



# THE WONDERFUL WORLD

OF  
Concrete

Acknowledgements

Minnesota Concrete Association

Josh Edwards

Priscilla Conway

Oklahoma DOT



# Why I do what I do

I believe concrete is the greatest material in the world.

I want to making it easier to construct, more durable, lower cost, and more sustainable.

I help build people and tools to make the concrete industry better.

> 99K subscribers  
> 10M views



# Structural Cracking in Reinforced Concrete

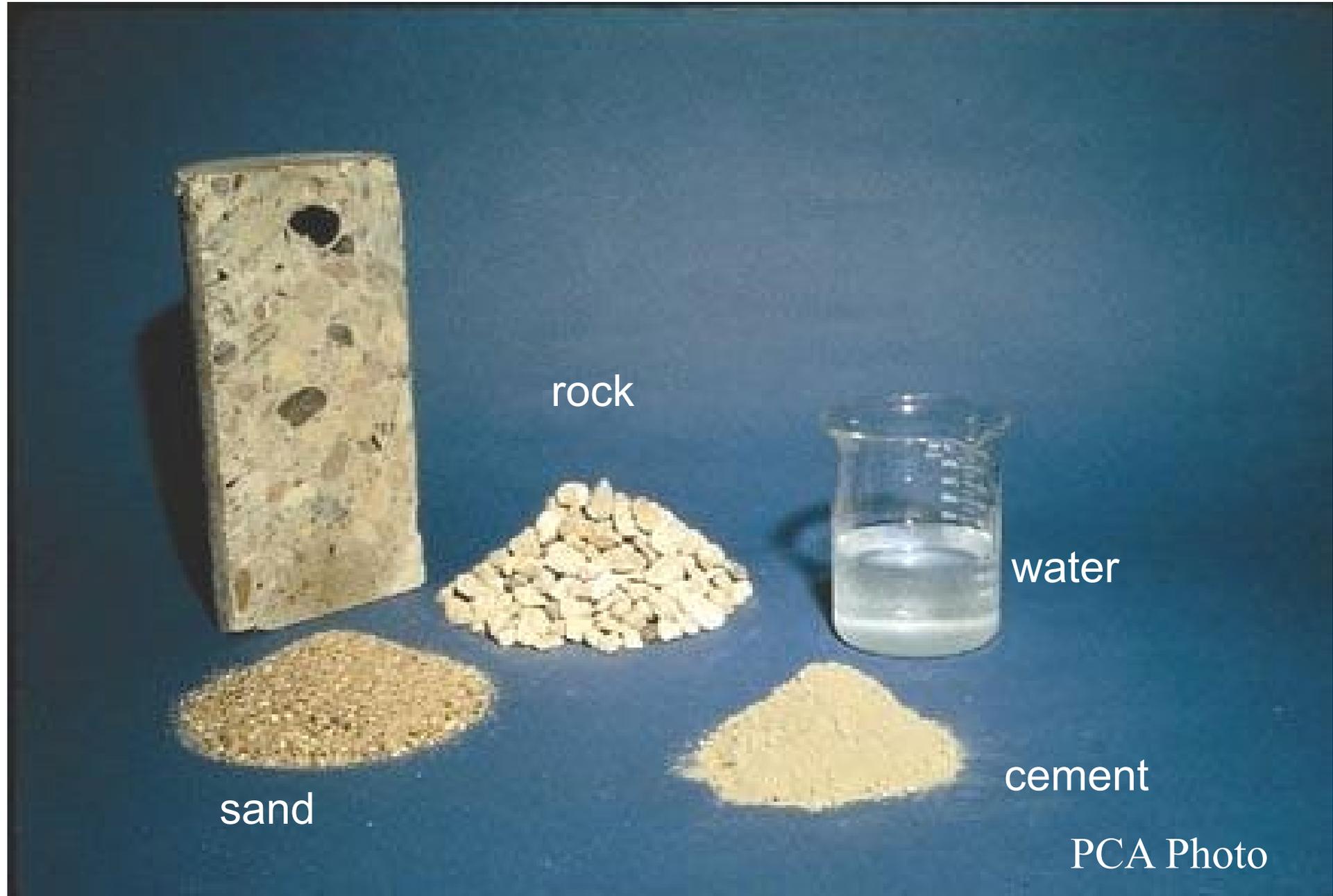
[www.youtube.com/tylerley](http://www.youtube.com/tylerley)

**TYLER LEY, PE, PhD**

# Outline

- Basics of Concrete
- Admixtures
- Fibers
- The Importance of Water

# The GREATEST material on the planet!!!



PCA Photo



Fallingwater, Frank Lloyd Wright



Salginatobel Bridge, Robert Maillart



Palazzetto dello Sport in Rome, Pier Nervi



Sydney Opera House, Jørn Utzon



City of Arts and Sciences in Valencia, Felix Candela



Hoover Dam and Bypass

Burj Khalifa in  
Dubai









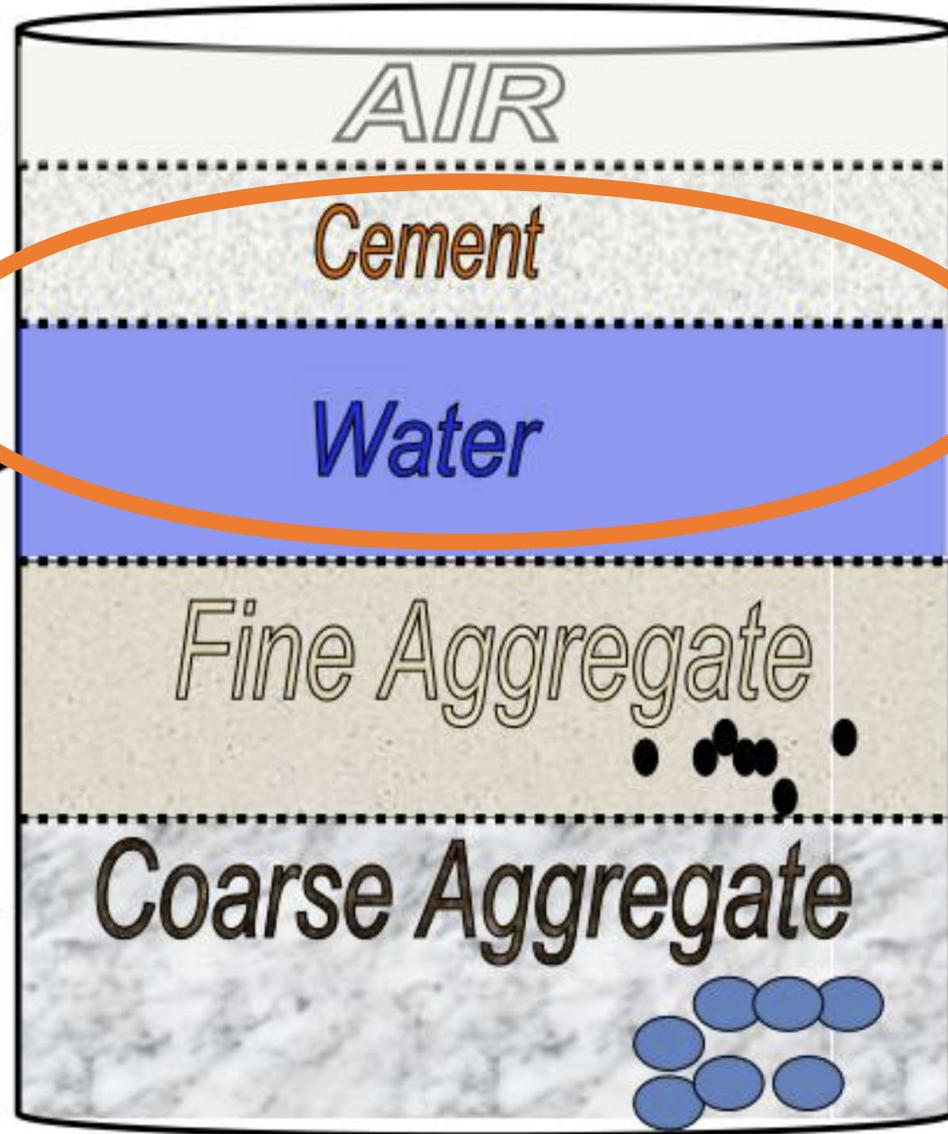
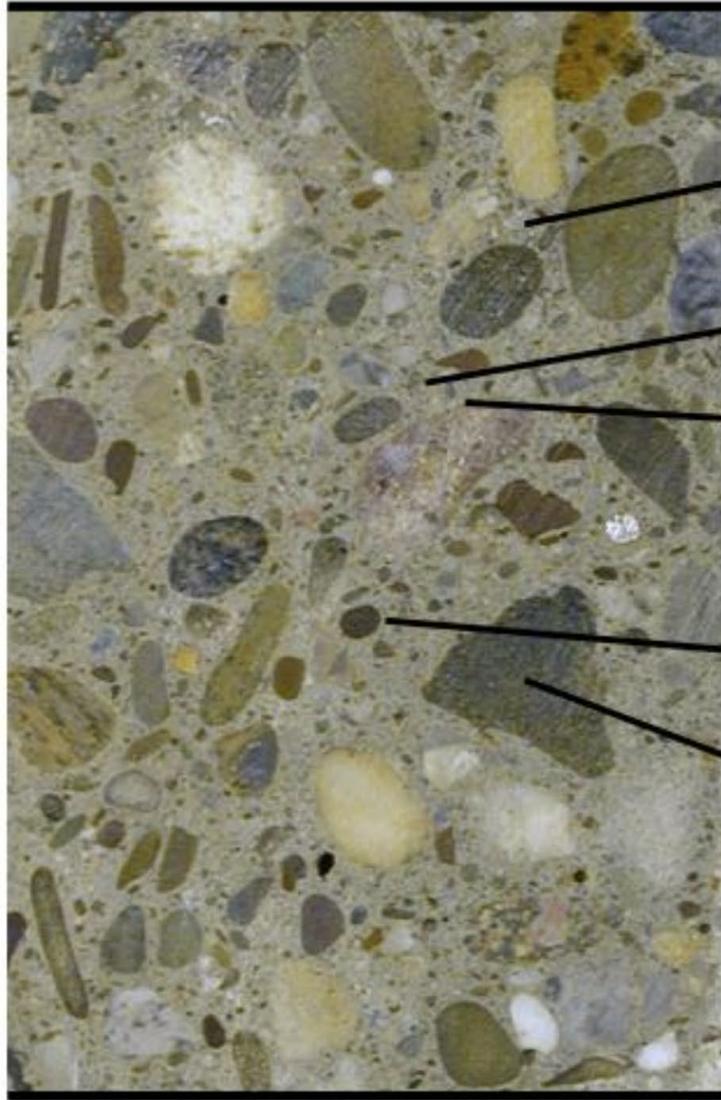


add



Garden Gnome  
R2D2





2% - 6%

*Cement*

Paste

*Water*

25% - 30%

*Fine Aggregate*

Aggregate

*Coarse Aggregate*

73% - 64%

# The basics...



+



=



When water and cement meet they react and form a **paste** that glues the aggregate together.

# The basics...

The paste gives concrete its strength and durability and it is the most costly component of the mixture.

Because of this we need to make sure we get it right!!!

Are there other binders?

These materials are waste products from other industries that make concrete stronger, more durable, and less permeable.

They are also less expensive than portland cement.

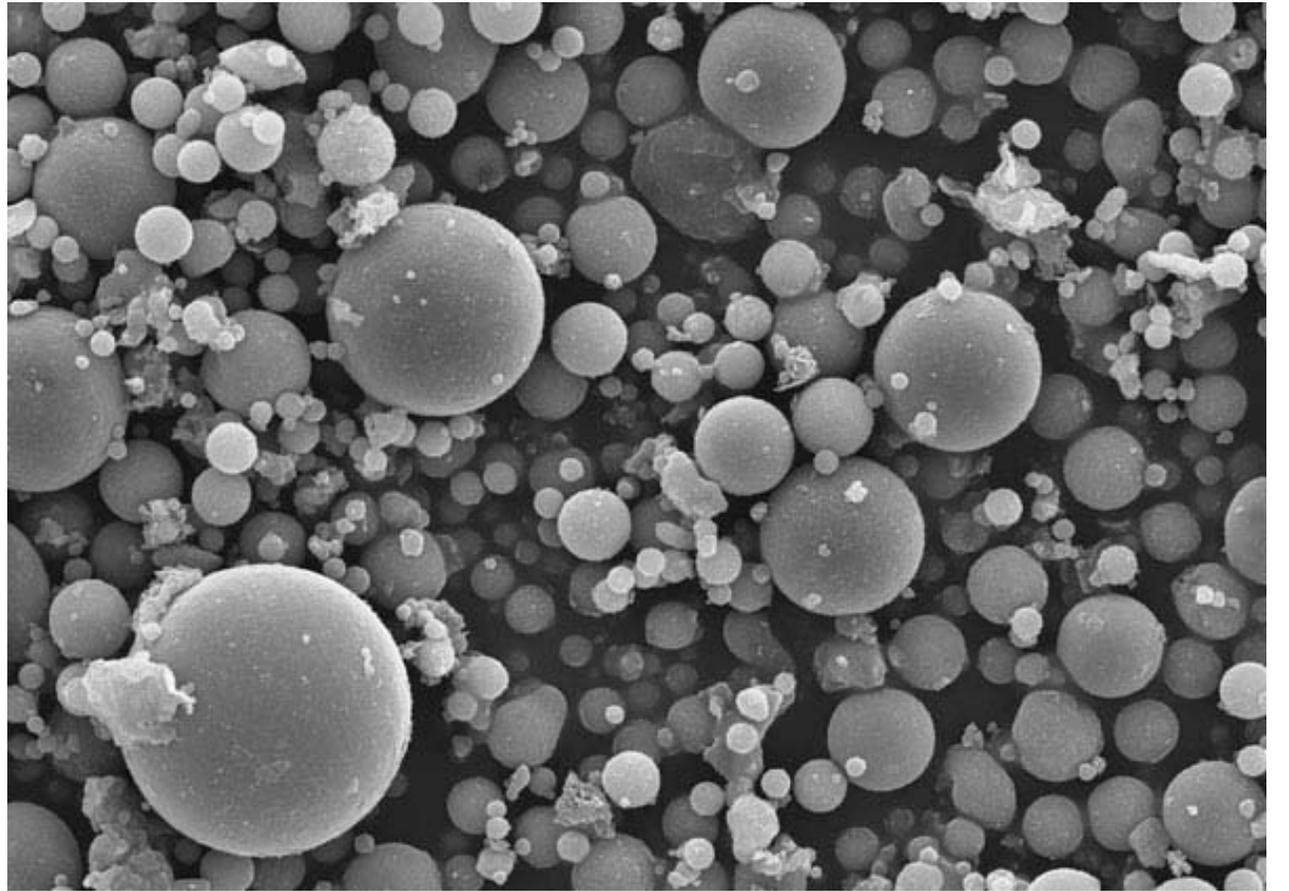
# Typical replacement levels of portland cement

- Fly Ash 20%
- Slag 40%
- Silica Fume 5%
- Natural Pozzolans 10%



# What is fly ash?





# Why is fly ash great?



It has long term reactions in the concrete and it improves the strength and durability.

It makes your concrete more workable.

It is cheaper than portland cement.

It is more sustainable than portland cement.

Why is fly ash challenging?



Tough to get a constant supply

The unburnt carbon can impact your admixtures.

# 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

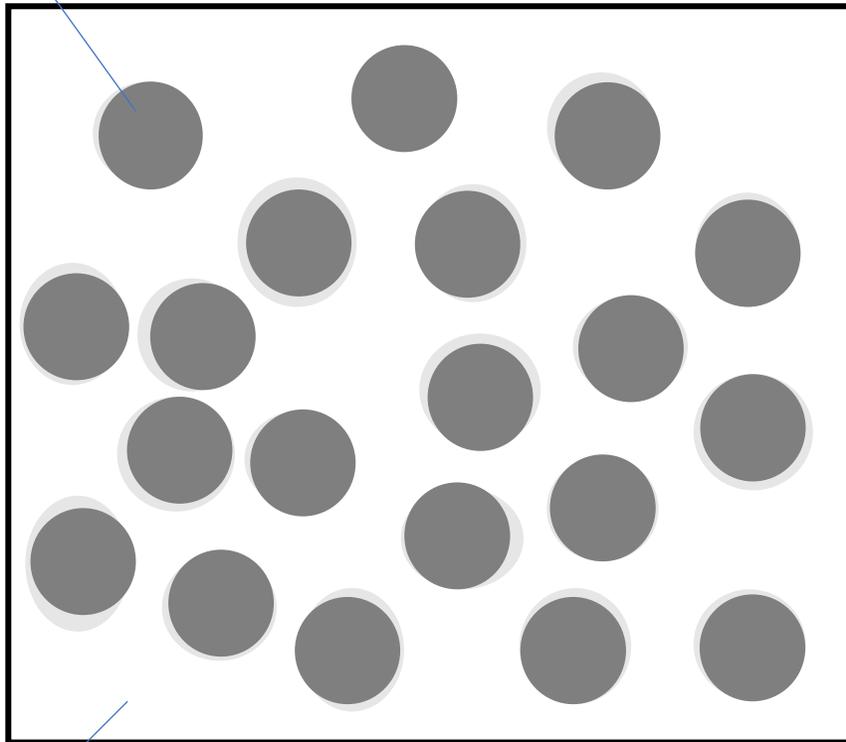
# Initial spacing of the cement grain



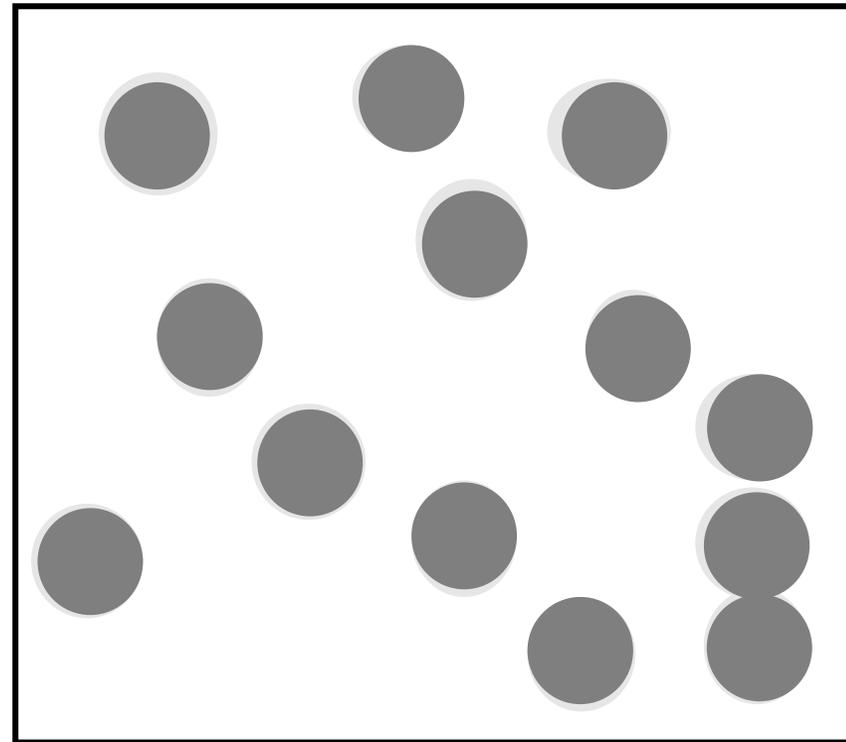
This is determined by the water to cement ratio

cement grain

$w/cm = 0.40$



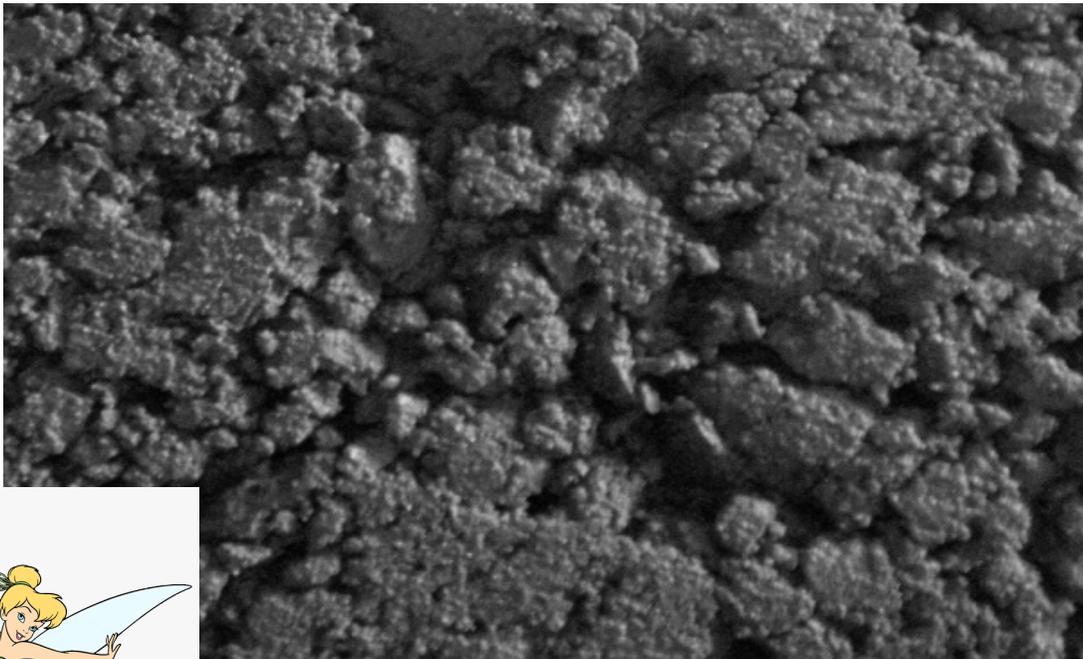
$w/cm = 0.50$



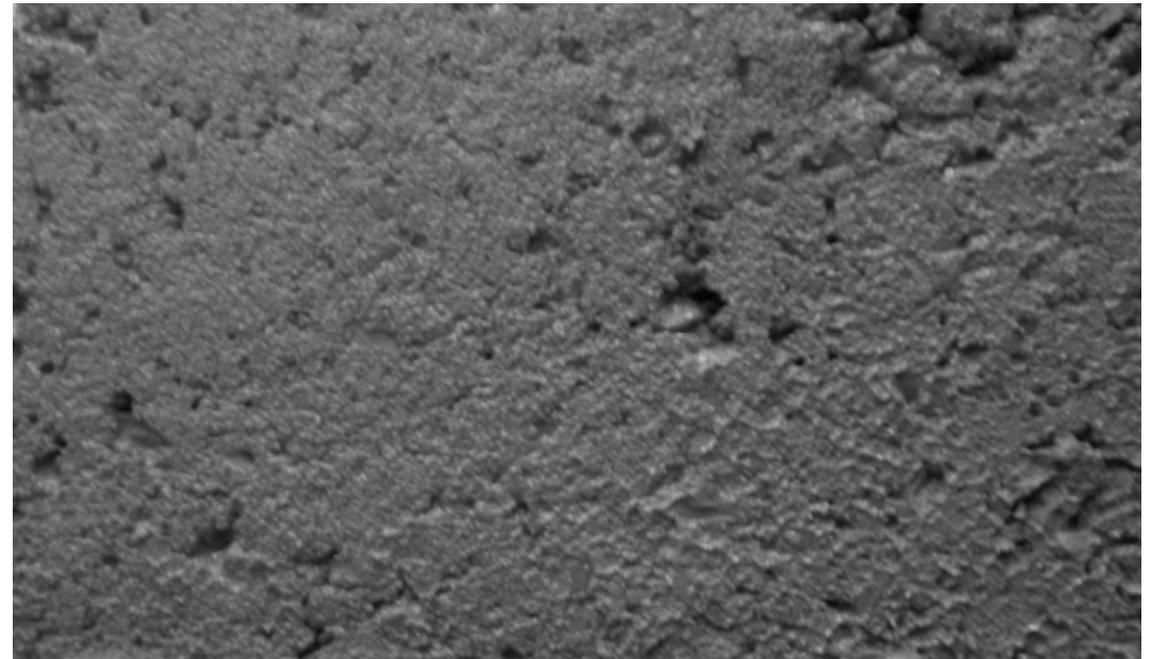
water

# Final spacing of the cement grain

This is determined by the consolidation



Poor Consolidation



Good Consolidation



# Good Curing!

Promote reaction

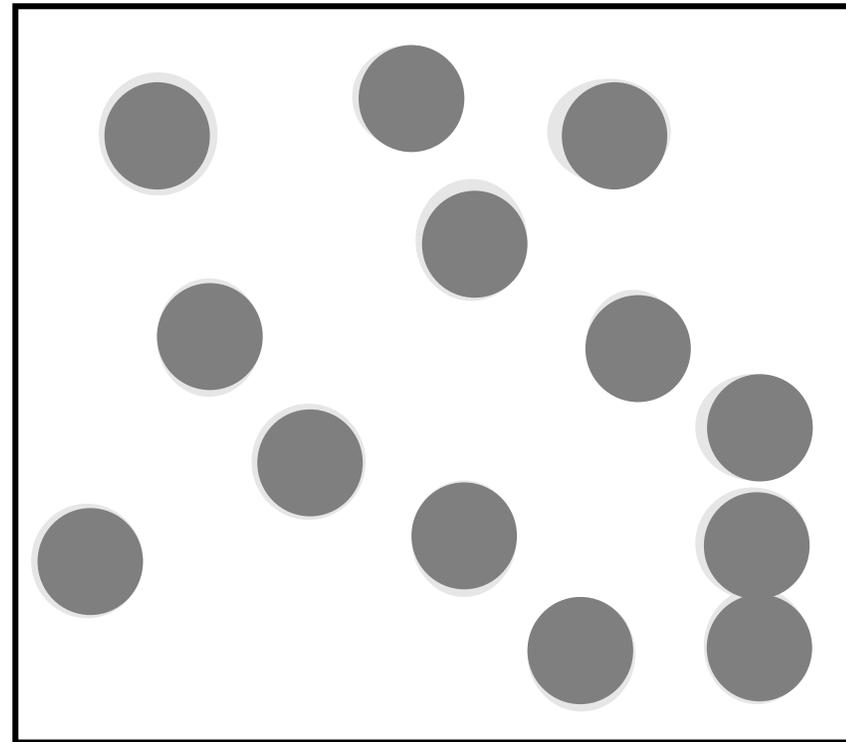
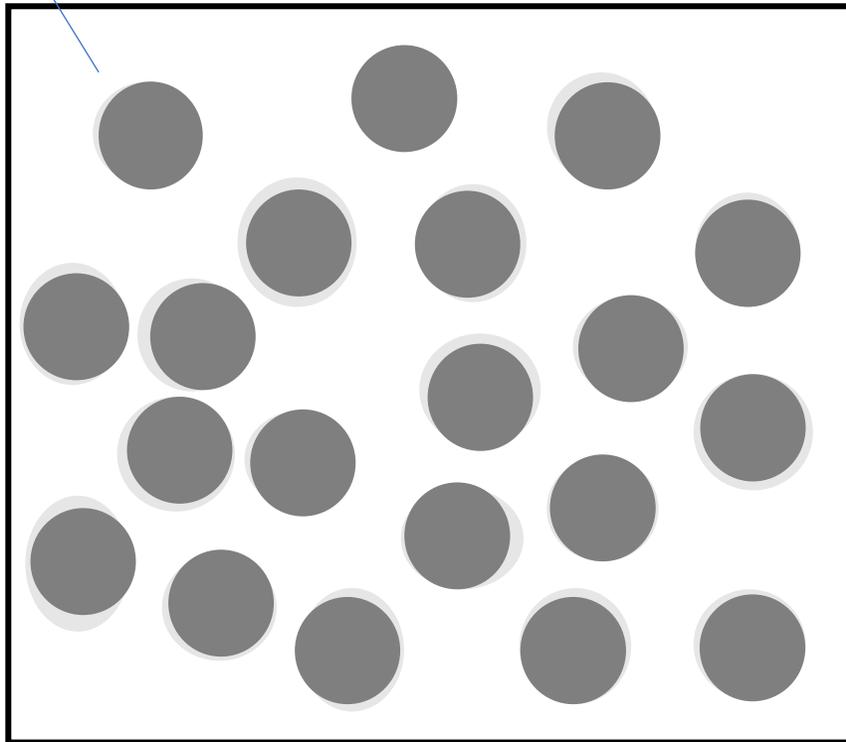
If you keep the concrete moist and warm then it will react.

Hydration

product

$w/cm = 0.40$

$w/cm = 0.50$



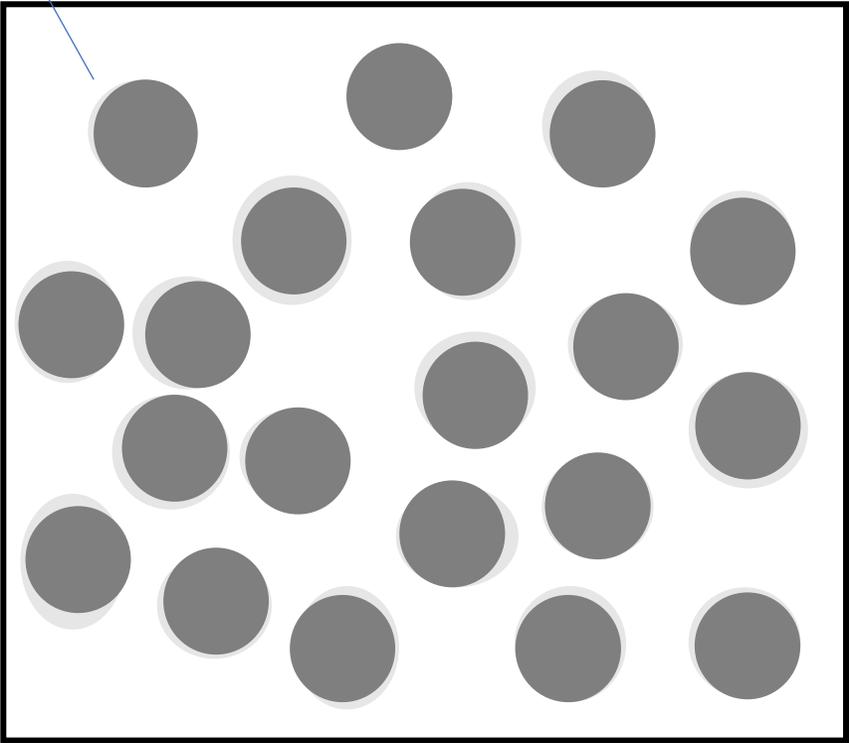
# Poor Curing

Promote reaction

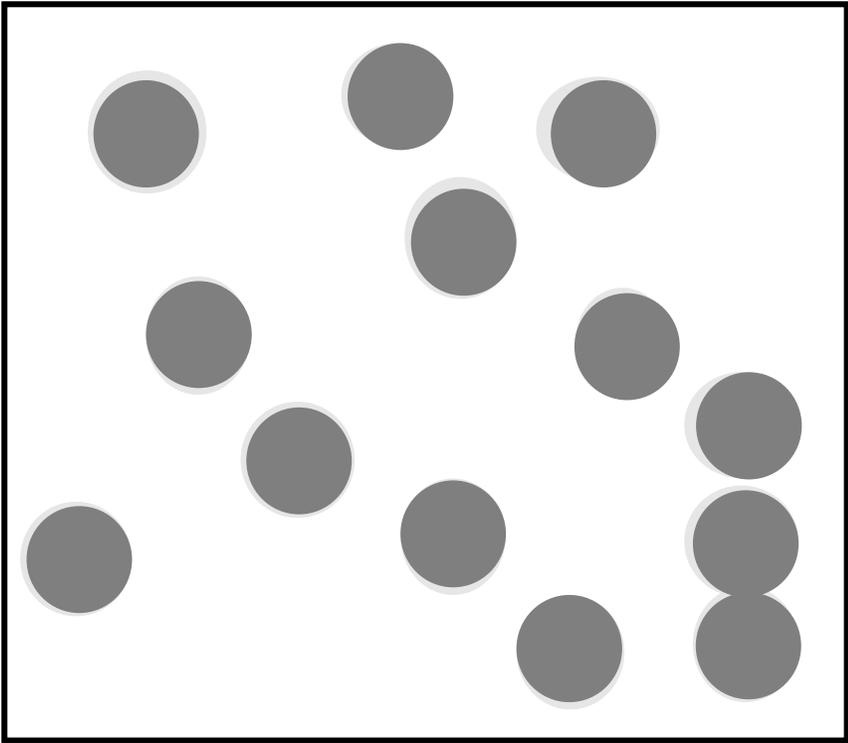
If you keep the concrete moist and warm then it will react.

Hydration  
product

w/cm = 0.40



w/cm = 0.50



# Curing promotes hydration!

We want to hold moisture and heat within the concrete

We want to protect and strengthen the surface







Curing

# What are the traditional methods of curing?

No curing



# 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?

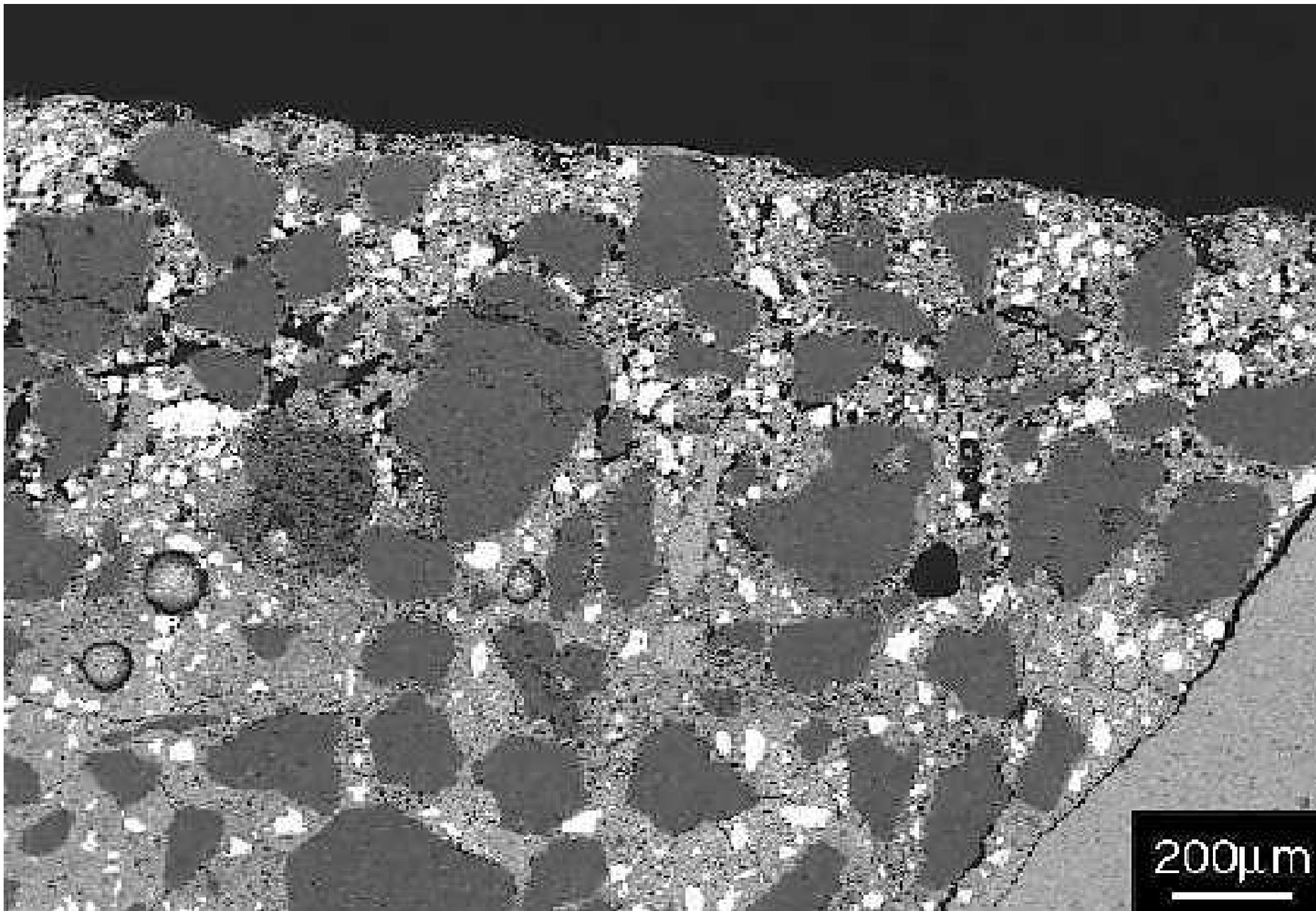
Form cure



# What are the traditional methods of curing?

## Wet curing



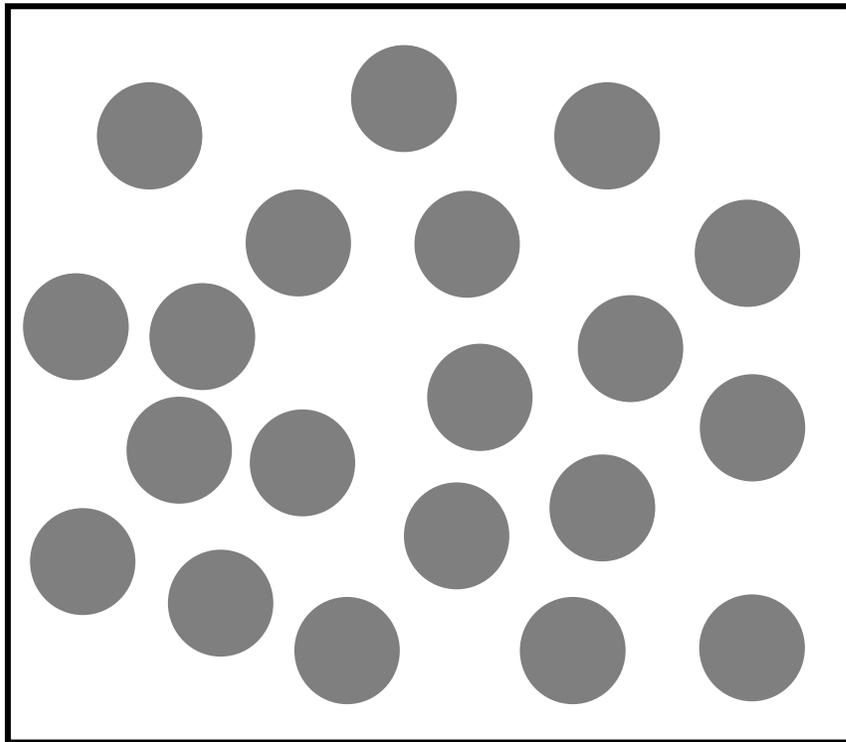


Poorly cured  
concrete

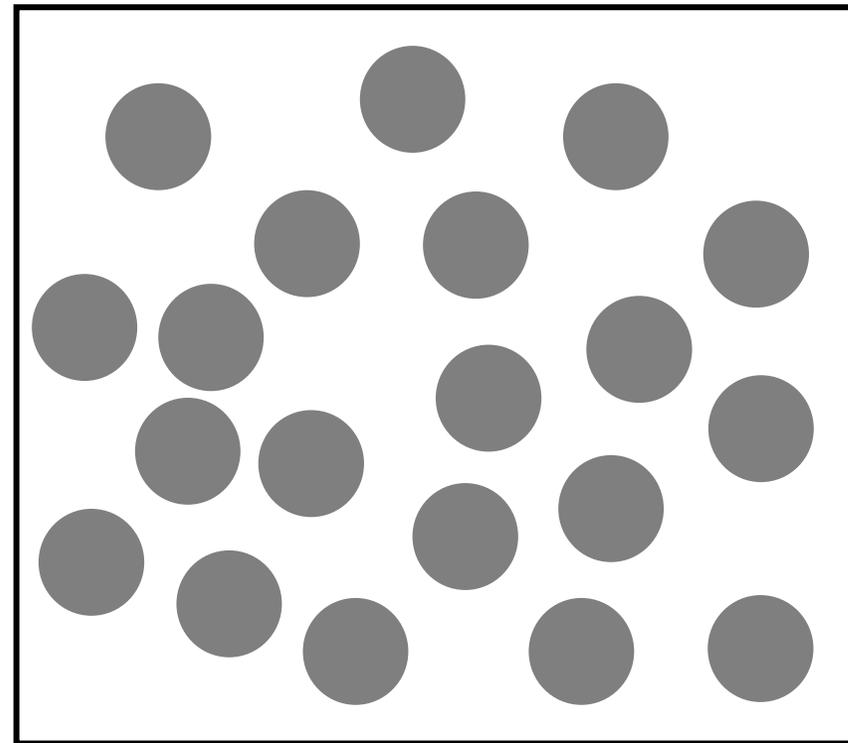


Let's compare two mixtures with the same  $w/cm$  but different qualities of curing

$w/cm = 0.40$

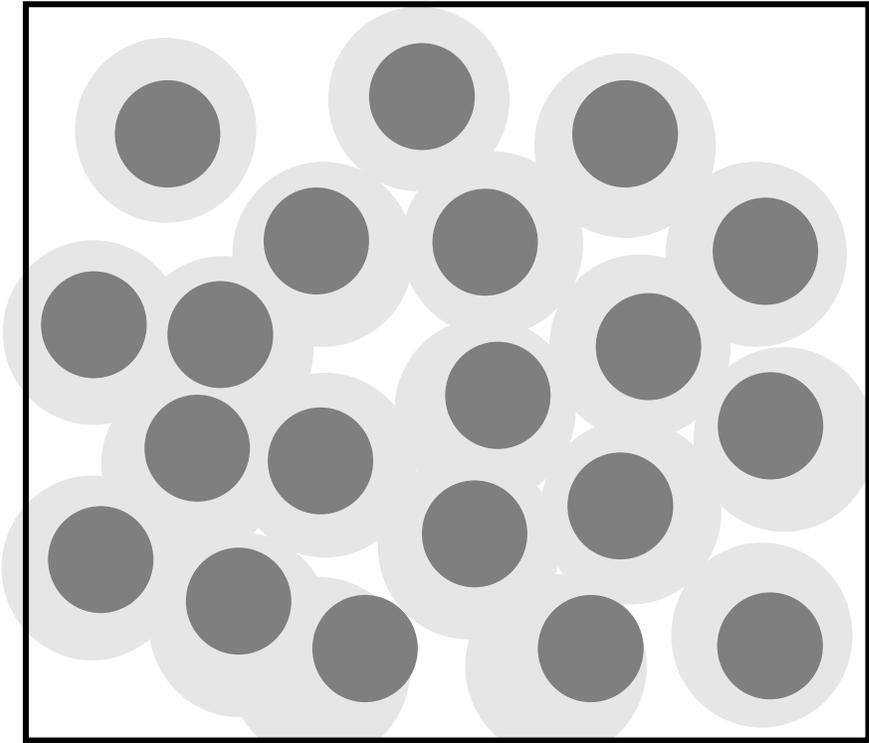


$w/cm = 0.40$



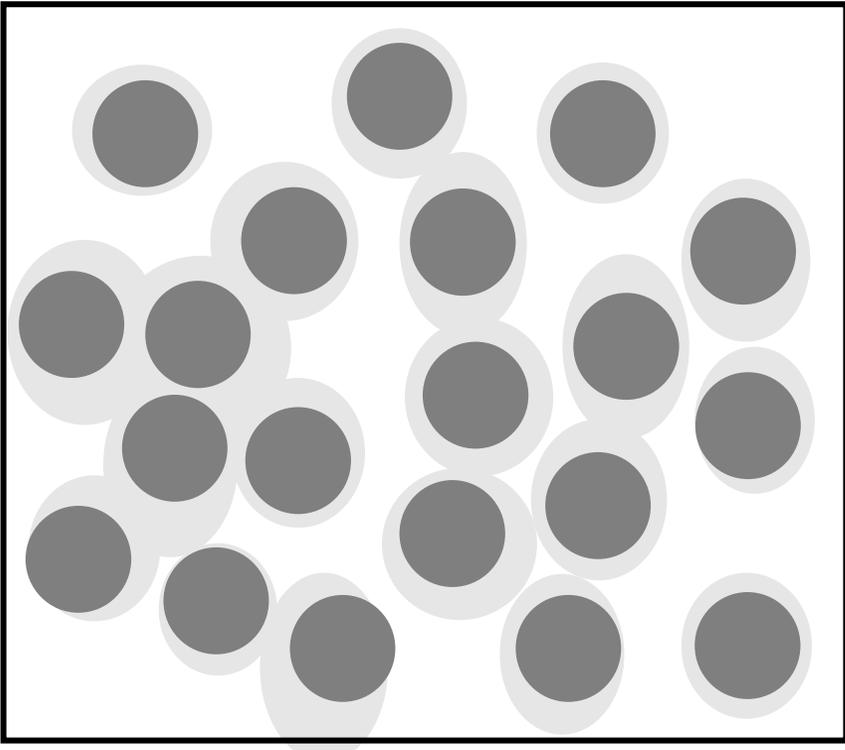
If you keep the concrete moist and warm then it will react.

$w/cm = 0.40$



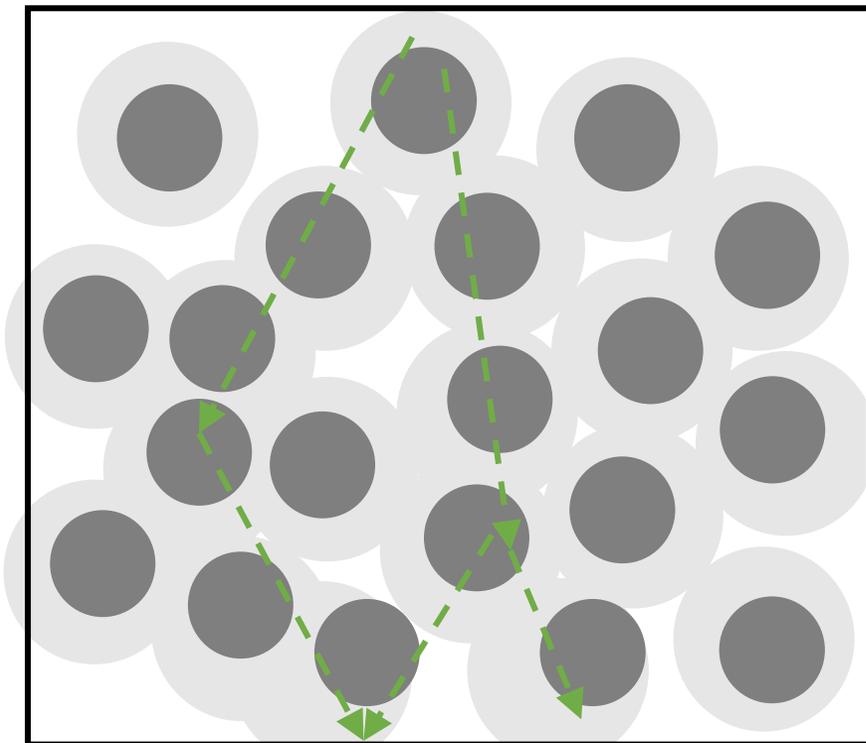
Good curing

$w/cm = 0.40$



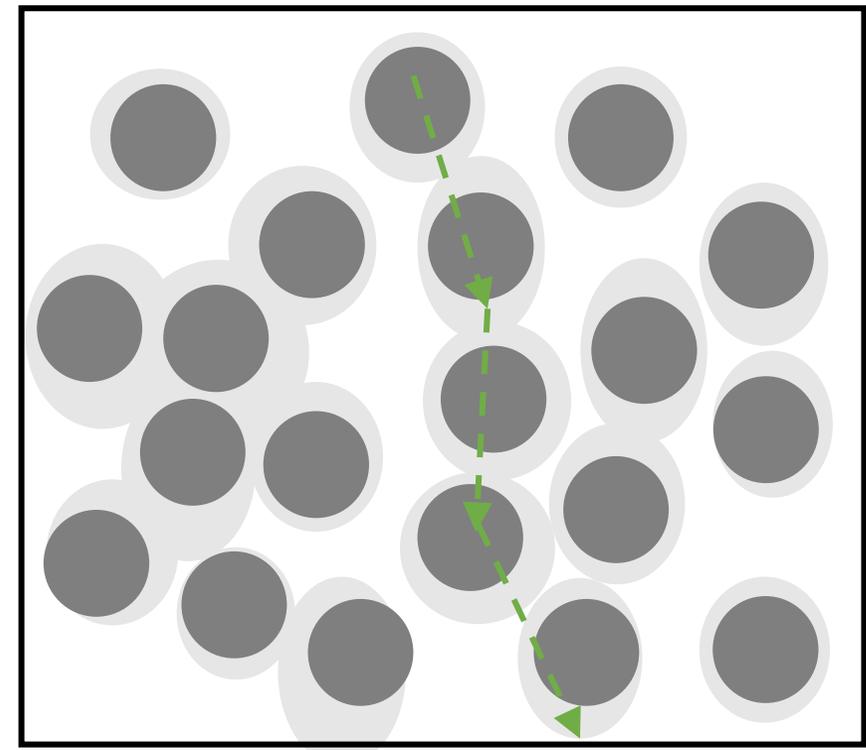
Poor curing

Load  
 $w/cm = 0.40$

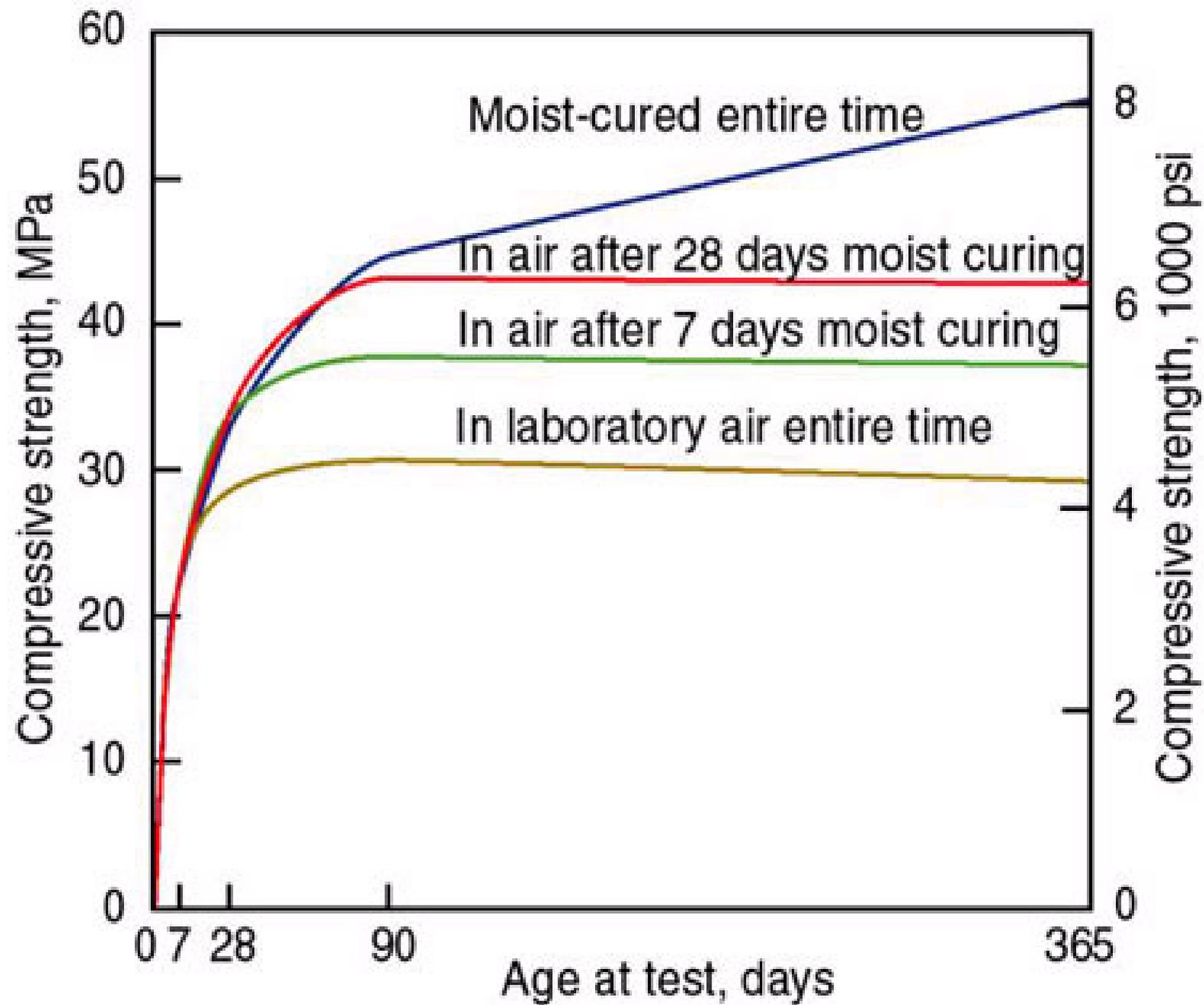


Good curing

Load  
 $w/cm = 0.40$



Poor curing

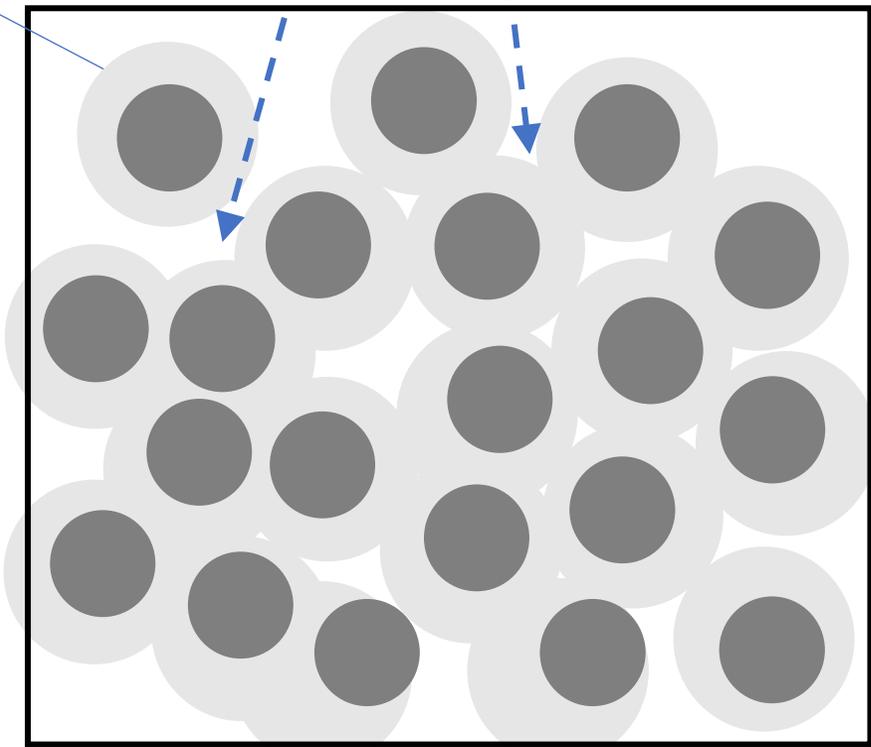


PCA

Hydration product

Water

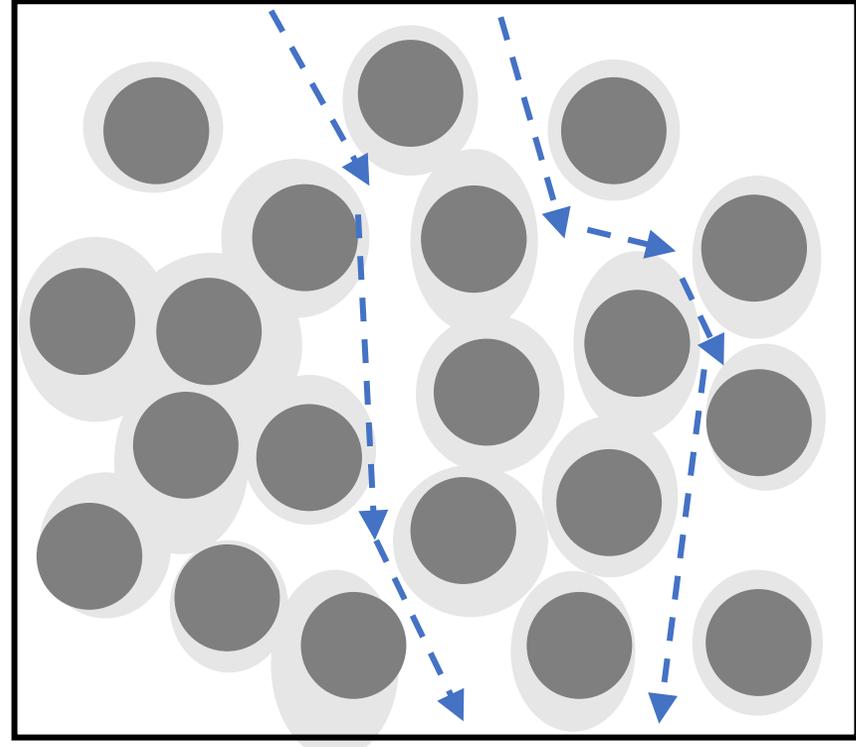
$w/cm = 0.40$



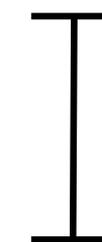
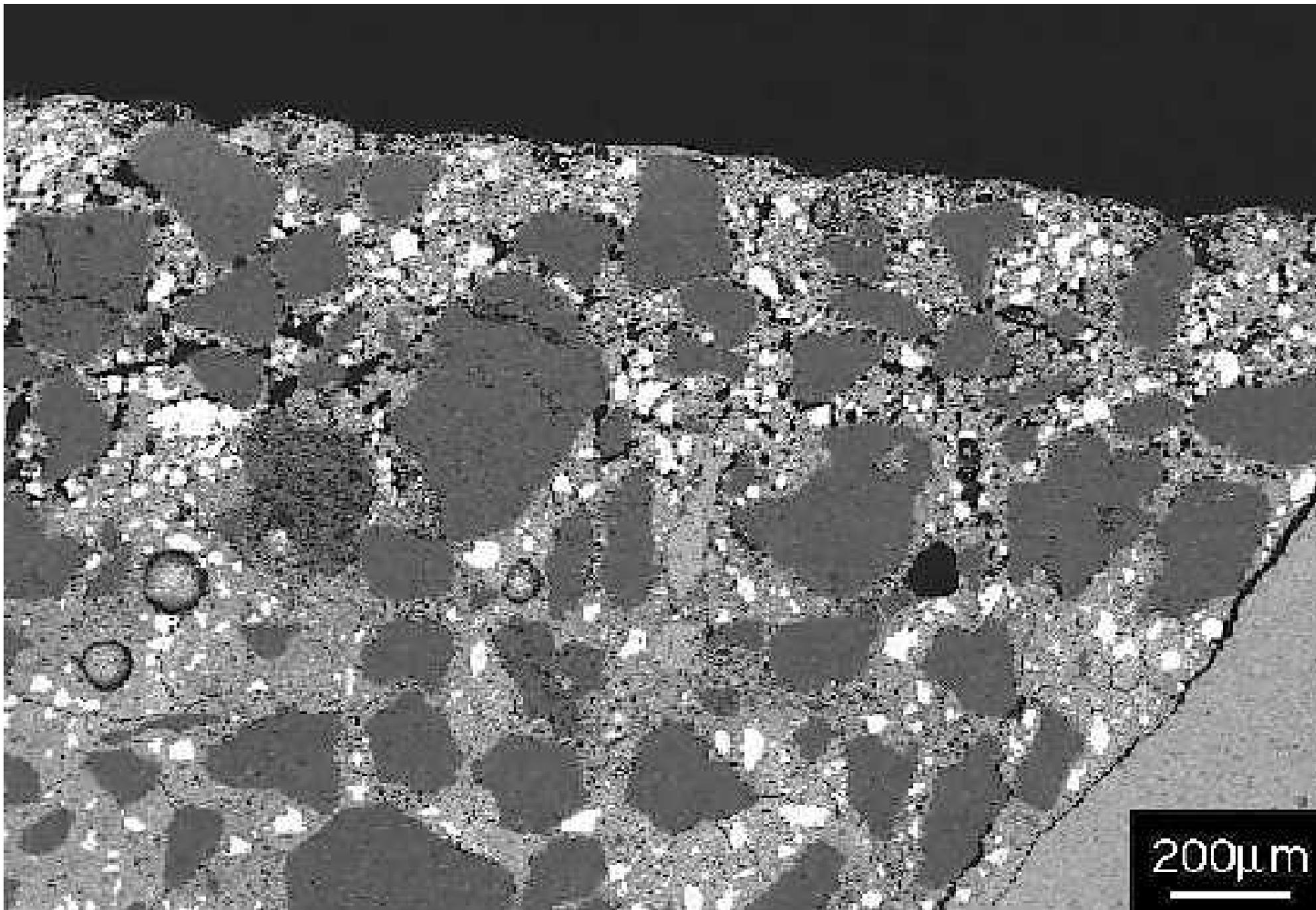
Good curing

Water

$w/cm = 0.40$



Poor curing



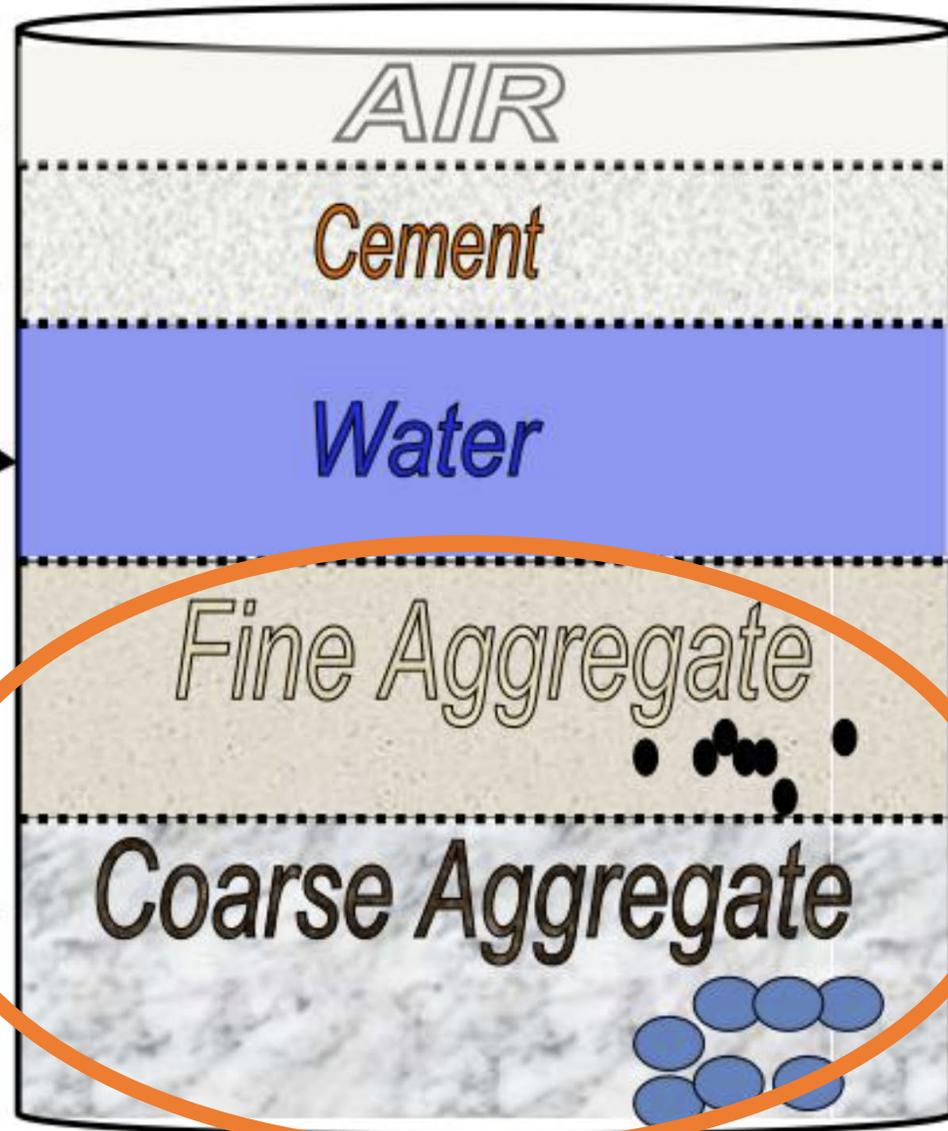
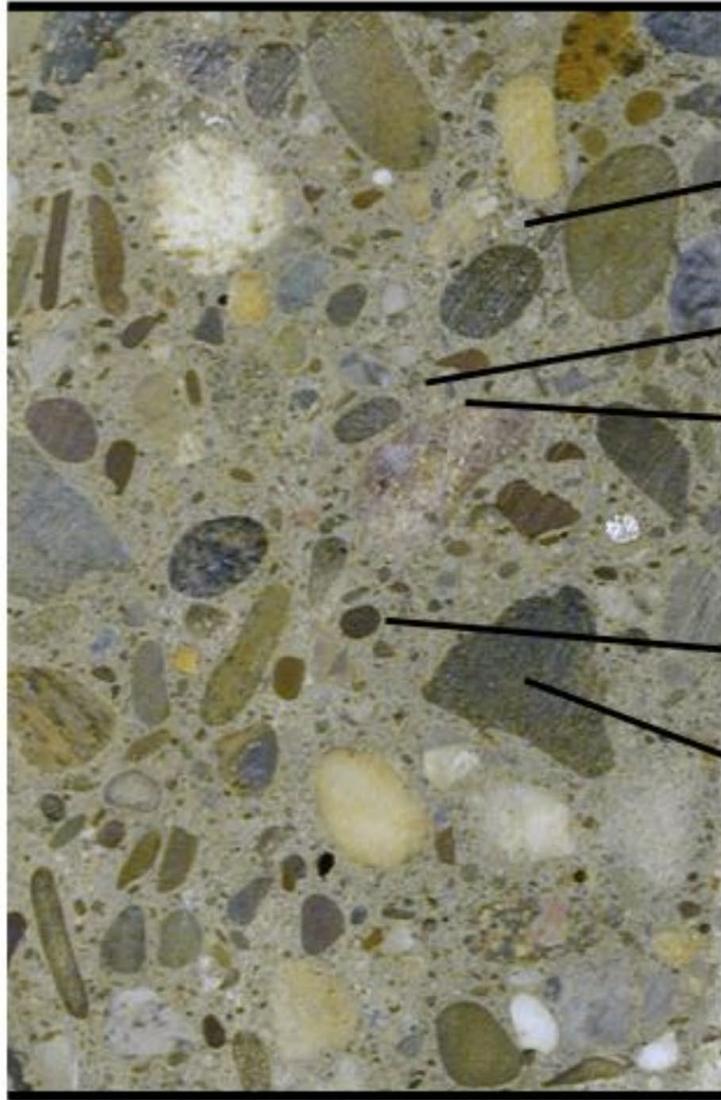
Poorly cured  
concrete



# Summary

For durable paste you want to use a low w/cm, consolidate the concrete, and do the best job curing you can.

The paste is important, but the paste is only about 25% of the volume.



2% - 6%

AIR

Cement

Water

Fine Aggregate

Coarse Aggregate

Paste

25% - 30%

Aggregate

73% - 64%

# Aggregates

Aggregates act as inert filler and they decrease cost, reduce shrinkage and cracking, and improve sustainability.

Because aggregates are a large volume of the concrete then they control the constructability and physical properties of the concrete.

If you ever hope to have control over the quality of your concrete then you need to understand your aggregates.

# Do aggregates really matter?

The following mixtures look the same on paper:

1850 lbs coarse

1250 lbs sand

445 lbs cement

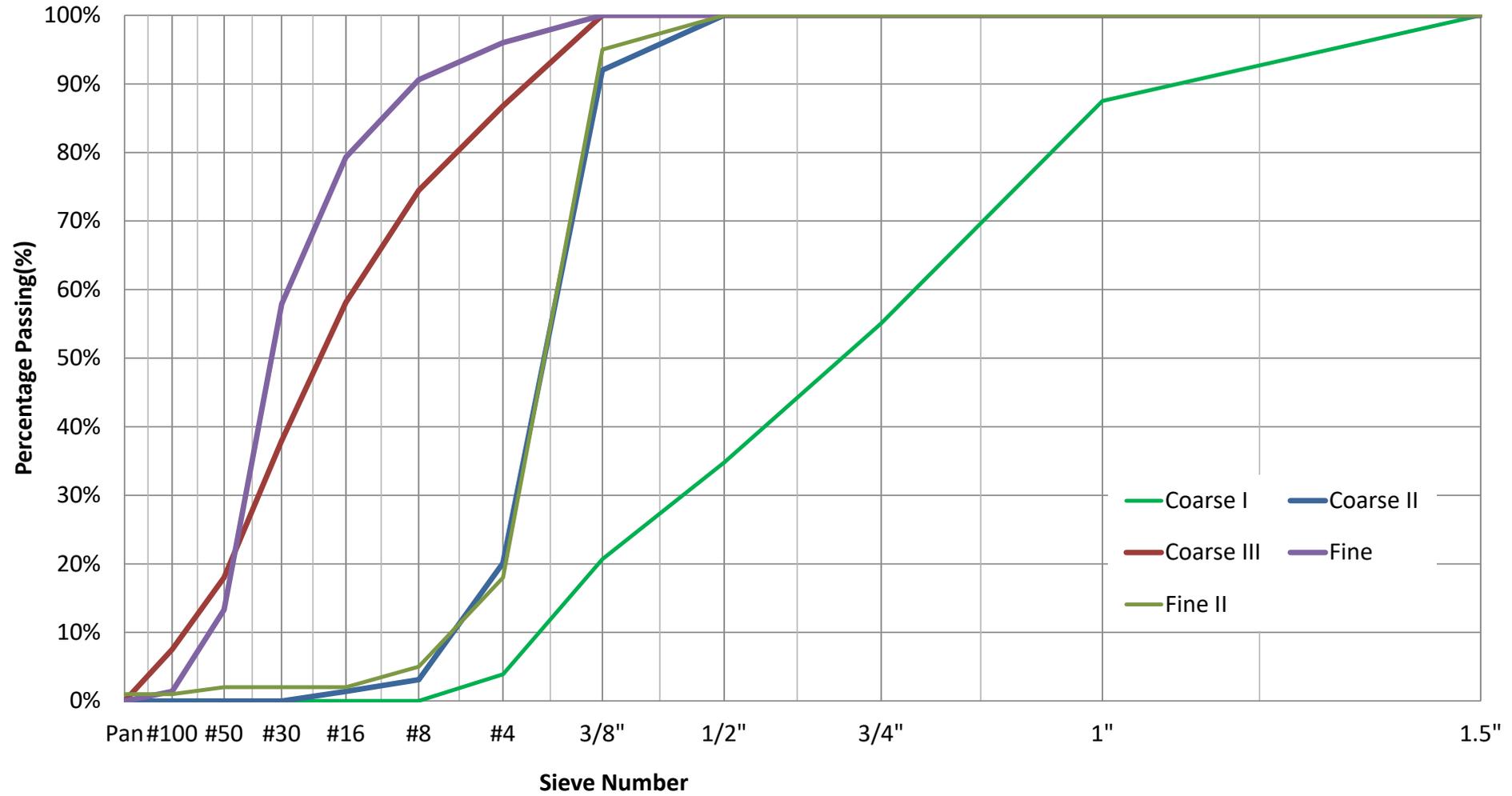
180 lbs fly ash

250 lbs water

} 625 lbs total

Each mix has a different aggregate gradation

The gradation is the particle size distribution.



**Deficient Fine Sand**



**Excessive fine sand**



**Just right...**



**High Intermediate**



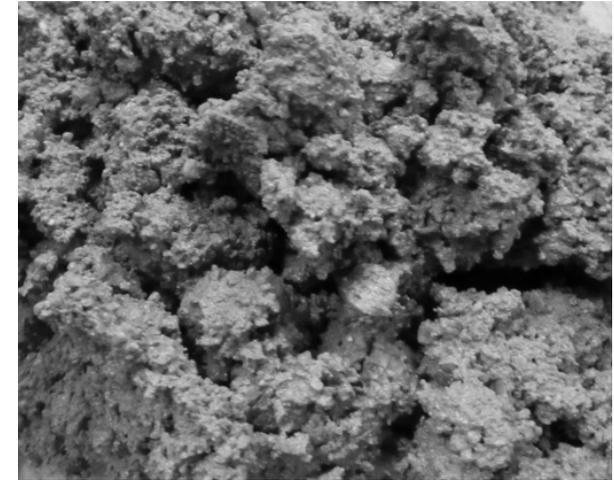
**High Coarse**



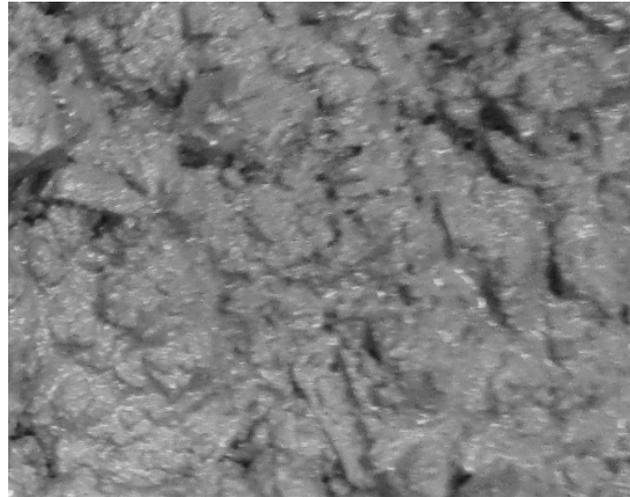
**Deficient Fine Sand**



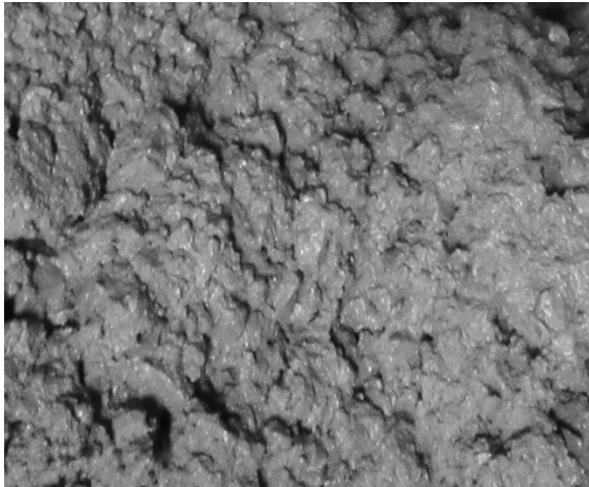
**Excessive Fine Sand**



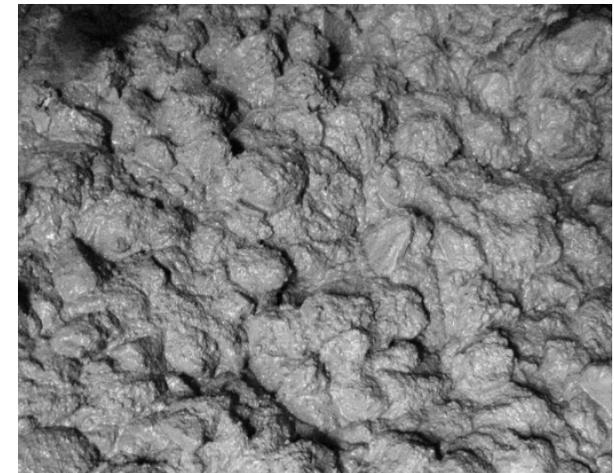
**Just right...**

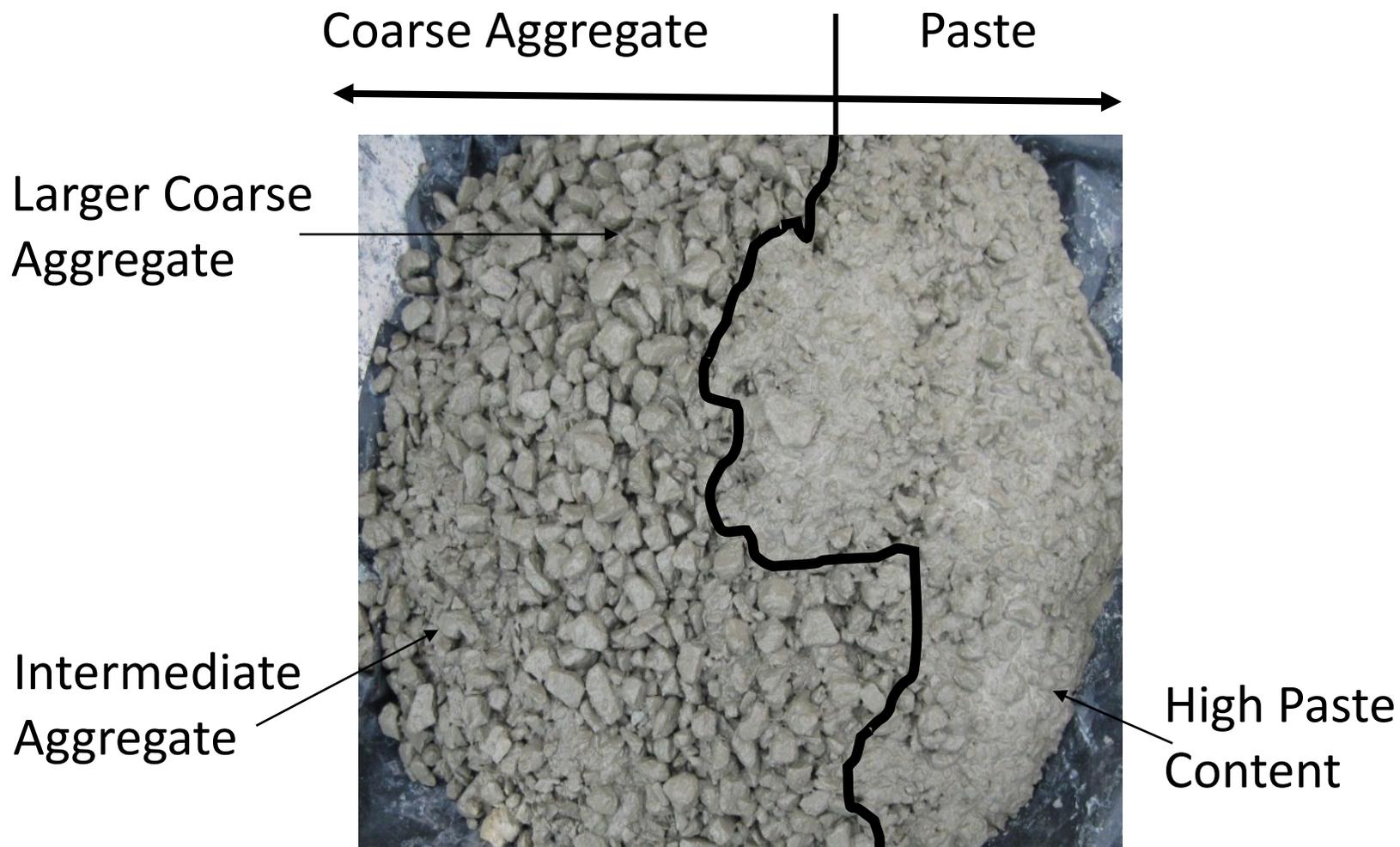


**Excessive Intermediate**



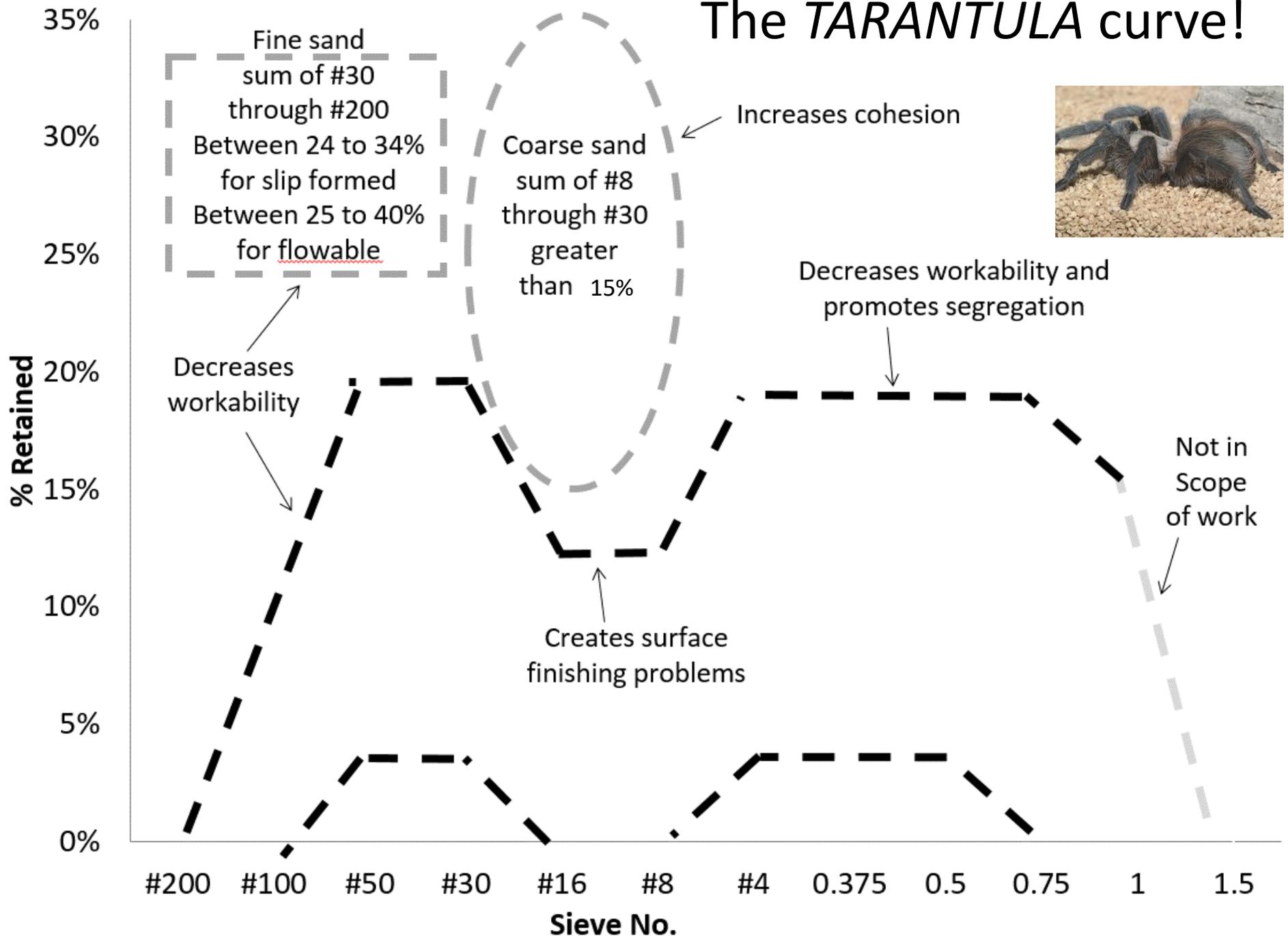
**Excessive Coarse**





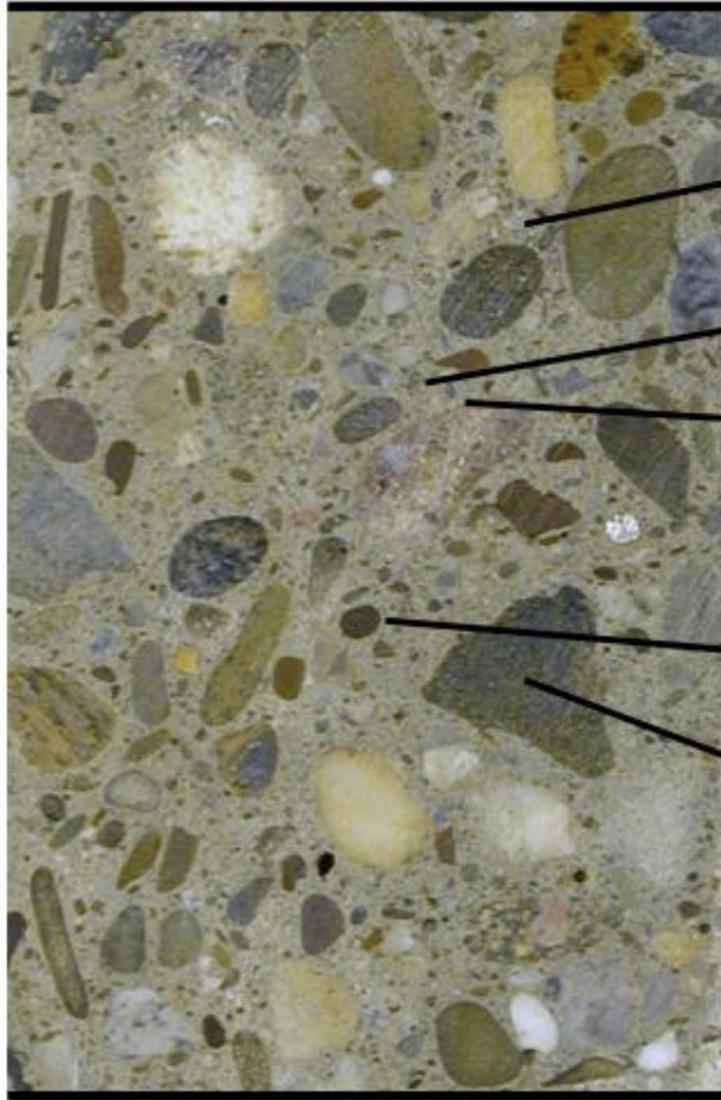
Segregation

# The *TARANTULA* curve!



[www.tarantulacurve.com](http://www.tarantulacurve.com)

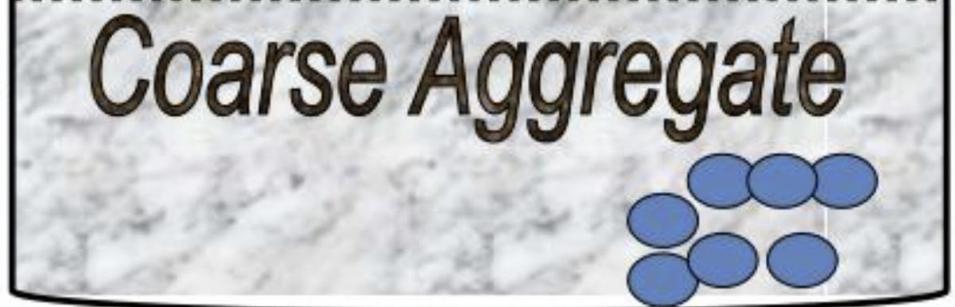
[www.tylerley.com/tarantulavideos](http://www.tylerley.com/tarantulavideos)



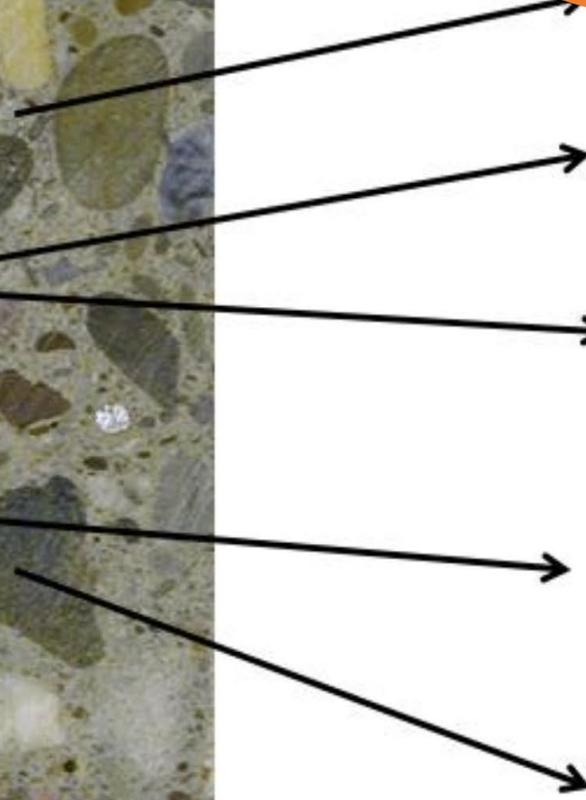
2% - 6%



Paste  
25% - 30%



Aggregate  
73% - 64%

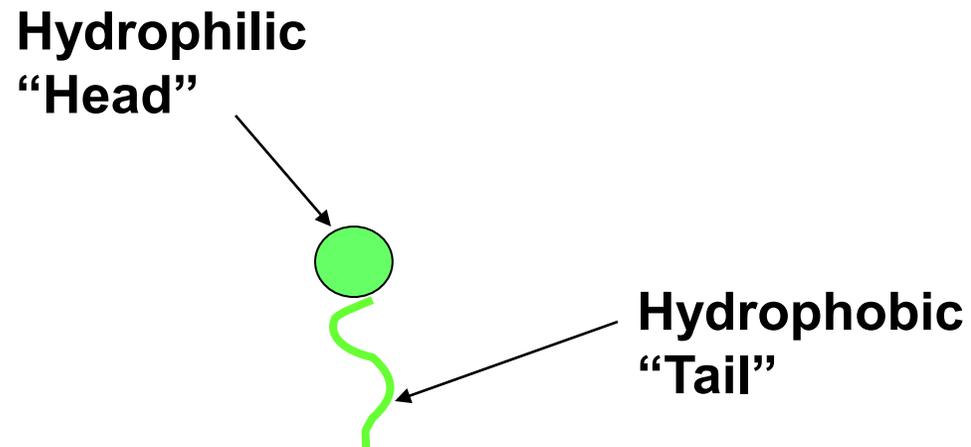


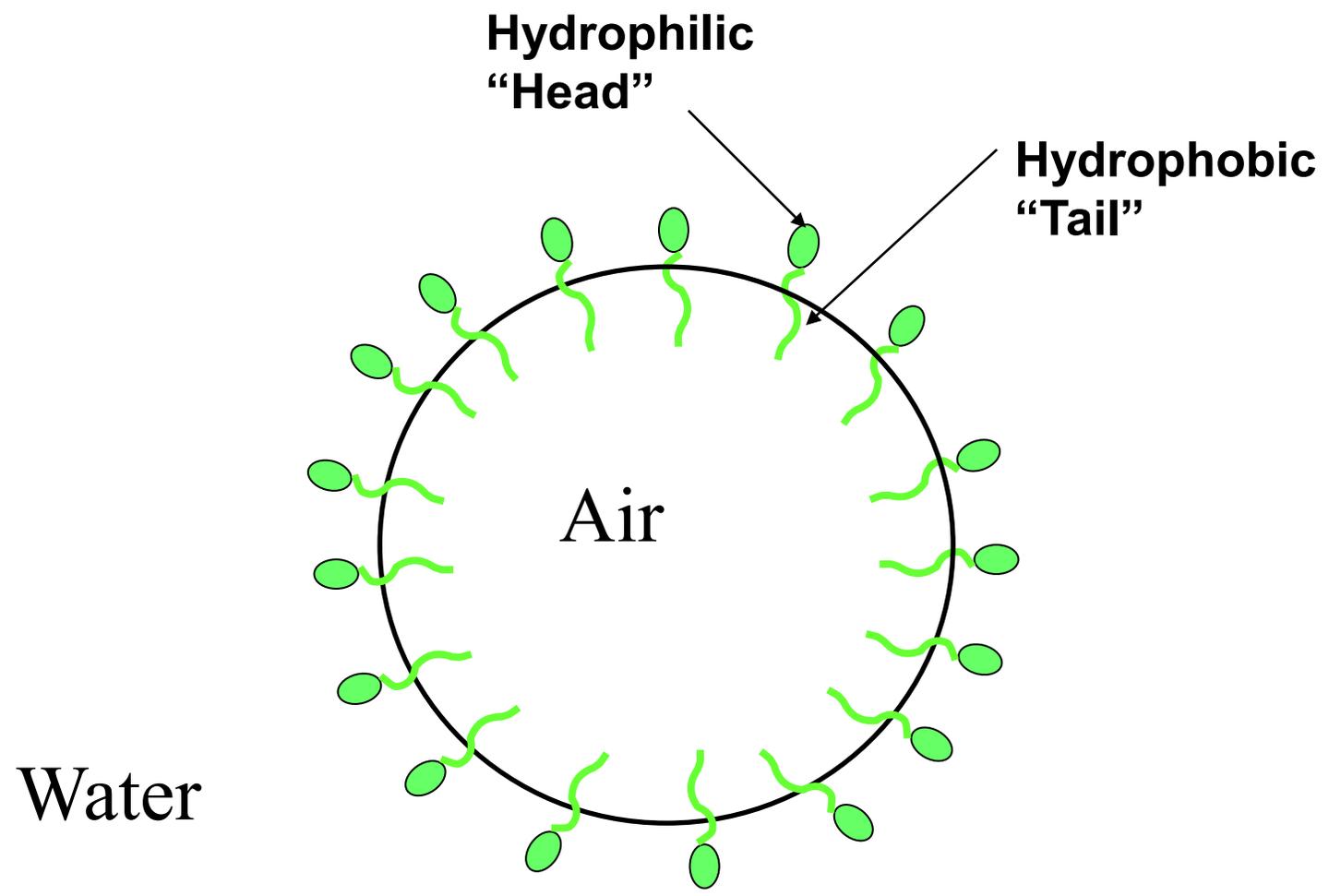
# Air-entrained concrete



# Air-Entrained Concrete

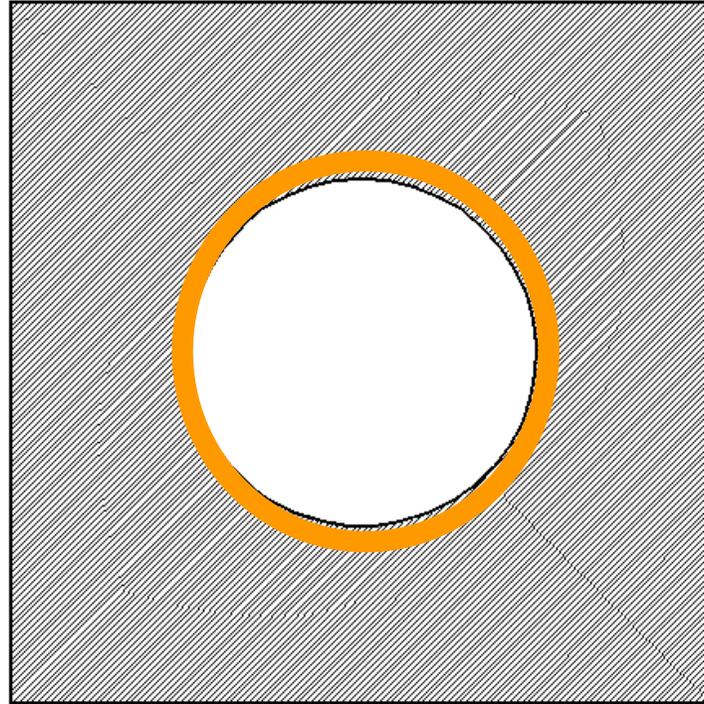
- A surfactant is used to stabilize the air bubbles created during mixing



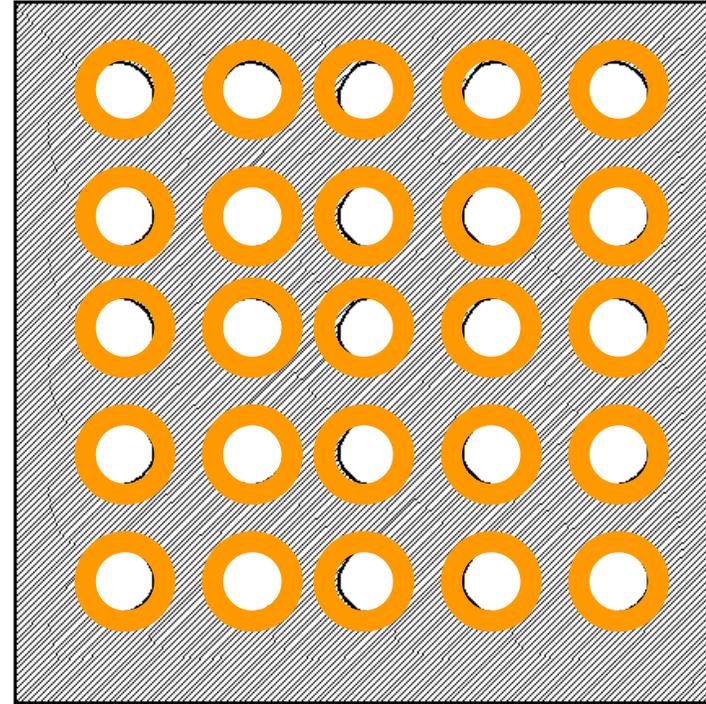


# What Do You Want in an Air-Void System?

A



B



- Volume of air provided is the same for both.
- Case B has a better air void distribution.



Large Bubbles



Small Bubbles

# Hardened Air Void Analysis



From Hover

# Super Air Meter!!!

AASHTO T 395



Ley, OSU

Why is an air entrainer useful?



Provides freeze thaw durability to the concrete

You get to sell the customer 5% air!!!!



10406052

LOW FAT  
LIGHT + FIT

DELISH  
**70**  
CALORIES



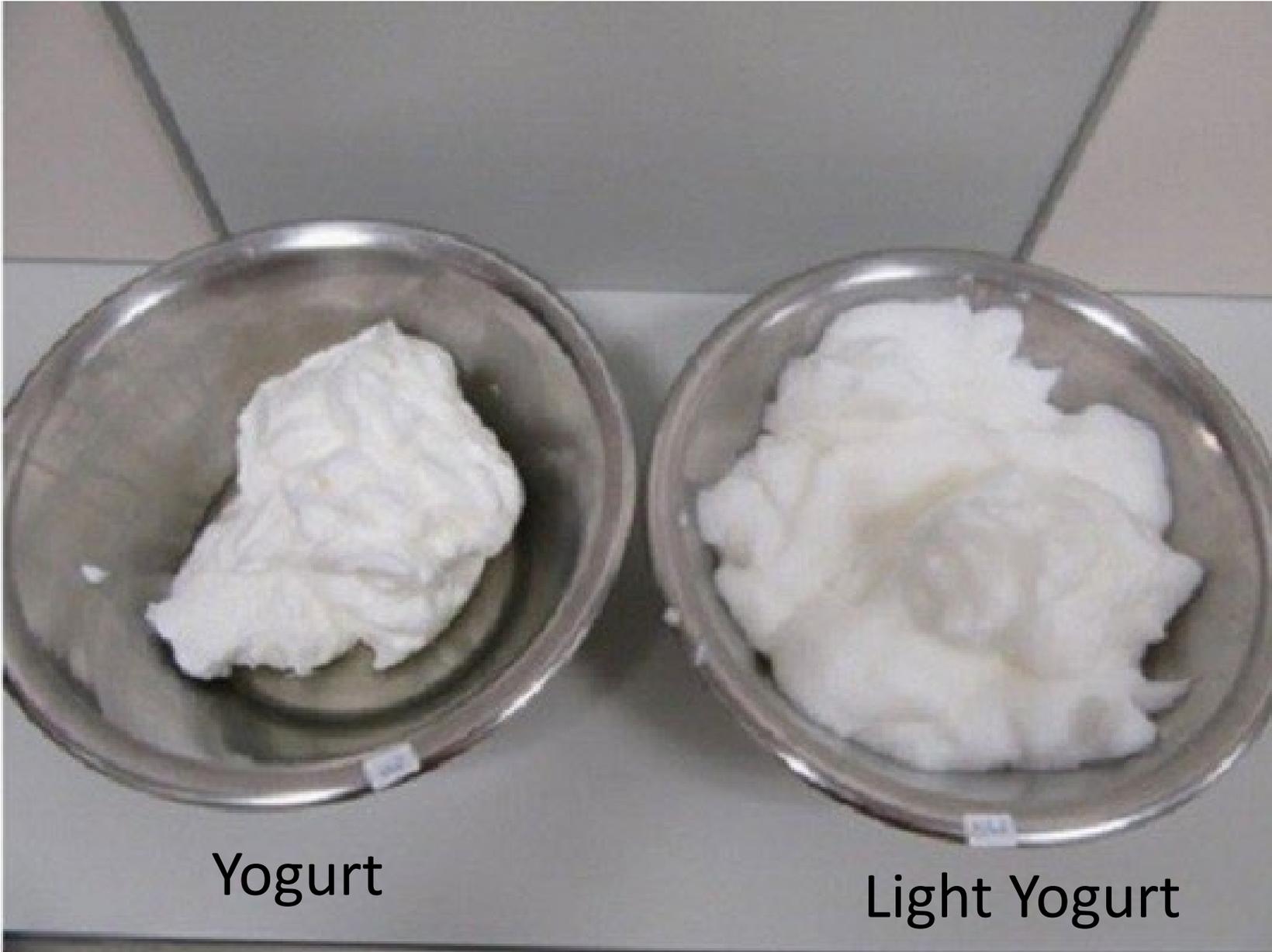
DANNON®  
**Light + Fit**

**SENSATIONAL  
STRAWBERRY**

NATURALLY & ARTIFICIALLY FLAVORED

**70**  
CALORIES  
**5g**  
PROTEIN





Yogurt

Light Yogurt

Why is an air entrainer challenging?



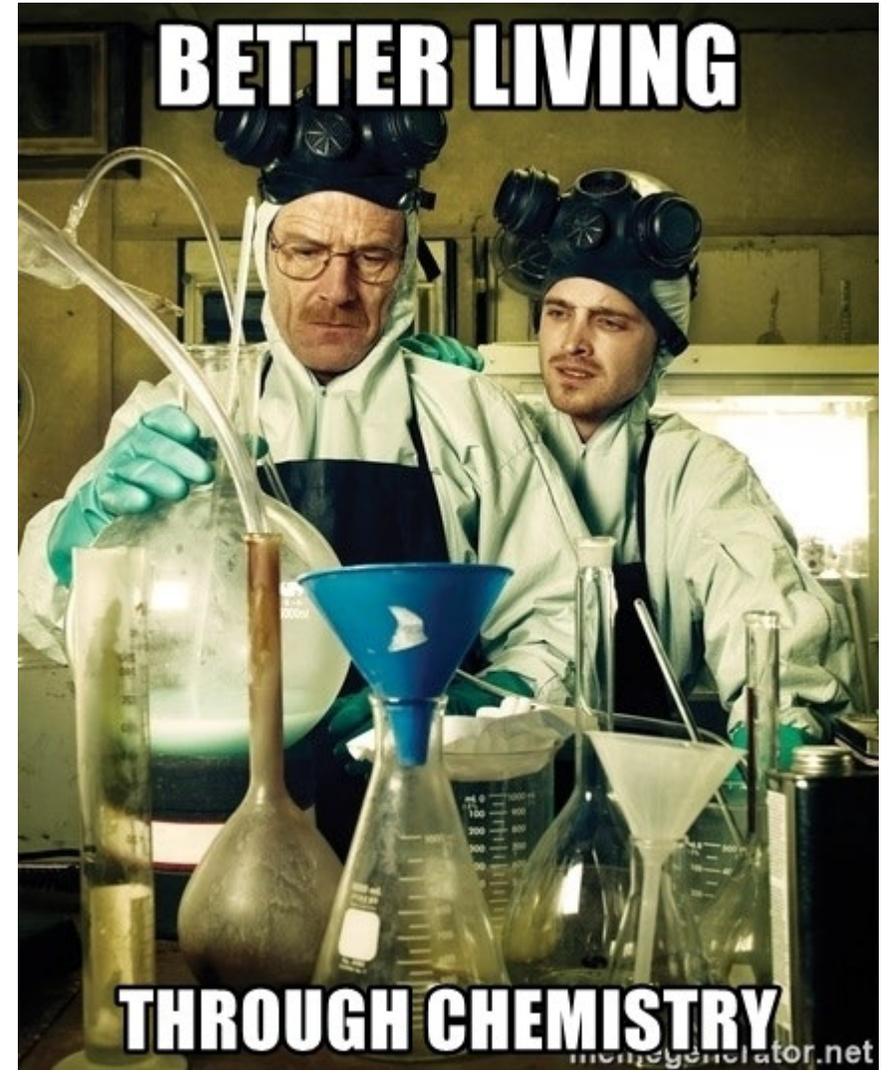
They are challenging to control!!!

It decreases your strength.

1% air = 200 psi decrease in strength

# Other Admixtures?

- Water Reducers
- Set Controlling
- Viscosity Modifying Agent

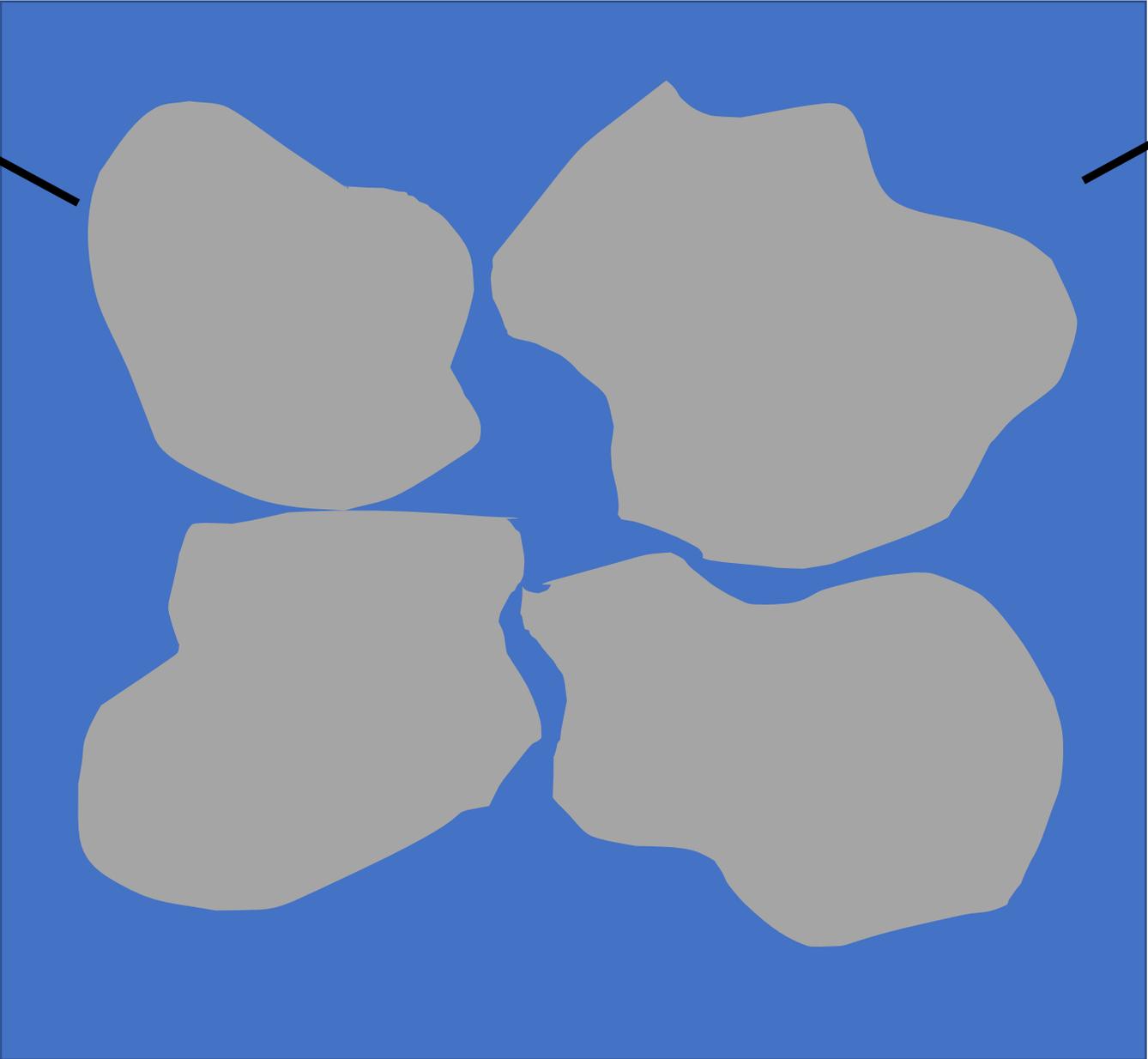


# Water Reducers

Water reducers are chemicals that attach to the surface of cement grains and cause them to separate.

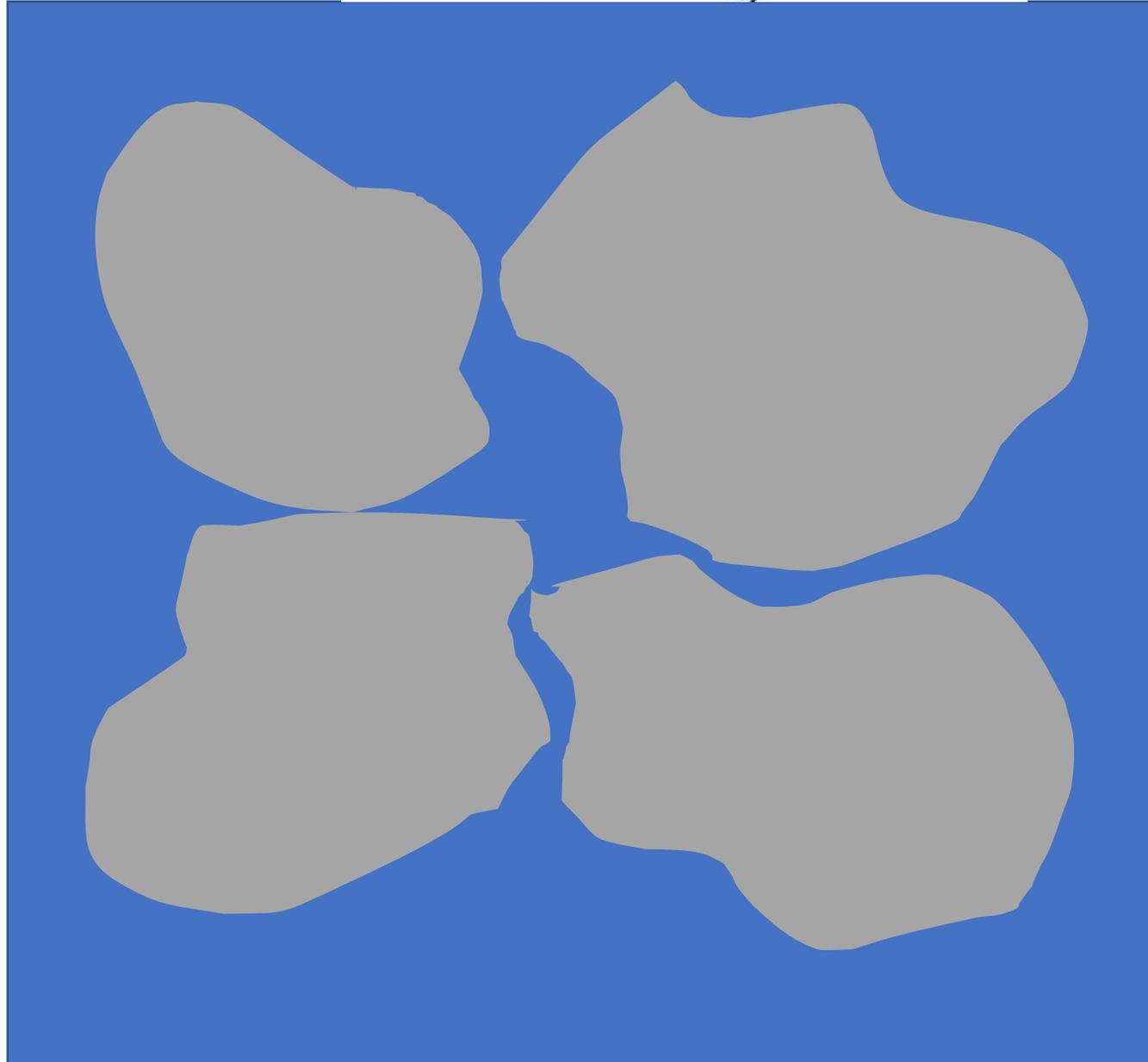
This helps the concrete flow.

Cement  
grains

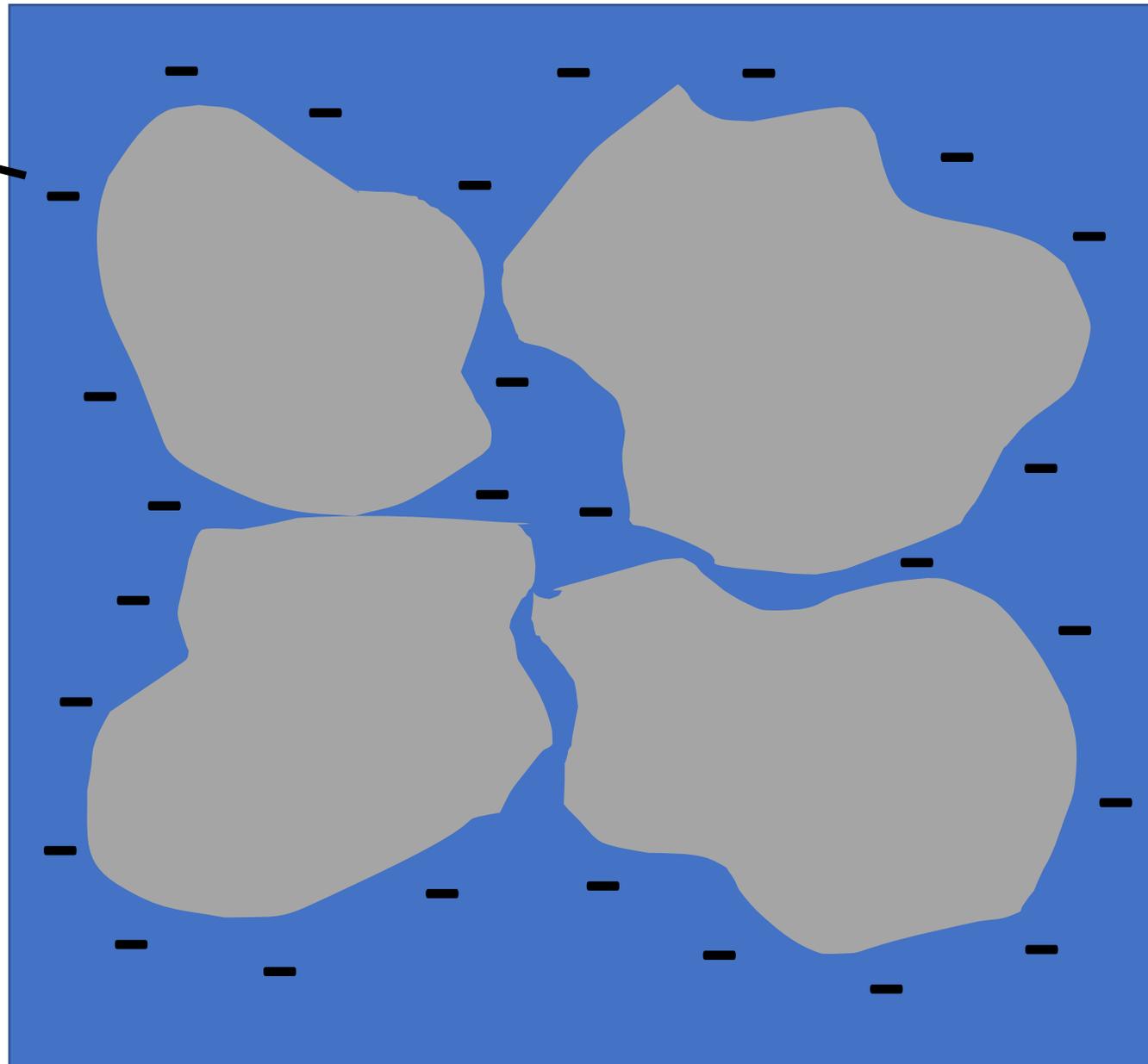


Water

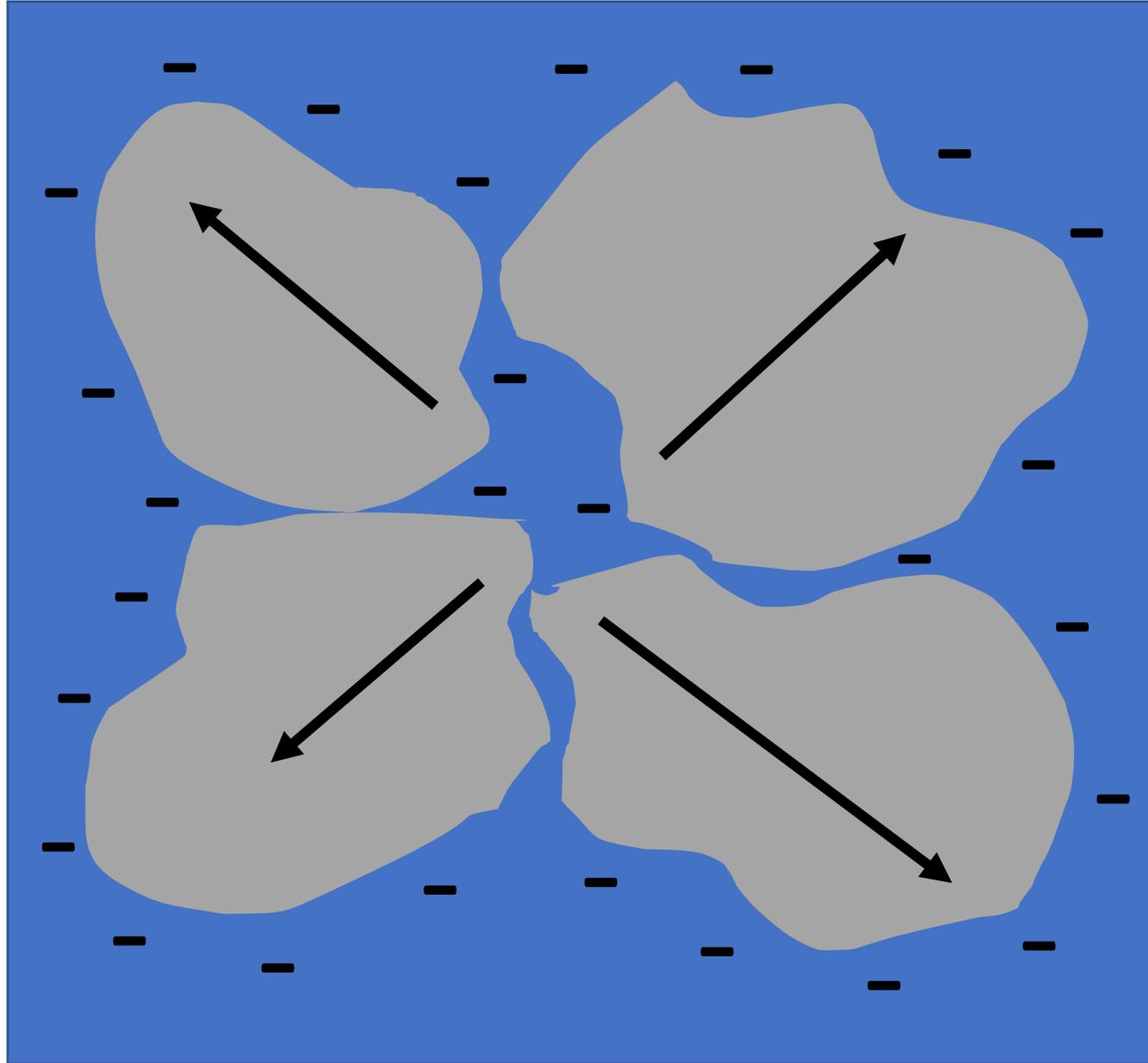
Water reducer



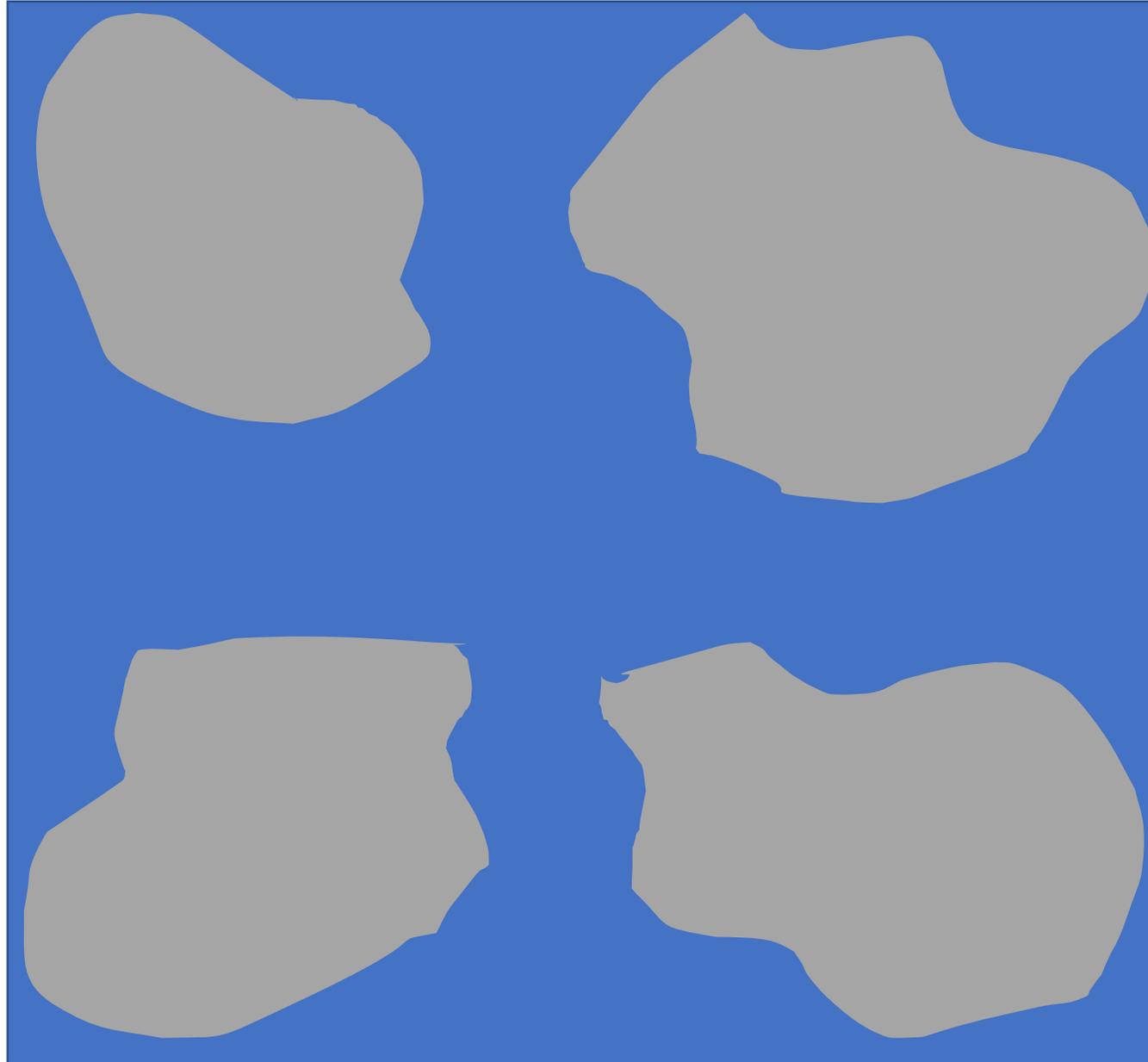
Negative  
surface  
charge



This pushes  
the grains  
apart



This makes  
the concrete  
more  
workable



Dryer sheets  
act like water  
reducers for  
clothes



They cause  
the clothes to  
repel each  
other.



Why are they called water reducers?



They are used to make the concrete more flowable with less water.

They can also be used to reduce the paste in a mixture to save \$\$\$.

# Why are water reducers different strengths?

- The strength of a water reducer is determined by the size and architecture of the molecule.

Water Reducer

Mid Range  
Water Reducer

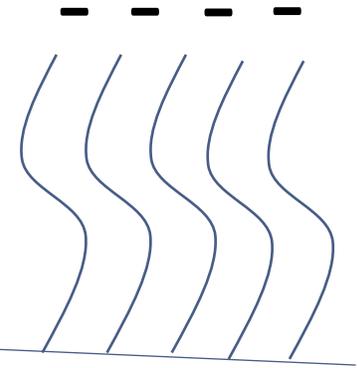
High Range  
Water Reducer



Good



Better



Best

Why are water reducers useful?



They can make concrete flow without adding water.

They can reduce the labor needed on a job site.

They can reduce the amount of cement you use.

They can increase your strength!

Almost all concrete should use a water reducer.

Why is a water reducer challenging?



You need to pick the right product for the right application.

They can increase the cost of the concrete.

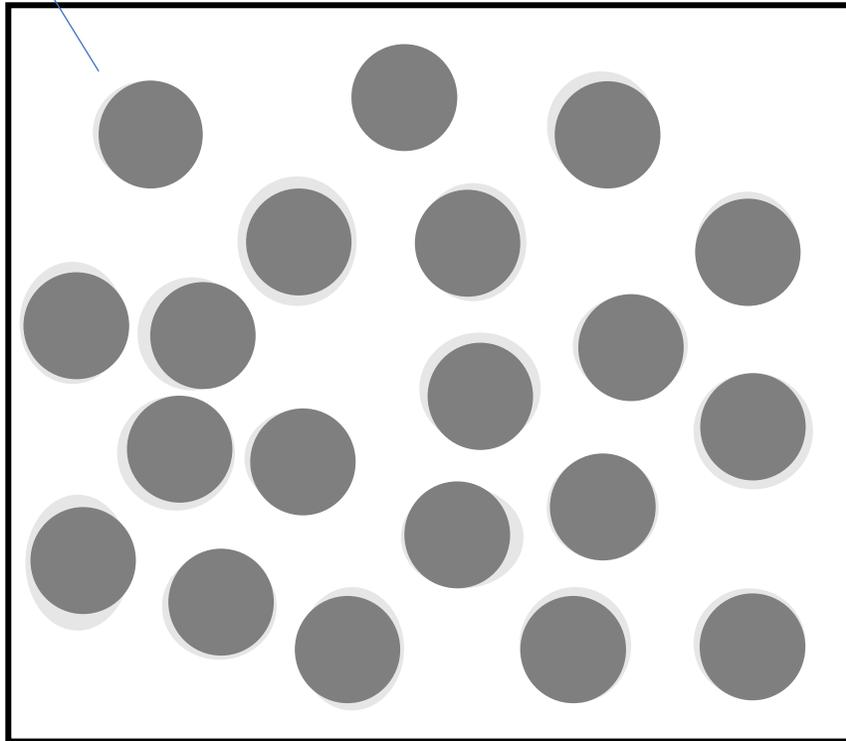
At high dosages the low range and mid range will change how the concrete sets.

# What is set?

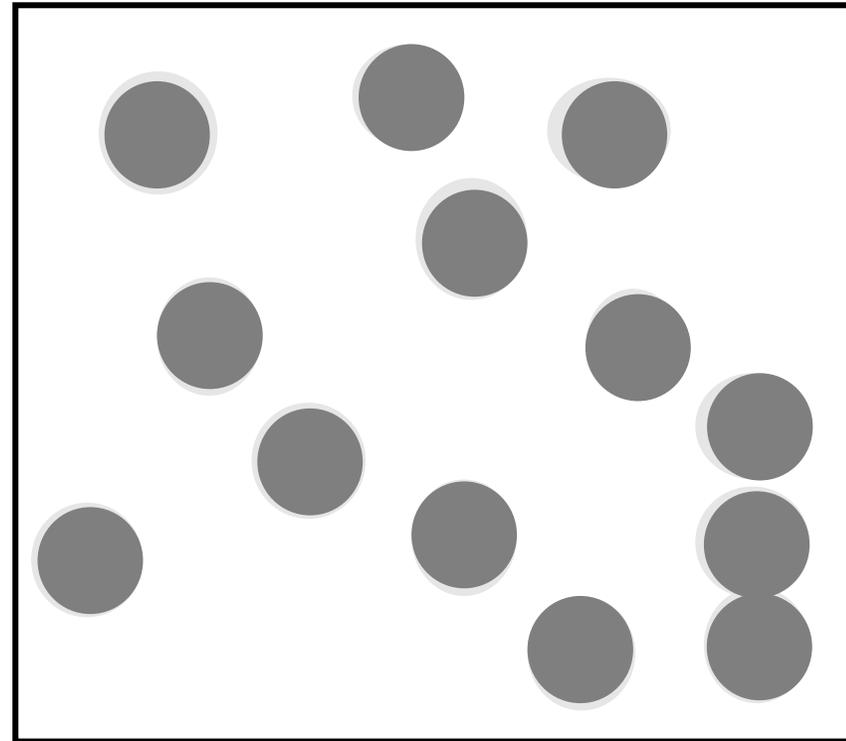
When a concrete mixture changes from a liquid to a solid.

Hydration  
product

$w/cm = 0.40$



$w/cm = 0.50$



How do I find the right admixture balance?

Adding too many admixtures at once can cause side effects.

Don't overuse admixtures.



# Types of fibers



Steel

Hardened Concrete



Macrosynthetic



Microsynthetic

Fresh Concrete

What is concrete's biggest weakness?

Tension Strength  $\approx \frac{1}{10}$  Compression Strength



# Why do we put rebar in concrete?

1. Carries load after concrete cracks
2. Reduces the size of the cracks



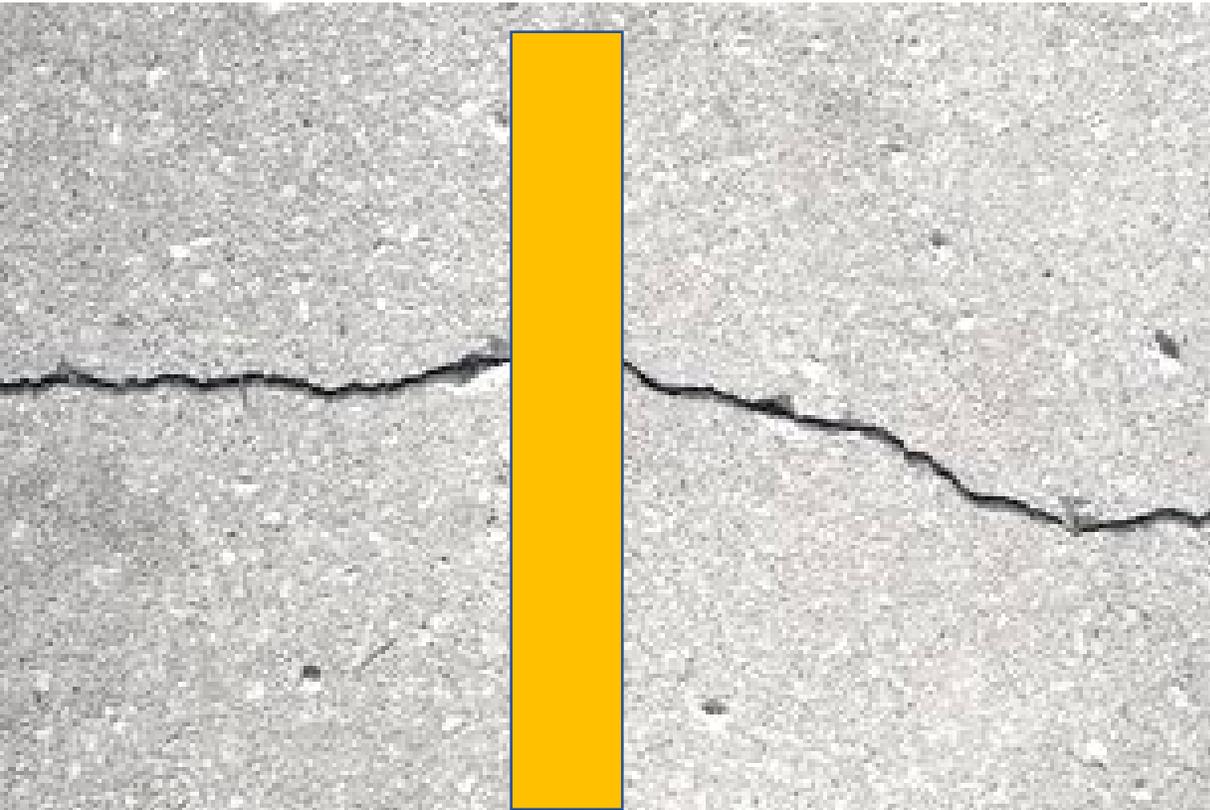
Lots of area in one spot!!!

# Why do we put fibers in concrete?

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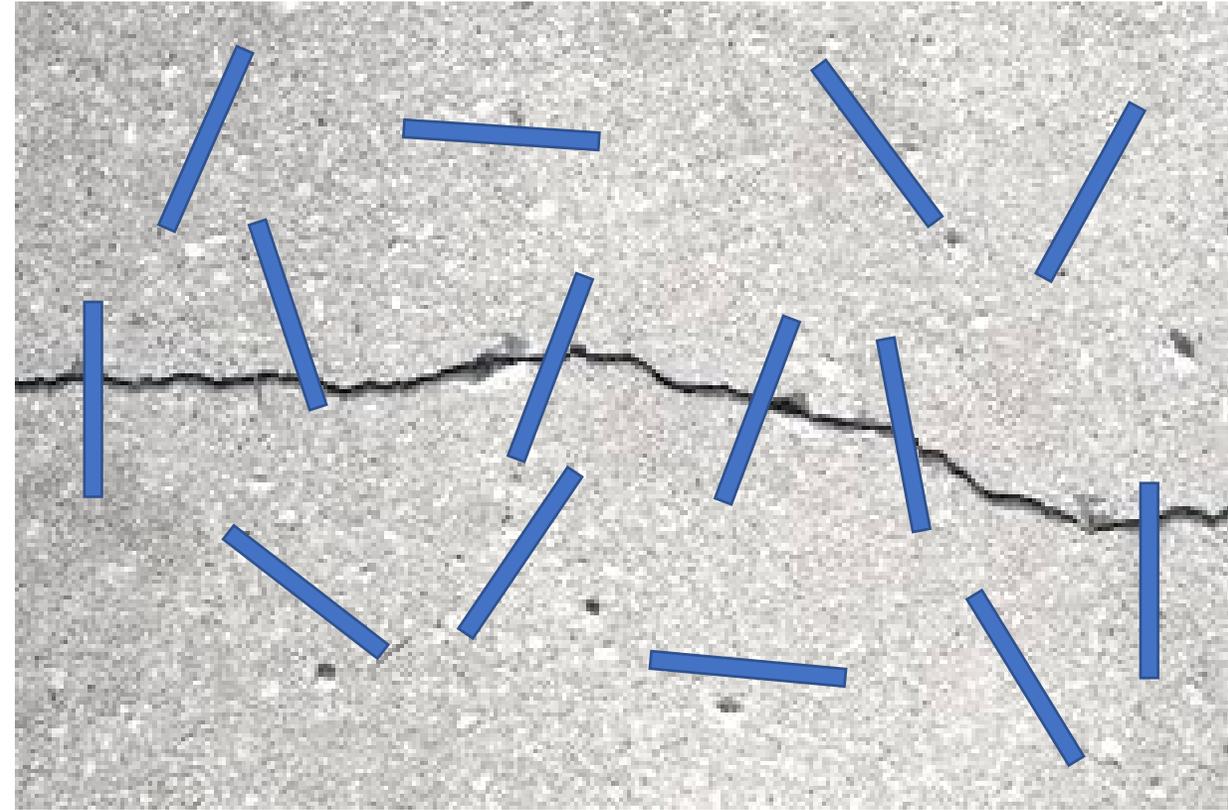
Small area in  
many spots.





## Rebar

Good at carrying the load  
Not as good at stopping cracks



## Fibers

Good at stopping cracks  
Not as good at carrying the load

Rebar + 7.5lb/cy  
macro-synthetic  
fiber

Rebar



# Plastic Macrofibers

Usually > 2"

Stiff plastic but

not as stiff as steel





# Benefits of Macrofibers in Concrete



Longer joint spacing

Less curl

Less cracking

More abrasion resistance

Thinner sections

Less rebar



# Warehouse Floor Slab

- 6 inch (15 cm) slab w/7.5 pcy (4.5 kg/m<sup>3</sup>) macrosynthetic fiber
- Longest slab panel is 127 feet (39 m) long & 60 feet (18 m) wide [2.1:1 ratio]
- No joints & no cracks in longest slab panel after 19 years
- Next shorter slab panel is 115 feet (35 m) by 85 feet (26 m). It has no joints and only one crack (due to improperly constructed dock pit) that does not cause any problems



Peach State  
TRAILERS  
404-635-9988

N. RTH. GEOR.  
SHIPPERS

53'

36404

# Distribution Center Truck Replacement Pavement

- 6 inch (150mm) fast-tracked replacement pavement over soft soil support system (normal concrete design per AASHTO would be 8"-9" [200-230mm])
- 7.5 pcy (4.5 kg/m<sup>3</sup>) macrosynthetic fiber
- No dowels – Only butt joints & no sawcut contraction joints
- Largest panel 66' (20 m) long & 46' (14m) wide
- Constant tractor trailer traffic
- No significant warping/curling & only one panel has a crack after 19 years

# Fiber Reinforced Concrete Design

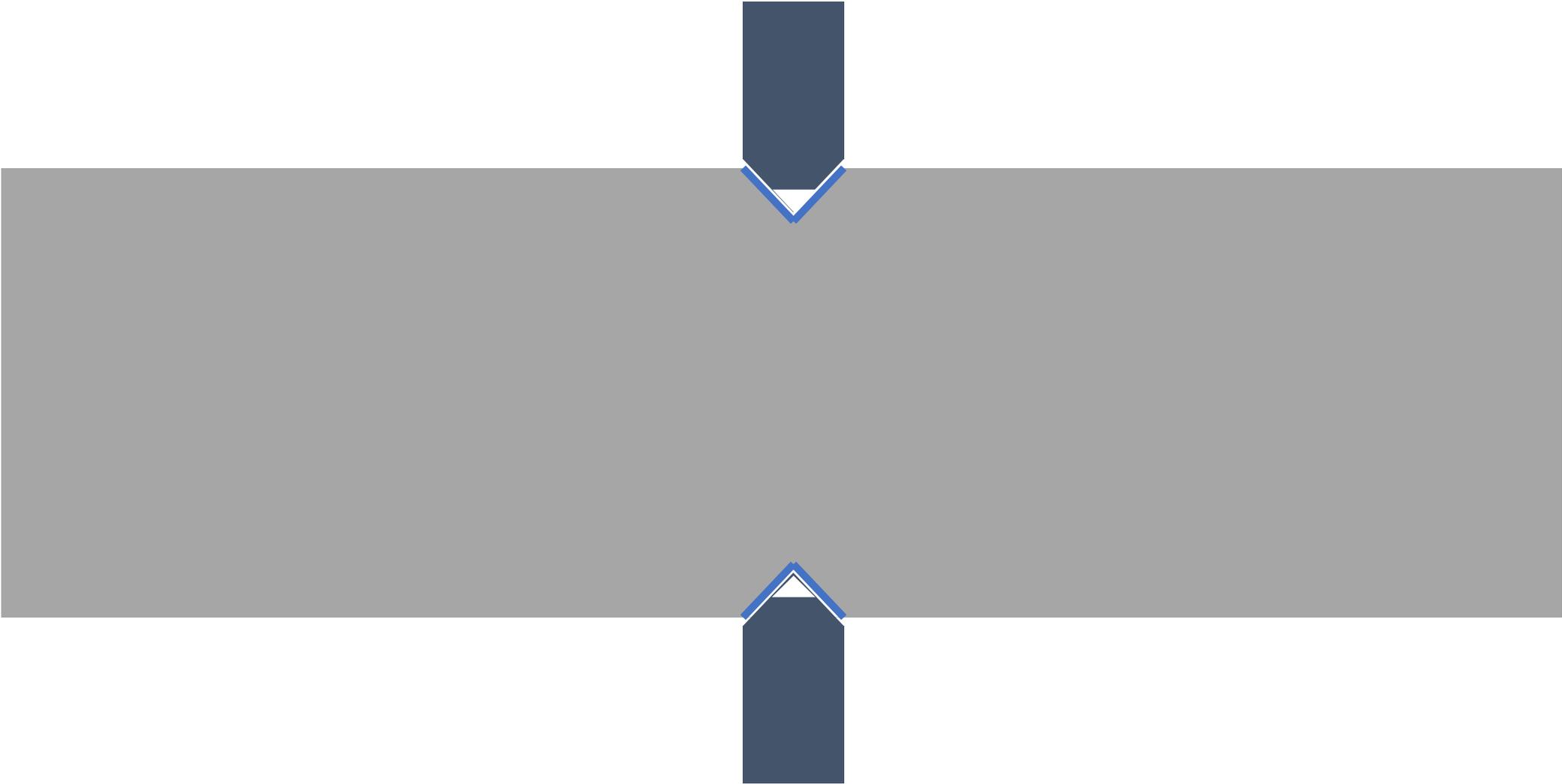
Post crack strength  
Crack size

Placement  
Finishing

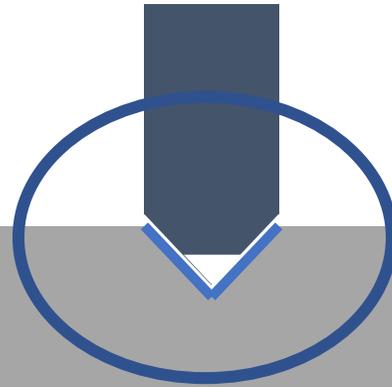


# Split Beam

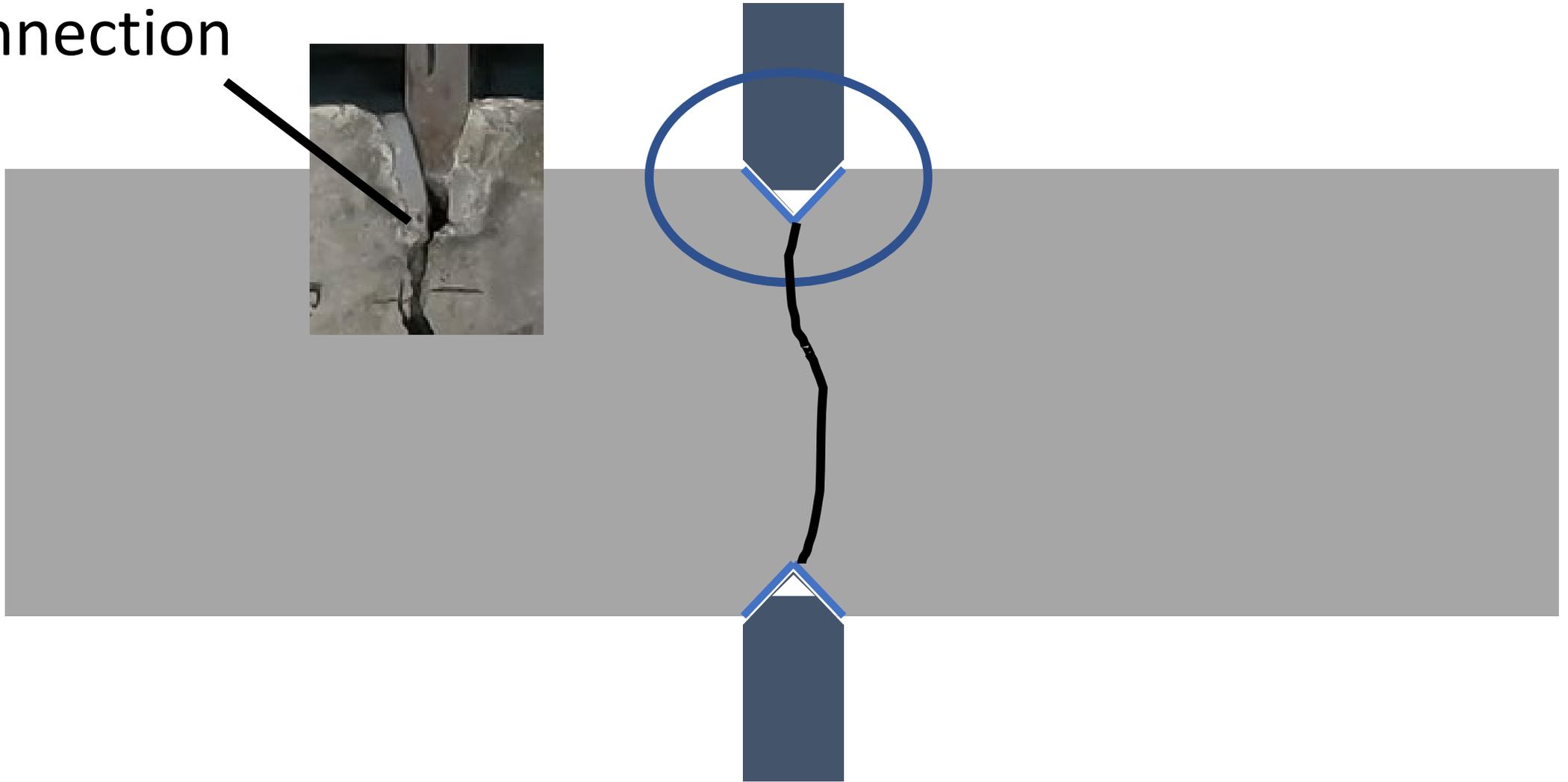
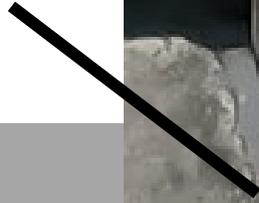


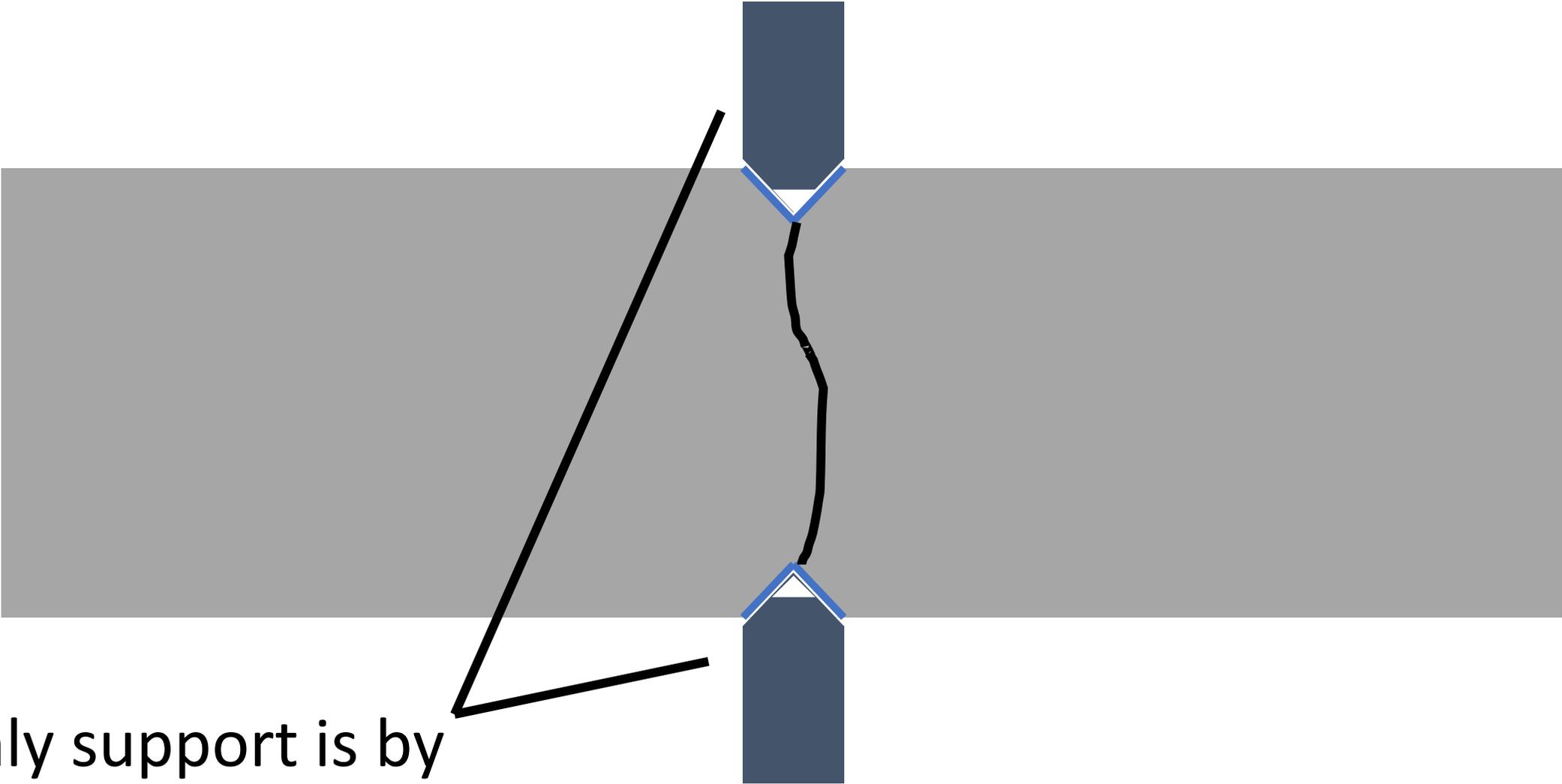


Two wedges that are  
not connected



No connection

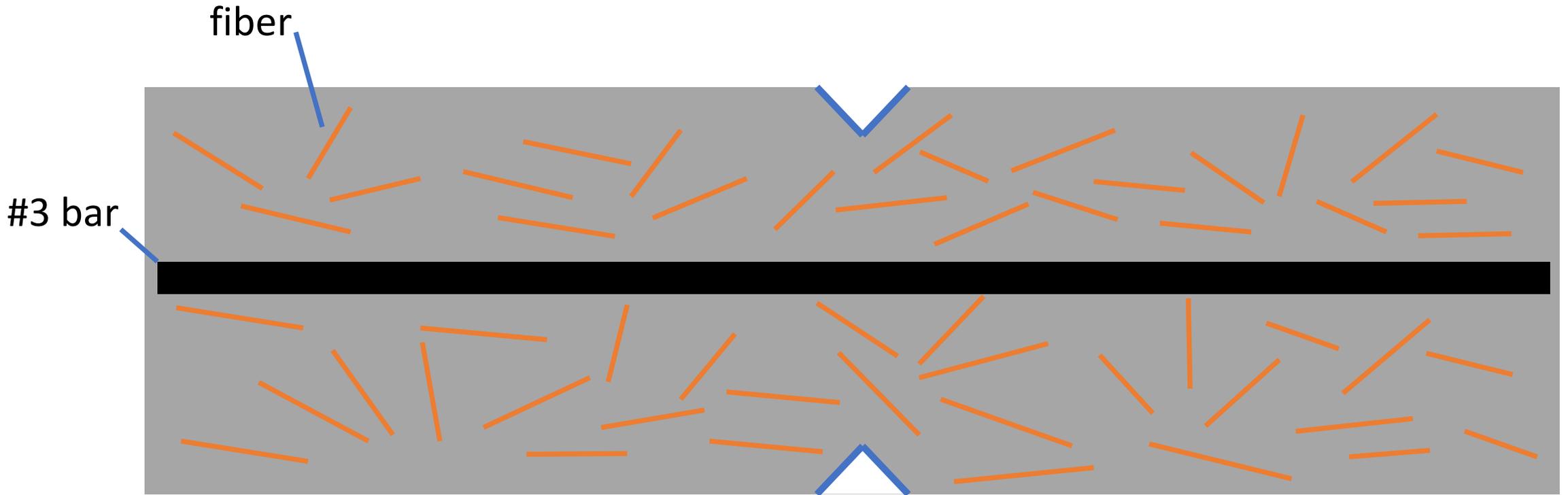


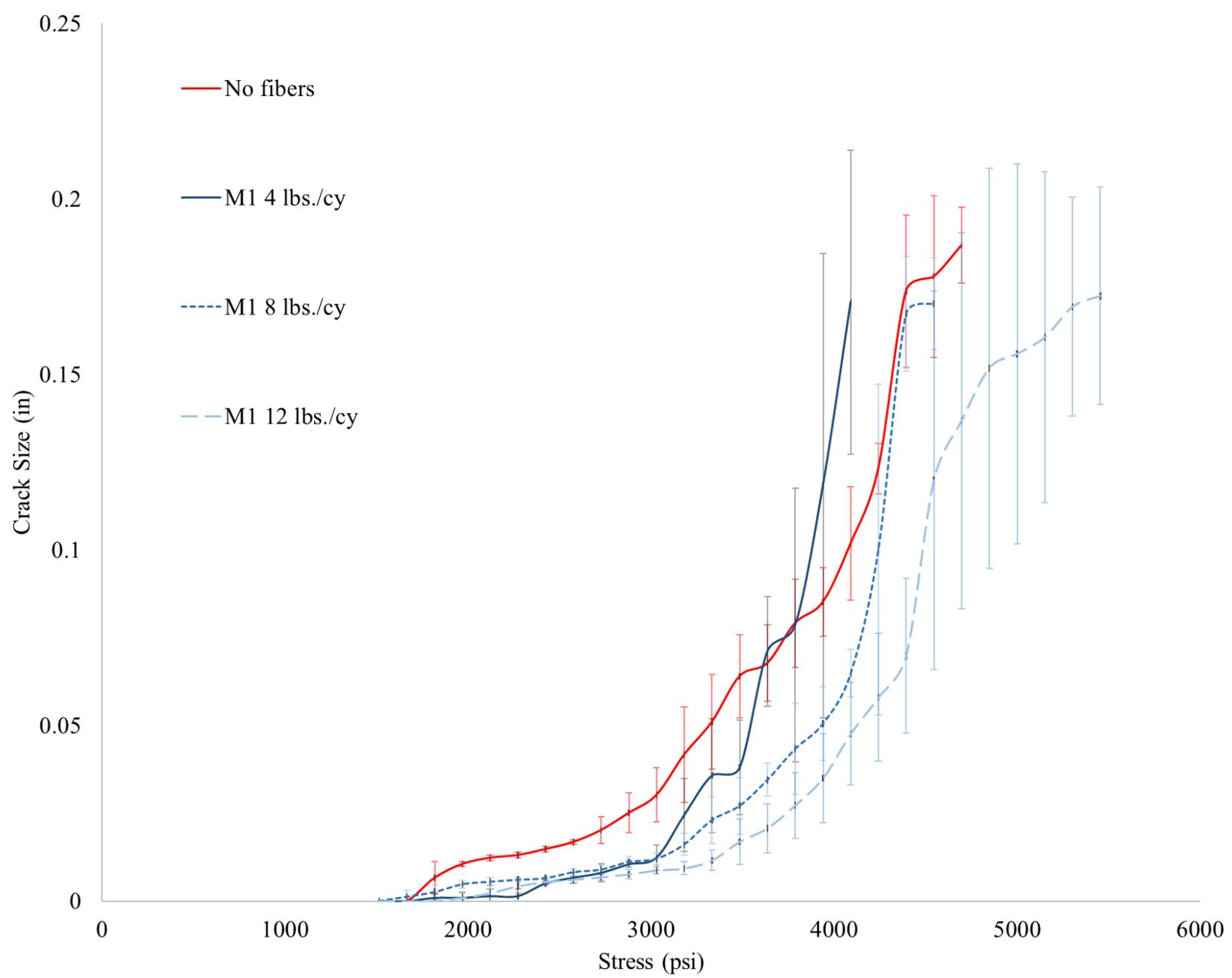


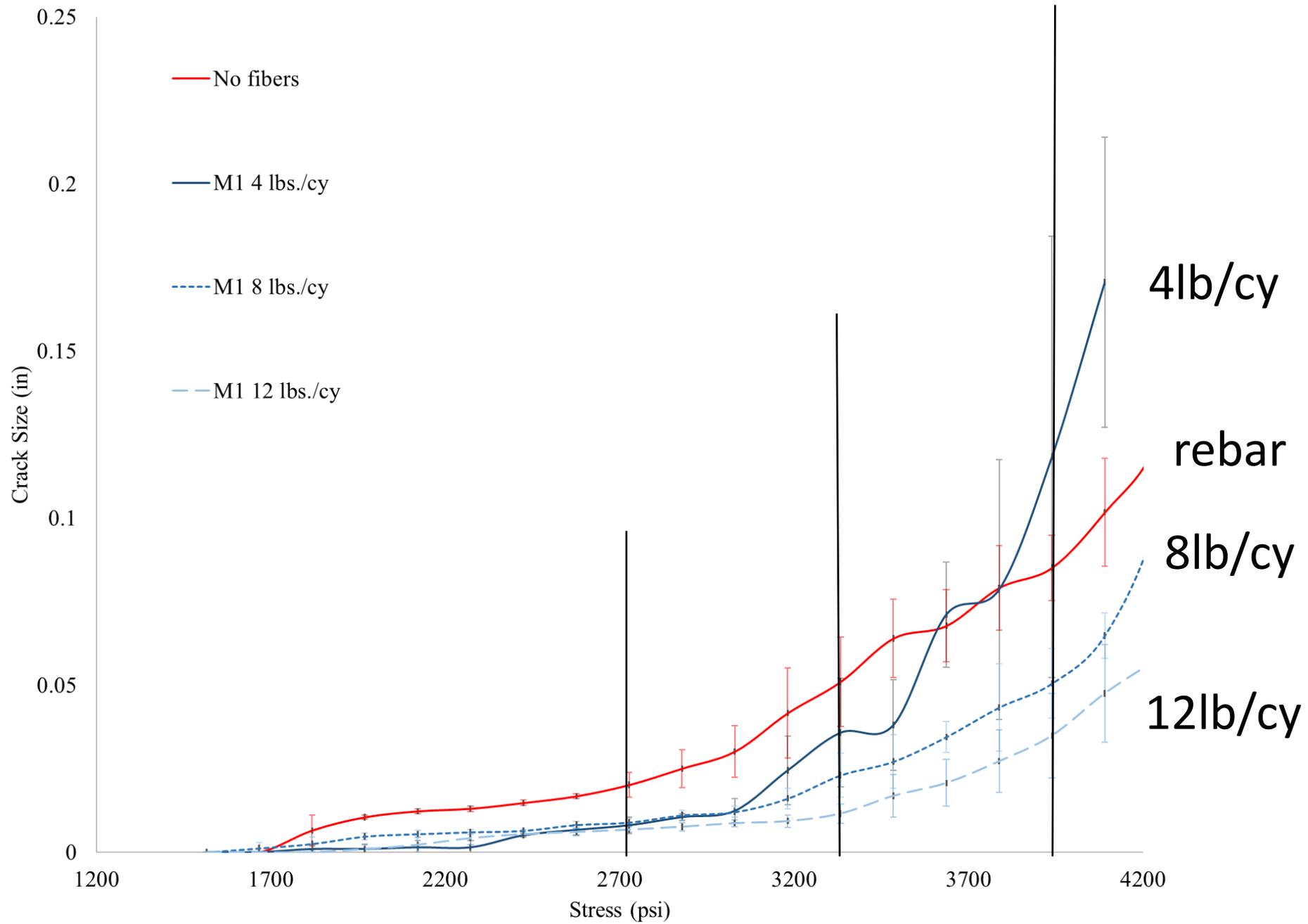
Only support is by  
the load platen

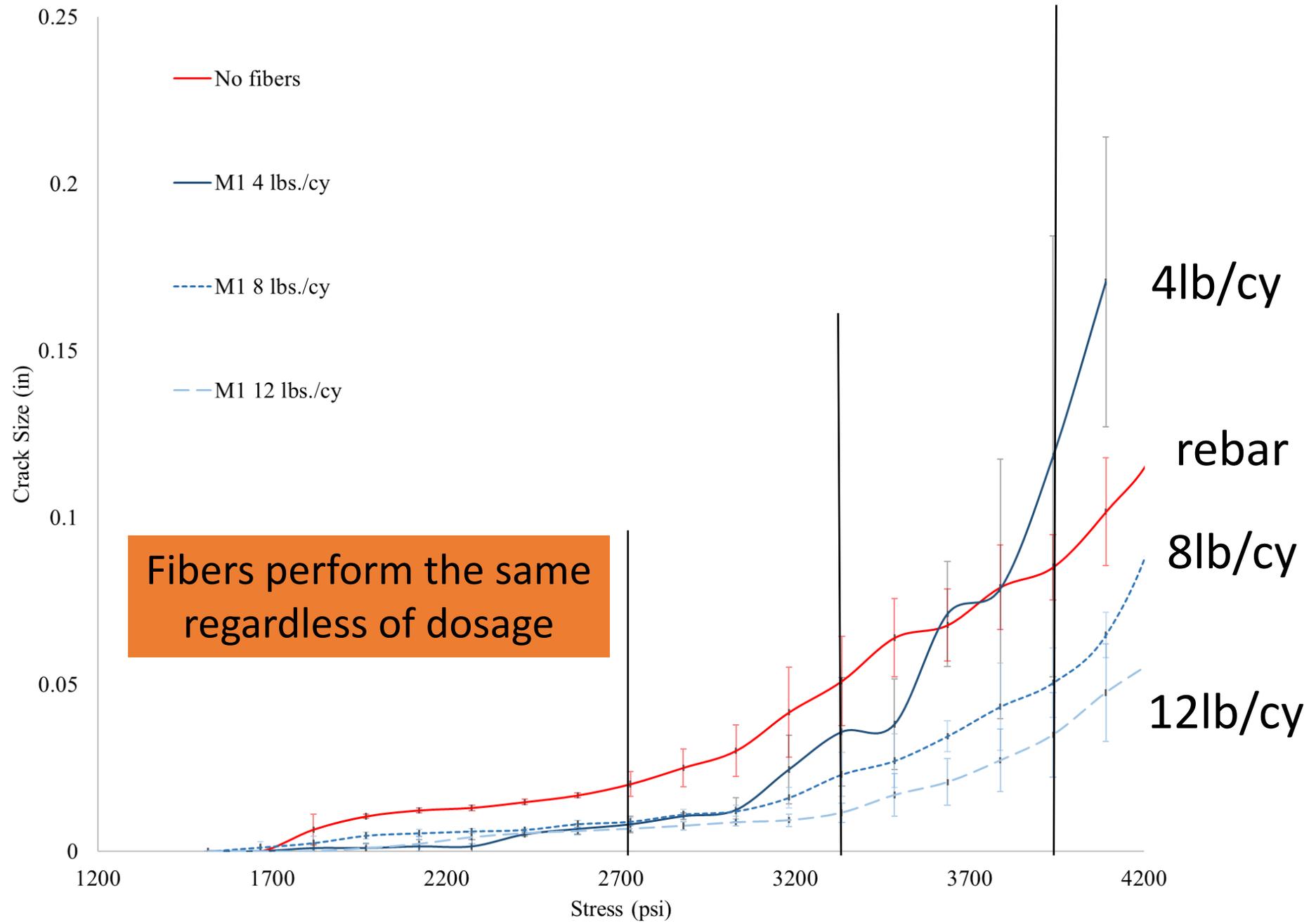


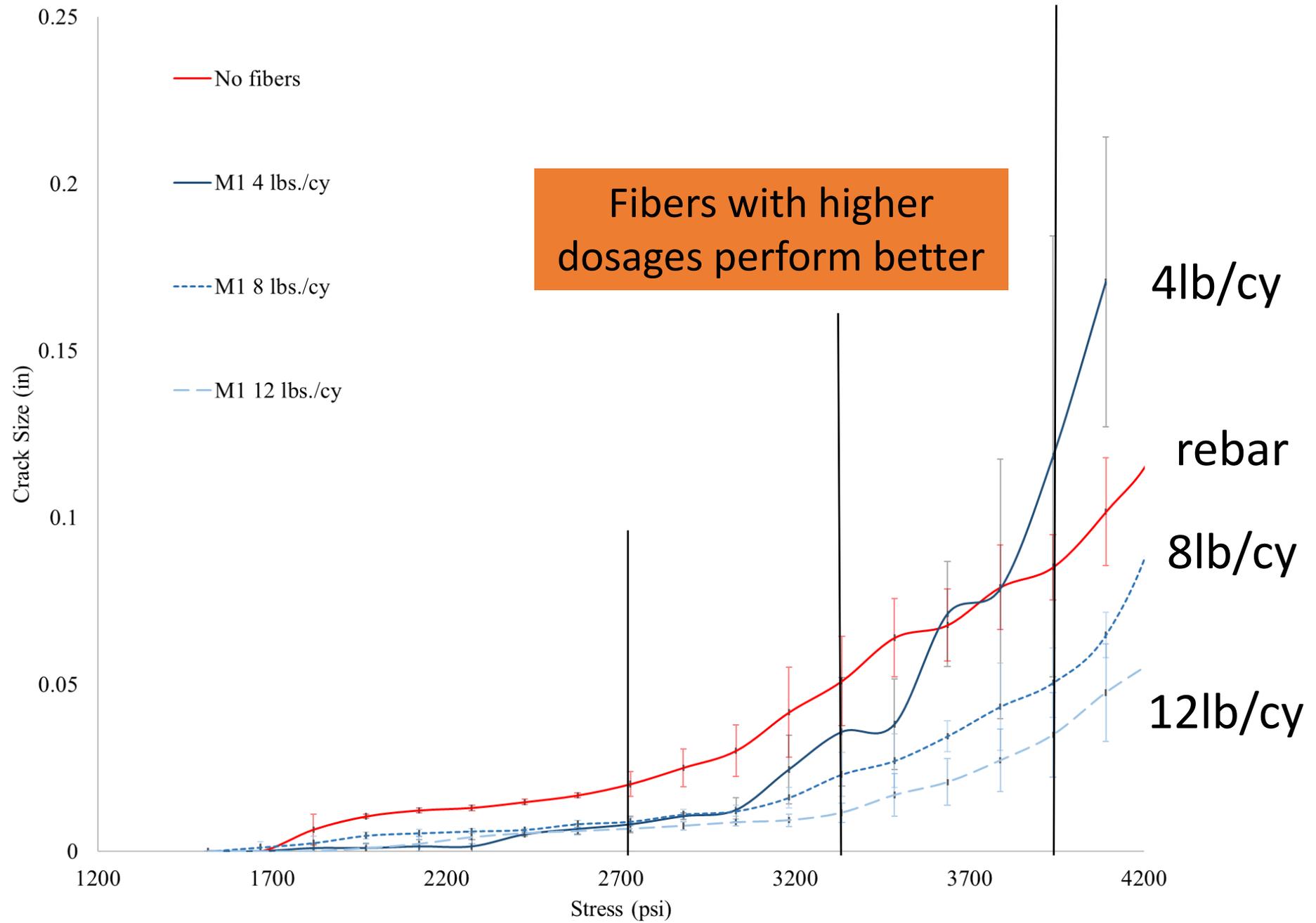
No supports

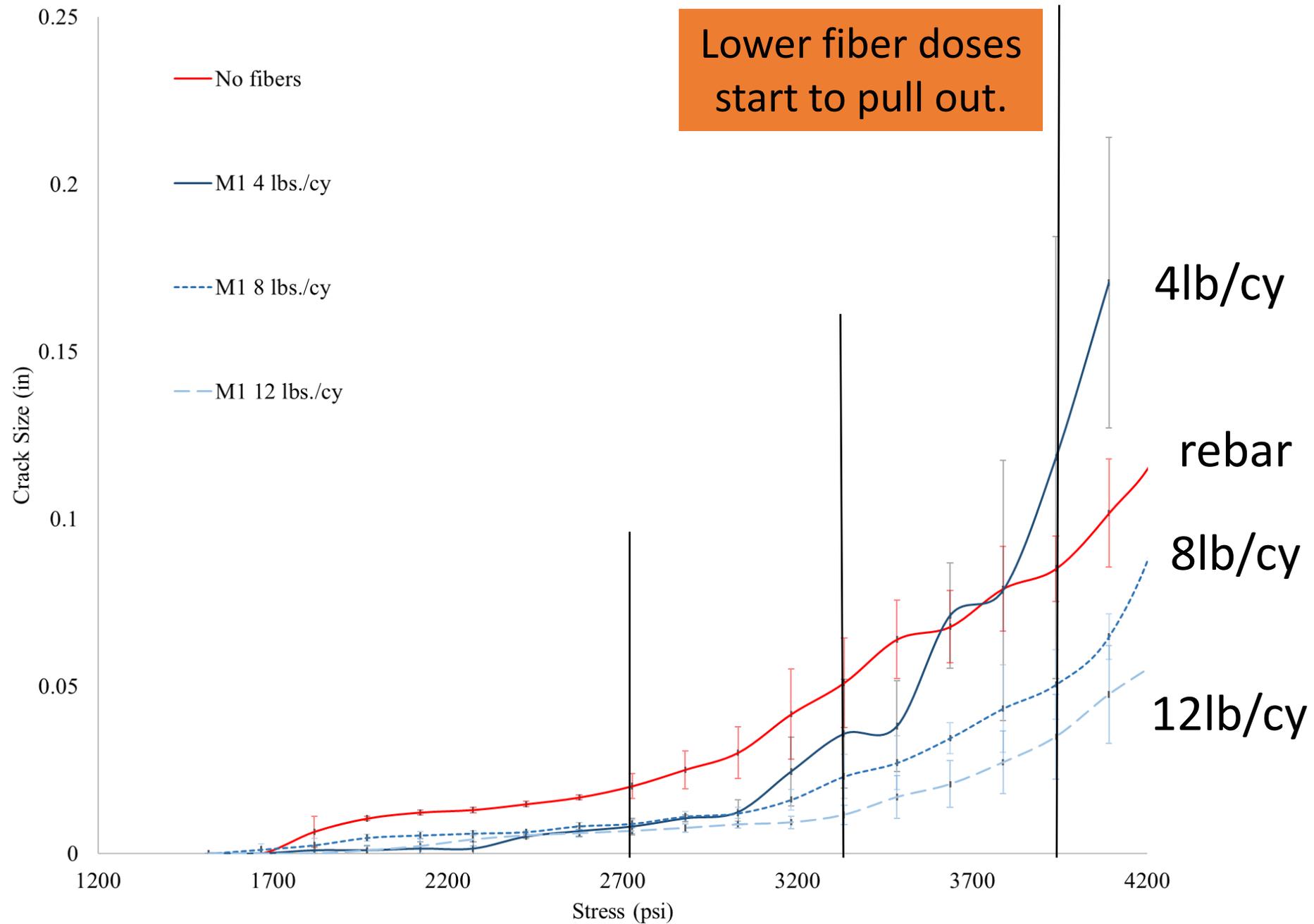


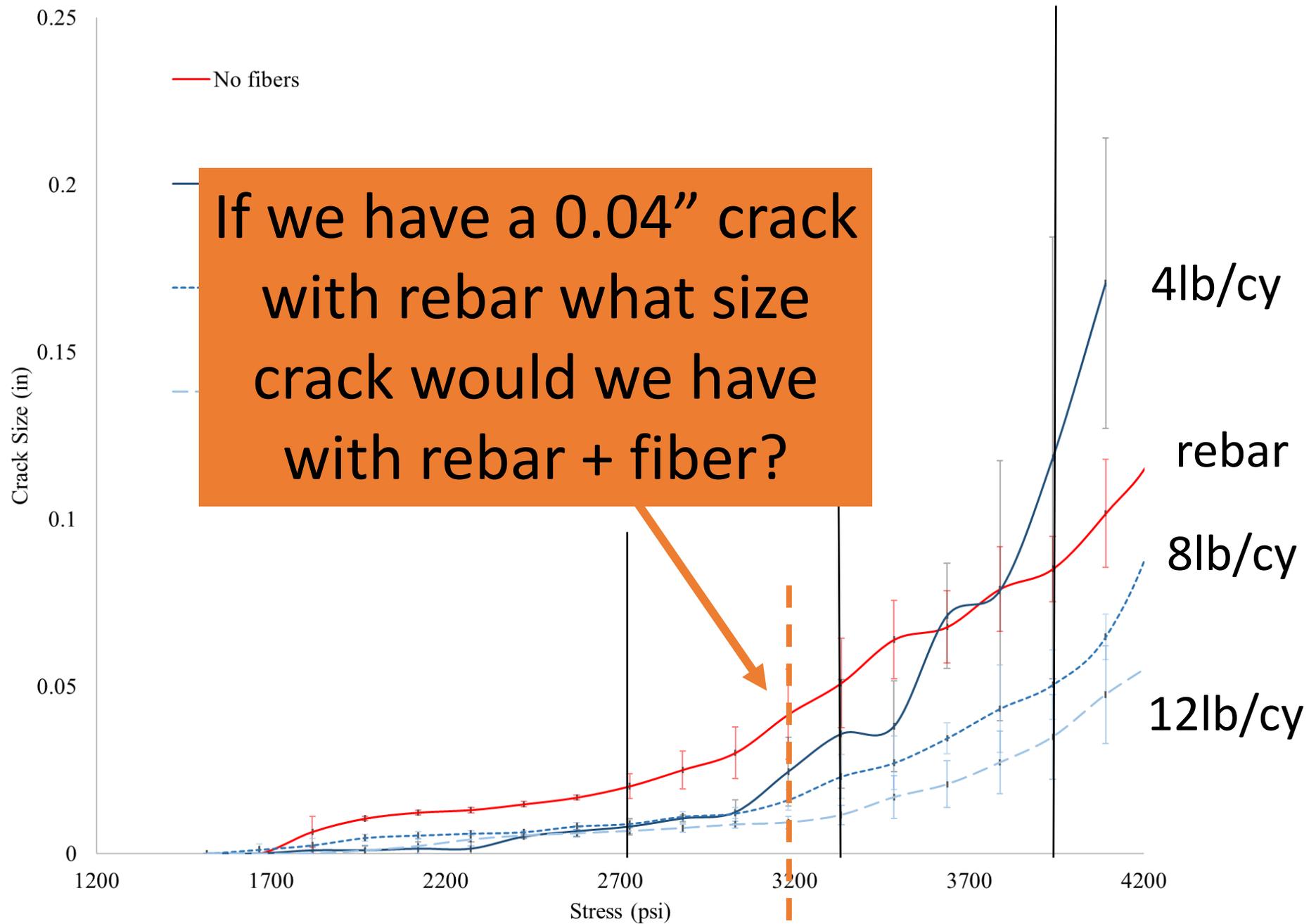












Rebar +

12 lb      8 lb      4 lb



No fiber



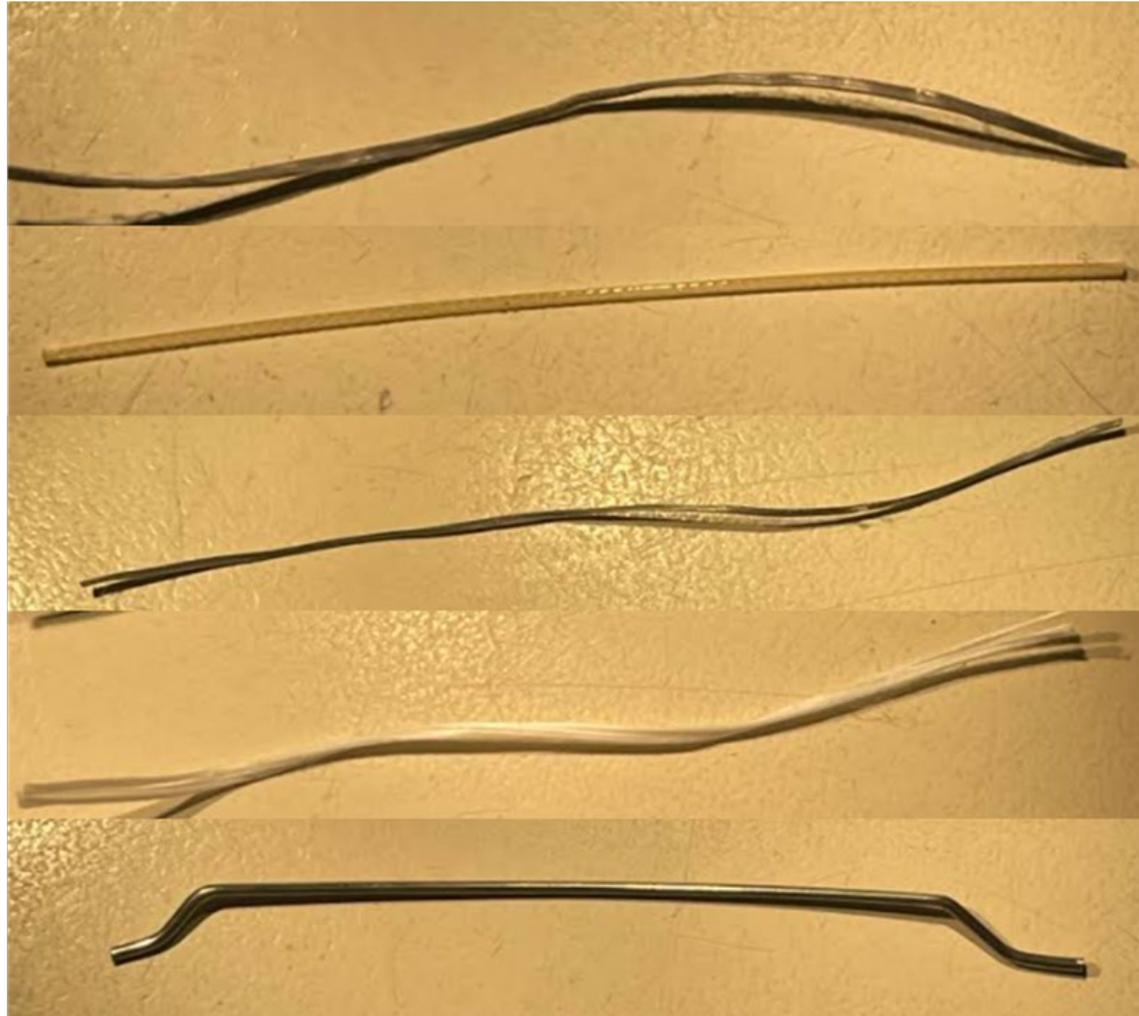
# Discussion

- Macrosynthetic fibers can significantly decrease the size of cracks in concrete.
- For a 0.04" crack in rebar –
  - 4lb/cy – 50% reduction in crack size
  - 8lb/cy – 75% reduction in crack size
  - 12lb/cy – 90% reduction in crack size

# Discussion

- The split beam test is a simple lab test that can run on a standard compression machine.
- The test can quantify the impact of fiber dosage on crack size.
- What else can we learn?

# How do different fiber types compare?



Copolymer

Polyolefin

Polypropylene

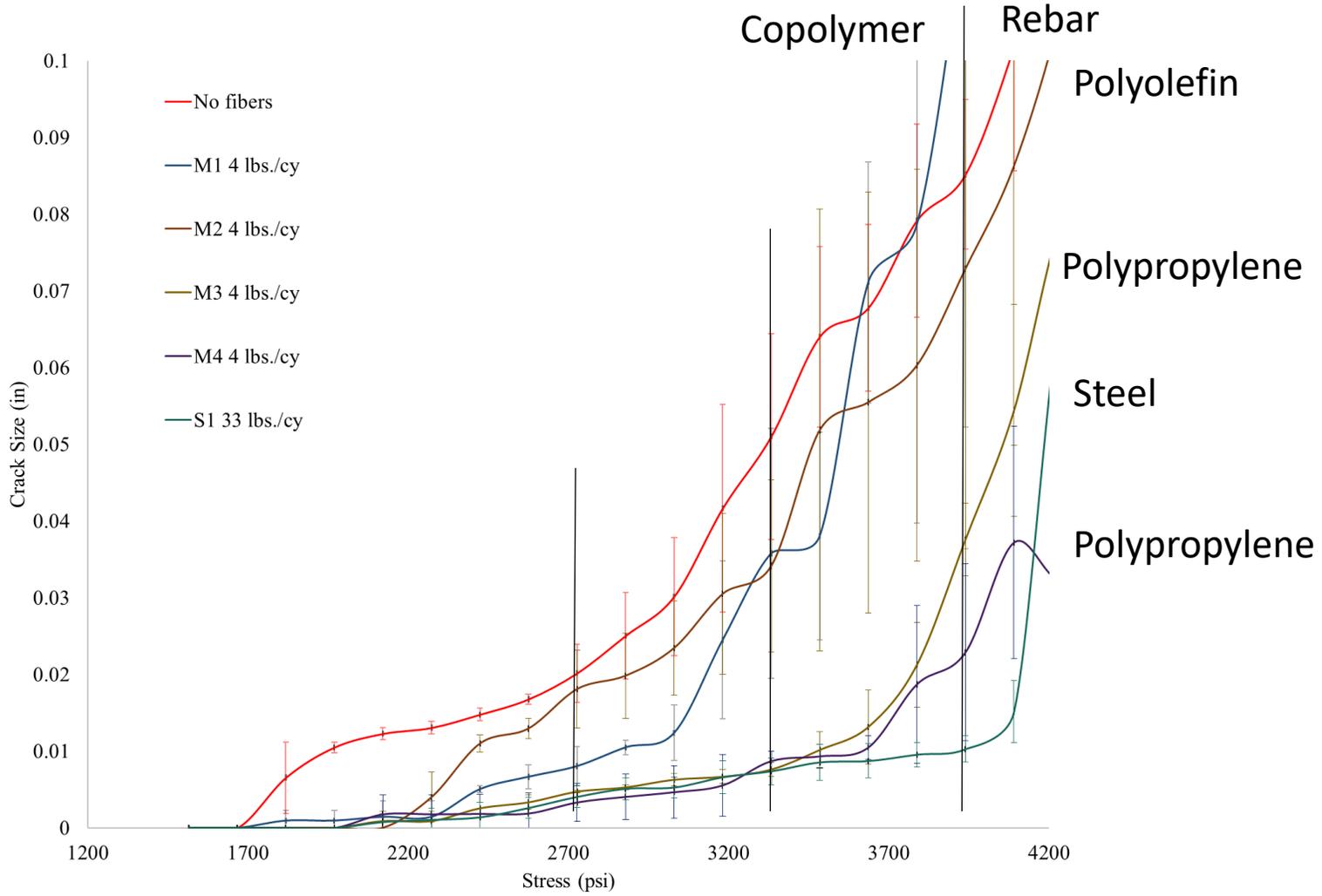
Polypropylene

Steel

0.25% by volume

4 lbs /cy macrosynthetic

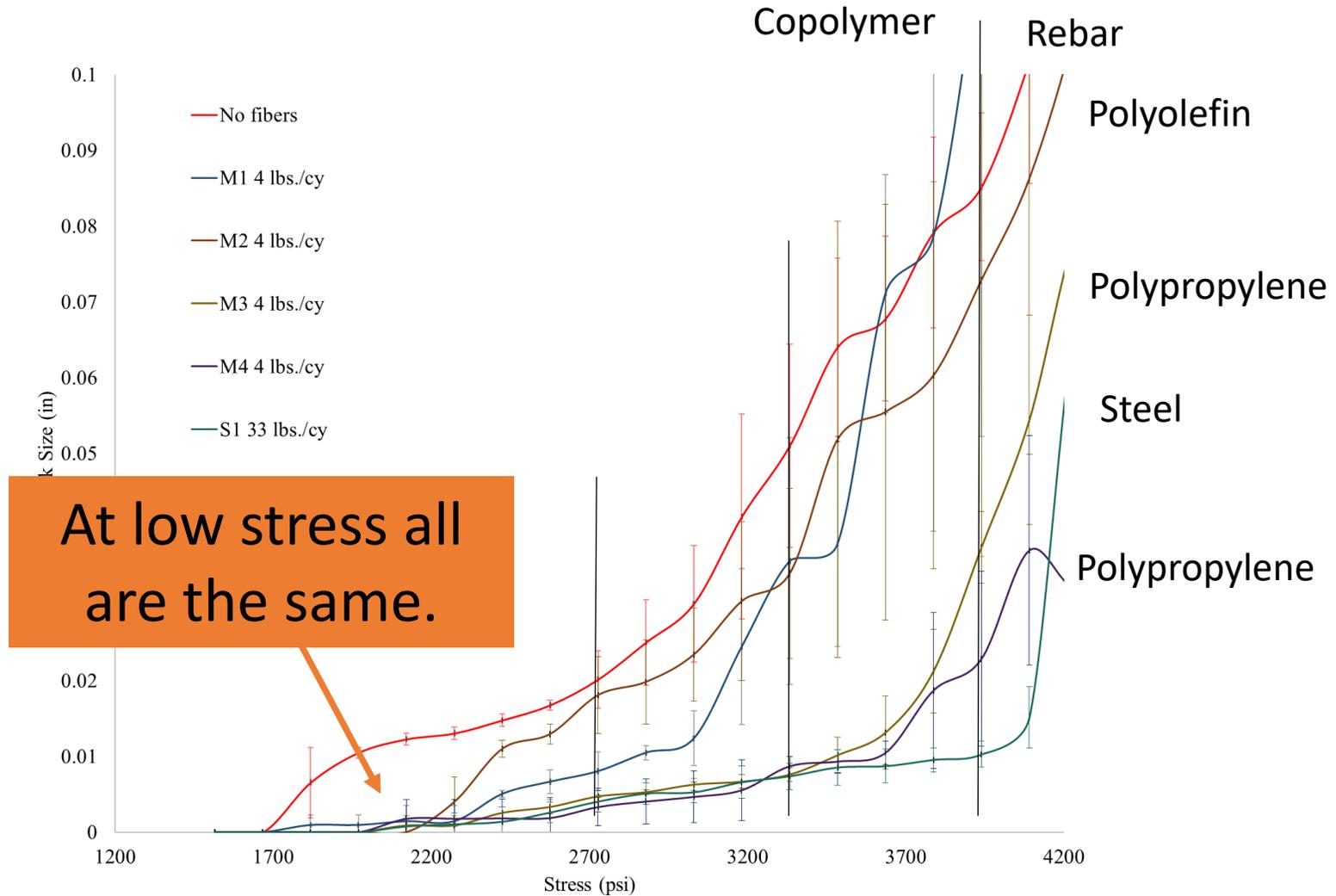
33 lbs/cy steel



0.25% by volume

4 lbs /cy macrosynthetic

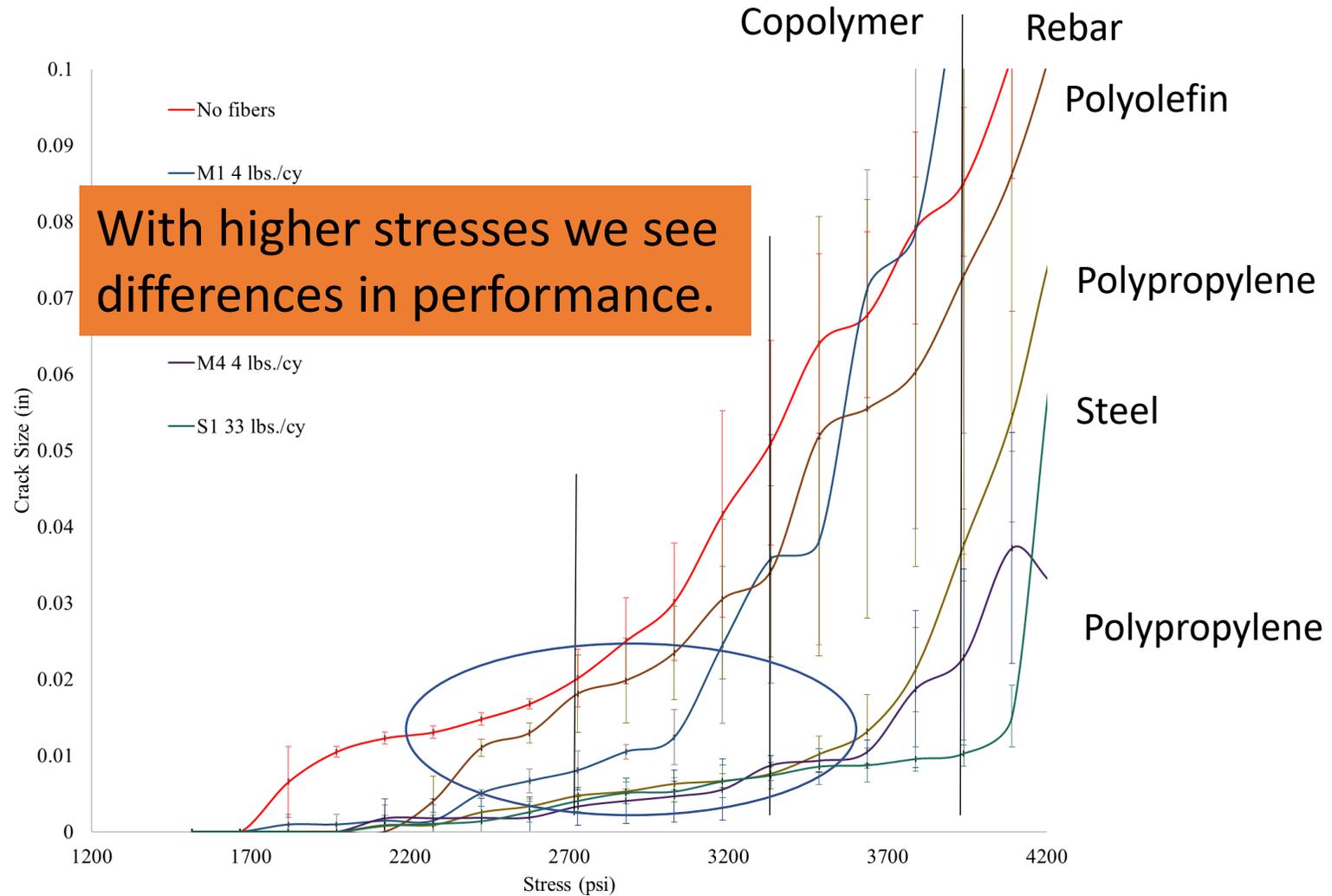
33 lbs/cy steel



0.25% by volume

4 lbs /cy macrosynthetic

33 lbs/cy steel





# Discussion

- At small cracks all fibers perform the same but as the cracks increase in size the fibers start performing differently.

Copolymer and Polyolefin show equal performance

Steel and Polypropylene show equal performance

- Steel or polypropylene reduced cracks by 60% more than copolymer or polyolefin fibers at the same volume.
- Similar performance is observed at higher dosages.

# Benefits of Macrofibers

Longer joint spacing

Less curl

Less cracking

More abrasion resistance

Thinner sections

Less rebar



# Challenges with Macrofibers

You may need to redesign your mixture

Slump decreases

Finishing can be challenging

Not all fibers are created equal



The most important thing...

Concrete is magical and it makes so much of the great things in our life possible.

But don't ever forget...

The most important thing...

There is no magic without you.

# Summary

Concrete is a very rewarding industry!

You are building society and there are massive opportunities.

You have lots of tools to bring more value to your customers.

# Topics

- Paste quality
- Aggregate distribution
- Curing
- Consolidation
- Water to cement ratio
- Fly ash
- Air entraining agents
- Water reducers
- Fiber design
- Crack control with fibers

Who learned something new?

Who learned something new?

Who is willing to try something new to  
make you better?

Who learned something new?

Who is willing to try something new to  
make you better?

What is holding you back?

> 99K subscribers  
> 10M views



# Structural Cracking in Reinforced Concrete

[www.youtube.com/tylerley](http://www.youtube.com/tylerley)

**TYLER LEY, PE, PhD**







Concrete

# Questions?

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