Determining the Effectiveness of Curing Concrete

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Acknowledgements

Oklahoma Department of Transportation

Oklahoma Transportation Center

Minnesota Department of Transportation

Three keys to successful concrete

1. Initial cement grain spacing
2. Final cement grain spacing
3. Promote reaction

Three keys to successful concrete

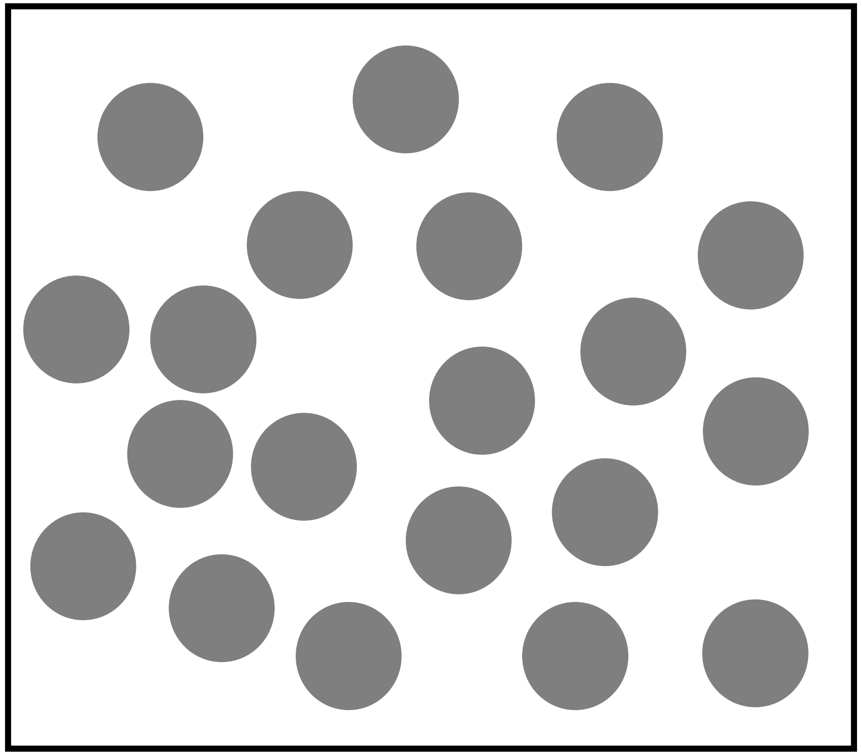
1. Initial cement grain spacing – water to cement ratio
2. Final cement grain spacing - consolidation and finishing
3. Promote reaction - curing

Three keys to successful concrete

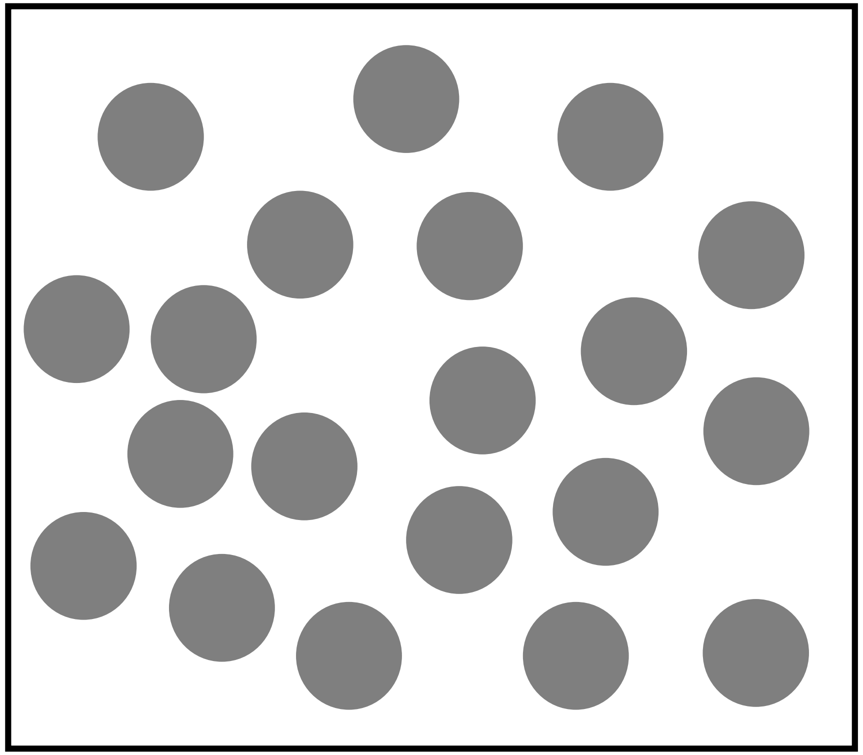
1. Initial cement grain spacing – water to cement ratio
2. Final cement grain spacing - consolidation and finishing
3. Promote reaction - curing

Let's compare two mixtures with the same w/cm but different qualities of curing

w/cm = 0.40

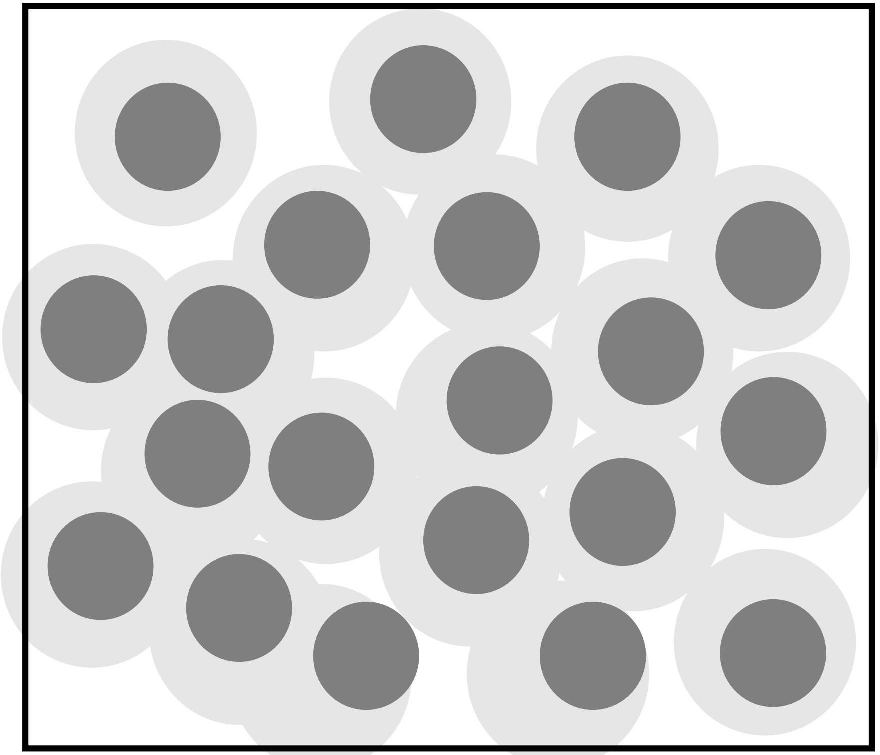


w/cm = 0.40



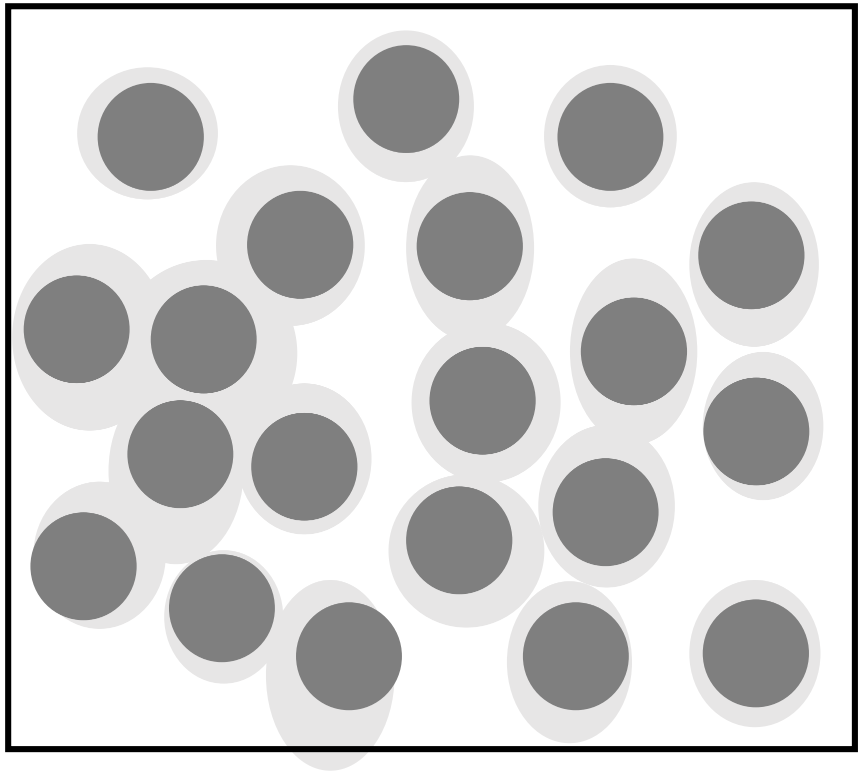
If you keep the concrete moist and warm then it will react.

w/cm = 0.40

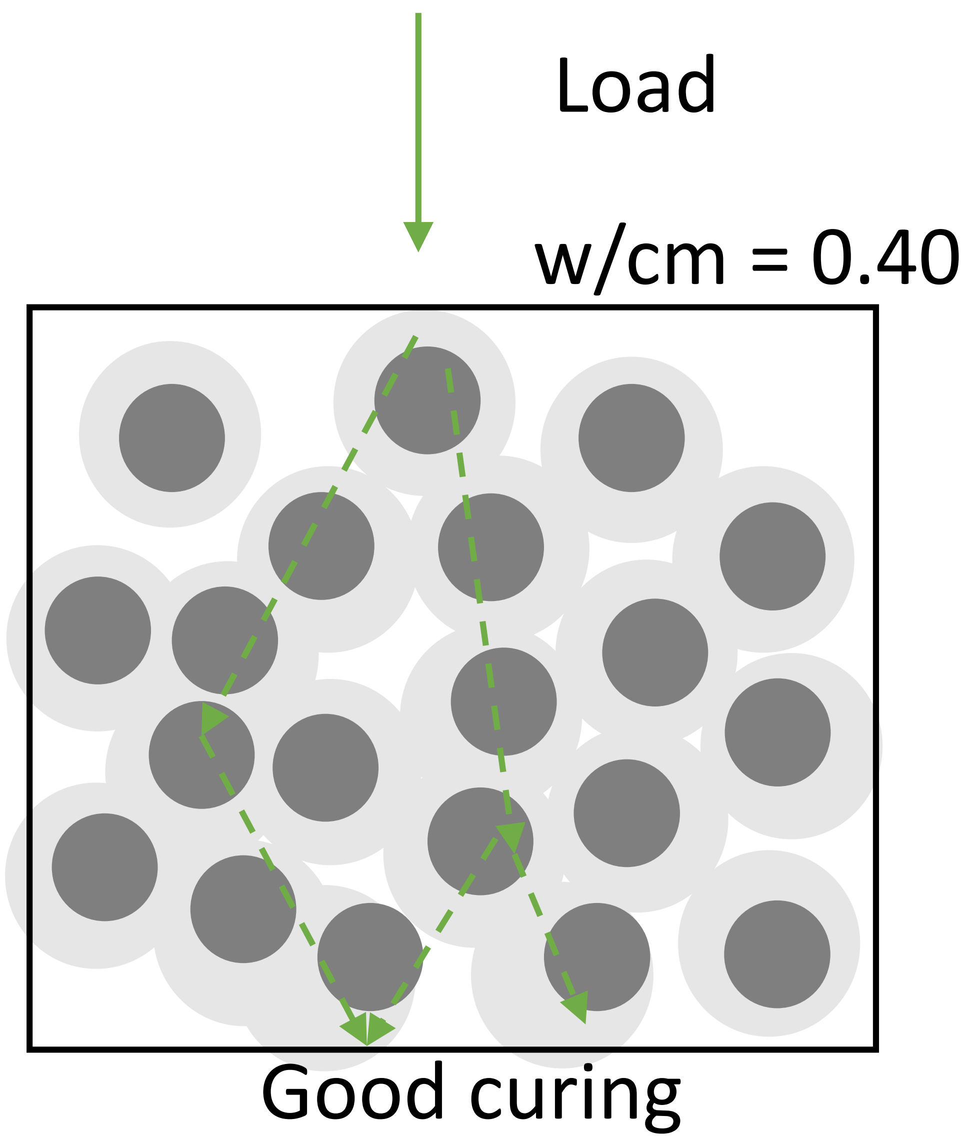


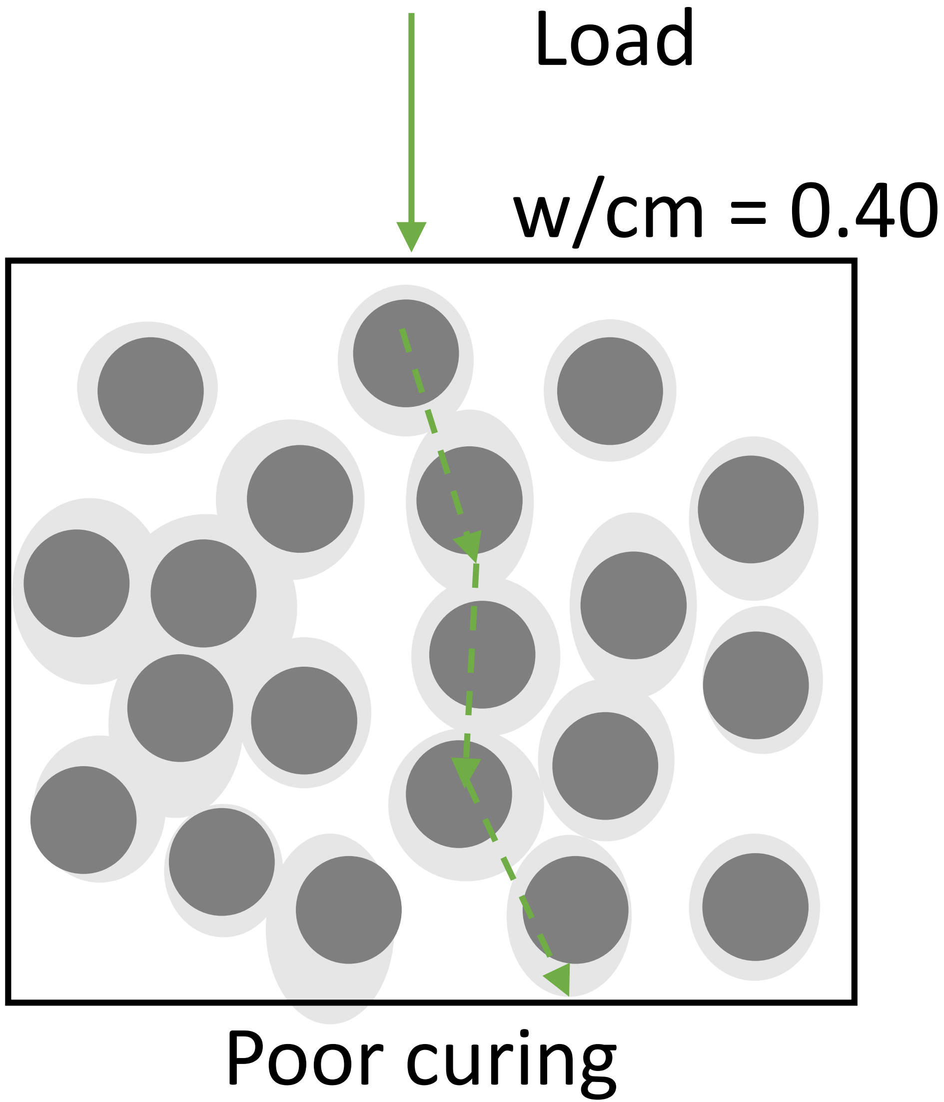
Good curing

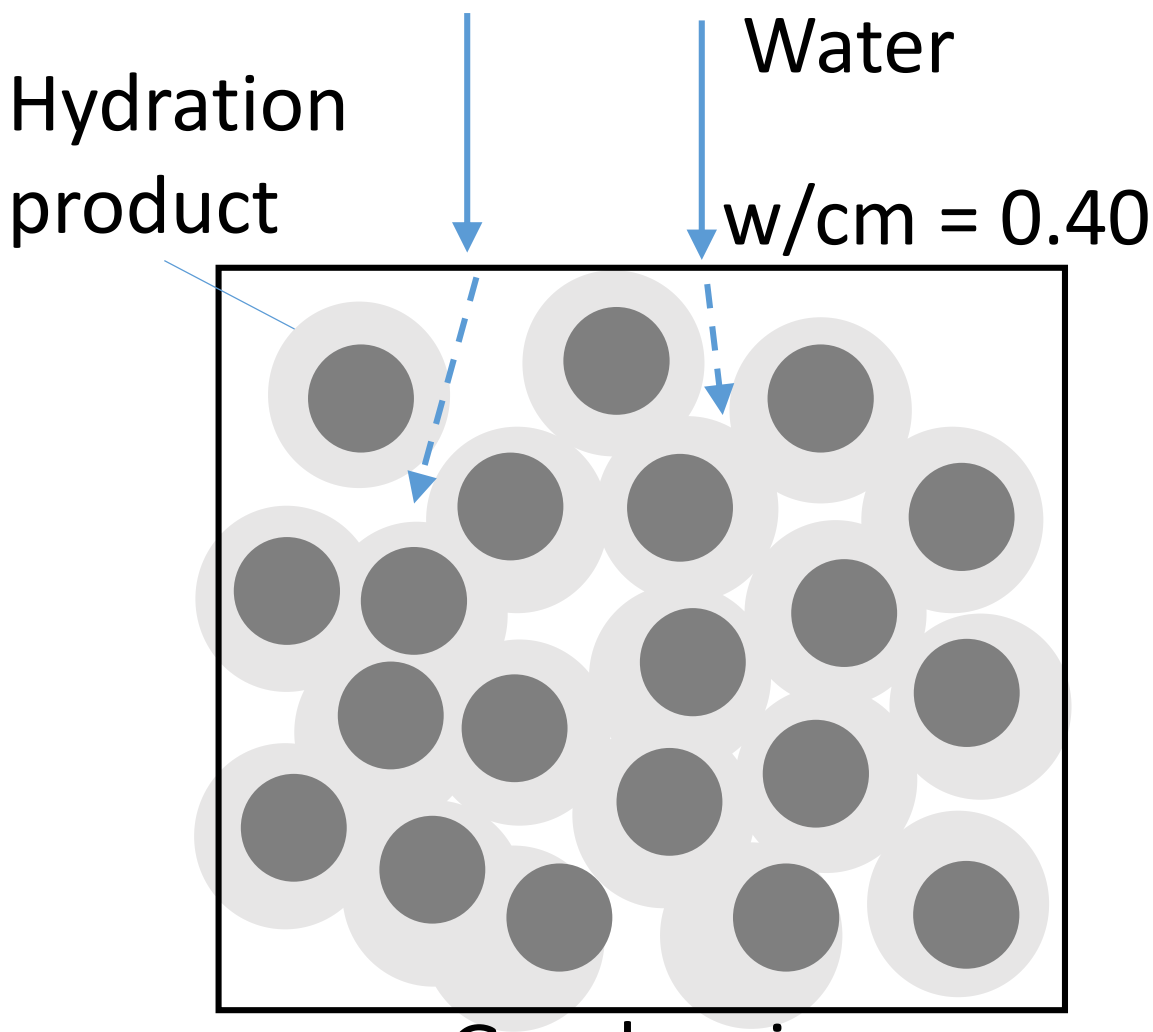
w/cm = 0.40



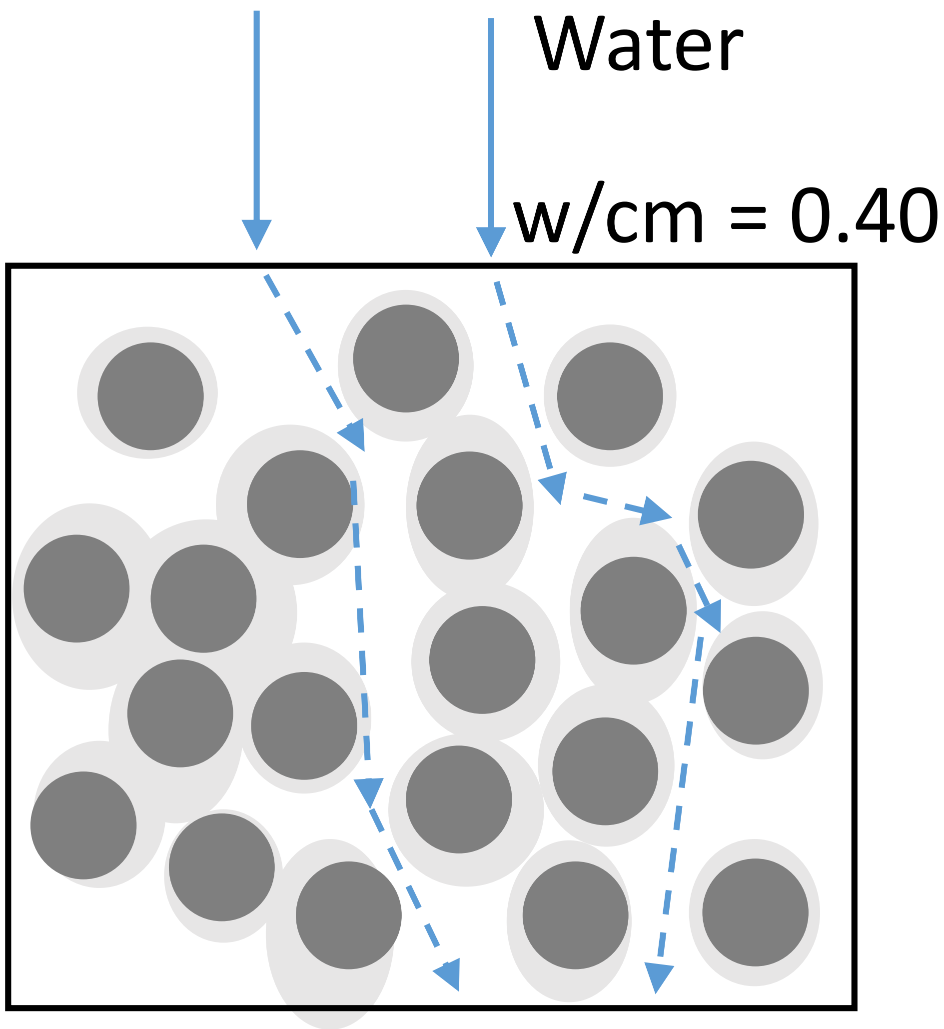
Poor curing


Load
w/cm = 0.40
Good curing

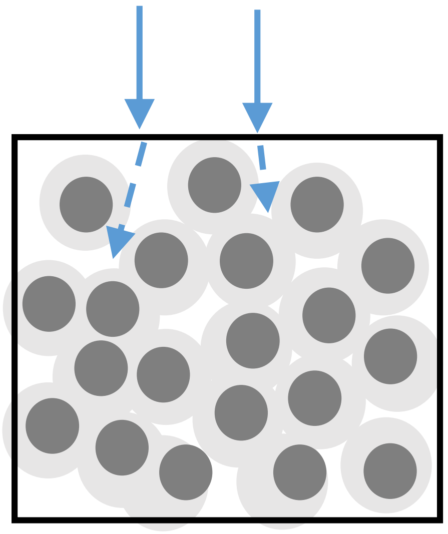

Load
w/cm = 0.40
Poor curing



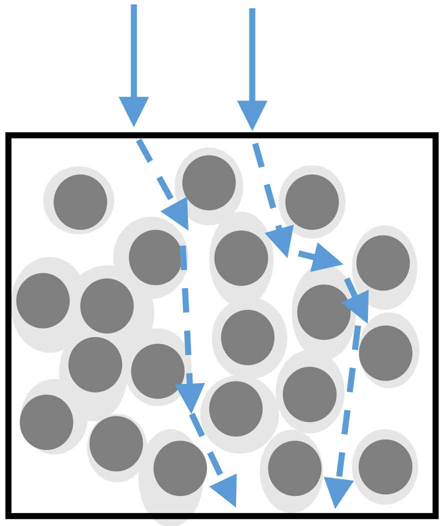
Good curing



Poor curing



Good curing



Poor curing

Summary

As curing improves then the mixture will be stronger and have a lower permeability

“Good” Curing

“Not as Good” Curing

Your concrete will be compromised if it is not properly cured.

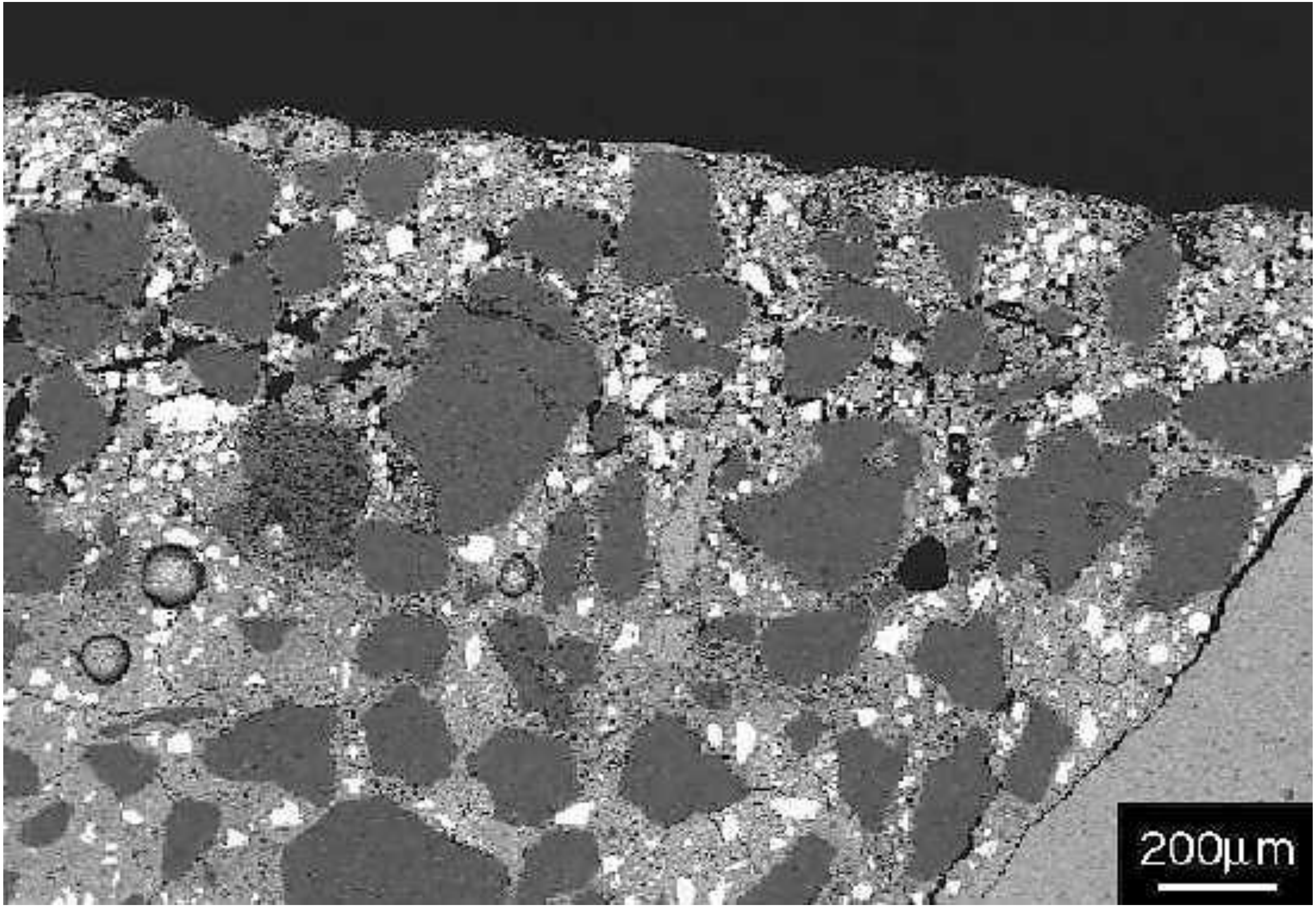
Curing helps the concrete reach its potential

No curing

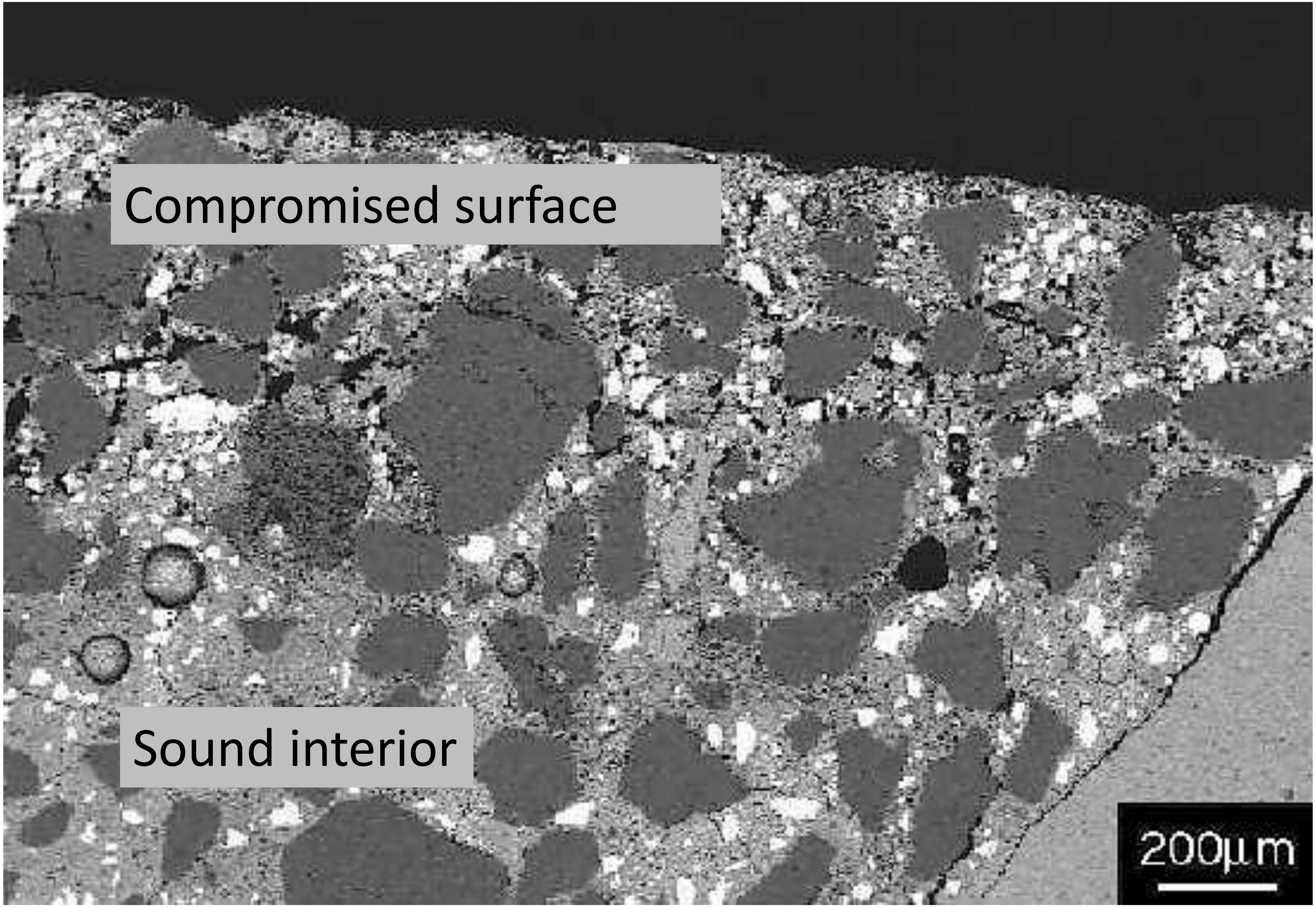
Curing

Uncured concrete

Cured concrete



Poorly cured concrete



Poorly cured concrete

Formed surfaces

If my concrete is strong enough can I remove the forms?

How does our curing choices impact the life of the concrete?

Overview

Contractors have requested to remove wall forms at 12 h to accelerate construction.

The concrete has sufficient strength but when you remove the forms you stop curing the concrete. Does that reduce the durability?

How are we going to do this?

Phase I

Compare the effectiveness of curing with wood, steel, and rubber forms curing for 12, 24, and 72 h.

Phase II

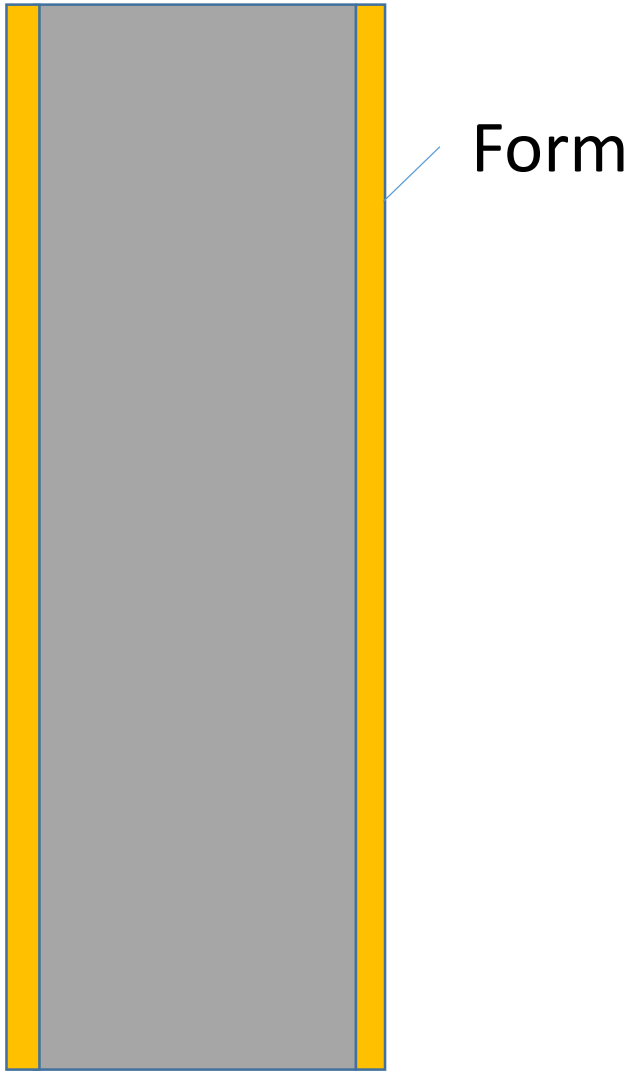
Can you use other curing methods to extend the effective curing after removing steel forms at 12 h?

Testing

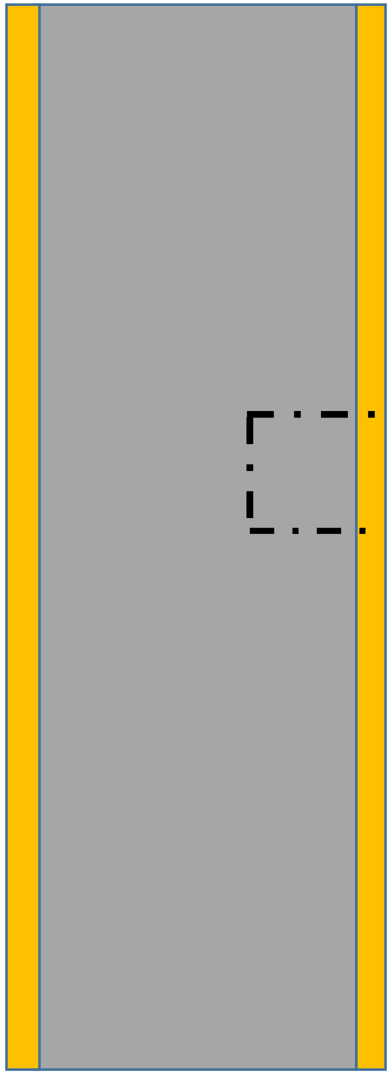
Typical wall concrete mixture

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

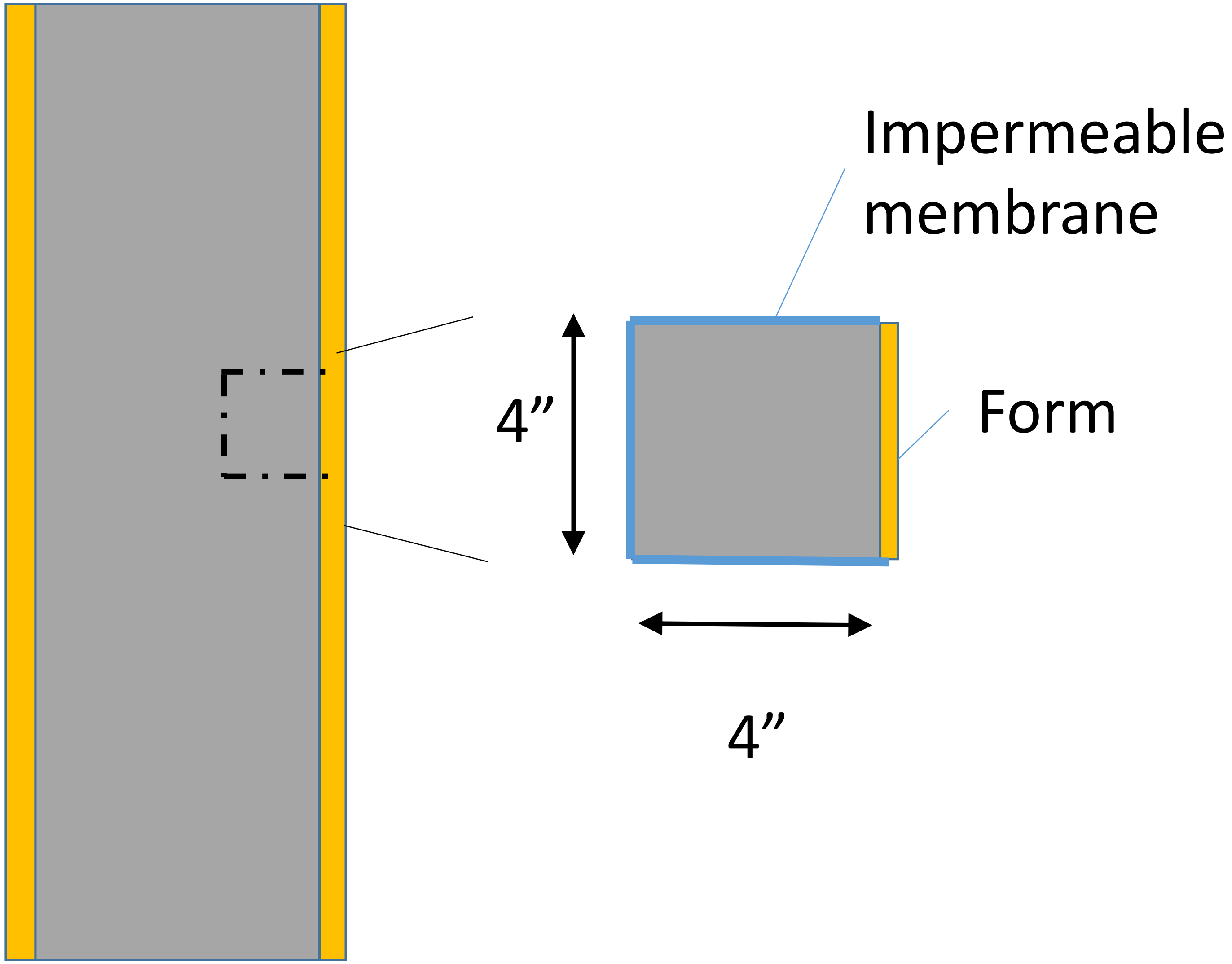
How do you test a wall?



What if we just test a piece of the wall.



What if we just test a piece of the wall.



Samples

- 4” concrete cubes were cast
- Phase I – compared steel, wood, or rubber forms
- We used steel forms for Phase II
- The other faces were surrounded by an impermeable membrane

After form removal

Testing

If the concrete is cured well 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.

We only ran this test in Phase I

“Good” Curing

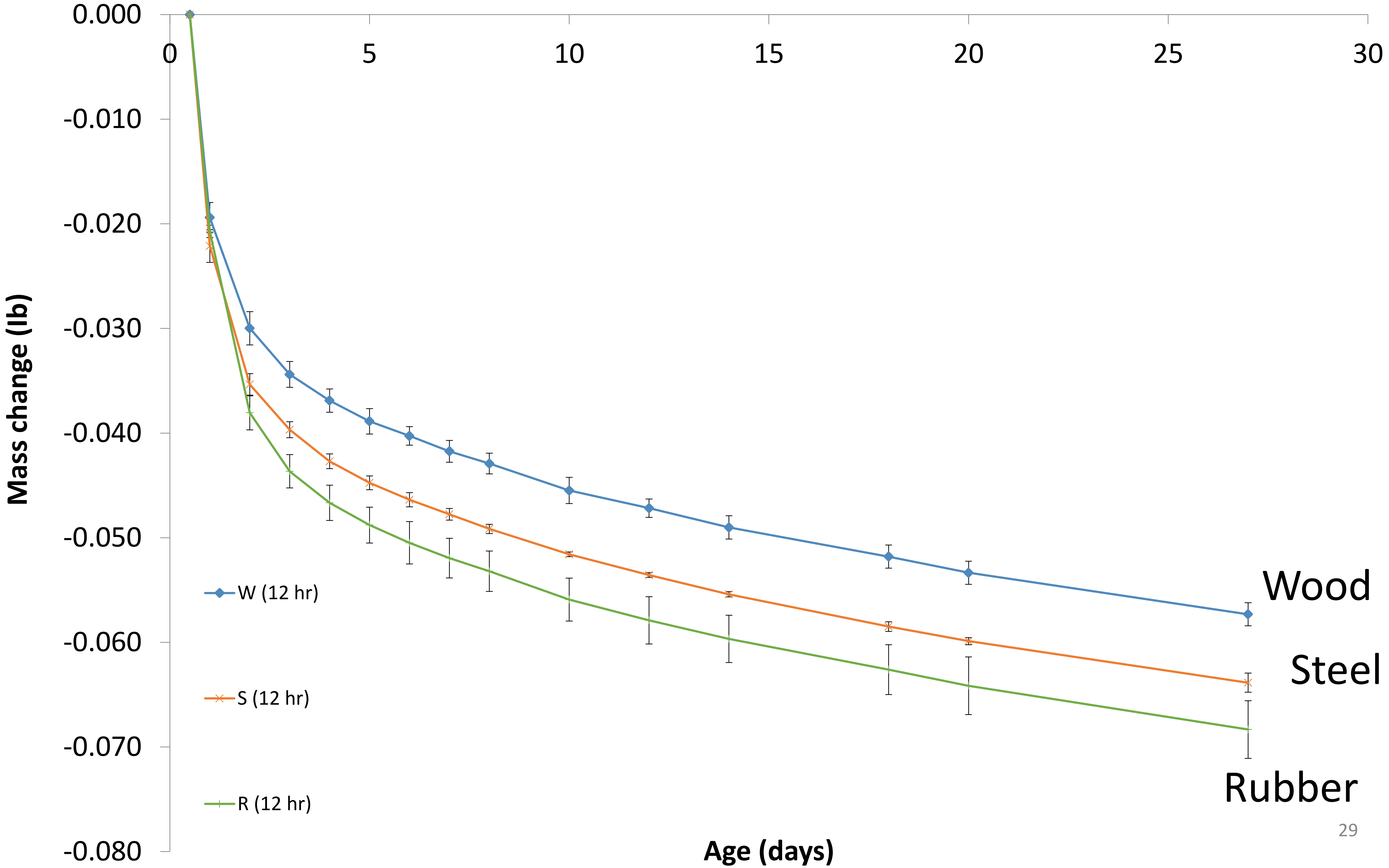
“Not as Good” Curing

What did we do?

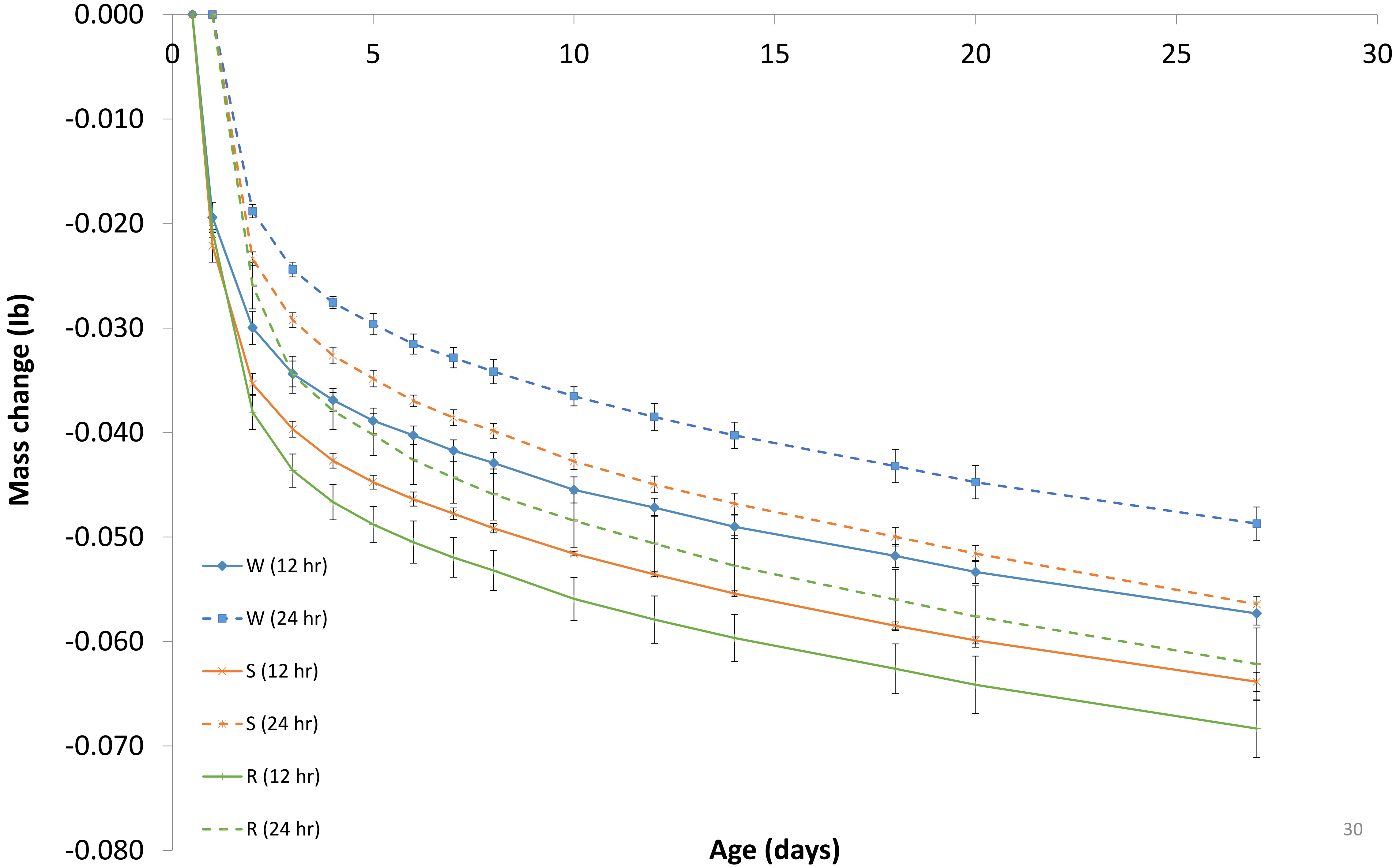
Step	Test	Details
1	drying	Mass change in 50% RH and 73^{o}F for 28 days
2	water uptake	Mass change in lime water for 6 days
3	chloride penetration	Mass change in 5% NaCl for 35 days Chloride profile

Step 1 – Dry the sample

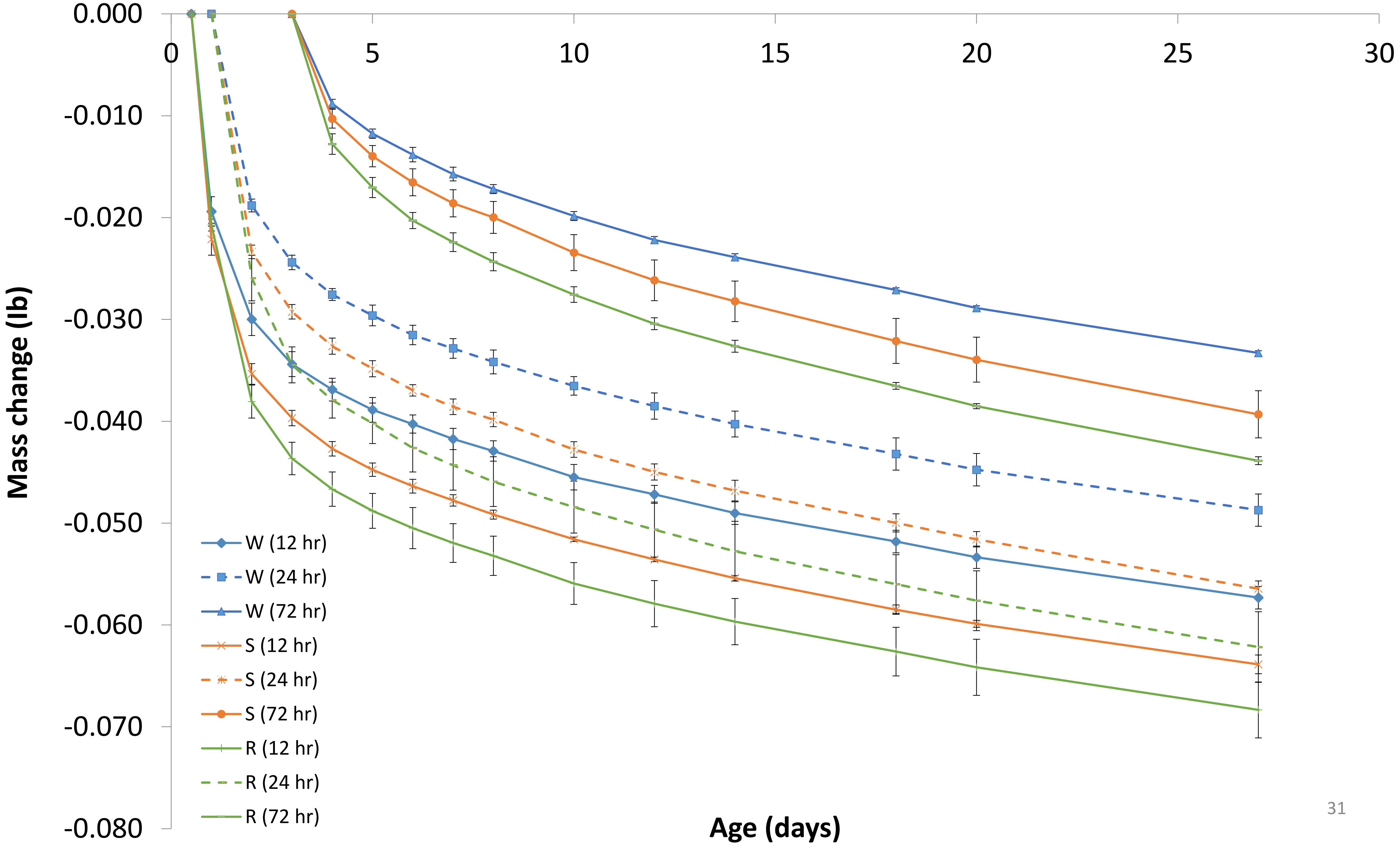
Measure mass change in 50% RH and 73^{o}F for 28 days



Mass change (lb)
0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
-0.070
-0.080
0
5
10
15
20
25
30
Age (days)
W (12 hr)
S (12 hr)
R (12 hr)
Wood
Steel
Rubber



0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
-0.070
-0.080
0
5
10
15
20
25
30
Mass change (lb)
Age (days)
W (12 hr)
W (24 hr)
S (12 hr)
S (24 hr)
R (12 hr)
R (24 hr)


0.000
-0.010
-0.020
-0.030
-0.040
-0.050
-0.060
-0.070
-0.080
0
5
10
15
20
25
30
Mass change (lb)
Age (days)
W (12 hr)
W (24 hr)
W (72 hr)
S (12 hr)
S (24 hr)
S (72 hr)
R (12 hr)
R (24 hr)
R (72 hr)

Discussion

- The samples are losing water as they dry.
- The better the curing the less mass was lost.
- Wood forms seem to be the best followed by steel and rubber.
- The longer you cure the sample the less moisture is lost.

- **This shows that extended curing in the forms helps resist water loss.**
- **This means that the concrete should be better at resisting outside chemical penetration.**

Discussion

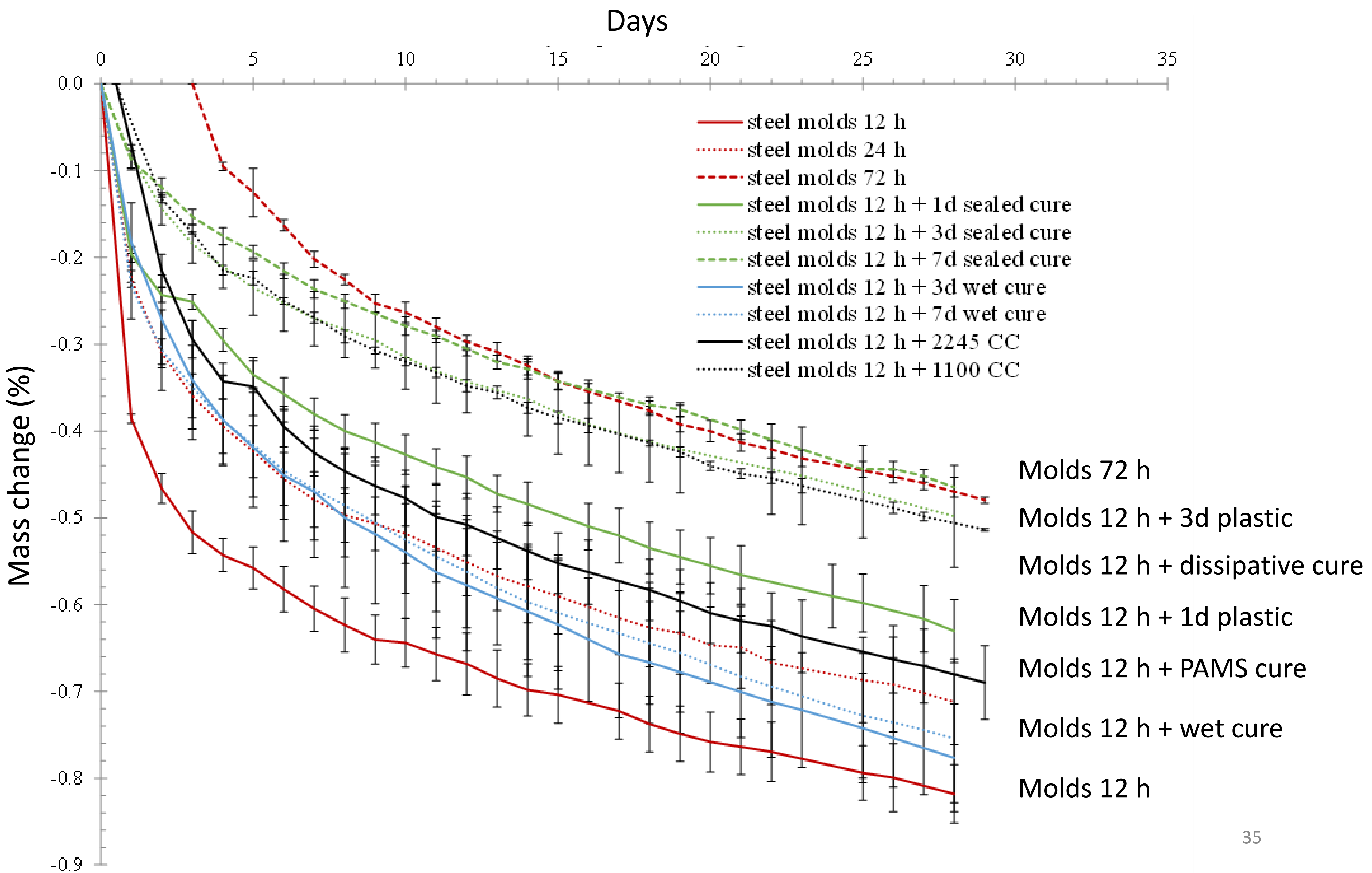
- While there was some differences between the different types of forms, the differences were not that large.

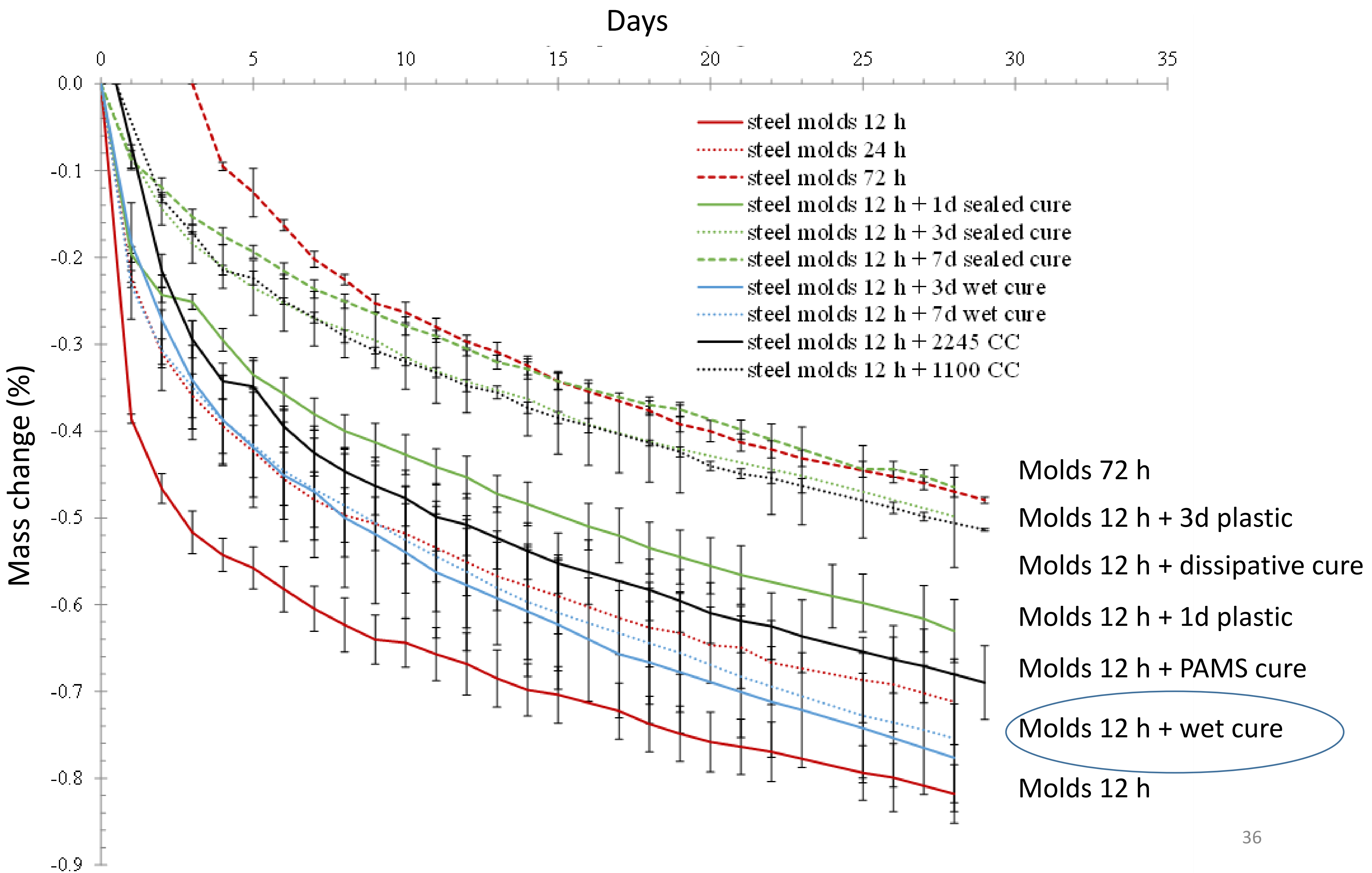
- For the Phase II testing we will use steel molds.

Curing in Phase II

- Cure samples within steel molds for 12 h
- Remove molds and then cure with:
  - Sealed curing for 1d, 3d, 7d
  - Wet curing for 3d, 7d
  - Curing compound PAMS and dissipative curing compound

We also looked at curing in steel molds for 24 h and 72 h


Days
0
5
10
15
20
25
30
35
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
Mass change (%)
steel molds 12 h
steel molds 24 h
steel molds 72 h
steel molds 12 h + 1d sealed cure
steel molds 12 h + 3d sealed cure
steel molds 12 h + 7d sealed cure
steel molds 12 h + 3d wet cure
steel molds 12 h + 7d wet cure
steel molds 12 h + 2245 CC
steel molds 12 h + 1100 CC
Molds 72 h
Molds 12 h + 3d plastic
Molds 12 h + dissipative cure
Molds 12 h + 1d plastic
Molds 12 h + PAMS cure
Molds 12 h + wet cure
Molds 12 h

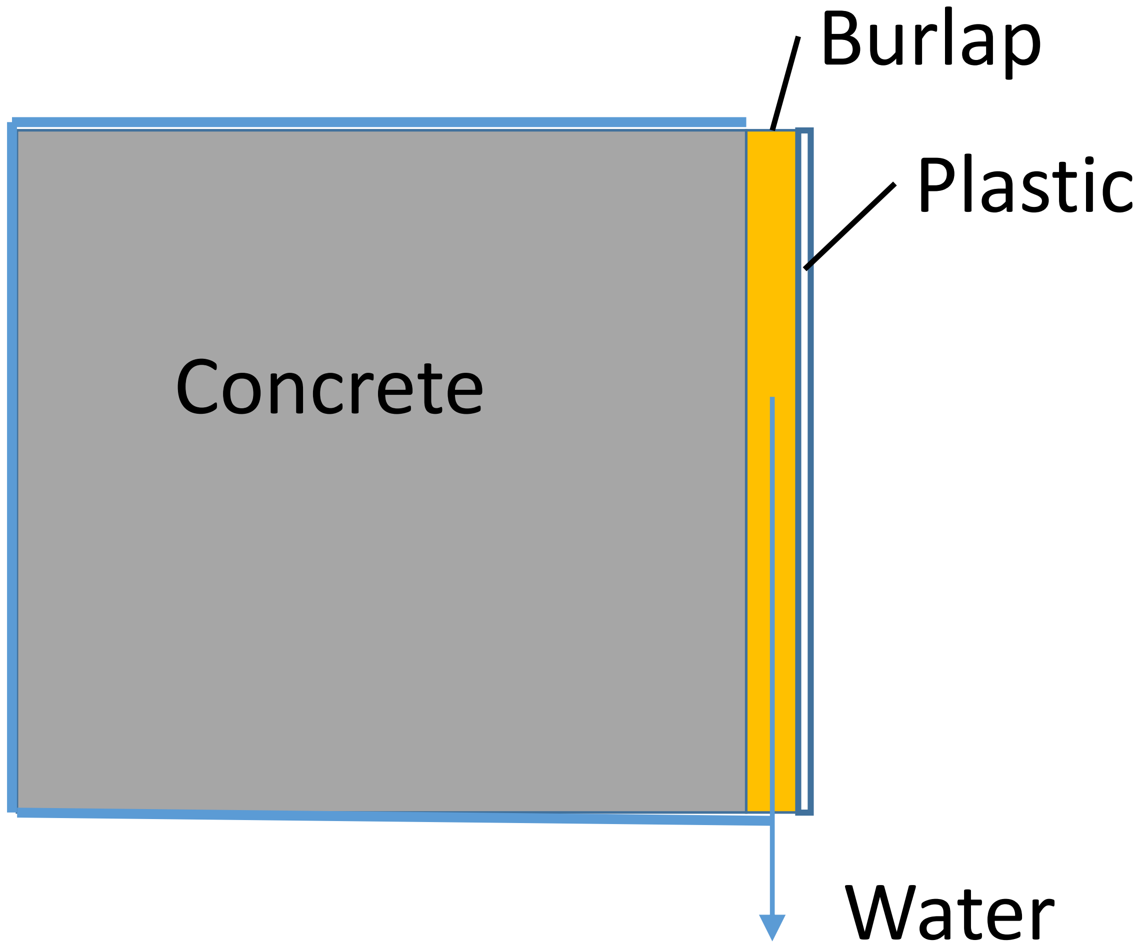


Days
Mass change (%)
steel molds 12 h
steel molds 24 h
steel molds 72 h
steel molds 12 h + 1d sealed cure
steel molds 12 h + 3d sealed cure
steel molds 12 h + 7d sealed cure
steel molds 12 h + 3d wet cure
steel molds 12 h + 7d wet cure
steel molds 12 h + 2245 CC
steel molds 12 h + 1100 CC
Molds 72 h
Molds 12 h + 3d plastic
Molds 12 h + dissipative cure
Molds 12 h + 1d plastic
Molds 12 h + PAMS cure
Molds 12 h + wet cure
Molds 12 h

Discussion

- The sample cured in steel molds for 12 h did the worst and the sample in the steel molds for 72 h did the best.
- The samples that were sealed with plastic for 3 d and 7 d and curing with the dissipative curing compound performed slightly less to samples cured in the steel molds for 72 h.

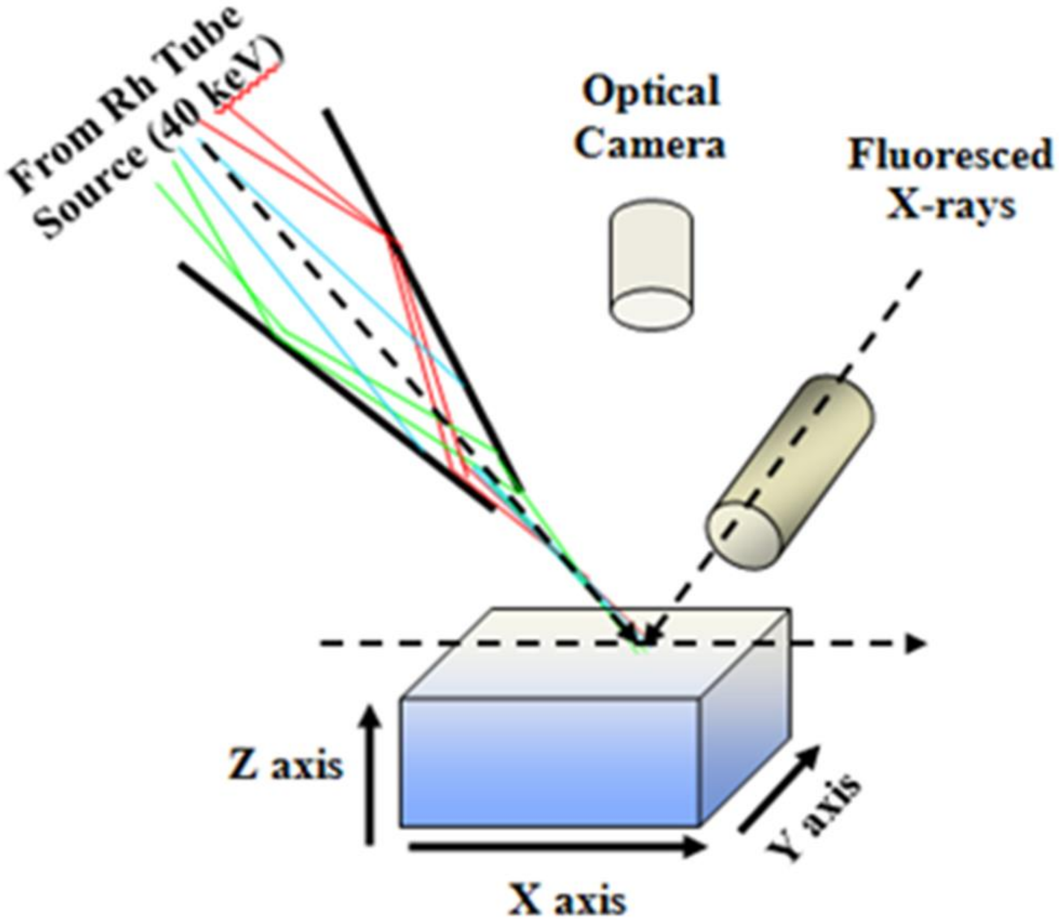
- The wet curing samples did not perform well. This is probably because the burlap did not hold the moisture on the surface of the concrete.


Burlap
Plastic
Concrete
Water

Chloride Profiles

- Next we cut the samples and investigated the surface with a XRF microscope

µXRF technique description



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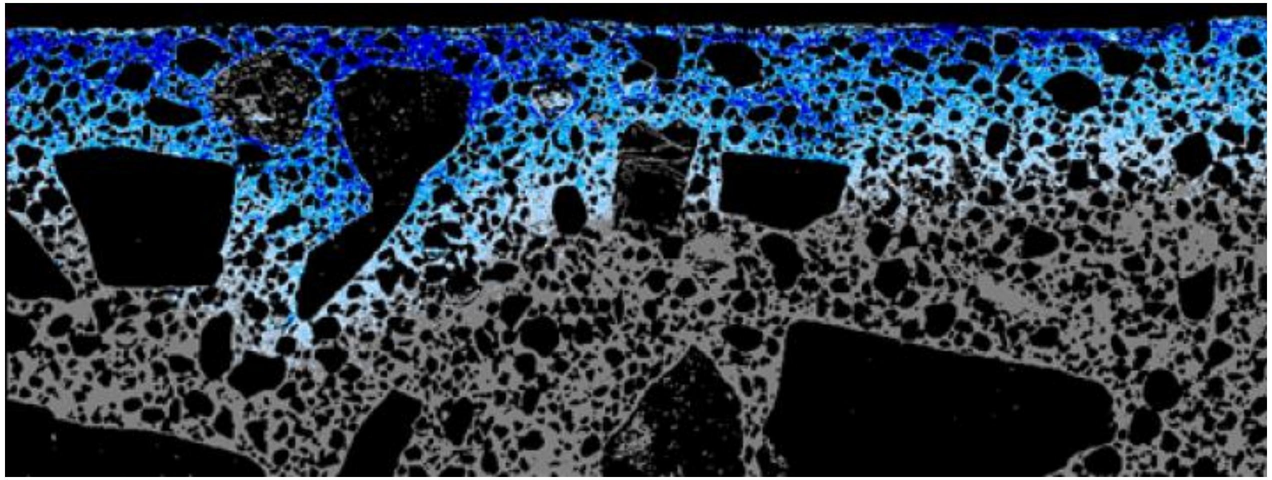
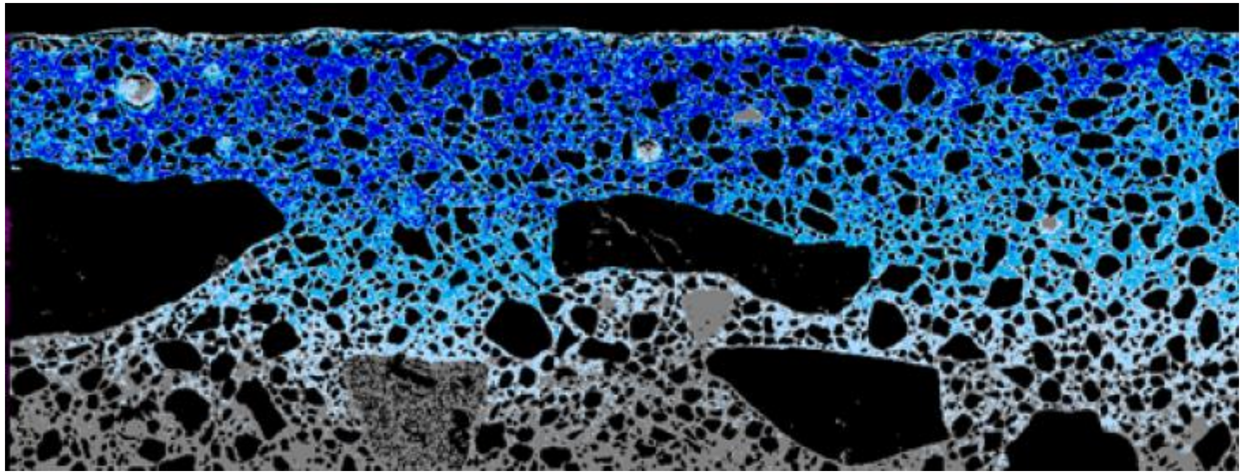
“Good”
Curing

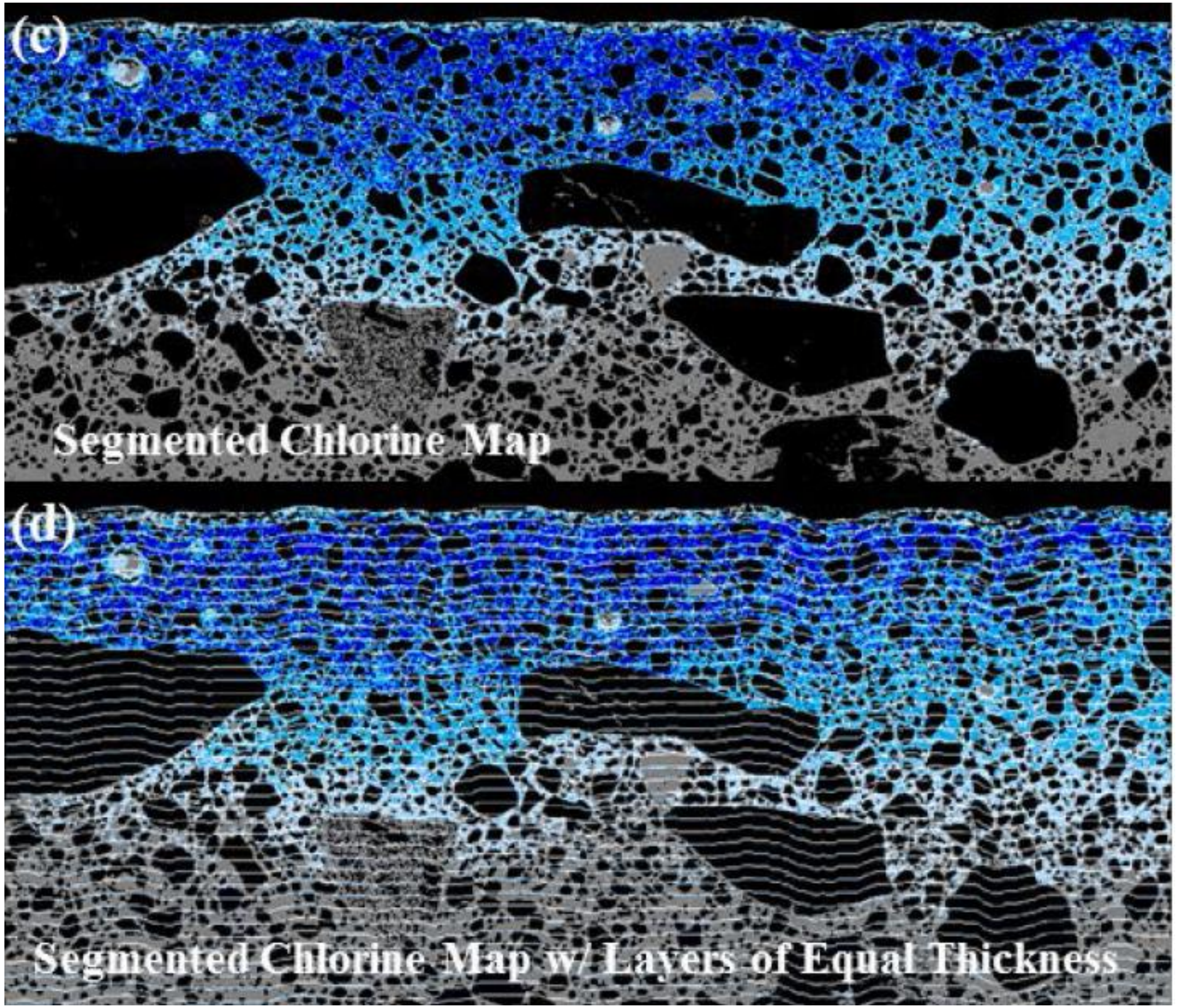
“Not as Good”
Curing



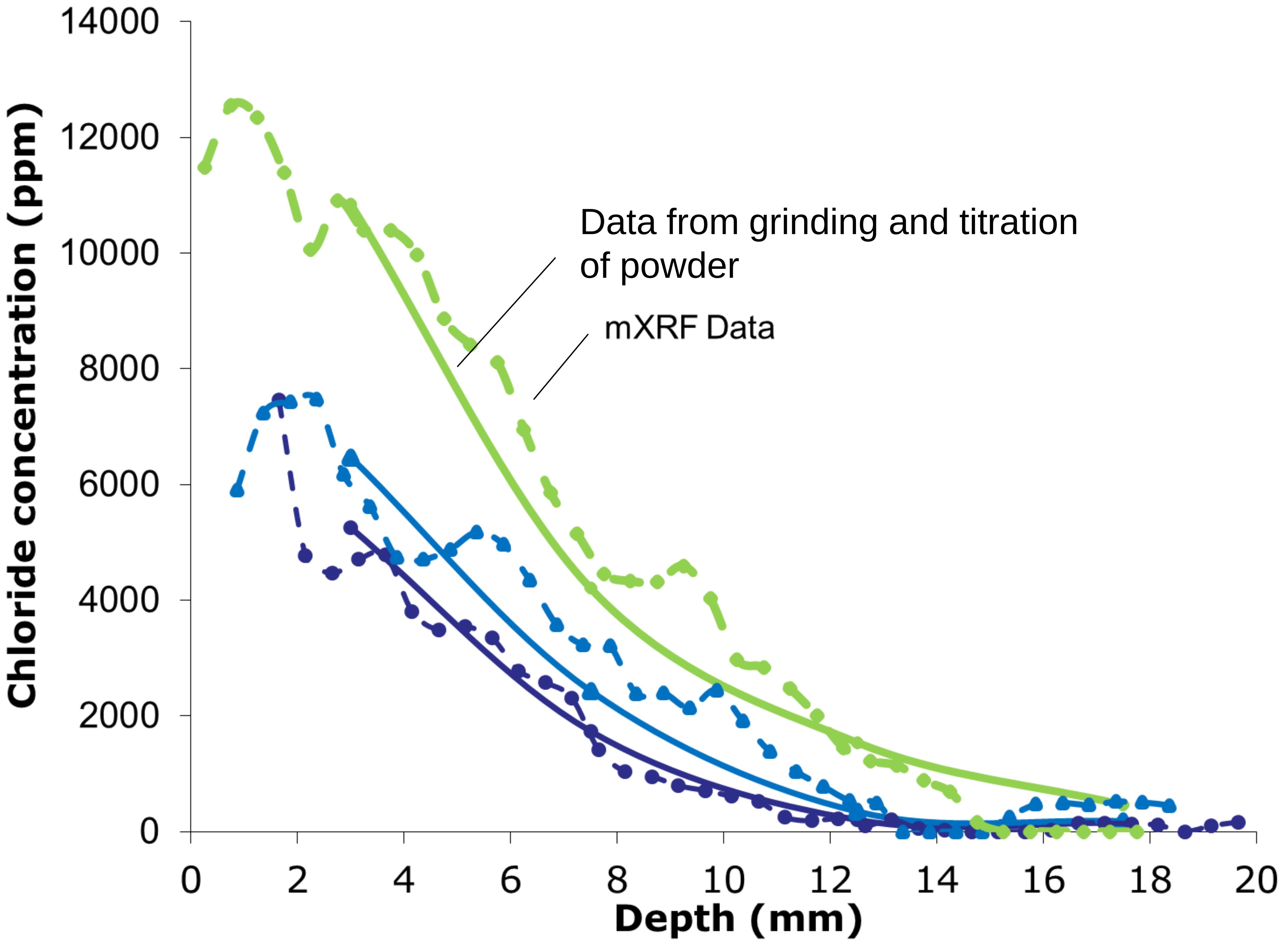


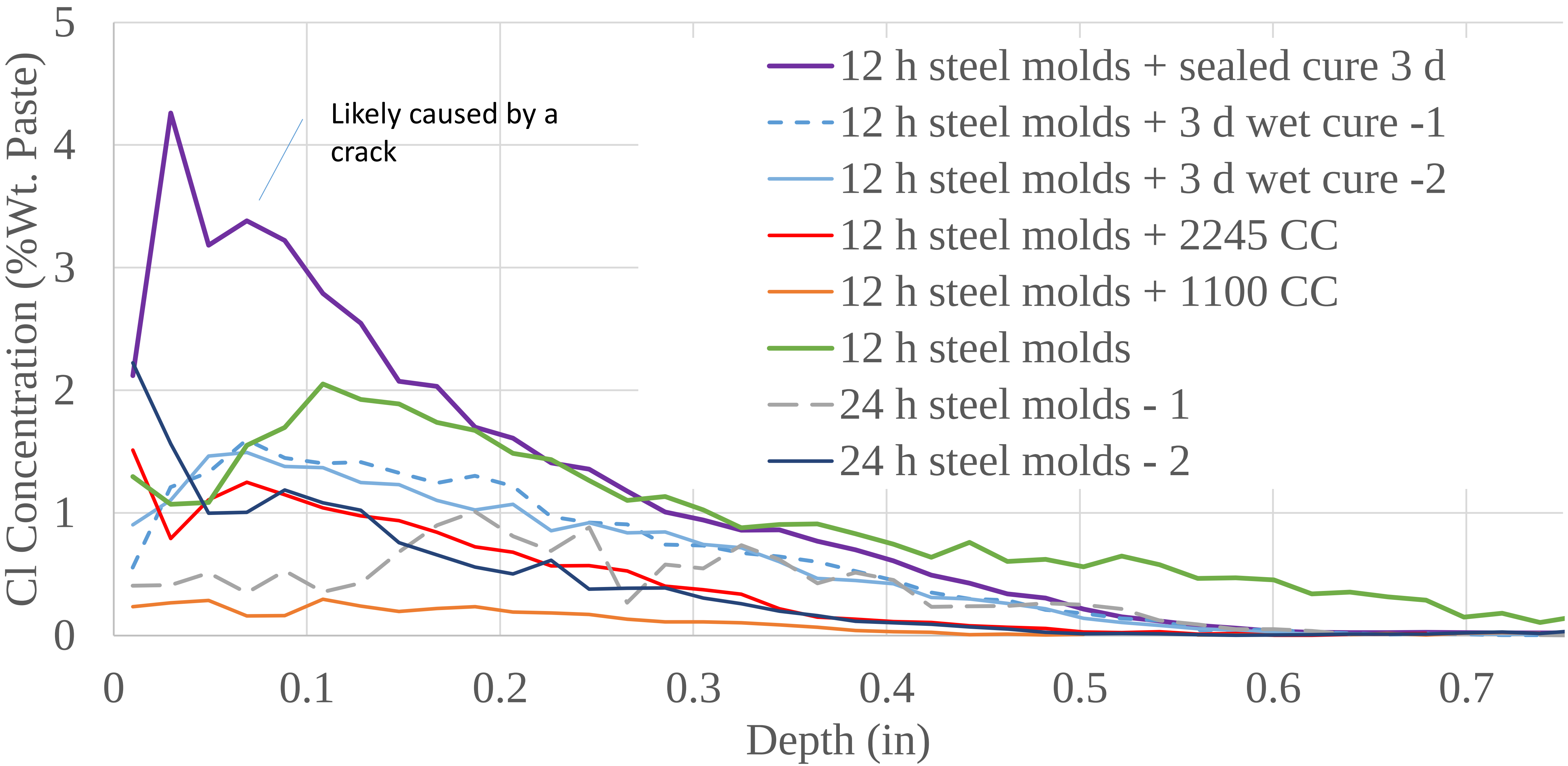
Black regions are aggregates

none	Low	medium	high
Paste: Cl <300 ppm	Paste: 0.3K< Cl <2K ppm	Paste: 2K< Cl <6K ppm	Paste: Cl > 6K ppm



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


Chloride concentration (ppm)
14000
12000
10000
8000
6000
4000
2000
0
0
2
4
6
8
10
12
14
16
18
20
Depth (mm)
Data from grinding and titration of powder
mXRF Data


Likely caused by a crack
12 h steel molds + sealed cure 3 d
12 h steel molds + 3 d wet cure -1
12 h steel molds + 3 d wet cure -2
12 h steel molds + 2245 CC
12 h steel molds + 1100 CC
12 h steel molds
24 h steel molds - 1
24 h steel molds - 2
Cl Concentration (%Wt. Paste)
Depth (in)
0
1
2
3
4
5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7

	Service life in years for 2'' cover of epoxy coated steel bar	% reduction in service life compared to 24 h curing in the steel molds
24 h steel molds - 2	42	~
12 h steel molds + 2245 CC	35	17
12 h steel molds + sealed cure 3 d	34	19
12 h steel molds + 1100 CC	32	24
12 h steel molds + 3 d wet cure -1	30	29
12 h steel molds + 3 d wet cure -2	28	33
12 h steel molds - 2	27	36
12 h steel molds - 1	27	36

Discussion

- Based on service life models in Minneapolis with epoxy coated rebar with 2” cover -
- You can increase your service life by 36% if you leave the forms in place for 24 h instead of 12 h.

Discussion

- If forms are removed at 12 h then it is suggested to use dissipative curing compound, PAMs curing compound, or require plastic to be placed for 3 days.

- The service life is reduced by about 20% for these concretes that use a combination of steel molds for 12 h plus some other method compared to leaving the forms in place for 24 h.

Discussion

- The wet curing samples did not perform well. This is likely because the burlap can not hold the moisture on the surface of the concrete on a vertical surface.

What does this mean?

Curing time in the forms does impact the durability of the concrete.

If concrete durability is important, then you should leave the forms in place for as long as practical.

If you remove the forms early, then you can continue to cure with a curing compound.

How about a bridge deck?

What is the cost of curing?

	$/sf*	Percentage of Oklahoma bridge cost/sf **
Burlap wet cure	0.42	0.47%
Premium curing compound	0.17	0.19%
Common curing compound	0.06	0.07%

* from an Oklahoma contractor

** Using $89/sf from 2013 NHS

Testing

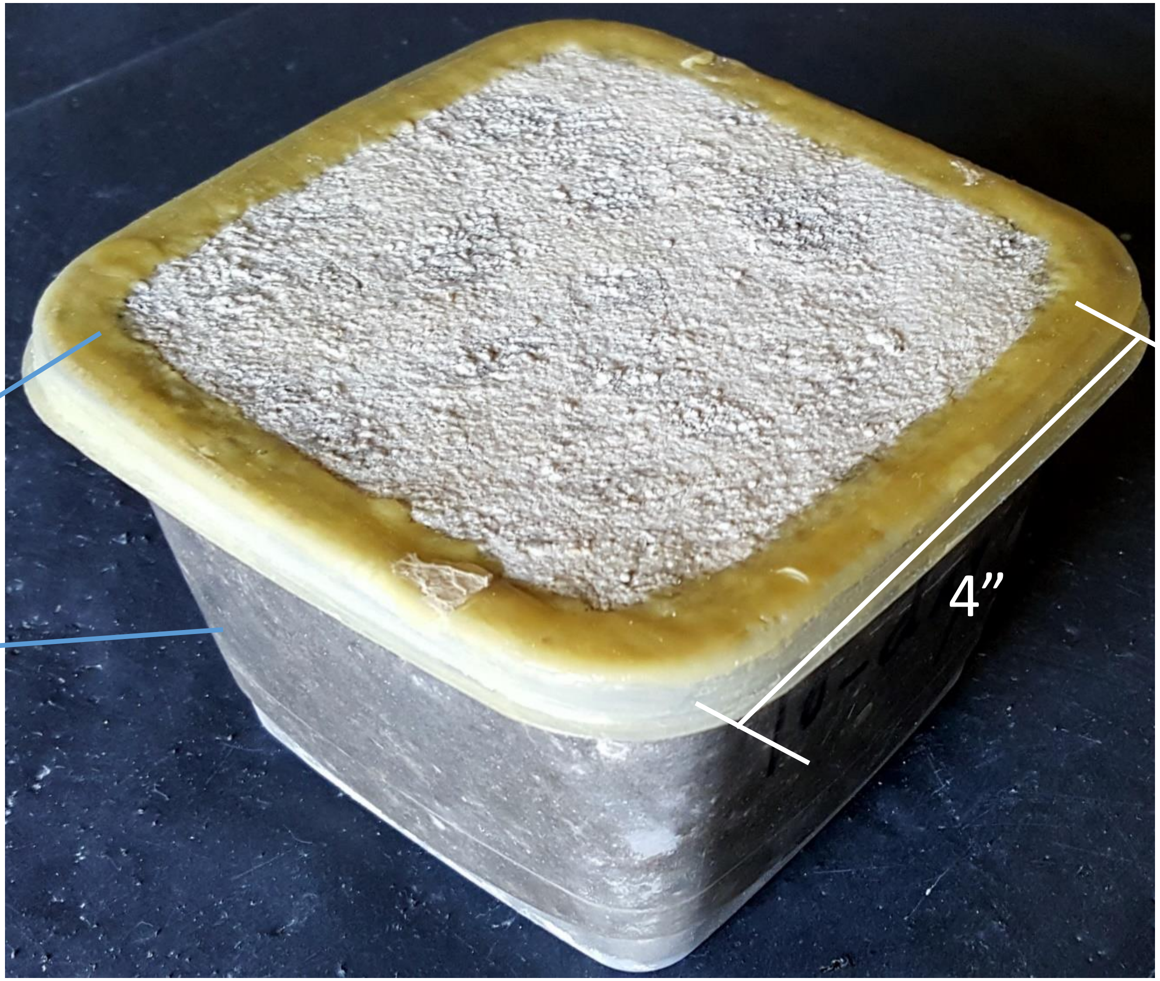
We developed a testing protocol to evaluate how curing impacts the concrete microstructure.

- 0.40 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

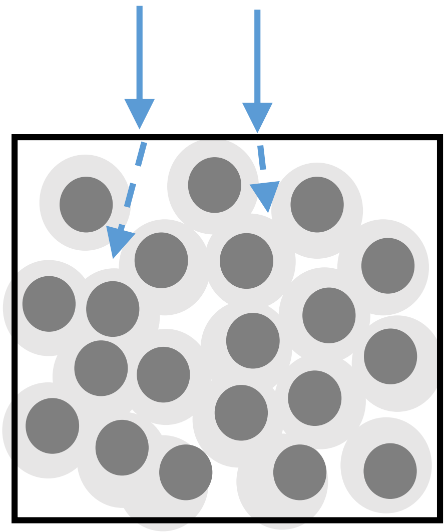

wax
plastic container
4”

Testing

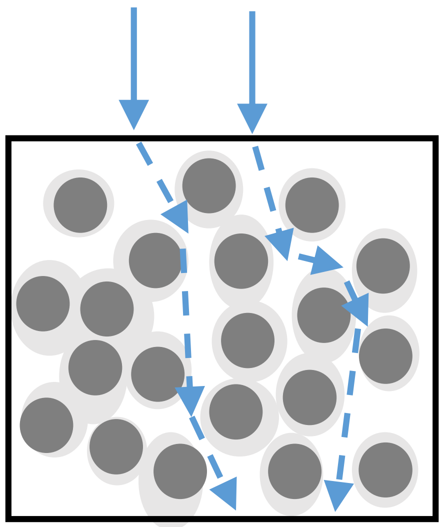
If the concrete is well cured then:

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.

Remember the straws!!!



Good curing



Poor curing

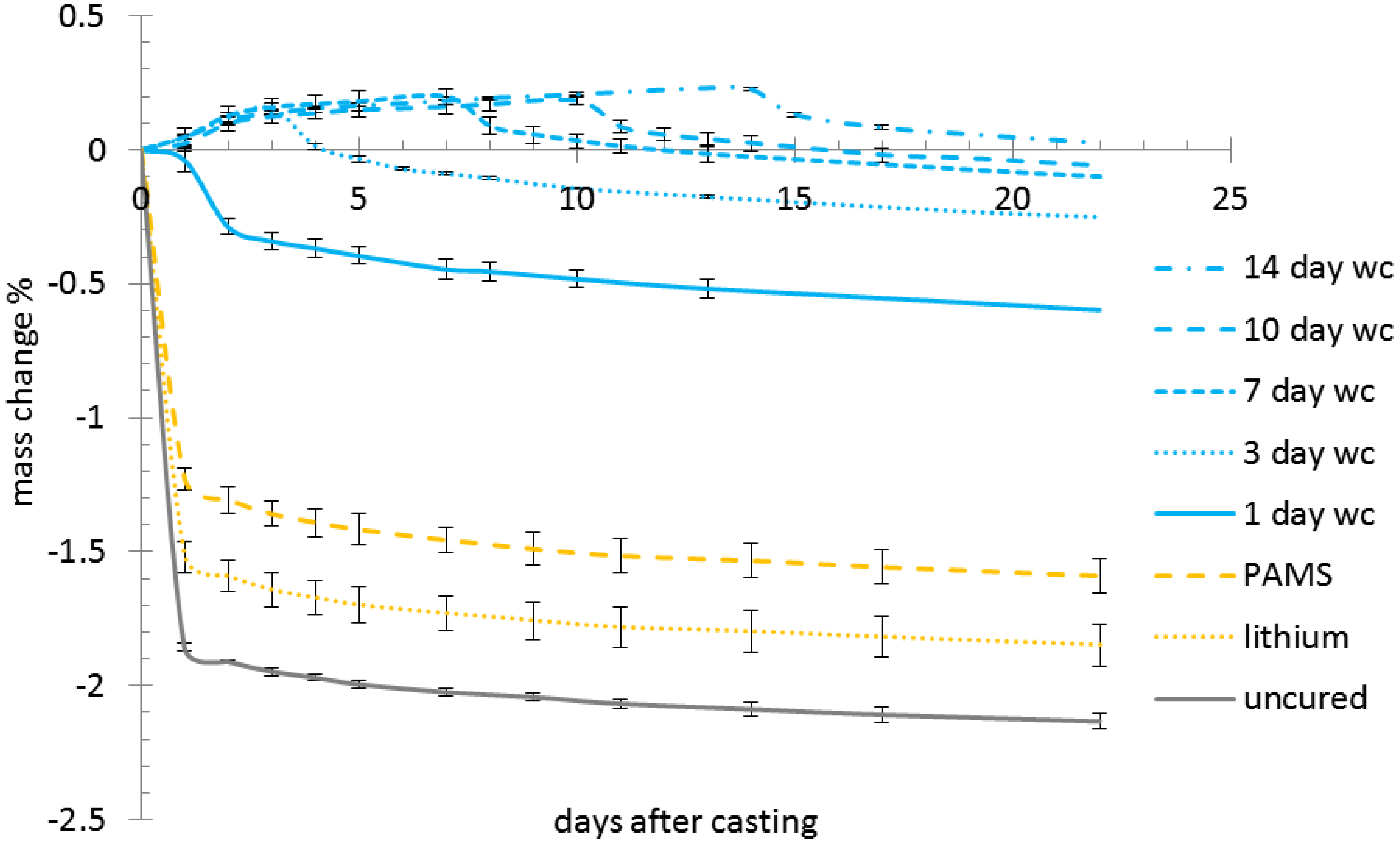
What did we do?

Step	Test	Details
1	drying	Mass change in 40% RH and 73^{o}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^{o}F for 22 days

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



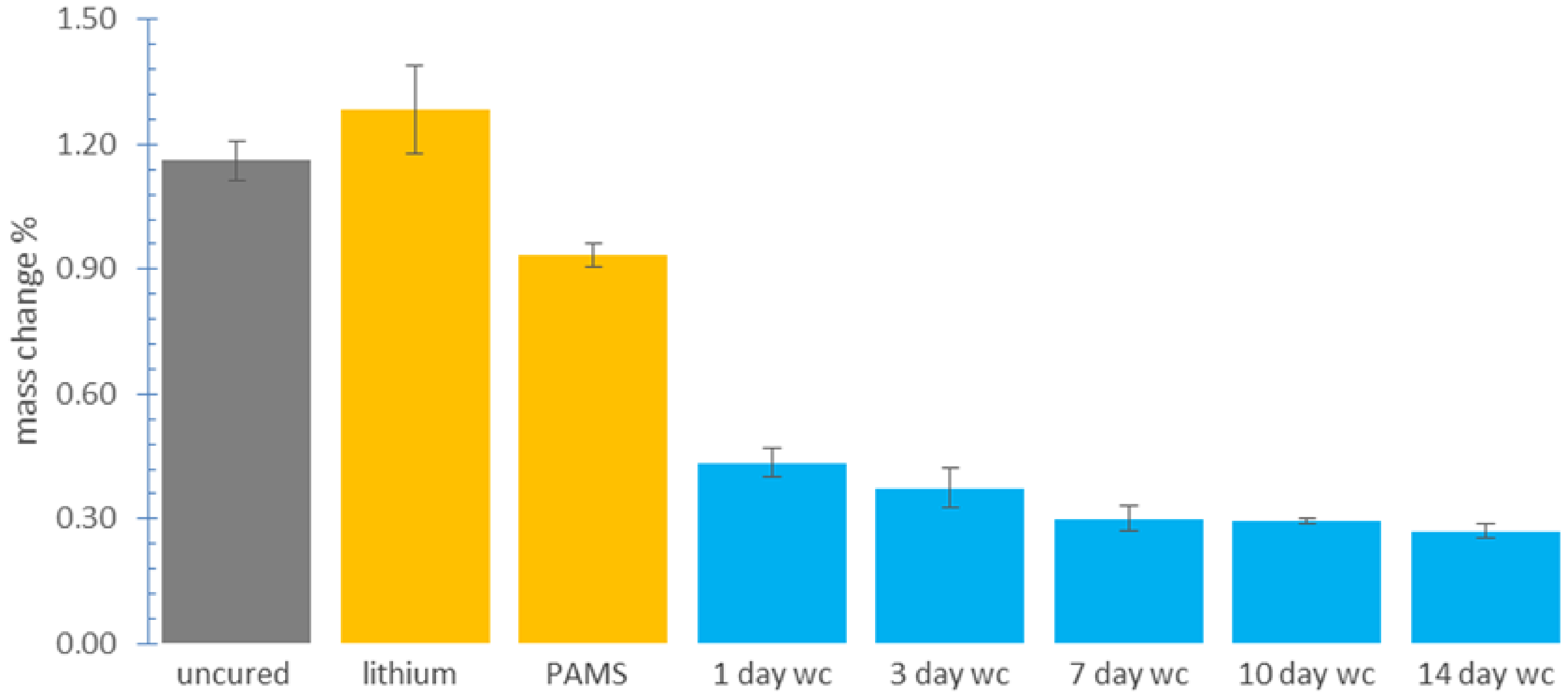
Discussion

- 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.

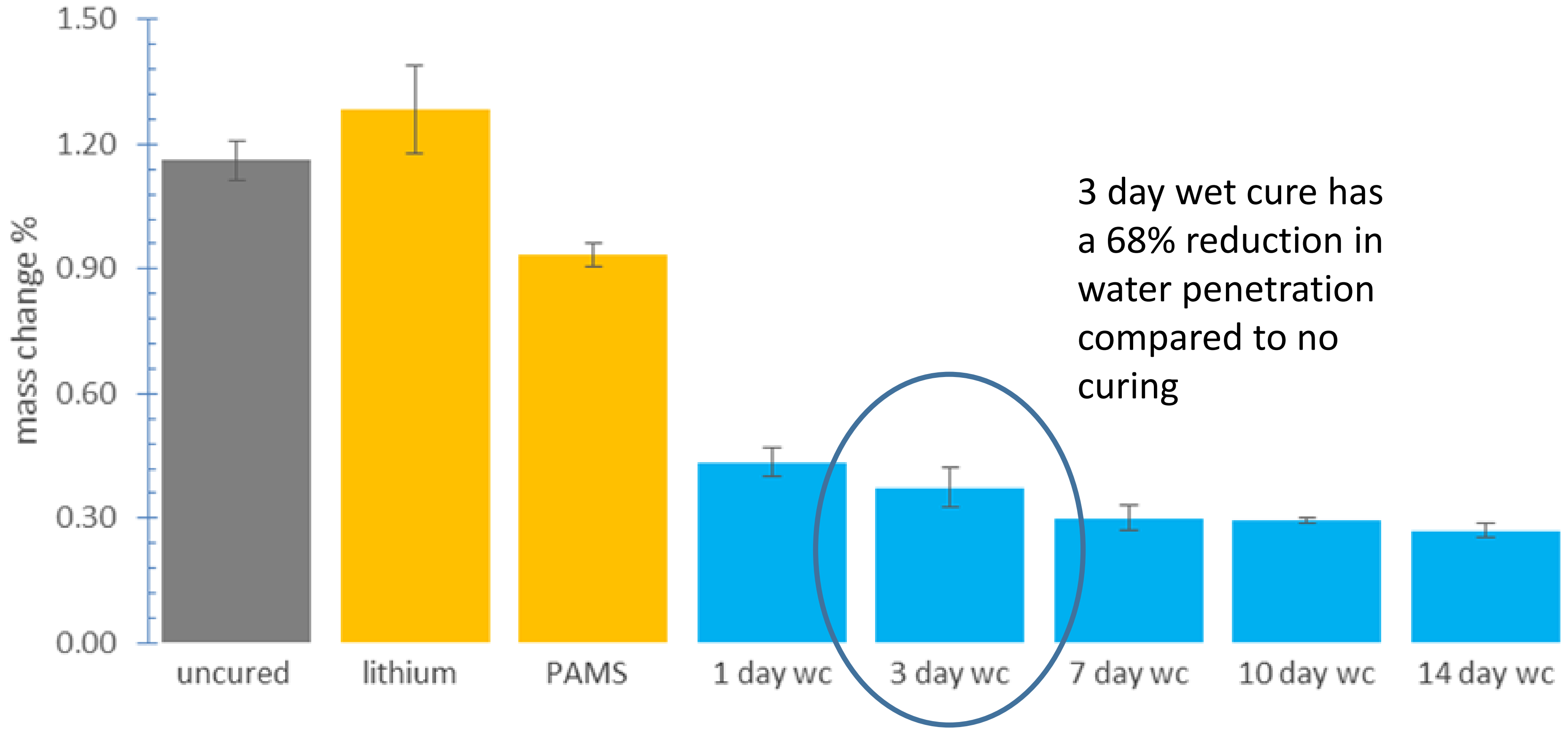
Step 2 – Place concrete in lime water

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

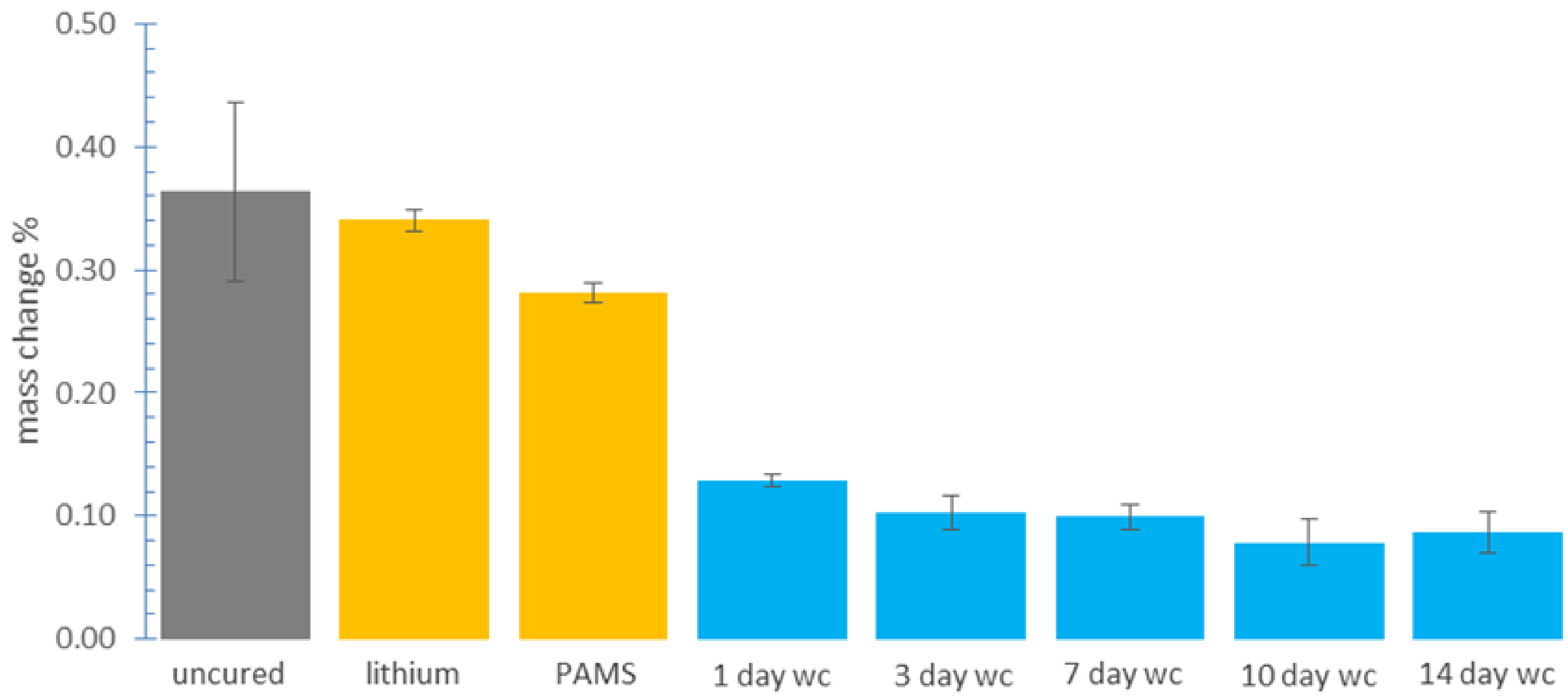


3 day wet cure has a 68% reduction in water penetration compared to no curing

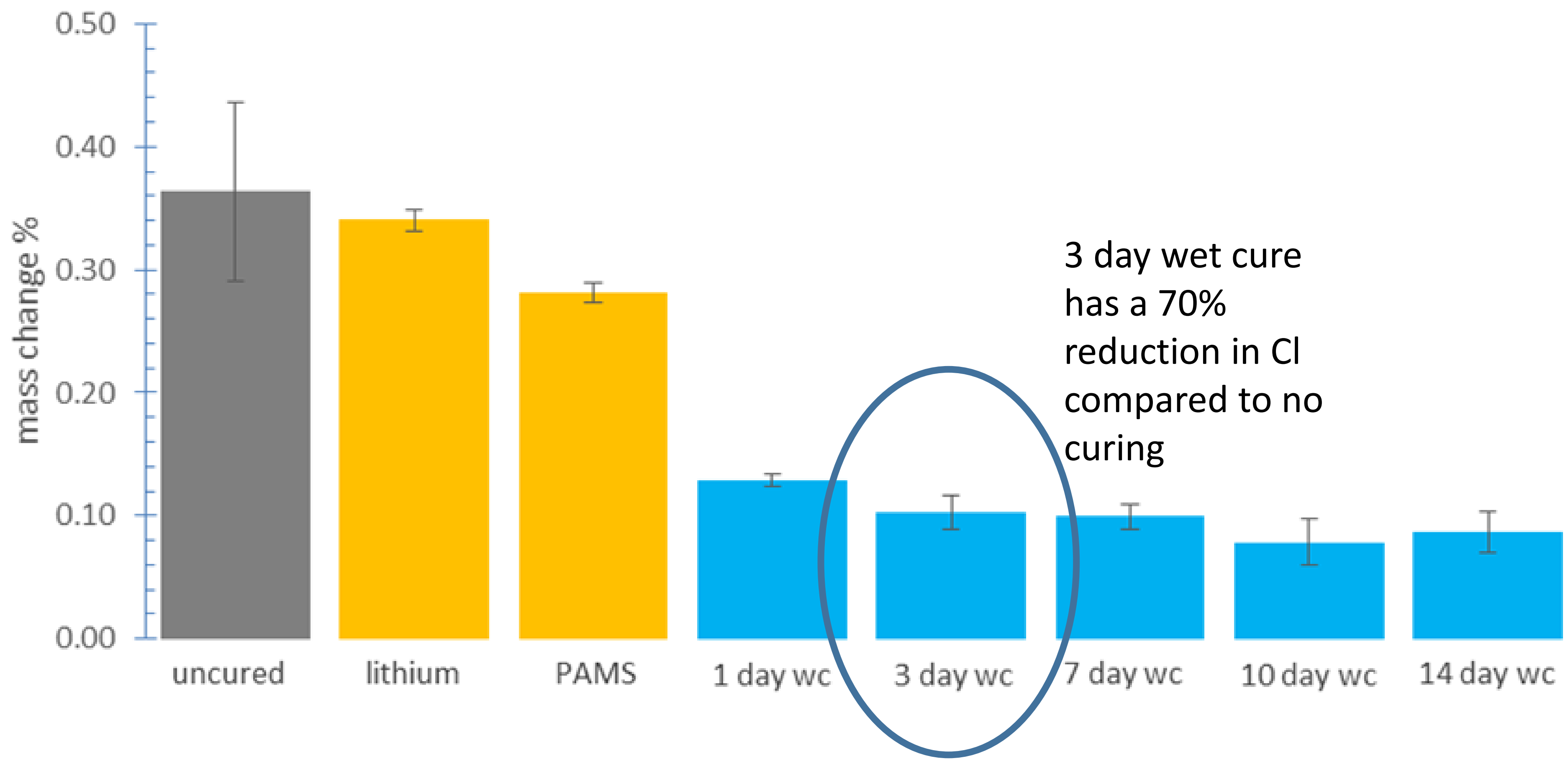
Step 3 – Place concrete in NaCl solution

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



3 day wet cure has a 70% reduction in Cl compared to no curing

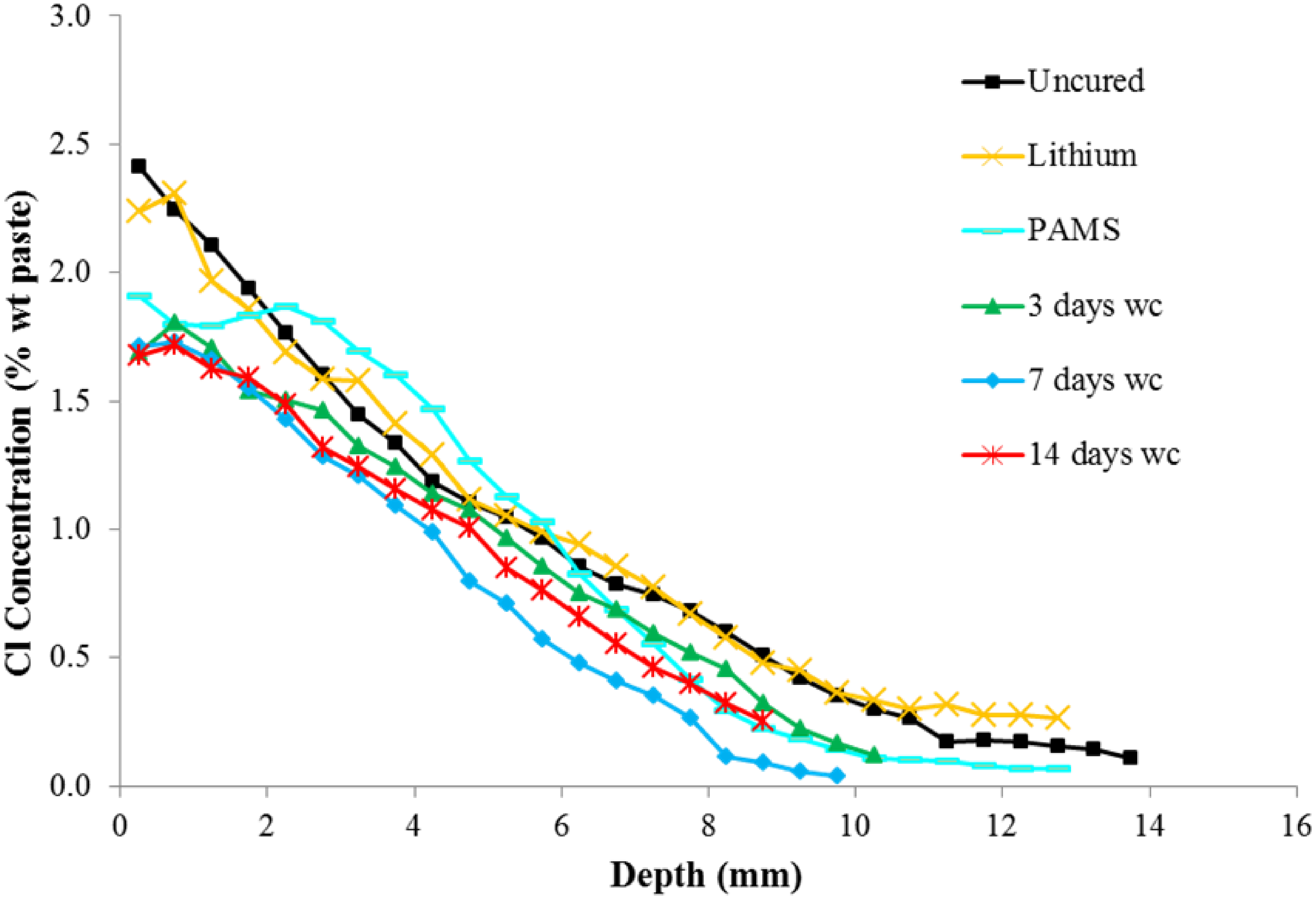
Discussion

- Concrete with a dense microstructure will gain less mass when wetting
- The trends are similar for initial water uptake and long term chloride penetration
- Lithium silicates performed similarly to no curing
- 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

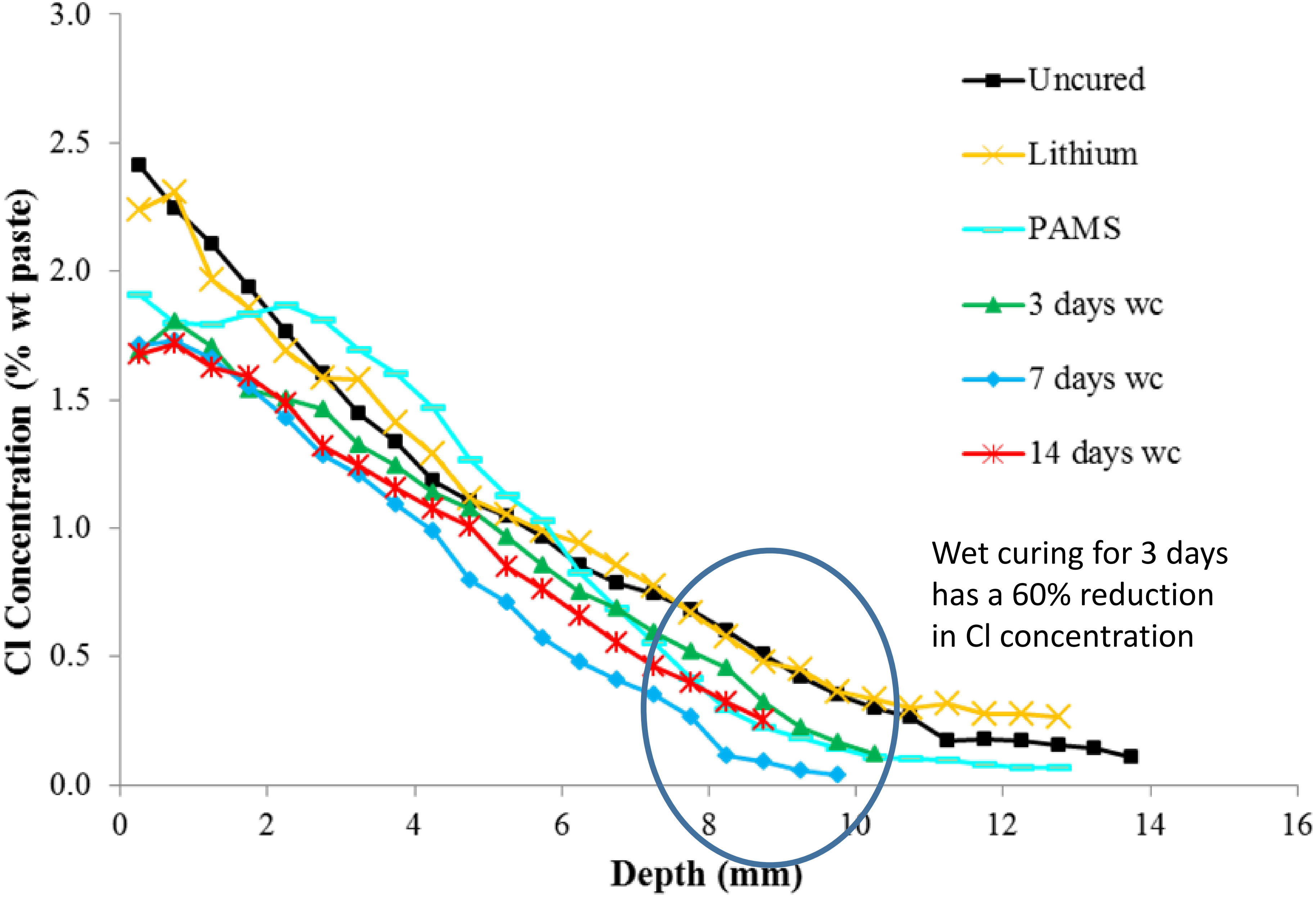
Chloride Profiles

- Next we cut the samples and investigated the surface with a XRF microscope

4. Chloride profile



4. Chloride profile



Wet curing for 3 days has a 60% reduction in Cl concentration

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	0.42	0.47%
Premium curing compound	0.17	0.19%
Common curing compound	0.06	0.07%

* from an Oklahoma contractor

** Using $89/sf from 2013 NHS

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

Discussion

- The mass change from drying, moisture absorption, and chloride diffusion showed similar trends
- Lithium silicate and no curing had similar performance
- PAMS showed improved performance but not as good as wet cure
- Curing for 7 days had slightly better performance than 3 days.
- You can approximately double the lifespan of your bridge deck against chloride ingress with wet curing for 3 days over not curing

Conclusions

- Curing is an important part of the construction process that is often overlooked.

- Just because the concrete is strong does not mean it has stopped reacting.

- Not all curing methods are created equal and they should be chosen based on the long term needs of the concrete.

Questions?
www.tylerley.com
www.youtube.com/tylerley

Thank You!

This concludes the Continuing Education Program.

Any Questions?

Tyler Ley

www.tylerley.com

www.youtube.com/tylerley

Instagram:

Concrete.tyler

Tyler.ley@okstate.edu

405-744-5257

Do you think curing compounds and wet curing provide the same quality of curing?

If not then how different are they?

Curing for Durability

Does curing really impact durability?

Is curing worth the cost?

Let’s compare different curing methods…

Wet curing

Curing compounds

No curing

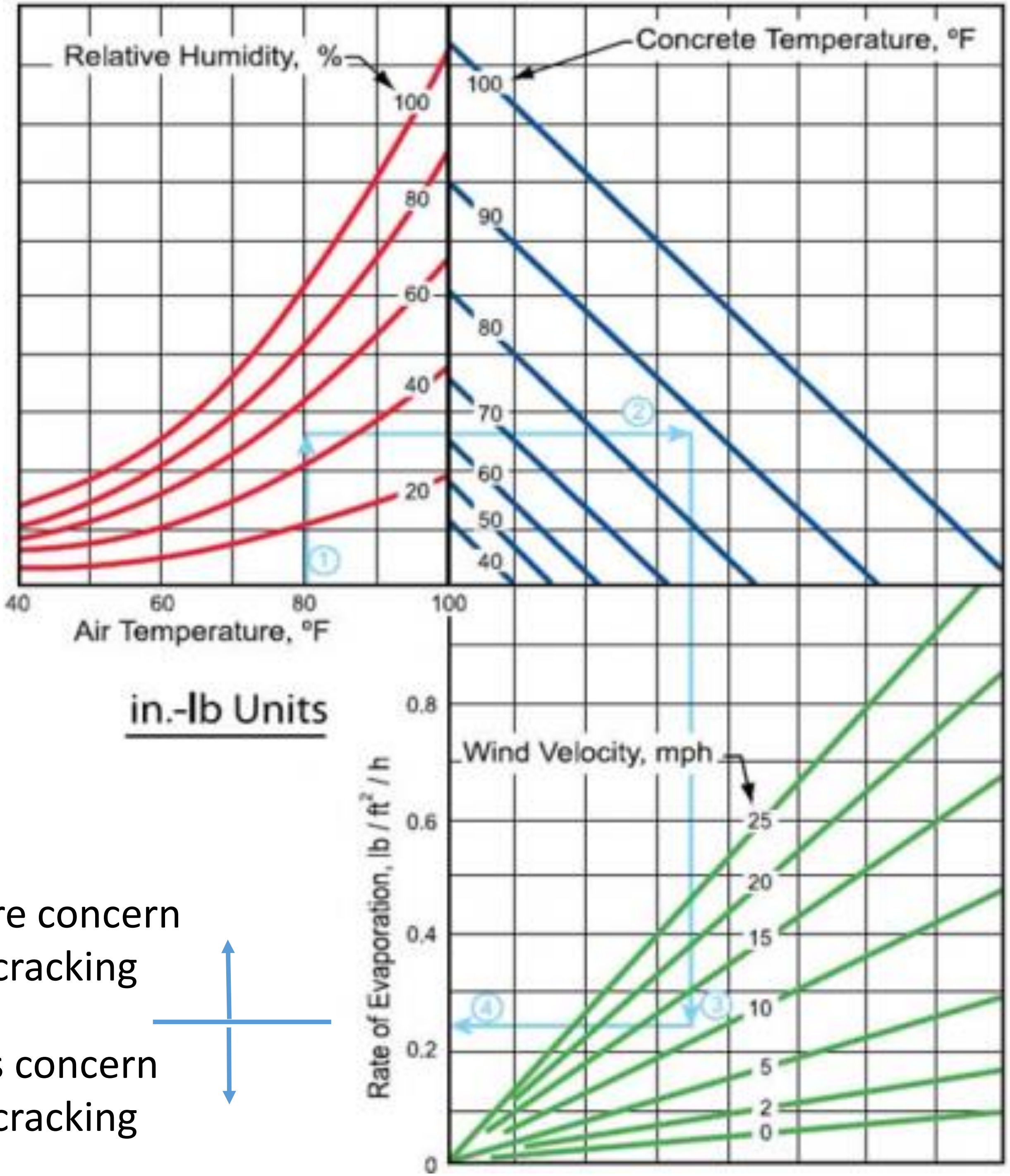
Why is wet curing challenging?

1. Wet curing requires significant labor
2. If placed too early wet burlap can scar the surface and reduce cover
3. We don’t do a good job of keeping the burlap wet
4. Challenging to inspect
5. Expensive

For more videos go to:

www.tylerley.com/WOCcure

Plastic shrinkage cracking nomograph

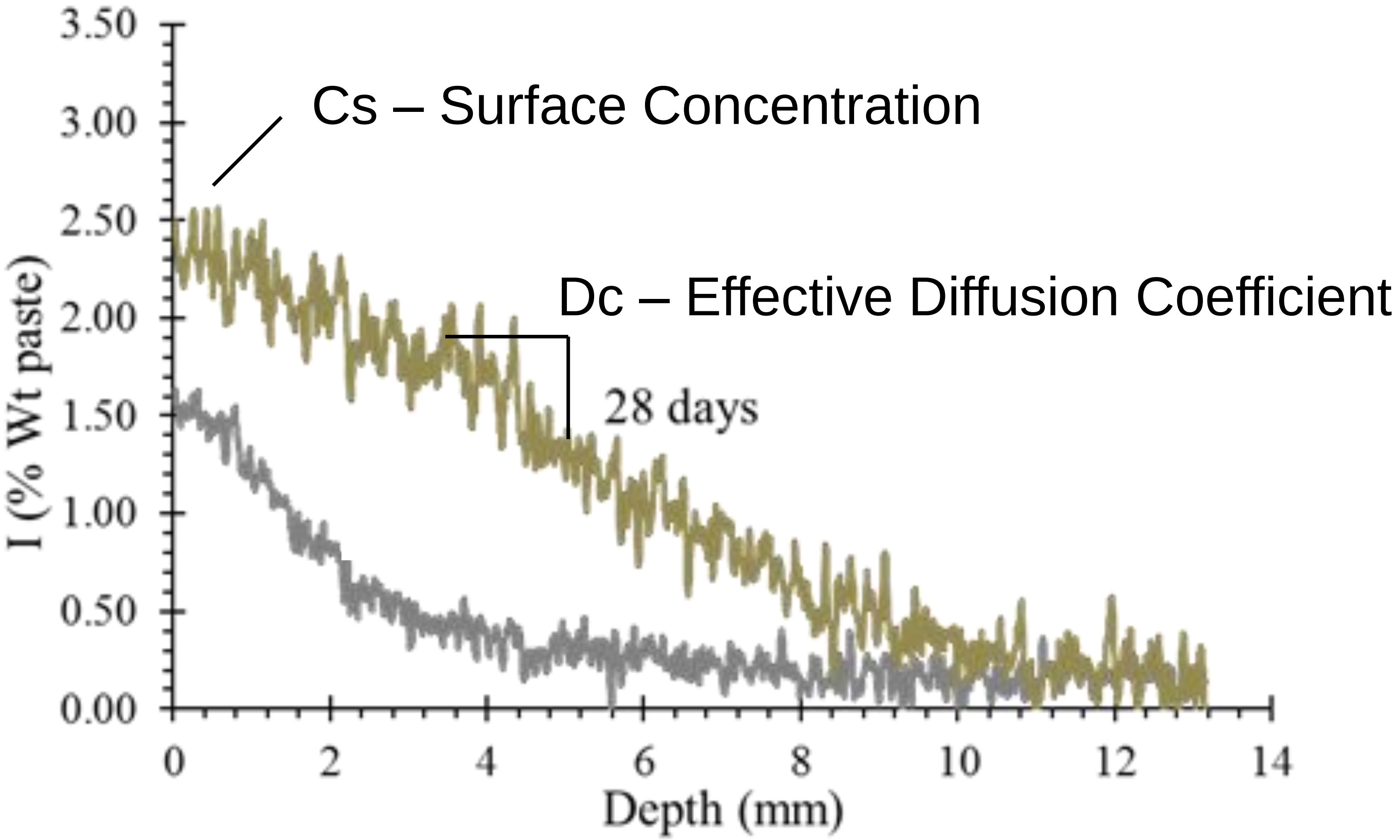


More concern for cracking

Less concern for cracking

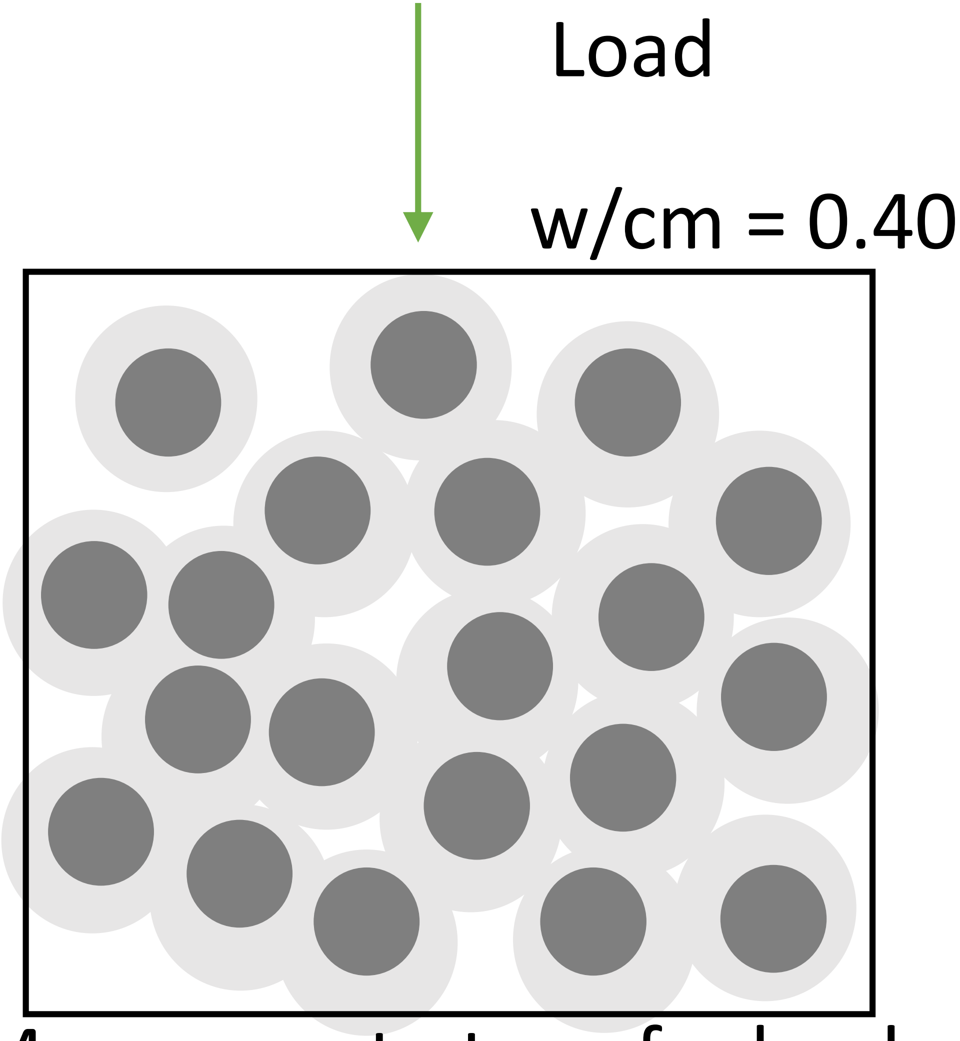
Ion penetration

$$C_{(x,t)} = C_s\left(1 - \mathrm{erf}\left(\frac{x}{2\sqrt{D_c t}}\right)\right)$$

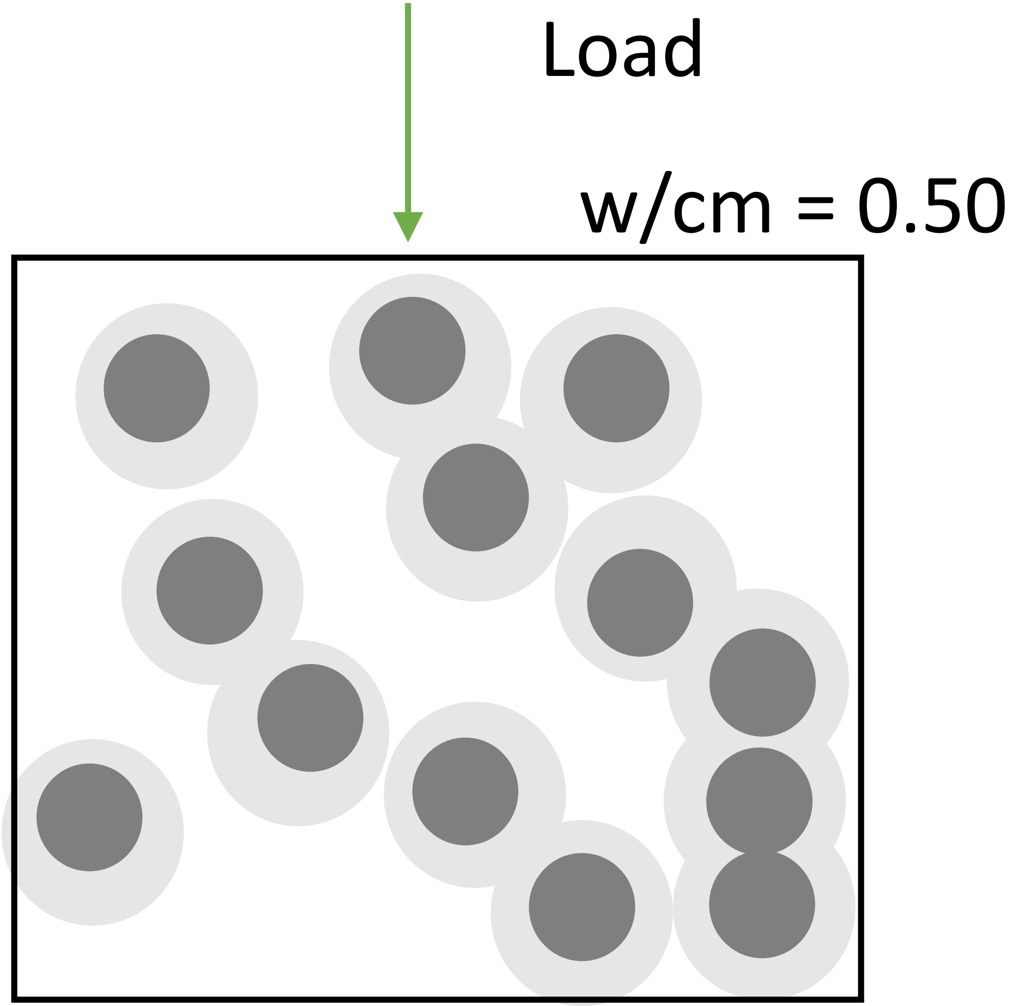


Why do we do this?

Strength

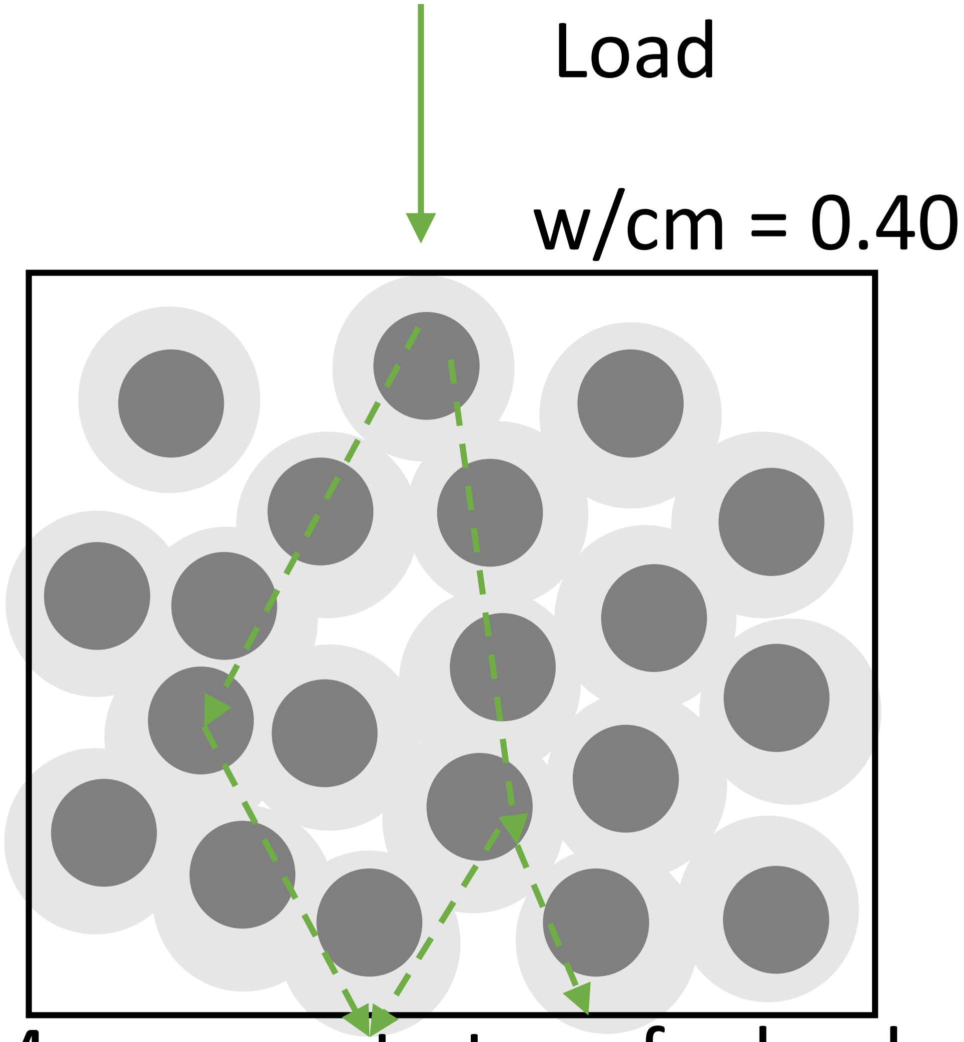


More ways to transfer load

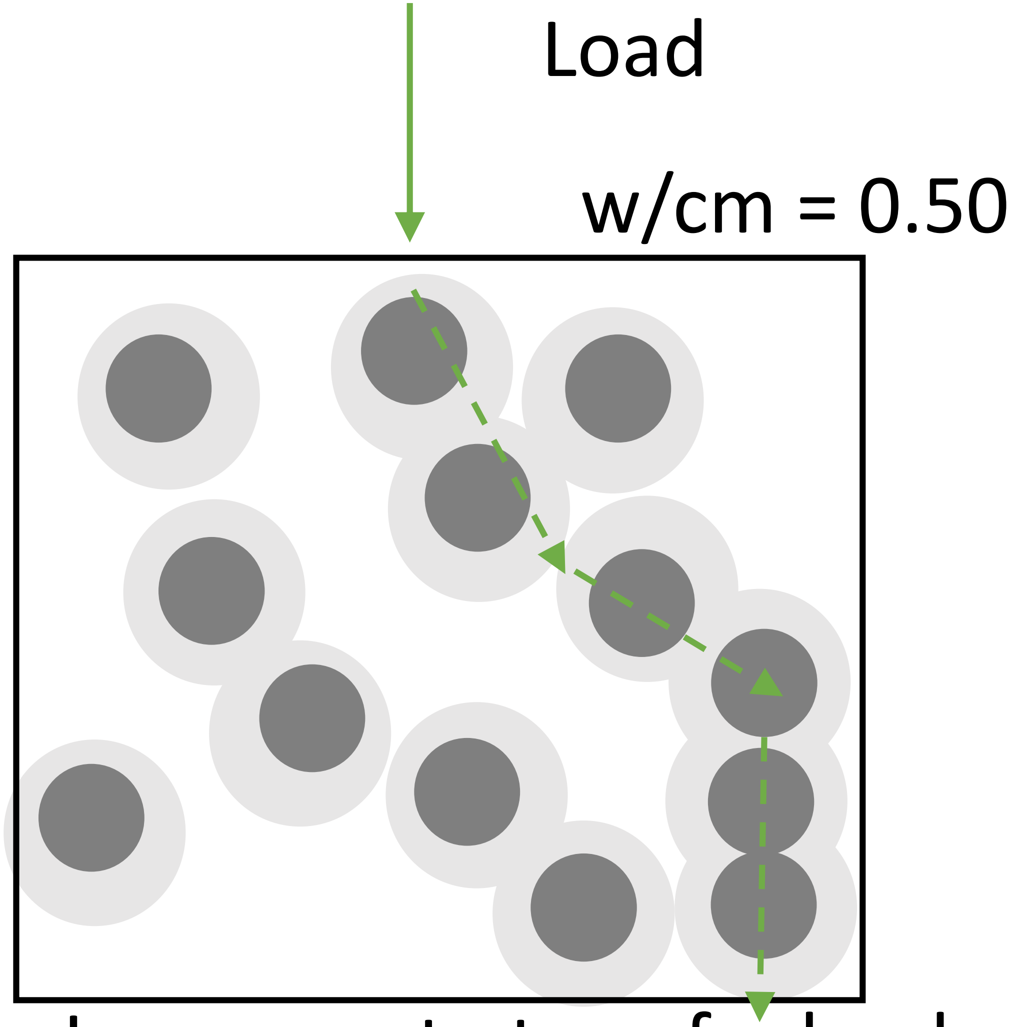


Less ways to transfer load

Strength

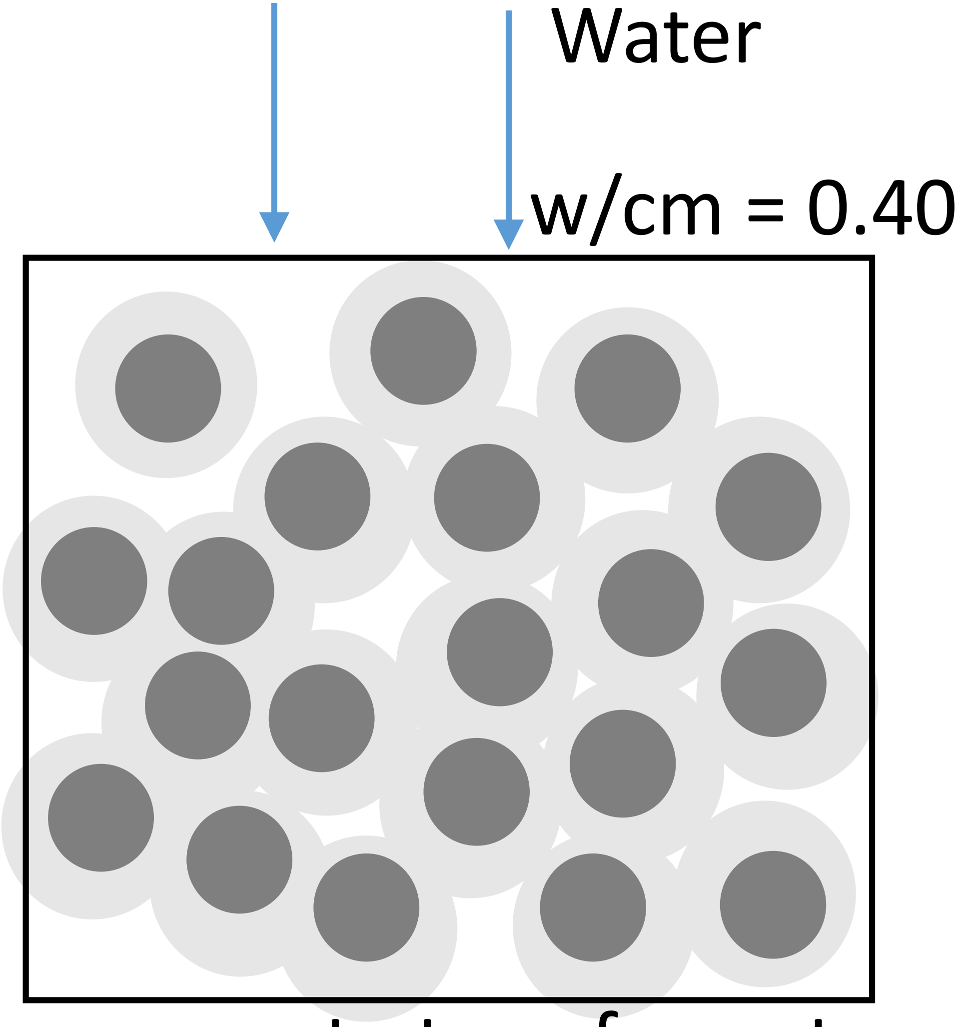


More ways to transfer load

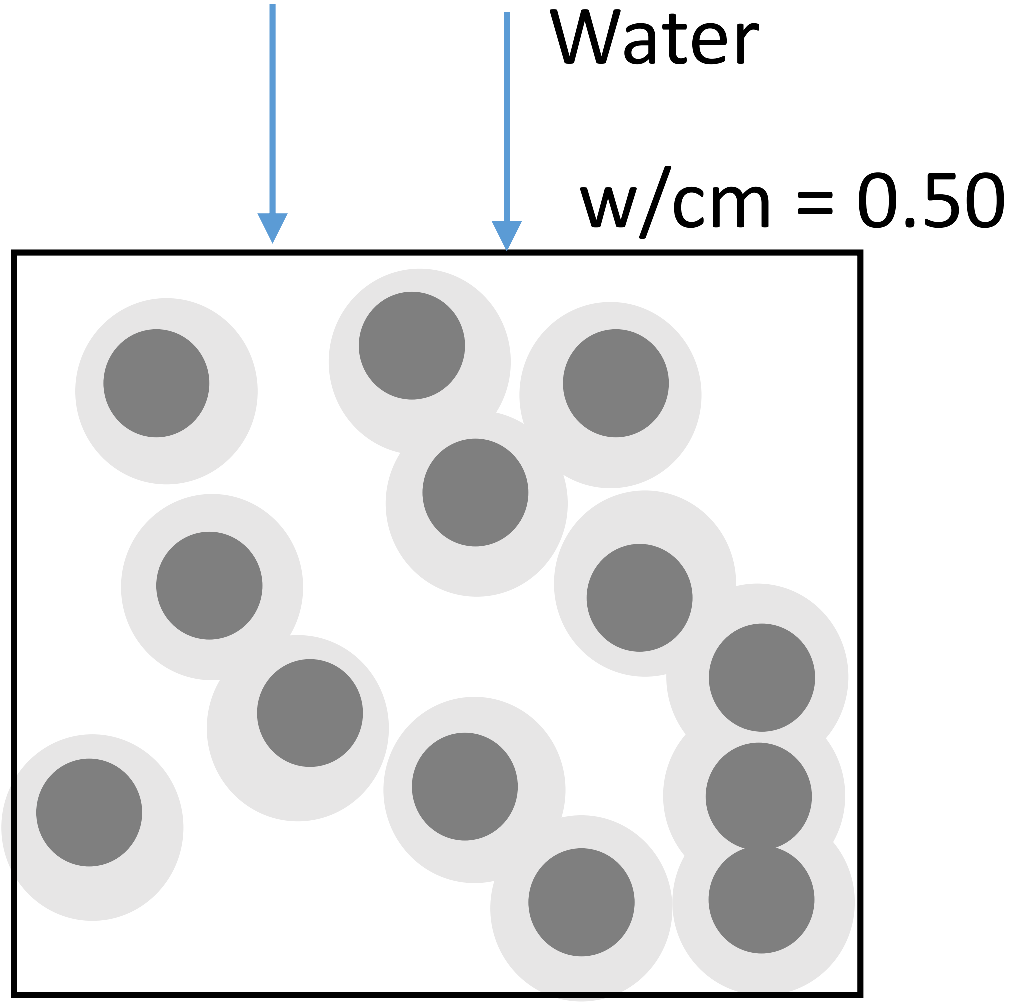


Less ways to transfer load

Permeability

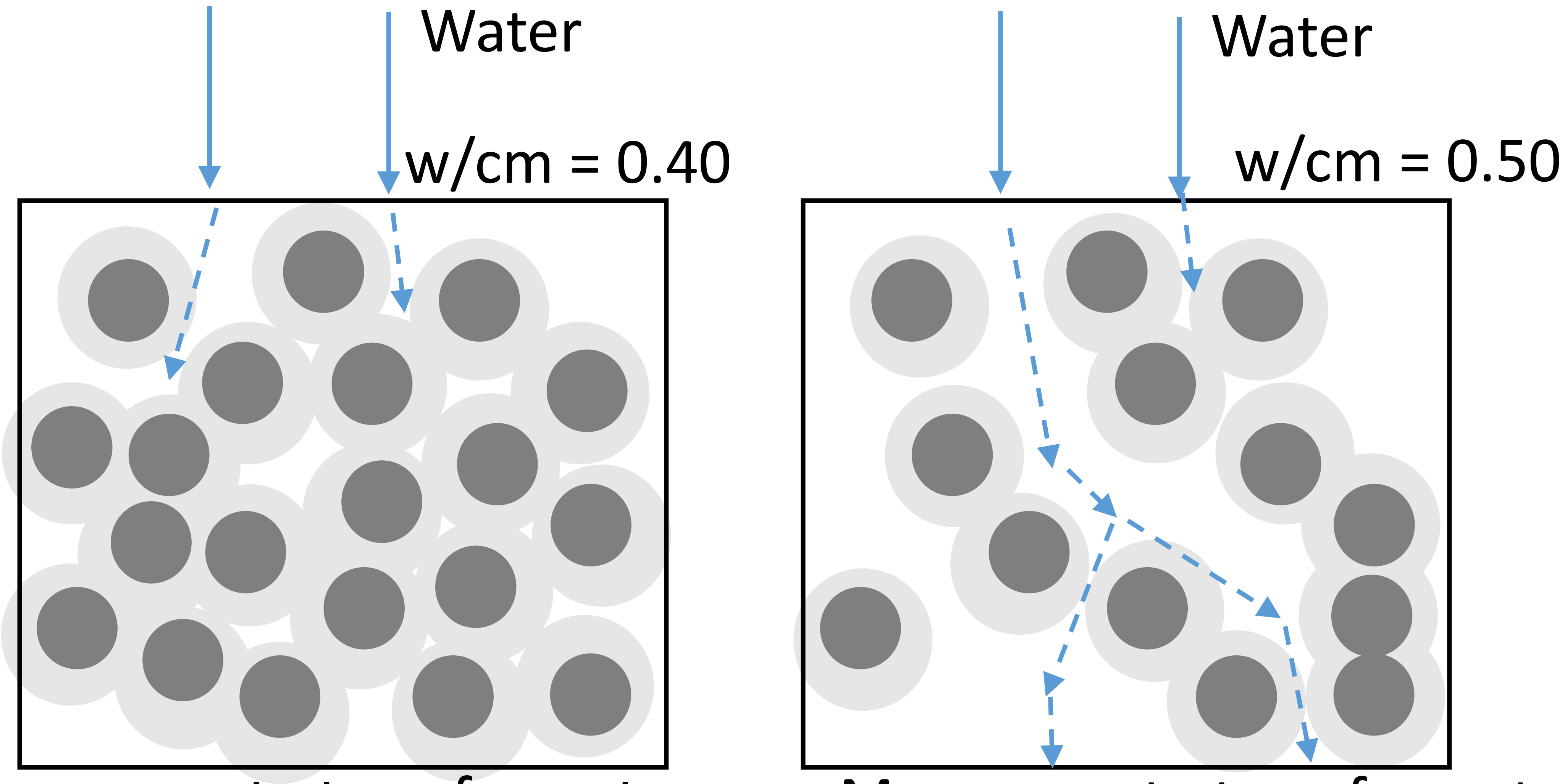


Less ways to transfer water



More ways to transfer water

Permeability



Less ways to transfer water

More ways to transfer water

Summary

The lower w/cm mixture did a better job at transferring load and keeping water out than the higher w/cm mixture.

Summary

The lower w/cm mixture did a better job at transferring load and keeping water out than the higher w/cm mixture.

Remember! w/cm is only the first step.

Curing promotes hydration!

We want to hold moisture and heat within the concrete

We want to protect and strengthen the surface