



VCNA Votorantim Cement North America

FT Durable Concrete -What's Up?

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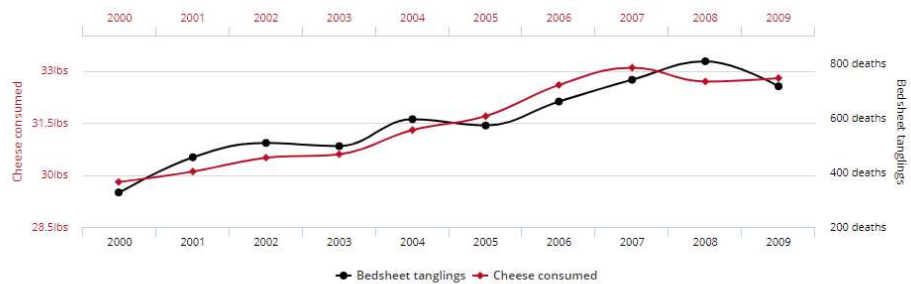


Someone told me...

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Per capita cheese consumption
correlates with
Number of people who died by becoming tangled in their bedsheets

Correlation: 94.71% ($r=0.947091$)



Data sources: U.S. Department of Agriculture and Centers for Disease Control & Prevention

tylervigen.com





Science of Mix Design

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- **Water content**
- **Air Entrainment**
- **Cementitious Materials**
- **Curing**
- **Exposure Conditions**



W/C Ratio- Duff Abrams

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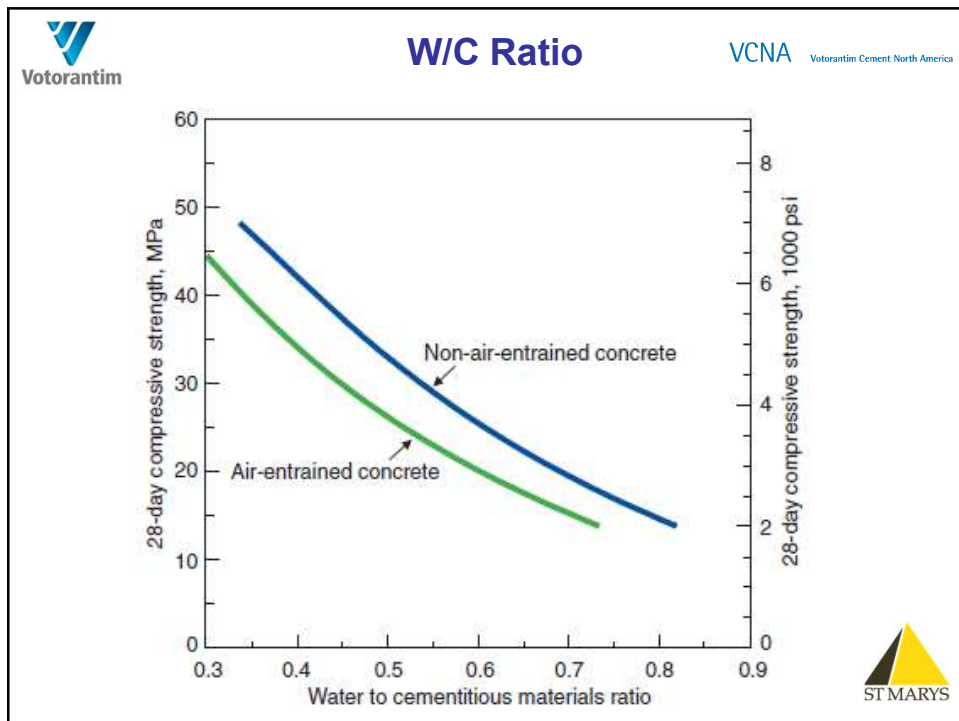
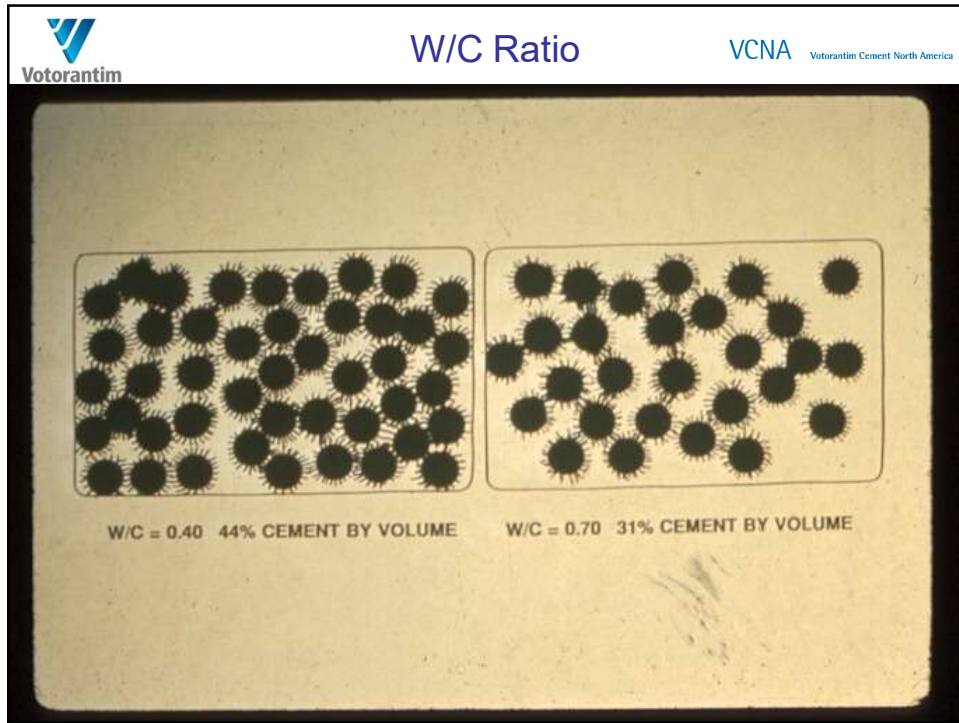
WATER/CEMENT RATIO LAW

For given materials the strength of the concrete depends **solely** on the amount of water for a given amount of cement.

100 years ago









Air Entrainment

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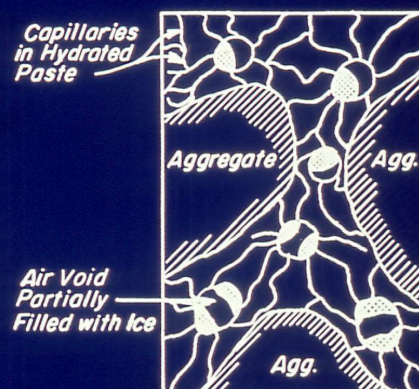
- Late 1930s
- One of the most significant discoveries in concrete history
- Freeze thaw durability



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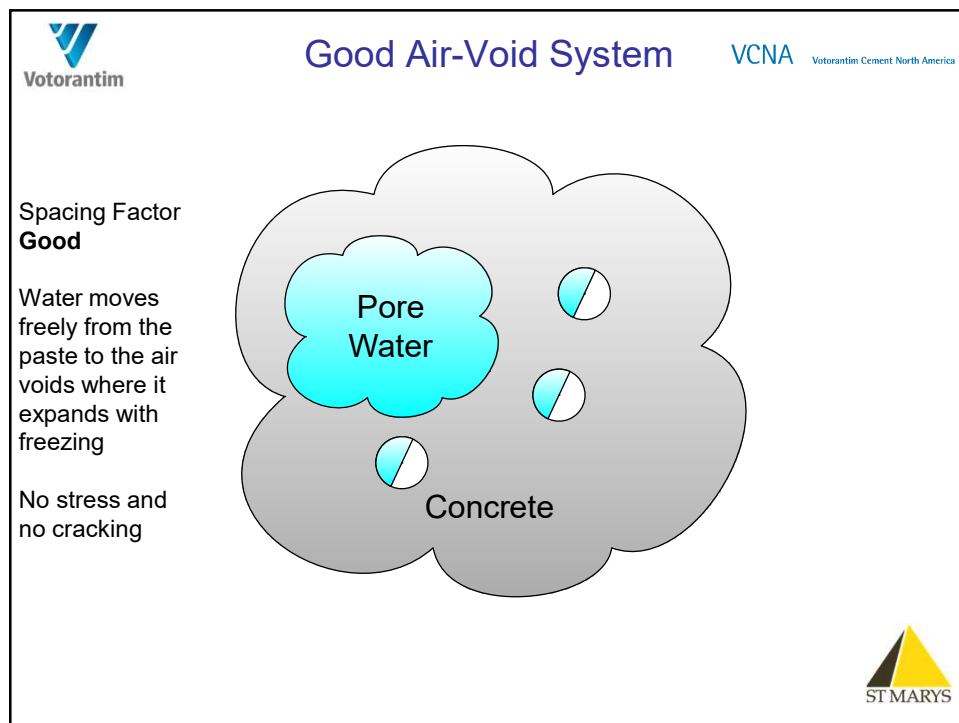
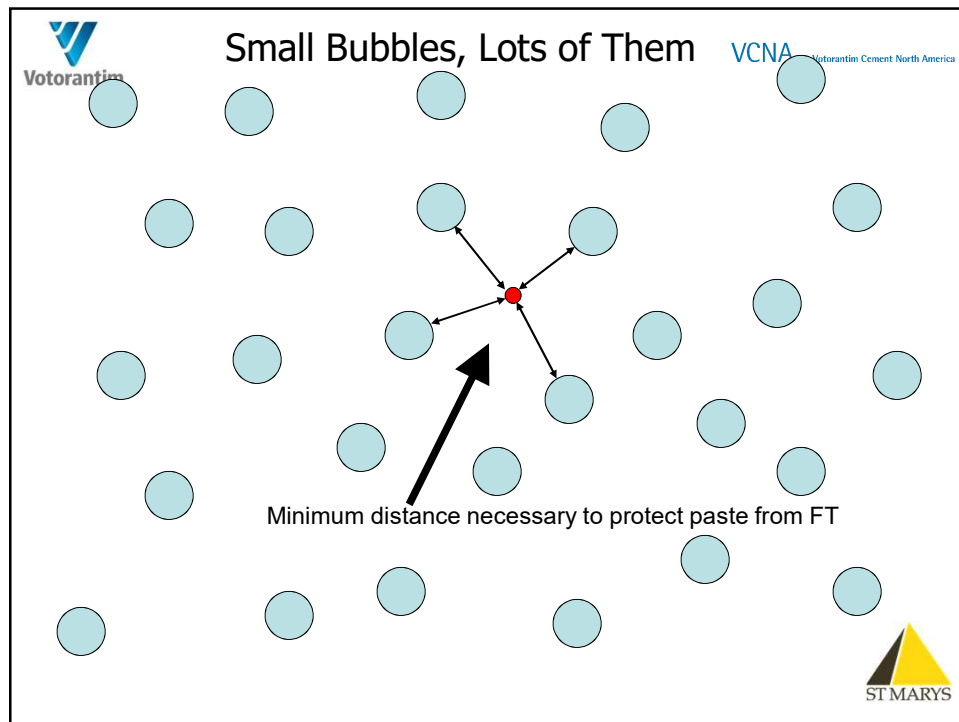


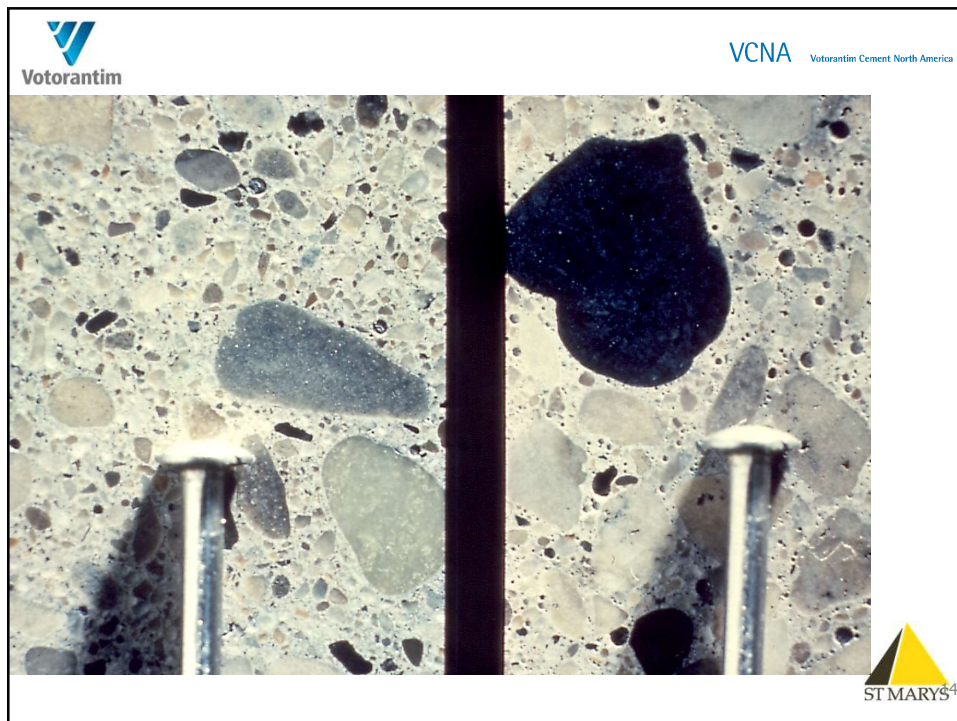
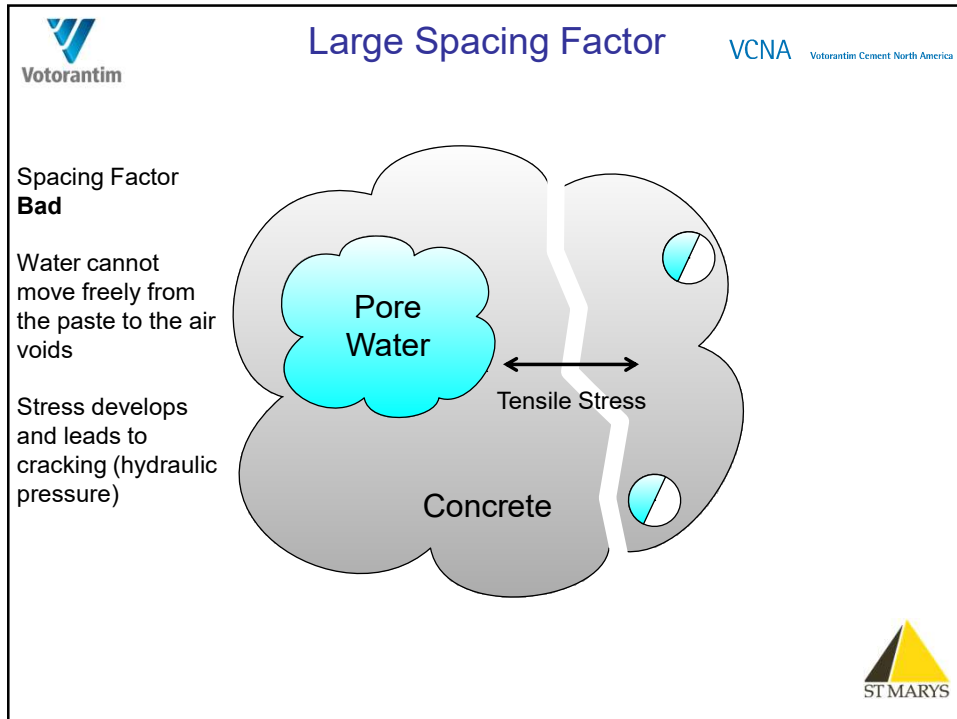
Assumed Manner in which Air Voids Accommodate Expansion of Freezing Water



Schematic Diagram of Frozen Air-entrained Concrete









Curing

Cured concrete looks like uncured concrete but doesn't perform the same.

The next greatest leap in technology will not come from new materials BUT learning to use the materials that we now have effectively.



Cement Hydration

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Hydration begins as soon as water contacts cement.

The rate of reaction increases as temperature increases and decreases as the temperature drops.

At about 32°F the reaction STOPS.

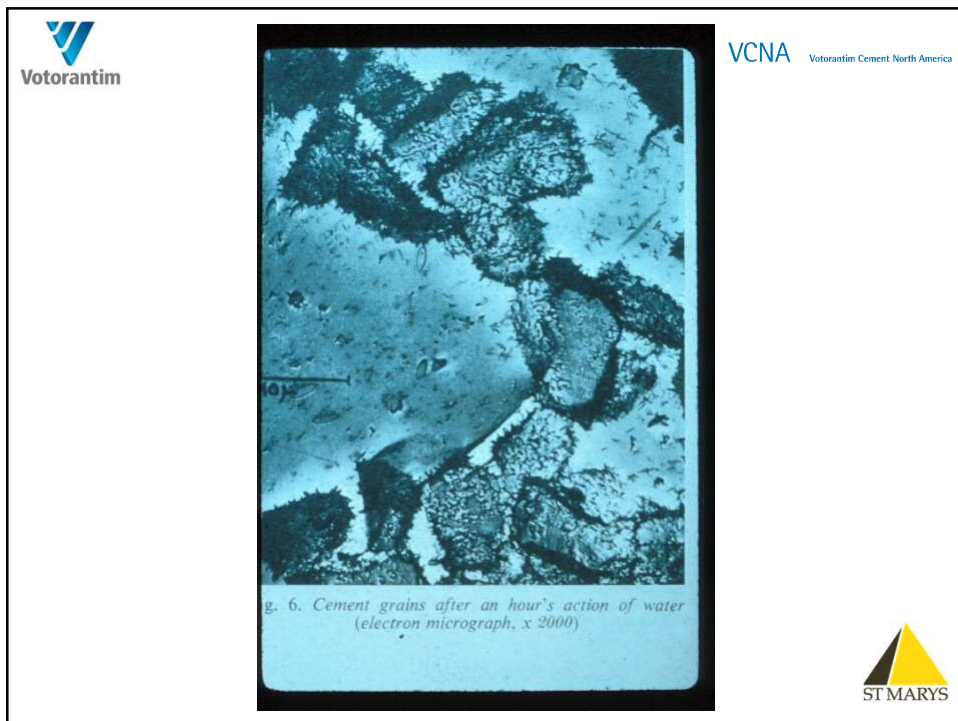
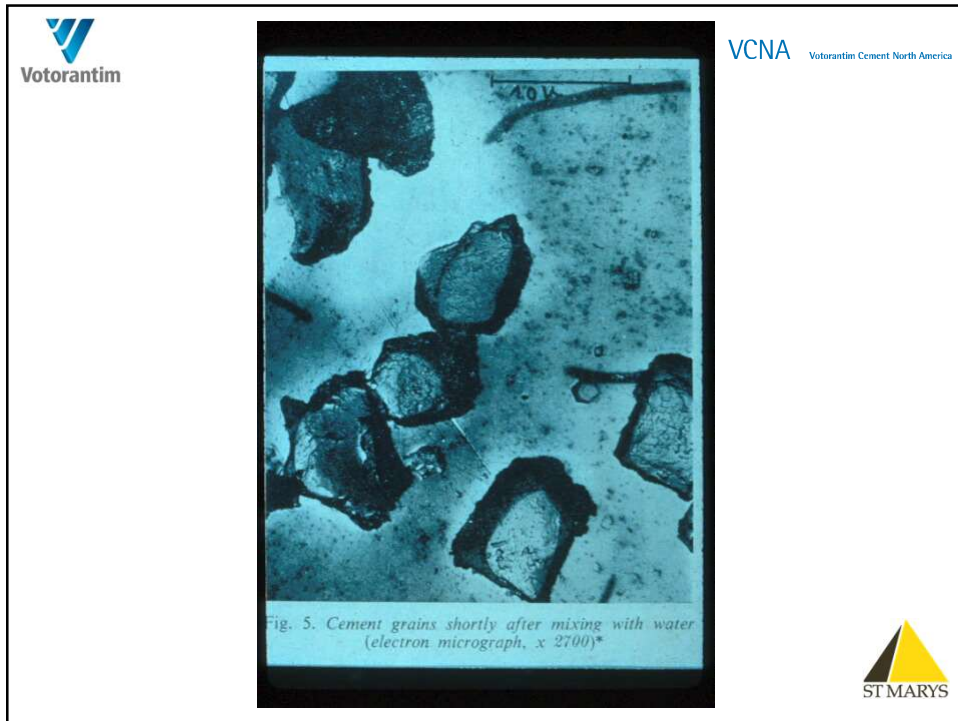
When the concrete dries out the reaction also STOPS.

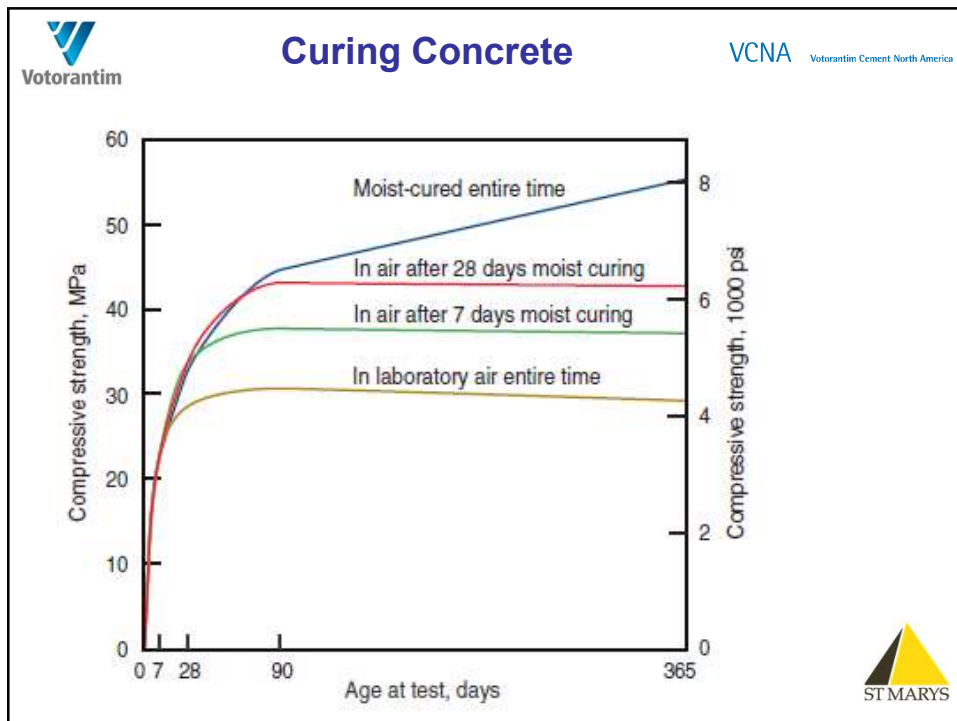
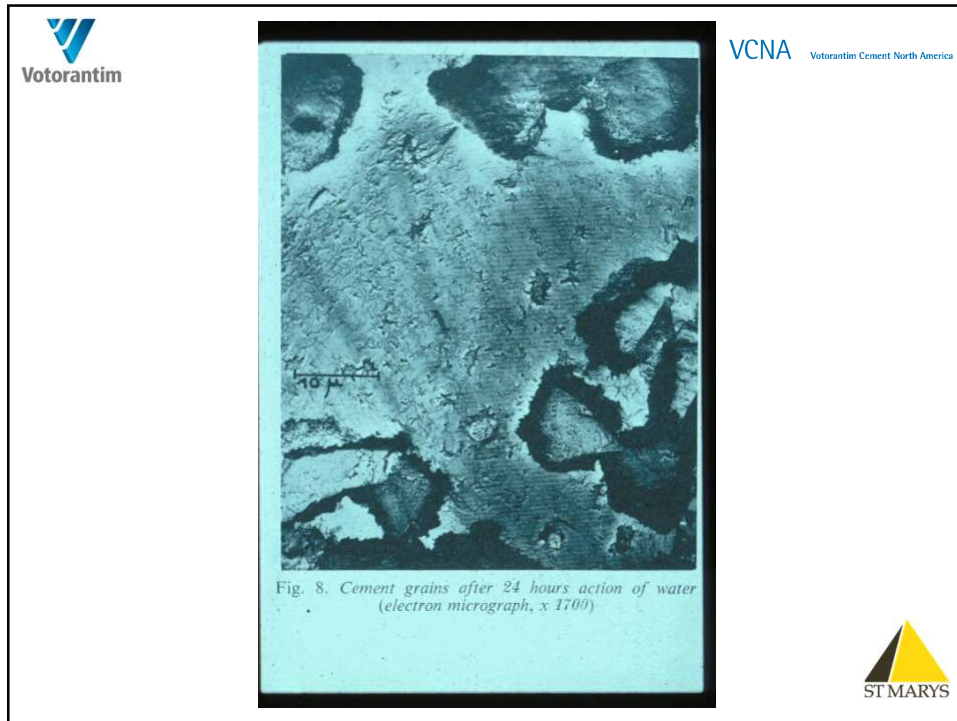



Hydration Reaction

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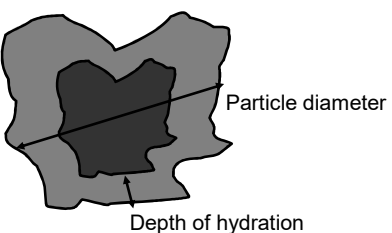
Fines Increase



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Cement Fineness

Relationship Between PSD and Hydration

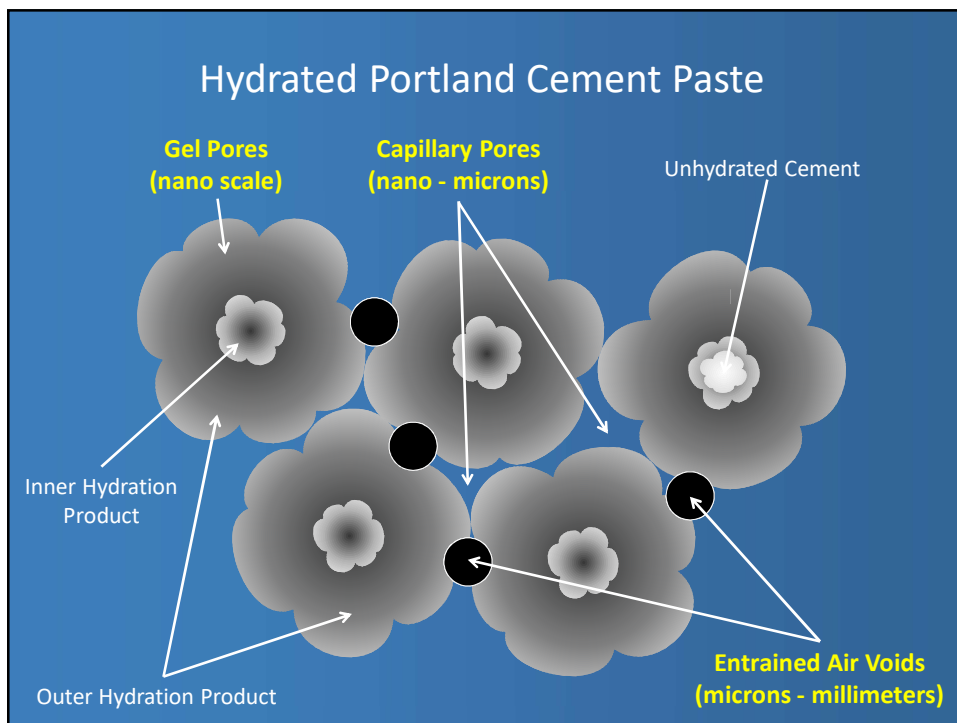


Typical Depths of Hydration

- 1 day h ~ 0.5 microns
- 3 days h ~ 2 microns
- 7 days h ~ 3-4 microns
- 28 days h ~ 6-7 microns



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Wet Coverings

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Plastic Sheets

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Membrane-Forming
Coumpounds


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Paste Freeze-Thaw Damage

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- The freeze-thaw (F-T) action of water is one of the most destructive forces that concrete faces
 - Places concrete "under tension"
- The hydrated cement paste is protected against F-T damage by
 - Reduced permeability
 - Acceptable air-void system
- Typically appears within 1 to 5 years after construction

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2006 SE MI Pavement Study

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Figure 1. 12 Mile Road in Franklin, six years old






Figure 2. Campbell Road in Madison Heights, twenty-one years old



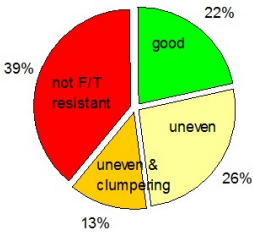


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2006 SE MI Pavement Study

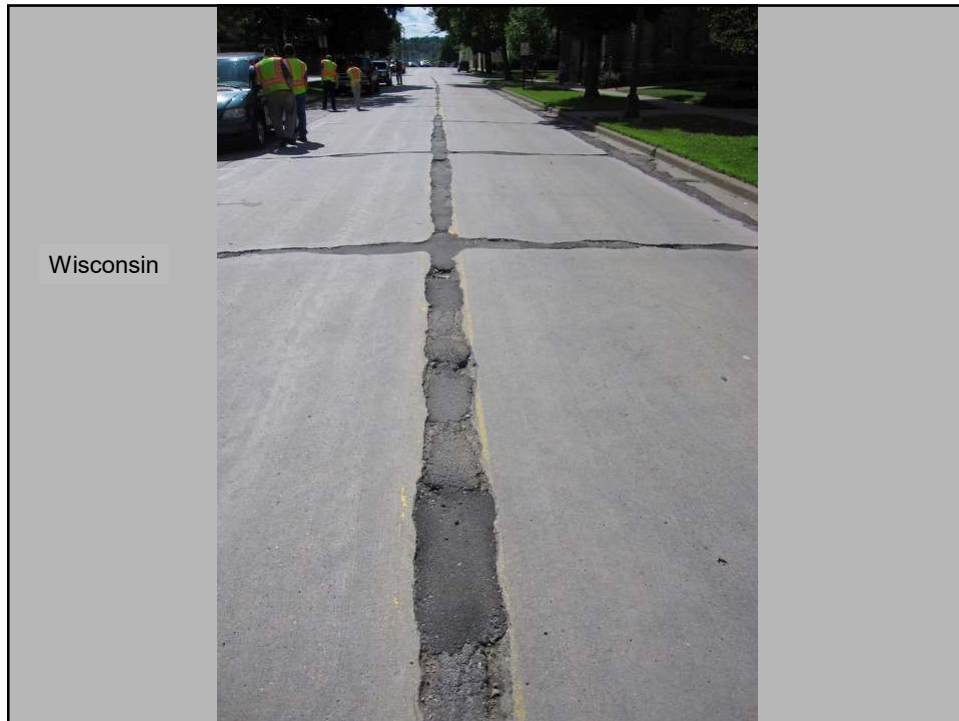
County	City/Township	Street/Highway	Year Paved
Wayne	Novi/Northville	Base Line Road	1994
	Belleville	Belleville Road	1995
	Farmington Hills	8 Mile Road	1996
Oakland	Franklin	12 Mile Road	1999
	Madison Heights	Campbell Road	1999
	Madison Heights	Campbell Road	1984
	Troy	Big Beaver Road	1995
	Troy	Dequindre Road	1996
Macomb	Fraser/Roseville	13 Mile Road	1992
	Fraser/Roseville	13 Mile Road	1994
	Clinton Township	Utica Road	1995
	Fraser	Utica Road	1994

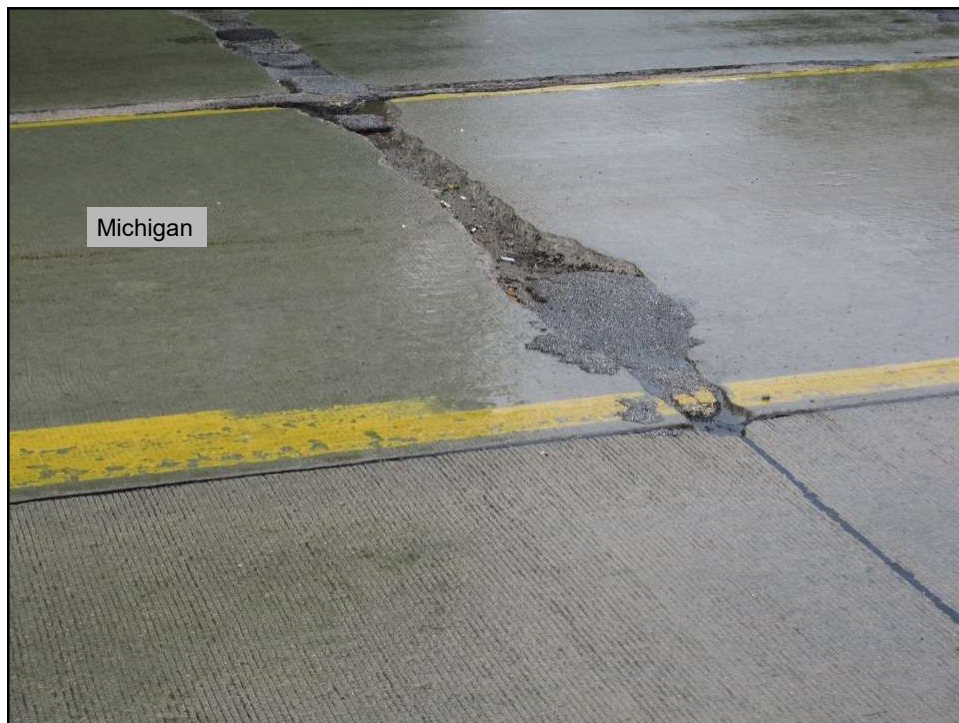
Air System

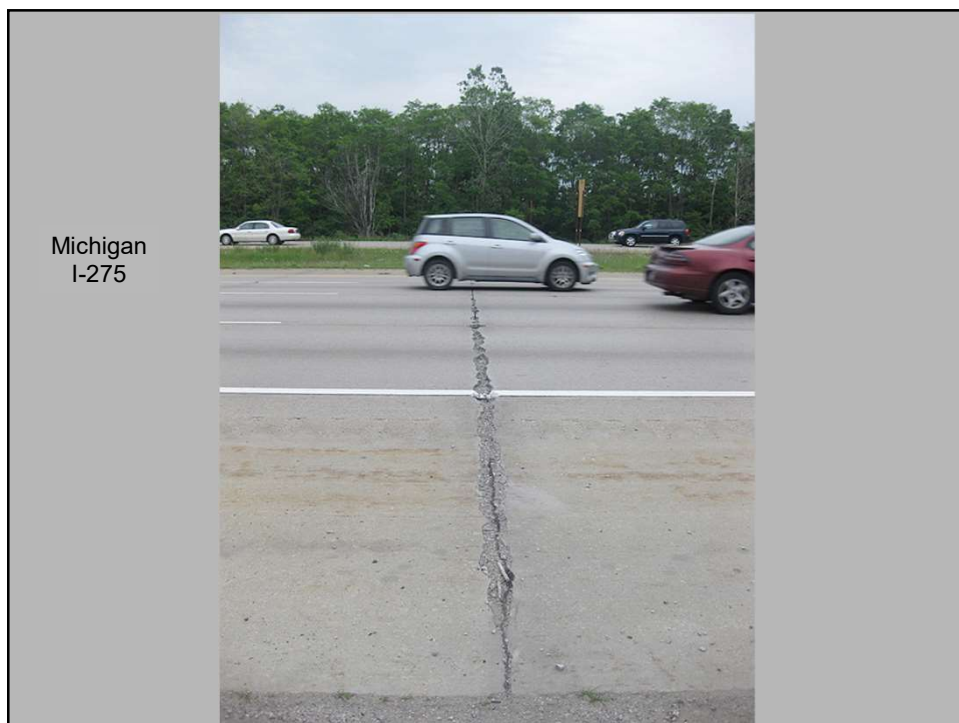


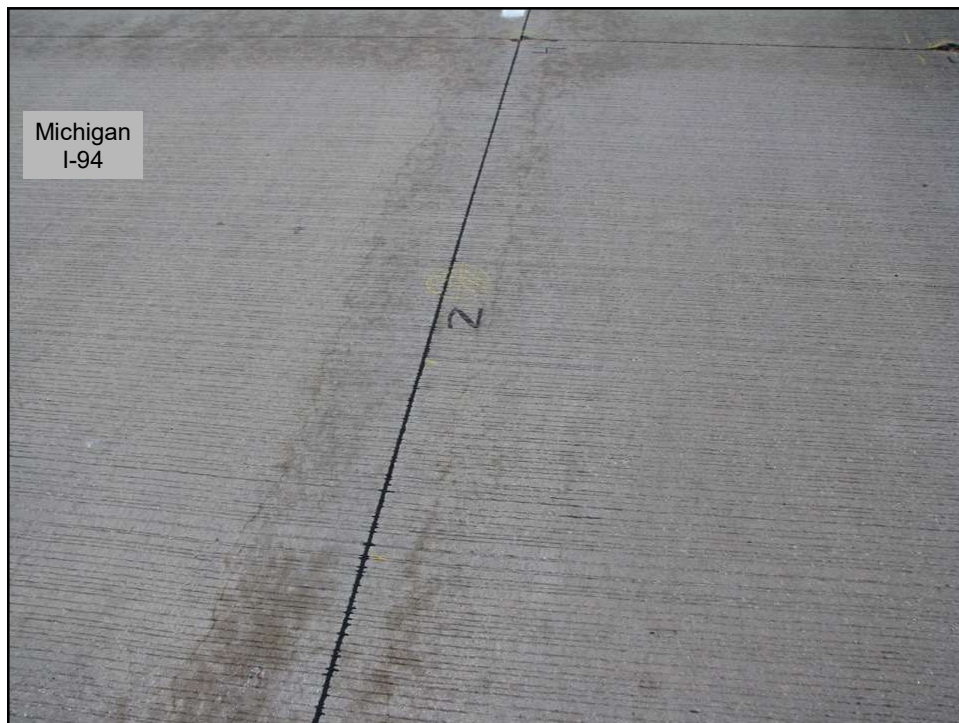
Status	Percentage
not F/T resistant	39%
good	22%
uneven	26%
uneven & clumping	13%















Materials & Permeability

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- **Concrete is a porous material – water goes in, out and is absorbed**
- Porosity (permeability) is a result of:
 - Degree of hydration
 - Mix design (w/c)
 - The materials used (aggregates) and SCMs

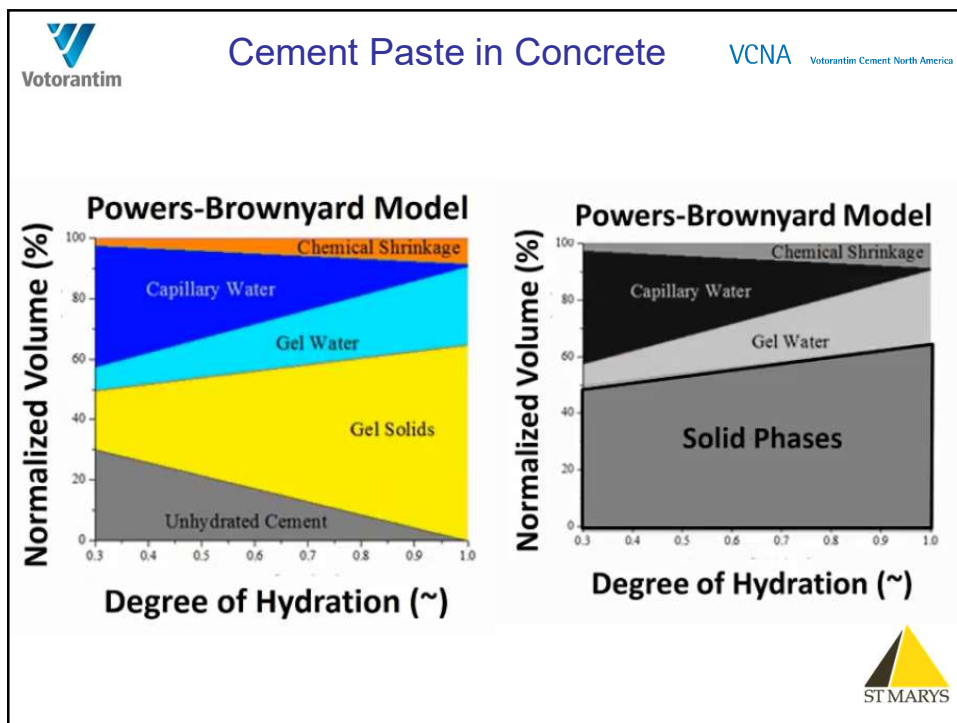
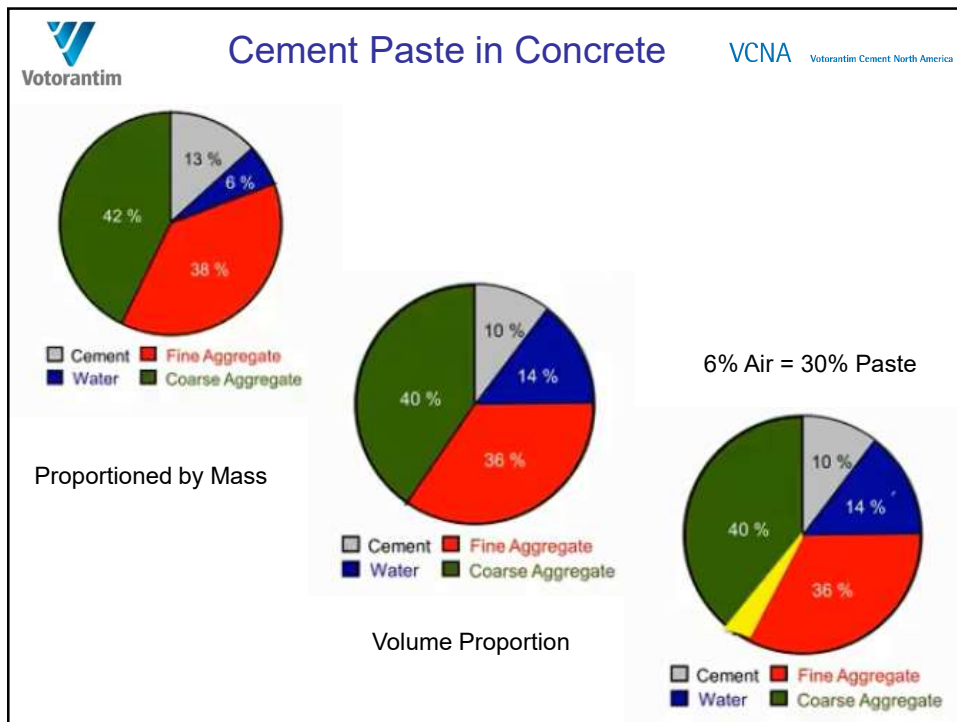



Pore Structure in Concrete

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- Capillary Pores
 - Depend on initial separation of cement particles, which is controlled by the w/c
- Gel Pores
 - Space between layers in CSH






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Hydration Reaction


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$$C_3S (C_2S) + H_2O = CSH + CH + \text{Heat}$$

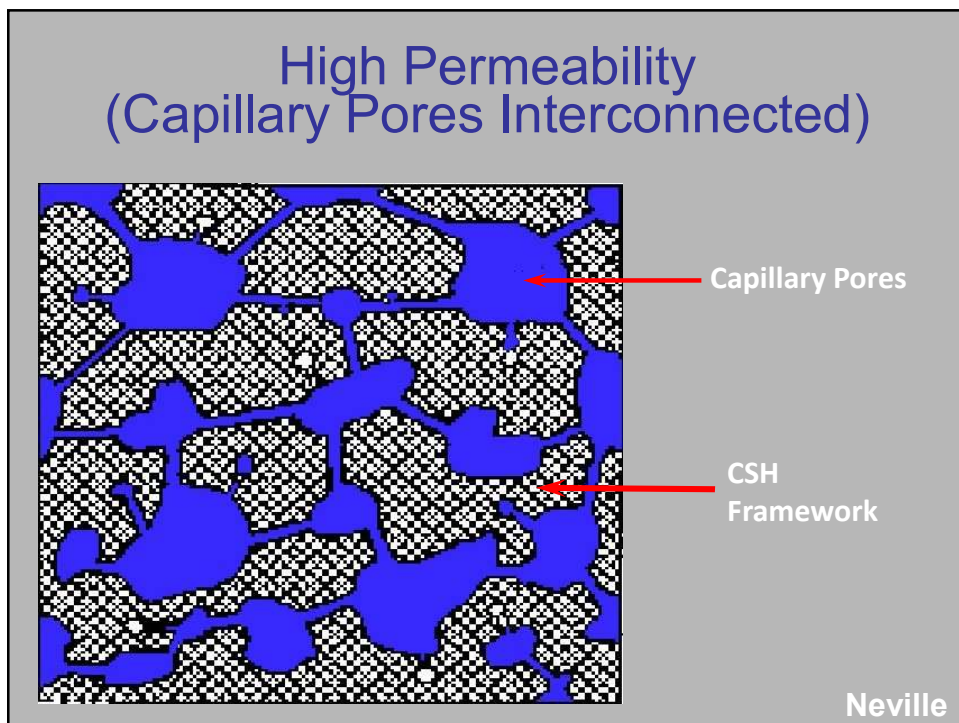
Calcium Silicates + Water = Tobermorite Gel + Calcium Hydroxide

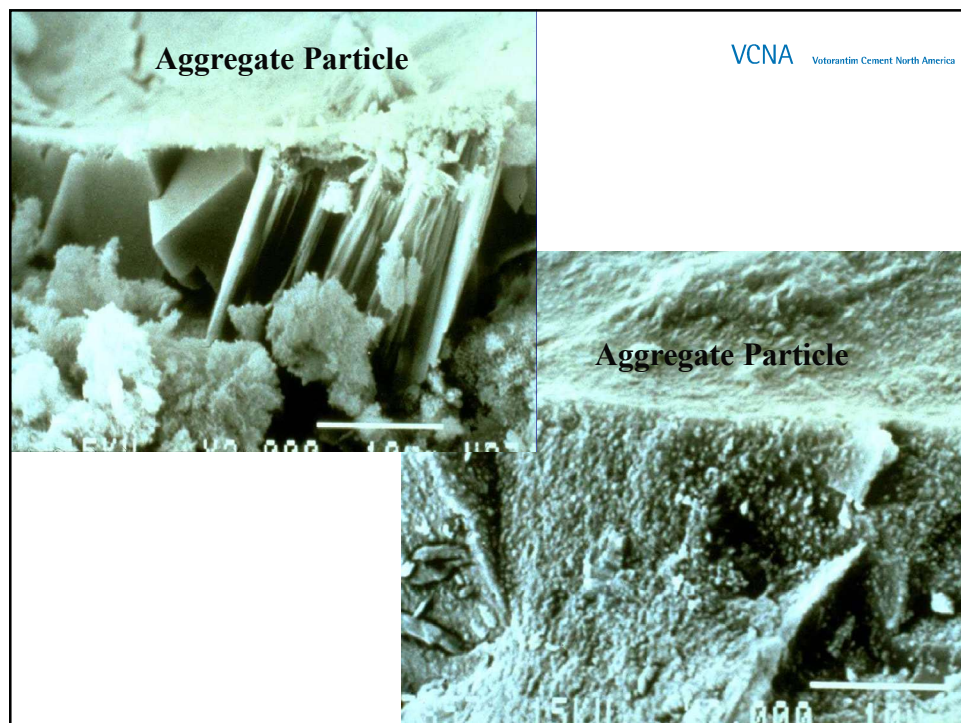
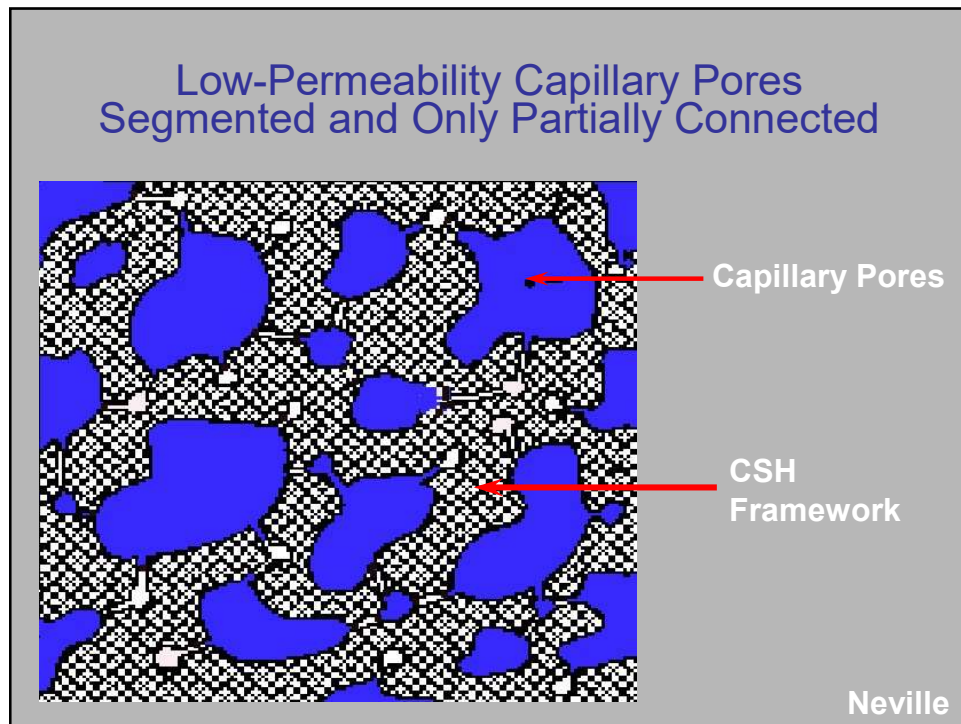
Supplementary Reaction

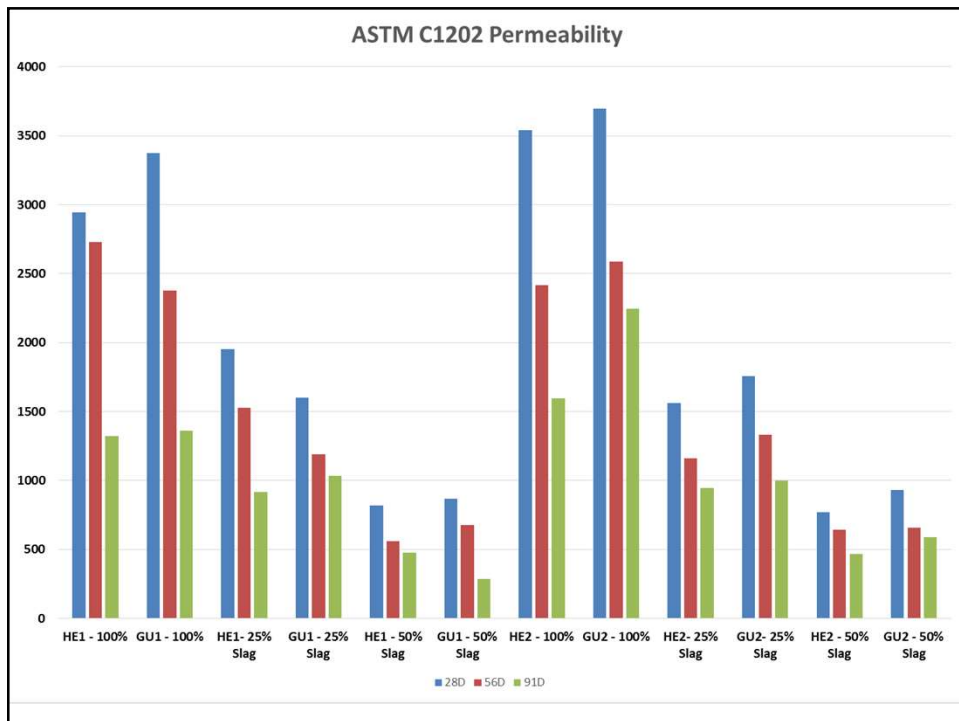
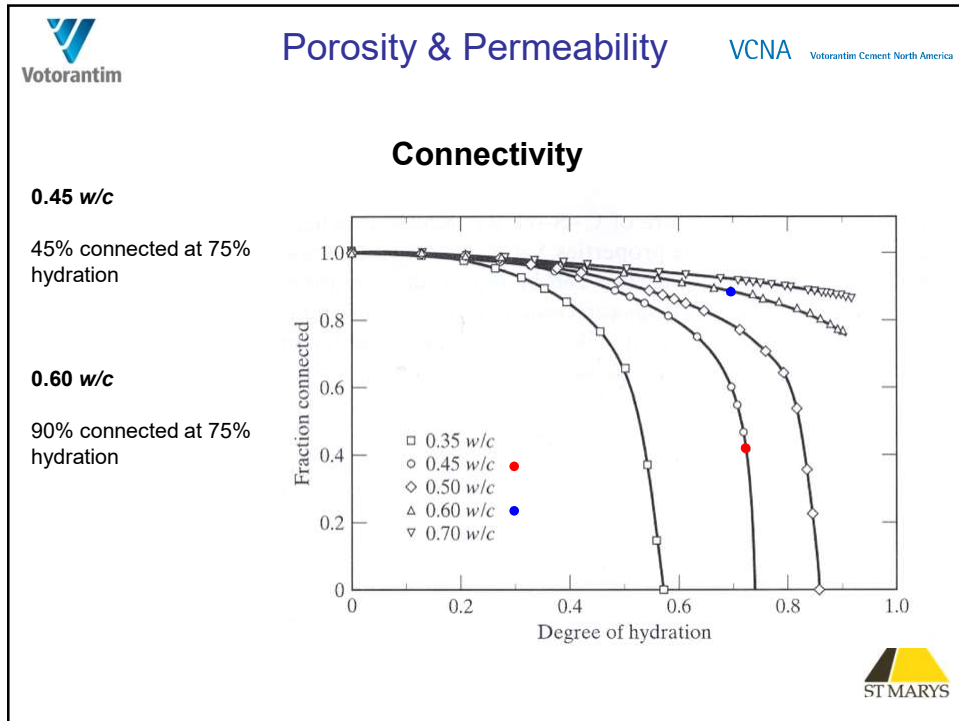
$$CH + S = CSH$$

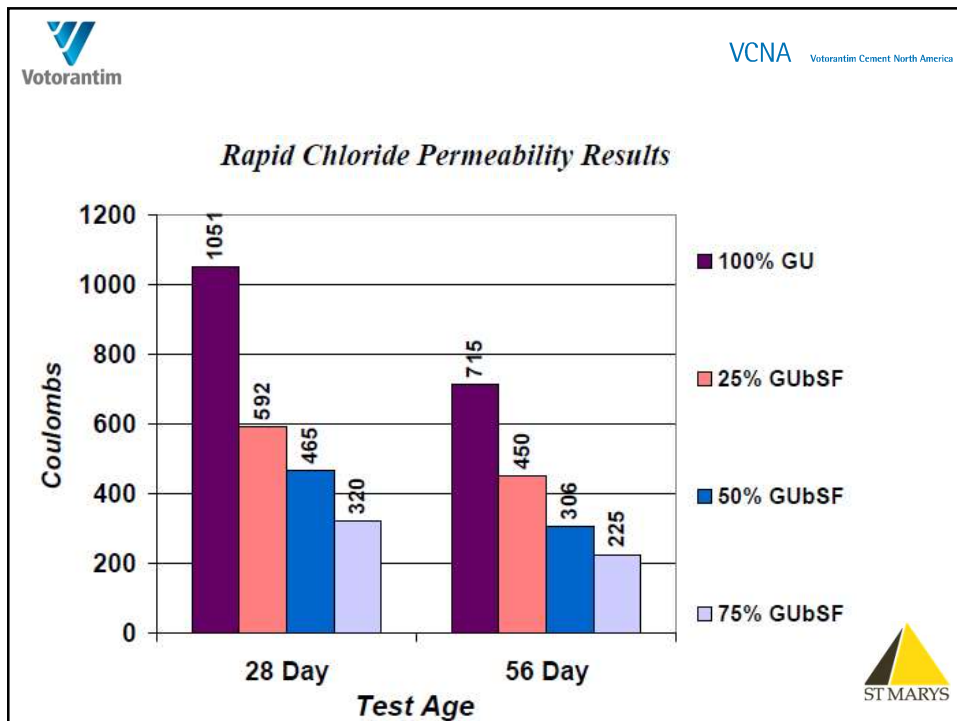
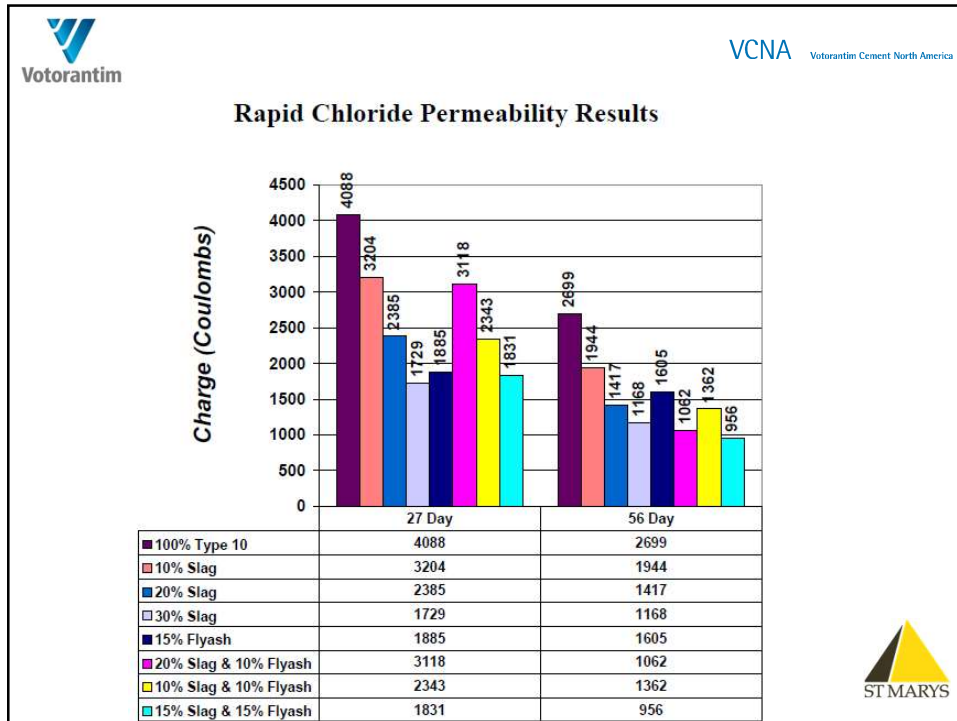
Calcium Hydroxide + Amorphous Silicates = Tobermorite Gel

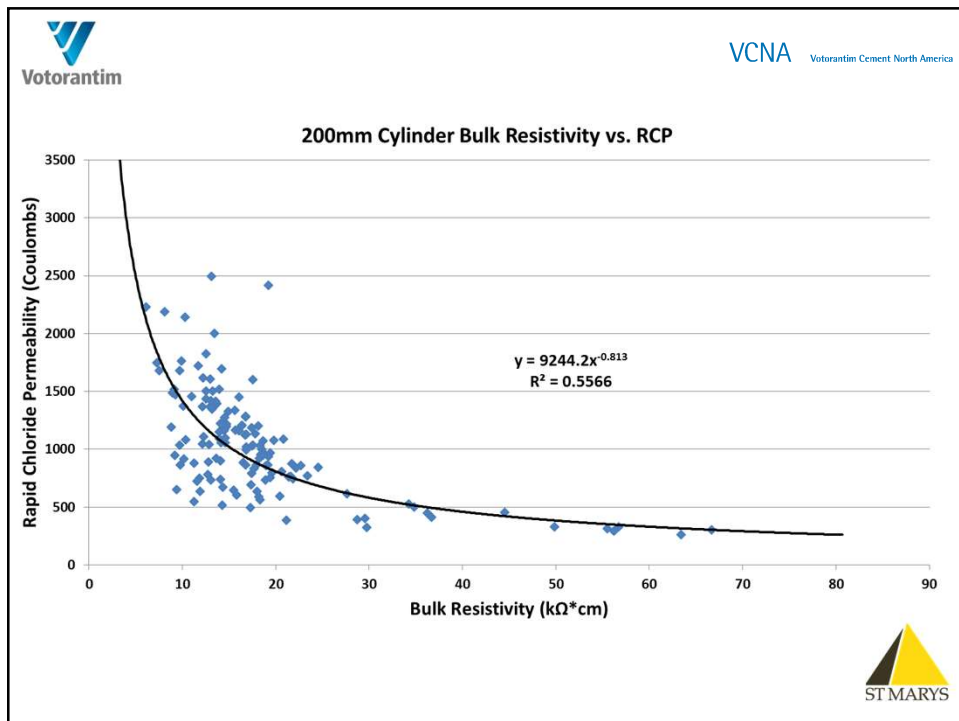
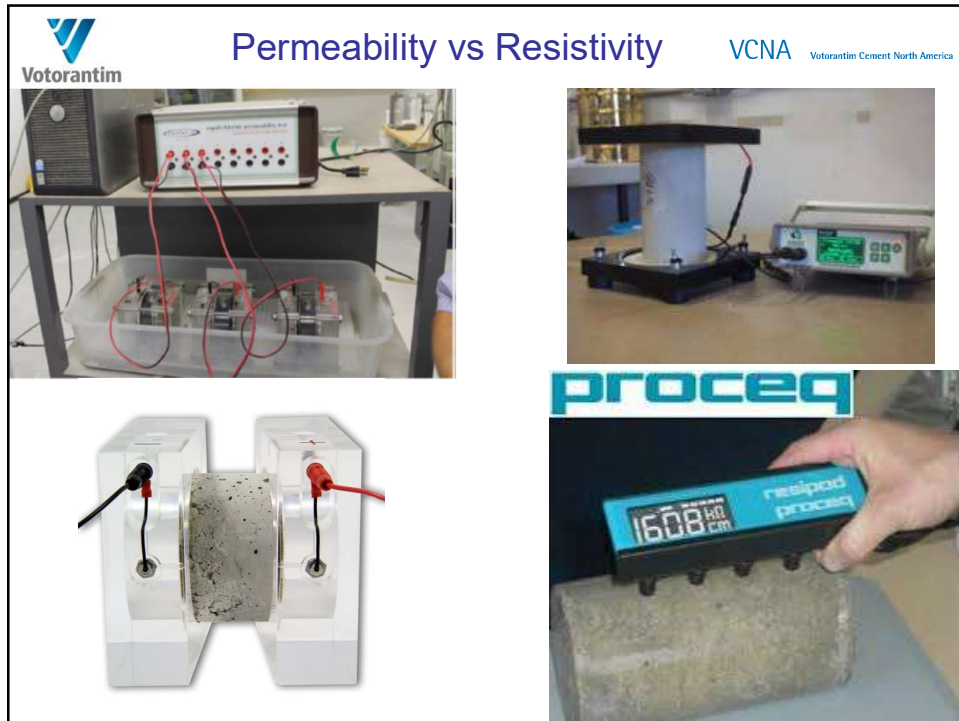

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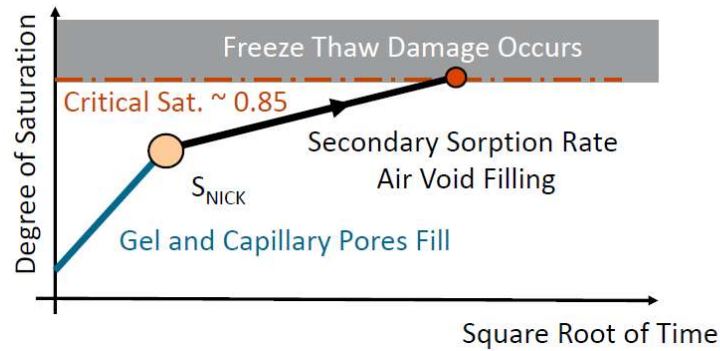






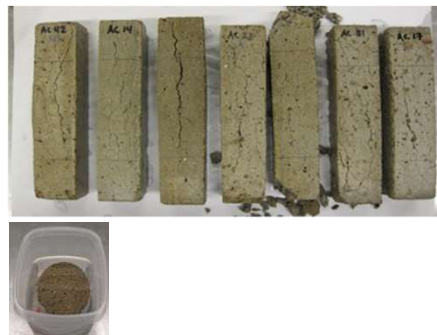
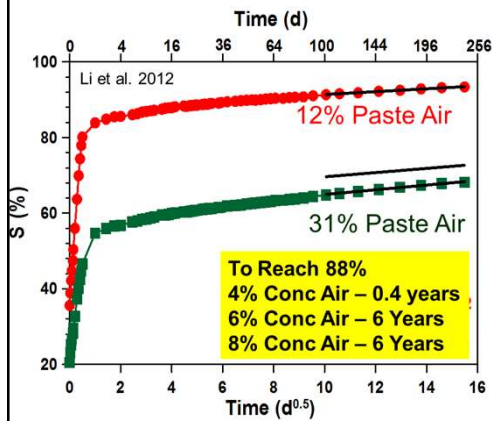
Freeze-Thaw Deterioration is Inevitable

FT Service Life Model



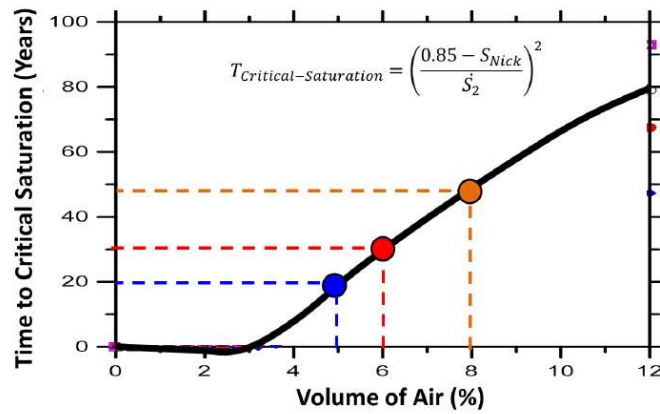
Freeze-Thaw Damage and the Degree of Saturation

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Freeze-Thaw Deterioration is Inevitable

FT Service Life Model

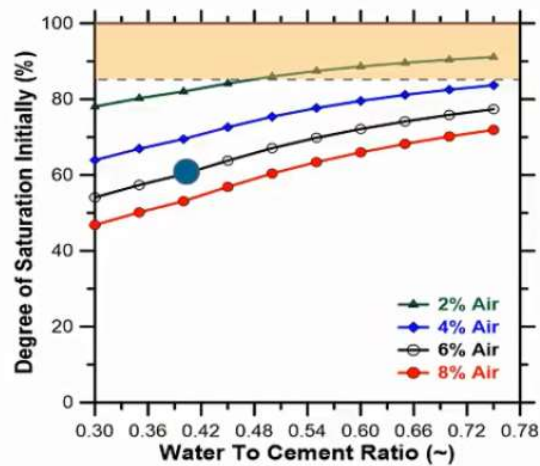


Malvar et al., 2014



Degree of Saturation

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Take Aways - Paste F-T

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- Concrete porosity is inevitable
- Concrete porosity (permeability) is directly linked to w/c
- Air is entrained to protect the paste – but it is not fool-proof
 - Critically saturated paste will crack when frozen
- Need proper air content and air-void system (spacing factor, specific surface)



Summary

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- Keep fluids out of concrete and all materials-related distress is minimized
- Good Quality AVS- stable during placement
- Materials selection is very important
 - Low w/c
 - Low paste content
 - Use SCMs
- Curing is essential
 - Keep the mixture water in and allow the materials time to form dense, impermeable, hydration products





Thank you
Any Questions?

