

Curing Blended Cements



Tyler Ley, PE, PhD

Anis Ghanei

MJ Uddin, PhD

Two part discussion

Part 1 – Fresh properties and strength

Part 2 – Curing

Project is finished in June

Let's start with the basics of curing!

Why is curing important to the quality of our concrete?

Curing is the final step to the construction practice.

If we don't get it right then everything else can be compromised.

This will get even more important as we use more blended cements.

Why do we cure concrete?

1. Reduce evaporation
2. Minimize temperature gradients
3. Promote hydration

What are the traditional methods of curing?

Curing compounds



What are the traditional methods of curing?

Plastic or sealed curing



What are the traditional methods of curing?

Form cure



What are the traditional methods of curing?

Wet curing



What are the traditional methods of curing?

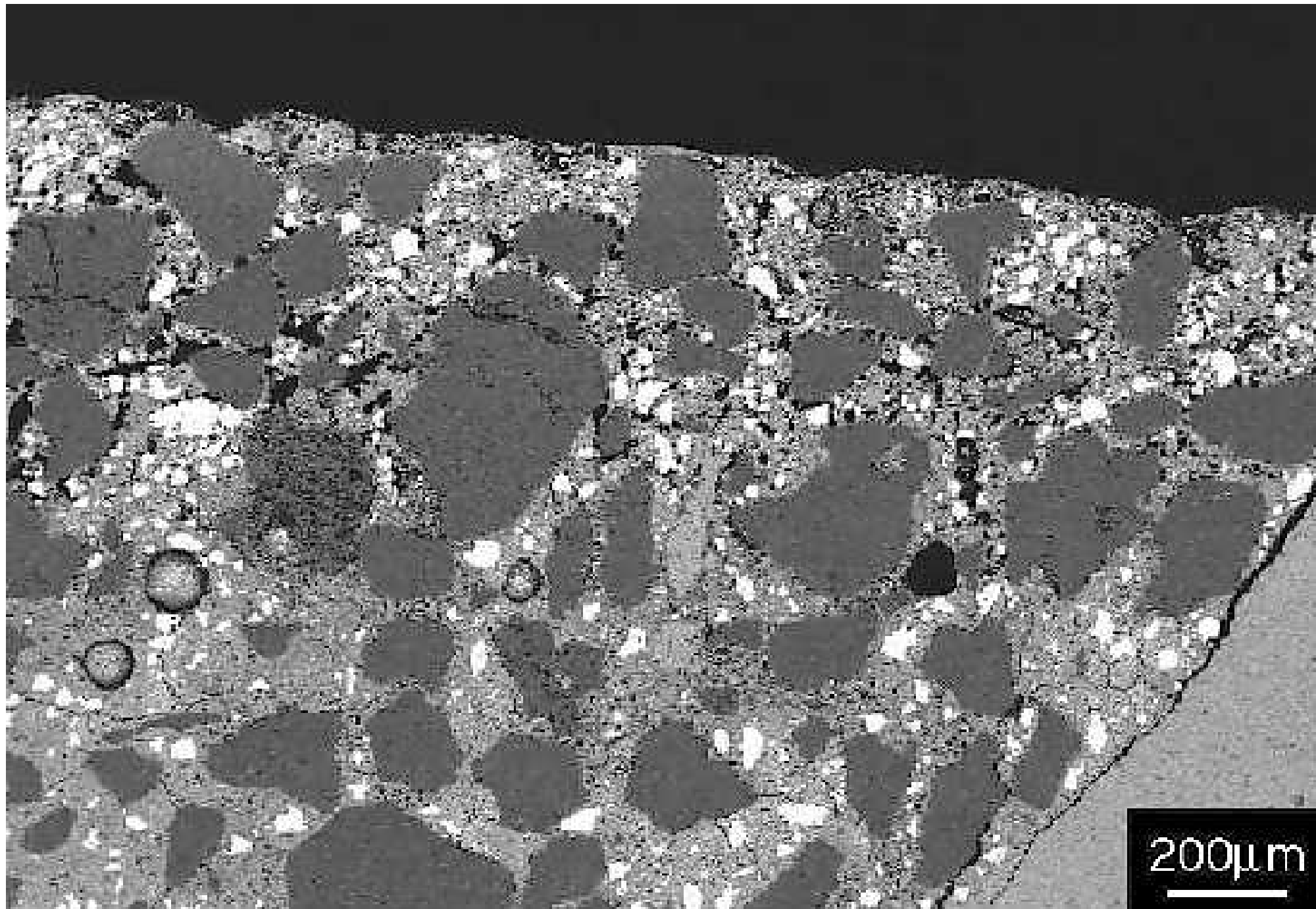
No curing



What are the traditional methods of curing?

No curing

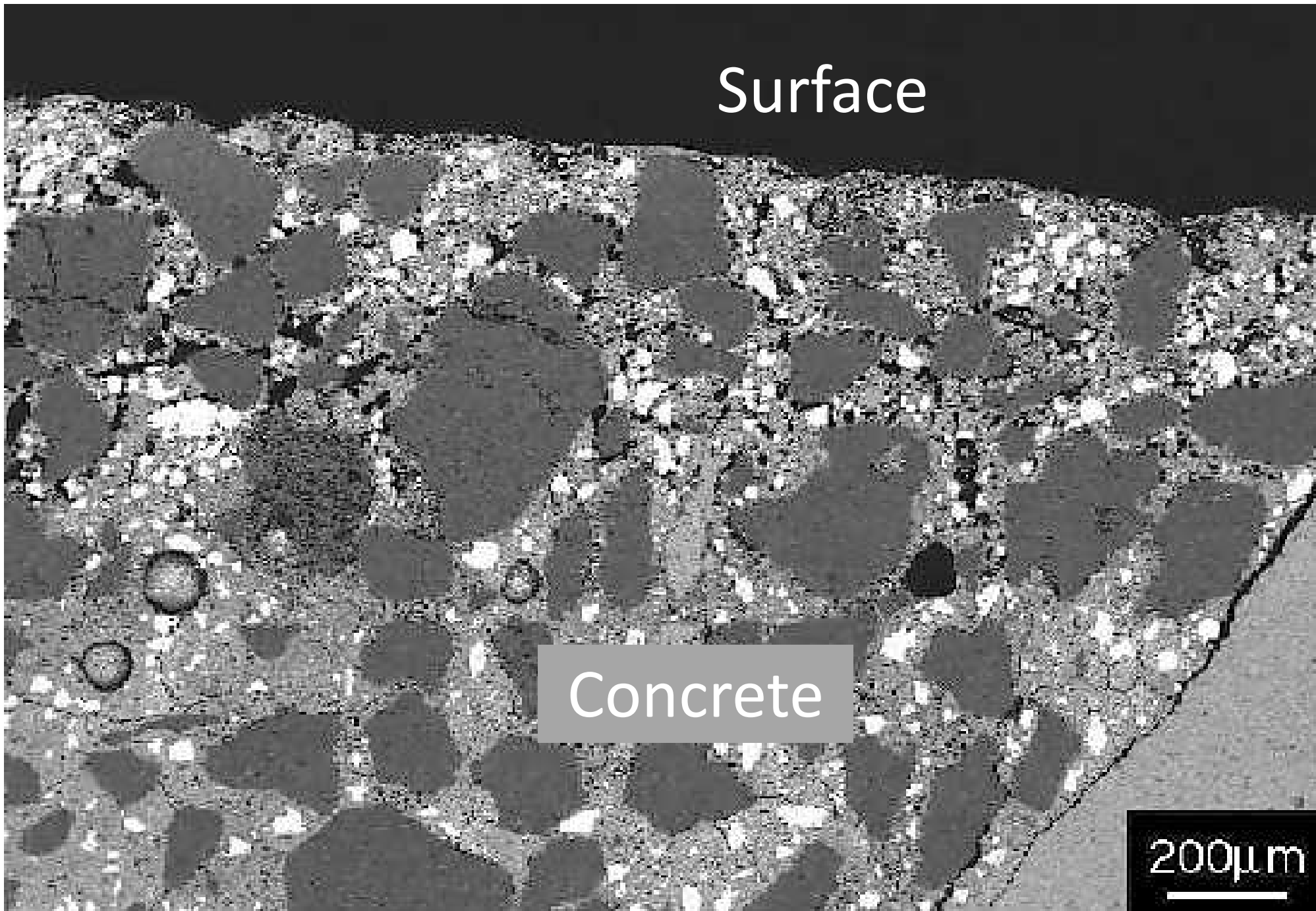


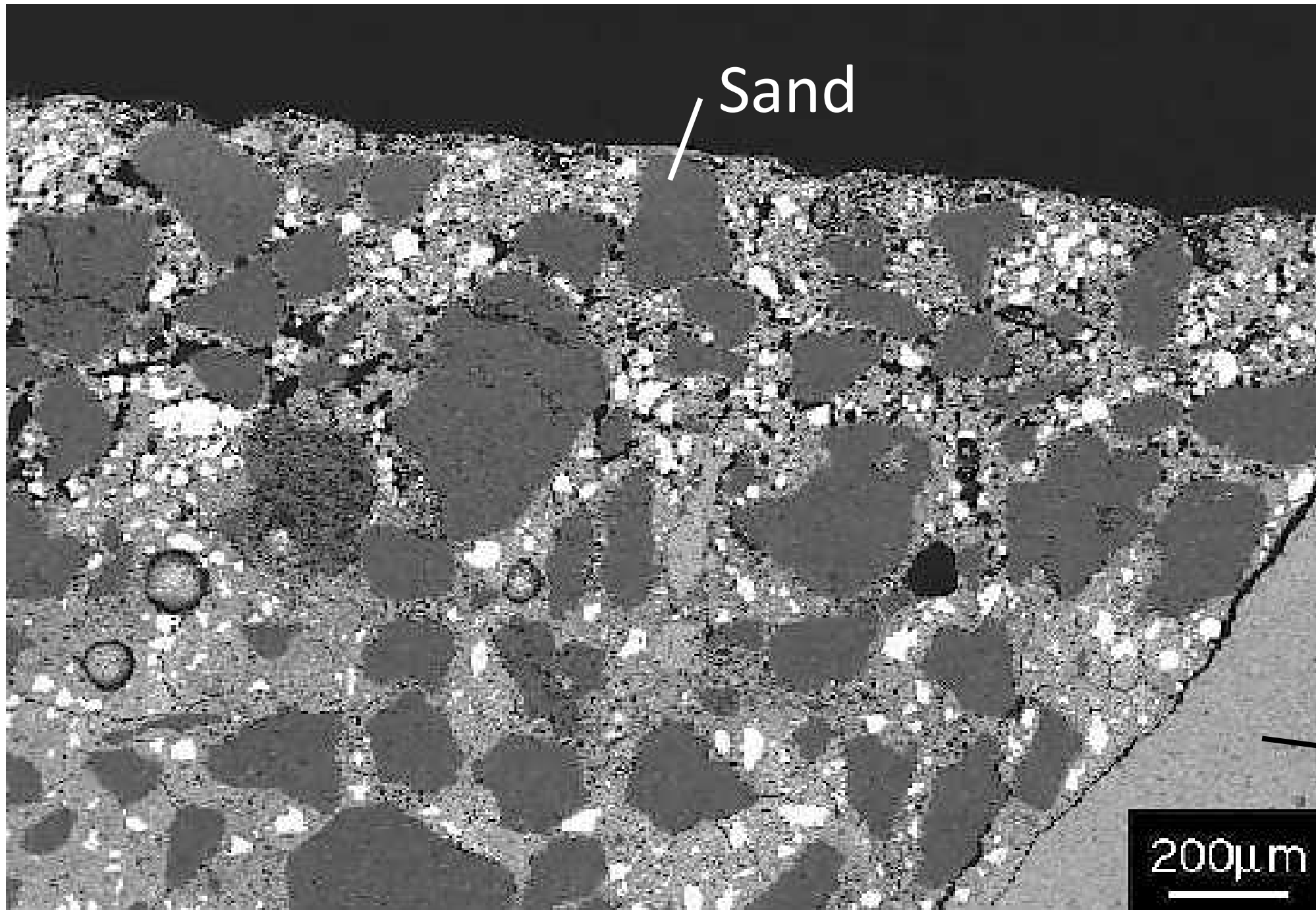


Surface

Concrete

200 μ m

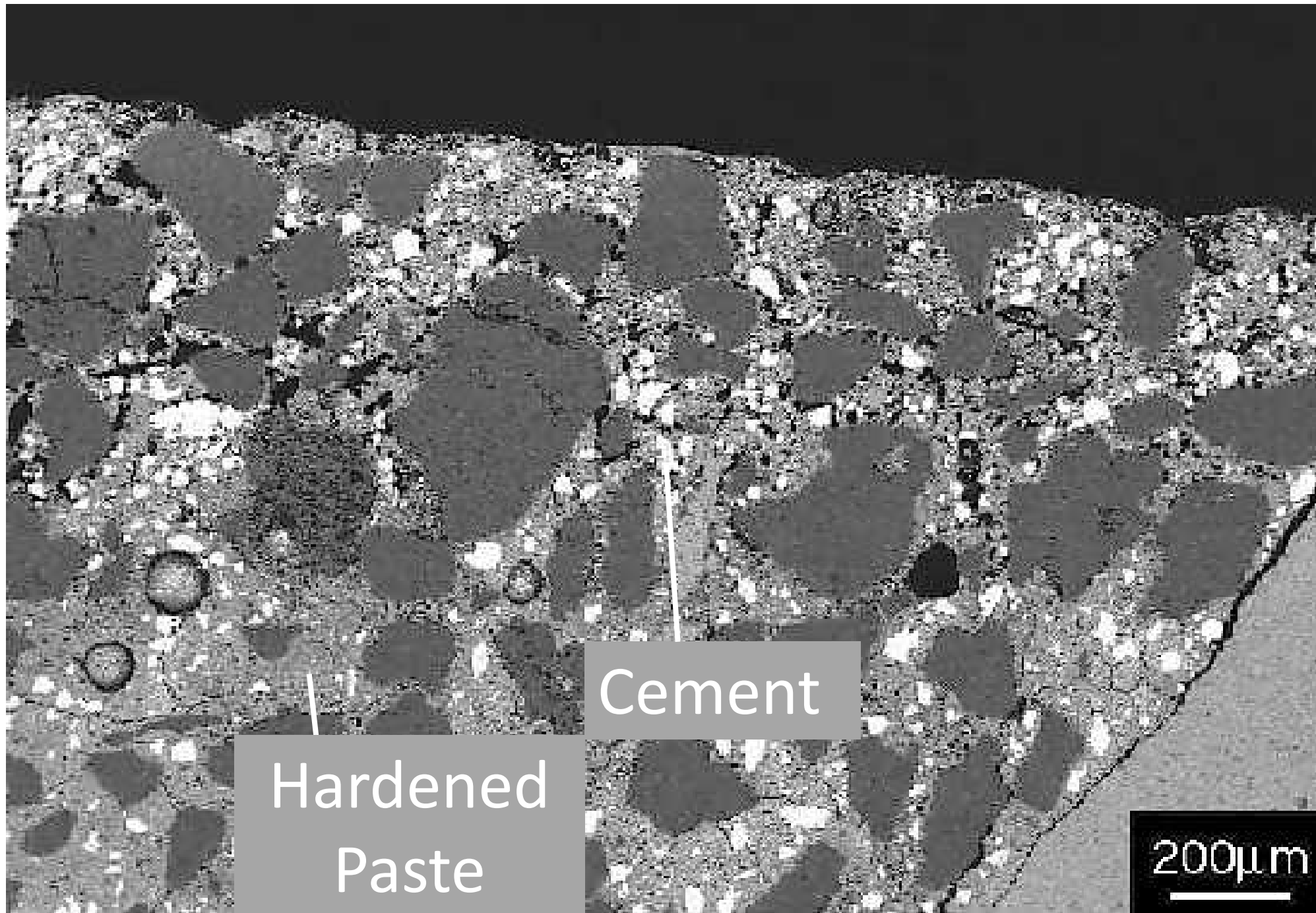


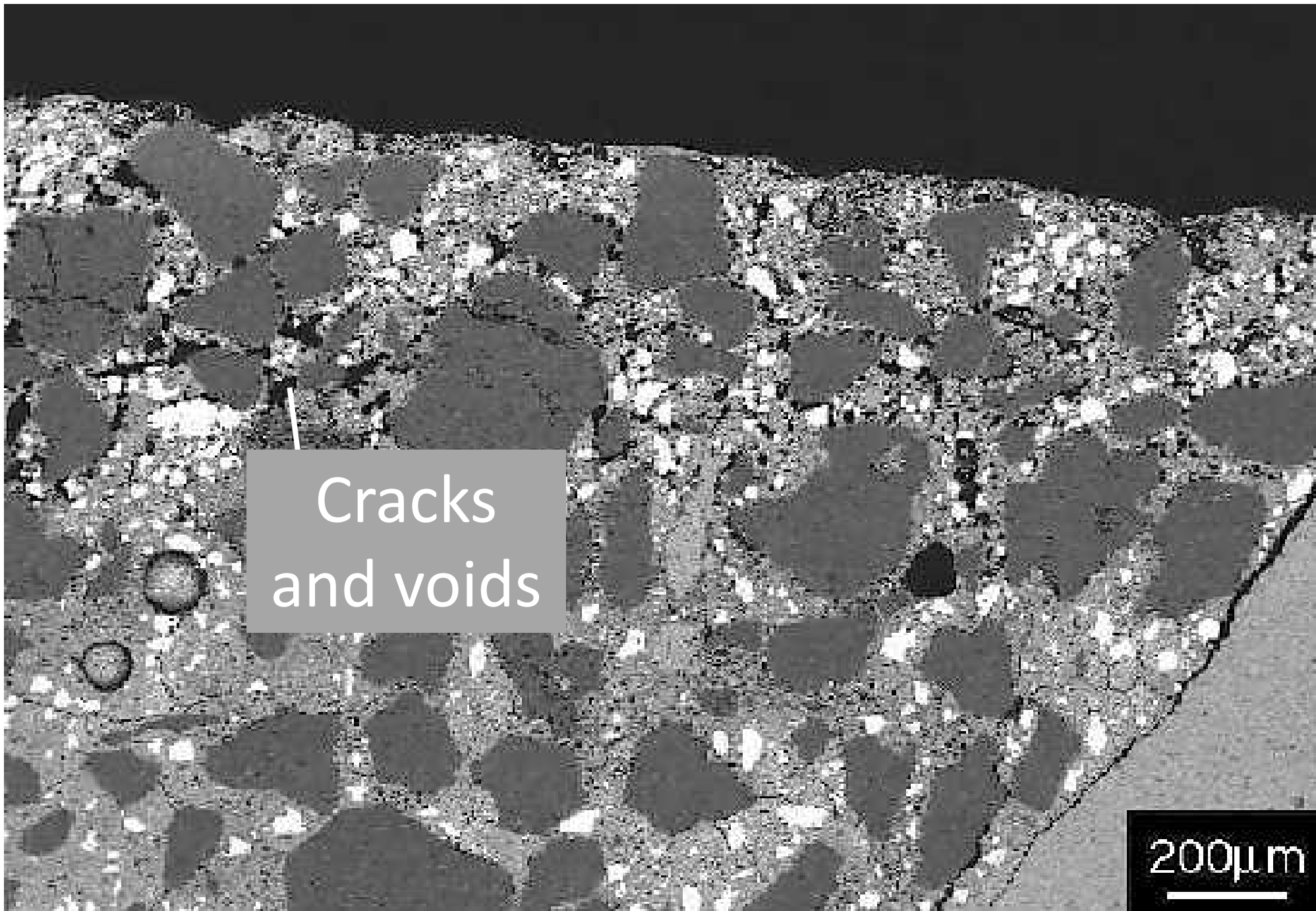


Sand

Coarse
agg

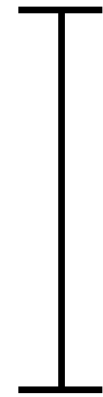
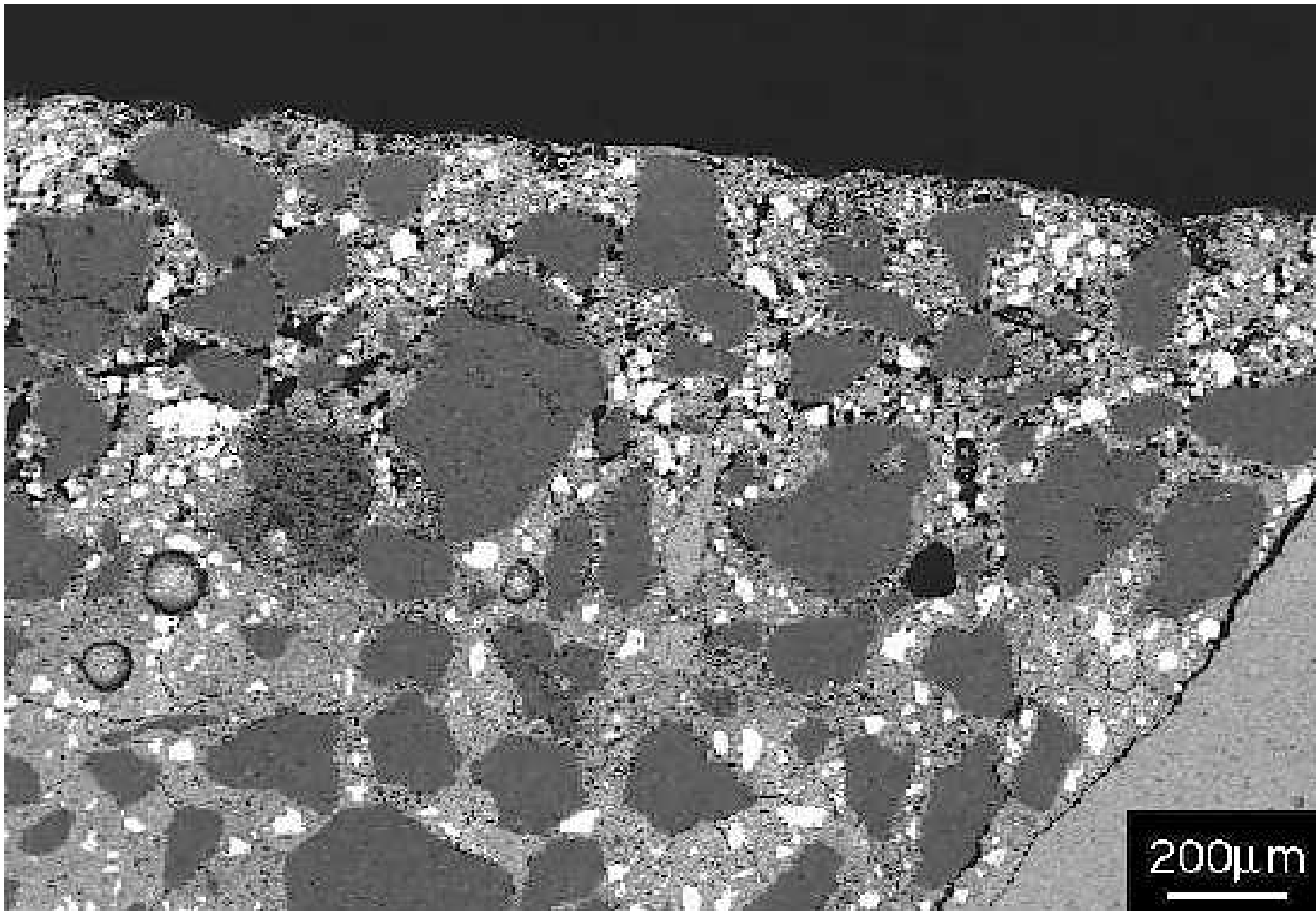
200µm





Cracks
and voids

200 μ m



Poorly cured
concrete

Discussion

When you don't cure, the surface of concrete loses strength, durability, and hardness

Inadequate curing can sour an otherwise amazing project.

When do we cure concrete?

- Period 1 - Placement to 6h to stop plastic shrinkage cracking
- Period 2 - 6h to several days to form a dense microstructure

When do we cure concrete?

- Period 1 - Placement to 6h to stop plastic shrinkage cracking
- Period 2 - 6h to several days to form a dense microstructure

Let's compare different curing methods...

Wet curing

Curing compounds

No curing

What is the cost of curing?

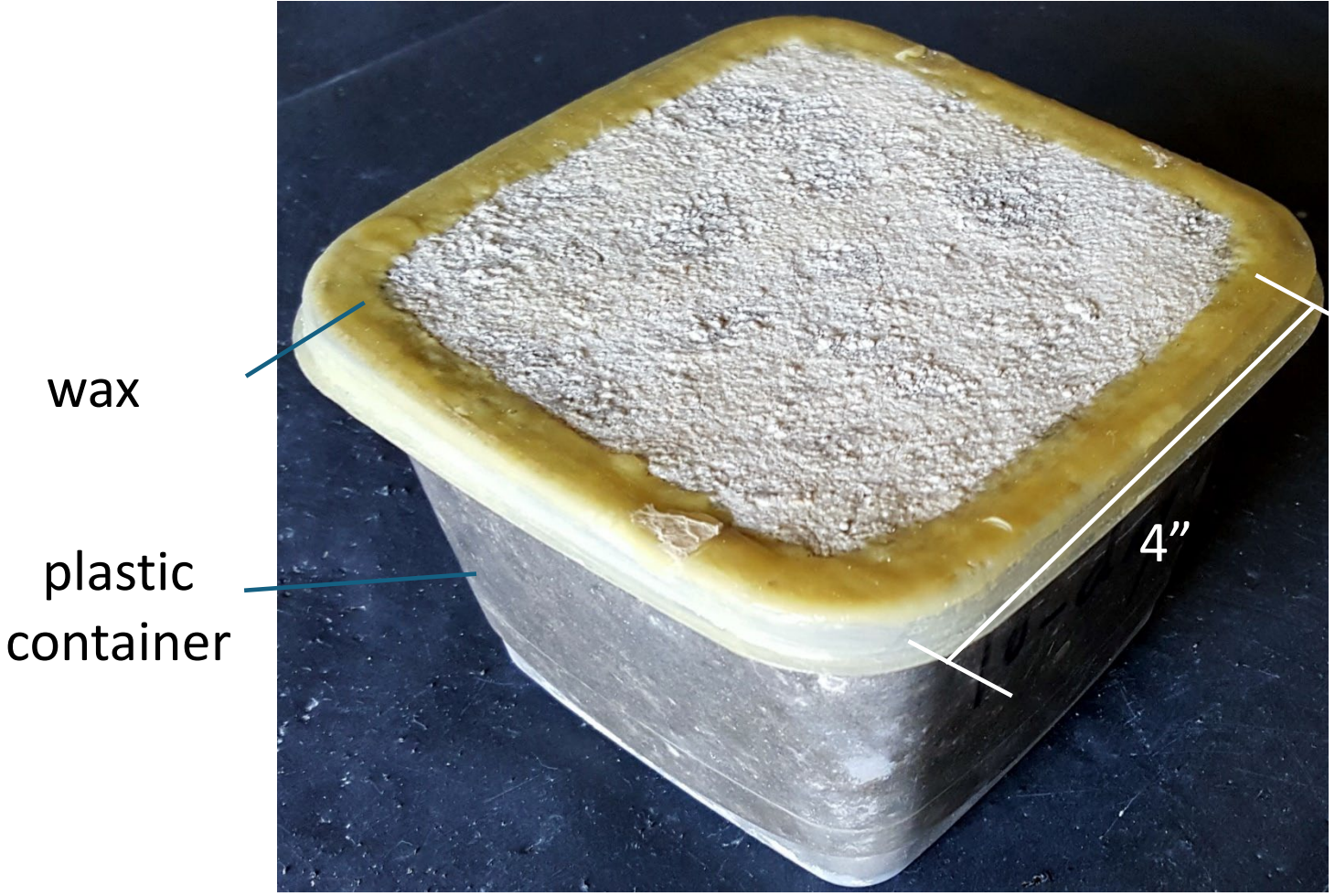
	\$/sf	Percentage of Oklahoma bridge cost/sf
Burlap wet cure	0.62	0.47%
Premium curing compound	0.25	0.19%
Common curing compound	0.08	0.07%

Mix Design

- 0.42 w/cm
- 20% Class C ash
- 6.5 sacks (611 lbs)
- Limestone and natural sand
- 5" slump

How did we cure them?

- No curing
- Wet curing for 1, 3, 7, 10, 14 days with wet burlap covered in plastic
- Lithium silicate curing compound
- Poly Alpha Methyl Styrene (PAMS) curing compound
- Curing compounds were applied in two layers with a total coverage of 200 sf/gal



wax

plastic
container

4"

Testing

If the concrete is well cured then:

1. It will be hard for the concrete to lose moisture.
2. The concrete will be resistant to water uptake.
3. The concrete will be resistant to chloride penetration.

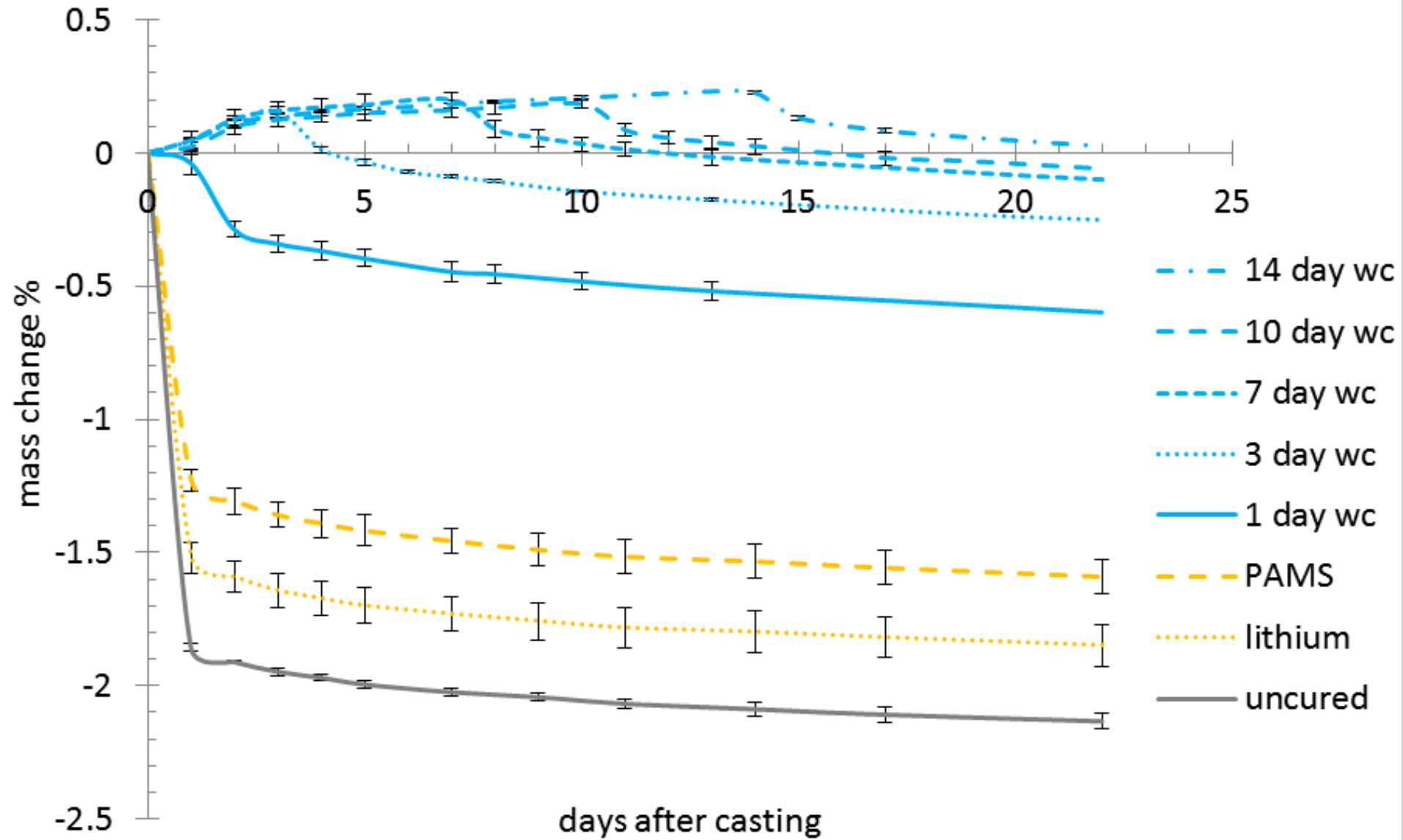
What did we do?

Step	Test	Details
1	drying	Mass change in 40% RH and 73°F for 22 days
2	water uptake	Mass change in lime water for 5 days
3	chloride penetration	Mass change in 5% NaCl for 35 days Chloride profile

Step 1 – Dry the sample

Measure mass change in 40% RH and 73°F for 22 days

1. Mass change in 40% RH and 73°F for 22 days



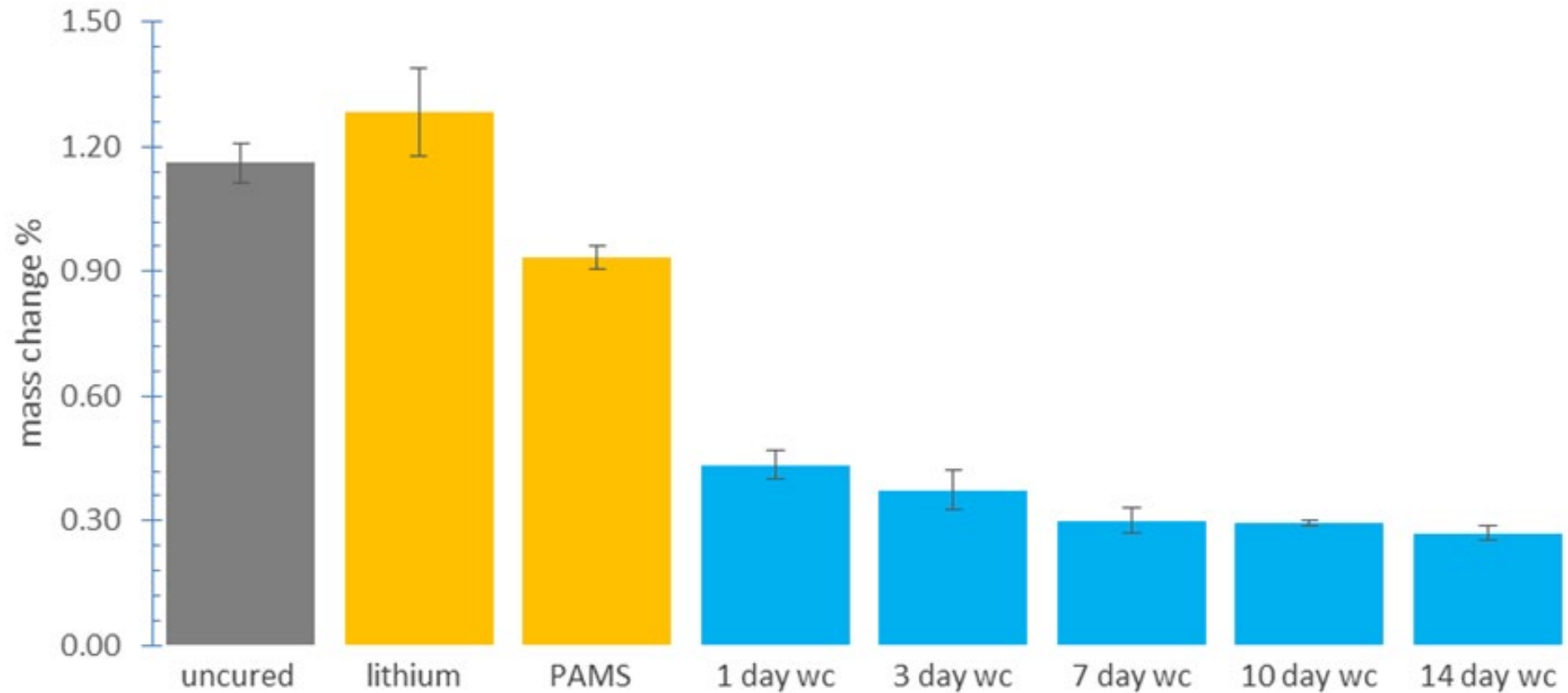
Discussion

- The samples are losing water as they dry.
- The better the curing the less mass was lost.
- Lithium silicate reduced mass loss by 12% and the PAMS by 38% when compared to not curing.
- After 7 days of wet curing there was a low mass loss.
- There was little difference between 7, 10, and 14 days of wet curing for these conditions and materials.

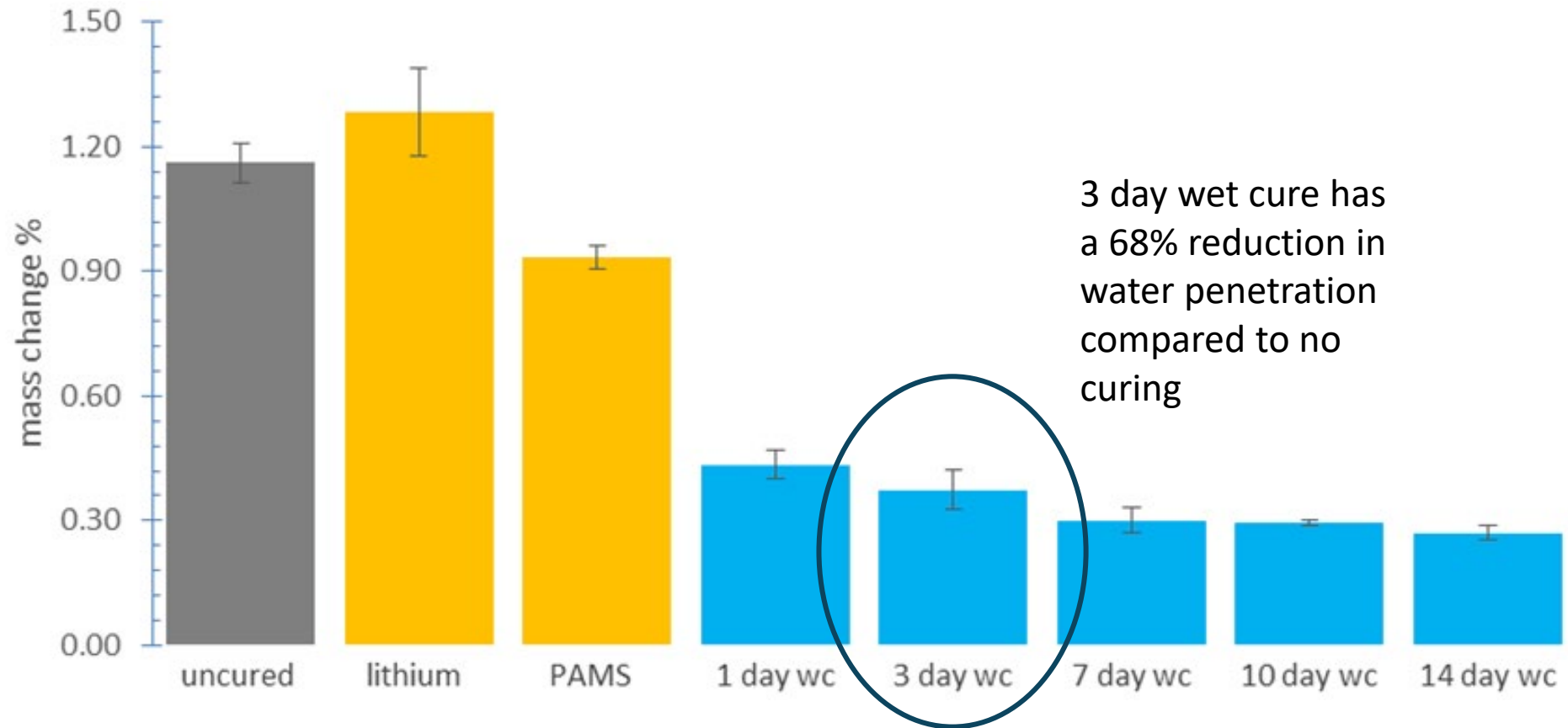
Step 2 – Place concrete in lime water

Measure mass change in lime water for 5 days

2. Mass change in lime water for 5 days



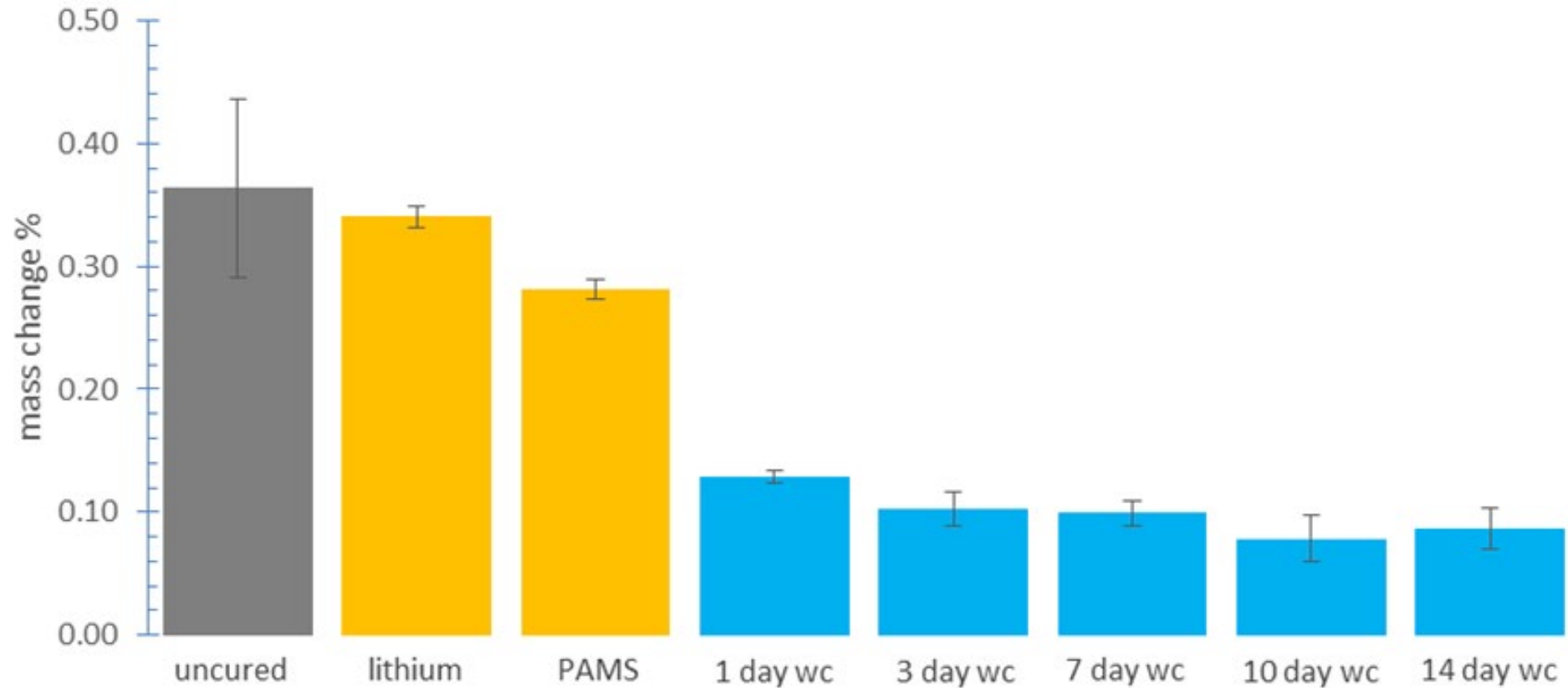
2. Mass change in lime water for 5 days



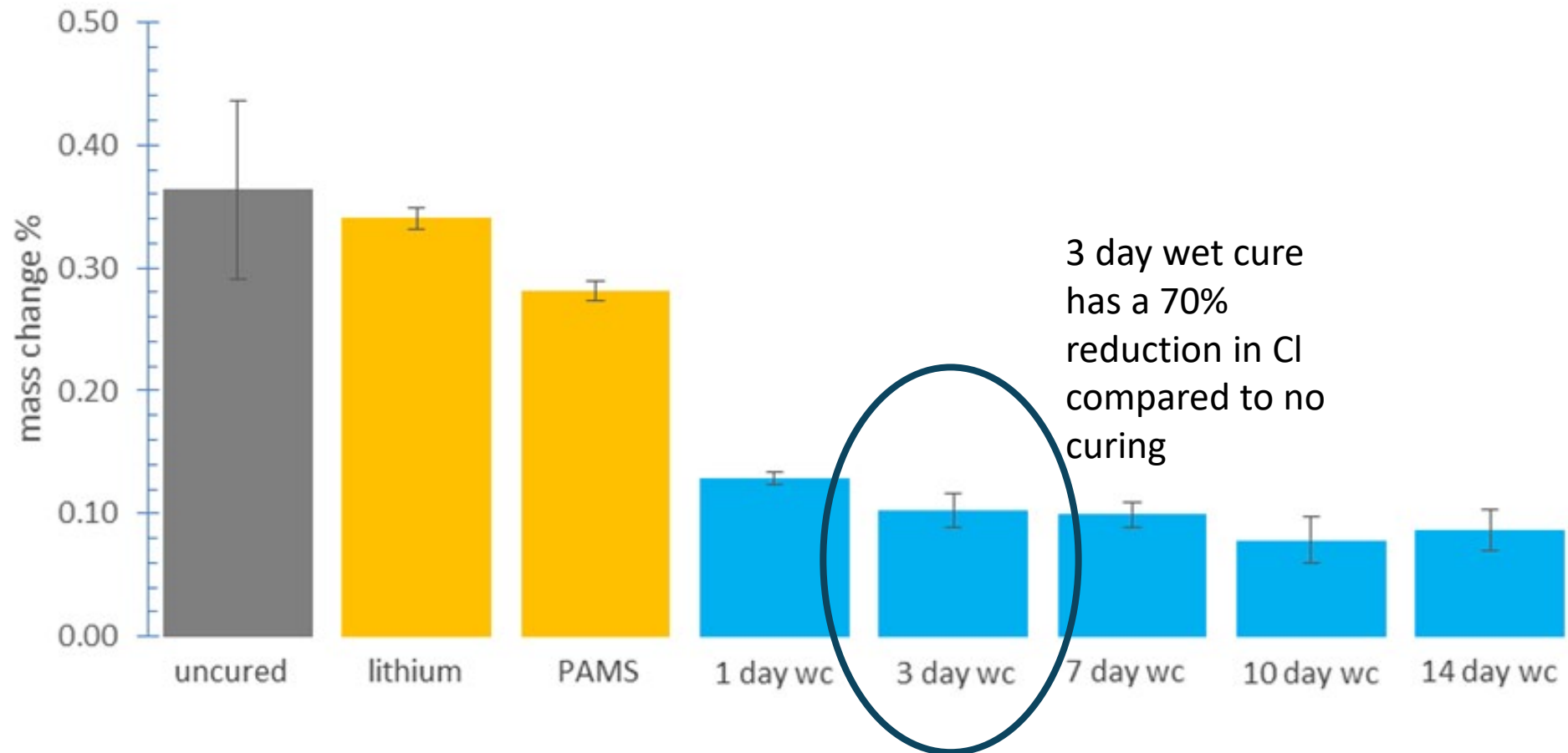
Step 3 – Place concrete in NaCl solution

Measure mass change in NaCl solution for 35 days

3. Mass change in 5% NaCl for 35 days



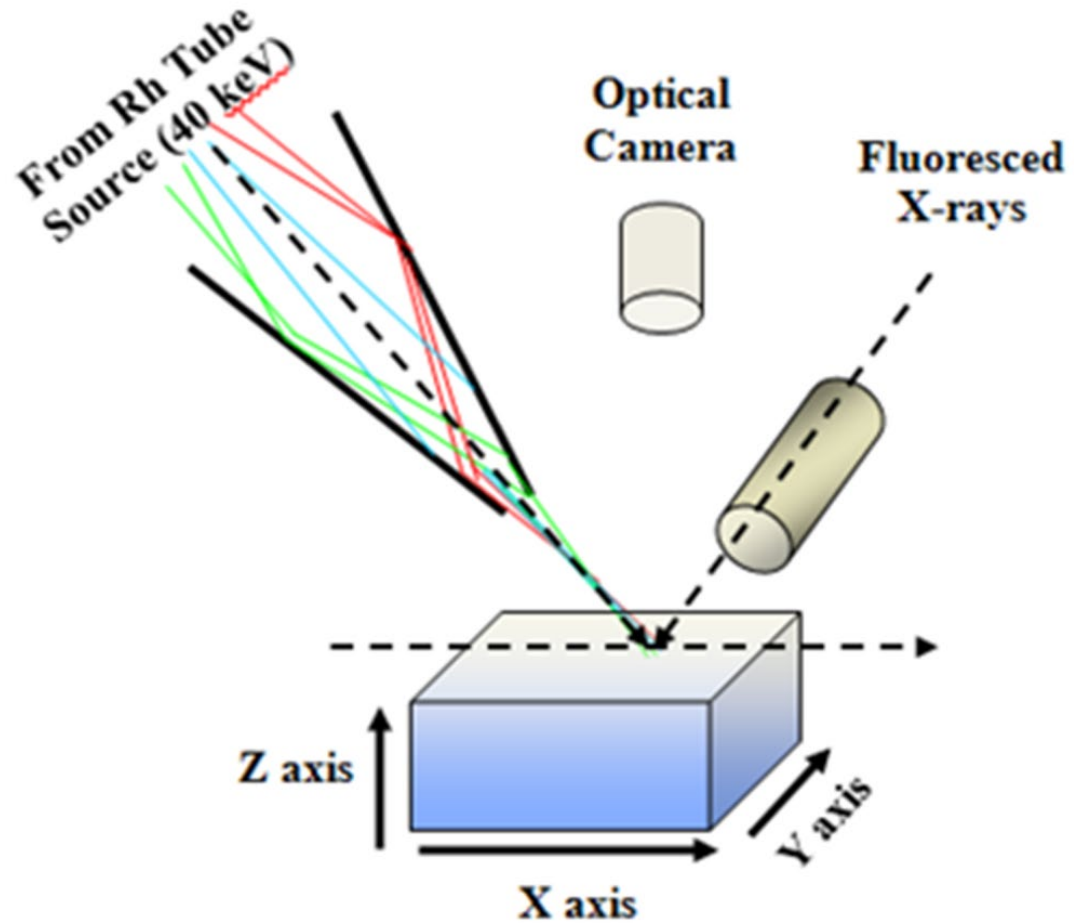
3. Mass change in 5% NaCl for 35 days



Discussion

- Concrete with a dense microstructure will gain less mass when wetting
- The trends are similar for initial water uptake and long term chloride penetration
- PAMS reduced fluid uptake by 25% when compared to no curing
- Wet curing for 3 days reduced fluid uptake by ~ 70%
- Very little difference between the fluid penetration for 3, 7, 10, and 14 days of wet curing

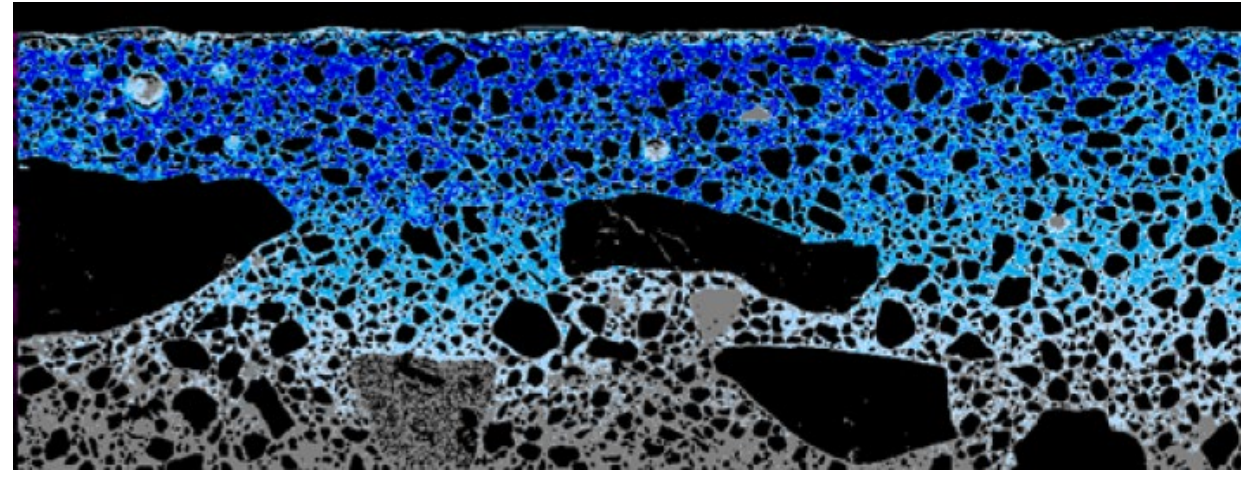
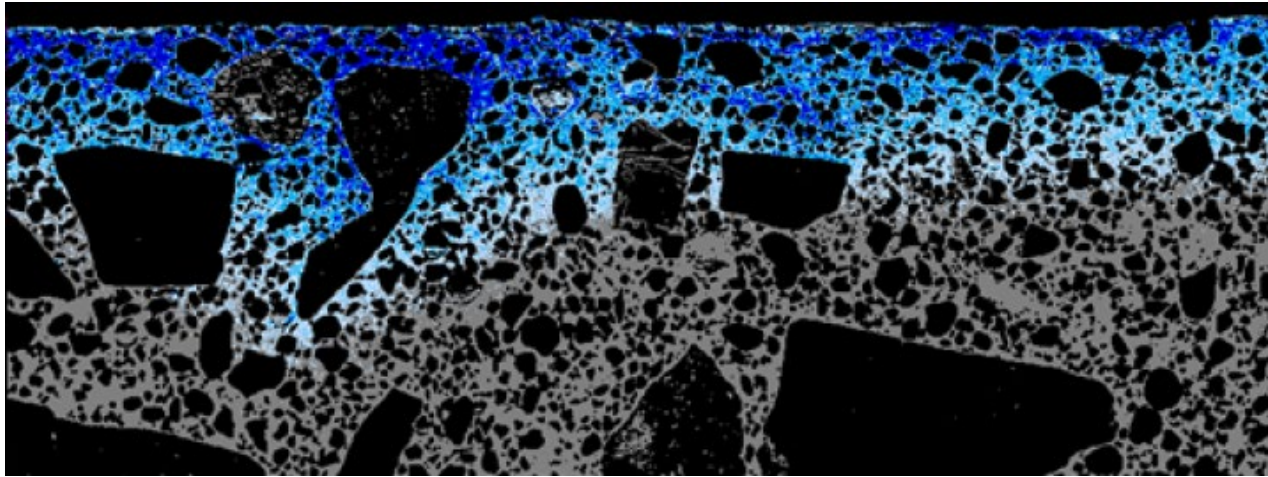
μ XRF technique description



Khazadeh Moradillo, Sudbrink and Ley, 2016

“Good”
Curing

“Not as Good”
Curing



Black
regions are
aggregates



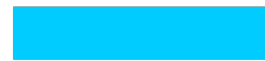
Paste: Cl <300 ppm

none



Paste: 0.3K < Cl <2K ppm

Low



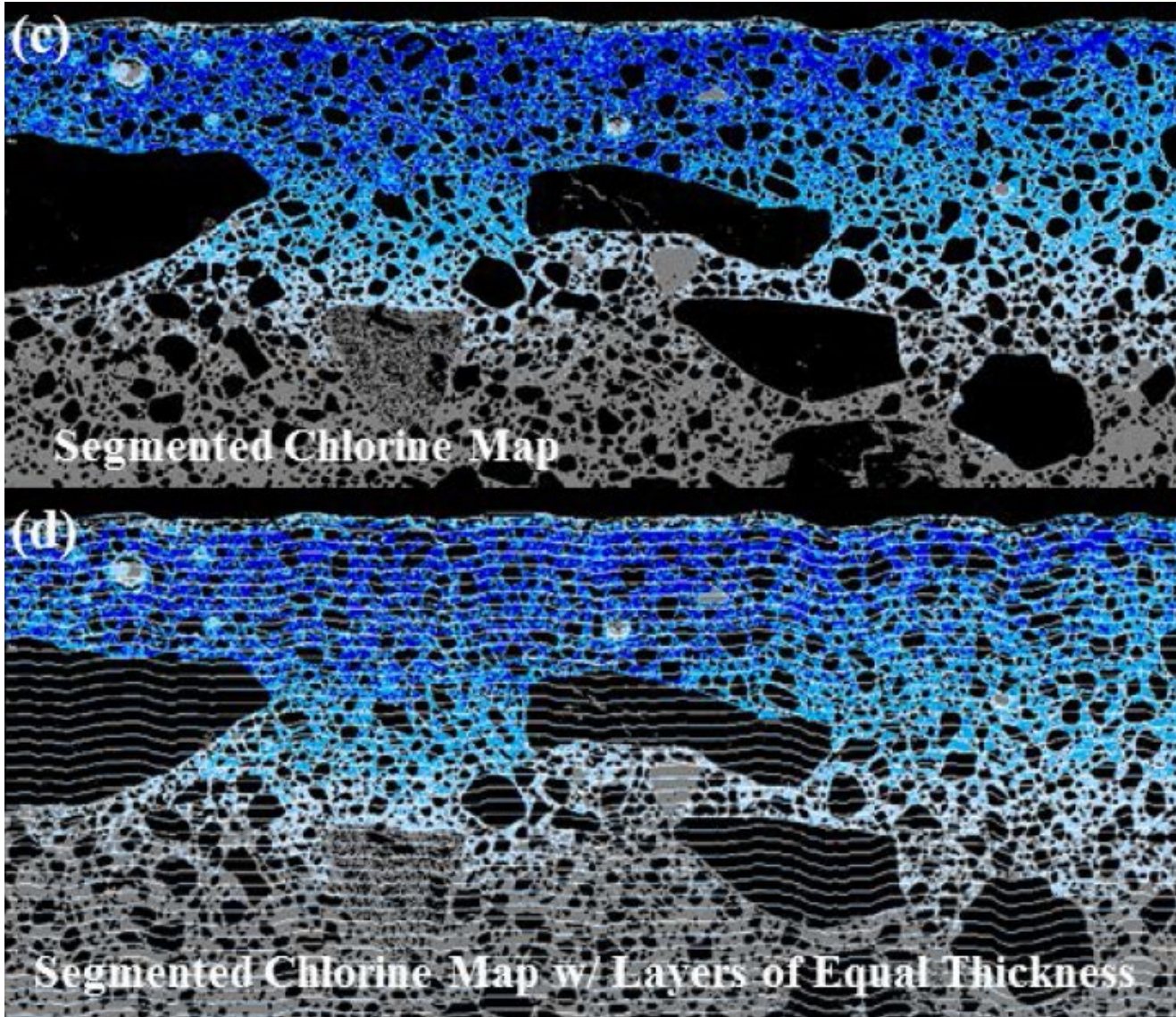
Paste: 2K < Cl <6K ppm

medium



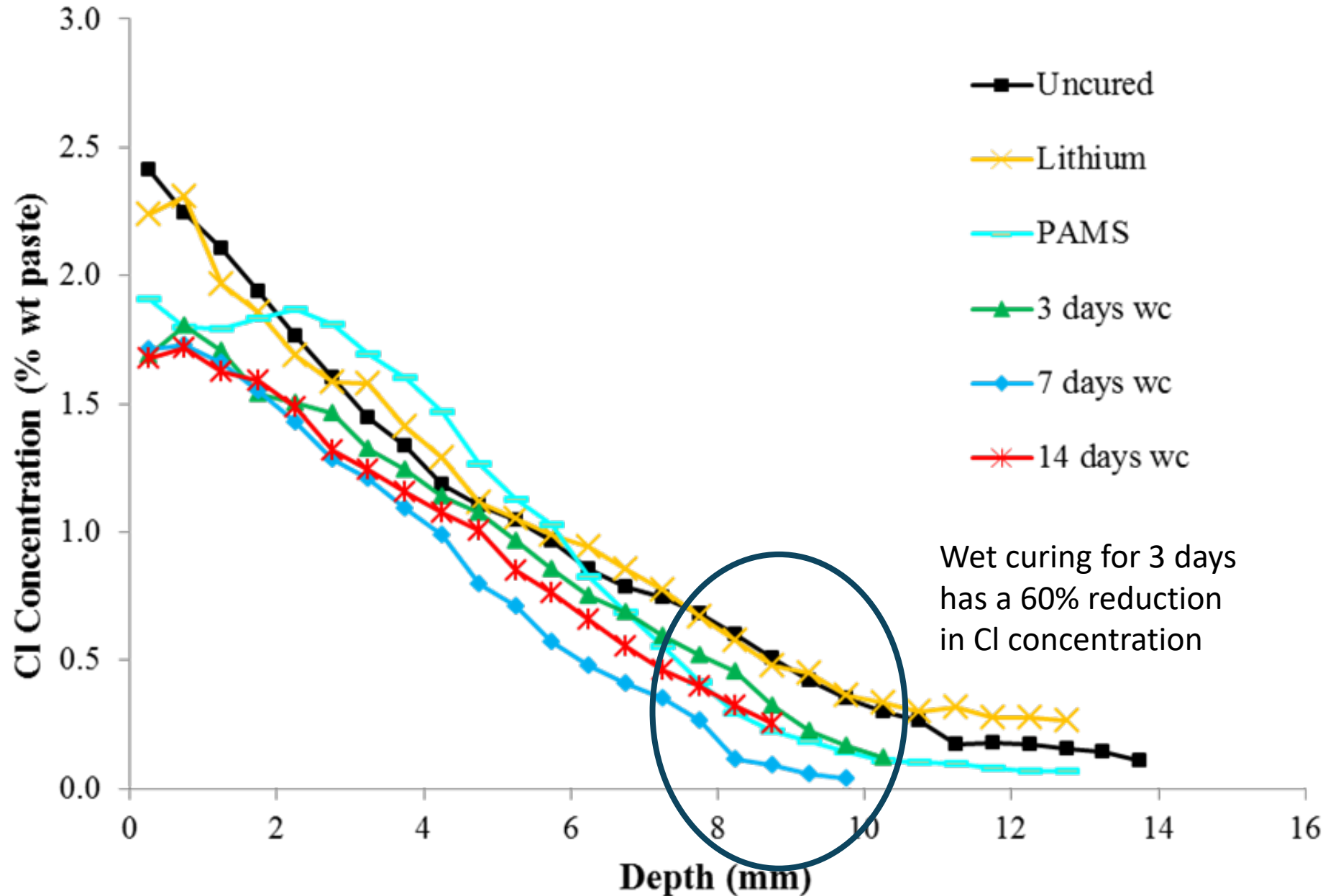
Paste: Cl > 6K ppm

high



We can digitally cut the sample into layers and find out how much is on each layer.

4. Chloride profile



Discussion

- The chloride penetration data had similar trends as the fluid uptake.
- No cure and lithium silicate performed similarly
- Wet curing performed better than the curing compounds
- There was about a 60% reduction in the chloride ingress for the 3 day wet cured sample compared to the sample that was not cured.
- ***This suggests you get approximately double the lifespan for chloride ingress from wet curing your concrete compared to not curing.***

What is the cost of curing?

	\$/sf	Percentage of Oklahoma bridge cost/sf
Burlap wet cure	0.62	0.47%
Premium curing compound	0.25	0.19%
Common curing compound	0.08	0.07%

← ***For ~ .5% of
your cost you
are doubling
the lifespan of
your concrete
against outside
chemicals***

COMPARING

CURING

METHODS

TYLER LEY, PE PHD.







Are those results with
Type I/II or Type IL?





I think they should be the same.



Not all **cements** are the same and so we shouldn't expect them to behave the same.

ASCC Project

16 - 1L cements

1 – I/II cement

Two plant with a Type I/II and 1L

The project ends in June.

Class Project

We decided to repeat the testing from our previous project with 6 Type IL cements.

We found something interesting and decided to test all 17 cements.

Concrete mixture design

0.45 w/cm

6.5 sacks (no SCMs)

Dolomitic Limestone

Natural Sand

Sieved to get a constant gradation

Water checked with the Phoenix

Mid Range WR

Keep in Mind

Two plants produced both a Type I and a Type IL.

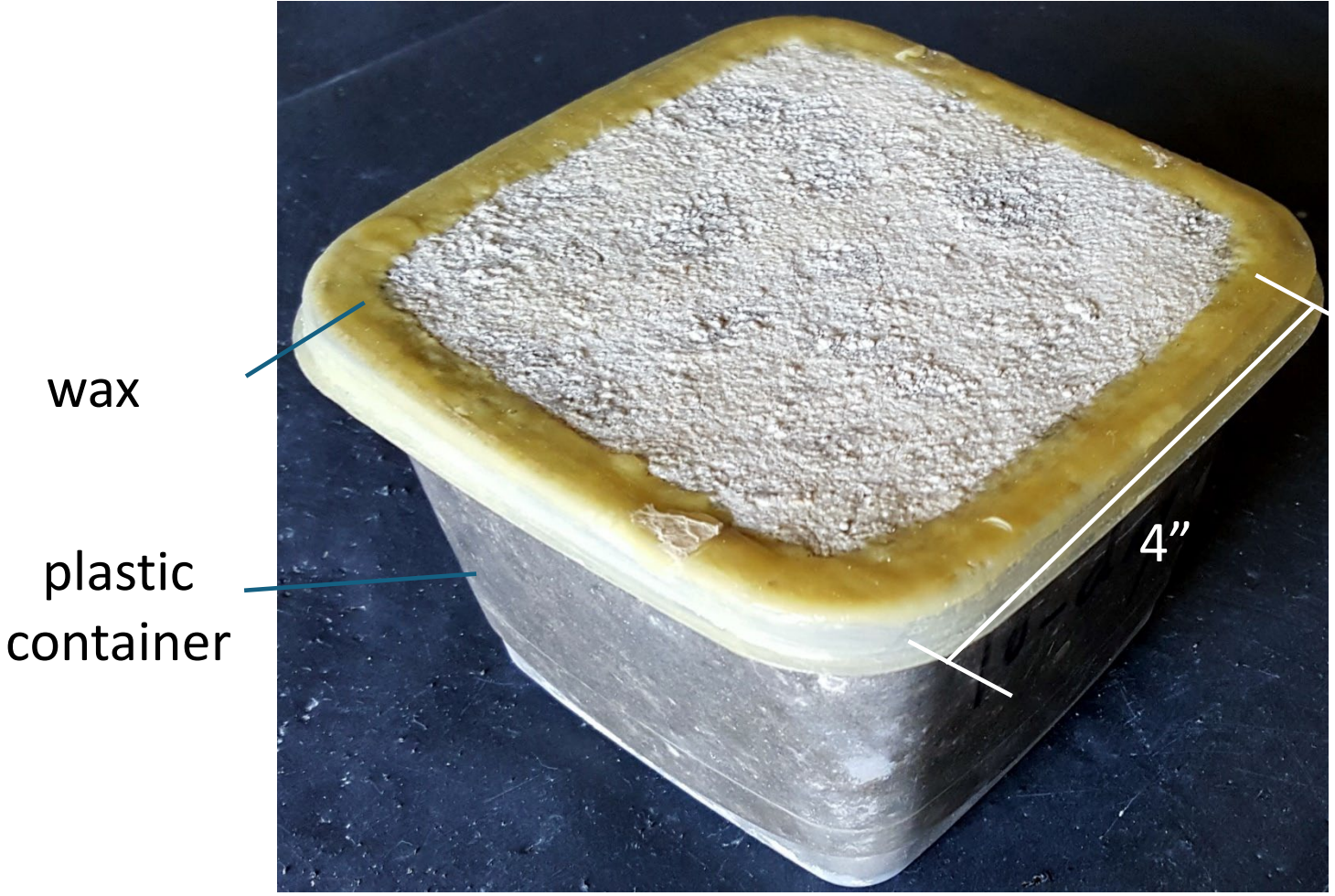
Type I/II – Blue

Type IL – Red

(For this work, we found another plant that produced a Type I and a Type IL)

How did we cure?

- No curing
- Wet curing for 5 days with wet burlap covered in plastic



What are we doing?

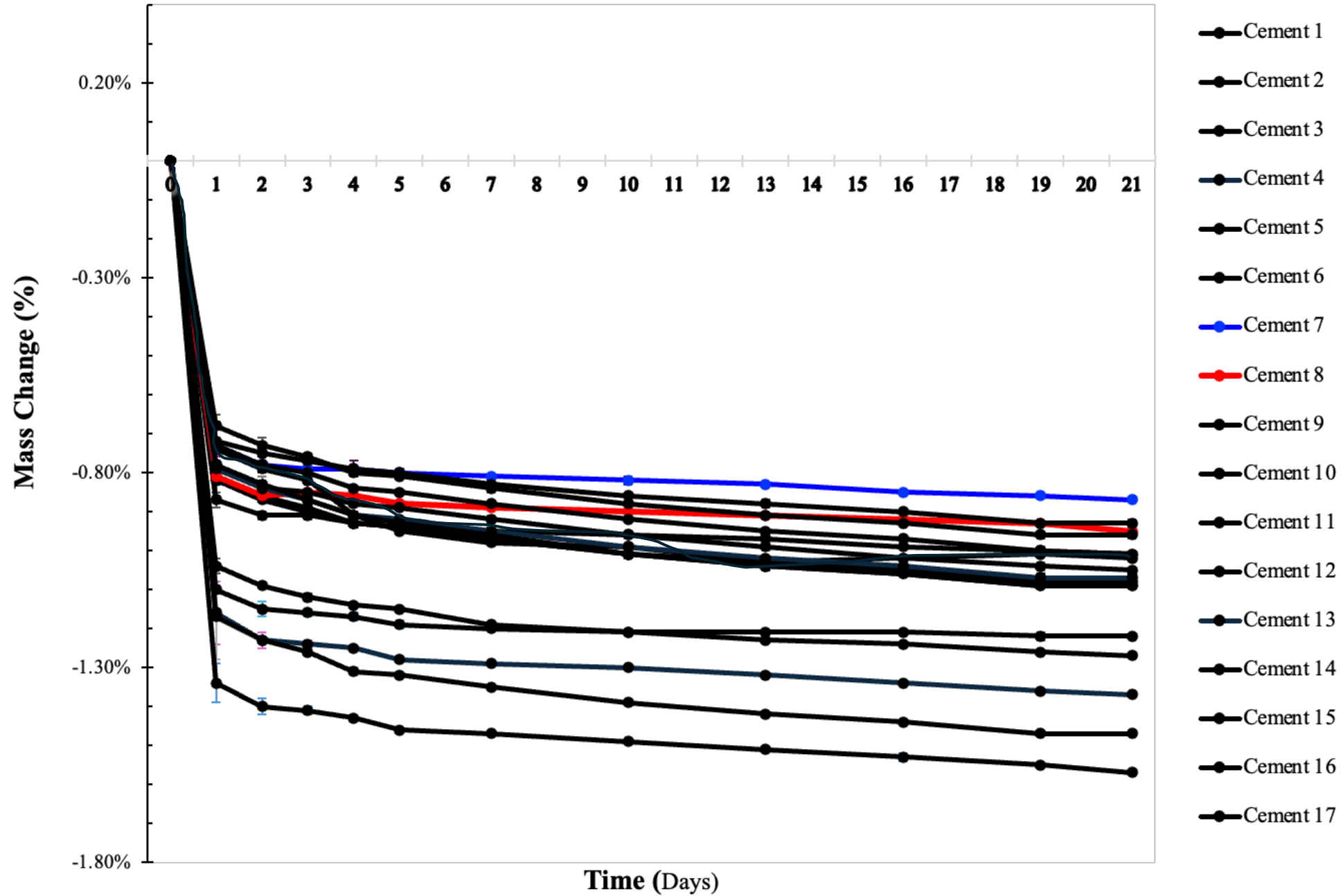
Step	Test	Details
1	drying	Mass change in 50% RH and 73°F for 22 days
2	water uptake	Mass change in lime water for 5 days

Step 1 – Dry the sample

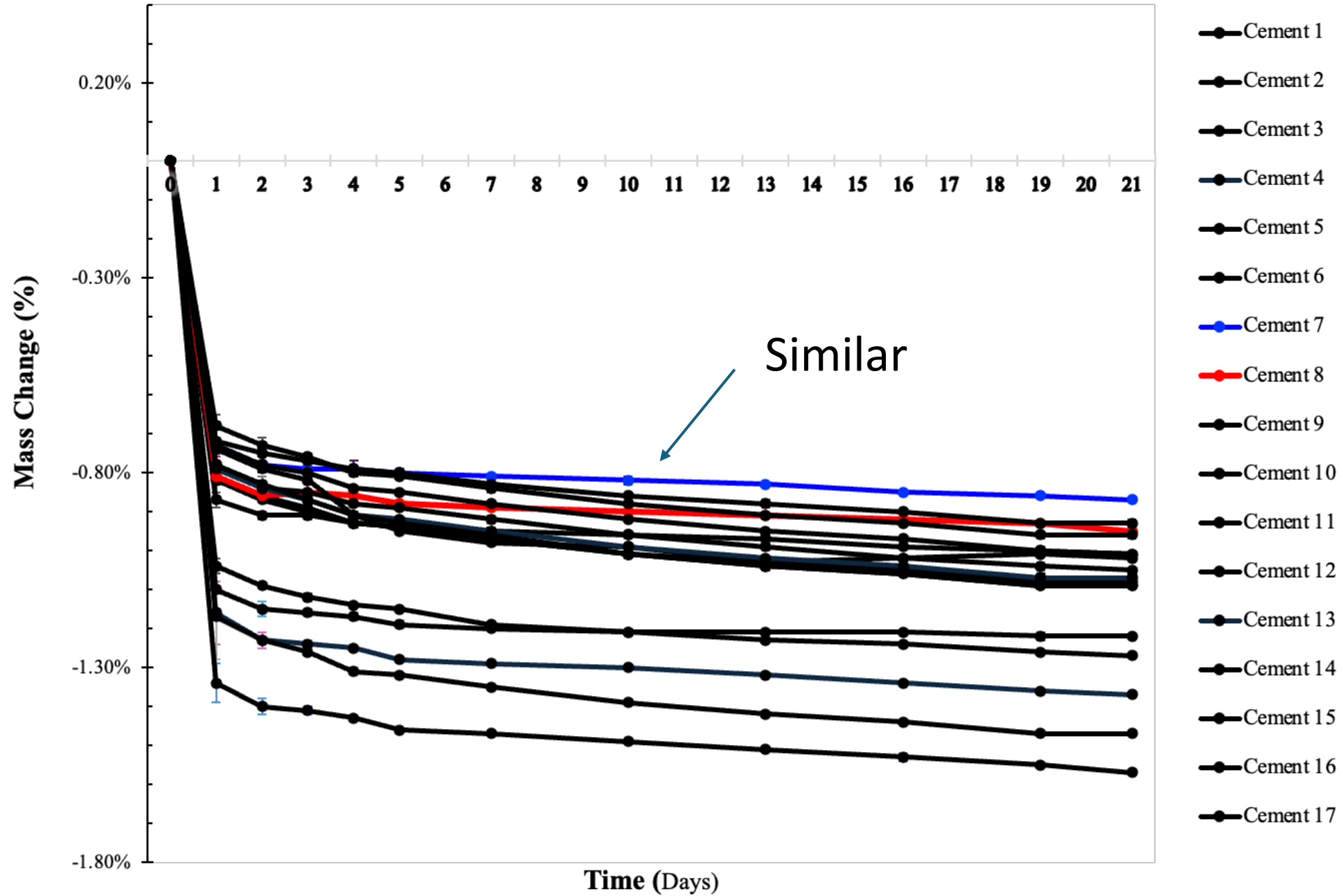
Measure mass change in 50% RH and 73°F for 22 days

No curing samples

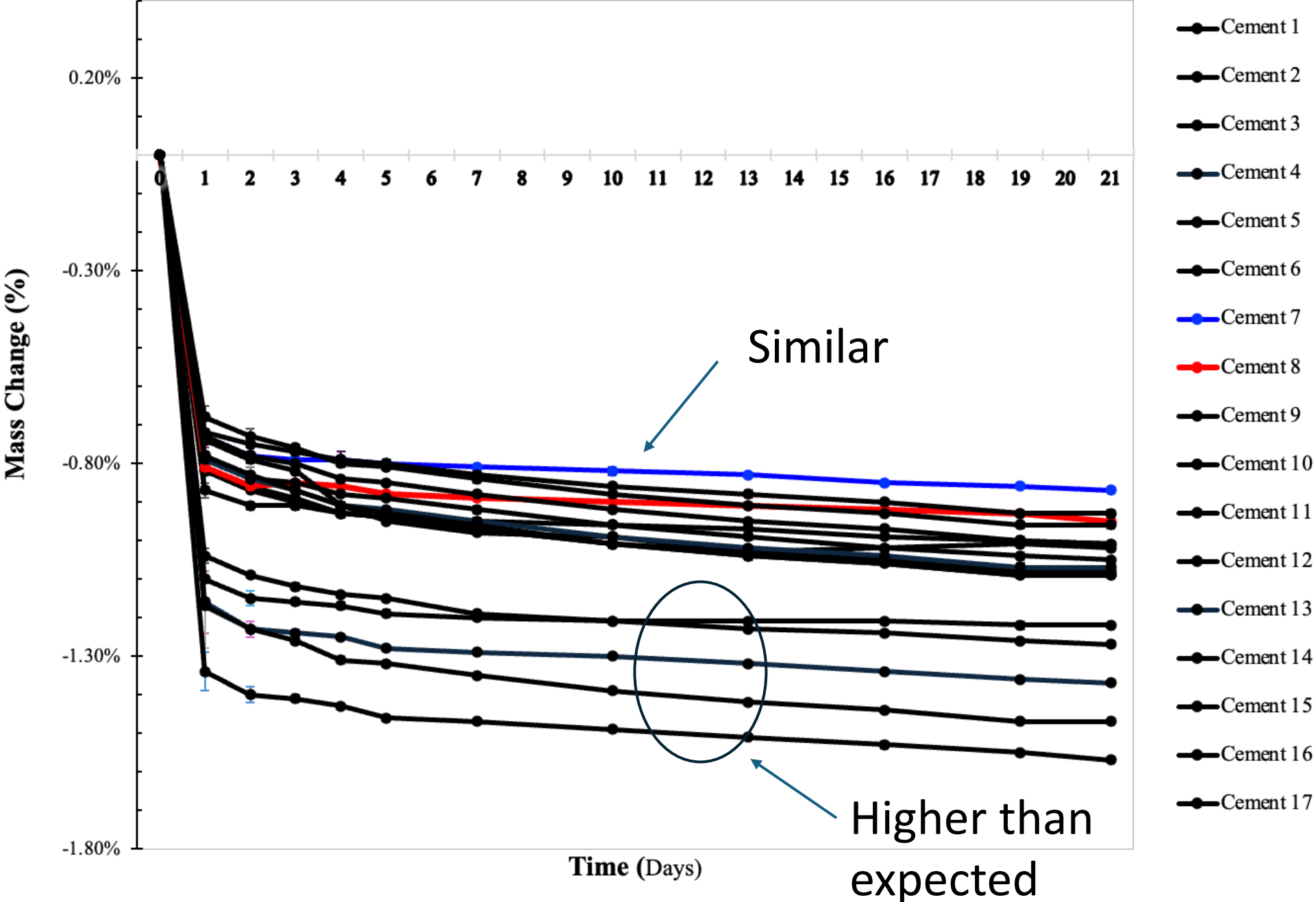
Mass Change Over Time - Uncured Samples



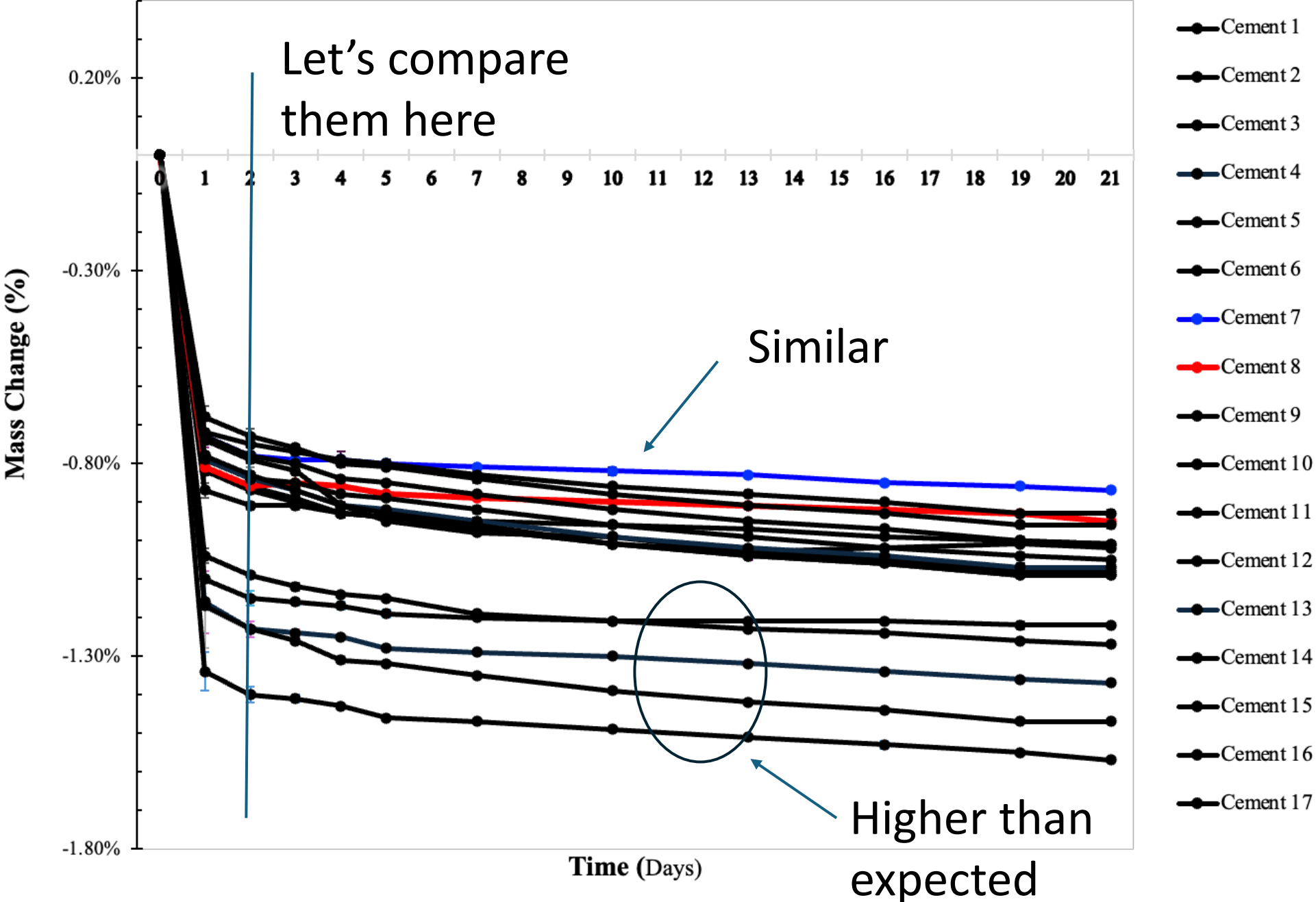
Mass Change Over Time - Uncured Samples

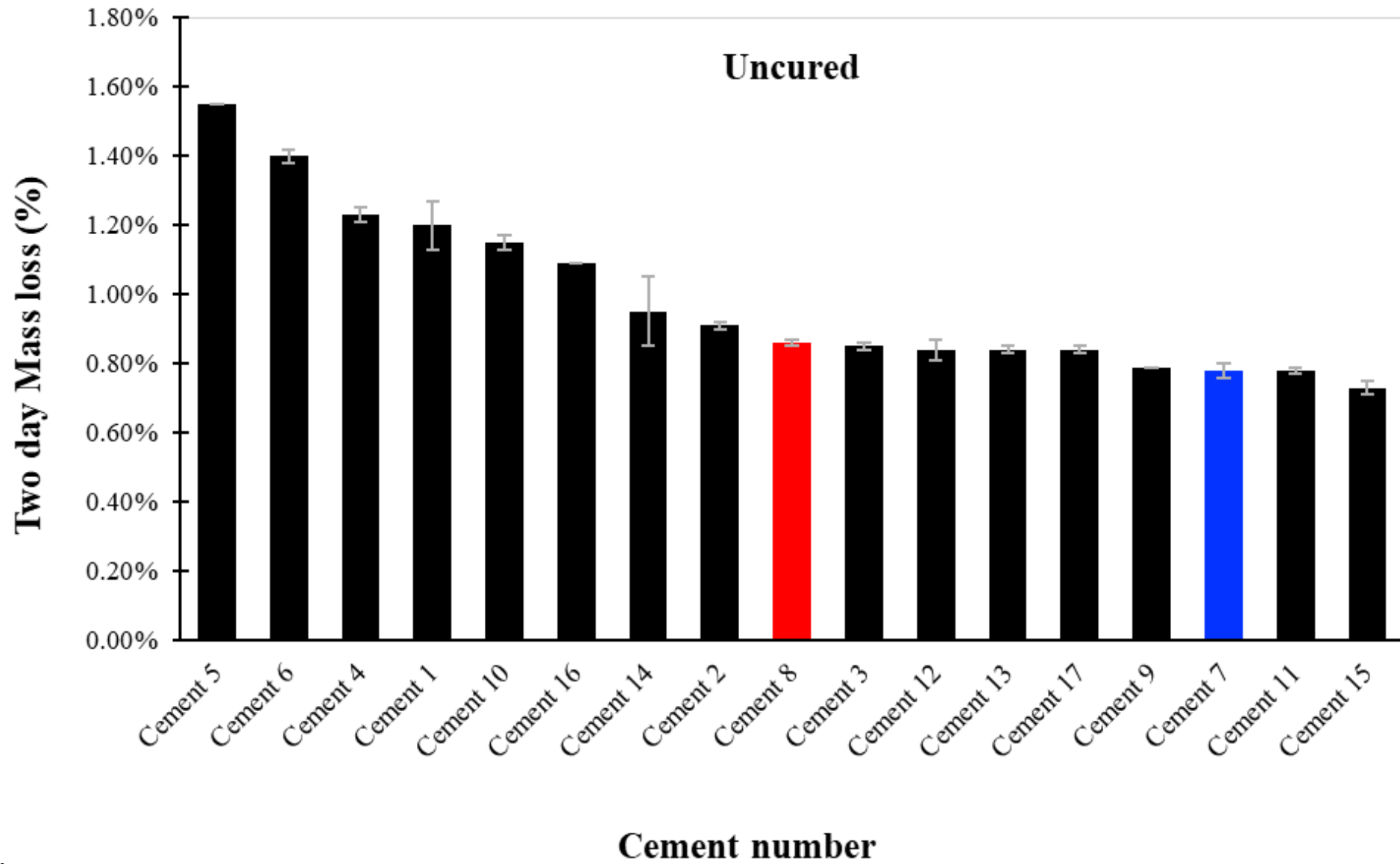


Mass Change Over Time - Uncured Samples

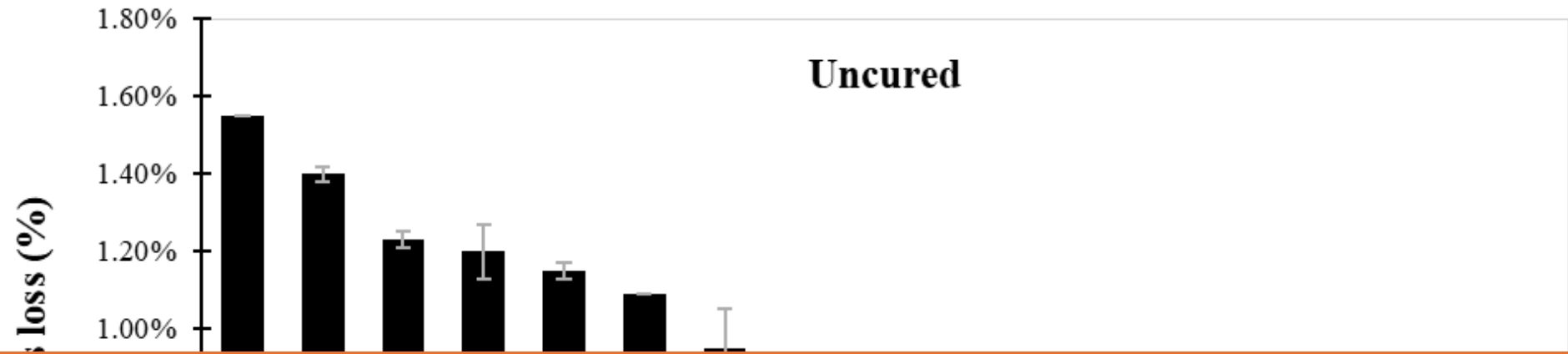


Mass Change Over Time - Uncured Samples

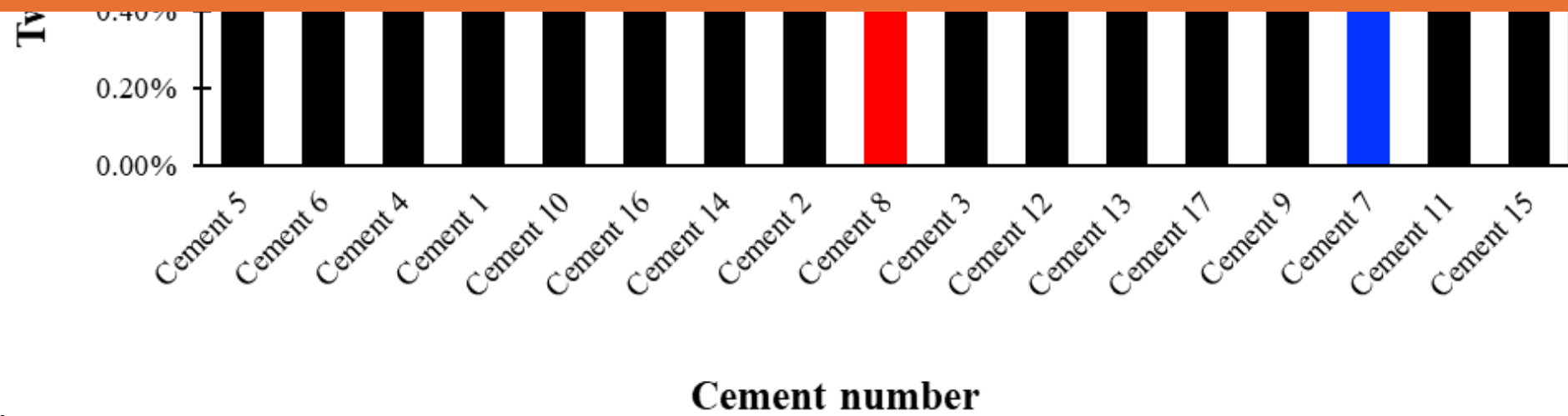




Red – Type II
Blue – Type I/II
at same plant

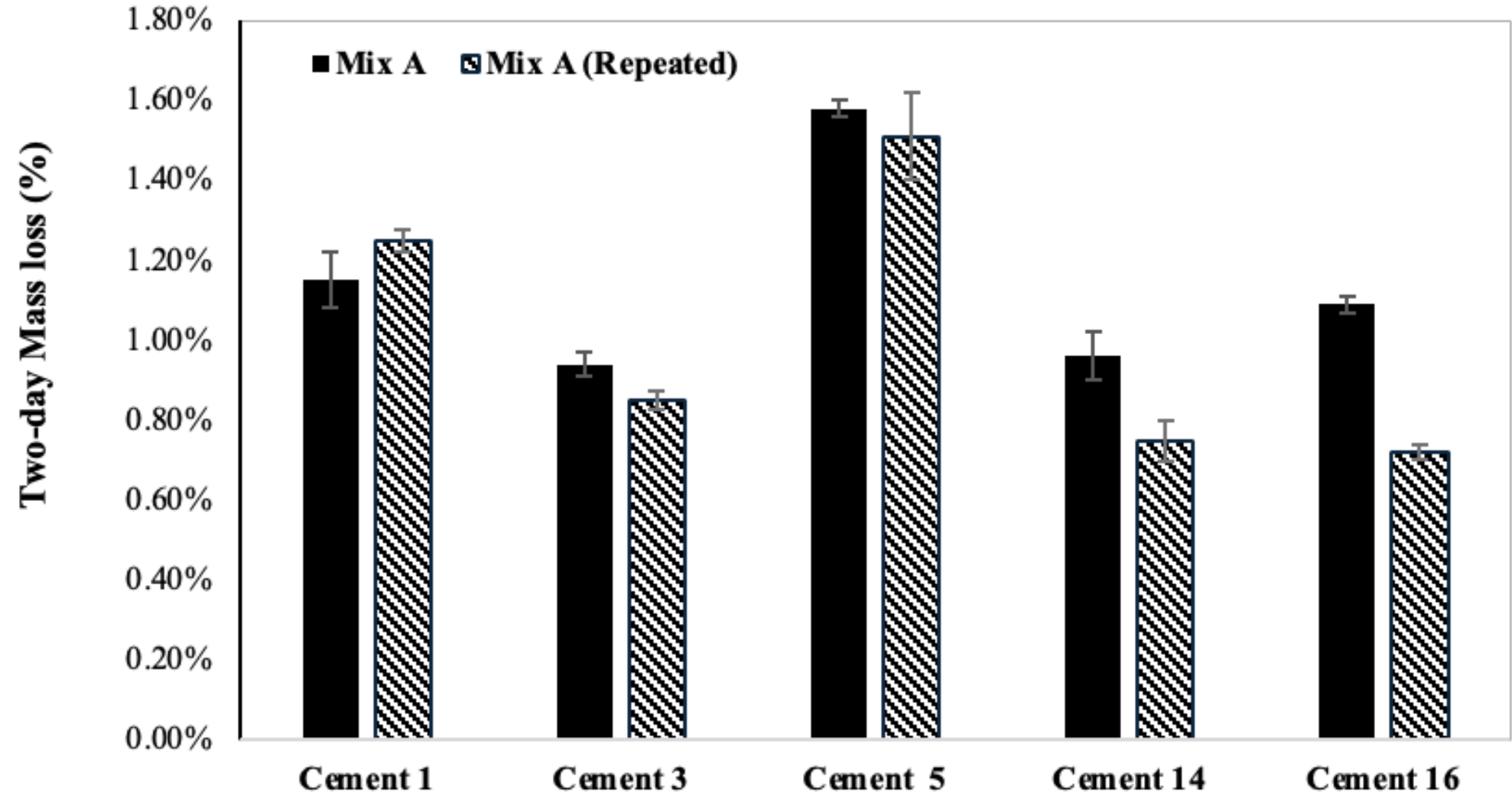


Have you replicated this?



Red – Type II
 Blue – Type I/II
 at same plant

Uncured



Discussion

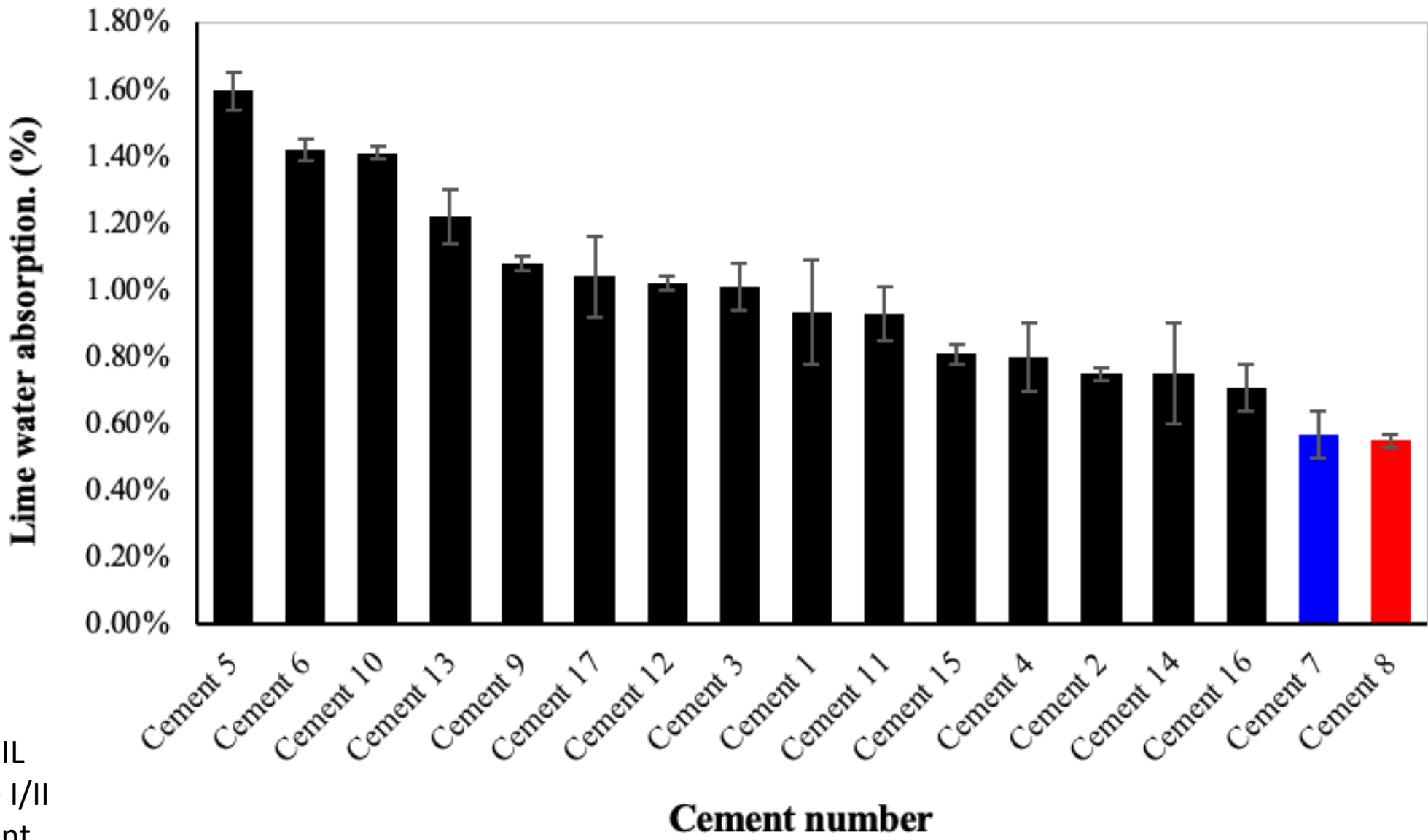
In poor curing conditions, 30% of the cements show a higher amount of mass loss.

This also occurs in replicate testing.

Step 2 – Place concrete in lime water

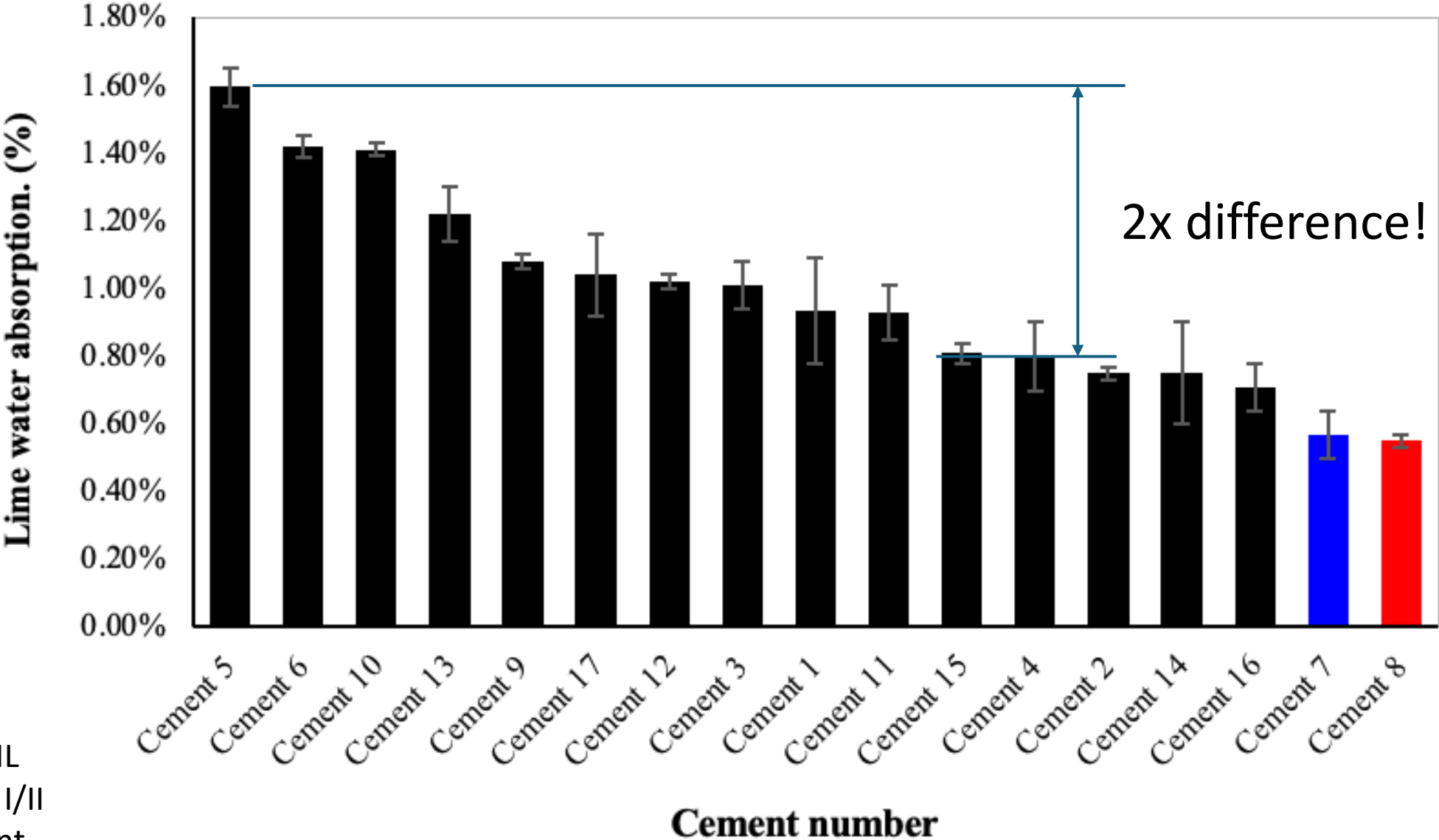
Measure mass change in lime water for 5 days

Uncured



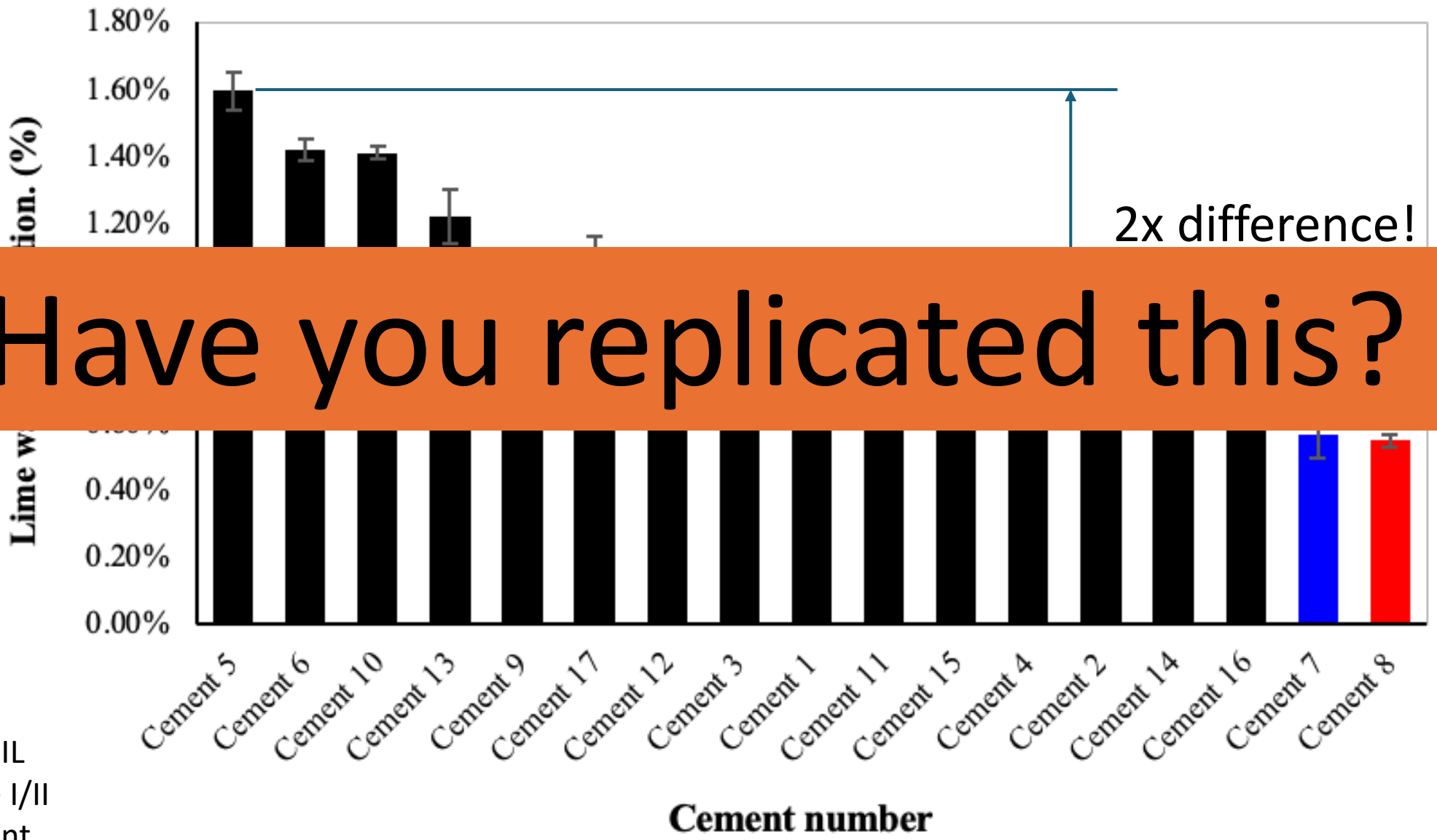
Red – Type II
Blue – Type I/II
at same plant

Uncured



Red – Type II
Blue – Type I/II
at same plant

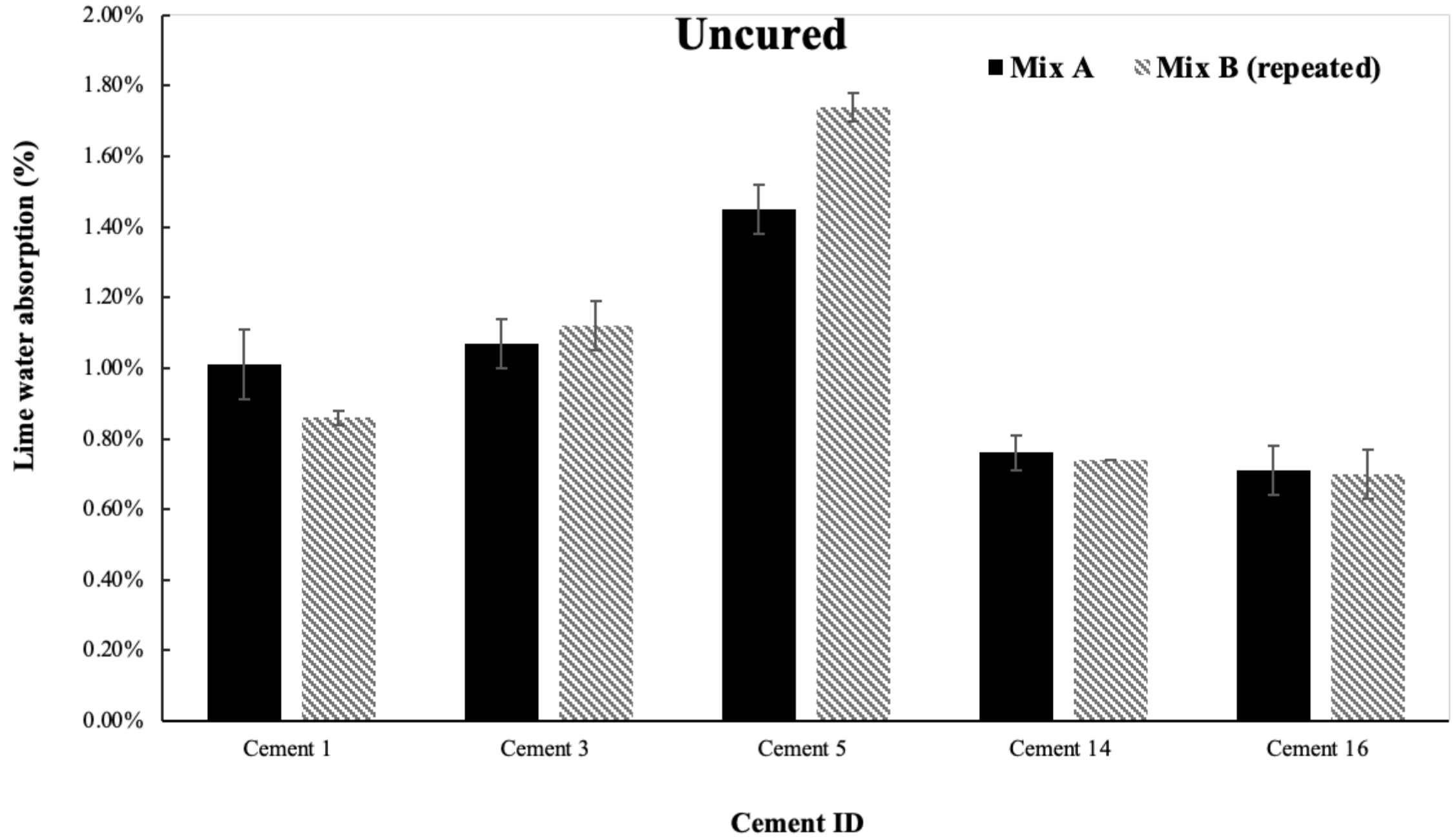
Uncured

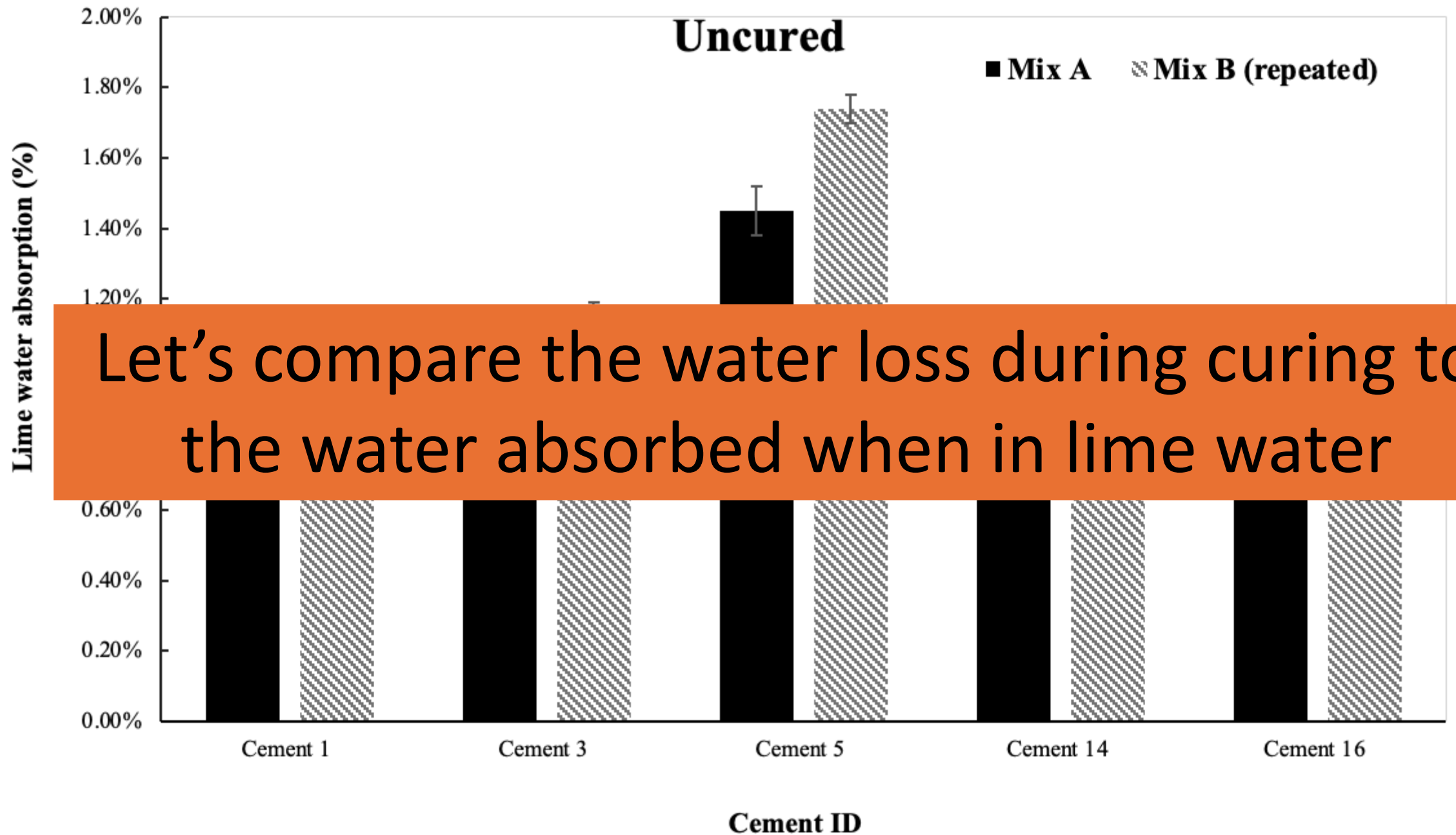


Have you replicated this?

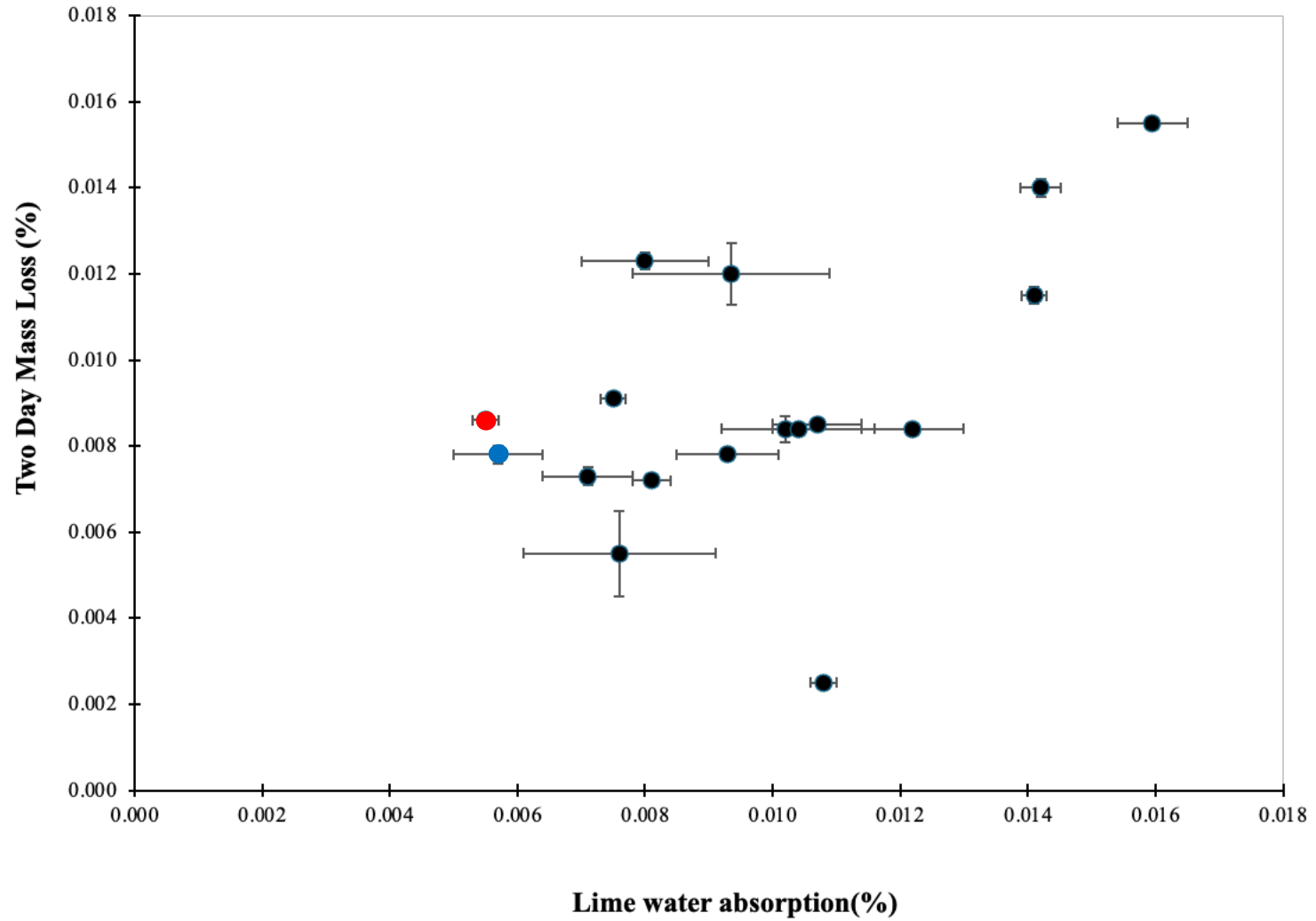
Red – Type II
Blue – Type I/II
at same plant

Uncured





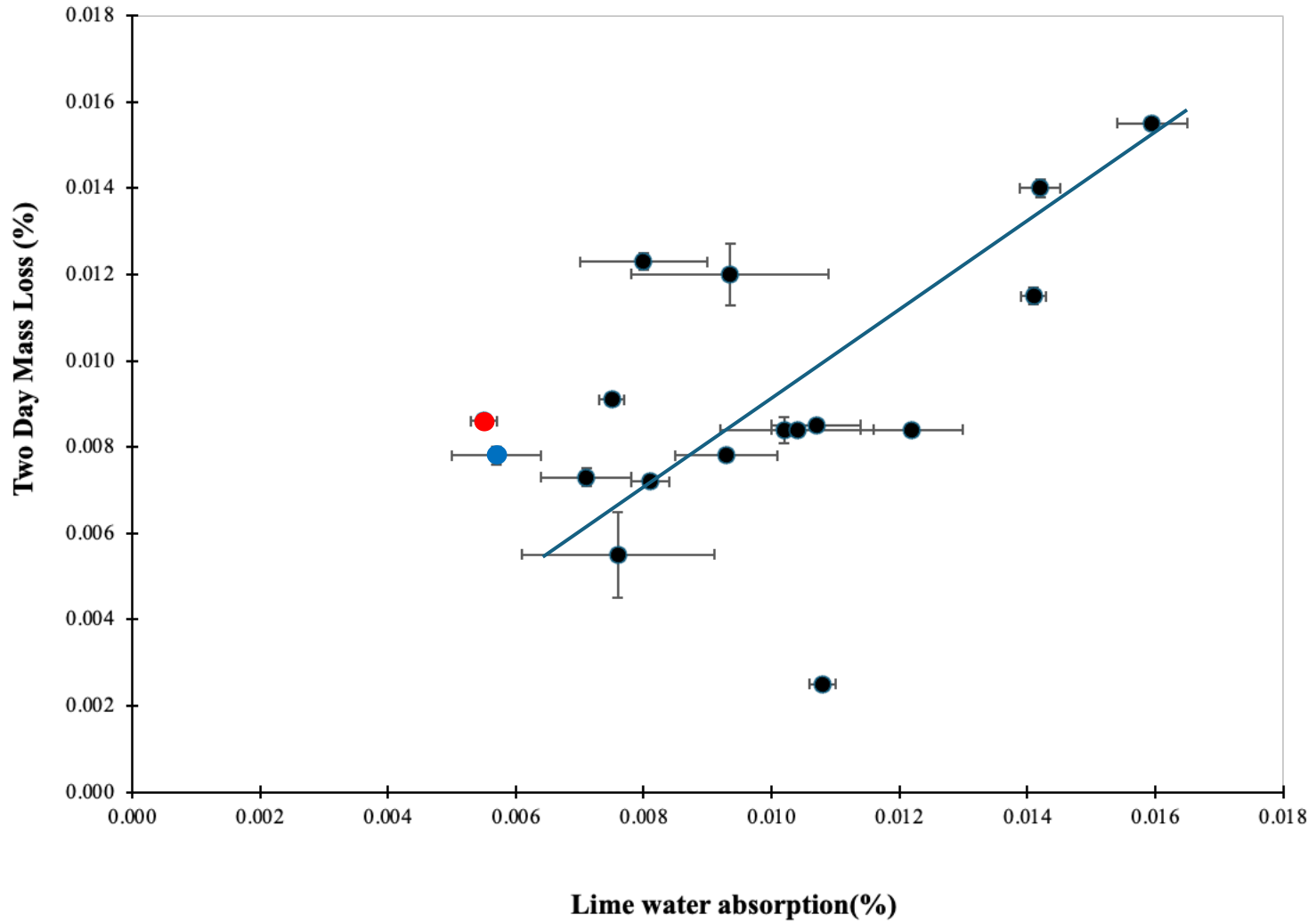
Uncured Condition



Water lost

Lime water gained

Uncured Condition



Water lost

Lime water gained

Discussion

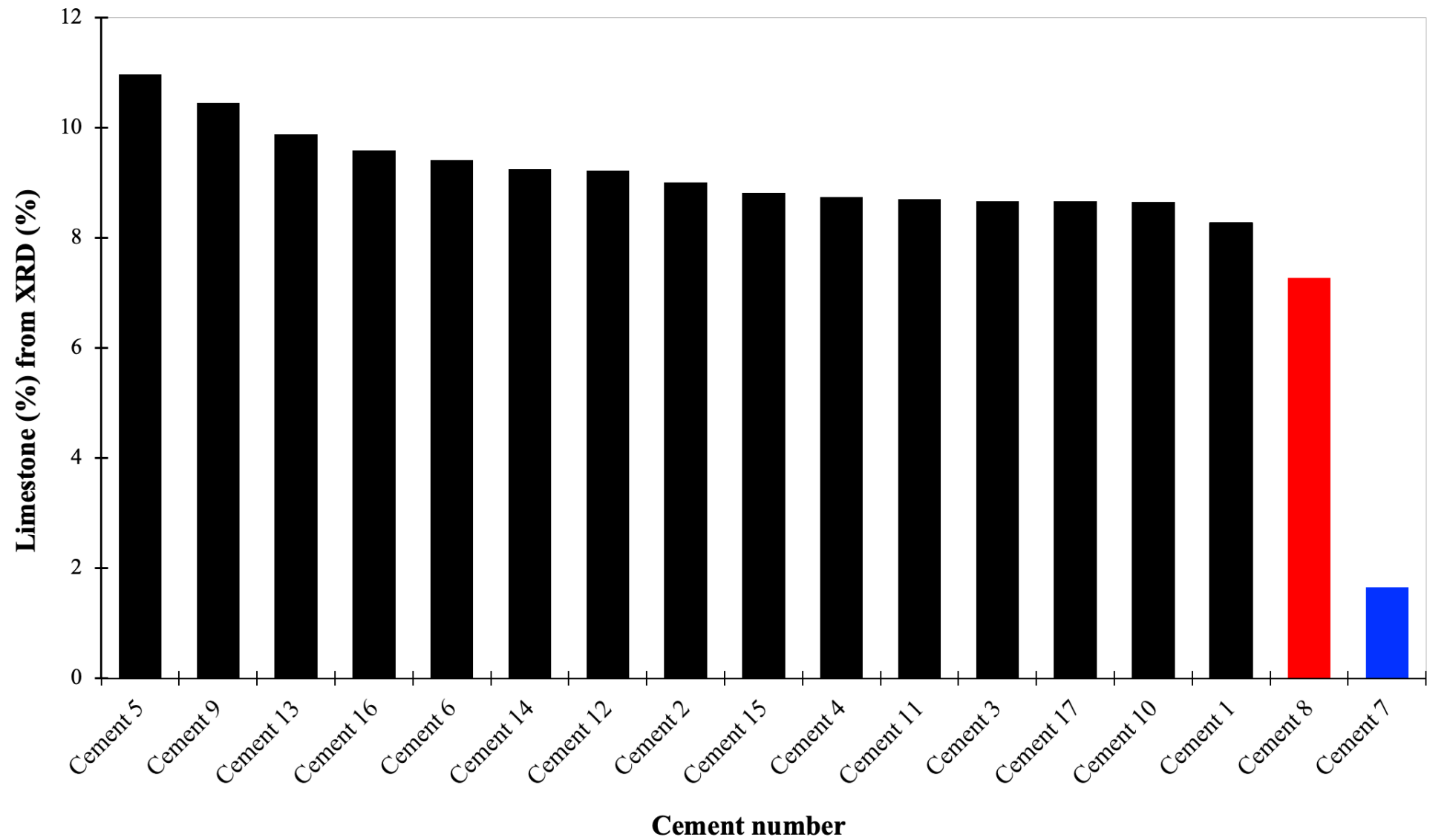
- There is a general trend that cements with high mass loss during drying also have higher absorption when placed in lime water.
- Samples with high moisture uptake after drying are more likely to draw outside chemicals into the concrete.

Discussion

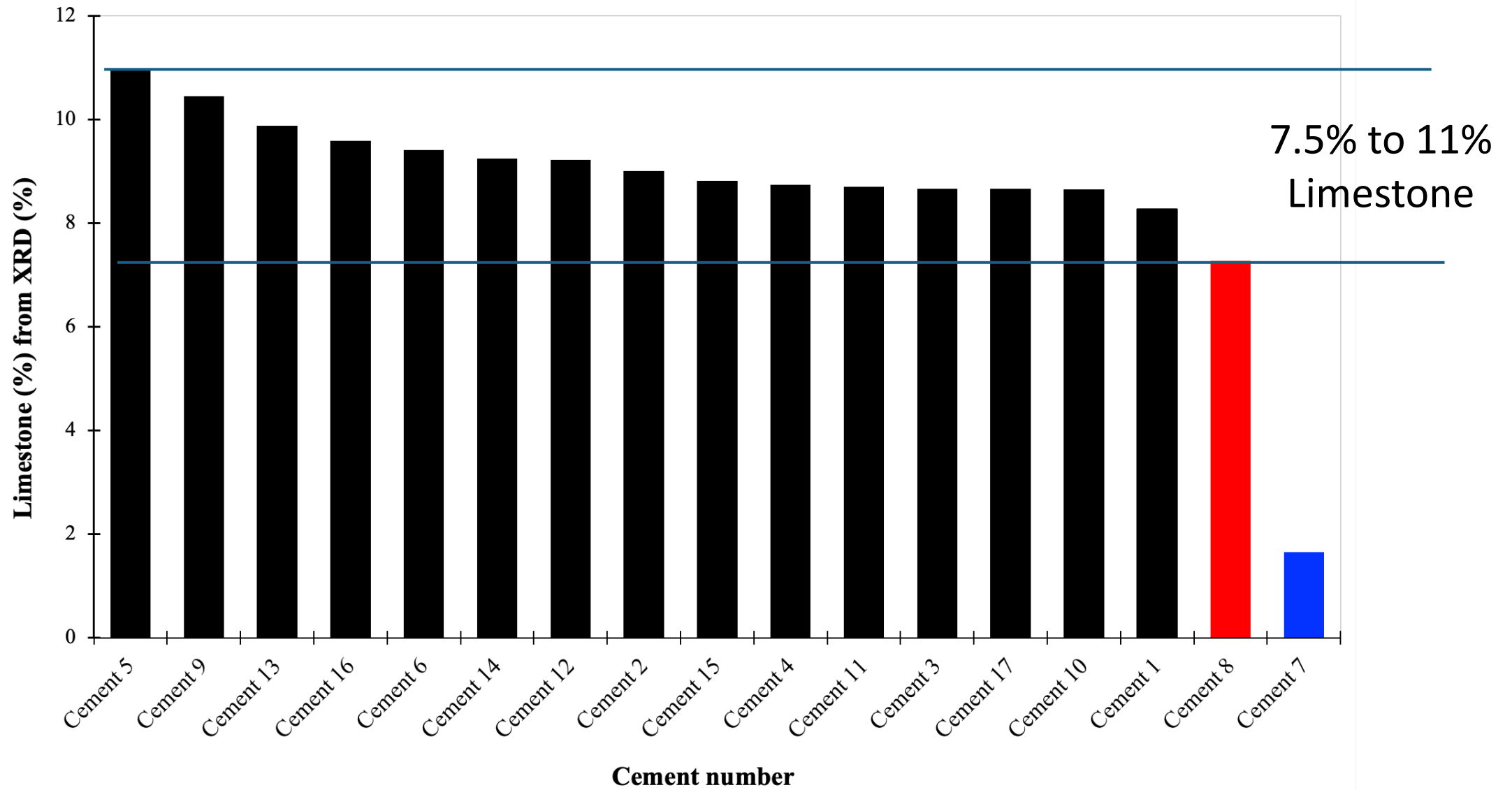
- There is a general trend that cements with high mass loss during drying also have higher absorption when placed in lime water.

Could the limestone cause this?

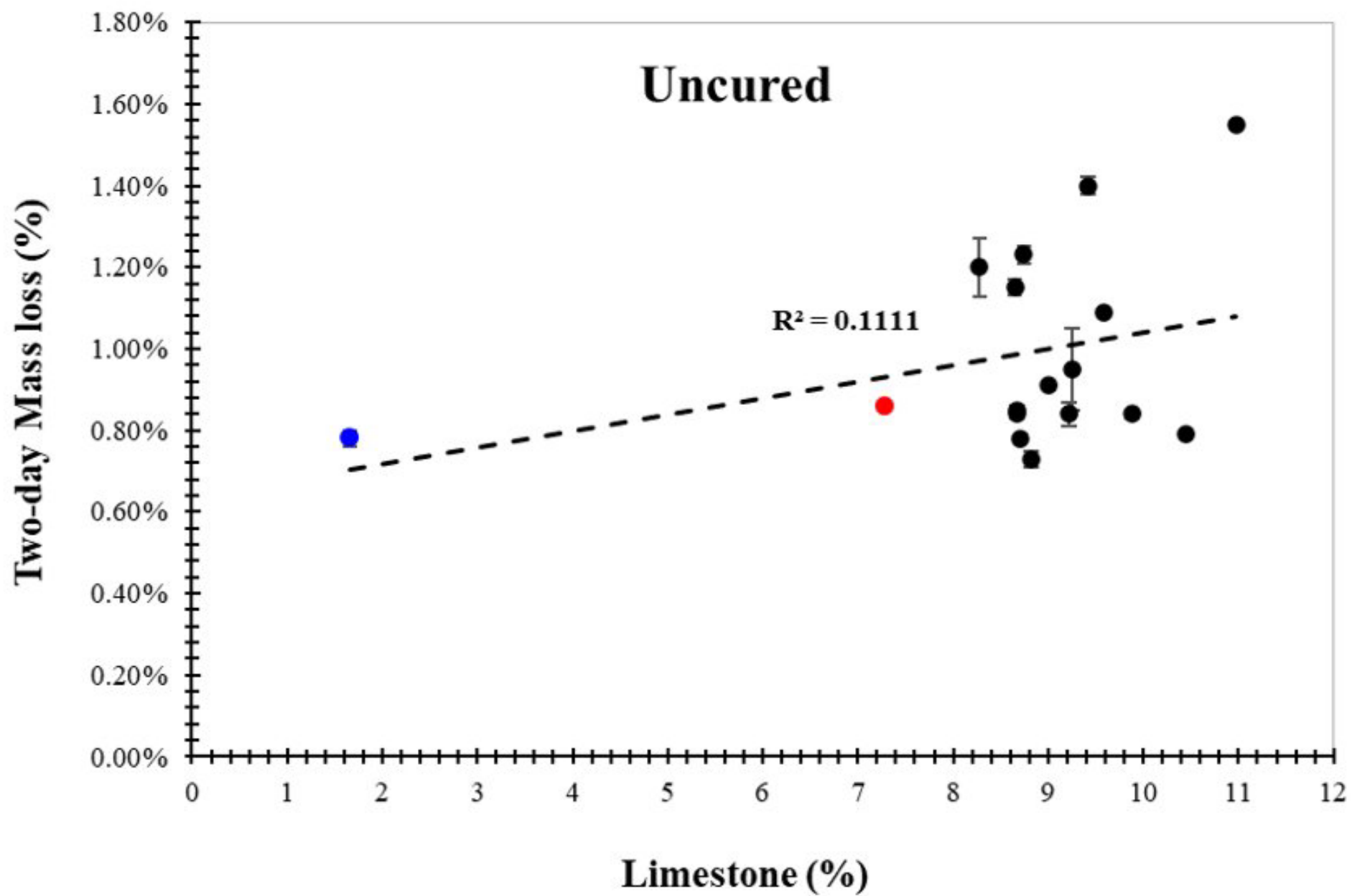
draw outside chemicals into the concrete.

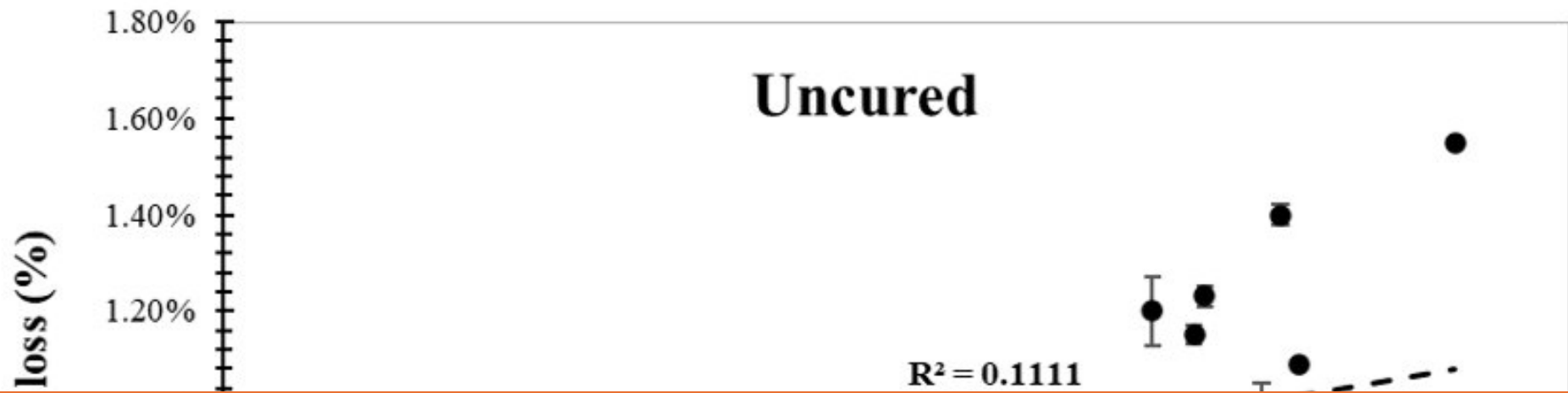


Red – Type II
Blue – Type I/II
at same plant

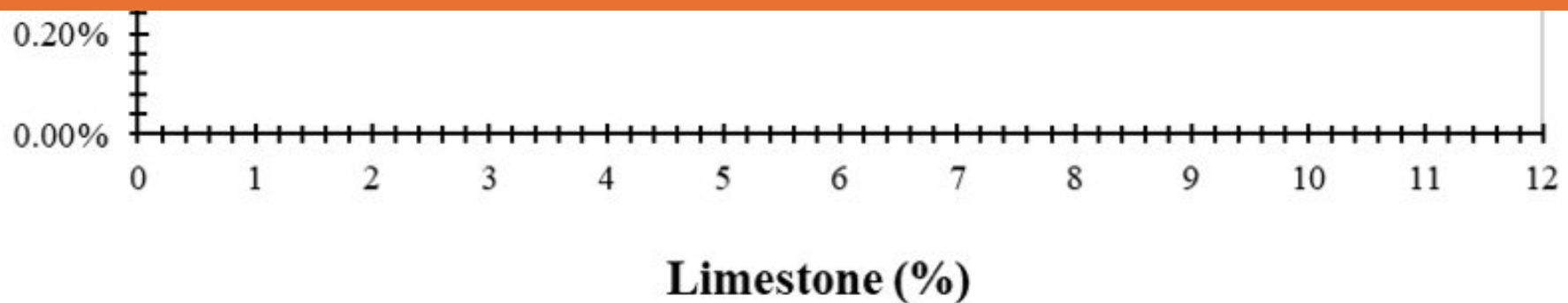


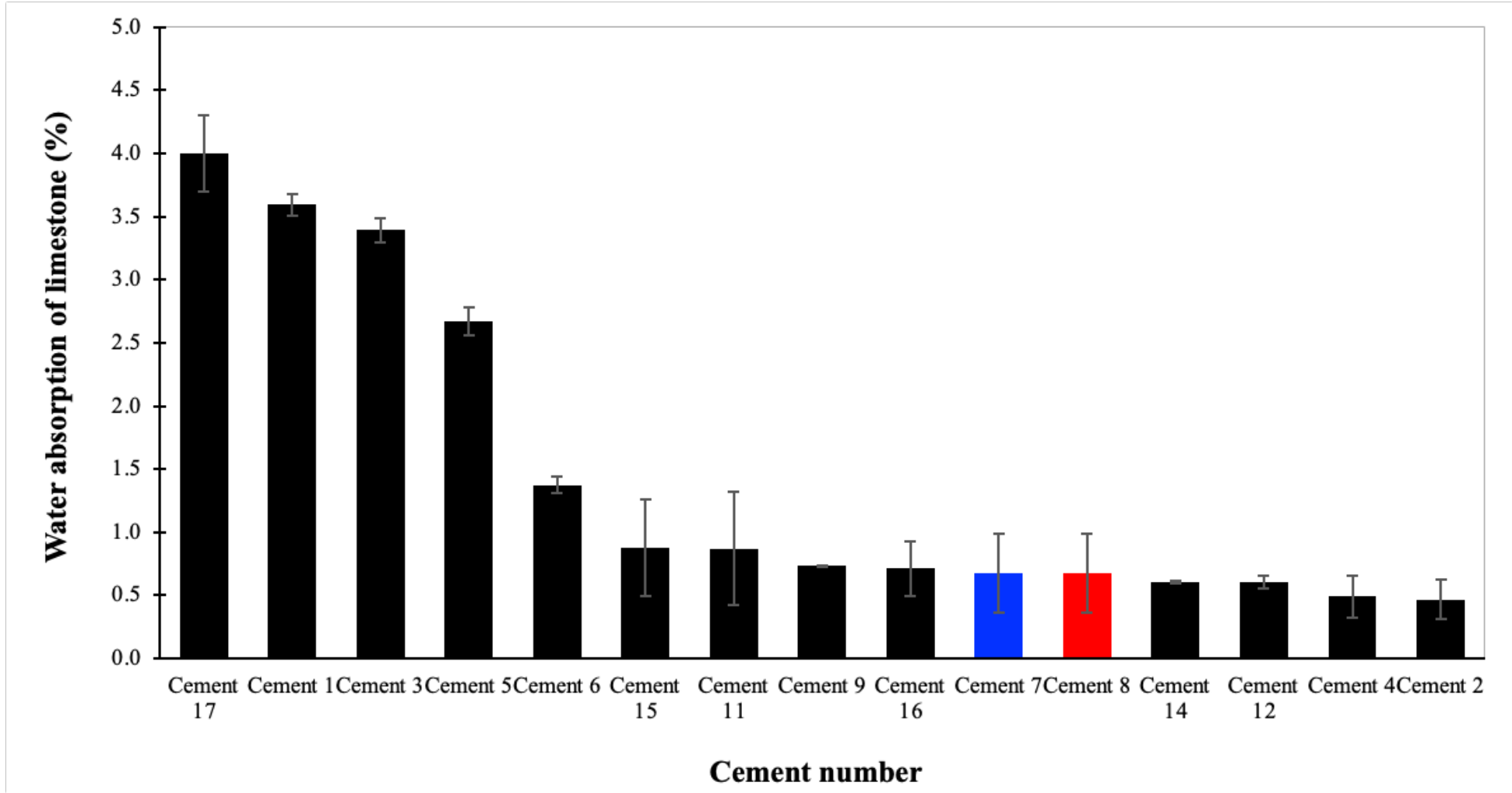
Red – Type II
Blue – Type I/II
at same plant



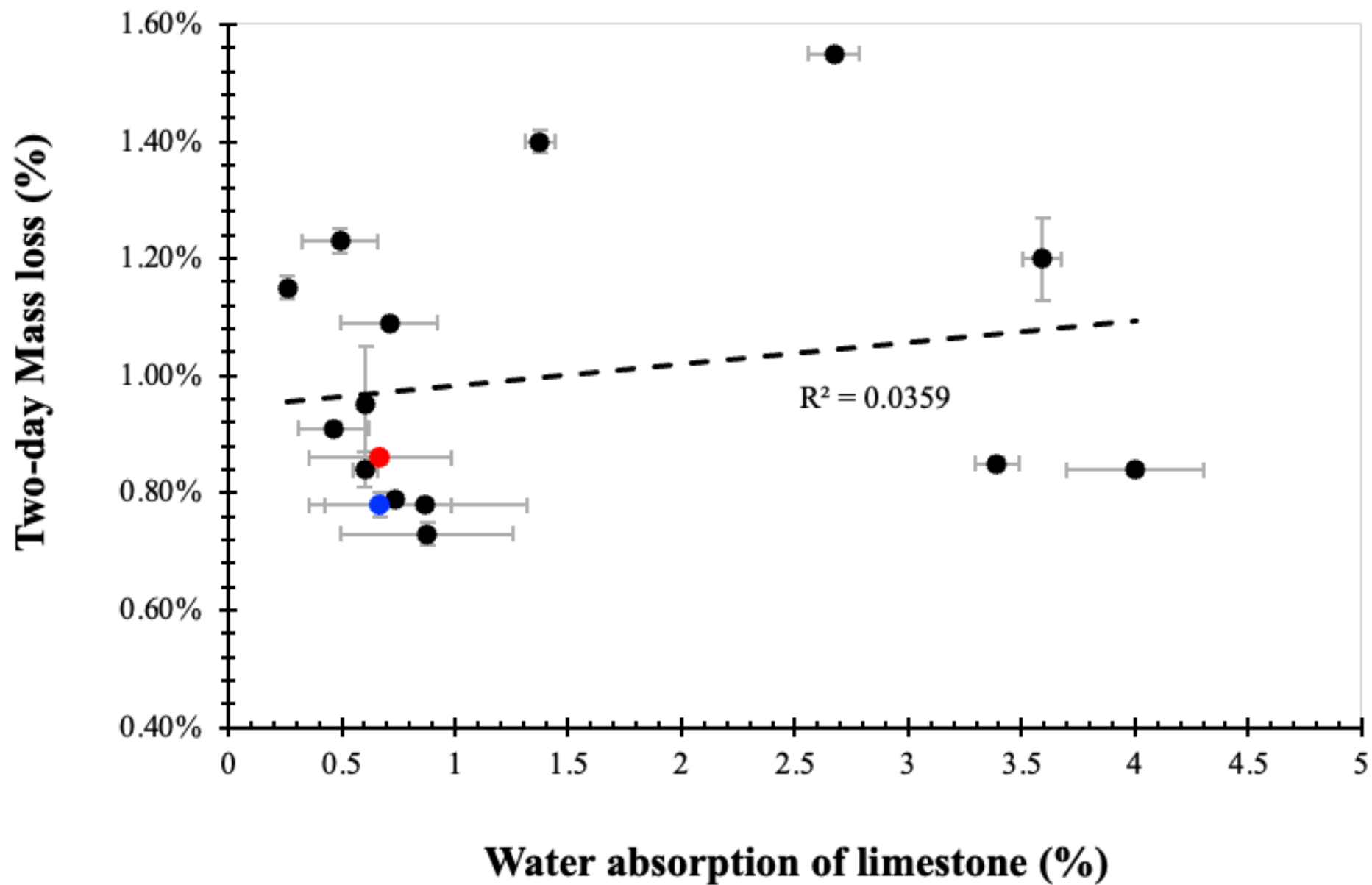


Could the absorption of the limestone cause this?

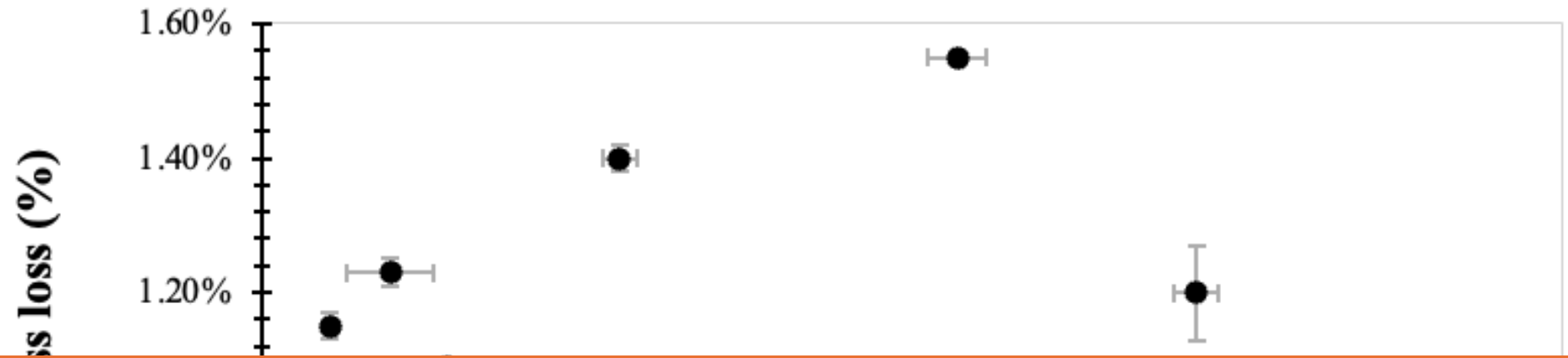




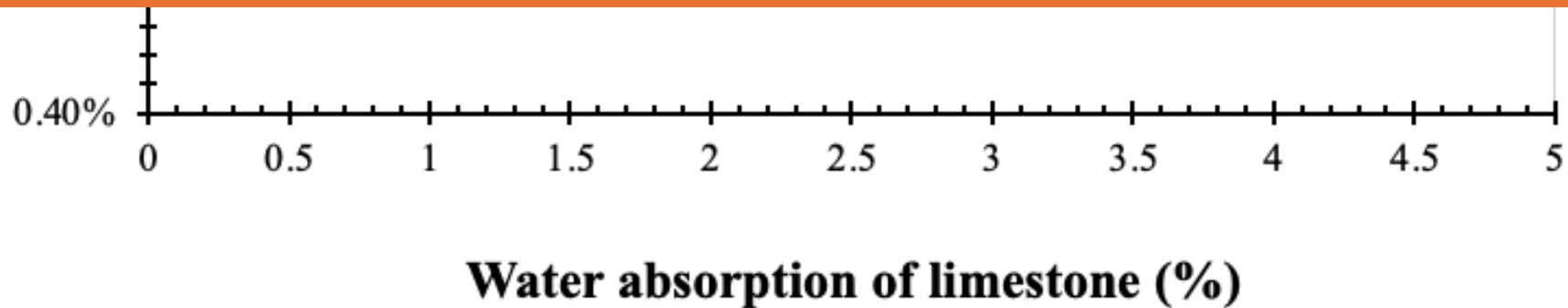
Uncured

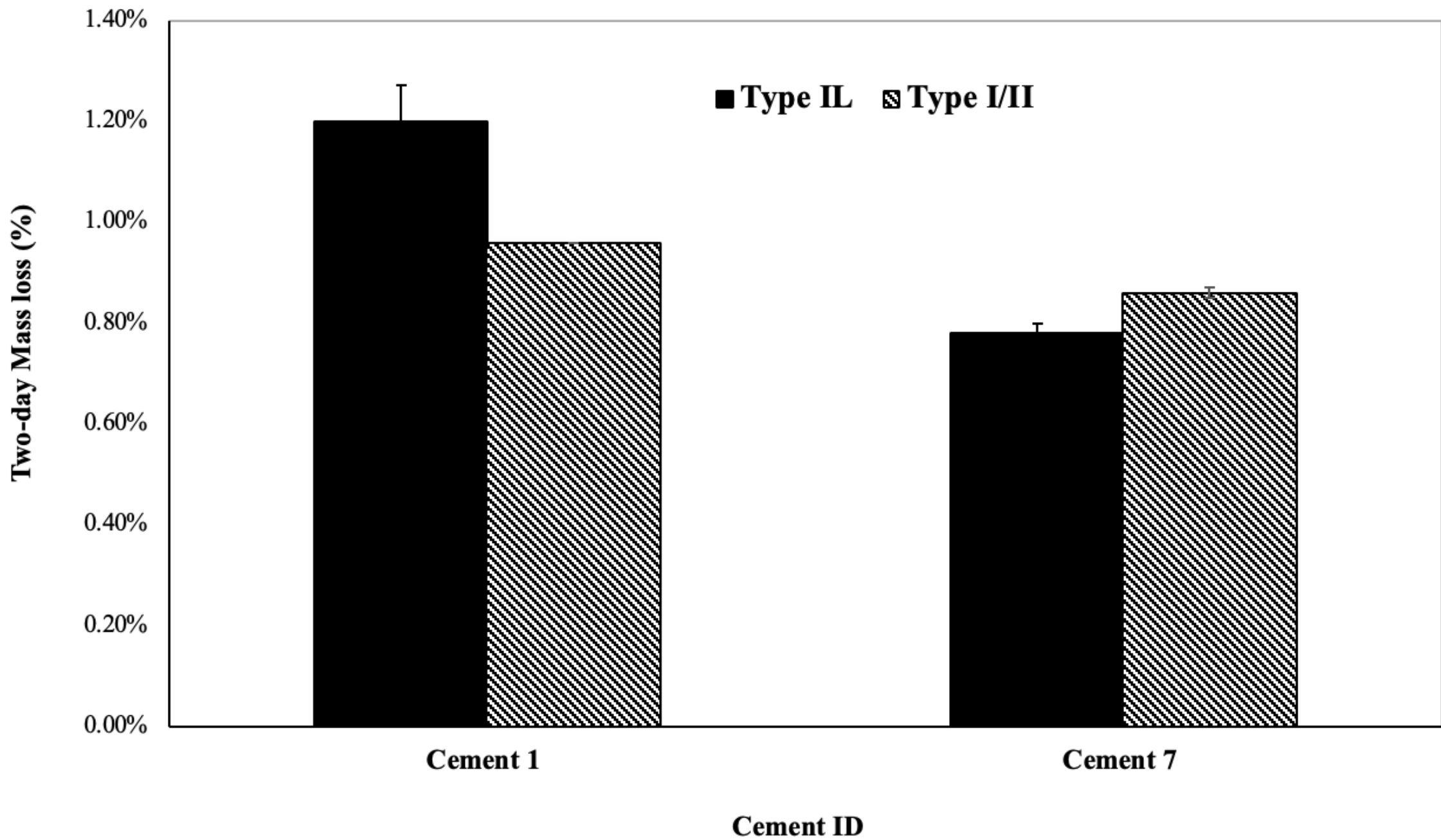


Uncured



Let's compare 1L and I/II from the same plant

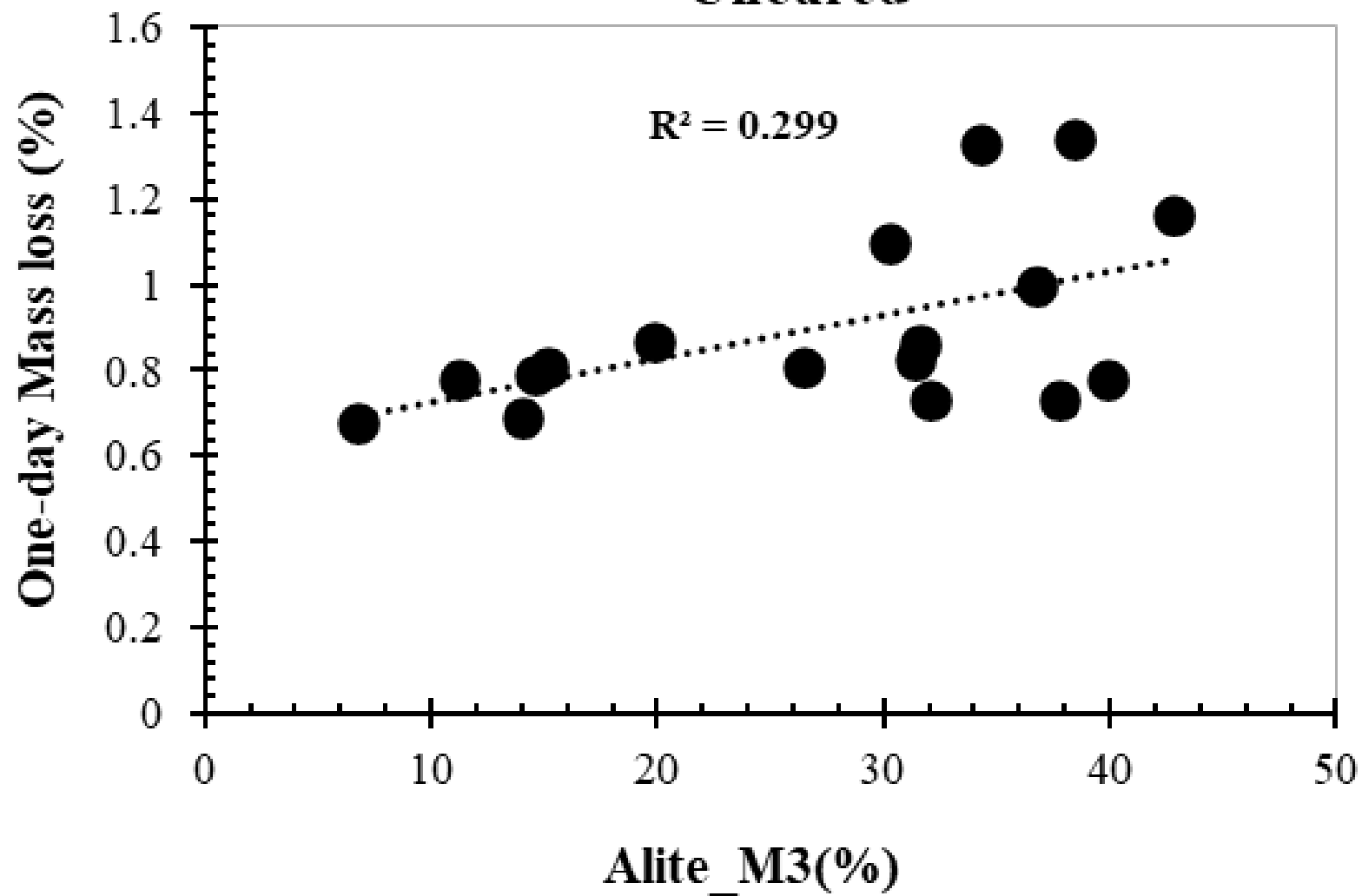




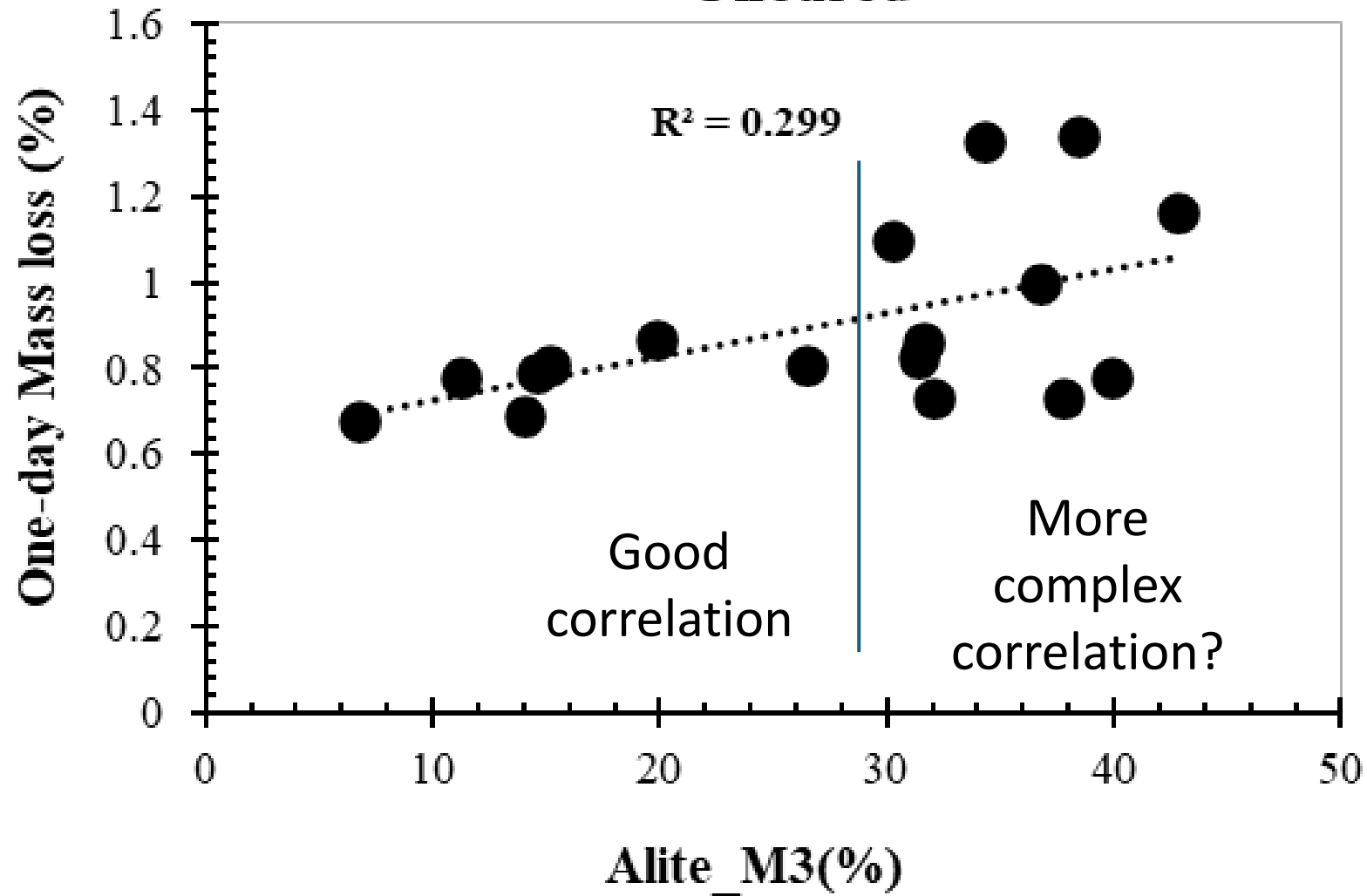
Discussion

- It doesn't look like the amount or absorption of the limestone plays a role
- What about clinker chemistry and phase?
- This is from the XRD analysis.

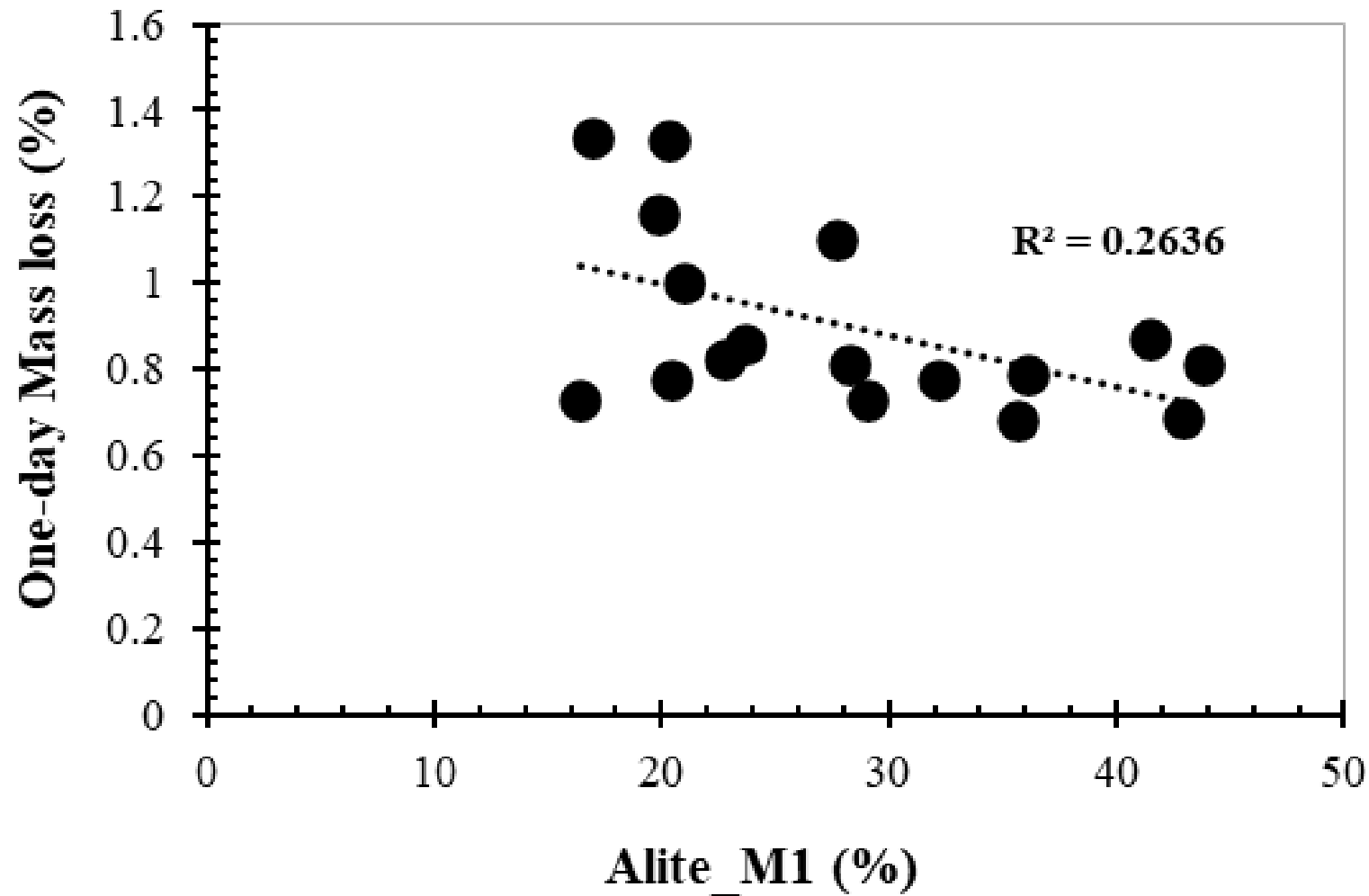
Uncured



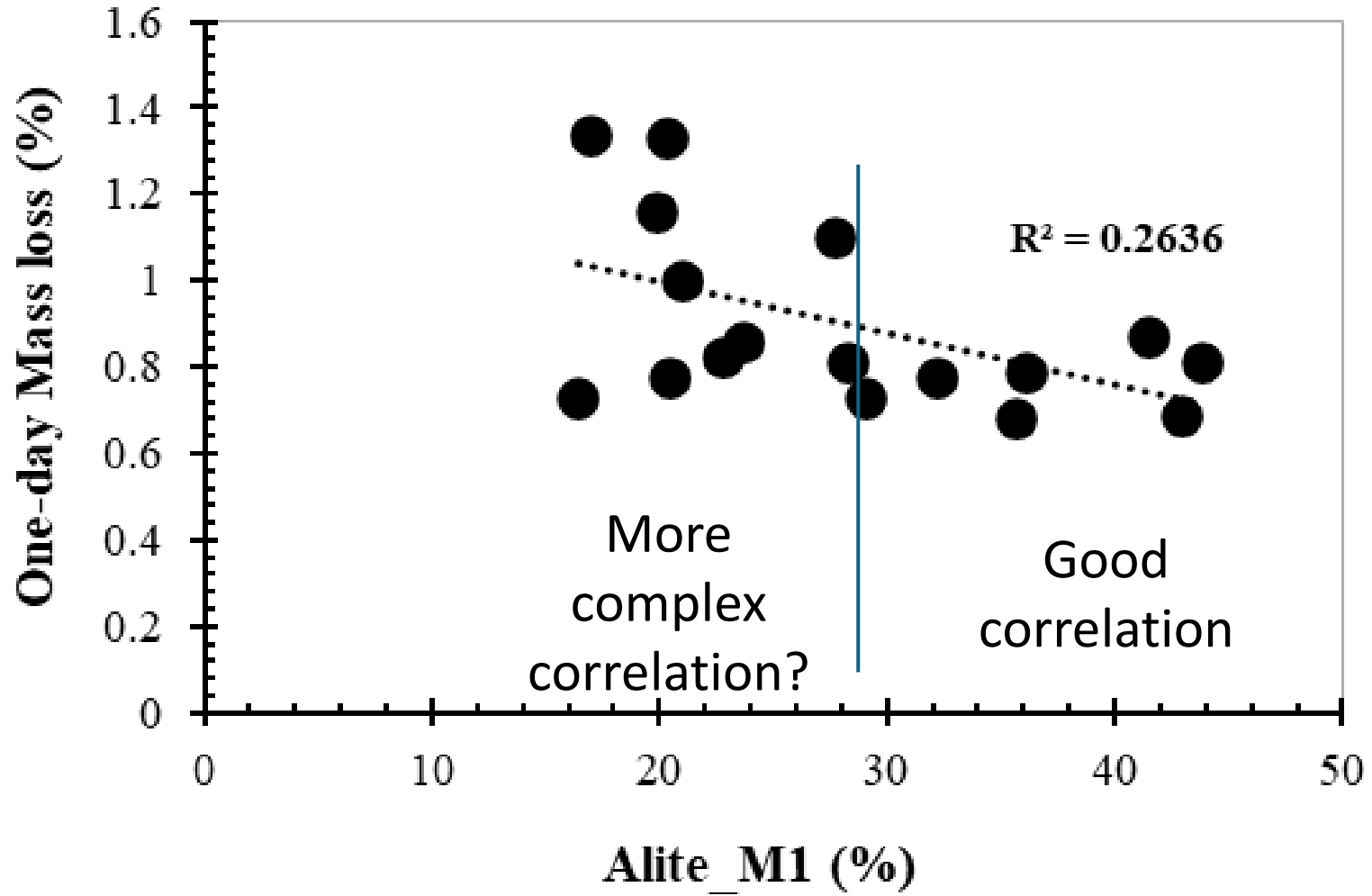
Uncured



Uncured



Uncured



Discussion

↓ Alite M3 ↓ mass loss during drying

↑ Alite M1 ↓ mass loss during drying

Discussion

↓ Alite M3 ↓ mass loss during drying

What is Alite M3 and M1?

Alite is C_3S

C_3S reacts with water to form CSH

CSH is the glue that gives concrete strength and permeability

Alite M1 and M3 are Polymorphs

Alite M1 is a more reactive version of C_3S

Alite M3 is a less reactive version of C_3S

↑ Alite M1 ↓ mass loss during drying

The higher reactivity phase may consume water before it is lost to drying.

Or it may be something more complex...

There may be a relationship between free lime, particle size, Alite M1 and M3

What determines the amount of M1 and M3?

The ratio of magnesium and sulfates of the aggregates used to make the clinker.

This means it is inherent to the quarry used to make the cement.

What determines the amount of M1 and M3?

The ratio of magnesium and sulfates of the aggregates used to make the clinker.

Now let's look at wet curing

This means it is inherent to the quarry used to make the cement.

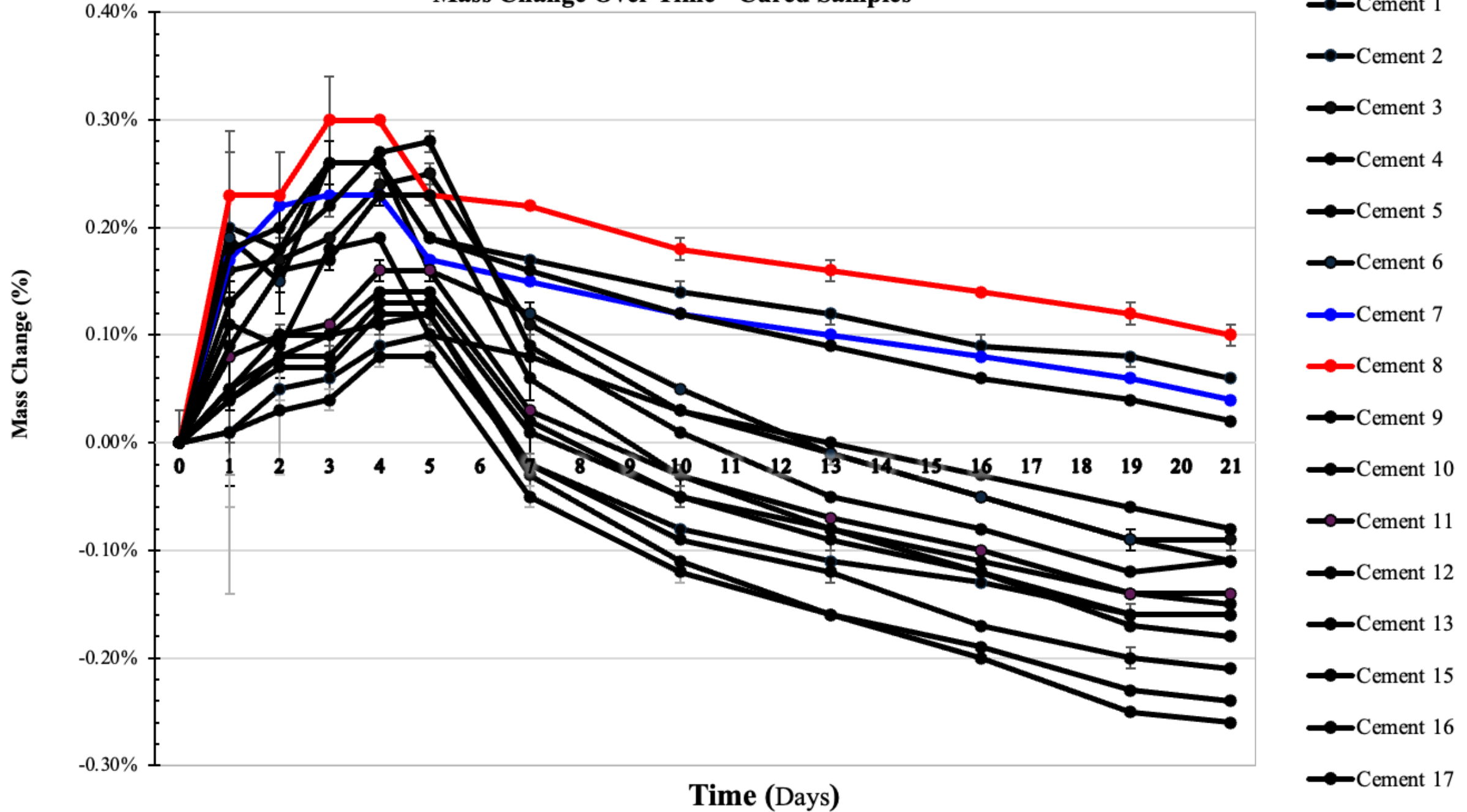
Step 1 – Dry the sample

Wet cure the samples for 5 days and

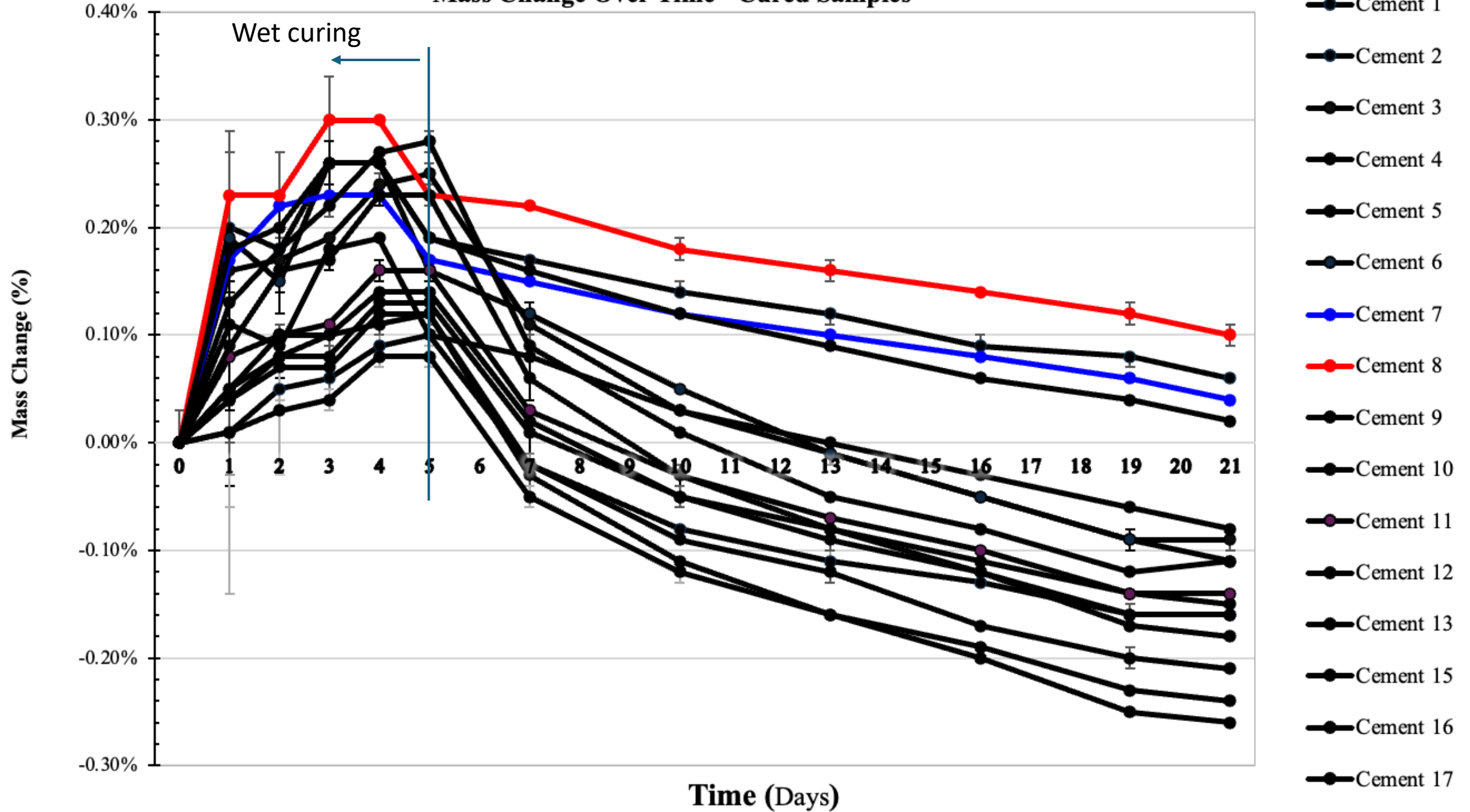
Dry the samples for 17 days in 50% RH and 73°F

This is a total of 21 days to match the uncured samples.

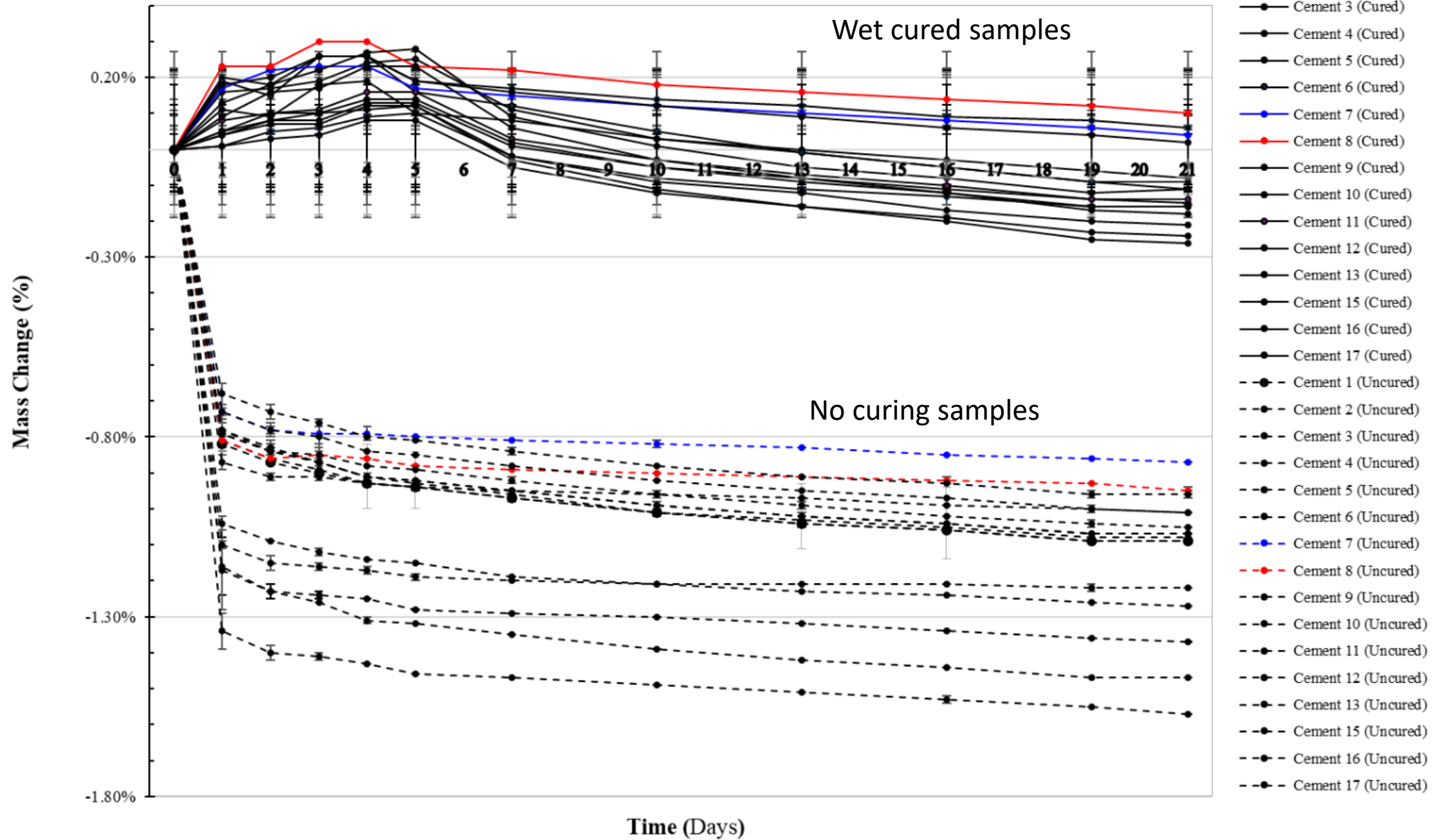
Mass Change Over Time - Cured Samples



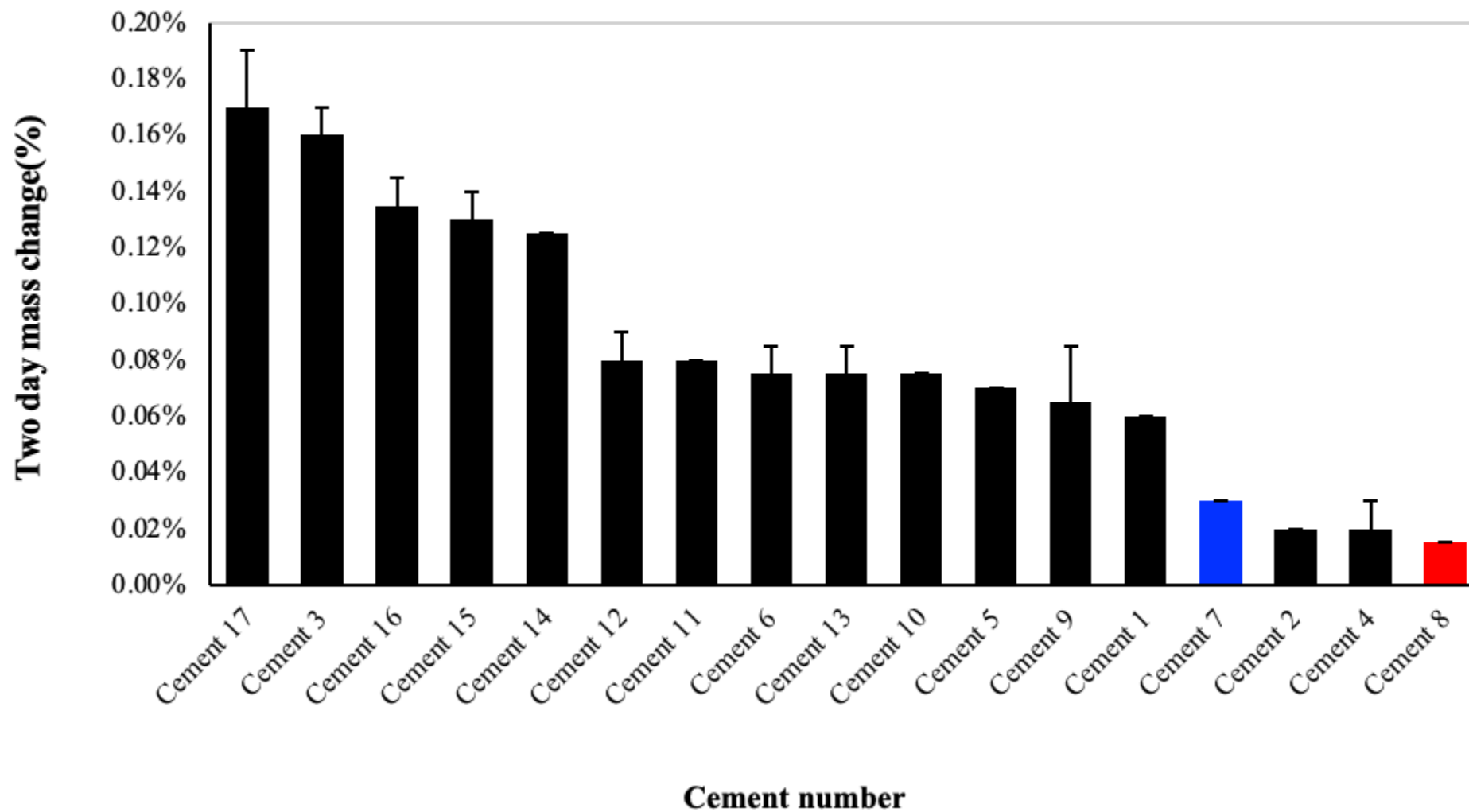
Mass Change Over Time - Cured Samples



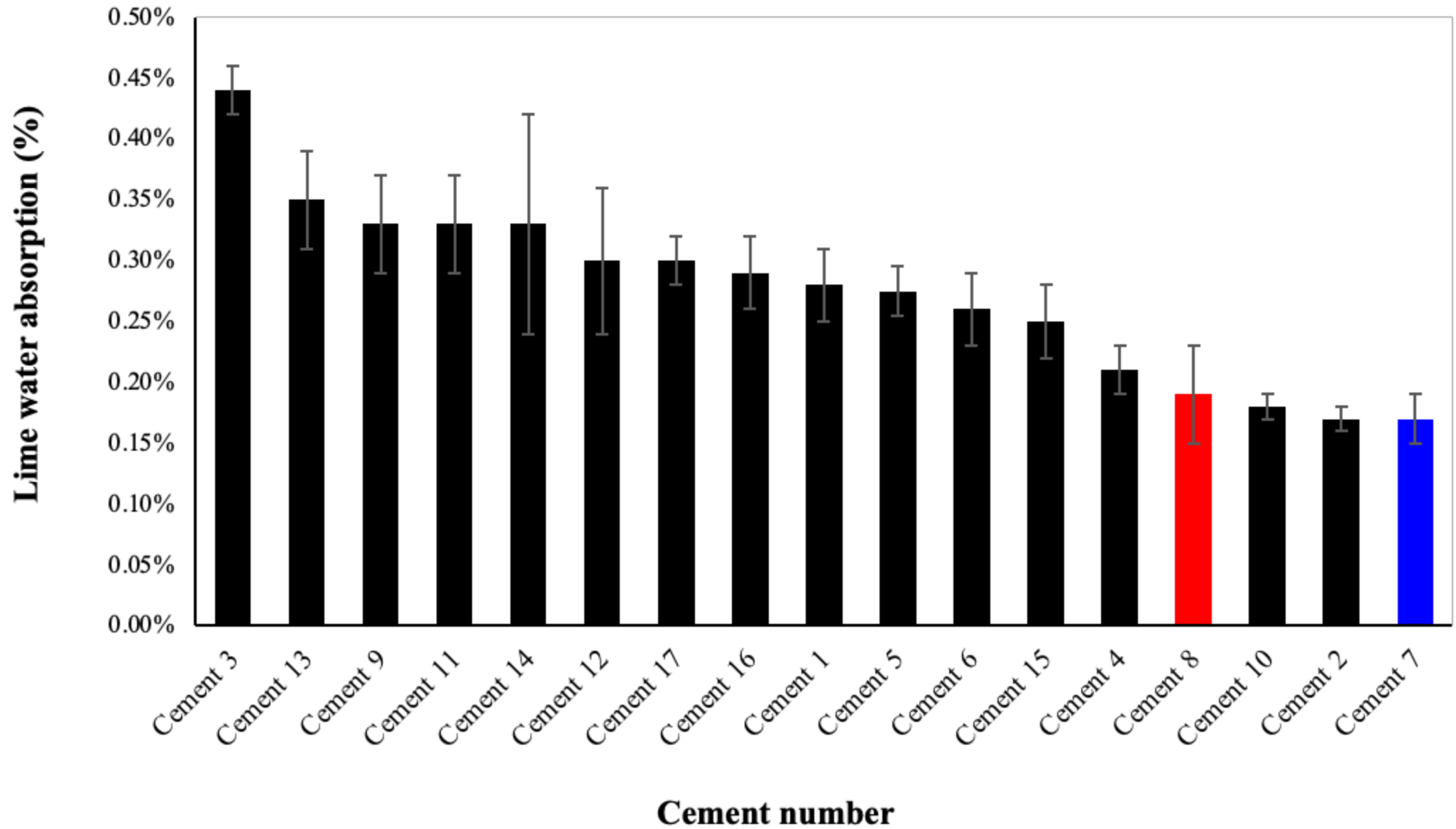
Mass Change Over Time



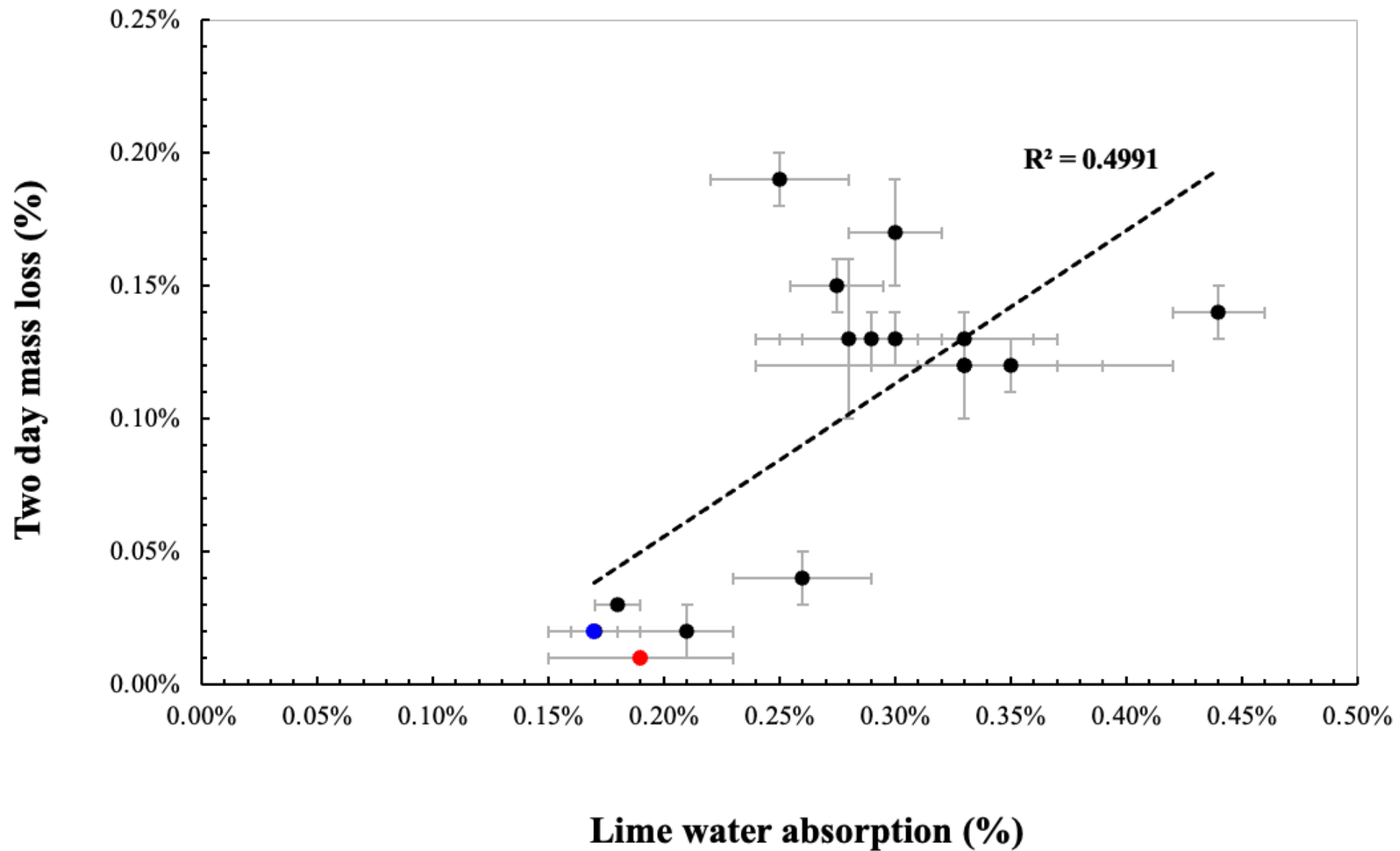
Mass loss after placing cured samples in dry condition



Wet cured



Wet cured



Discussion

- All the cements have similar performance when they are wet cured.
- There is a low amount of mass loss and a low amount of lime water absorption.

What does this mean?

Not all cements perform the same.

What does this mean?

When you wet cure, the cements perform similarly.

When you have no curing, the difference in performance can be significant.

What does this mean?

The difference in performance is not caused by the limestone.

It may be caused by the amount of Alite M1 and M3 or maybe something else.

What does this mean?

When the cements are poorly cured, they are more porous, and they absorb more water.

This is bad for durability and can reduce the service life of a bridge deck by about 50%.

What else should we think about...

Curing compounds have a performance that is closer to no curing and so similar issues could be happening.

The performance of these cements with curing compounds should be investigated.

What else should we think about...

The drying environment (73F and 50% RH) is not severe.

Higher drying environments will be even worse.

What else should we think about...

This increased mass loss from drying may also impact drying shrinkage cracking.

What should we do about this?

Wet cure bridge decks.

We need to understand why different cements perform differently.

There may be a way to stop or at least predict when this will happen.

What should we do about this?

Would you be willing to fund
research to do this?

There may be a way to stop or at least predict when this will happen.

www.concretefreaks.com



Structural Cracking in Reinforced Concrete

www.youtube.com/tylerley

TYLER LEY, PE, PhD

Questions?
Tyler.ley@okstate.edu



When do we cure concrete?

- Period 1 - Placement to 6h to stop plastic shrinkage cracking
- Period 2 - 6h to several days to form a dense microstructure

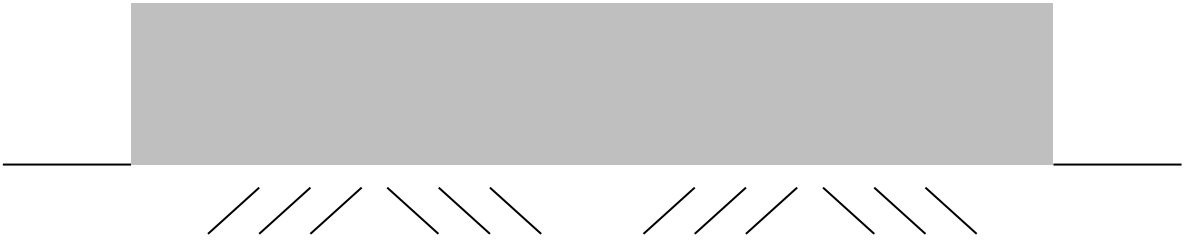
Plastic Shrinkage Cracking



Have you ever seen plastic shrinkage cracking?

What was the weather like?

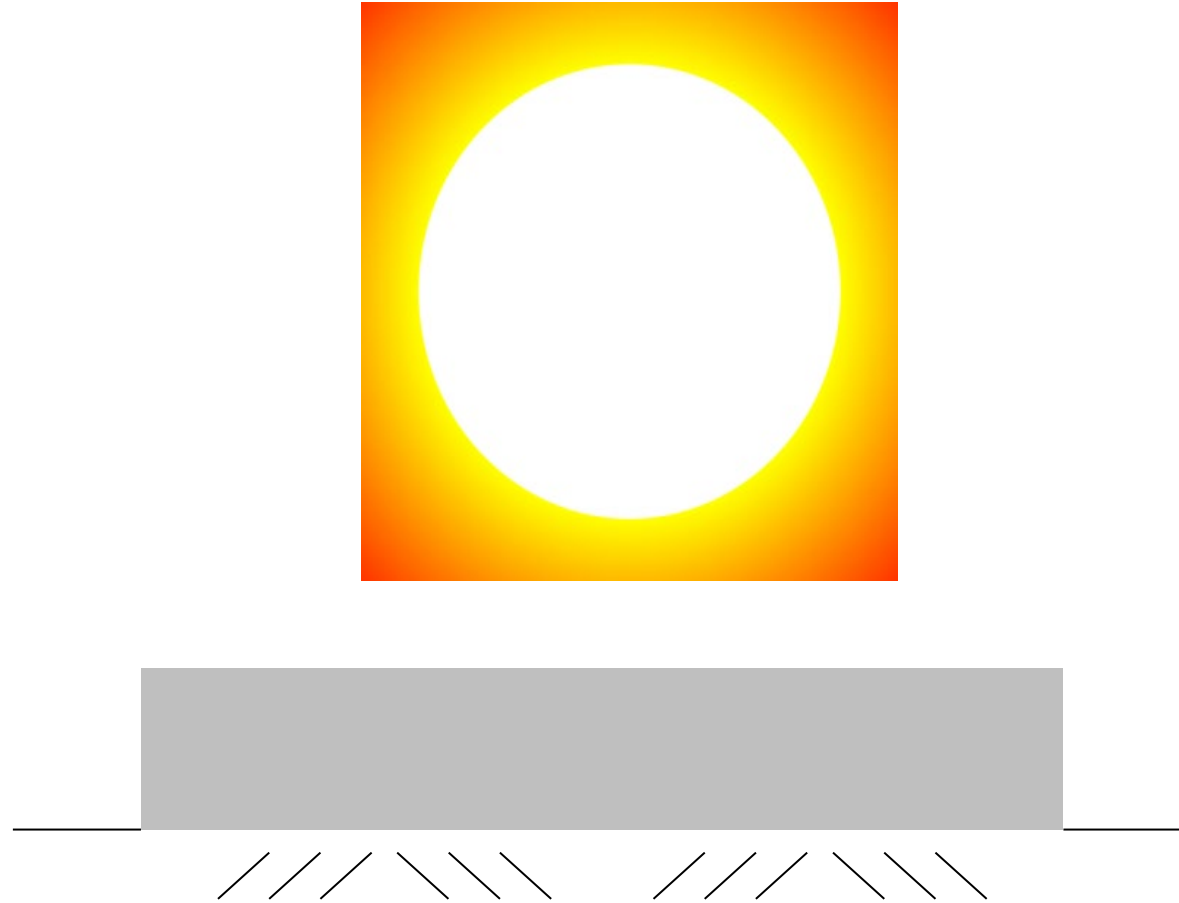
Do you see it on all concrete?



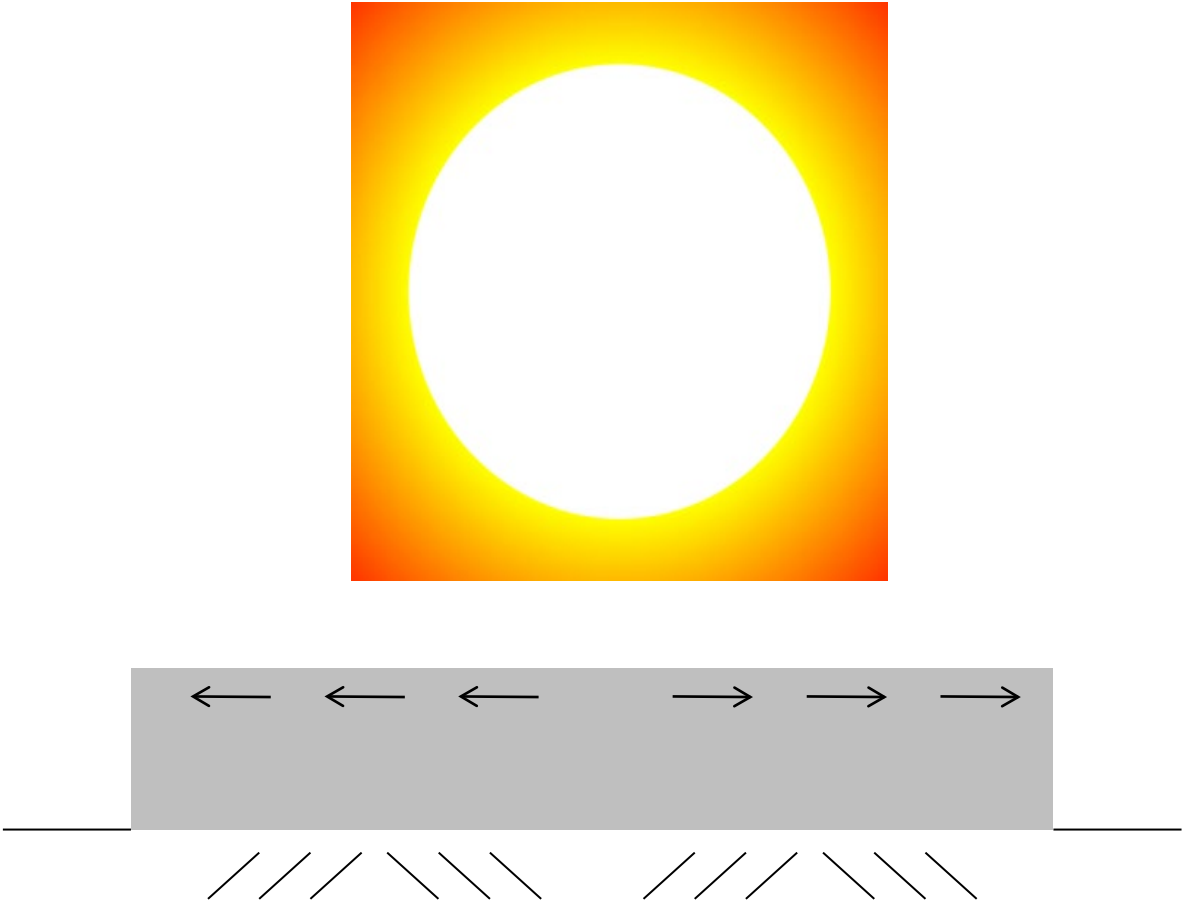
Bleed water appears after finishing



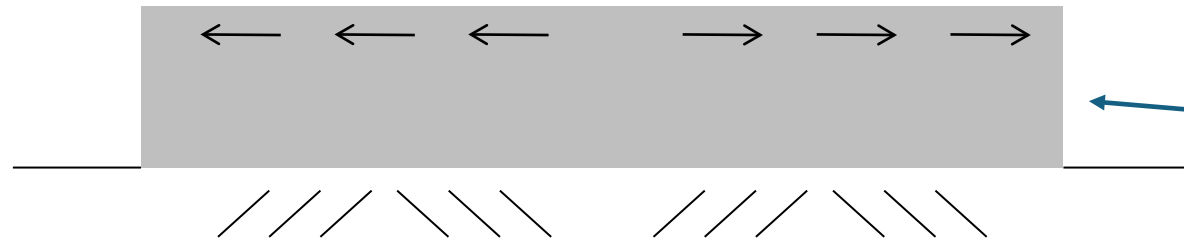
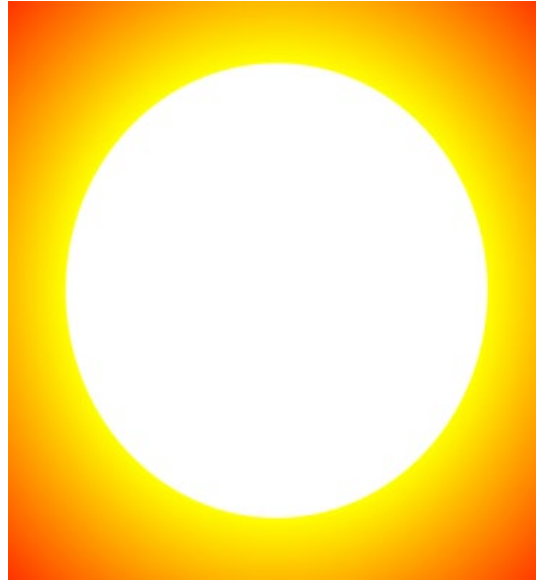
When the evaporation rate exceeds the rate of bleeding



The concrete at the surface dries and shrinks

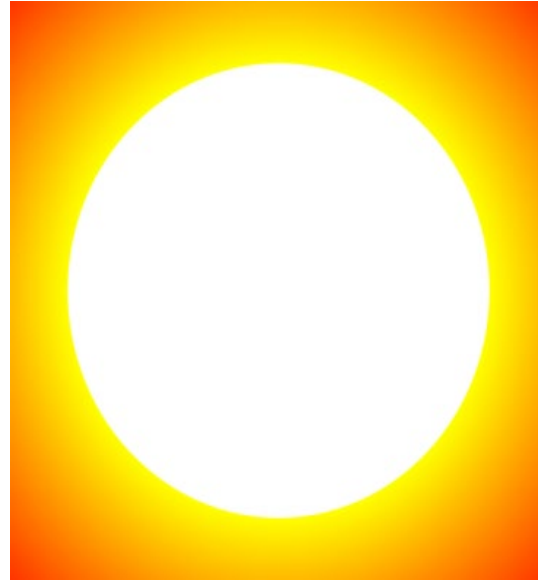


The concrete at the surface dries and shrinks



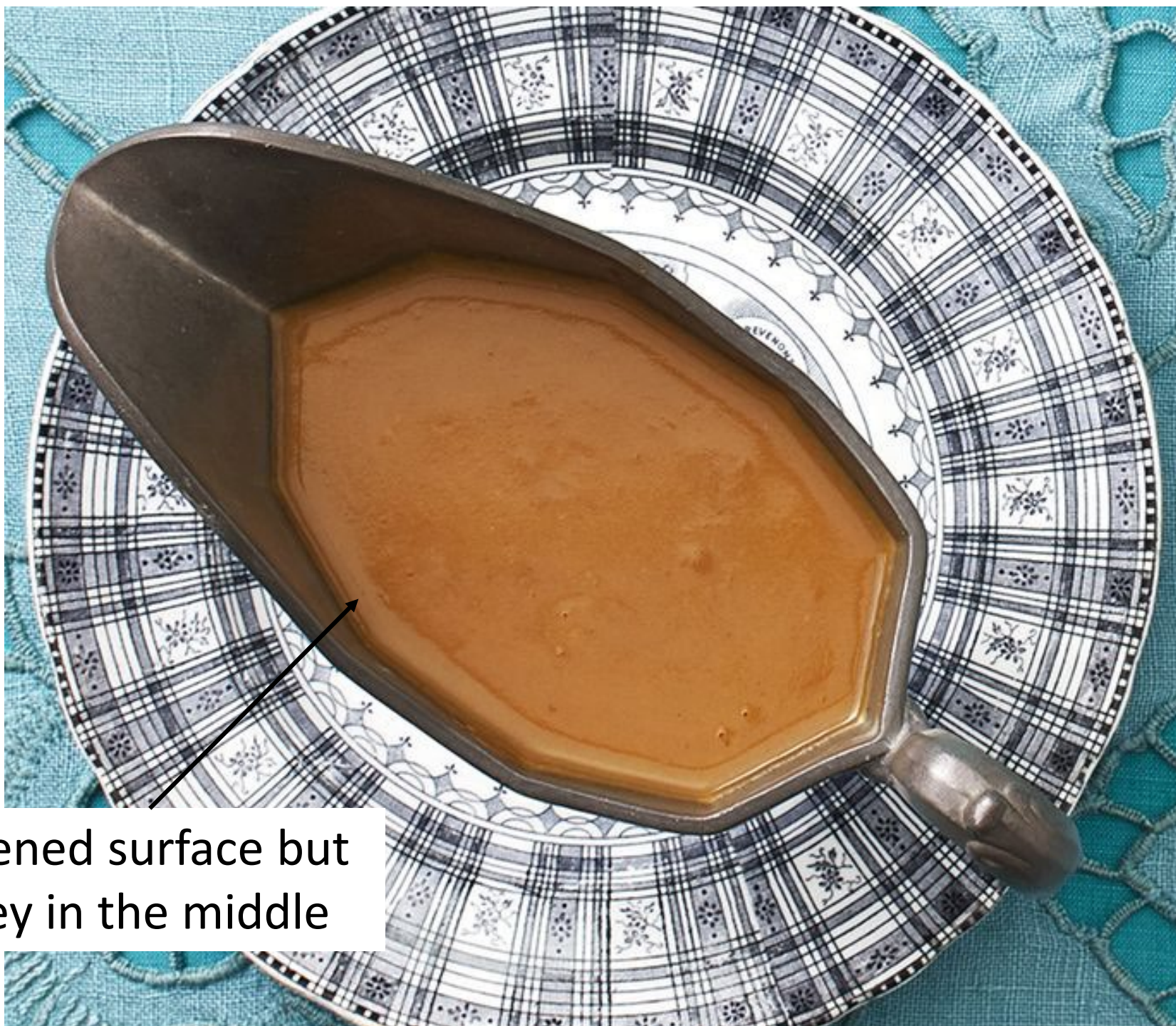
The moist concrete below restrains the shrinkage

The “plastic” concrete cracks



The cracks are near the surface





Hardened surface but
gooey in the middle

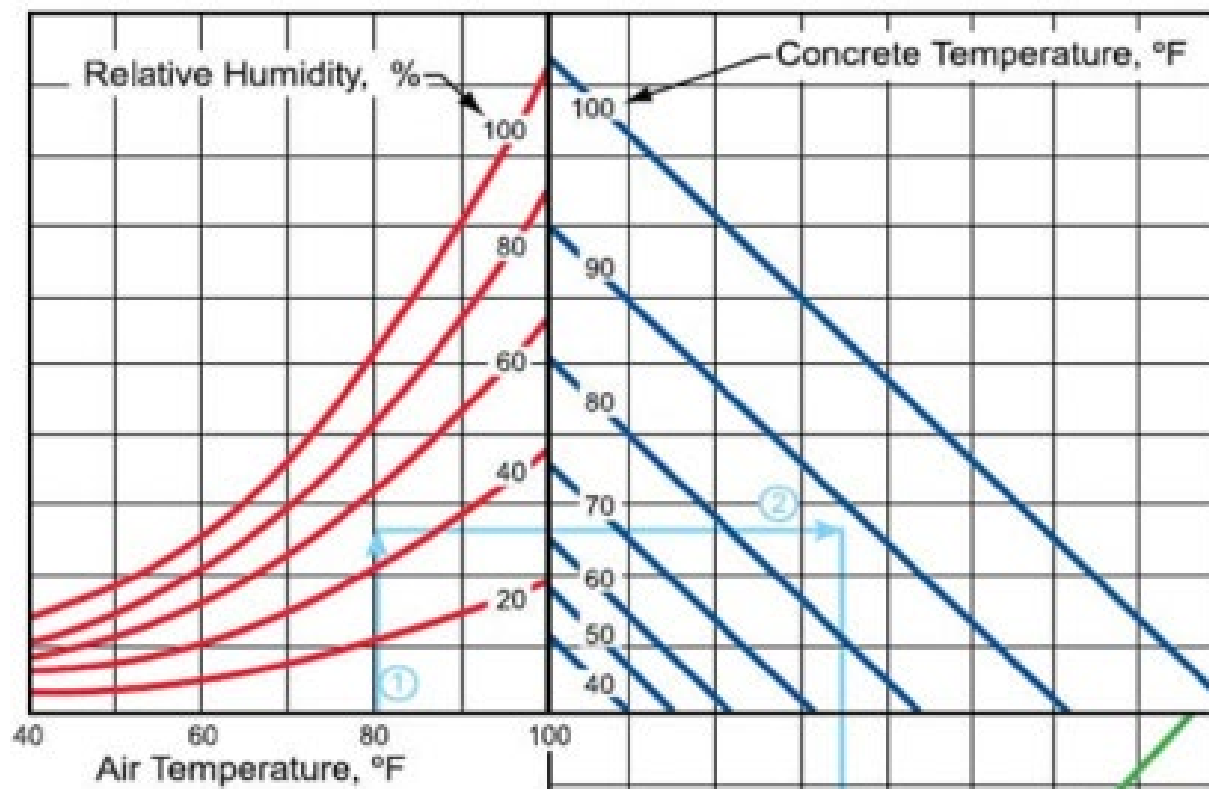


Hardened surface but
gooey in the middle

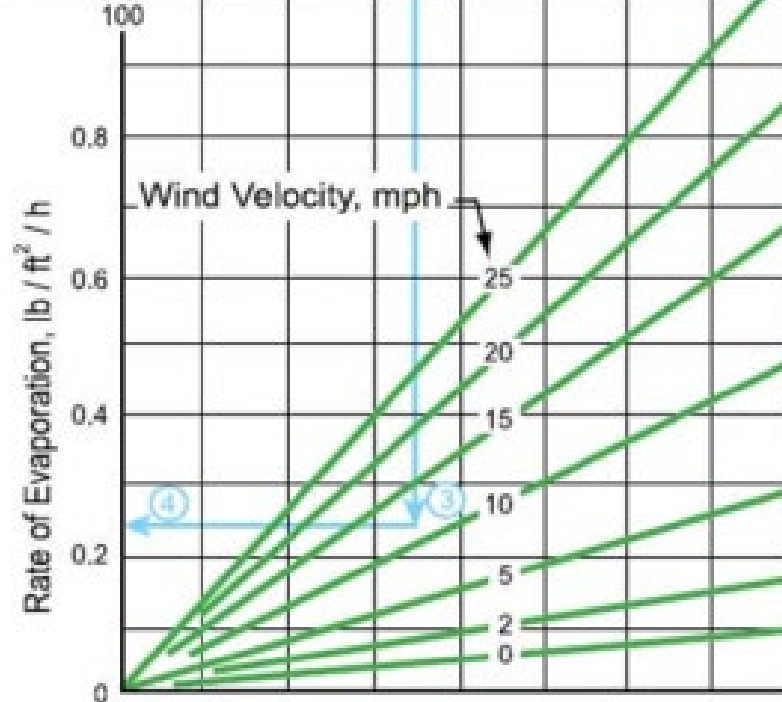
Plastic Shrinkage Cracking is a function of

The paste content, the water to cement ratio, the amount of SCMs, age of your mixture at strike off, admixtures

air temperature, relative humidity, concrete temperature, wind speed, sun exposure

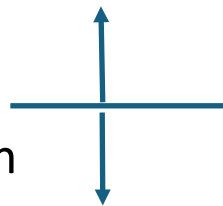


in.-lb Units



More concern
for cracking

Less concern
for cracking



Remember!

Mixtures with more paste and are slower setting are more susceptible.

If you remove paste (binder and water) then you can lower the amount of plastic shrinkage cracking.

What else can you do to stop plastic shrinkage cracking?

Fog surface

Evaporation retarder

Wind breaks

Curing compound

Plastic

Avoid mixtures with long setting times

Microsynthetic fibers