CHOOSING THE PROPER PCC MIX FOR DURABILITY

Paste (cement + water)
- 9 - 15% Cement
- 15 - 16% Water

Mortar (paste + fine aggregate)
- 25 - 35% Fine aggregate

Concrete (mortar + coarse aggregate)
- 30 - 45% 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.
Adding Cement Goes so Far with Strength
### Strength Gain

#### Cementitious Material Properties

<table>
<thead>
<tr>
<th>Type</th>
<th>Silica (%)</th>
<th>Alumina (%)</th>
<th>Calcium Oxide (%)</th>
<th>Sulfate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I Cement</td>
<td>22%</td>
<td>5%</td>
<td>65%</td>
<td>1%</td>
</tr>
<tr>
<td>Class F</td>
<td>52%</td>
<td>23%</td>
<td>5%</td>
<td>0.80%</td>
</tr>
<tr>
<td>Class C</td>
<td>35%</td>
<td>18%</td>
<td>21%</td>
<td>4.10%</td>
</tr>
<tr>
<td>Slag</td>
<td>35%</td>
<td>12%</td>
<td>40%</td>
<td>9%</td>
</tr>
</tbody>
</table>

SCM’s 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.
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
## Aggregate Moisture States

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

<table>
<thead>
<tr>
<th>State</th>
<th>Oven dry</th>
<th>Air dry</th>
<th>Saturated, surface dry</th>
<th>Damp or wet</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total moisture</strong></td>
<td>None</td>
<td>Less than potential absorption</td>
<td>Equal to potential absorption</td>
<td>Greater than absorption</td>
</tr>
</tbody>
</table>
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
How to Achieve Durability

The Right Mix for Durable Concrete

- Low w/c (low permeability)
  - Freeze-Thaw Resistance
- 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.
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
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
Water & Permeability

• More water – means more space between cement grains
Effects of Extra Water on Concrete

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

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

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

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

Weiss 2014
Sizes of Concrete Components

- Water
- Silica fume
- Cement, slag, fly ash
- Rock
- Sand
- CH crystals
- Capillary voids
- C-S-H agglomerations
- Interfacial zone
- Minimum Air Space
- Entrained air
- Entrained air

- Spacing between C-S-H

Units:
- 0.1 nm
- 1 nm
- 10 nm
- 100 nm
- 1 μm
- 10 μm
- 100 μm
- 1 mm
- 10 mm
- 100 mm
First – Filling of Smallest Pores -Gel and Capillary Pores- (10 to 18 hours)

\[ S_{\text{Nick}} = S_{\text{Mat}} \]

Weiss 2014
Second- Filling of Larger Pores - Entrained and Entrapped Air- (months to years)

- Capillary Pores
- Air Entrainment
- Gel Pores
- Entrapped Air

$S_{\text{Nick}} = S_{\text{Mat}}$

Degree of Saturation

$S_{\text{Int}}$

Gel Pores

$\sqrt{\text{Time}}$

Weiss 2014
Critical Saturation Rates

Weiss 2014
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
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.
Temperature for Calcium Oxychloride Formation (when hydrated cement paste is brought into contact with calcium chloride solution)

Weiss 2014
How Do Also SCMs Work?

\[
\text{Cement} + \text{Water} = \text{C-S-H} + \text{SCM} + \text{Water} + \text{CH} = \text{more C-S-H}
\]
Putting It Together

Concrete Durability Approach

Engineer the Mix

Engineer the Drainage

Engineer the Deicing Chemical Application
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)
Conventional PCC - C Mix

C - 4 WR – C20

Concrete Class

No. relates to coarse/fine aggregate percentages

Water Reducer

% of SCM

SCM designation, Fly Ash (C) or Slag (S)
Conventional PCC - C Mix

C - 4 WR – C20

Use of SCMs will improve durability!!
How Much SCMs?

<table>
<thead>
<tr>
<th>SCMs Type</th>
<th>% of Total Cementitious</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class F fly ash</td>
<td>15% - 25%</td>
</tr>
<tr>
<td>Class C fly ash</td>
<td>15% - 40%</td>
</tr>
<tr>
<td>Slag</td>
<td>25% - 50%</td>
</tr>
</tbody>
</table>

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.
C-Mixes - Common for Conventional paving

<table>
<thead>
<tr>
<th>Type</th>
<th>Aggregate Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2</td>
<td>40% fine and 60% coarse</td>
</tr>
<tr>
<td>C3</td>
<td>45% fine and 55% coarse</td>
</tr>
<tr>
<td>C4</td>
<td>50% fine and 50% coarse</td>
</tr>
<tr>
<td>C5</td>
<td>55% fine and 45% coarse</td>
</tr>
<tr>
<td>C6</td>
<td>60% fine and 40% coarse</td>
</tr>
</tbody>
</table>

Target w/cm = 0.430
Max w/cm = 0.488
**Conventional PCC - C Mix**

Basic Absolute Volumes of Materials Per Unit Volume of Concrete

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Cement</th>
<th>Water</th>
<th>Air</th>
<th>Fine</th>
<th>Coarse</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-2</td>
<td>0.110</td>
<td>0.149</td>
<td>0.060</td>
<td>0.272</td>
<td>0.409</td>
</tr>
<tr>
<td>C-3</td>
<td>0.114</td>
<td>0.154</td>
<td>0.060</td>
<td>0.302</td>
<td>0.370</td>
</tr>
<tr>
<td>C-4</td>
<td>0.118</td>
<td>0.159</td>
<td>0.060</td>
<td>0.331</td>
<td>0.332</td>
</tr>
<tr>
<td>C-5</td>
<td>0.123</td>
<td>0.166</td>
<td>0.060</td>
<td>0.358</td>
<td>0.293</td>
</tr>
<tr>
<td>C-6</td>
<td>0.128</td>
<td>0.173</td>
<td>0.060</td>
<td>0.383</td>
<td>0.256</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Cement</th>
<th>Water</th>
<th>Air</th>
<th>Fine</th>
<th>Coarse</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-3WR</td>
<td>0.108</td>
<td>0.146</td>
<td>0.060</td>
<td>0.309</td>
<td>0.377</td>
</tr>
<tr>
<td>C-4WR</td>
<td>0.112</td>
<td>0.151</td>
<td>0.060</td>
<td>0.338</td>
<td>0.339</td>
</tr>
<tr>
<td>C-5WR</td>
<td>0.117</td>
<td>0.158</td>
<td>0.060</td>
<td>0.366</td>
<td>0.299</td>
</tr>
<tr>
<td>C-6WR</td>
<td>0.121</td>
<td>0.163</td>
<td>0.060</td>
<td>0.394</td>
<td>0.262</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Cement</th>
<th>Water</th>
<th>Air</th>
<th>Fine</th>
<th>Coarse</th>
</tr>
</thead>
<tbody>
<tr>
<td>M-3</td>
<td>0.149</td>
<td>0.153</td>
<td>0.060</td>
<td>0.287</td>
<td>0.351</td>
</tr>
<tr>
<td>M-4</td>
<td>0.156</td>
<td>0.161</td>
<td>0.060</td>
<td>0.311</td>
<td>0.312</td>
</tr>
<tr>
<td>M-5</td>
<td>0.160</td>
<td>0.165</td>
<td>0.060</td>
<td>0.338</td>
<td>0.277</td>
</tr>
</tbody>
</table>

More cement than C mixes
### Conventional PCC

**Minimum Opening Strength – Full Depth Repairs**

<table>
<thead>
<tr>
<th>Slab Thickness (in.)</th>
<th>Strength for Opening to Traffic (psi)</th>
<th>Repair Length &lt;10 ft</th>
<th>Slab Replacements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Compressive</td>
<td>3rd Point Flexural</td>
<td>Compressive</td>
</tr>
<tr>
<td>6.0</td>
<td>3000</td>
<td>490</td>
<td>3600</td>
</tr>
<tr>
<td>7.0</td>
<td>2400</td>
<td>370</td>
<td>2700</td>
</tr>
<tr>
<td>8.0</td>
<td>2150</td>
<td>340</td>
<td>2150</td>
</tr>
<tr>
<td>9.0</td>
<td>2000</td>
<td>275</td>
<td>2000</td>
</tr>
<tr>
<td>10+</td>
<td>2000</td>
<td>250</td>
<td>2000</td>
</tr>
</tbody>
</table>

*Table 6.6. Minimum Opening Strengths for FDRs (ACPA 2006)*
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
- Can add SCM for enhanced durability
Urban Durability Mixes (C-SUD)

- Proportion Table 4 (I.M. 529)

<table>
<thead>
<tr>
<th>Mix No.</th>
<th>Cement</th>
<th>Water</th>
<th>Air</th>
<th>Fine</th>
<th>Coarse</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-SUD</td>
<td>0.106</td>
<td>0.133</td>
<td>0.060</td>
<td>0.315</td>
<td>0.386</td>
</tr>
</tbody>
</table>

Using Article 4110 and 4115 Aggregates

Basic Absolute Volumes of Materials Per Unit Volume of Concrete

Basic w/c = 0.400

Max w/c = 0.450
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
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.
# Rural Durability Mixes (QM-C)

<table>
<thead>
<tr>
<th>Table DS-15038.03-1: Concrete Mixture Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nominal Maximum Coarse Aggregate Size</strong></td>
</tr>
<tr>
<td><strong>Gradation</strong></td>
</tr>
<tr>
<td><strong>Cementitious Content</strong></td>
</tr>
<tr>
<td><strong>Fly Ash Substitution Rate</strong></td>
</tr>
<tr>
<td><strong>Water/Cementitious Ratio</strong></td>
</tr>
<tr>
<td><strong>Air Content</strong></td>
</tr>
<tr>
<td><strong>28 Day Flexural Strength, Third Point</strong></td>
</tr>
</tbody>
</table>
CONSTRUCTION
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)
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
Questions

www.cptechcenter.org