Measuring and Monitoring Curing

Iowa Concrete Paving Association – Annual Workshop

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ACI 308 - CURING

Curing is an action taken to maintain **moisture** and **temperature** conditions in a freshly placed cementitious mixture to allow hydraulic cement hydration and, if pozzolans are used, pozzolanic reactions to occur so that the potential properties of the mixture may **develop**.

The Paving Concrete Process

1

Planning

What do we want? What can we afford?

2

Material Selection

Materials and mixture proportion development and approval

3

Production

Mix up some rocks, cement, sand, and water

4

Construction/ Finishing

Get it in place without screwing it up

5

Cure/Hope

What? Who care?

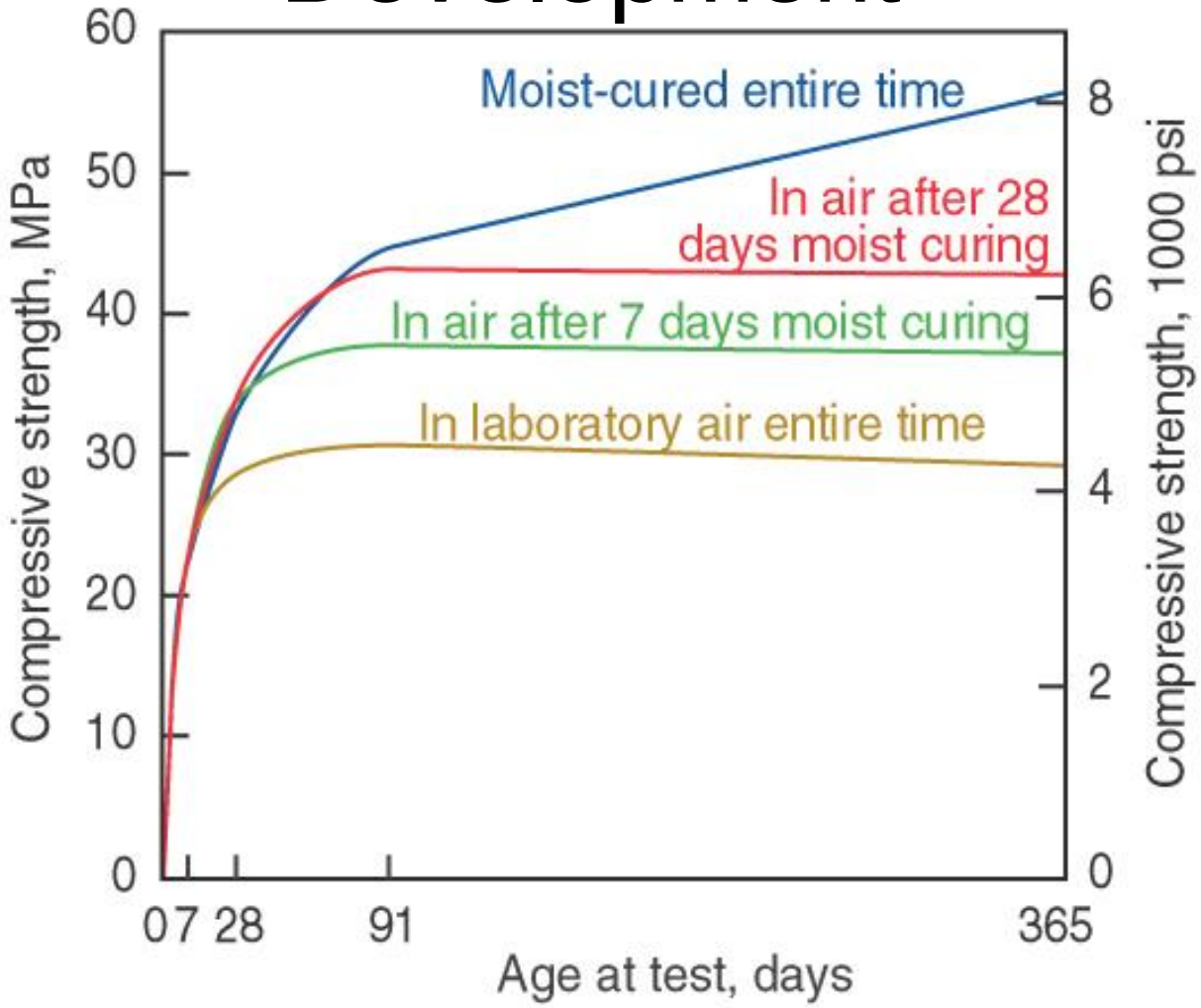
Concrete Curing

Good curing leads to:

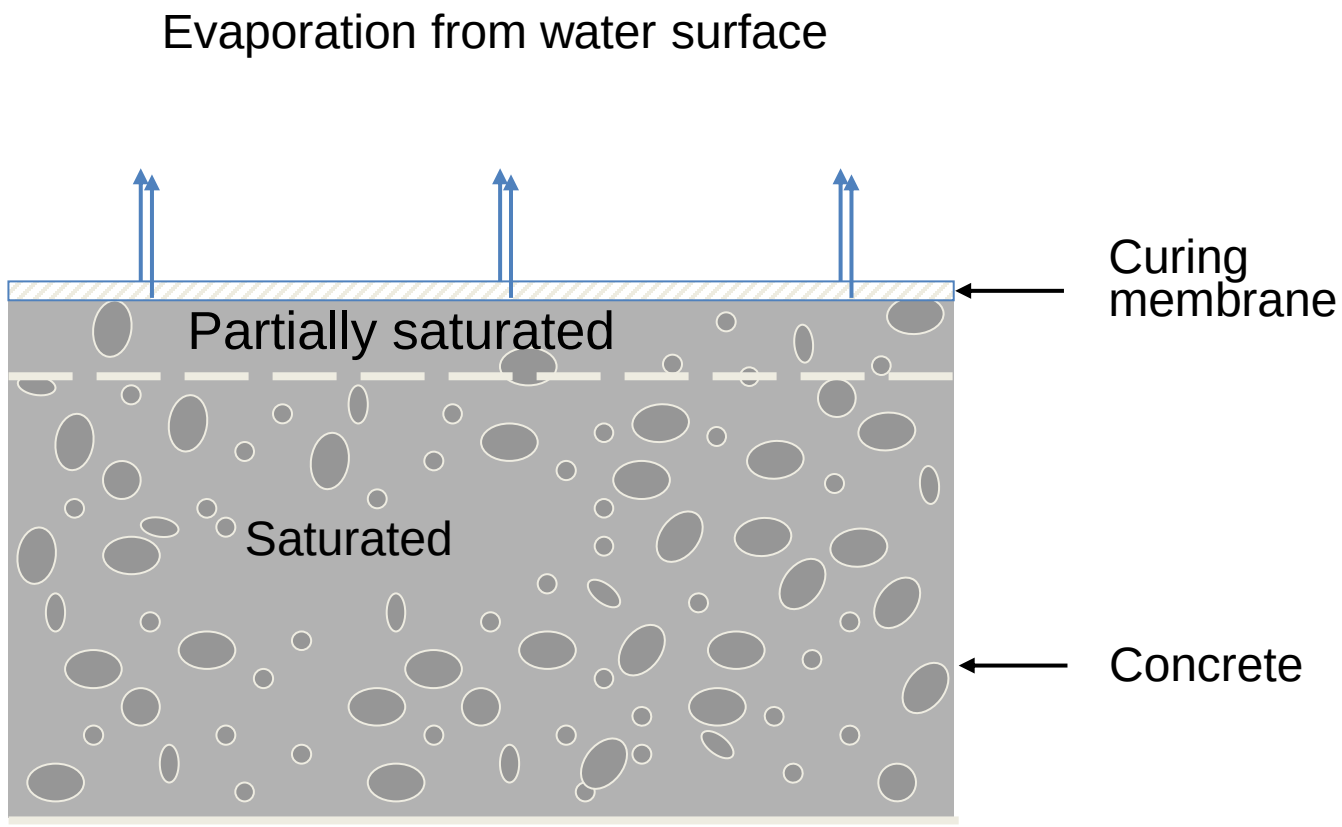
- Increased Strength
- Reduced Permeability
- Improved abrasion resistance
- Improved freeze-thaw resistance
- Better volume stability

f(Moisture, temperature, time), need at least 50% RH for hydration

Effect of Curing on Strength Development



Membrane Curing of Concrete



High evaporation rate (hot, dry) can cause plastic shrinkage cracking, excessive curling

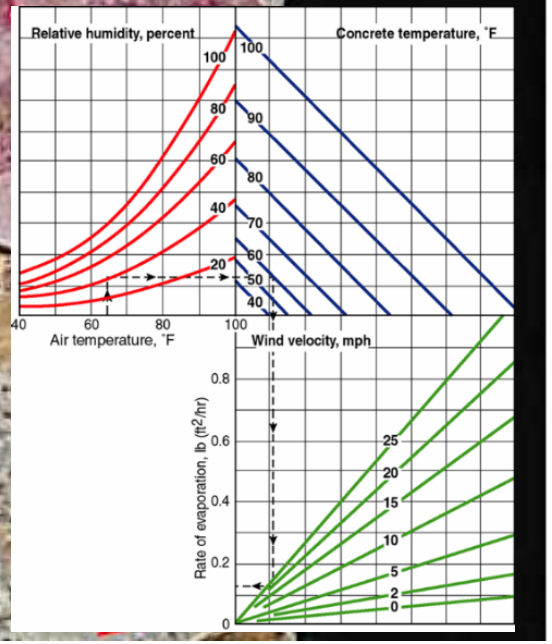
Low albedo causes increased temperature resulting in higher surface temperature and evaporation rates

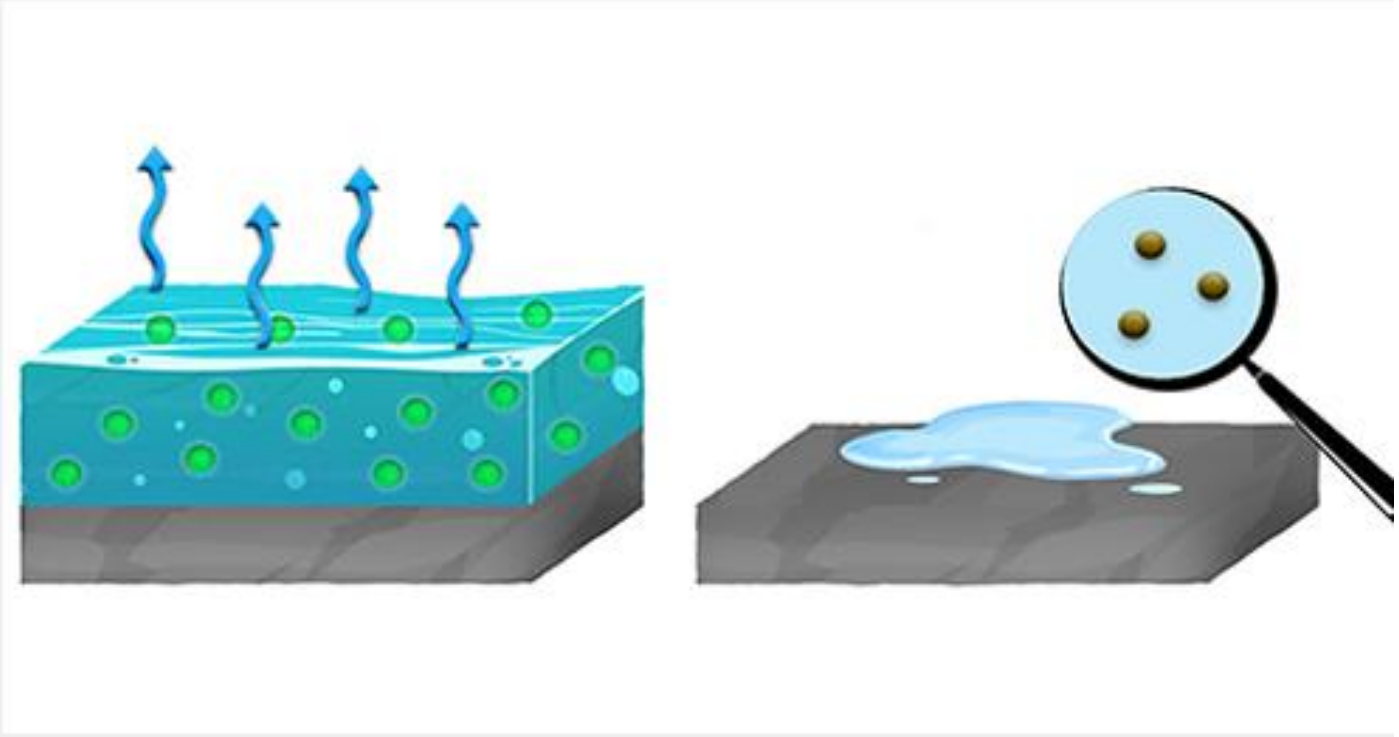
High surface permeability results in scaling and other surface issues

Under curing (late/light)

Scaling

Plastic Shrinkage Cracking





MEMBRANE-FORMING CURING COMPOUNDS (CURRENT STATE OF THE PRACTICE)

AASHTO T148/ ASTM C309

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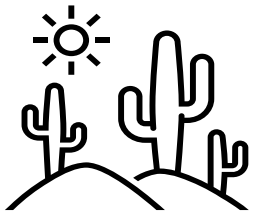
ASTM C309

color		Solid Constituent	
Types	Description	class	Description
1	Clear or Translucent w/out Dye	A	No Restriction
1-D	Clear or Translucent w/ Fugitive Dye	B	Resin
2	White pigmented		

- Moisture loss (ASTM C156)
  - <0.55kg/m^2 @ 100°F/32%RH at 72 hrs @ 200sf/gal
  - Note, this is performed on mortar, w/c = 0.40; 18.6in^2 and 3/4in thick
- Reflectance (Type 2, ASTM E1347) > 60%
- Drying time < 4hrs @ 73F/50%RH
  - Finger test



resin, n—a solid or pseudosolid organic material often of high molecular weight, which exhibits a tendency to flow when subjected to stress, usually has a softening or melting range, and usually fractures conchoidally.
DISCUSSION—In a broad sense, the term is used to designate any polymer that is a basic material for plastics.

Select MFCC Specifications

- Wisconsin
  - ASTM C309: PAM Type 2 Class B
  - 100% PAM w/ > 42% solids
  - <0.15 kg/m^2 in 24 hrs, 0.40 kg/m^2 in 72 hrs; R>65%; VOC <350g/L
- Missouri
  - White pigmented membrane, ASTM Type 2A/B
- Kansas
  - Type 1-D or Type 2

Select MFCC Specifications

- Texas
  - DMS 4650, ASTM C309 Type 1D/2A
  - R>50%
- California
  - ASTM C309 Type 2B (PAM)

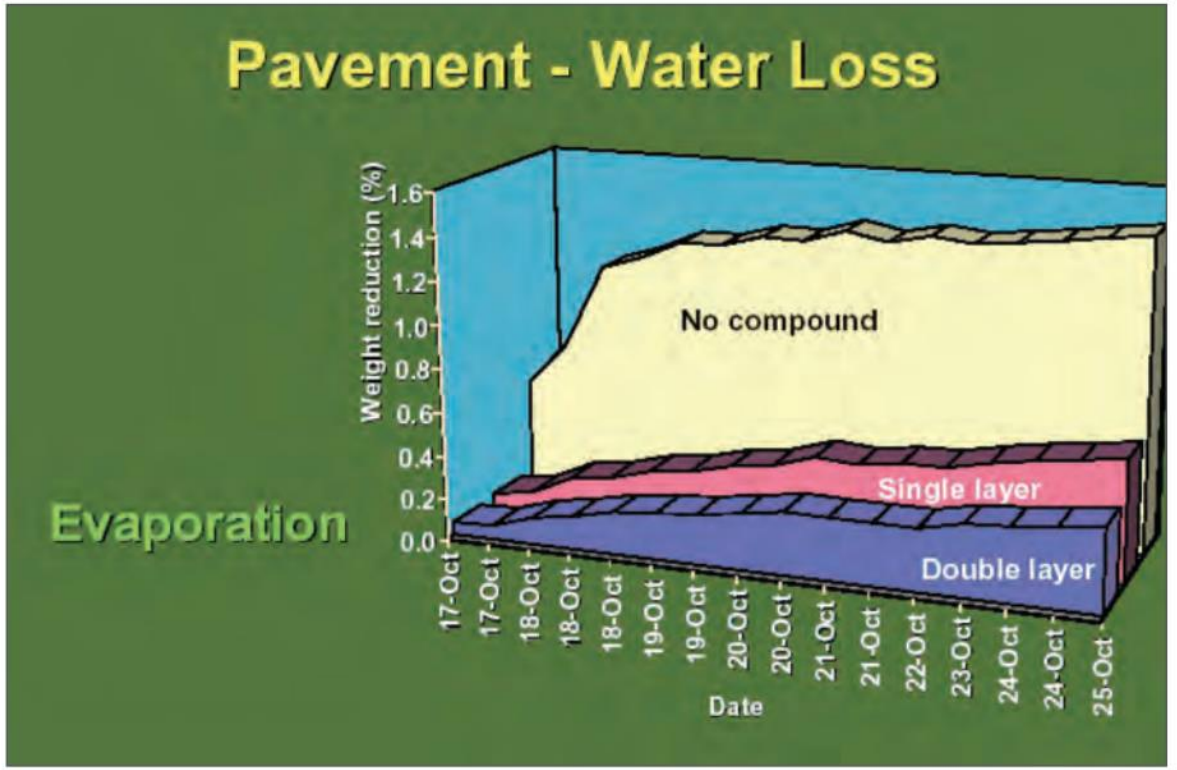


Figure 4. Concrete Moisture Loss vs. Curing Application (ref: CTR R.S. 0-5106).

Curing evaluation – State of the Practice

- Wisconsin
  - Provide sufficient agitation while spraying to ensure uniform consistency and dispersion of pigment within the curing compound during application.
  - Tined not less than 150sf/gal
- Missouri
  - Immediately after finishing without marring, not more than 30 min.
  - Not less than 200sf/gal

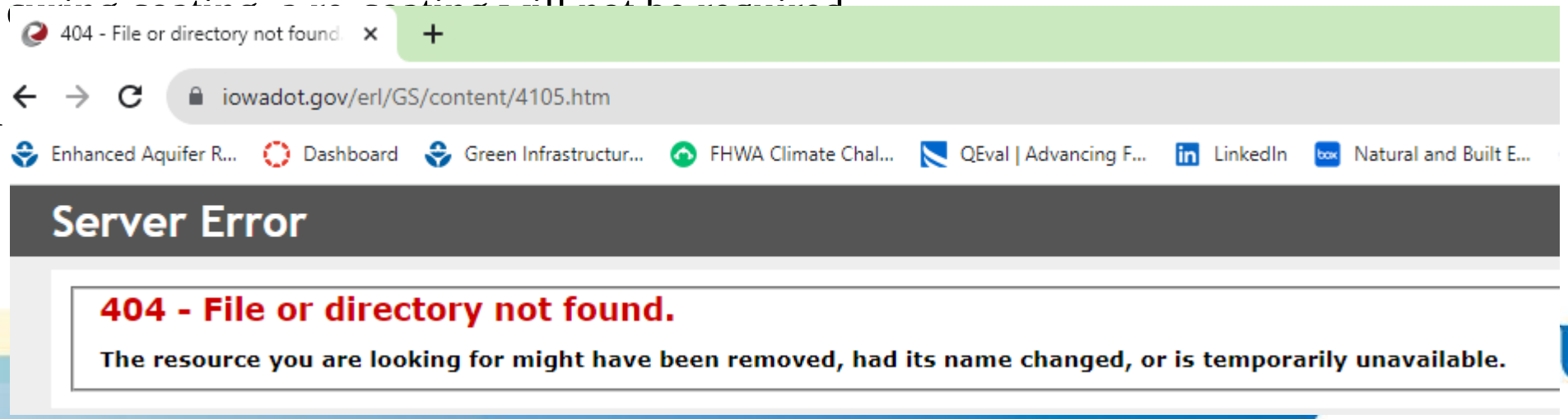
Curing evaluation – State of the Practice

- Texas
  - 10 and 30 minutes after tining
  - Two coats not less than 180sf/gal
  - 8-9 mils (0.20-0.23mm)
- California
  - CT535 METHOD OF TEST FOR THE APPLICATION RATE OF CONCRETE CURING COMPOUND IN THE FIELD
  - 150 sf/gal ±50sf/gal max, ±25sf/gal average

Select MFCC Specifications

- Iowa
  - Apply curing compound in a fine spray to form a continuous, uniform film on the surface and vertical edges of the pavement slab.
  - Apply curing compound as soon as the free water has appreciably disappeared, but no later than 30 minutes after finishing. With the Engineer's approval, cure application timing may be adjusted due to varying weather conditions and concrete mix properties to achieve acceptable macrotexturing.
  - Use an application rate of no less than 0.067 gallon per square yard covering 15 square yards per gallon (135sf/gal).
  - If, due to other operations, the coating is damaged within 72 hours after being applied, immediately re-coat the affected areas. Coating of the sawed surface with curing compound will not be permitted on joints that are to be sealed. When pavement is opened to traffic prior to 72 hours after application of the

Apply a



Select MFCC Specifications

4105.01 GENERAL REQUIREMENTS.
Comply with ASTM C 309 and the following requirements.

4105.03 MOISTURE RETENTION.

- **White pigmented liquid curing compounds, when tested in accordance with ASTM C 156 using an application rate of 200 square feet per gallon shall restrict the loss of water to not more than 0.20 kg/m2 in 24 hours or 0.40 kg/m2 in 72 hours.**

4105.05 WHITE PIGMENTED COMPOUNDS.

A. Use compounds consisting of finely ground white pigment and vehicle, ready mixed for use without alteration.
C. Use a compound that after being sprayed on a test slab and drying has an apparent daylight reflectance no less than 60% relative to magnesium oxide.

4105.06 DARK COLORED COMPOUNDS.

- Use asphalt emulsion or asphalt cut back with a volatile solvent. Use a mixture containing no less than 50.0% asphalt. Use an application rate of no less than 0.08 gallon per square yard (12.5 square yards per gallon). 113sf/gal

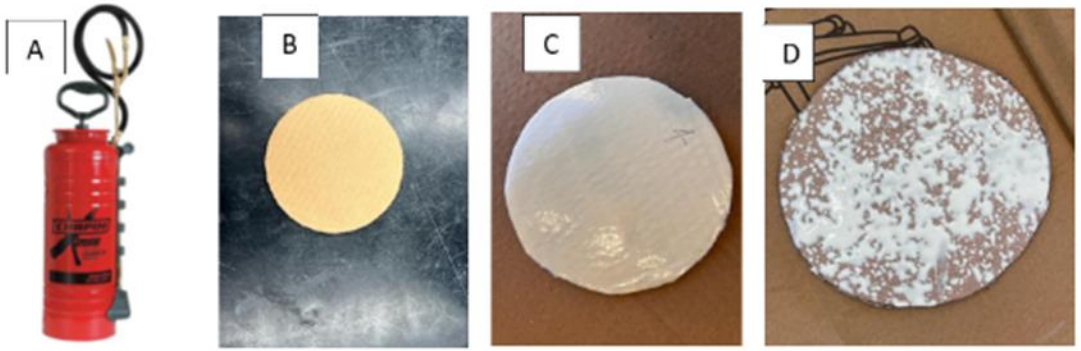
4105.07 CLEAR COMPOUNDS.

- Apply the following in lieu of other requirements of this section:

A. Use clear liquid membrane curing compounds complying with the requirements of ASTM C 309, Type 1-D, Class A. Use only one type of compound on a structure. Do not use different compounds on the same structure.

Techniques to evaluate curing compound effectiveness

- Visual – Eyes…White sheet of paper…image analysis



400sf/gal 180sf/gal

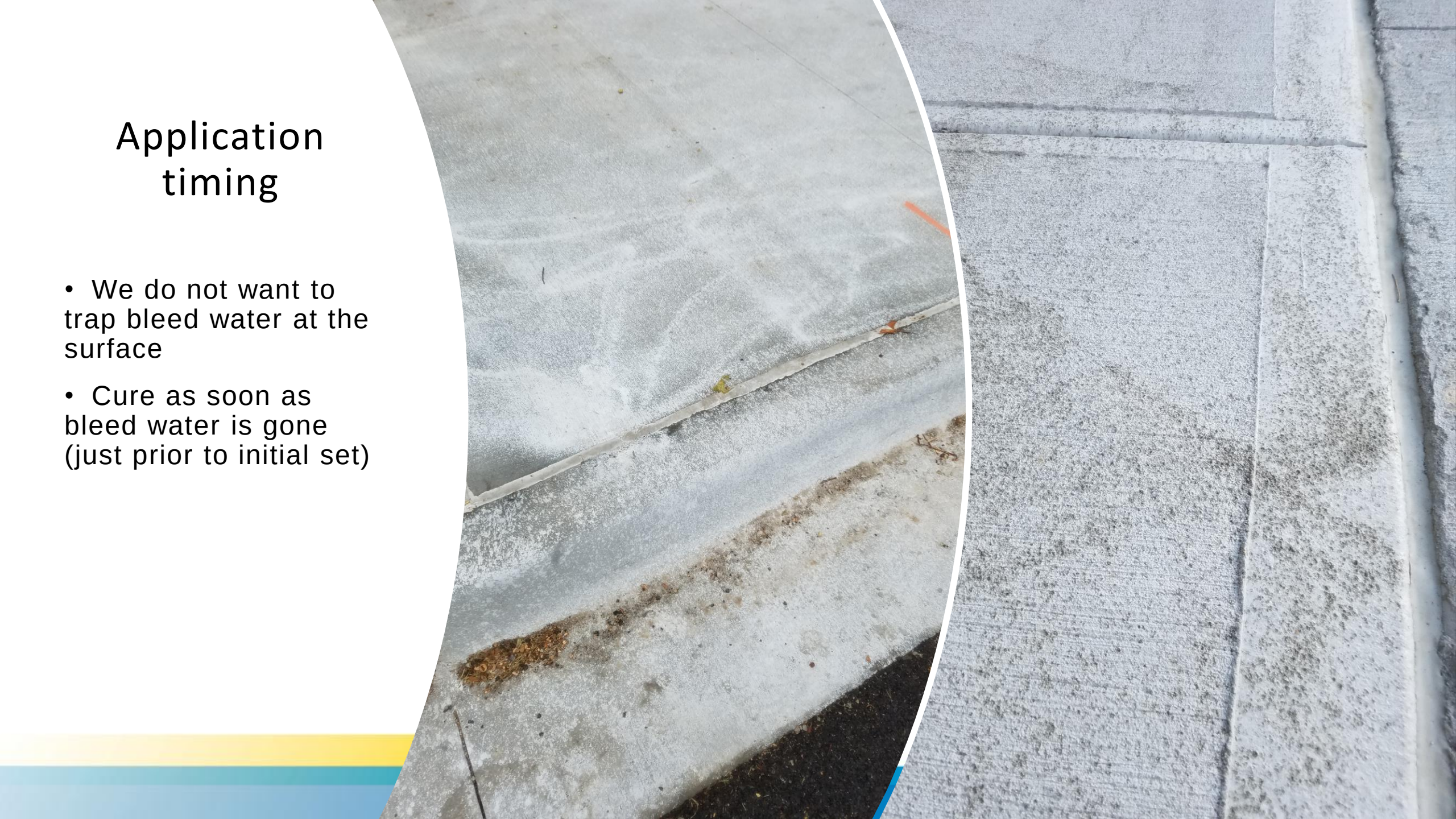
Is this ok?

Or this?

- Better than nothing, but?

Application timing

- We do not want to trap bleed water at the surface
- Cure as soon as bleed water is gone (just prior to initial set)



Techniques to evaluate curing compound effectiveness

- Volume/Area – Simple, CT535 (Long:5 test pads, 3 ft from edge randomly for 50 ft; Trans: 5 test pads under abnormal sprayers)

$$v = \frac{coeff. \times F}{C \times w}$$

MnDOT method

where:

v	=	cart speed (km/h, or miles/h),
coeff.	=	6 for SI units, or 0.13636 for English units,
F	=	flow rate (L/min, or gal/min) per nozzle,
C	=	desired coverage (L/m^2, or gal/ft^2), and
w	=	nozzle spacing (cm or in.).

Which of these has a higher application Rate?

Techniques to evaluate curing compound effectiveness

- Moisture retention – modified ASTM C156 has been attempted unsuccessfully
- Penetration resistance – Winsor probe…not correlated
- Reflectance – Retroreflectivity condition-specific

Who puts down the curing compound?

This guy, or your equivalent

When? When there is a break or he gets yelled at
How much?

When?

How much?

Trouble shooting?

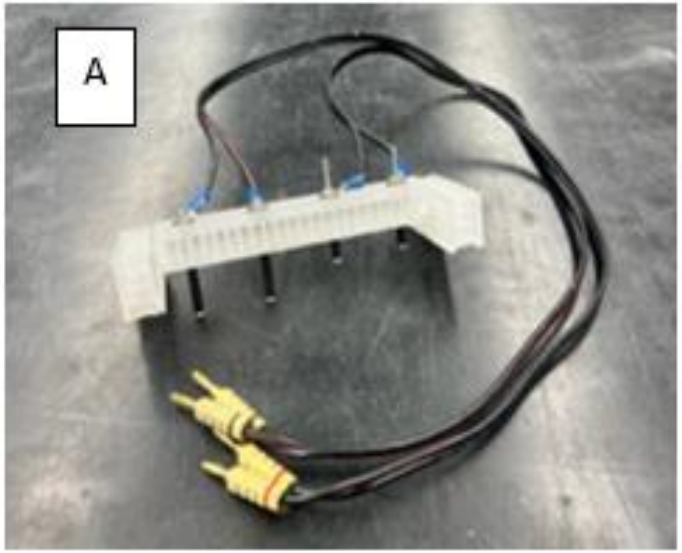
Field Evaluation-Results

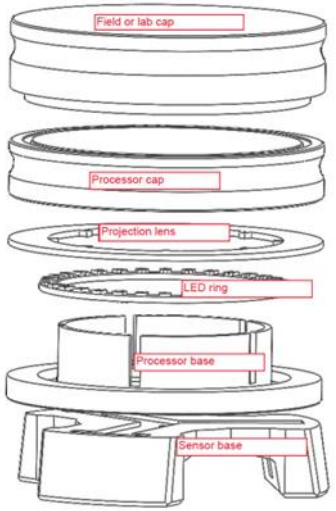
- Comparing Caltrans (pee pad) and area volume

Sample ID	A (275 ft^2/gal)	B (167 ft^2/gal)	C (275 ft^2/gal)	D (167 ft/gal)
1	331	245	235	148
2	158	202	172	170
3	193	416	202	114
4		374	190	112
5		261	190	138
Avg	**227**	**300**	**198**	**136**
Std Dev	91	91	23	24
COV (%)	40%	30%	12%	18%
	Fast	Slow	Fast	Slow

Field Evaluation

- Observe curing application using embedded resistivity





Sensor card connected to instrument

Does Rate Matter? (73F/50%RH)

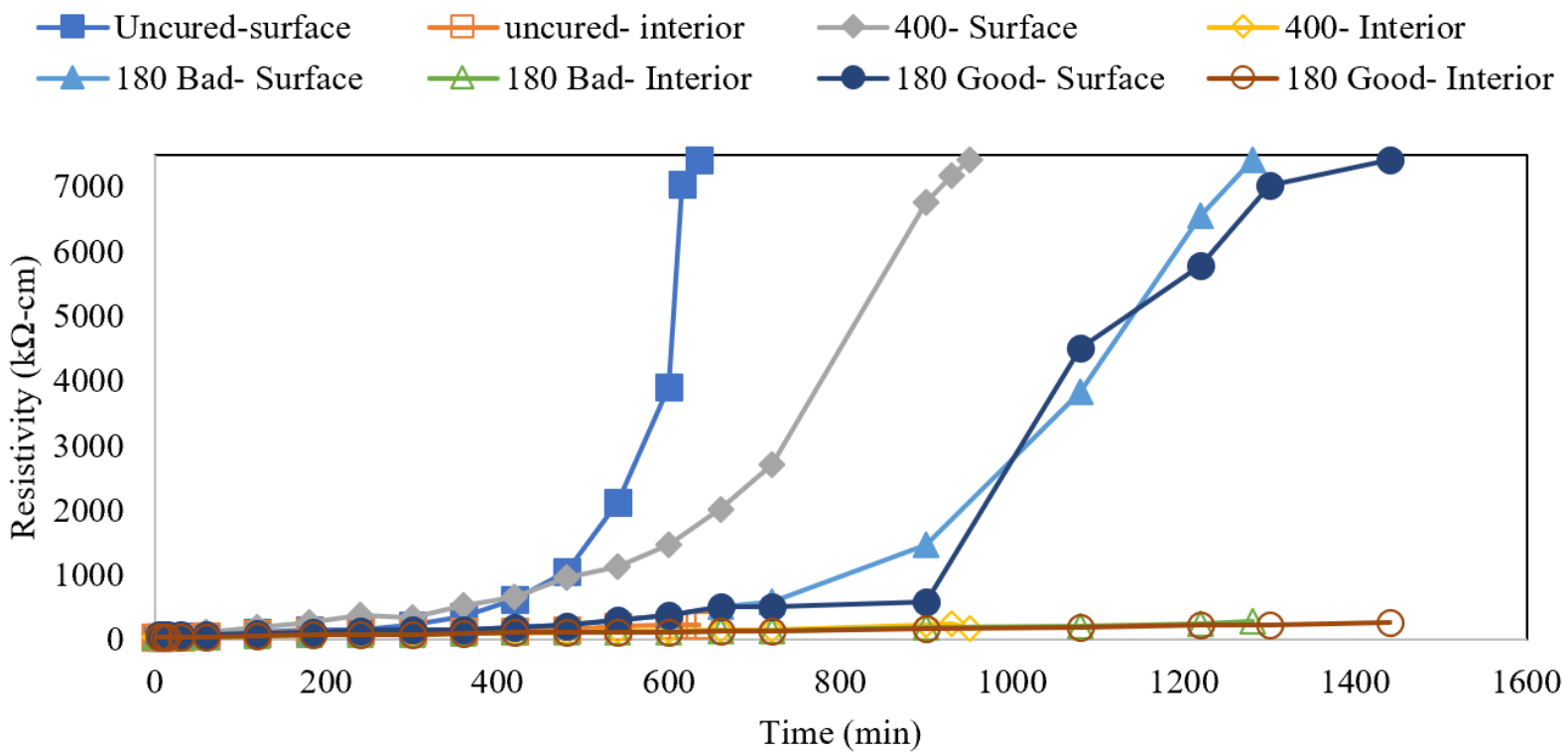


Figure 5 Resistivity for low evaporative condition

Does Rate Matter? (100F/32%RH)

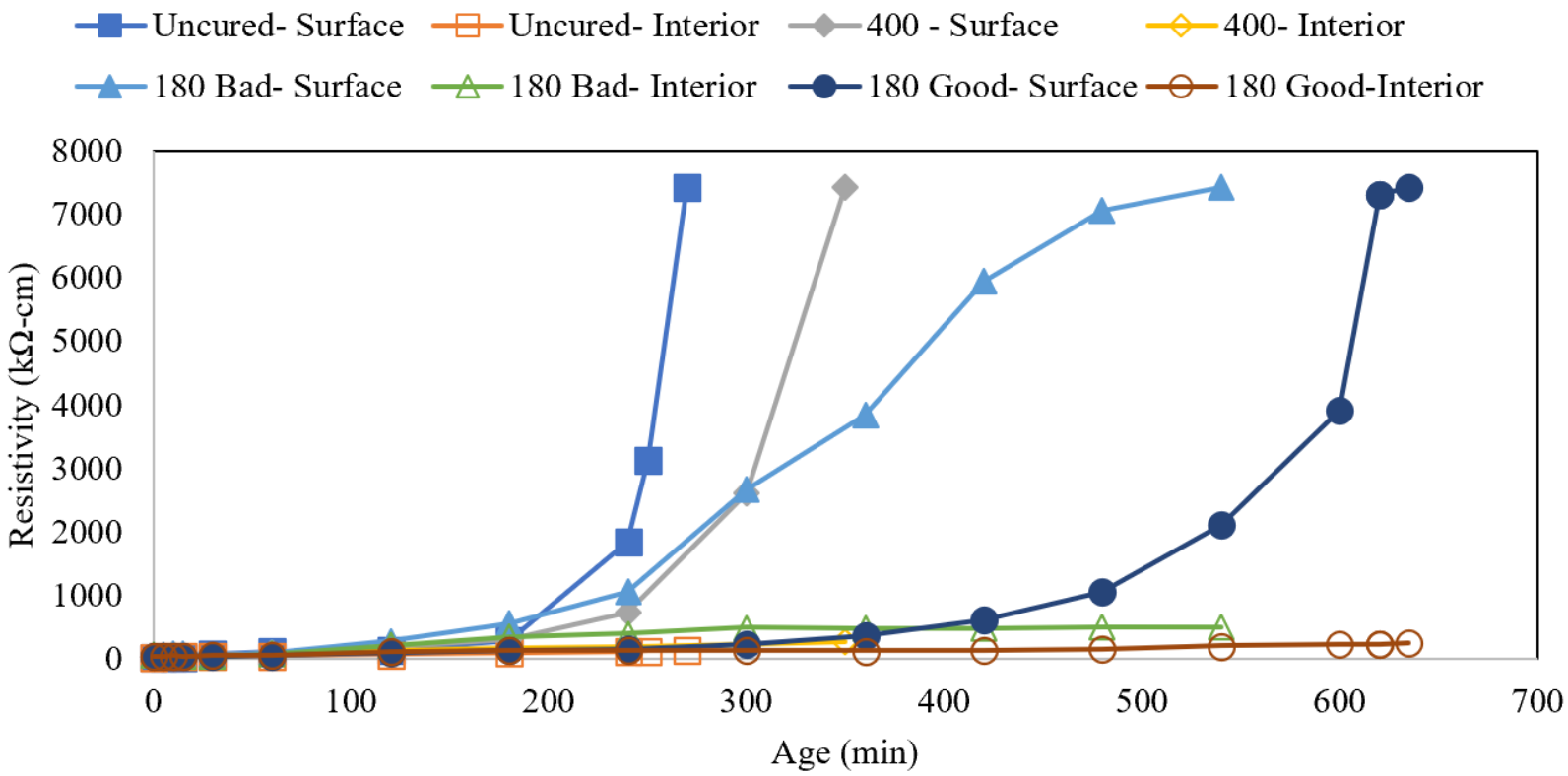


Figure 6 Resistivity for high evaporative condition

Does Rate Matter? YES!!!!

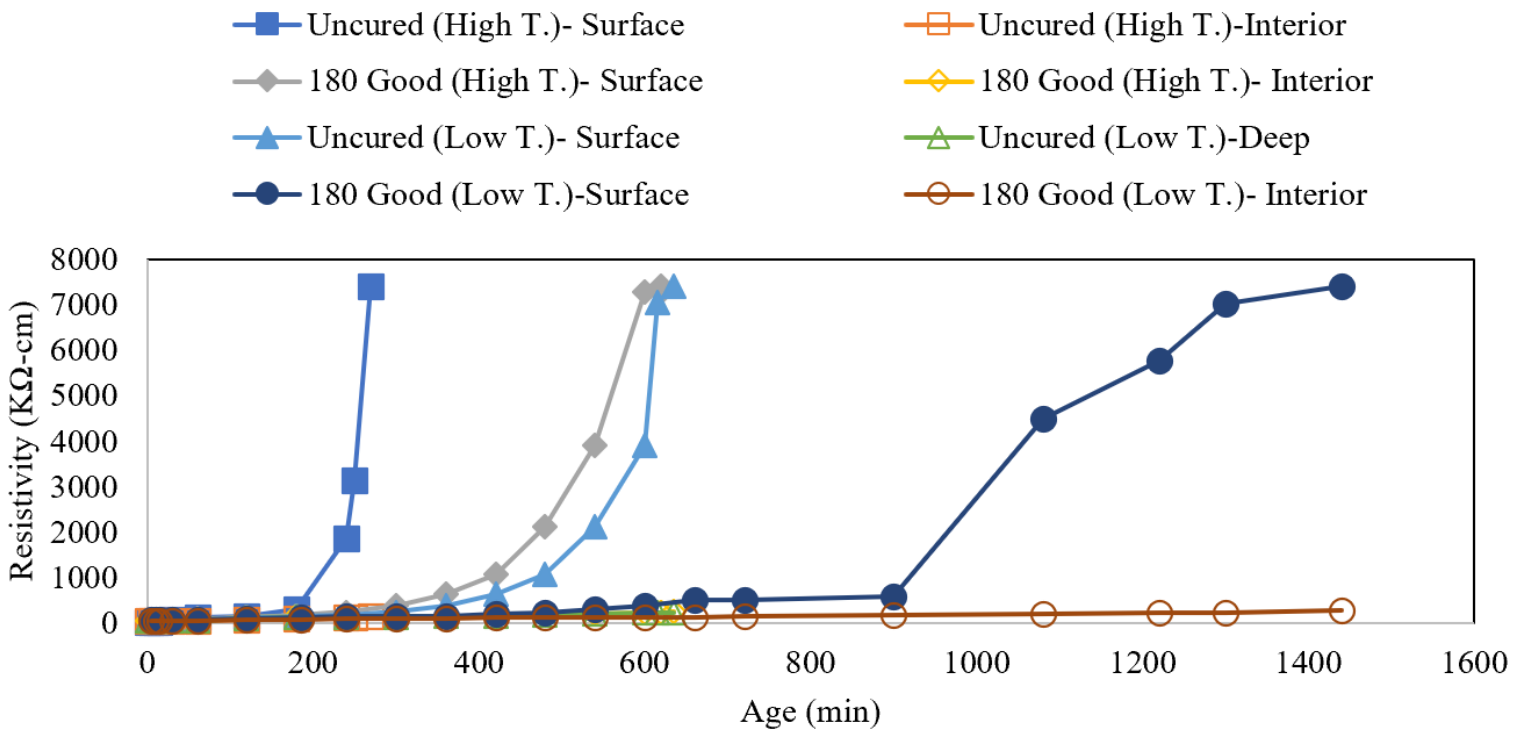


Figure 7 Resistivity data comparison between low curing and hot curing condition

SUMMARY

- Curing is critical for short and long-term performance
- Curing is often overlooked and right now there really isn’t a good way to quantitatively measure
- Calculate the volume needed for an area and get it visually uniform

SUMMARY

- Cure as soon as the bleed water is gone (even more critical for Type 1L)
- For the vast majority of applications, there is no such thing as over curing
- Your human visual sensors (eyes) are better than current AI, so unfortunately you are responsible and can’t let the robots take over yet.

WHAT IF?

WHAT IF?

Weather station, active timing control, active rate monitoring, and active rate control on cure cart

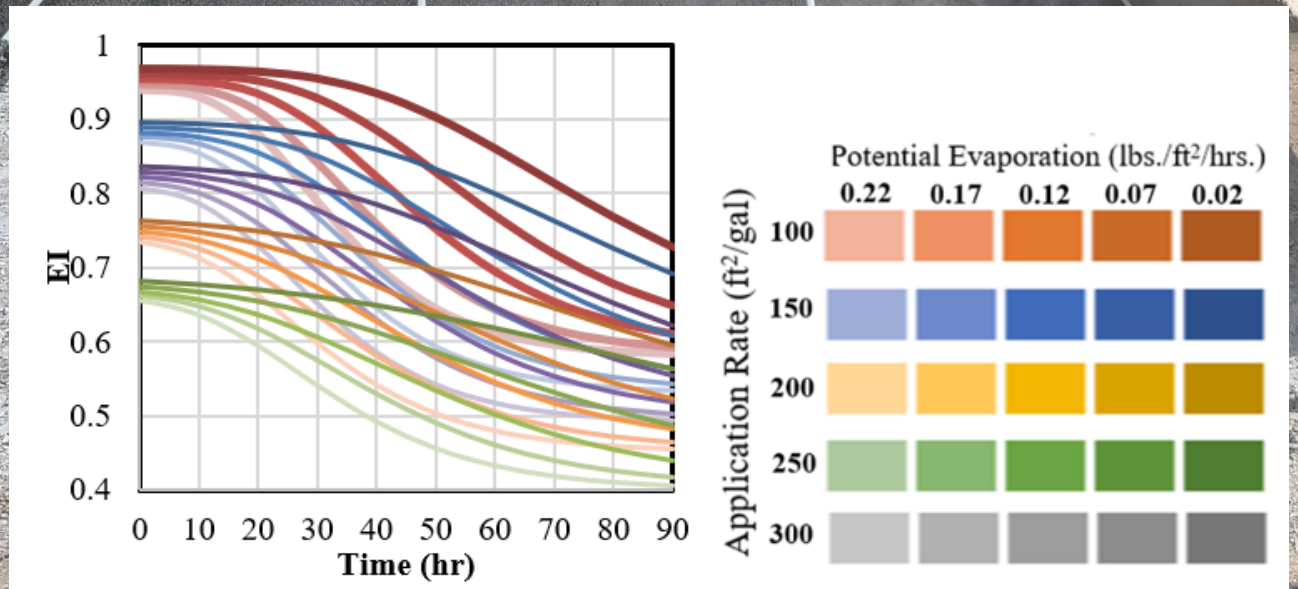
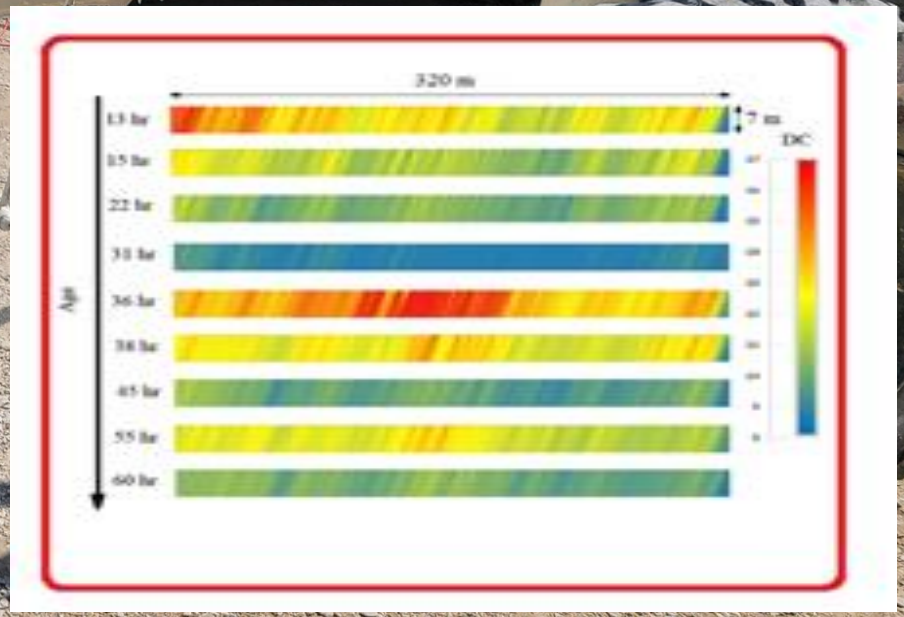


Figure 5 Establishing Reference Curves Based on the Preliminary Testing.



WHAT IF?

All integrated from texture through sawing
The future is now!

Thank you

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