MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

03 30 00	Cast in Place Concrete
03 40 00	Precast Concrete
03 70 00	Mass Concrete

MCI®-2005 NS

DESCRIPTION

MCI®-2005 NS (normal set) is a water-based, organic, corrosion inhibiting admixture for protection of metallic reinforcement in concrete structures.

When incorporated into concrete, MCI®-2005 NS forms a protective, monomolecular layer on embedded metals that inhibits corrosion. In new construction, this is quantified by an increase in critical chloride threshold and subsequent reduction in corrosion rates when corrosion does initiate. When used with repair mortars and grouts, MCI®-2005 NS not only protects rebar within the patch, it is able to migrate into undisturbed concrete adjacent to the repair, to protect reinforcement already in place. MCI®-2005 NS is available with added fragrance (bubble gum) as MCI®-2005 NSB.

PACKAGING & STORAGE

Available in 5 gallon (19 Liter) pails, 55 gallon (208 Liter) drums, and 275 gallon (1040 Liter) totes.

DO NOT ALLOW PRODUCT TO FREEZE. Store away from direct sunlight and at ambient temperatures – above 32ºF (0ºC) and up to 131ºF (55ºC). When properly stored, MCI®-2005 NS has a shelf life of 24 months.

HOW IT WORKS

MCI®-2005 NS is an organic corrosion inhibitor. It is considered ambiodic (mixed), meaning it protects both anodic and cathodic areas within a corrosion cell. MCI®-2005 NS contains a blend of amine salts of carboxylic acids which form a protective layer on embedded reinforcement delaying the onset of corrosion as well as reducing existing corrosion rates.

MCI®-2005 NS is effective at enhancing the durability and extending the service life of concrete structures exposed to corrosive environments (carbonation, chlorides, and atmospheric attack).

WHERE TO USE

- Reinforced concrete including precast, pre-stressed, and post-tensioned structures
- Corrosive environments including exposure to deicing salts, saline groundwater, airborne chlorides, and carbonation
- Marine and coastal structures, highways and bridges, parking decks, balconies, pools, concrete tanks, pilings, substructures, piers, pillars, pipes, and utility poles

ADVANTAGES

- Biobased (27%)
- Earns credit towards LEED certification
- Lower toxicity and environmental impact than traditional corrosion inhibiting admixtures such as calcium nitrite
- Low dosage rate with minimal effect on concrete properties (i.e. workability, strength development, air entrainment, etc.)
- Single dosage rate which is independent of expected exposure to chlorides
- Ability to migrate through porous substrates (concrete, masonry, limestone, etc.) by capillary action, vapor diffusion and ionic attraction
- Meets all requirements of ASTM C1582

MCI®-2005 NS

- Certified to meet ANSI/NSF Standard 61 for use on structures holding potable water
- Field and lab tested worldwide
- Complies with CSA S413, Section C1.2, for corrosion inhibiting

PHYSICAL PROPERTIES

Appearance	Dark brown liquid
pH	11-12 (1% solution)
Non-volatile Content	25-30%
Density	9.8-10.3 lb/gal (1.17-1.23 kg/l)

DOSAGE

Add MCI®-2005 NS to concrete mix at the rate of 1.5 pts/yd^3 (1l/m^3).

APPLICATION

MCI®-2005 NS is best added with the mix water into ready mix concrete at the plant. Alternatively, it can be dosed into the ready mix truck using portable dosing equipment. Concrete should be mixed thoroughly before placement.

STANDARD TEST RESULTS

Slump	ASTM C143	Neutral
Air Content	ASTM C231	Neutral
Density	ASTM C138	Neutral
Set Time	ASTM C403	Neutral
Flexural Strength	ASTM C78	Neutral
Compressive Strength	ASTM C192	Neutral
Corrosion Properties	ASTM C1582 ASTM G109	Meets requirements
Biobased Content	ASTM D6866	27%
Workability	N/A	No adverse effects when used with pozzolans or other high performance concrete admixtures

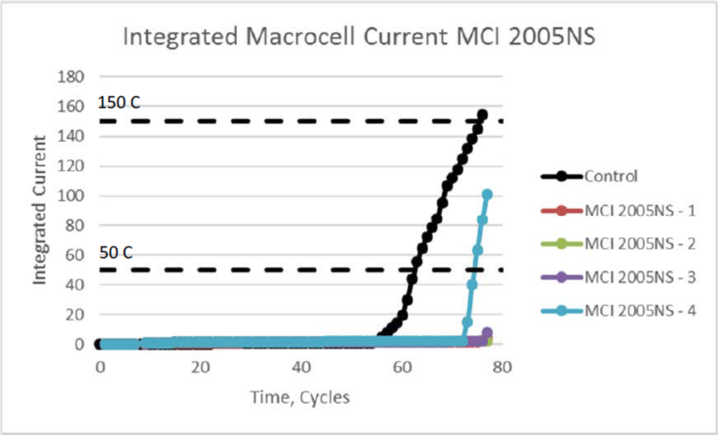
ASTM C1582 PHYSICAL PROPERTY RESULTS

Setting Time					
	Control	MCI®-2005 NS	Relative to Control	ASTM C1582 Requirement	Result
Initial Set (Minutes)	308	318	+10	+/- 210 Min of Control	Meets Requirement
Final Set (Minutes)	406	419	+13	+/- 210 Min of Control	Meets Requirement
Compressive Strength					
3 Day (psi)	3297	3137	95%	Min 80% of Control	Meets Requirement
7 Day (psi)	4080	4087	100%	Min 80% of Control	Meets Requirement
28 Day (psi)	5167	5340	103%	Min 80% of Control	Meets Requirement
6 Month (psi)	6207	6517	105%	Min 80% of Control	Meets Requirement
1 Year (psi)	6463	6773	105%	Min 80% of Control	Meets Requirement
Flexural Strength					
3 Day (psi)	575	591	103%	Min 80% of Control	Meets Requirement
7 Day (psi)	645	654	101%	Min 80% of Control	Meets Requirement
28 Day (psi)	747	767	103%	Min 80% of Control	Meets Requirement
Shrinkage					
Length Change (%)	-0.0245	-0.021	-0.004	Max 0.010 Over Control	Meets Requirement
Durability					
Freeze/Thaw Durability	98.5	97.1	98.6%	RDF 80%	Meets Requirement

ASTM C1582 CORROSION PROPERTIES - ASTM G109 RESULTS

	Control	MCI®-2005 NS	Relative to Control	ASTM C1582 Requirement	Results
Average Integrated Current, C	155	29	n/a	≤ 50C When Control is 150 C	Meets Requirement
Average Area Corroded, in^2	8.93	2.36	29%	≤ 1/3 of Control	Meets Requirement
Critical Chloride Content*, ppm	2861	2898	101%	≥ Critical Control	Meets Requirement

ASTM C1582 RESULTS



CONSIDERATIONS

Concrete properties are always best determined in a trial using the actual mix components. Cortec recommends a trial batch anytime you are using MCI®-2005 NS with new mix components.

Consult with Cortec's Technical Support Department for further guidance if necessary.

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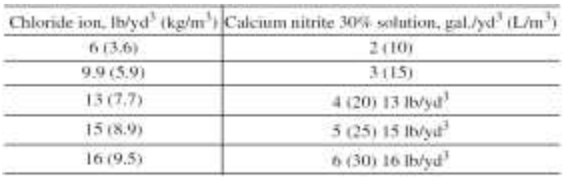
MCI 2005NS vs Calcium Nitrites

<table>
<tr><th></th><th>MCI 2005 NS</th><th>Calcium Nitrites</th></tr>
<tr><td>Active Ingredient</td><td>Amine Carboxylate</td><td>Calcium Nitrites</td></tr>
<tr><td>Dosage Rate</td><td>1.5 pints/yd^3 or (1L/m^3)</td><td>2 to 6 gal/yd^3 (10-30L/m^3) Depending on chlorides exposure.
Calcium Nitrites Dosage Rate Determination Steps:
1. Determine the design life of the structure.
2. Estimate how much chloride will reach the rebar in that amount of time.
3. And add enough calcium nitrite in the concrete mix design to protect against the expected chloride level.
<table><tr><th>Chloride ion, lb/yd^3 (kg/m^3)</th><th>Calcium nitrite 30% solution, gal./yd^3 (L/m^3)</th></tr><tr><td>6 (3.6)</td><td>2 (10)</td></tr><tr><td>9.9 (5.9)</td><td>3 (15)</td></tr><tr><td>13 (7.7)</td><td>4 (20) 13 lb/yd^3</td></tr><tr><td>15 (8.9)</td><td>5 (25) 15 lb/yd^3</td></tr><tr><td>16 (9.5)</td><td>6 (30) 16 lb/yd^3</td></tr></table>Table reference: ACI 212.3R-10</td></tr>
<tr><td>Design mix</td><td>Not affected</td><td>Mixing water should be reduced (7 lb. water omitted for every gallon), retarder and air entrainer needed to neutralize</td></tr>
<tr><td>Under dosing</td><td>Does not affect concrete performance</td><td>promotes pitting corrosion of steel reinforcement (Source)</td></tr>
<tr><td>Inhibitor Type</td><td>Mixed (Anodic and Cathodic)</td><td>Anodic</td></tr>
<tr><td>Mechanism</td><td>Each amine carboxylate molecule has positive and negative charges that are attracted to the anodic and cathodic portions of a corrosion cell. These inhibitors adsorb onto metal, forming a protective molecular layer on steel surfaces. This film prevents corrosive elements from further reacting with embedded reinforcement, and also reduces existing corrosion rates. (Reference: ACI 212.3R-10)</td><td>Calcium Nitrites interferes with the chloride complexing process by oxidizing the more easily attacked Fe2+ form of iron to the more stable Fe3+ form. The nitrite species is responsible for this effect. The more stable barrier increases the concentration of chlorides needed to start corrosion, and reduces the rate of corrosion once initiated. Although this process strengthens the passivating barrier, due to inevitable imperfections in this barrier, it does not make the steel immune to high concentrations of chloride, so different levels of calcium nitrite will be required, depending on the chloride level expected during the design life of the structure. (Reference: ACI 212.3R-10)</td></tr>
<tr><td>Setting Time</td><td>No Effect</td><td>Accelerates setting</td></tr>
<tr><td>Retarder addition</td><td>Not required</td><td>Required (to adjust the accelerating effect)</td></tr>
<tr><td>Air content</td><td>Not affected</td><td>Less, an air entrainer should be added to compensate</td></tr>
<tr><td>28 day compressive strength</td><td>Same or higher</td><td>Less</td></tr>
</table>

Shrinkage	Less shrinkage than Calcium Nitrites	More (the higher the dose, the more shrinkage) – (reference 1, reference2)
Concrete conductivity	Not affected	More - RCPT cannot be conducted (Ref. CSA S413-14)
NSF 61 Certification	Yes	No
Workability	Not affected	Less
Compatibility with CP Systems	Yes	No
Performance in cracked concrete	~ 80% reduction in corrosion rates versus control (MCI-2005 NS at 1L/m3 (1.5 pt/yd3) dosage rate)	~ 25% reduction in corrosion rate versus control (20L/m3 or 4 gal/yd3 dosage rate)
Toxicity	Lethal Dose 50 (LD50) ~ 283 mg/kg; BOD 28 days 0%	LD50 ~ 2300 mg/kg (table salt 3000 mg/kg); BOD 28 days > 60%
Other remarks	Bio-based from renewable resource(Corn) Gives LEED credits	Calcium Nitrites based corrosion inhibitors require high performance concrete and sufficient cover to stay in concrete as they leach out with time. (Reference)

References

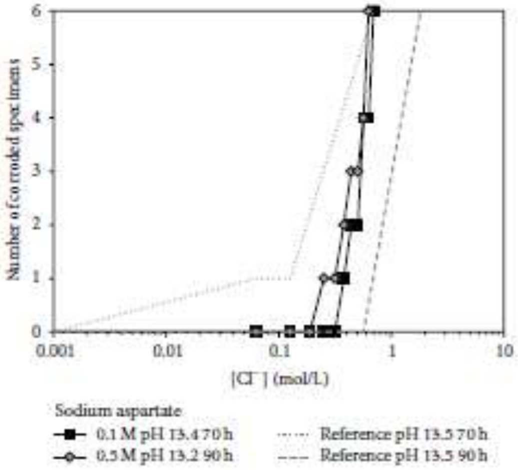


Figure 7: Number of corroded specimens as a function of chloride addition during potentiostatic test in solutions with sodium aspartate.

surface of embryo pit, which thus does not reach a stable propagation. On the contrary, the pit propagates by occluded cell mechanism and consequently repassivation gradually becomes less probable, because of acidification and high concentration of chlorides. The formation and repassivation of metastable pits are evident in the current versus time graph as spikes in the current that do not reach the threshold current value corresponding to specimen failure. Finally, once the pitting starts to propagate by the occluded cell mechanism, the current increases.

Corrosion inhibitors can act during one or more of the different stages of pitting initiation and propagation, by stabilizing the passivity state and increasing the critical chloride concentration to have embryo pitting initiation, by increasing the kinetic of repassivation of embryo pit or by decreasing the propagation rate of the initiated pit.

3.4. FTIR Spectra. Fourier Transform Infrared Spectroscopy (FTIR) was performed in order to evidence the formation of compounds on the surface, promoted by inhibitors. Figure 11 reports the FTIR spectrum of polished steel compared to the spectrum of steel passivated for 48 hours, at 0 V versus SCE, at pH 13.5. The two spectra are superimposable, with the exceptions of a broad band between 3500 and 3000 cm^{-1}, a small band near 2600 cm^{-1}, and a group of peaks between 1586 and 1552 cm^{-1}, only observed on the passivated specimen.

The broad band is in the range of the stretching frequency of the –OH groups of the different allotropic forms of FeOOH (α-goethite, β-akaganeite, γ-lepidocrocite, and δ-feroxyhyte) [26].

The passivity film present on carbon steel in pore solution was studied in previous works using cyclic voltammetry [5–7]. The peaks on the voltammogram indicated that film formation proceeds by initial oxidation of Fe to $Fe^{(II)}$ in the form of $Fe(OH)_2$; this reaction is partially reversible. The value of the peak current associated with this reaction remained constant with increasing of the number of voltammetry cycles, which indicates that the $Fe(OH)_2$ film did not increase. The $Fe(OH)_2$ film is further oxidised to different species depending on the environment and the potential scan rate. [27, 28]. In the test conditions adopted in the considered works, the most probable oxidation product is lepidocrocite, γ-FeOOH. Joiret et al. [29] emphasized the magnetite (Fe_3O_4) formation. Following Andrade et al. [30] the external layer is constituted by magnetite Fe_3O_4 partially oxidised to γ-FeOOH. γ-FeOOH can subsequently dehydrate to give Fe_2O_3. Electrochemical Impedance Spectroscopy confirmed the double nature of the passivity film [23, 31]. Montemor et al., using XPS analysis, reported that the outermost layers of passive films were mostly composed of FeOOH (Montemor et al.) [32].

FTIR spectra analysed only the external surface of the passivity film. It is reasonable to think that the peak in the range 3500 ÷ 3000 cm^{-1} is due to a mixture of the polymorphic forms of FeOOH present on the external side of the film.

The other peaks are not typical of these hydroxides. Spectra with peaks in the range of 1650 and 1540 cm^{-1} were observed on specimens covered by amorphous or crystalline Fe(II) and Fe(III) hydroxides and carbonates, with different stoichiometric ratios, called green rust [33].

The peaks at 1430, 1785, and 2530 cm^{-1} are characteristic of calcium carbonate, which can form by reaction of $Ca(OH)_2$, incorporated in the passivity film [27, 28], with atmospheric CO_2. Ghods et al. determined by means of XPS that microsize calcium hydroxide and/or calcium carbonate particles are present on the film surface and remained also after the specimens were removed from the calcium hydroxide solution and dried [34].

In Figure 12 the FTIR spectrum registered on the specimen passivated at 0 V versus SCE in alkaline solution added with 1 M sodium nitrite is compared with that obtained in solution without inhibitor. The absence of FeOOH signals in the nitrite-containing sample is evident.

The inhibitive action of nitrite ions depends on their reaction with Fe^{2+} ions according to the following reactions:

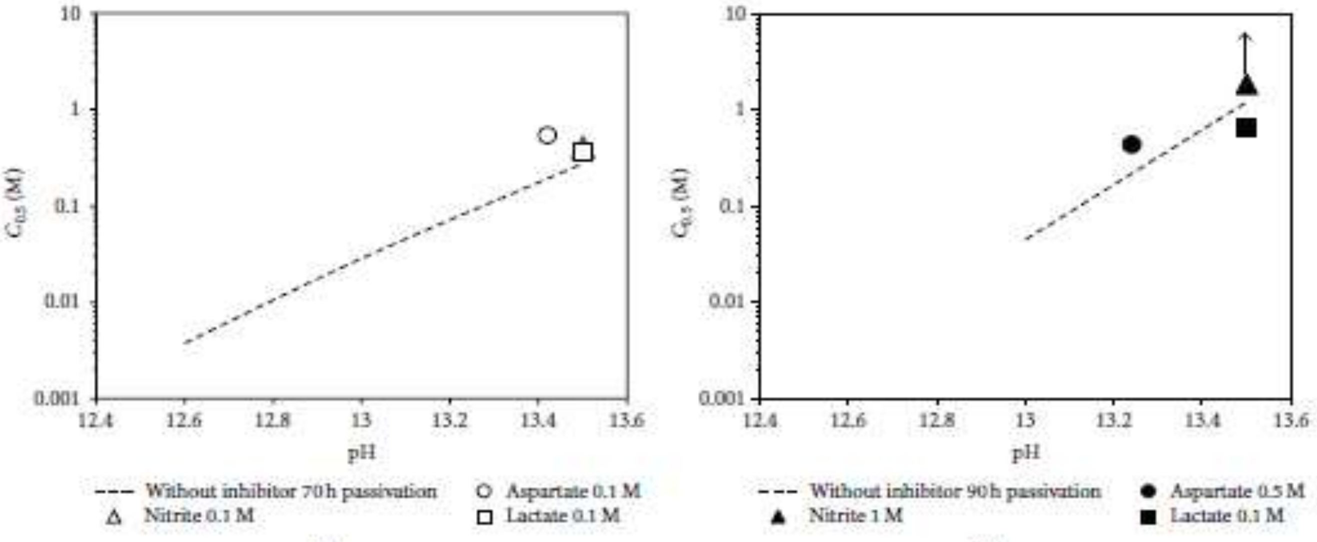
$$Fe^{2+} + OH^{-} + NO_2^{-} \longrightarrow NO + \gamma\text{-FeOOH} \qquad (2)$$

$$2Fe^{2+} + 2OH^{-} + 2NO_2^{-} \longrightarrow 2NO + Fe_2O_3 + H_2O \qquad (3)$$

In the literature there is unanimous accord on the effect of nitrite in accelerating the oxidation reaction of the Fe(II) to Fe(III), but there are conflicting data about the composition of the passivity film in the presence of nitrite. According Girčienė, the outer layer of the film consists of FeO. AFM analysis demonstrated that the film formed in presence of nitrite ions is less porous and more compact than those formed on $Ca(OH)_2$ without inhibitor [35].

FTIR spectra seem to confirm the decrease of –OH groups in the outermost layer of the film, in the presence of nitrite.

Nitrite ions aid the formation of a stable passive layer even in the presence of chloride ions, because reactions (2) and (3) are faster than the transport of ferrous by means of a chloride



(a) (b)

Figure 8: Effect of pH on critical chloride content during multispecimen potentiostatic tests (a) at 70 h of passivation and (b) at 90 h of passivation; $C_{0.5}$ was not reached in the case of nitrites.

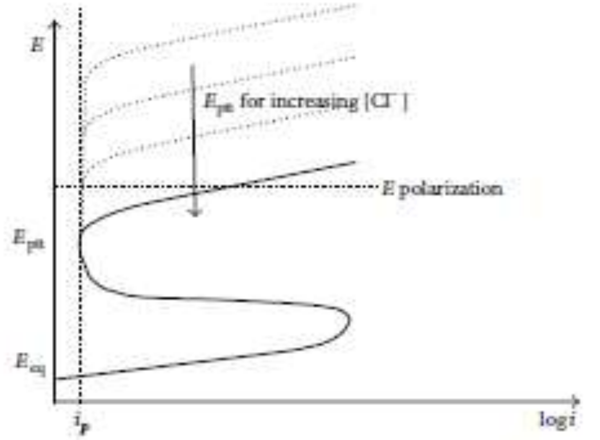


Figure 9: Example of polarization curves of carbon steel in alkaline solution as a function of chloride concentration.

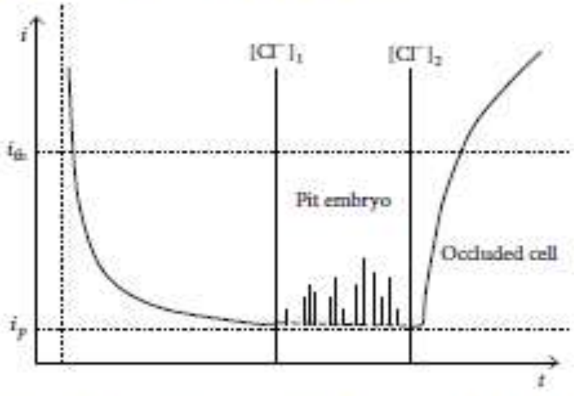


Figure 10: Effect of time and chloride concentration on pitting initiation.

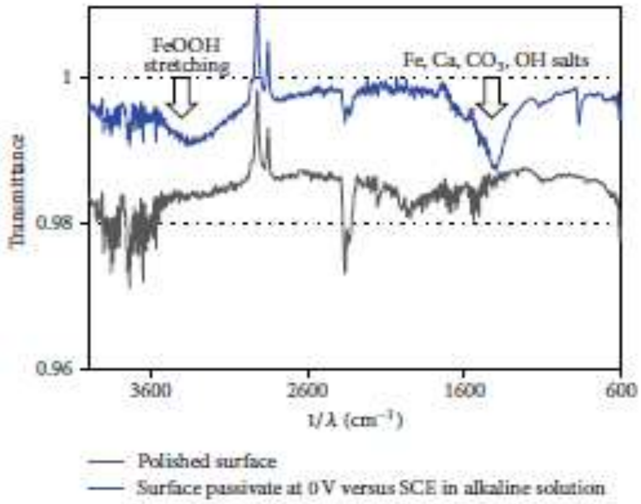


Figure 11: FTIR spectra of a polished specimen and a specimen passivated in solution at pH 13.5 and 0 V versus SCE.

ion complex formation [2, 5, 26]. However, full protection depends greatly on the concentration of chloride ion [5], and severe pitting may occur when insufficient quantity of inhibitor is used compared to the level of chloride in the concrete [3, 11].

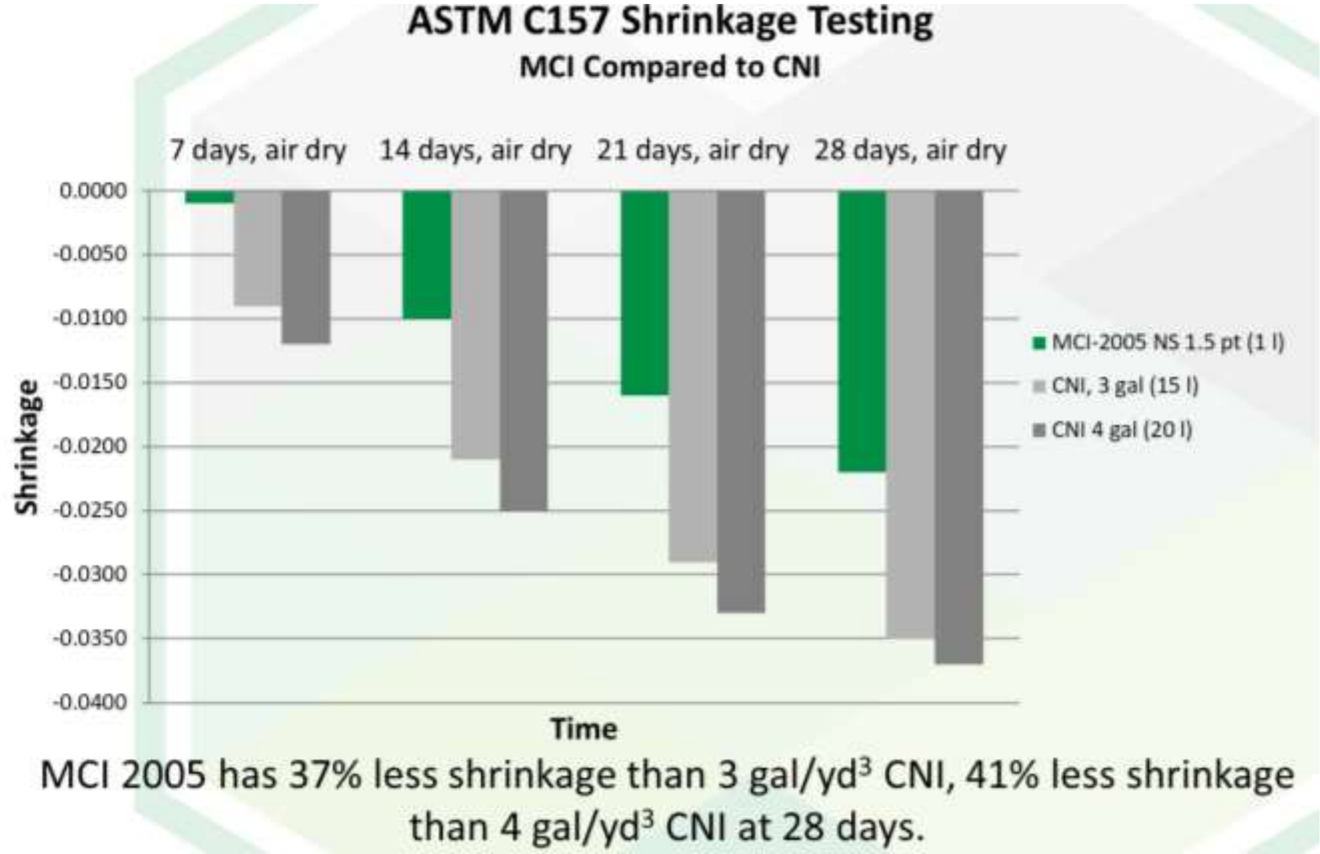
Nitrite ions cooperate with hydroxyl ions to rebuild the protective film [5, 6], one nitrite and one hydroxyl ion being involved to counteract the chlorides. This effect is only operating during the nucleation period, before acidification caused by the occluded cell mechanism becomes too severe. After initiation, nitrite ions produce deep penetration of

CORTEC
CORPORATION
Environmentally Safe VpCI™/MCI® Technologies

MCI 2005 NS SHRINKS 30% LESS THAN DCI!

During the Wells Fargo parking ramp project, concrete was tested for shrinkage. The concrete suppliers switched to MCI 2005 NS early in the project. Shrinkage tests were run and allow a comparison. Mix design and shrinkage data for Wells Fargo parking ramp project is as follows.

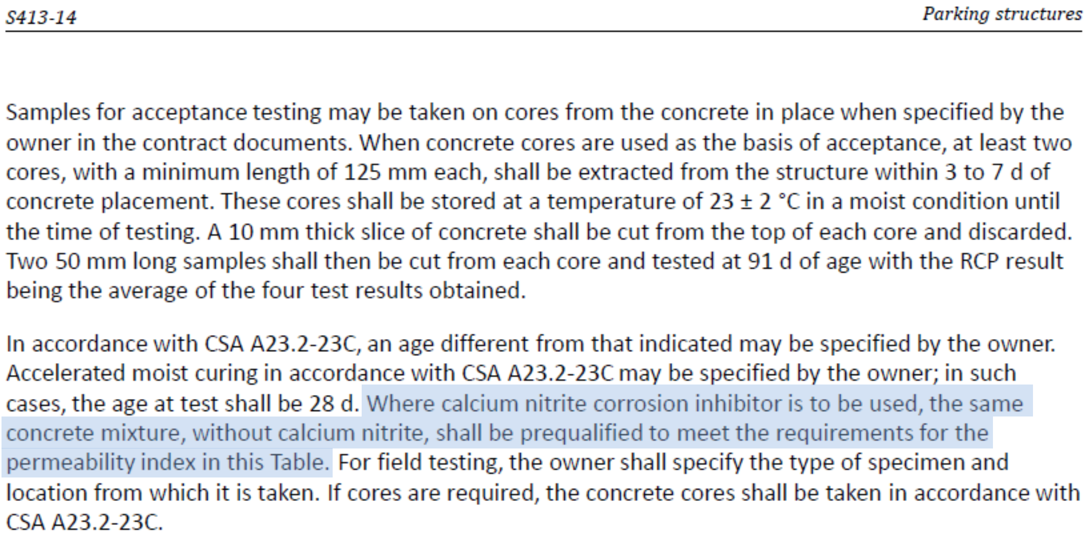
INGREDIENT	**MCI 2005 NS**	**DCI**
LaFarge Cement	560#	560#
Portage Fly Ash	90#	90#
#4 Gravel	667#	667#
#67 Gravel	636#	636#
3/8" Gravel	454#	454#
Safety Grit	394#	394#
Sand	900#	900#
Enduracon HR	72 oz/yd^3	---
Euclid WR75	---	72 oz/yd^3
Euclid HR Eucon 37	---	34 oz/yd^3
Euclid AirMix 250	7 oz/yd^3	7 oz/yd^3
MCI 2005 NS	1.5 pints/yd^3	---
DCI	---	3 Gallons/yd^3
Water	220#	220#
W/C	0.34	0.34
SHRINKAGE AT 28 DAYS	**0.035%**	**0.046%**



ASTM C157 Shrinkage Testing

MCI Compared to CNI

MCI 2005 has 37% less shrinkage than 3 gal/yd³ CNI, 41% less shrinkage than 4 gal/yd³ CNI at 28 days.



S413-14 *Parking structures*

Samples for acceptance testing may be taken on cores from the concrete in place when specified by the owner in the contract documents. When concrete cores are used as the basis of acceptance, at least two cores, with a minimum length of 125 mm each, shall be extracted from the structure within 3 to 7 d of concrete placement. These cores shall be stored at a temperature of 23 ± 2 °C in a moist condition until the time of testing. A 10 mm thick slice of concrete shall be cut from the top of each core and discarded. Two 50 mm long samples shall then be cut from each core and tested at 91 d of age with the RCP result being the average of the four test results obtained.

In accordance with CSA A23.2-23C, an age different from that indicated may be specified by the owner. Accelerated moist curing in accordance with CSA A23.2-23C may be specified by the owner; in such cases, the age at test shall be 28 d. Where calcium nitrite corrosion inhibitor is to be used, the same concrete mixture, without calcium nitrite, shall be prequalified to meet the requirements for the permeability index in this Table. For field testing, the owner shall specify the type of specimen and location from which it is taken. If cores are required, the concrete cores shall be taken in accordance with CSA A23.2-23C.

Certificate of Compliance

Certificate Number **20091222 – MH25692A**
Report Reference **MH25692, 1998 January 02**
Issue Date **2009 December 22**

Underwriters
Laboratories Inc.®

Issued to: **CORTEC CORP**

4119 WHITE BEAR PKY
ST PAUL, MN 55110 USA

This is to certify that representative samples of

Drinking Water System Components

Model Descriptions: "MCI-2005", "MCI-2005 NS", "MCI-2006" and "MCI-2006 NS".

FACTORY LOCATION:
Cortec Corp., St. Paul, MN.

Have been investigated by Underwriters Laboratories Inc.® in accordance with the Standard(s) indicated on this Certificate.

Standard(s) for Safety: **The basic standard used to investigate products in this category is ANSI/NSF 61-2007a, "Drinking Water System Components - Health Effects."**

Additional Information: **See UL On-line Certification Directory at www.ul.com for additional information.**

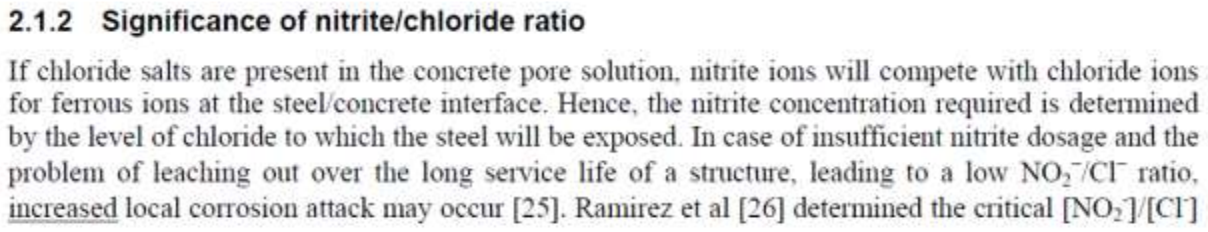
Only those products bearing the UL Listing Mark should be considered as being covered by UL's Listing and Follow-Up Service.

The UL Listing Mark generally includes the following elements: the symbol UL in a circle: Ⓤ with the word "LISTED"; a control number (may be alphanumeric) assigned by UL; and the product category name (product identifier) as indicated in the appropriate UL Directory.

Look for the UL Listing Mark on the product

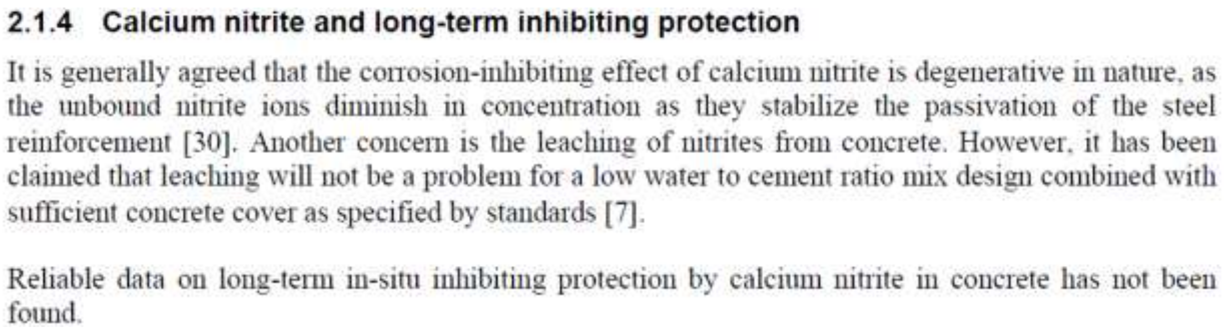
William R. Carney
Director, North American Certification Programs

Underwriters Laboratories Inc.



2.1.2 Significance of nitrite/chloride ratio

If chloride salts are present in the concrete pore solution, nitrite ions will compete with chloride ions for ferrous ions at the steel/concrete interface. Hence, the nitrite concentration required is determined by the level of chloride to which the steel will be exposed. In case of insufficient nitrite dosage and the problem of leaching out over the long service life of a structure, leading to a low NO_2^-/Cl^- ratio, increased local corrosion attack may occur [25]. Ramirez et al [26] determined the critical $[NO_2^-]/[Cl^-]$



2.1.4 Calcium nitrite and long-term inhibiting protection

It is generally agreed that the corrosion-inhibiting effect of calcium nitrite is degenerative in nature, as the unbound nitrite ions diminish in concentration as they stabilize the passivation of the steel reinforcement [30]. Another concern is the leaching of nitrites from concrete. However, it has been claimed that leaching will not be a problem for a low water to cement ratio mix design combined with sufficient concrete cover as specified by standards [7].

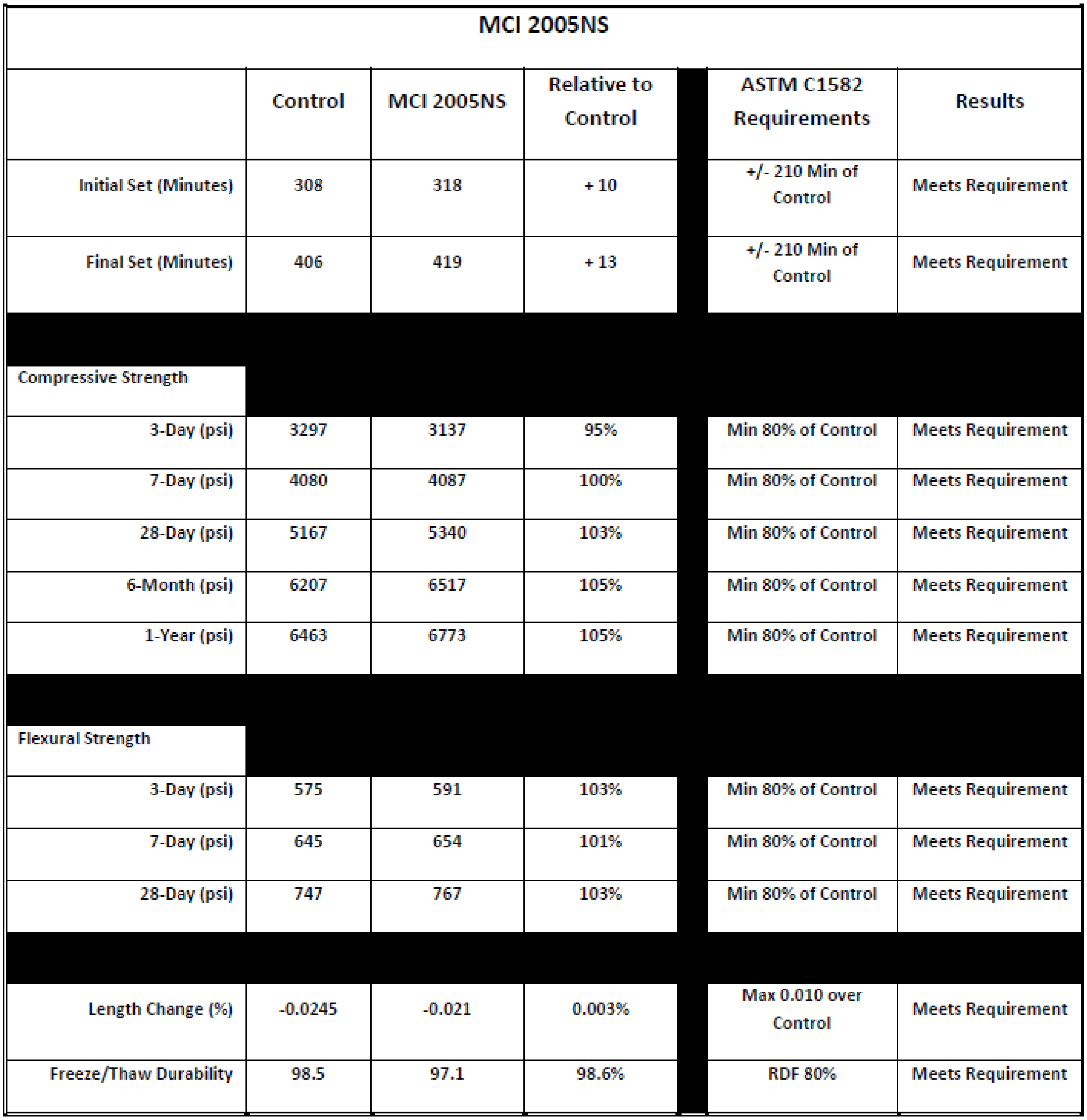
Reliable data on long-term in-situ inhibiting protection by calcium nitrite in concrete has not been found.

Paper link:

https://www.sintefbok.no/book/download/1003/vinfopubutgivelsercoincoin_project_reportscoin_report_no_22nettcoin-no22pdf

ASTM C494 part of our ASTM C1582:

Table 1 – MCI 2005NS Physical Properties



MCI 2005NS					
	Control	MCI 2005NS	Relative to Control	ASTM C1582 Requirements	Results
Initial Set (Minutes)	308	318	+ 10	+/- 210 Min of Control	Meets Requirement
Final Set (Minutes)	406	419	+ 13	+/- 210 Min of Control	Meets Requirement
Compressive Strength					
3-Day (psi)	3297	3137	95%	Min 80% of Control	Meets Requirement
7-Day (psi)	4080	4087	100%	Min 80% of Control	Meets Requirement
28-Day (psi)	5167	5340	103%	Min 80% of Control	Meets Requirement
6-Month (psi)	6207	6517	105%	Min 80% of Control	Meets Requirement
1-Year (psi)	6463	6773	105%	Min 80% of Control	Meets Requirement
Flexural Strength					
3-Day (psi)	575	591	103%	Min 80% of Control	Meets Requirement
7-Day (psi)	645	654	101%	Min 80% of Control	Meets Requirement
28-Day (psi)	747	767	103%	Min 80% of Control	Meets Requirement
Length Change (%)	-0.0245	-0.021	0.003%	Max 0.010 over Control	Meets Requirement
Freeze/Thaw Durability	98.5	97.1	98.6%	RDF 80%	Meets Requirement