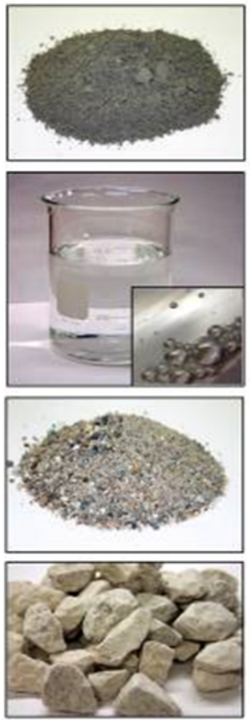
CHOOSING THE PROPER PCC MIX FOR DURABILITY



9 - 15%
Cement

15 - 16%
Water

Paste
(cement + water)

25 - 35%
Fine aggregate

Mortar
(paste + fine aggregate)

30 - 45%
Coarse aggregate

Concrete
(mortar + coarse aggregate)

National Concrete Pavement Technology Center
Iowa's Lunch–Hour Workshop
In cooperation with the Iowa DOT
and the Iowa Concrete Paving Association

What Properties from Mix are Needed

Assuming we have quality aggregates and quality cementitious materials

1. **Strength**
2. **Workability**
3. **Crack Resistance**
4. **Freeze Thaw Resistance**
5. **Deicing Chemical Resistance**

Strength

- Standard mixes are adequate to obtain proper strength gain in a reasonable time.
- Exceptions may be special circumstances where early opening is required.
  - IDOT maintenance mixes provide for the early openings but have increased potential for dry shrinkage
  - Standard mixes with excess accelerator admixtures can result in cracking before finishing and/or saw cutting can be completed.

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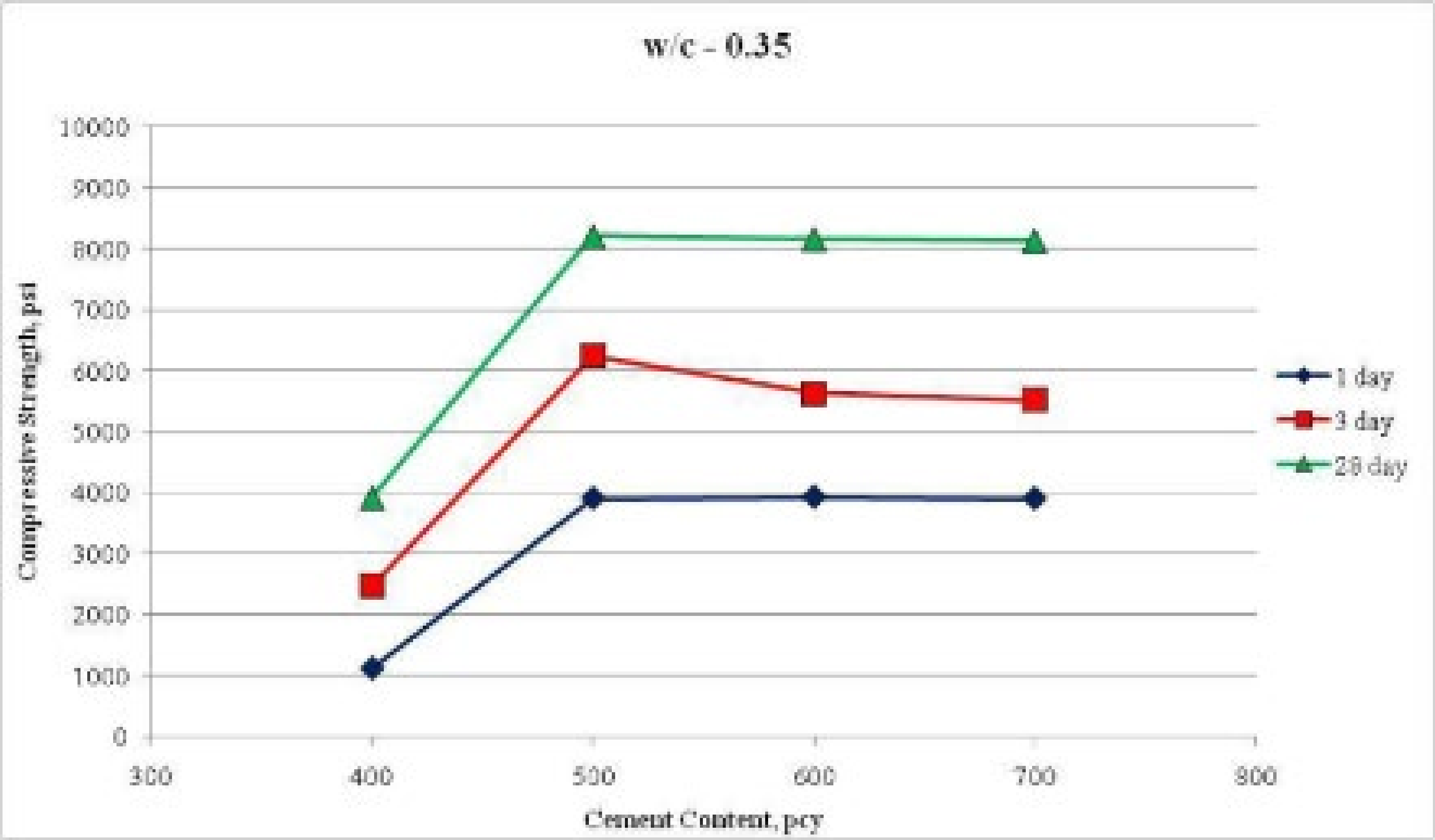
Adding Cement Goes so Far with Strength



Strength Gain
Cementitious Material Properties

	Silica	Alumina	Calcium Oxide	Sulfate
Type I Cement	22%	5%	65%	1%
Class F	52%	23%	5%	0.80%
Class C	35%	18%	21%	4.10%
Slag	35%	12%	40%	9%

SCM's can can slow initial strength gain but improves long term strength

Silica – Ties up alkalies to help control ASR

Alumina – Set off right away and to control flash set use gypsum (sulfate)

Calcium Oxide –Provides faster set possibilities

Sulfates – Help control aluminates to prevent permanent hardening (flash set). Too much sulfate causes false set but can be overcome.

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Workability

- Important property of fresh concrete
- Amount of mechanical work required to place and consolidate the concrete
- Provides adequate consolidation and reduced entrapped trapped air voids
- Proper aggregate gradation greatly improves workability
  - Proper filling of voids between larger particles

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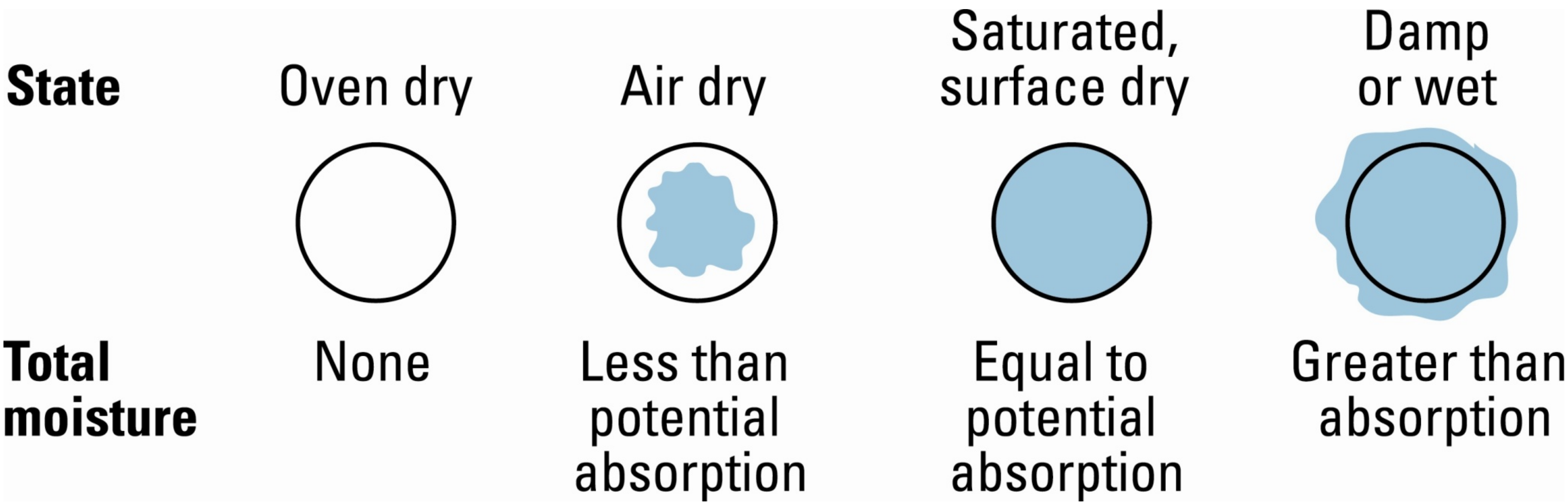
Aggregate Moisture States

Absorption is a function of the amount of void space in the aggregate



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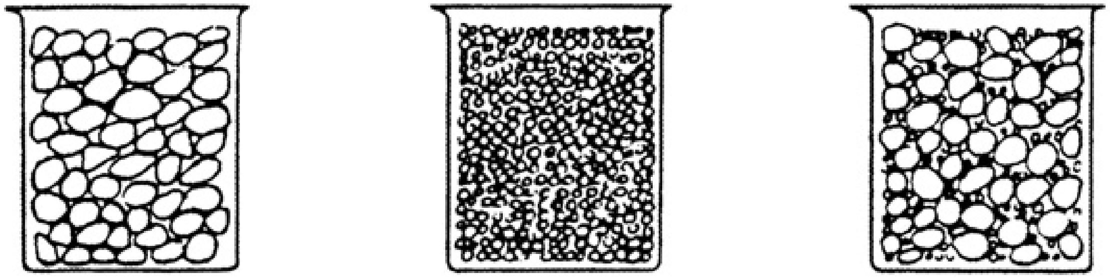
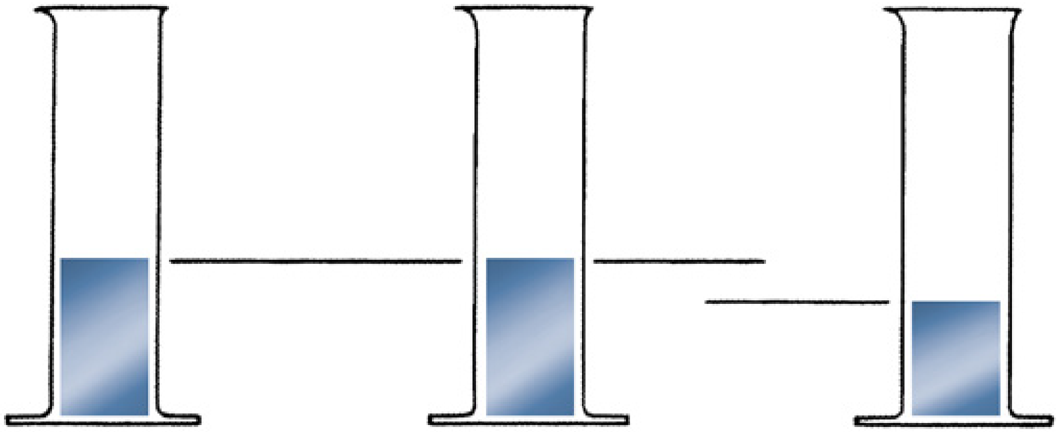
Aggregate Gradation

- Should be well-graded
- Control combined grading to increase amount of aggregate in the mix
  - Reduced paste (shrinkage, heat, cost)

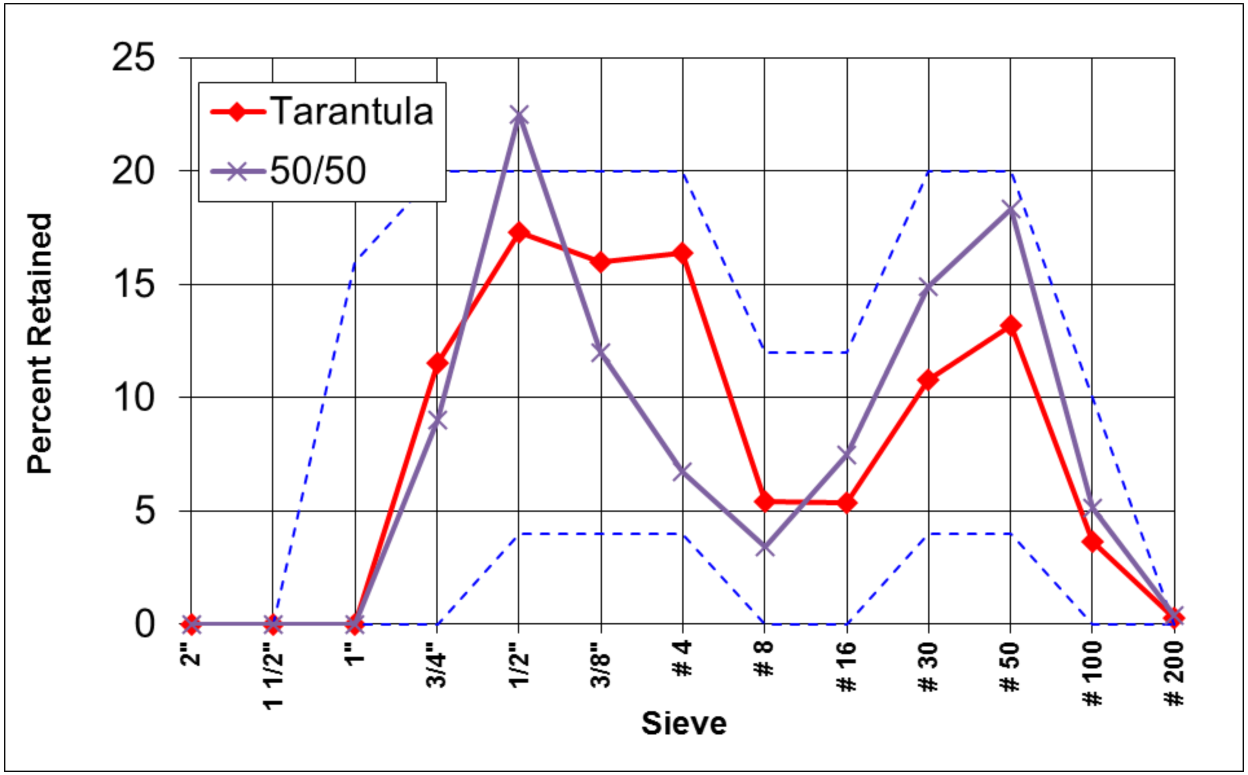


Aggregate is inexpensive and a good filler



Aggregates Gradation

- Most of the volume of a mixture
- Influences:
  - Strength
  - Workability
  - Durability



Crack Resistance

- Use Type I/II cements (avoid high early strength except special conditions)
  - Minimize shrinkage
  - Helps with slab warping
- Use SCM to reduce thermal shrinkage
- Use low CTE aggregates
  - Minimize curvature & stress
  - Helps prevent aggregate expansion

DURABILITY

Durability

Iowa Concrete Pavements are Durable

Some joint distress have appeared in the last 5 years

Primary factors causing distress:

1) Reaction between certain deicers in the matrix of concrete
2) Lack of proper air entrainment; freeze-thaw damage
3) Saturation (permeability);freeze-thaw damage

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How to Achieve Durability

Low w/c (low permeability)

Freeze-Thaw Resistance

The Right Mix for Durable Concrete

Proper Entrained Air /Lower Saturation

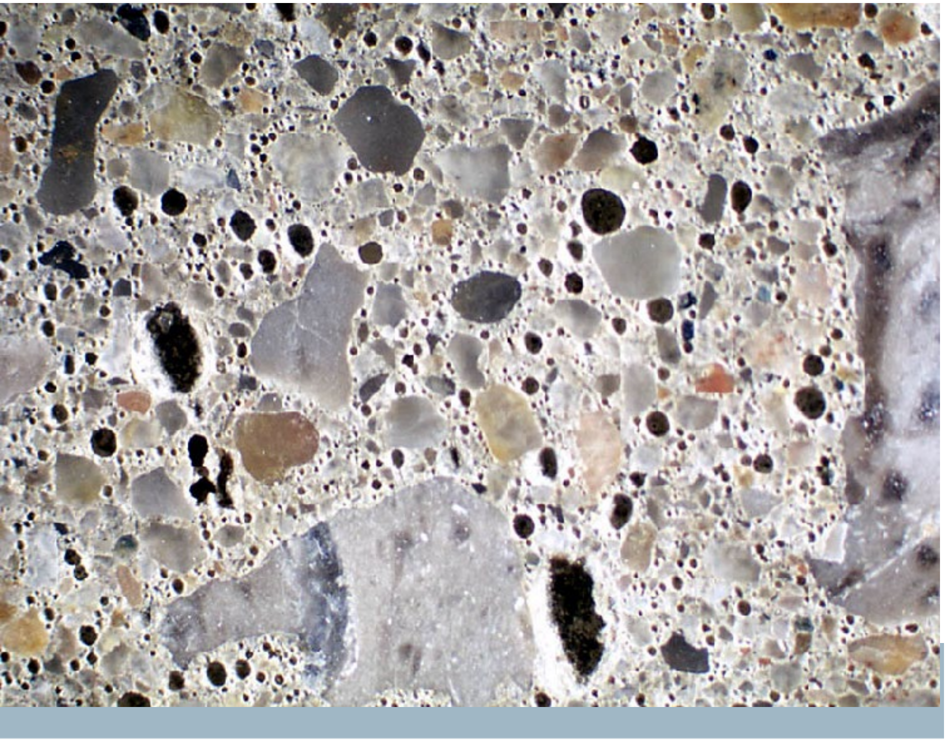
Freeze-Thaw Resistance

Use of SCM’s

Deicing Salt Resistance

Air Entrainment

- Vinsol / Resin / Tall Oil / Synthetics
- Air Void System
  - Spacing factor <0.008 inch
  - Air content >5% behind the paver
  - SAM



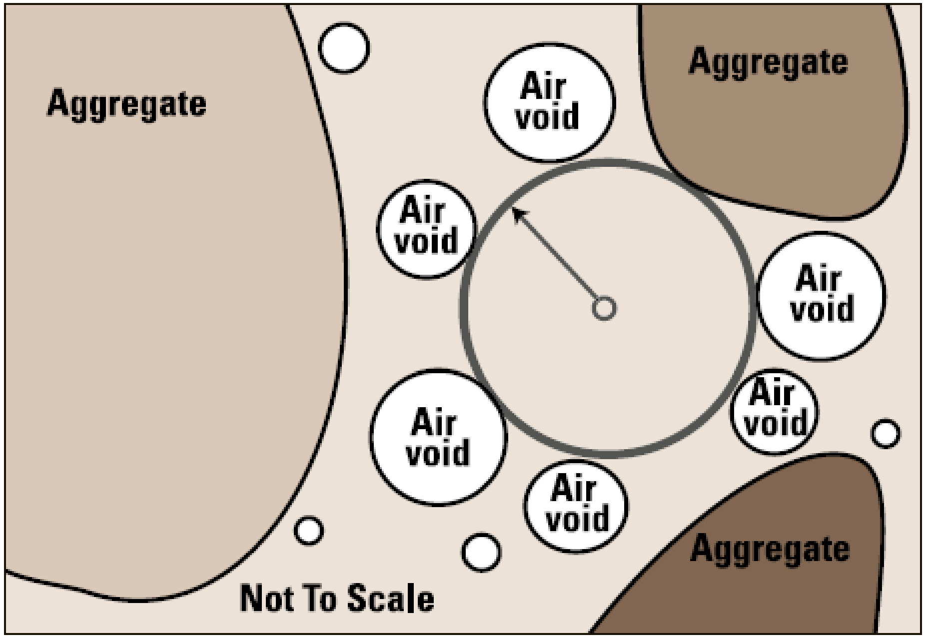
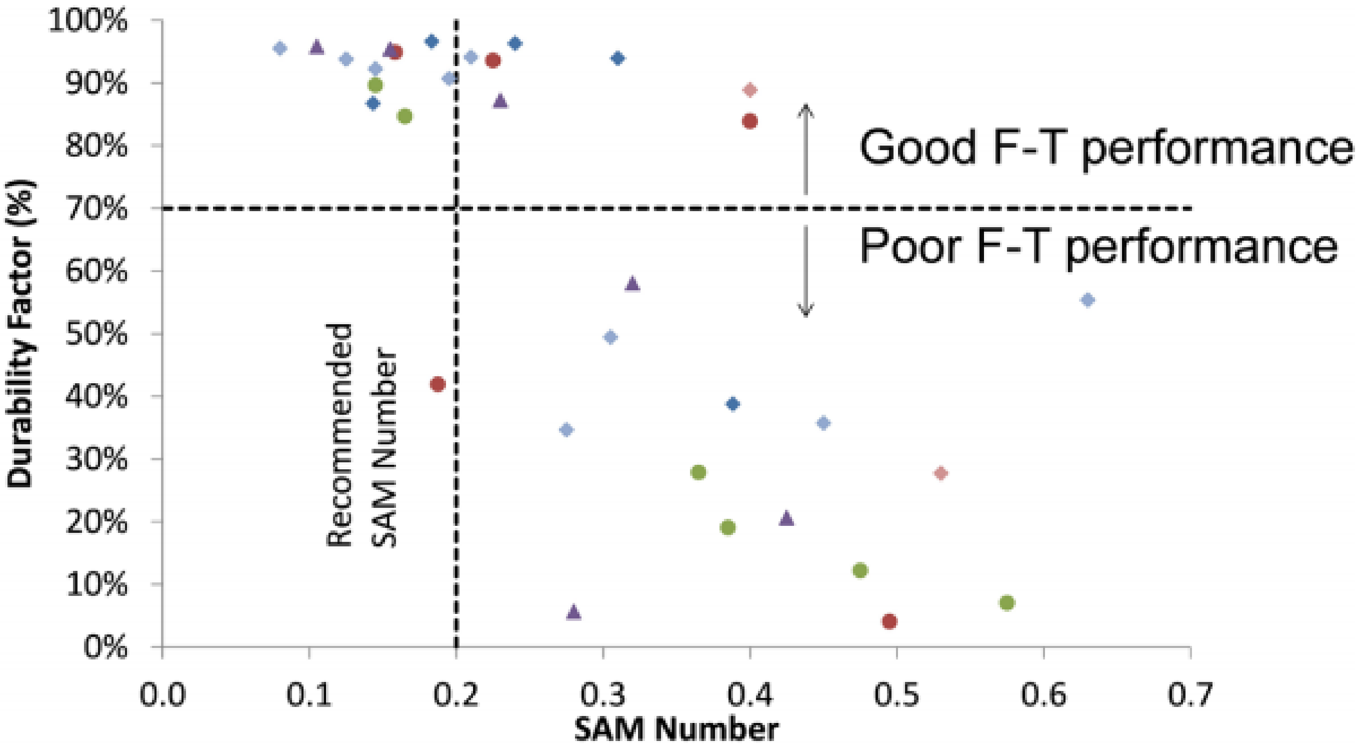


Figure 3-16. Spacing factor is the average distance from any point to the nearest air void. (Ozyildirim)

Super Air Meter (SAM)



- Over 90% of test mixes, a SAM number of 0.20 has been shown to correctly determine whether the spacing factor is above or below the 0.008 inch.

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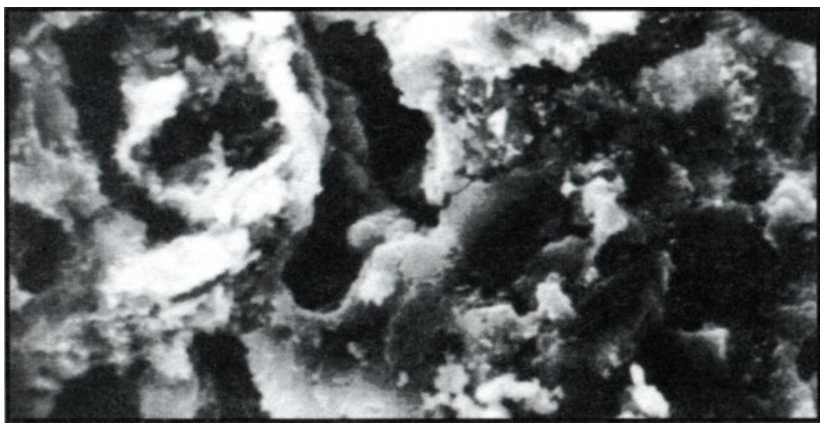
Lower Water/ Cement Ratio

Low W/C=
Low Permeability =
Less Saturation=
Improve Durability



- w/c 0.42
- w/c 0.60 – dark voids where water once occupied space – left pores

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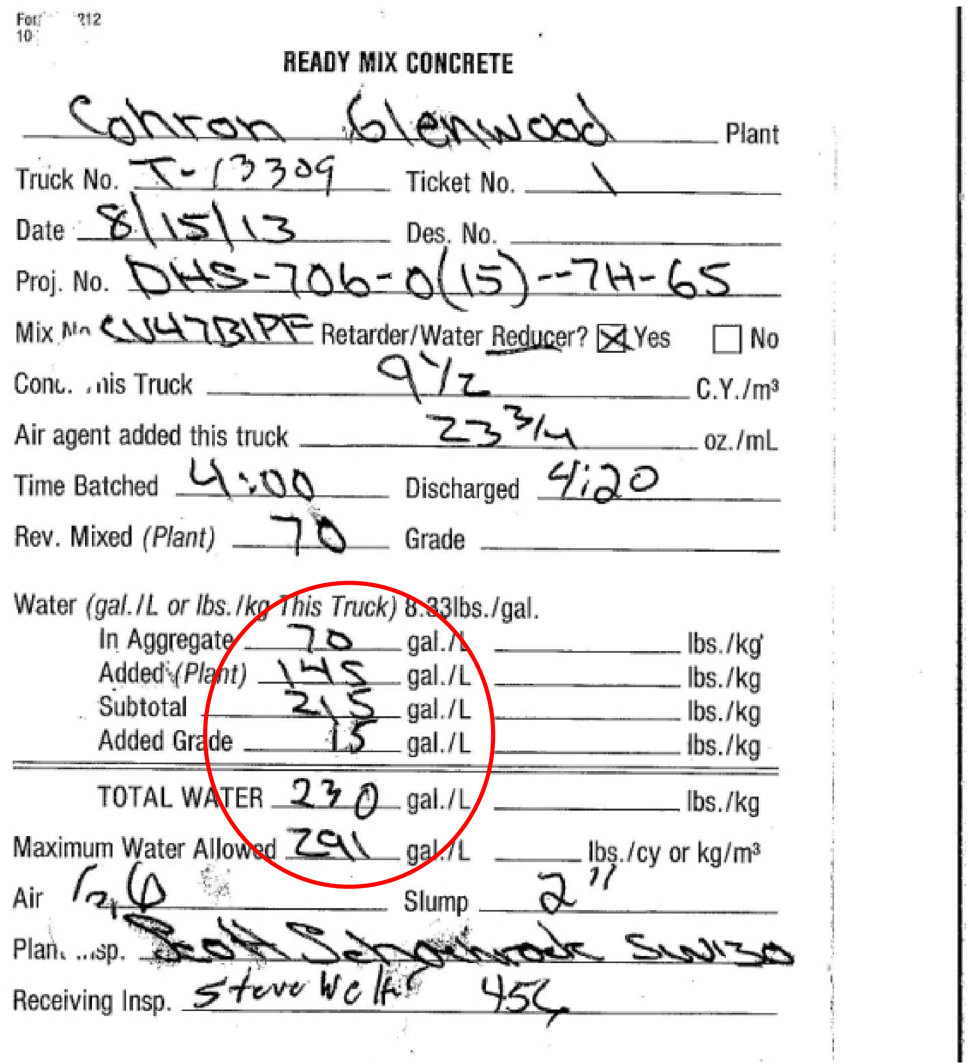
Water

- Watch the amount of added water!
- Added water not to exceed max w/c (check batch tickets)
- If water added, mix for additional 30 revolutions



Form 212

READY MIX CONCRETE

Cohron Glenwood Plant

Truck No. T-13309 Ticket No. 1

Date 8/15/13 Des. No.

Proj. No. DHS-706-0(15)--7H-65

Mix No CW47B1PF Retarder/Water Reducer? ☒ Yes ☐ No

Conc. This Truck 9 1/2 C.Y./m³

Air agent added this truck 23 3/4 oz./mL

Time Batched 4:00 Discharged 4:20

Rev. Mixed *(Plant)* 70 Grade

Water *(gal./L or lbs./kg This Truck)* 8.33lbs./gal.

In Aggregate	70	gal./L		lbs./kg
Added *(Plant)*	145	gal./L		lbs./kg
Subtotal	215	gal./L		lbs./kg
Added Grade	15	gal./L		lbs./kg
TOTAL WATER	230	gal./L		lbs./kg
Maximum Water Allowed	291	gal./L		lbs./cy or kg/m³

Air 6.6 Slump 2"

Plant Insp. Scott Schonhorst SW130

Receiving Insp. Steve Wolfe 454

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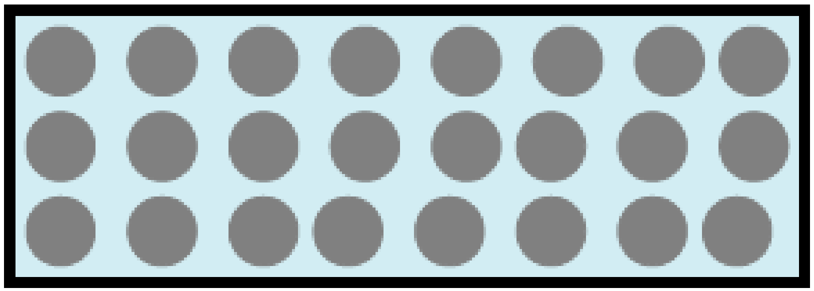
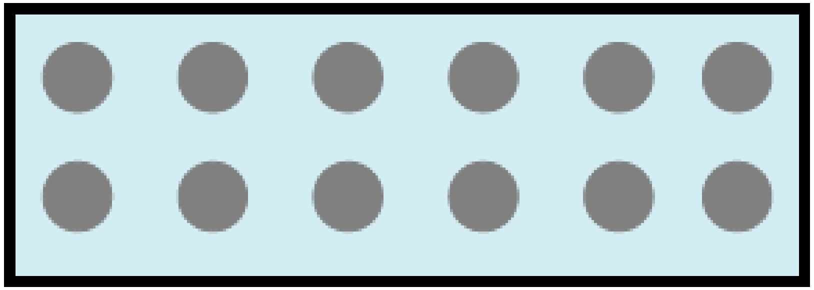
Water & Permeability

- More water – means more space between cement grains





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Effects of Extra Water on Concrete

- Adding 1 gallon / yd3
- Increases workability ~1”
- Lowers strength ~200 psi
- Increases drying shrinkage ~10%
- Increases permeability ~ 50%

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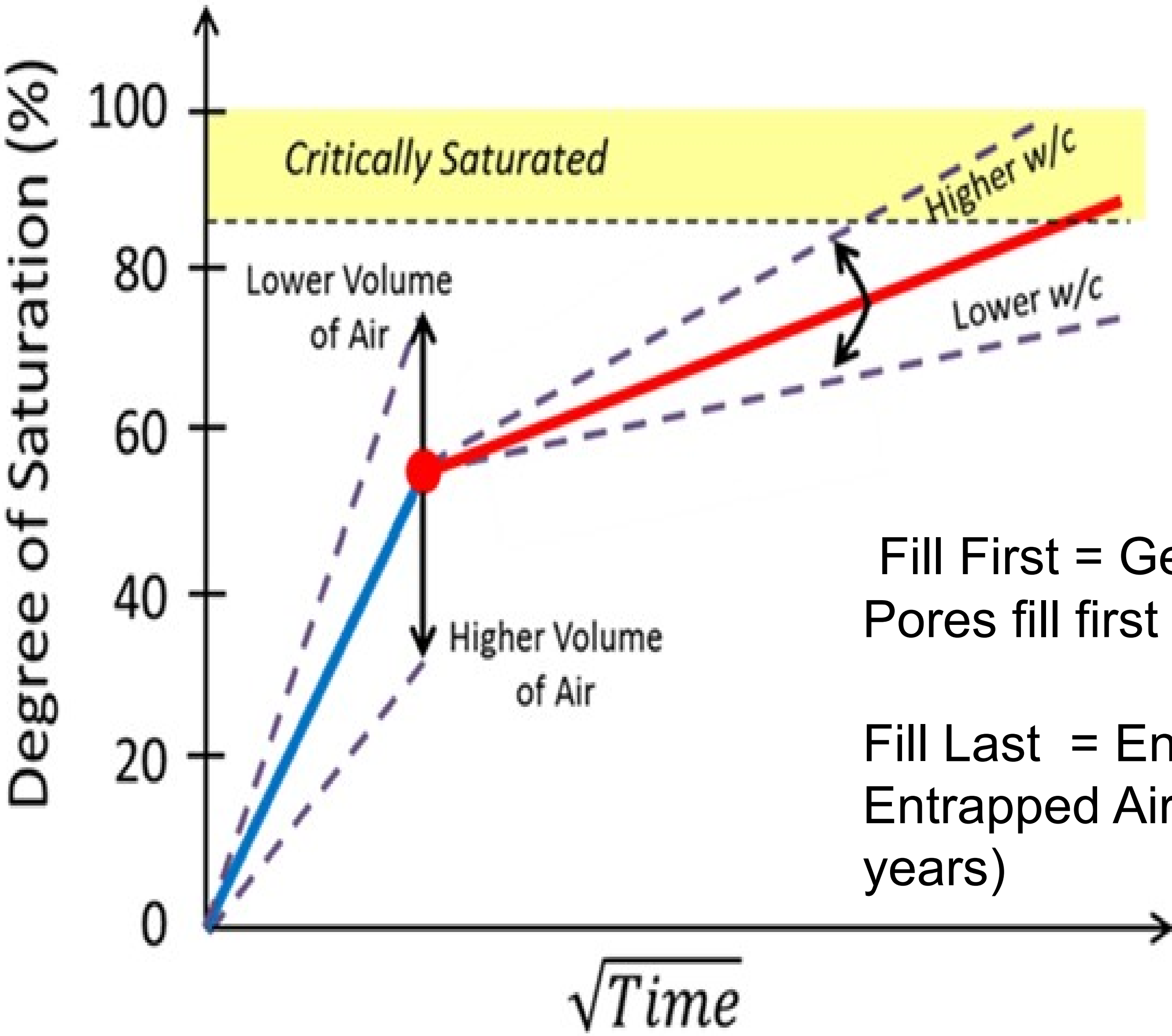
Low Permeability



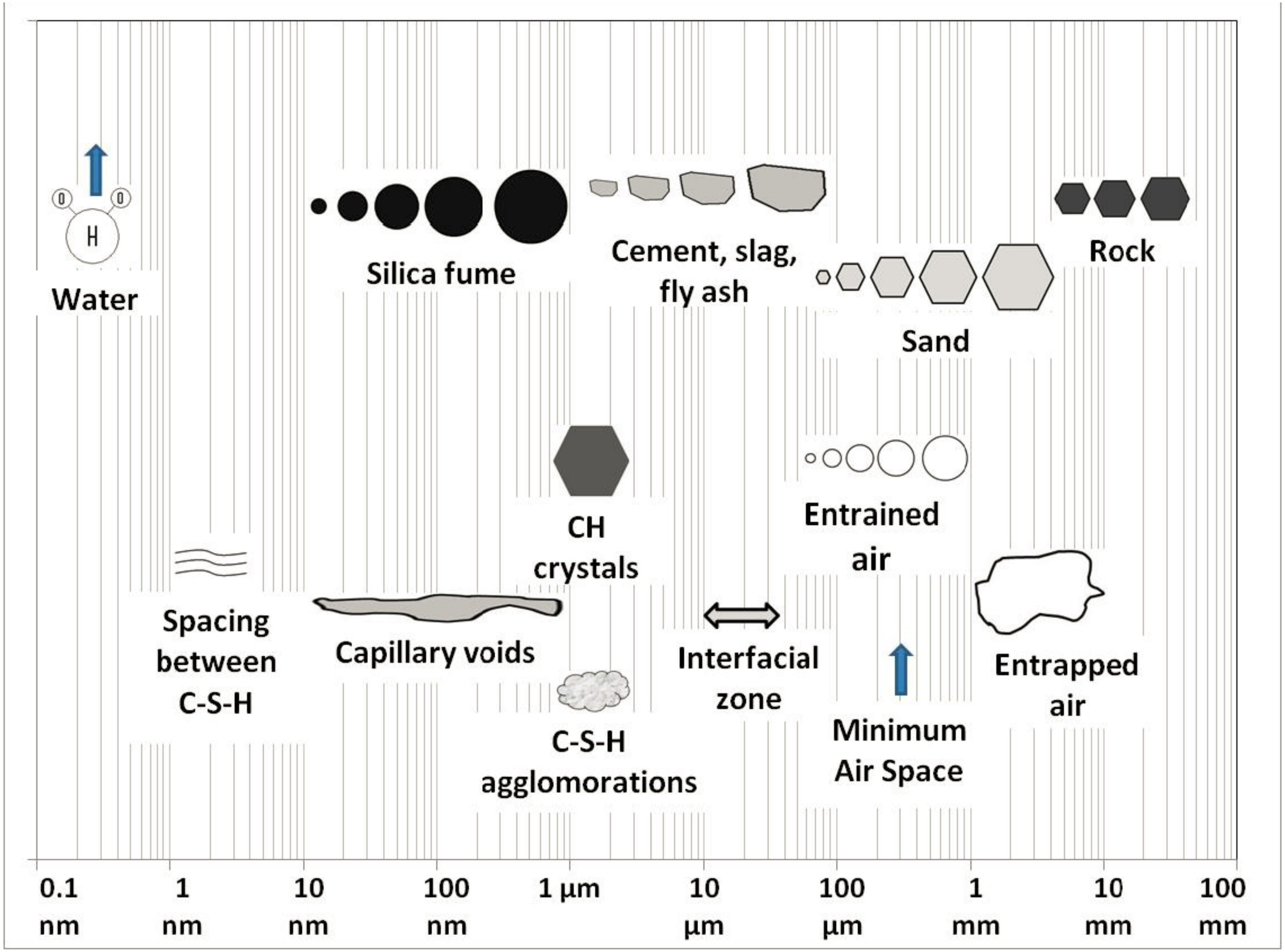
If undergoes Freeze-Thaw in critical saturated state damage will occur within a few cycles regardless of air volume

Fill First = Gels & Capillary Pores fill first (10-18 hours)

Fill Last = Entrained and Entrapped Air (Months to years)

Weiss 2014

Sizes of Concrete Components



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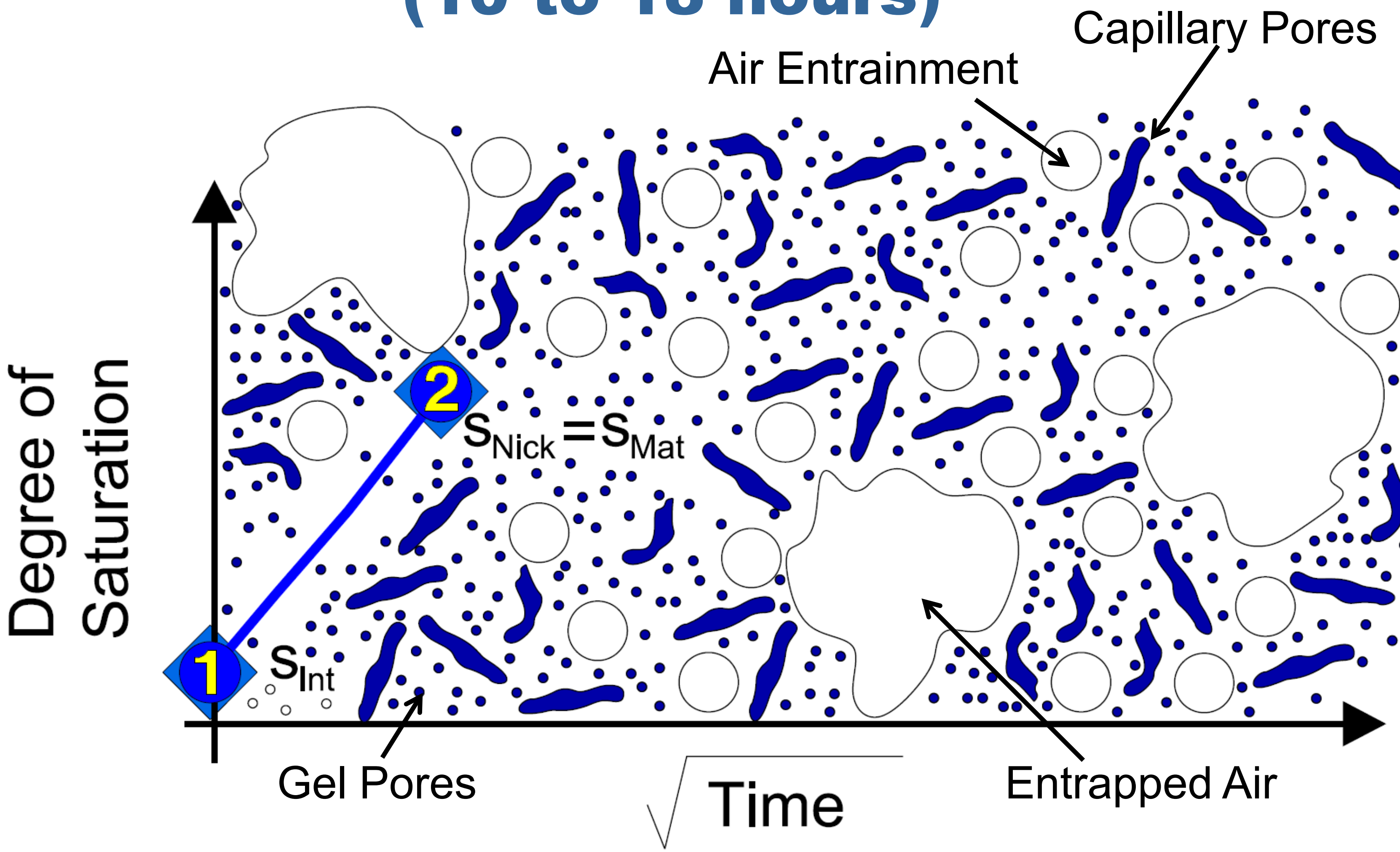
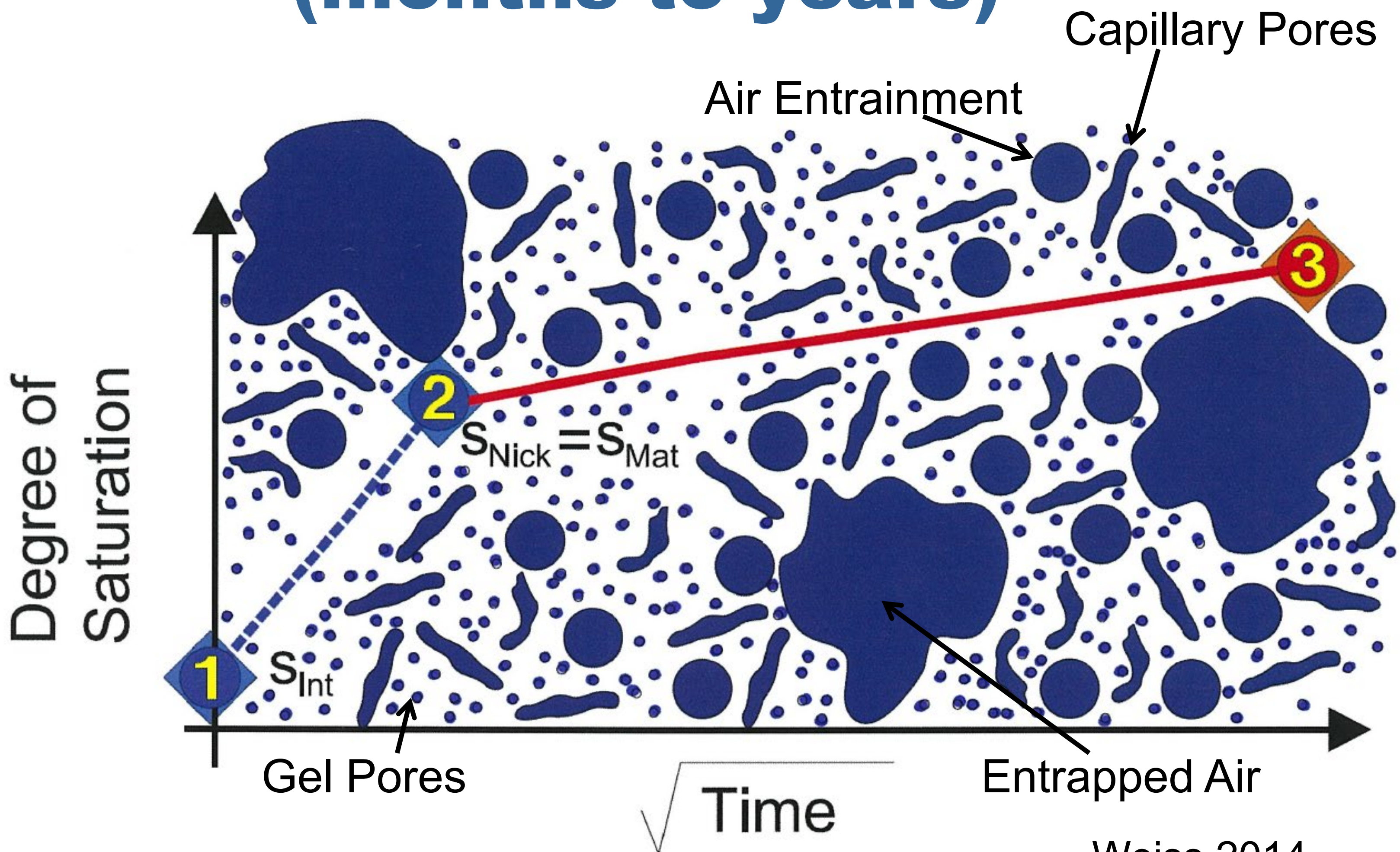
First – Filling of Smallest Pores -Gel and Capillary Pores- (10 to 18 hours)



Weiss 2014

Second- Filling of Larger Pores -Entrained and Entrapped Air- (months to years)



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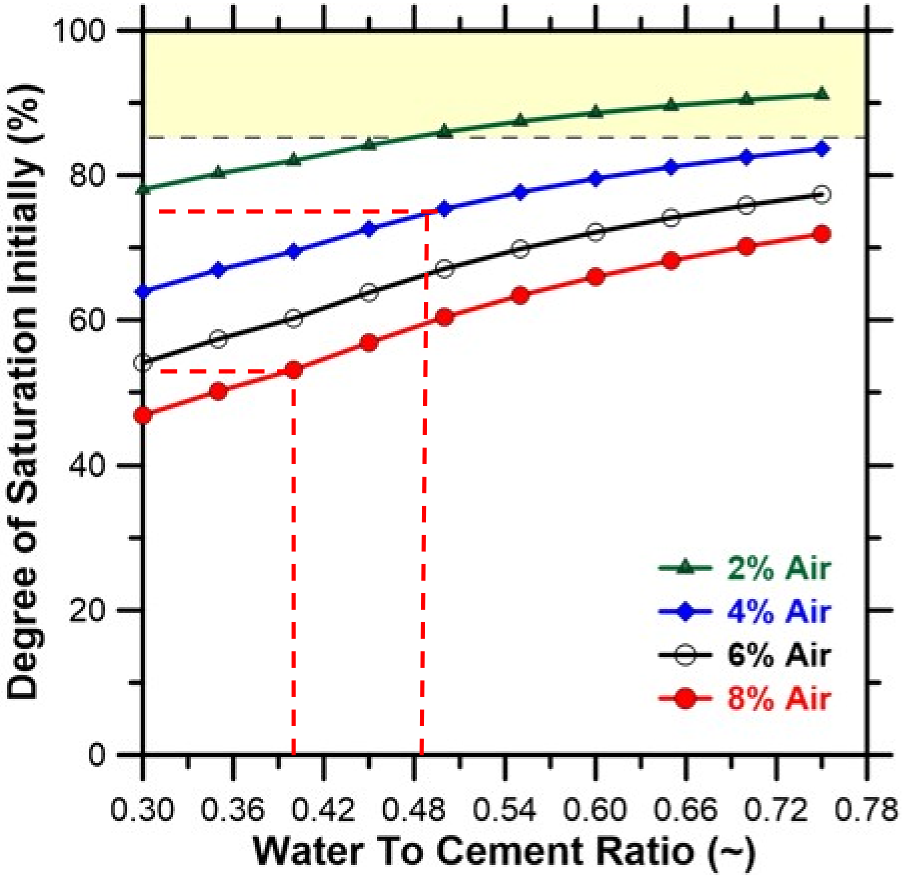
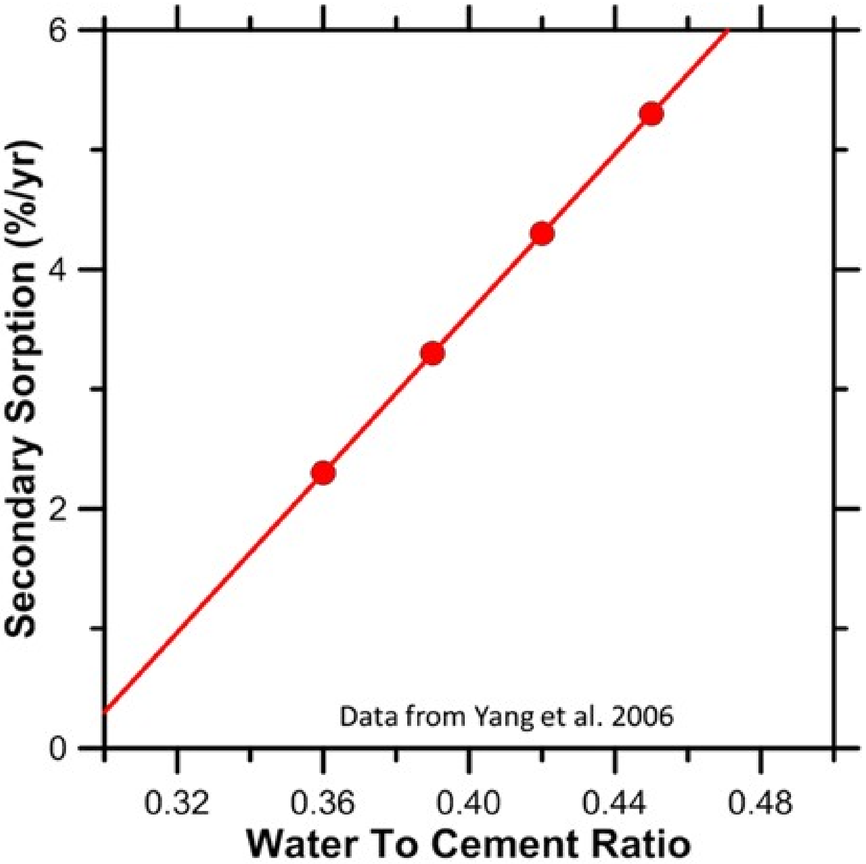
Critical Saturation Rates





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High Concentrations of Deicers

- High concentration of magnesium and or calcium chlorides (deicers) can react with cementitious matrices.

- This results in expansive deposits that can lead to diminished durability.

Impact on Joints

- These types of deicers can be more effective for ice removal
- Even when low concentration of deicers are applied to the pavement, evaporation that occurs during drying cycles will eventually produce a highly concentrated deicing solution
- At some point these levels will reach a level of super saturation that affects mineral deposits in the concrete

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Impact on Joints

- The formation of Calcium Silicate Hydrate (C-S-H) and Calcium Hydroxide (CH) are the two principal ingredients that mesh into a solid mass forming concrete pavement.
- Magnesium and calcium chloride will react with CH with water at between 32°F and 122°F, depending on the salt concentration.

Impact on Joints

- This reaction results in the formation of calcium oxychloride which results in flaking (expansion) of the hardened paste causing significant damage particularly in joints.
- Oxychloride expansion can be 3 times greater than freeze-thaw expansion.
- The use of SCM's (fly ash, slag, and silica fume) has shown to reduce the formation of calcium oxychlorides by tying up CH.
- Use of sealers has also shown the potential to limit the interaction between salts and CH by reducing exposure.

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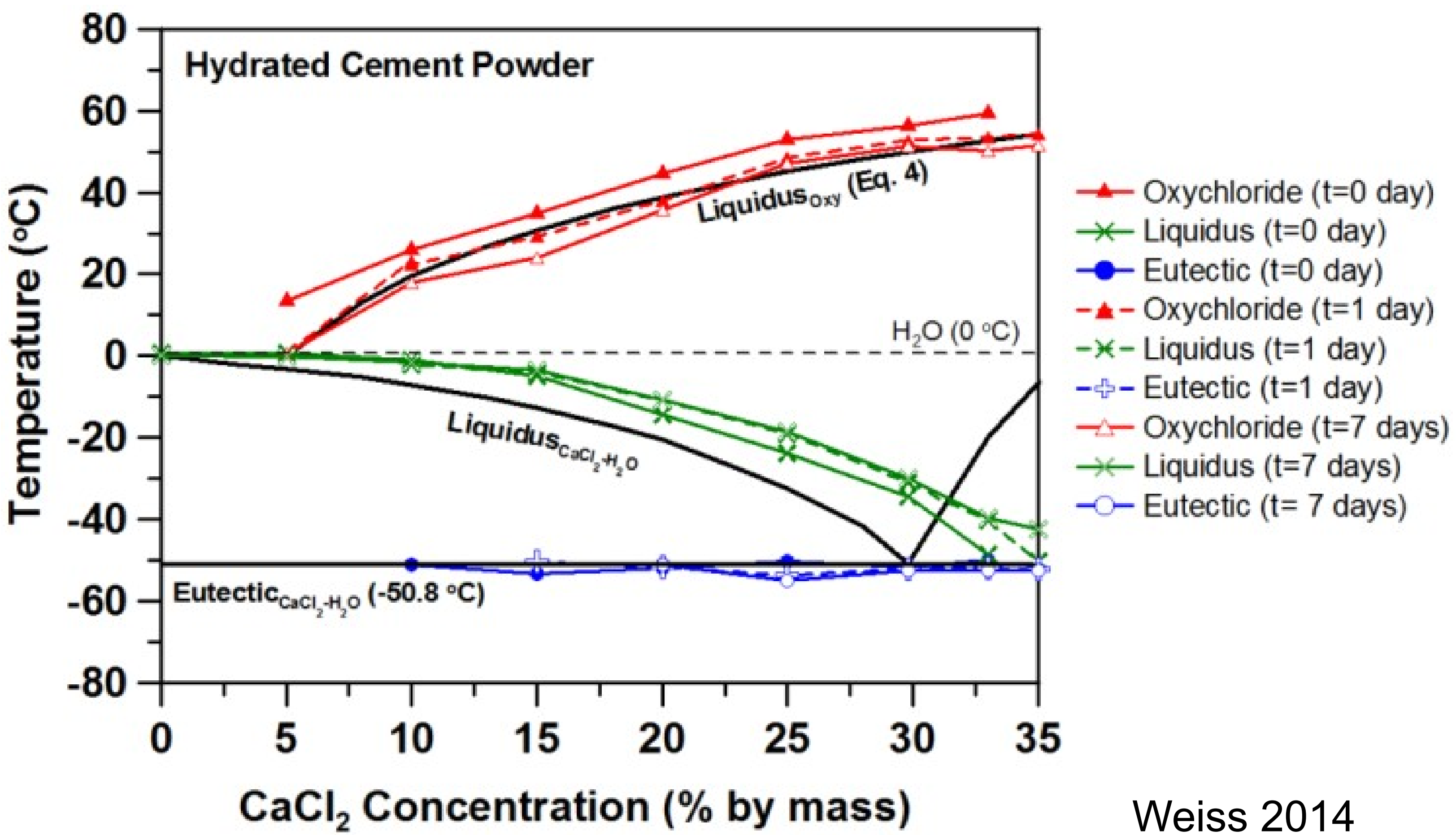
Temperature for Calcium Oxychloride Formation (when hydrated cement paste is brought into contact with calcium chloride solution)



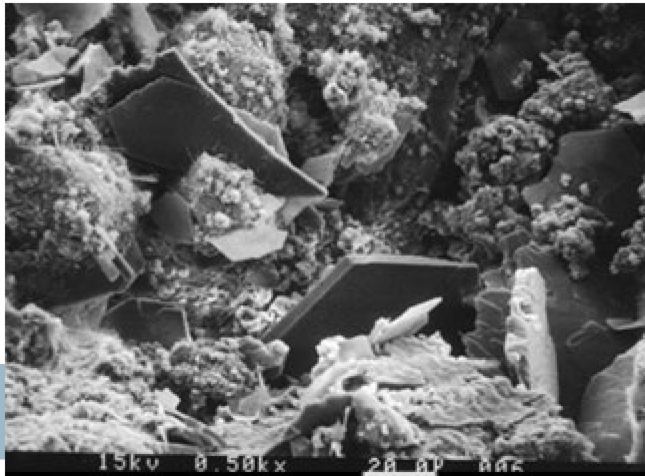
Weiss 2014

How Do Also SCMs Work?

Cement
+
Water = C-S-H

+

SCM + Water + CH = more C-S-H



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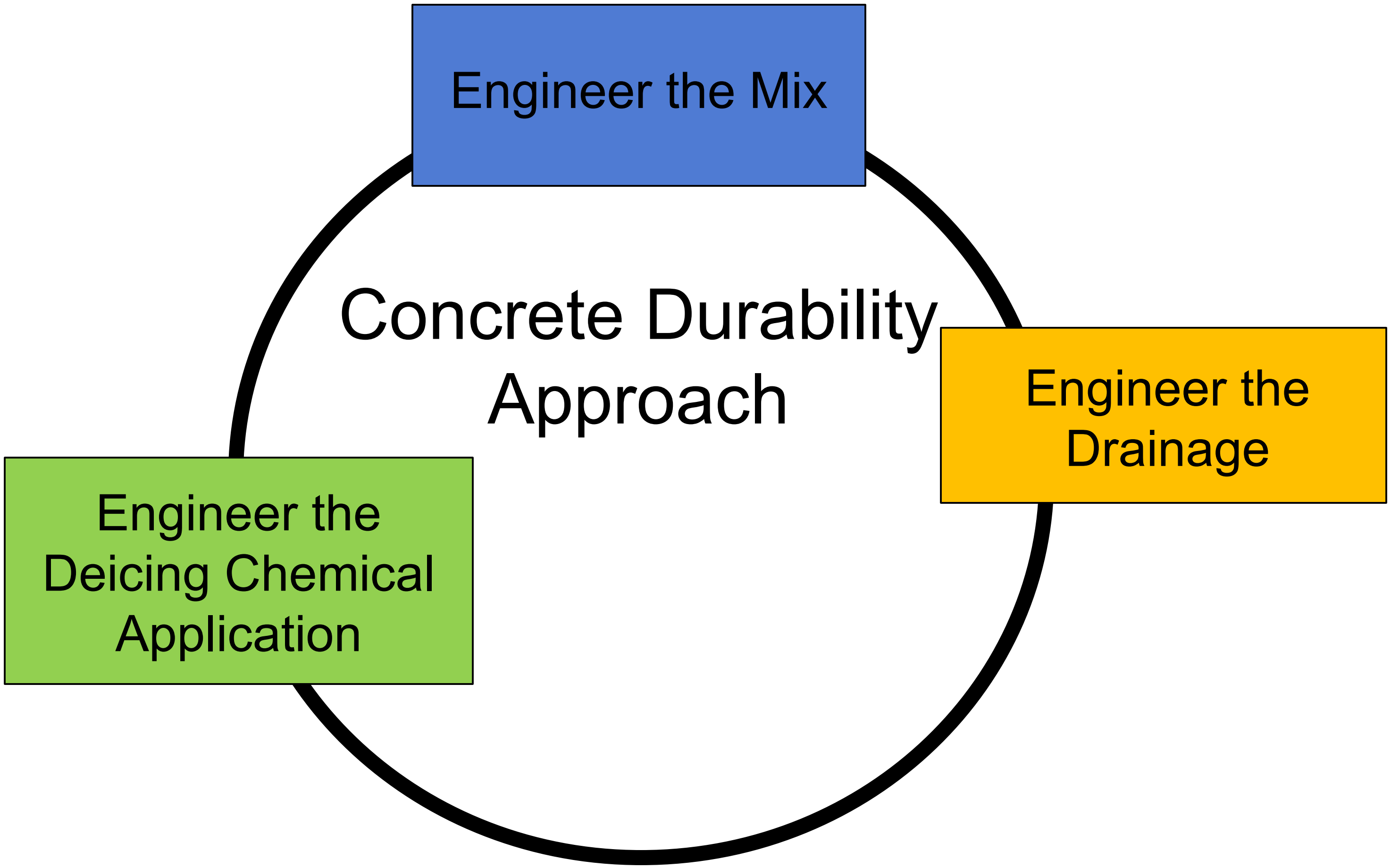
Putting It Together



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Defining PCC Mix Types

How do we know what PCC mix to use?

Conventional PCC: Class C & M Mixes (SUDAS & Iowa DOT)

Urban Durability PCC: Class C-SUD Mix (SUDAS)

Rural Durability PCC: QM-C Mix (Iowa DOT)

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Conventional PCC - C Mix

C - 4 WR – C20

Concrete Class

Water Reducer

% of SCM

No. relates to coarse/fine aggregate percentages

SCM designation, Fly Ash (C) or Slag (S)

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Conventional PCC - C Mix

C - 4 WR – C20

Use of SCMs will improve durability!!

How Much SCMs?

	% of total cementitious
• Class F fly ash:	15% - 25%
• Class C fly ash:	15% - 40%
• Slag:	25% - 50%

Too little – no benefit
Too much – slow setting, slow strength gain, cracking risk

Blended at the concrete batch plant, or blended or interground at the cement plant

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Conventional PCC - C Mix

C-Mixes - Common for Conventional paving

Type	Aggregate Composition
• C2	40% fine and 60% coarse
• C3	45% fine and 55% coarse
• C4	50% fine and 50% coarse
• C5	55% fine and 45% coarse
• C6	60% fine and 40% coarse

Target w/cm = 0.430
Max w/cm = 0.488

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Conventional PCC - C Mix

Basic Absolute Volumes of Materials Per Unit Volume of Concrete

C MIXES Basic w/c = 0.430		Max w/c = 0.488			
Mix No.	**Cement**	**Water**	**Air**	**Fine**	**Coarse**
C-2	0.110	0.149	0.060	0.272	0.409
C-3	0.114	0.154	0.060	0.302	0.370
C-4	0.118	0.159	0.060	0.331	0.332
C-5	0.123	0.166	0.060	0.358	0.293
C-6	0.128	0.173	0.060	0.383	0.256
C-WR MIXES Basic w/c = 0.430		**Max w/c = 0.489**			
Mix No.	**Cement**	**Water**	**Air**	**Fine**	**Coarse**
C-3WR	0.108	0.146	0.060	0.309	0.377
C-4WR	0.112	0.151	0.060	0.338	0.339
C-5WR	0.117	0.158	0.060	0.366	0.299
C-6WR	0.121	0.163	0.060	0.394	0.262

C-3 & C-4 most common

Conventional PCC – M Mix

M-Mixes

High early strength for patching

Basic Absolute Volumes of Materials Per Unit Volume of Concrete

M MIXES **Basic w/c = 0.328** **Max w/c = 0.400**

Mix No.	Cement	Water	Air	Fine	Coarse
M-3	0.149	0.153	0.060	0.287	0.351
M-4	0.156	0.161	0.060	0.311	0.312
M-5	0.160	0.165	0.060	0.338	0.277

More cement than C mixes

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Conventional PCC

Minimum Opening Strength – Full Depth Repairs

	Strength for Opening to Traffic (psi)			
	Repair Length <10 ft		Slab Replacements	
Slab Thickness (in.)	Compressive	3rd Point Flexural	Compressive	3rd Point Flexural
6.0	3000	490	3600	540
7.0	2400	370	2700	410
8.0	2150	340	2150	340
9.0	2000	275	2000	300
10 +	2000	250	2000	300

Table 6.6. Minimum Opening Strengths for FDRs (ACPA 2006)

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Urban Durability Mix (C-SUD)

- If joint deterioration is not a concern, recommend Class C mix (with SCM)

- If future joint deterioration is a concern on higher volume roads
  - Consider C-SUD (SUDAS mix)

Urban Durability Mix (C-SUD)

C-SUD (SUDAS Mix)

- Lower w/cm for durability
- Target w/cm = 0.40, Max. w/cm = 0.45
- Lower permeability than C-mix
- Can consider 3 aggregate mixes for greater workability and lower permeability
- <u>Can add SCM for enhanced durability</u>

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Urban Durability Mixes (C-SUD)

- Proportion Table 4 (I.M. 529)

Using Article 4110 and 4115 Aggregates
Basic Absolute Volumes of Materials Per Unit Volume of Concrete

C-SUD MIXES **Basic w/c = 0.400** **Max w/c = 0.450**

Mix No.	Cement	Water	Air	Fine	Coarse
C-SUD	0.106	0.133	0.060	0.315	0.386

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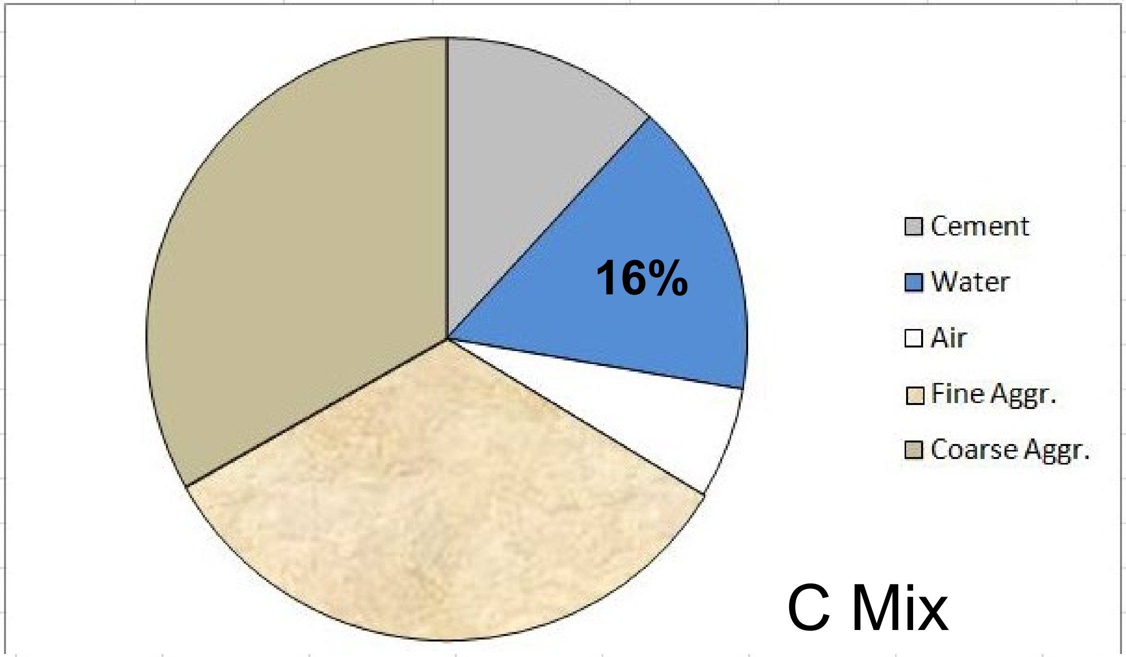
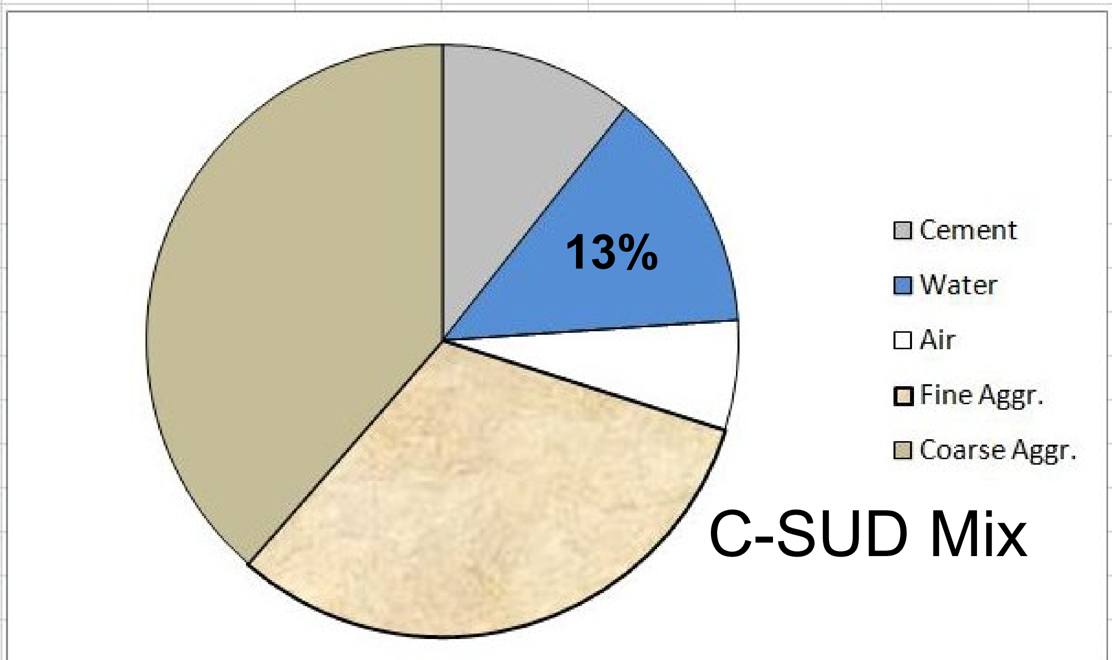
Class C & Class C-SUD



Class C-4 Mix

Cement	0.118
Water	0.159
Air	0.06
Fine Aggr.	0.331
Coarse Aggr.	0.332



Class C-SUD Mix

Cement	0.106
Water	0.133
Air	0.06
Fine Aggr.	0.315
Coarse Aggr.	0.386

Rural Durability Mixes (QM-C) (by Contractor)

- Quality Management Concrete (QM-C) mix
  - Improved placement characteristics (workability) for slip form only
  - Improved workability = improved durability
  - Required on Iowa DOT projects > 50,000 SY
  - Three gradation aggregate (typ. central plant not ready mix)
  - Ideal for large mainline rural paving projects
  - Not ideal for small, urban or extensive staging projects

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Rural Durability Mixes (QM-C)

- Quality Management Concrete (QM-C) mix
  - Iowa DOT DS-15038
  - Basic w/cm ratio is 0.40
  - Max. w/cm ratio is 0.42.

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Rural Durability Mixes (QM-C)

Table DS-15038.03-1: Concrete Mixture Constraints

Nominal Maximum Coarse Aggregate Size	Greater than or equal to 1 inch
Gradation	Materials I.M. 532
Cementitious Content	Minimum, 560 pounds per cubic yard*
Fly Ash Substitution Rate	See Article 2301.02, B, 6
Water/Cementitious Ratio	Maximum, ~~0.45~~ 0.42
Air Content	6% ± 1%, Design Absolute Volume = 0.060
28 Day Flexural Strength, Third Point	Minimum, 640 pounds per square inch

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CONSTRUCTION

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Concrete Materials Performance:
Ch. 9.6 Iowa DOT Field Inspection Manual

Check air after paver to determine loss

Air Content (on grade before consolidation)

- Slip form (8.0% +/- 2.0%)
- Non slip form (7% +/- 1.5%)

- Adjust the mix when:
  - Slip form Air < 7% or > 9%
  - Non slip form Air <6% or > 8%

  (on grade before consolidation)

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Concrete Materials Performance:
Ch. 6 Iowa DOT Field Inspection Manual

Aggregate Correction Factor (Iowa DOT I.M. 318)

- For quarries with highly absorptive aggregate
- Example:
  - Specified air is 8% +/- 2%
  - Using highly absorptive aggregate
  - Correction factor is 1%
  - Target air is 9% (8% + 1%)

Concrete Materials Performance:
Ch. 6 Iowa DOT Field Inspection Manual

- Air content outside tolerance
  - Make immediate adjustments to mix
  - Take test after paver to identify limits
  - Need compliance in two consecutive loads
  - Price adjustments

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Questions

www.cptechcenter.org