Hot and Cold Weather Concrete and Freeze-Thaw Resistance

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The Weather Challenge in Ohio

USDA Plant Hardiness Zone Map
Why Concrete Temperature Matters

1. Reaction only proceeds in a “water-filled space”
2. Rate of reaction exponentially dependent on temperature
3. Volume depends on extent of reaction and loss of water

Hydration

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Temperature and Stages in the Life of Concrete

Temperature and Water Demand for Workability

Increased Water Demand with Higher Concrete Temperature

About 1 gallon / yard per 10 degrees F
Temperature and Compressive Strength

Curing Temperature (°C)
20 30 40

Curing Temperature (°F)
0 1000 2000

Temperature and Compressive Strength

Curing Temperature (°C)
13 23 32 41 49

Curing Temperature (°F)
55 73 90 105 120

These Observations Lead to Concrete Temperature Specifications

Constructability Problems!

Columbus, Ohio Monthly Average Temperatures

52°F = 50% Hydration rate compared to 73°F Lab Temp
52°F = 200% Set Time compared to 73°F Lab Temp

Average Temperatures

http://www.city-data.com/city/Columbus-Ohio.html

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Heat of Hydration

6 Sack Mix = 564 lb x 190 BTU = 107,000 BTU / CY
Cold Weather Concreting

- Relative Hydration Rate Compared to Lab Cure

Concrete Temperature (C)

Concrete Temperature (F)

Hot Weather Concreting

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Moisture Matters

1.) Reaction only proceeds in a “water-filled space”
2.) Rate of reaction exponentially dependent on temperature
3.) Product depends on extent of reaction and loss of water

Surface Drying and Shrinkage

Concrete Slab on Ground in dry air
1.) Bleed water appears on concrete surface
2.) Bleed water evaporates
3.) Drying of concrete surface
Freeze Thaw Damage and Deicer Scaling Resistance
Freeze Thaw Damage and Deicer Scaling Resistance

- Control porosity by controlling water
- Control Finishing
- Curing & Shrinkage control
- Temperature Control
- Frost-Resistant Aggregate
- Air-Entrained Paste

Air Entrained Concrete

- Concrete to which a detergent has been intentionally added for the purpose of stabilizing air bubbles formed during the concrete-mixing process.

Disadvantages

- Strength Reduction
  - Porous Paste
- Aggregate Interface
- Required Compensations
  - Lower water content
  - Admixtures
  - Higher cement content
  - Cost
  - Heat
  - Shrinkage
Clustering of Air Bubbles

Disadvantages
- Stickiness
- Finishing Problems
  - Bleeding, Plastic Cracking, Delaminations
- Variable Volume – Yield problems
- Interaction with other admixtures

ACI 302 - Construction of Floors
- Entrained air not recommended when smooth, dense, hard troweled finish required

ACI 301 - Specification
- Intentionally entrained air should not be incorporated in normalweight concrete slabs to be given a smooth, dense, hard troweled finish.

Porous Paste

Air Voids

Random point: freezing begins

Ice Expands
Water and ice move in direction of least resistance

The longer the flow path, the higher the pressure for a given pumping rate.
The less permeable the concrete, the higher the pressure.

How far can water and ice travel in the capillary pores until the pressure cracks the paste?

"0.010 INCHES OR THEREABOUTS"

10 mil poly slab underlayment

Double thickness = 20 mils

"0.020 INCHES OR THEREABOUTS"
Does a Large Air Void protect more paste than a Small Air Void?

YES!

Protected Paste: Asset

This is why we want the air voids!

Costs 200-250 psi Per percent Air Volume

And leads to other problems like delayed bleeding and blisters

Does a Small Air Void protect more paste PER PERCENT Air Volume than a Large Air Void?

Absolutely!

The smaller the air void, the higher the ratio of Asset/Liability!

Does a Large Air Void protect more paste PER PERCENT Air Volume than a Small Air Void?

YES!

Absolutely!

The smaller the air void, the higher the ratio of Protected Paste Volume/Air Content

\[
\text{Wanted:}
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- Large number of small voids
- Well distributed in paste
- Prefer bubbles around 5 mils
- < About 10 mils to nearest bubble
- Air vol about 18% of paste vol
Characteristics of AE Concrete

- 4-8% air bubbles by volume of concrete
- 1 to 2 ft³ Air bubbles / CY
- 10-15 billion air bubbles / CY
- 2 million in² of air bubble surface area / CY
- 1500 SY of bubble surface area / CY

Bubble Size Matters!

How much Air do you need?

- How much paste do you have to protect?
- How severe is the exposure?
- Who are you asking?

These measure Volume Only!
Durability Vs. Spacing Factor

Materials Issues
- Frost-Resistant Aggregate
- w/c or w/cm ≤ 0.45
- Controlled water content
- Air content 18-22% of paste content
- Periodic check of air bubble size
- Periodic check of air bubble stability
- Control the water

 SCM’s and Scaling
- Slag/FA/OPC concrete can be scale-resistant.
- Air quality key. Charcoal is the problem.
- Cure for at least 7 days.
- Finish on time. (Delayed Bleeding)
- Slag & Fly Ash may be more sensitive to poor construction practice than OPC.
- Late season placement needs protection

Construction Issues
- Control water
- Periodic check of air stability
- Timing of finishing operations
- No surface water addition
- Wet curing
Standard Specs won’t produce scaling resistance!

Specifying Freeze-Thaw Resistance

- W/C max = 0.45 (in-place)
- Air content = 18% paste vol
- In place spacing factor max 0.010
- Check ability of materials to stabilize a satisfactory air void system

Specifying Scale Resistant Concrete

- W/C max = 0.45 (in-place)
- Wet cure 7 days (truly wet)
- Air vol = 20% of paste vol
- Spacing factor ≤ 0.008 inches
- Check ability of materials to stabilize a satisfactory air void system
- Timing of Finishing is critical
  – Not too soon / not too late