CRACKED BEAM/PONDING TESTS 2019

ASTM C876 – Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete.

This protocol is widely accepted to determine and rank supplemental cementitious materials and corrosion inhibiting admixtures, in concrete samples containing steel. It is performed and provided to meet and exceed the relevant areas of ***ASTM C1582 - Standard Specification for Admixtures to Inhibit Chloride-Induced Corrosion of Concrete Reinforcing Steel in Concrete and supplemental to ASTM C494, Type S Admixture – Standard Specification for Chemical Admixtures for Concrete.*** *This protocol incorporates Half Cell readings of aggressive ponding over cracked beam specimens to illustrate concrete's "resistivity" and/or "transportability" of chloride ions through concrete and "de-passivity" of reinforcement steel.*

We've included summary data outlining the basis of technology of the Half-Cell protocol, specimen preparations (including mix designs), and finally followed by primary data/readings performed.

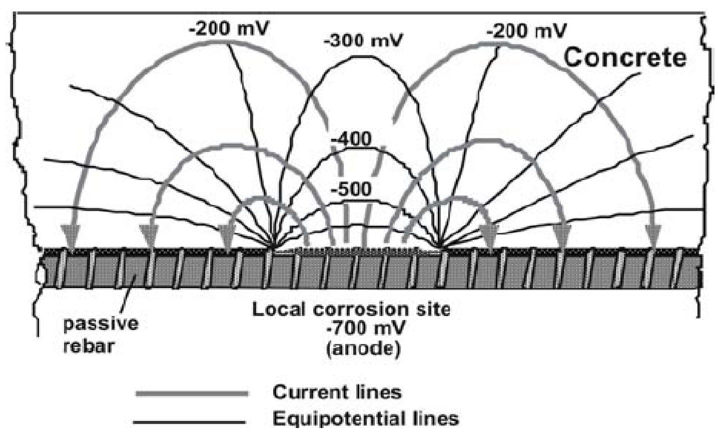
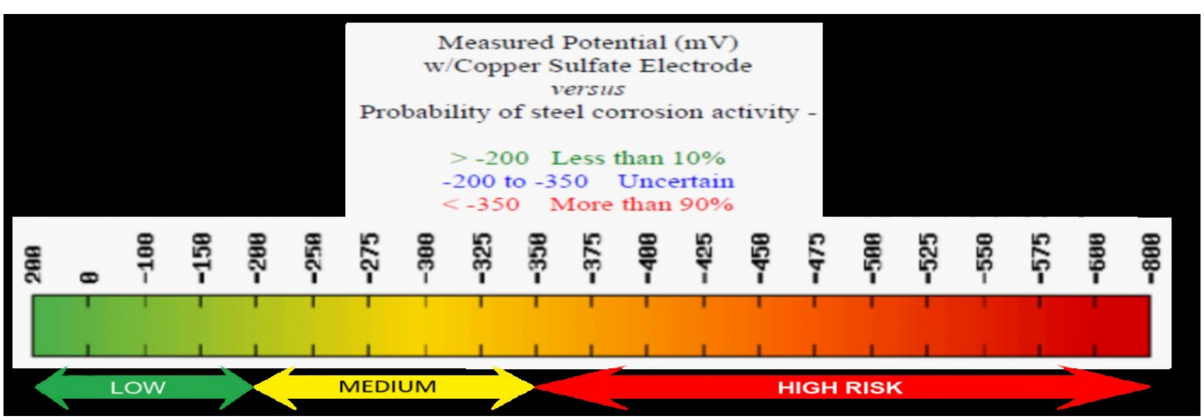


Fig. 2 - Schematic view of the electric field and current flow in an active / passive macrocell on steel in concrete.



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(Summarized)

1. Scope

1.1 This test method covers the estimation of the electrical corrosion potential of uncoated reinforcing steel in field and laboratory concrete, for the purpose of determining the corrosion activity of the reinforcing steel.

1.2 This test method is limited by electrical circuitry. Concrete surface in building interiors and desert environments lose sufficient moisture so that the concrete resistivity becomes so high that special testing techniques not covered in this test method may be required (see 5.1.4.1). Concrete surfaces that are coated or treated with sealers may not provide an acceptable electrical circuit. The basic configuration of the electrical circuit is shown in Fig. 1.

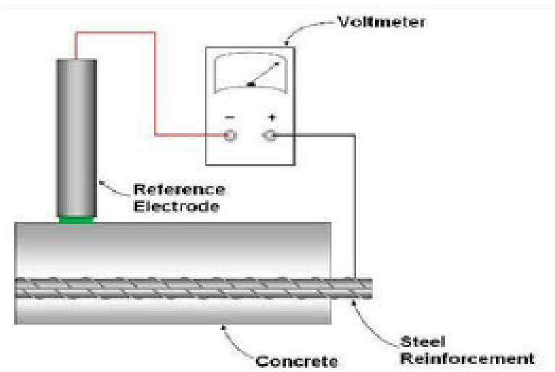


Figure 1

4. Significance and Use

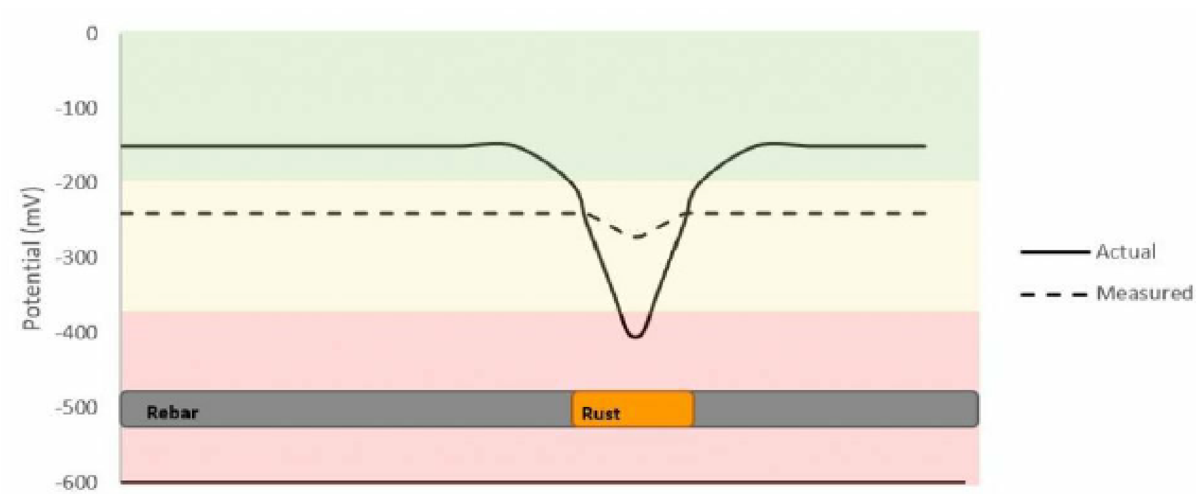
4.1 This test method is suitable for in-service evaluation and for use in research and development work.

4.2 This test method is applicable to members regardless of their size or the depth of concrete cover over the reinforcing steel. Concrete cover in excess of 3 in. (75 mm) can result in an averaging of adjacent reinforcement corrosion potentials that can result in a loss of the ability to discriminate variation in relative corrosion activity.

4.3 This test method may be used at any time during the life of a concrete member.

4.4 The results obtained by the use of this test method shall not be considered as a means for estimating the structural properties of the steel or of the reinforced concrete member.

4.5 The potential measurements should be interpreted by engineers or technical specialists experienced in the fields of concrete materials and corrosion testing. It is often necessary to use other data such as chloride contents, depth of carbonation, delamination survey findings, rate of corrosion results, and environmental exposure conditions, in addition to corrosion potential measurements, to formulate conclusions concerning corrosion activity of embedded steel and its probable effect on the service life of a structure.



Actual corrosion rate is usually greater than half-cell readings.

Cracked Beam/Ponding protocol –

To expedite the process (while eliminating microcell current) and show rapid chloride corrosion, we utilized a roughly 20% sodium chloride ponding solution (instead of 3-5% solution).

The specimens were created to accommodate this Cracked Beam/Ponding protocol and the subsequent G109; ultimate autopsy and corrosive product review.

The Mix Design tested; and six industry accepted variations are below –

<u>0.45 w/c Ratio, with a 4” (+/- 1”) Slump Mix Design</u>

28-Day comp. strengths @ 28 days = 5,300 psi

Cement; Type II & V – 658 lbs.

Water – 300.4 lbs. (36 gallons)

1” Agg. (#4) – 1392 lbs.

3/8” Agg. (#8) – 310 lbs.

Washed Con Sand – 1393 lbs.

WR-91, Type A water reducer – 26.32 ounces/yd^3

Air – 1%, 149.8 lbs./ft^3 Plastic Weight, 4045 lbs., 27.0 ft^3

(Aggregate Gradations available upon request)

Specimen X – crystalline growth mix; newer product marketing by Xypex on the west coast. A dry, concentrated dry powder (cement delivery with treated silicates) added at 1.25% of cement weight (this product replaces the previous 2.5% by weight commercial product) = 8.225 lbs. per cu. yard.

Specimen D – calcium nitrite mix; popular admixture with min. 30% calcium nitrites = 5.5 gallons per cu. yard.

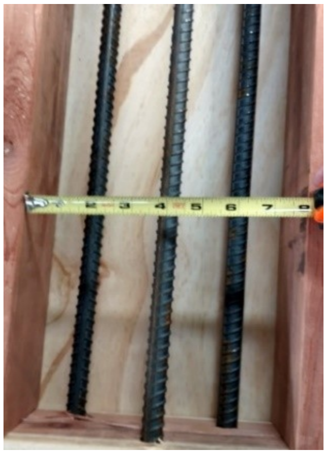
Specimen F – 20% fly ash (Class C) mix; a direct replacement of 20% (131.6 lbs.) replacement of cement.

Specimen V – Vapor Lock 40/40 mix; 10 ounces per hundred lbs. of cement = 65.8 ozs. per cu. yard.

Specimens VL – Vapor Lock 40/40 + lightweight sand mix; 10 ounces per hundred weight of cement, with 22% replacement of fine aggregate (sand) with lightweight sand provided by Arcosa Lightweight, Southern California source = 278.6 lbs. of lightweight sand.

Specimen C – Plain Control; straight mix, above.

Using “off-the-shelf” #4 rebar (1/2”, not cleaned or conditioned in any way), positioned into a standard triangle pattern, with the top bar having exactly 1” of concrete cover. Forms are standard 2” x 6” wood and fastened at each corner with two screws. *No form release/oils were used. Specimen size was a nominal 5.5” deep, 24” long, and 8” wide (this gives a 3:1 geometry that would also promote a mid-point crack).



The 1” of concrete cover was compromised (to simulate an acceptable crack) with a 0.030” (1/32”) metal shim, left mid-point on the top rebar for 4 hours and then removed.

Mixes were placed into the specimens, vibrated in two spots with a stinger, screeded with a wood float, then hit with a mag float, and finally a steel edger. *There was no ability to use a power trowel, which should be taken into consideration. After the beams were cast, that evening a 3-mil black poly was laid over the specimens and weighted down with wet sand for 7 days to provide a “wet cure”.

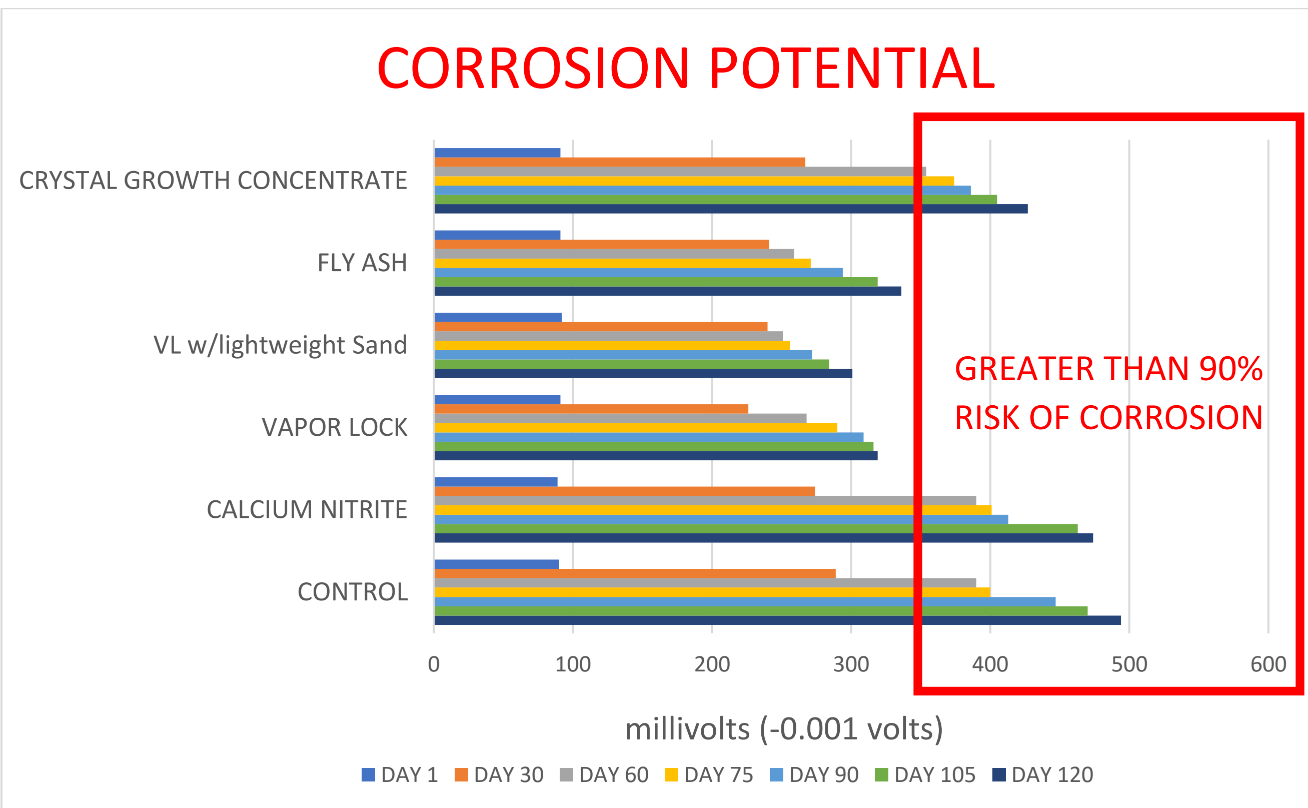
After seven days of common curing (wet cure), the specimens were stripped of forms and air dried for 24 hours. At Day 9, four-inch-high plexi-glass reservoirs were adhered to the surfaces with silicon; 6” wide and 16” long. This was to produce ponding at roughly half the surface area of the specimens.

At Day 10 a 20% salt solution was added to an approximate depth of 1” for each specimen. The tap water was heated to approximately 120 degrees Fahrenheit. 20% (by weight) fine salt crystals are added and agitated/stirred for approximately 5-7 minutes. It is thought that the increase in water temperature would allow for the highest saturation levels possible.

Salt water was added every Monday morning at 8am. Half-Cell readings were all performed within 45 minutes of adding salt solution. Specimens were out in the open and have semi to direct sun on them, with full thermal night and day cycles. With April weather in Southern California, they were getting about a 30 to 35-degree swing in temperature; which held constant throughout the year. Wind and rain are sporadic. Monday mornings, a new 20% salt solution is added to a depth of 1" for each specimen. Some weeks, it took all week to evaporate (April, May) and later in the year it took a day and half to evaporate (July, August). Once a month, the inside of the reservoirs were rinsed out with water to remove the salt build-up and their order was rearranged once on the raised bench during the protocol. The reservoirs were repaired once after the first month as well; additional silicone was added to the corners and joints to fix leaks. *Substantial corrosive product developed by day 100 on the protruding rebar (side where specimens were accessed) on all specimens as they received full moisture and salt solutions without any protection. Minimal product was observed on the opposite side of protruding rebar by Day 100 (against wall, minimal contact with salt solution). Full inspection can be gleamed from the G109 autopsy results (under separate copy).

Half Cell Readings (average of 3, - 0.001 volts)

	Day 1	Day 30	Day 60	Day 75	Day 90	Day 105	Day 120
X (crystal growth)	91	267	354	374	386	405	427
F (Fly Ash)	91	241	259	294	294	319	336
VL (VL & LW Sand)	92	240	251	256	272	284	301
V (Vapor Lock)	91	226	268	290	309	316	319
D (calcium nitrite)	89	274	390	401	413	463	474
C (Control, Plain mix)	90	289	390	400	447	470	494



Results/Readings Plotted

CONCLUSIONS

The quick movement of all specimens into the 'Medium Risk' zone (yellowish) by Day 30 illustrates the aggressive ponding (20%+ salt solution) protocol. From there, the specimens move apart in regard to the Probability of Steel Corrosion Activity; the Control, crystal growth, and calcium nitrite specimens moving into the High-Risk zone by Day 60. The Vapor Lock enhanced samples and Fly Ash sample showing superior readings throughout, never reached the High-Risk zone.

Regarding both the "conventionalism" of the test specimens and Half-Cell protocols, we can only look at the latest recommendations from ASTM G01 – Corrosion of Metals, sub-committee 14.02 – in Concrete & Mortar and their latest prescribed changes to G109, including:

- leaving scale on rebar to promote greater cathode activity,
- using 10 ohms resistance for improved voltmeter sensitivity and more acute low-end resistance.

Both were incorporated in the above protocols; steel was purchased from a local building supply company and not cleaned in any way. Also, the millivolt (one thousand of a volt) measurements above, were all from the 10 ohms resistance setting prescribed in the newest changes of the sub-committee. Beyond the "newest" nuances in corrosion ponding-type testing, only time and the ultimate physical inspection of the encased rebar will show agreement with the resistance/half-cell results; supplied under separate copy.

If you adopt the AASHTO T259 protocol, removing the 28-day cure (for 7 days) and the 4% NaCl (increase to 20%+), you can extrapolate the results at 90 days as conclusive with the Half-Cell device. Otherwise, the full 120 Days of data can be inferred too, as there is good agreement.

DATA REGARDING LIGHTWEIGHT SAND/INTERNAL CURE MECHANISM

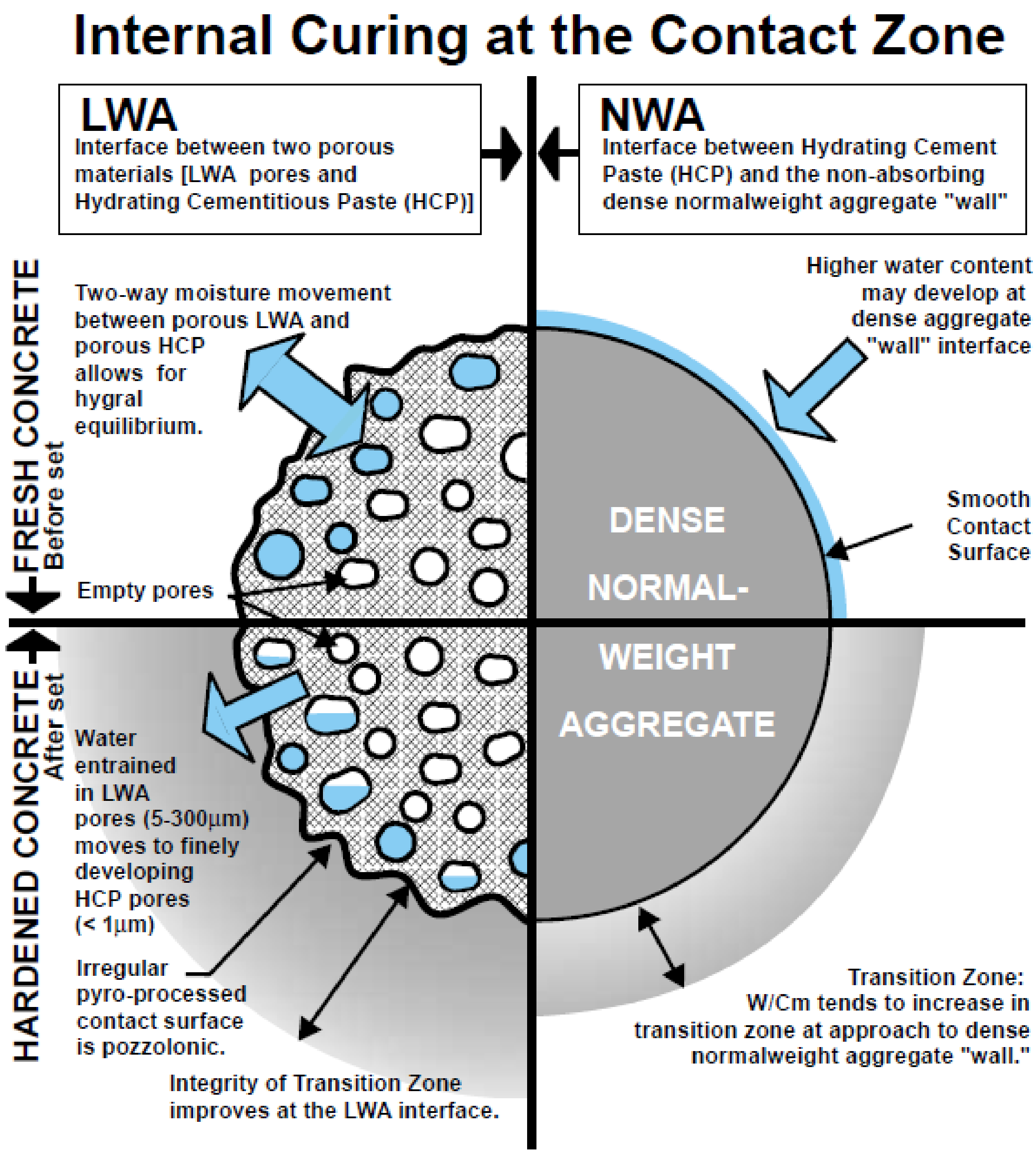
"Internal Curing Lightweight aggregates, batched at a high degree of absorbed water may be substituted for normal weight aggregates to provide 'internal curing' in concrete containing a high volume of cementitious materials. High cementitious concretes are vulnerable to self-desiccation and early-age cracking, and benefit significantly from the slowly released internal moisture. Field experience has shown that high strength concrete is not necessarily high-performance concrete and that high-performance concrete need not necessarily be high strength. A frequent, unintended consequence of high strength concrete is early-age cracking. Blending lightweight aggregate containing absorbed water is significantly helpful for concretes made with a low ratio of water-to-cementitious

material or concretes containing high volumes of supplementary cementitious materials that are sensitive to curing procedures. This process is often referred to as water entrainment. Time dependent improvement in the quality of concrete containing pre-wet lightweight aggregate is greater than with normal weight aggregate. The reason is better hydration of the cementitious materials provided by moisture available from the slowly released reservoir of absorbed water within the pores of the lightweight aggregate. The fact that absorbed moisture in the lightweight aggregate is available for internal curing has been known for more than four decades. The first documentation of improved long-term strength gains made possible by the use of saturated normal weight aggregates, was reported in 1957 by Paul Klieger [2], who, in addition, commented in detail on the role of absorbed water in lightweight aggregates for extended internal curing."

"The benefits of internal curing go far beyond any improvements in long-term strength gain, which from some combinations of materials may be minimal or non-existent. The principal contribution of internal curing results in the reduction of permeability that develops from a significant extension in the time of curing. Powers [6] showed that extending the time of curing increased the volume of cementitious products formed which caused the capillaries to become segmented and discontinuous."

"The benefits of internal curing are increasingly important when supplementary cementitious materials, (silica fume, fly ash, metokaolin, calcined shales, clays and slates, as well as the fines of lightweight aggregate) are included in the mixture. It is well known that the pozzolanic reaction of finely divided alumina-silicates with calcium hydroxide liberated as cement hydrates is contingent upon the availability of moisture."[4]

The thesis above is directly quoted from research performed by the Expanded Shale, Clay & Slate Institute (ESCSI) and we thank them for their contributions on this topic. Our thinking is that in combination with Vapor Lock as a pozzolan, the disrupted capillary system will only enhance the "Internal Curing" or more accurately "curing from the inside out". This is the action and process the above mix/specimen (Vapor Lock w/ lightweight sand) is trying to illustrate – greater cement product, ultimately lowering the permeability of the cement pore structure ***and*** severely disrupted capillary system equating to ***Ultra-Low Permeability Concrete or Durable Concrete.***



4. INTERNAL CURING Using Expanded Shale, Clay and Slate Lightweight Aggregate https://www.escsi.org/wp-content/uploads/2017/10/4362.0-Internal-Curing-Using-ESCS-LWA-1.pdf Quoted passage and above exhibit.