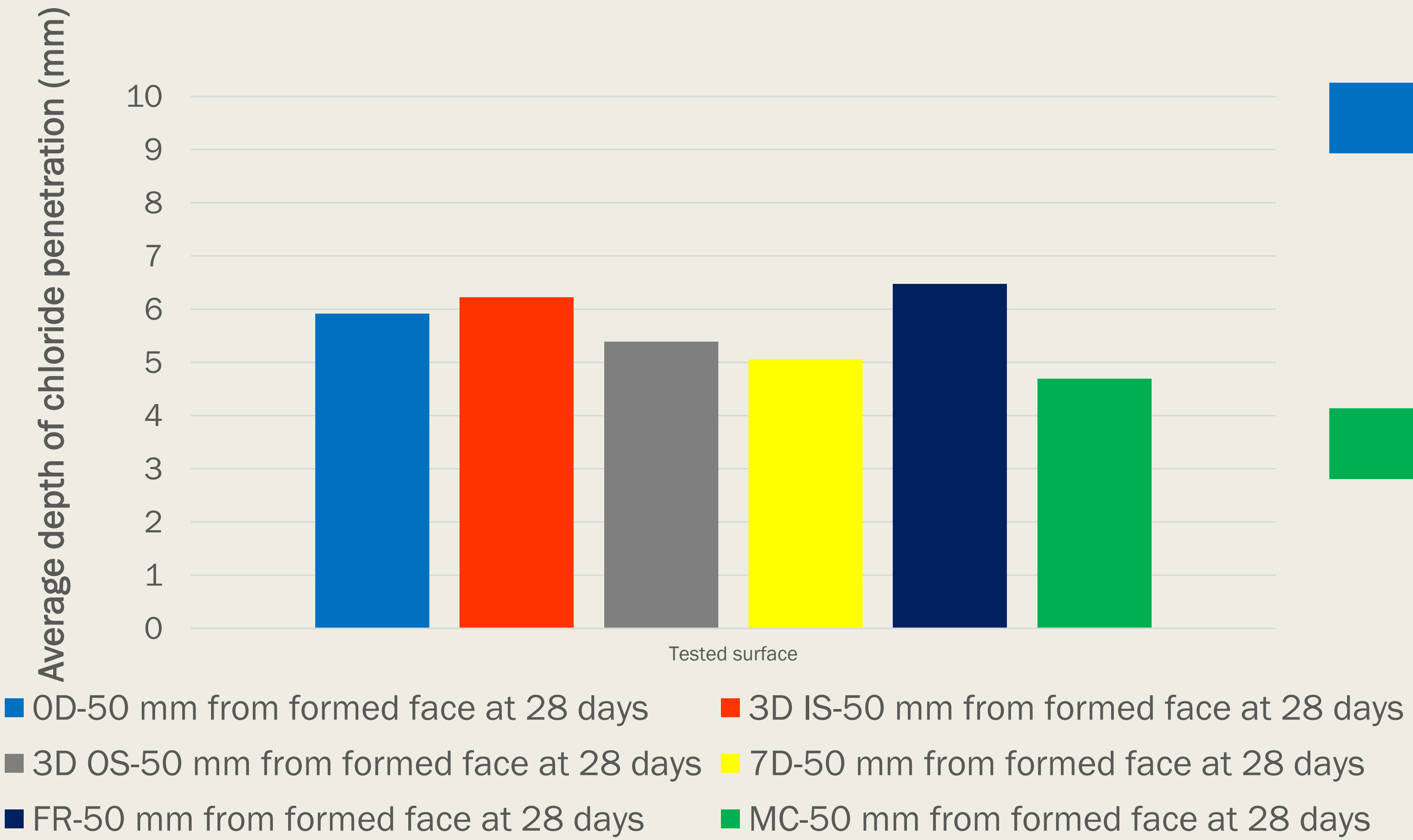
Samples tested at formed faces



ASTM C1585 results

Average depths of chloride penetration for **C-1** mix at 28 days

<u>Samples tested 50 mm from formed surfaces</u>

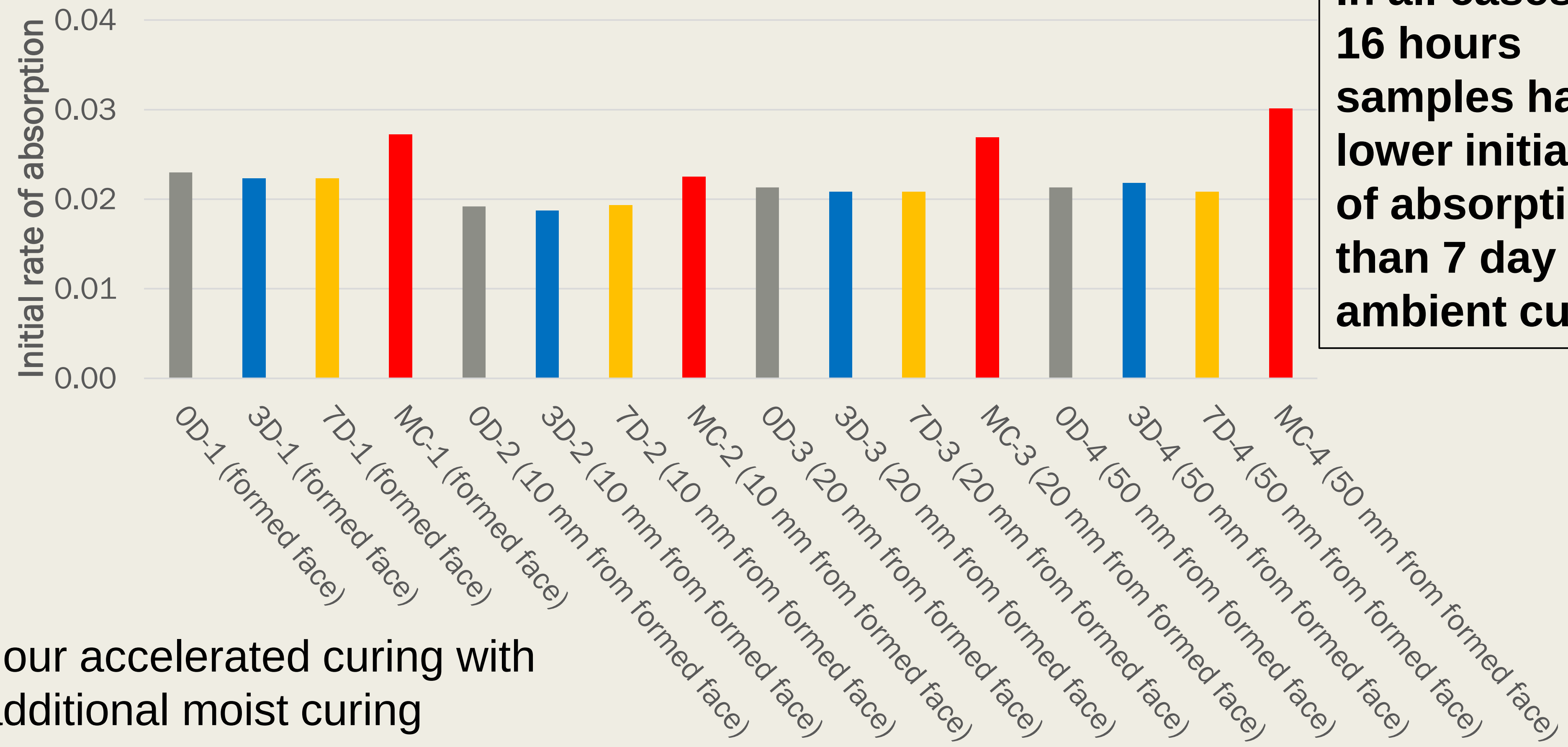


16 hours accelerated cured with no additional moist curing

ambient 7 days moist cured

ASTM C1585 results

Initial rates of absorption for **C-XL** mix at 28 days



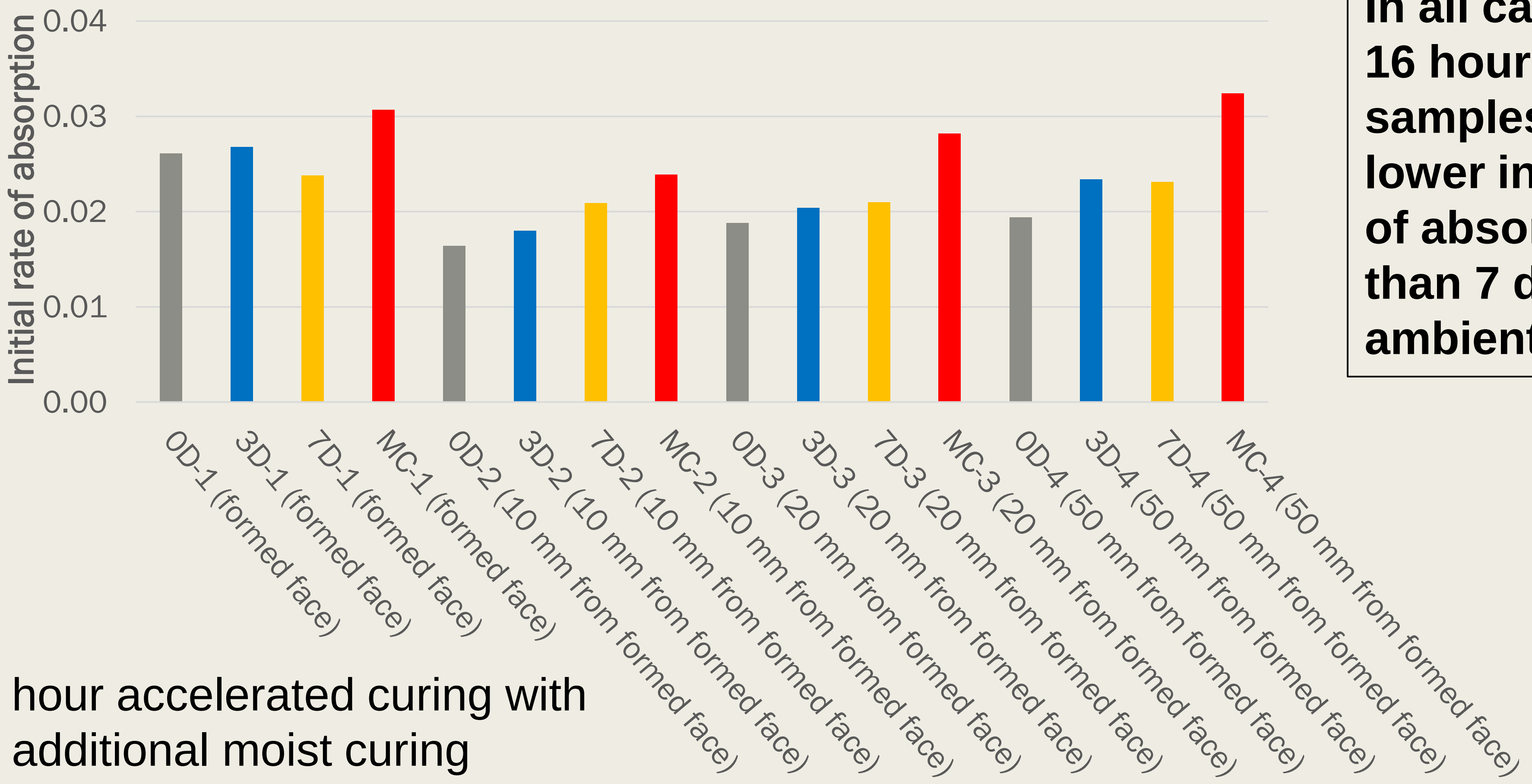
In all cases the 16 hours samples had lower initial rate of absorption than 7 day ambient curing

16 hour accelerated curing with no additional moist curing

Ambient 7 days moist cured

ASTM C1585 results

Initial rates of absorption for **C-XL** mix at 56 days



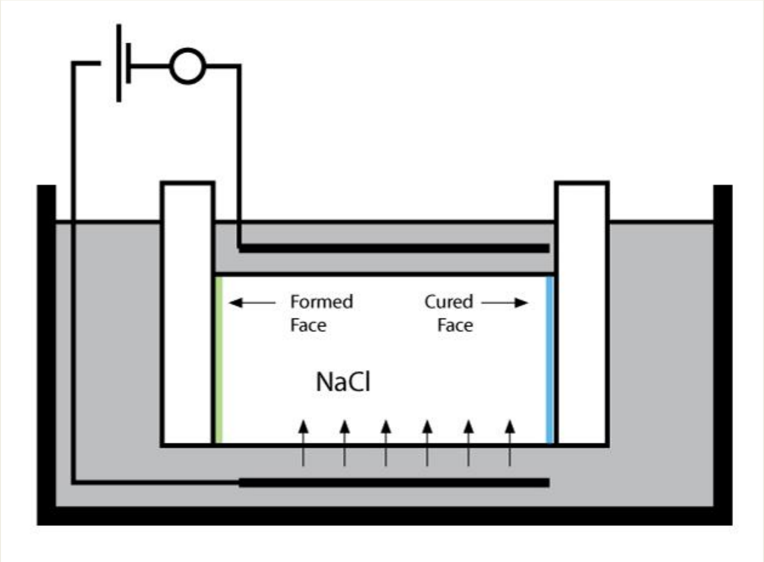
In all cases the 16 hours samples had lower initial rate of absorption than 7 day ambient curing

16 hour accelerated curing with no additional moist curing

Ambient 7 days moist cured

Modified NT 492 Test

- Concrete slice is sealed on sides with bitumen membrane and exposed to NaCl solution on bottom and NaOH solution on top.
- Fixed DC voltage is applied for a fixed time.
- Slice is then spit open and sprayed with $AgNO_3$ solution to image the depth of chloride penetration.



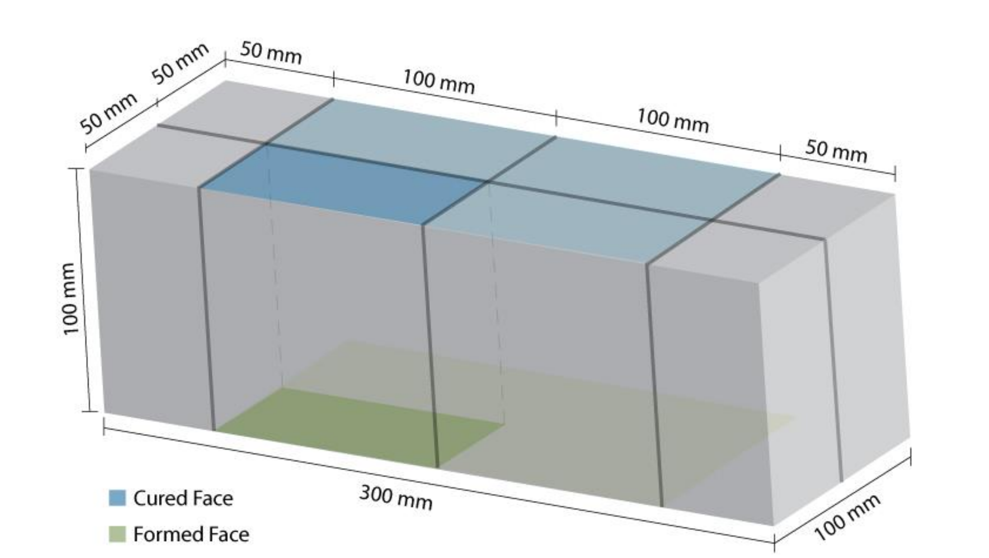
Modified NT 492

- This approach was used by Hooton et al (2002) and by Ha (2003) to demonstrate the impact of curing on the chloride resistance and service life of concrete.
- This test is used by COWI on their projects
- **The advantage of this method, is that both the depth and magnitude of the curing-affected zone is determined.**
- Non-Steady State Diffusion equation:

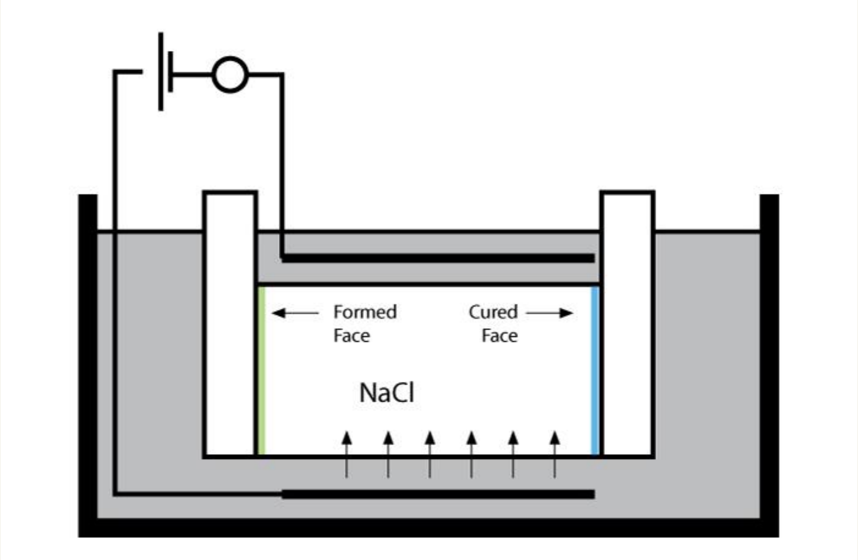
$$D_{nssm} = \frac{0.0239(273+T)L}{(U-2)t}\left(x_d - 0.0238\sqrt{\frac{(273+T)Lx_d}{U-2}}\right)$$

T = Temp.(^{o}C) ; L = sample thickness (mm); U = voltage; t = time under voltage (h)
xd = average depth of Cl penetration (mm)

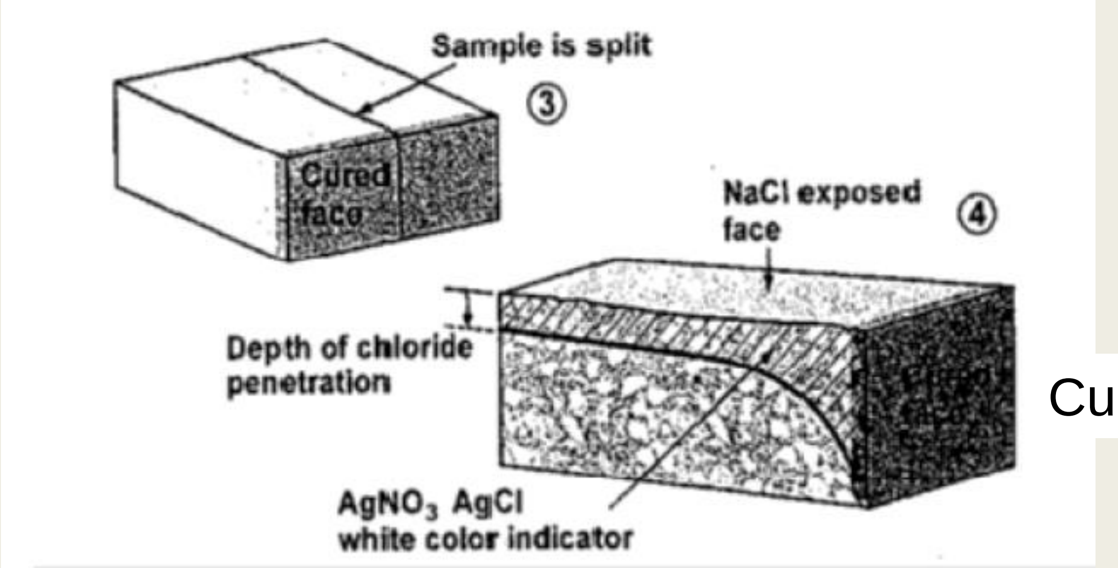
Modified NT 492



Prism cutting plan



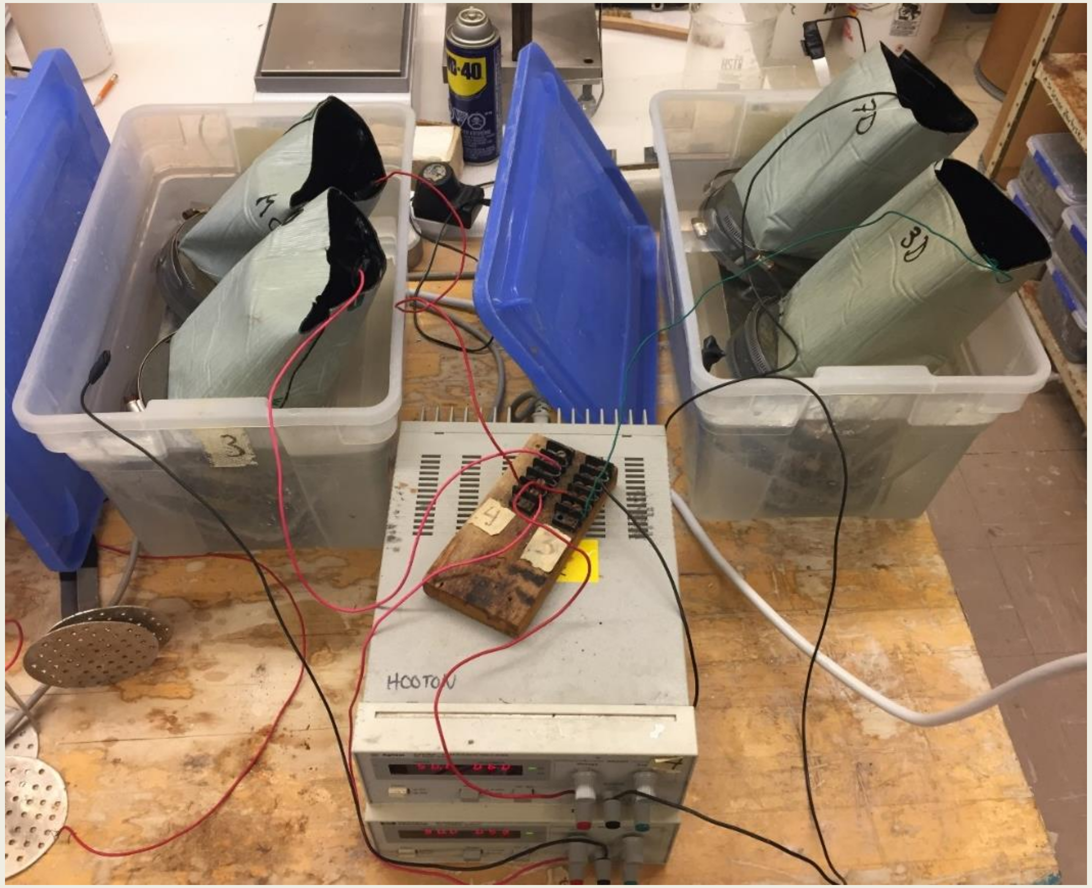
NT492 test set-up



Cured Face

Modified NT 492

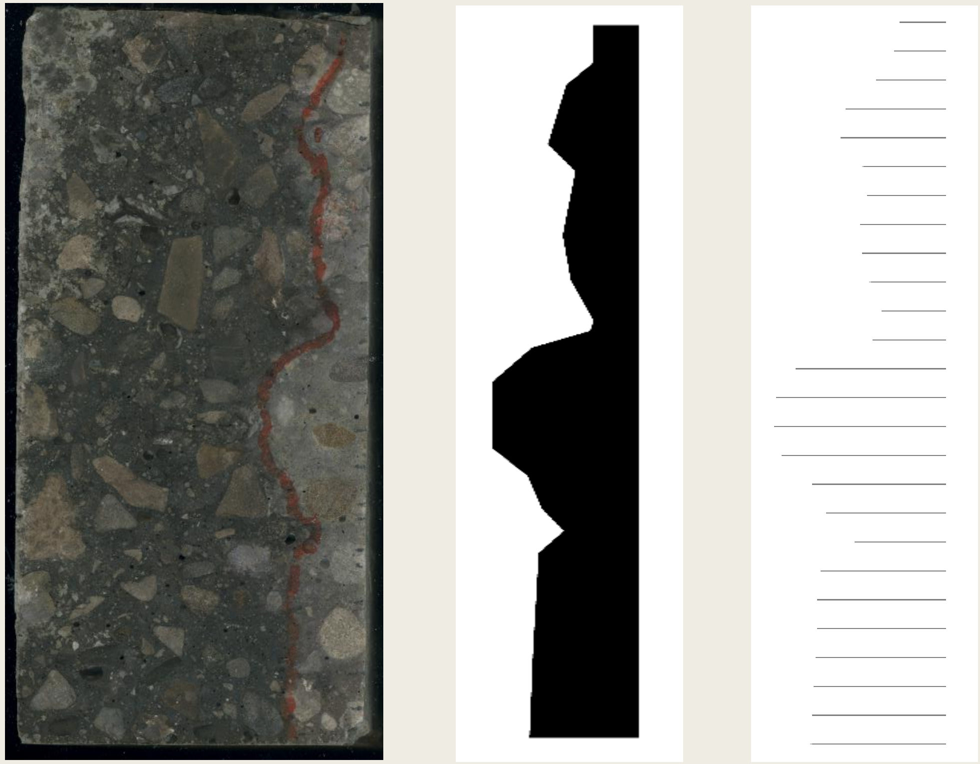
Prism cutting



Slices in migration test (voltage driving chloride ingress)

Analysing modified NT 492

NT 492 depths of chloride penetration with distance from formed and cast faces are analysed with ImageJ software:



Program written in ImageJ can measure depth of chloride penetration every mm.

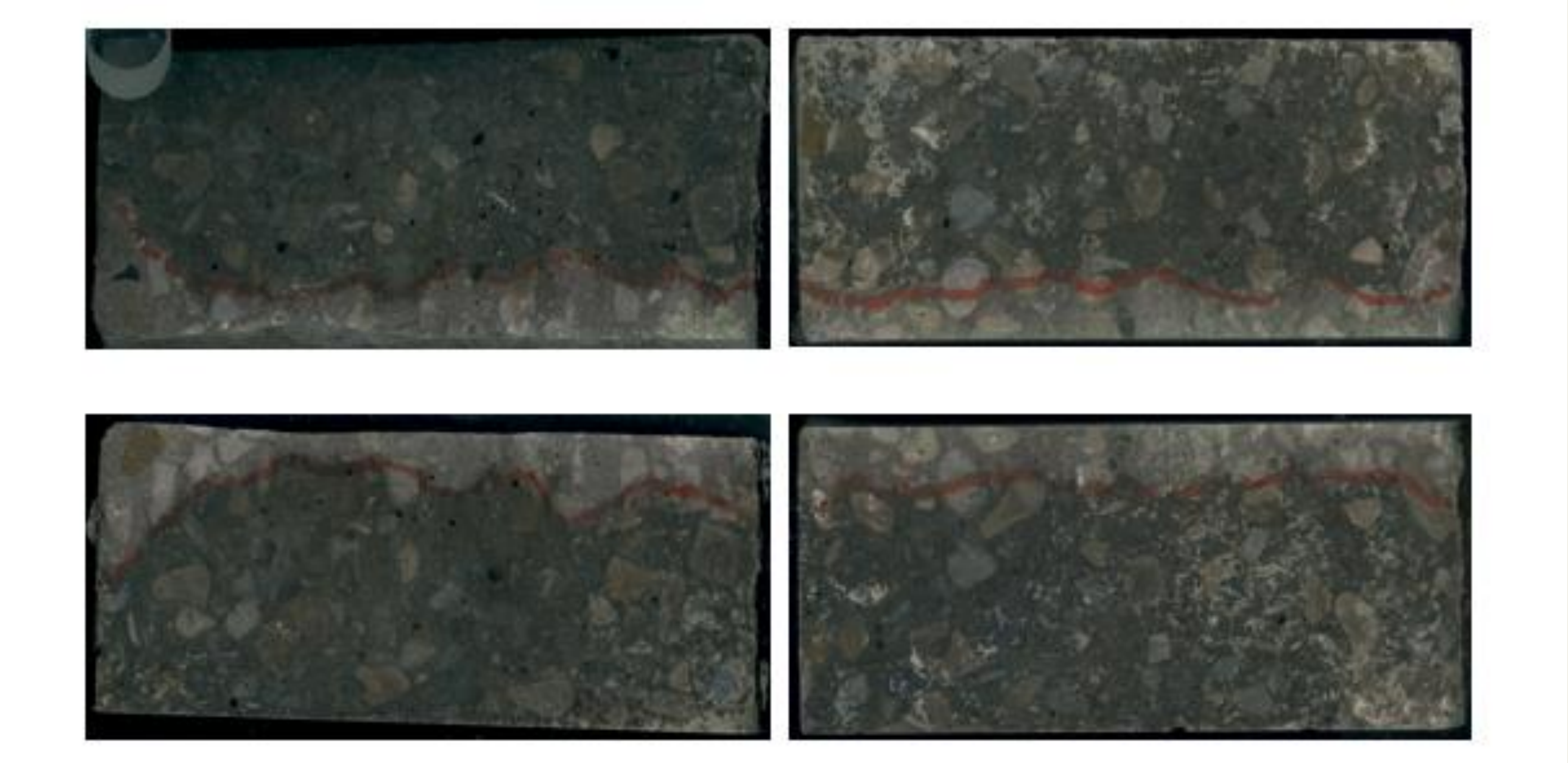
Grid is overlapped with selected area.

Note: some variability largely due to coarse aggregate

Analysing modified NT 492

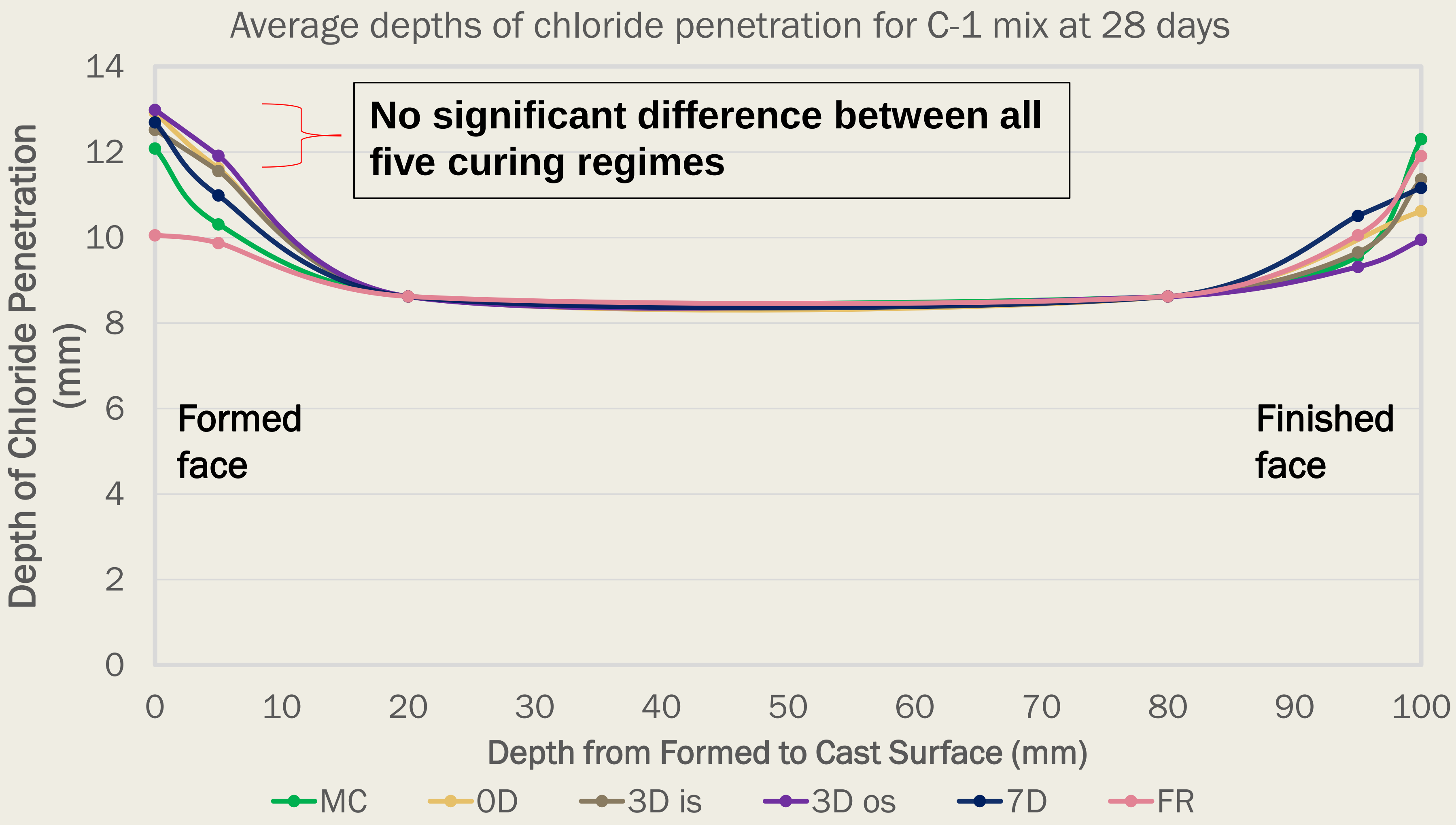
C-XL mix: Accel. Cured +0D Mc split faces

Formed face

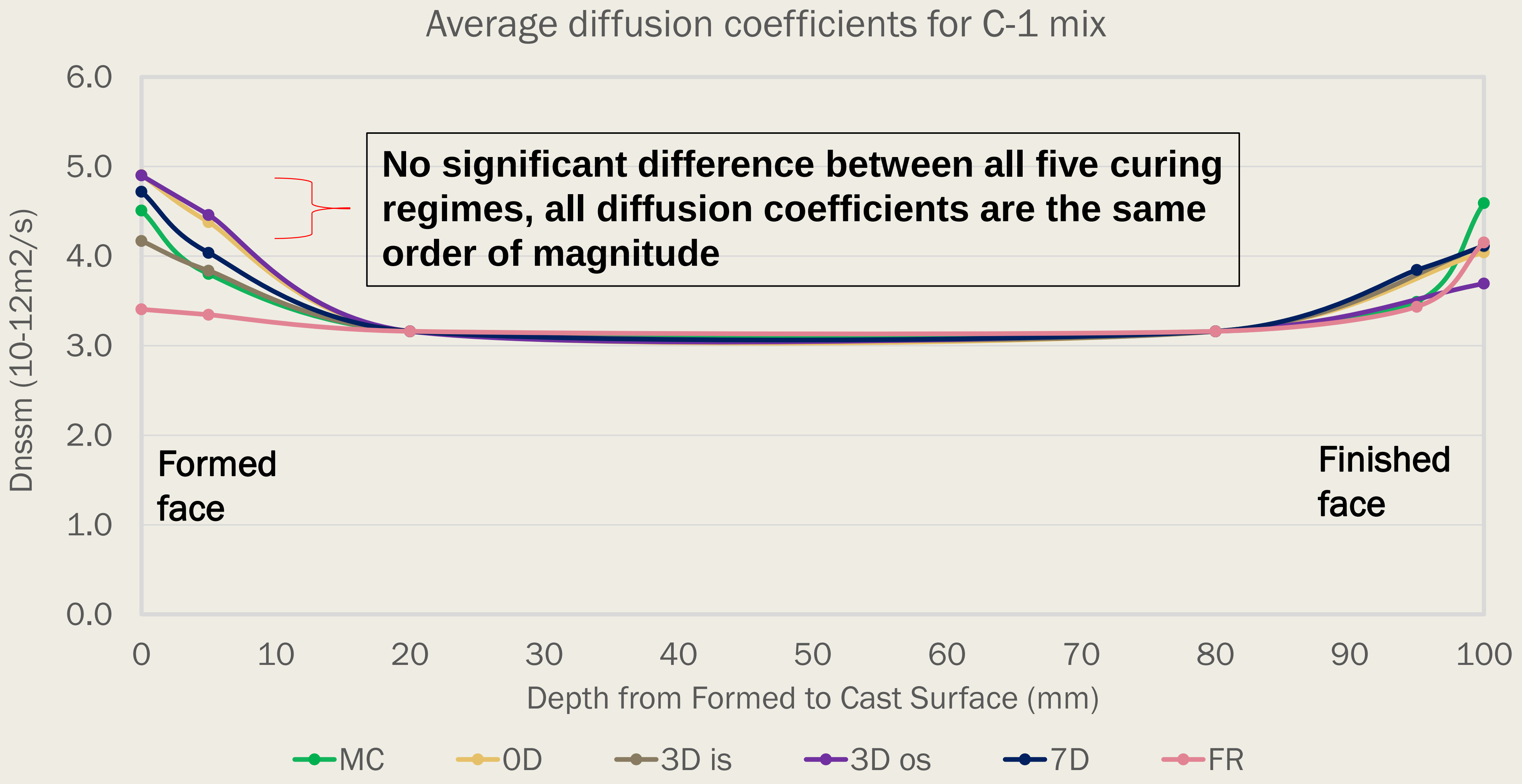


Cured face

NT 492 Average depths of Cl penetration



NT 492 Diffusion results with depth



Conclusions: Modified C1585 test

- The modified ASTM C1585 test using a salt solution can provide both an initial rate of absorption as well as a depth of chloride penetration at cured and formed surfaces and at different depths from these surfaces.
- By comparison of test results of core slices taken at different depths from the formed or finished faces, it is possible to determine the depth of the curing affected zone for a given concrete.
- This modified test procedure is relatively easy to set up and perform. There is no need for expensive equipment or extensive training.
- This test method <u>is</u> recommended as a potential standard test method for near surface durability.

Conclusions: Modified NT492 Test

- The modified Nordtest NT 492 can be used to observe the chloride penetration with depth from either formed or cured surfaces and calculate depth-dependent diffusion coefficients.
- However, coarse aggregates cause interference in the chloride penetration depth measurements.
- As well, this test is more time consuming and requires more labor and equipment than the modified C1585 test.
- This test method is not recommended as a potential standard test method for near surface durability.

Conclusions: Effect of Curing Regimes

- The tests performed on both the precast concretes designed for CSA C-1 and C-XL exposures have shown that 7-day moist curing of the concrete at ambient temperature is not as effective in resisting chloride penetration compared to 16 hours of accelerated curing with no additional curing thereafter.
- Provision of additional moist curing to concrete that has been given accelerated curing does not result in improved resistance to chloride penetration.

Thank you!