Basics of a Good Road - Concrete Pavements

Road Scholar Program

Part II

Mike Byers

Indiana Chapter – American Concrete Pavement Association
Changes have occurred in Materials & Construction

Demand to build it faster, under traffic & last longer
Central Mix Batch Plant
Cross Section of Hardened Concrete

Concrete made with siliceous rounded gravel

Concrete made with crushed limestone
Range in Proportions

Mix 1
- Cement: 15%
- Water: 18%
- Air: 8%
- Fine agg.: 28%
- Coarse agg.: 31%

Mix 2
- Cement: 7%
- Water: 14%
- Air: 4%
- Fine agg.: 24%
- Coarse agg.: 51%

Mix 3
- Cement: 15%
- Water: 21%
- Air: 3%
- Fine agg.: 30%
- Coarse agg.: 31%

Mix 4
- Cement: 7%
- Water: 16%
- Air: 1%
- Fine agg.: 25%
- Coarse agg.: 51%

Air-entrained concrete
Non-air-entrained concrete
Consider the Difference Between Lab and Production Concrete

Although all batches are intended to be exact duplicates, this is not so in practice.

Larger Measuring Tools
More Rapid Production
Concrete Mix Design Variance and Corrections

- Mix Design Sheet includes a number of variables that can affect the quality of concrete
  - Water Cement (W/C) Ratio
  - Aggregate info
  - Air Entrainment %
  - Unit Weights (Yields)

<table>
<thead>
<tr>
<th>Design Factors</th>
<th>Design Factors (cont.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Batch Size</td>
<td>27 cuft</td>
</tr>
<tr>
<td>Cement Content</td>
<td>470 #/cy</td>
</tr>
<tr>
<td>Fly Ash Content</td>
<td>70 #/cy</td>
</tr>
<tr>
<td>W/C ratio</td>
<td>0.420</td>
</tr>
<tr>
<td>Air Content</td>
<td>6.50%</td>
</tr>
<tr>
<td>Fine Agg/total Agg</td>
<td>47.00%</td>
</tr>
<tr>
<td>Air Entr. Content</td>
<td>2.50 oz/cyd</td>
</tr>
<tr>
<td>Admix #1 Content (WR)</td>
<td>4.00 oz/cwt Cemt.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>Size/Type</th>
<th>Source</th>
<th>Bulk S.G.(SSD)</th>
<th>Absorb.</th>
<th>Moist.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>Type 1</td>
<td>lone STAR</td>
<td>3.15</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Fly Ash</td>
<td>Class C</td>
<td>ROCKPORT</td>
<td>2.74</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Fine Agg.</td>
<td>#23 Sand</td>
<td>M.M.KY.AVE.</td>
<td>2.68</td>
<td>0.85%</td>
<td>1.00%</td>
</tr>
<tr>
<td>Coarse Agg.</td>
<td>#8 Stone</td>
<td>M.M.WAVERLY</td>
<td>2.65</td>
<td>0.95%</td>
<td>4.00%</td>
</tr>
<tr>
<td>Air Entrmnt.</td>
<td>Dairavair 1400</td>
<td>WR GRACE</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Admix. #1</td>
<td>WRDA 82</td>
<td>W.R.GRACE</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Water Weights for 1 CYD</th>
<th>Aggregate Weights for 1 CUYD</th>
</tr>
</thead>
<tbody>
<tr>
<td>(in pounds)</td>
<td>(in pounds)</td>
</tr>
<tr>
<td>Free Water</td>
<td>52.01</td>
</tr>
<tr>
<td>Mix Water</td>
<td>174.79</td>
</tr>
<tr>
<td>Total Water</td>
<td>226.80</td>
</tr>
</tbody>
</table>

Batch Weight for:

<table>
<thead>
<tr>
<th>Material</th>
<th>1 Cyd</th>
<th>1 Cft</th>
<th>27.0 Cft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>470 #</td>
<td>17.41 #</td>
<td>470.00 #</td>
</tr>
<tr>
<td>Fly Ash</td>
<td>70 #</td>
<td>2.59 #</td>
<td>70.00 #</td>
</tr>
<tr>
<td>Mix Water</td>
<td>175 #</td>
<td>6.47 #</td>
<td>174.79 #</td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td>1,481 #</td>
<td>54.84 #</td>
<td>1,480.63 #</td>
</tr>
<tr>
<td>Coarse Aggregate</td>
<td>1,698 #</td>
<td>62.90 #</td>
<td>1,698.32 #</td>
</tr>
<tr>
<td>Air Entrainment</td>
<td>2.5 oz</td>
<td>0.093 oz</td>
<td>2.500 oz</td>
</tr>
<tr>
<td>Admix #1 (WR)</td>
<td>21.6 oz</td>
<td>0.800 oz</td>
<td>21.600 oz</td>
</tr>
</tbody>
</table>

Total 3,894 # 144.21 # 3,893.75 #
Batching
Batching/Mixing

Course aggregate & sand being transferred to aggregate bin
Central Mix Batch Plant
Truck Mixed Concrete

Aggregates

Cement
Fly Ash
Portland Cement is a hydraulic cement, meaning that it hardens by a CHEMICAL REACTION with water.
SEMs of Hardened Cement Paste
Cement and Its Impact on Concrete Performance

Module 1 - Cement’s Role in Sustainability
Module 2 - Cement Manufacturing
Module 3 - Types and Applications of Cement
Module 4 - Cement Characteristics
Module 5 - Impact of Cement on Concrete Properties
Module 6 - Abnormal Reactions and Compatibility of Materials with Cement

If you work with concrete, you need to understand cement.
Cement Paste

Mix 1
- Cement: 15%
- Water: 18%
- Air: 8%
- Fine agg.: 28%
- Coarse agg.: 31%

Mix 2
- 7%
- 14%
- 4%
- 24%
- 51%

Mix 3
- 15%
- 21%
- 3%
- 30%
- 31%

Mix 4
- 7%
- 16%
- 1%
- 25%
- 51%

Air-entrained concrete

Non-air-entrained concrete
Aggregate Gradation Affects

- Workability
- Pumpability
- Economy
- Porosity
- Shrinkage
- Durability
Admixtures

- Air-entraining admixtures
- Water-reducing admixtures
- Plasticizers
- Accelerating admixtures
- Retarding admixtures
- Hydration-control admixtures
- Corrosion inhibitors
- Shrinkage reducers
- ASR inhibitors
- Coloring admixtures
Pozzolans

• Fly Ash
• Microsilica – silica fume
• GGBFS – ground granulated blast furnace slag
SEM of Fly Ash Particles
SEM of Silica Fume Particles
CEMENT + WATER

CS(glue) + Ca(OH)$_2$ +H$_2$O
\[ \text{Ca(OH)}_2 + \text{H}_2\text{O} + \text{Pozzolan} \rightarrow \text{CS(glue)} + \text{H}_2\text{O} \]
Types of Fly Ash

• Class F
• Class C
Class F Fly Ash

- Eastern Coal
- High Sulfur Content
- LOI varies with source
- No cementitious properties
Class C Fly Ash

- Western Coal
- Low Sulphur Content
- Low LOI
- Consistent LOI
- Slightly cementitious
Effects of Fly Ash

- Placability
- Durability
- Time of Set
Air Entraining Admixtures
We all know that water expands when it freezes.

Entrained Air acts as a natural shock absorber when the water in the concrete freezes.

Entrained Air loses some of its effectiveness in a soupy mix.
Air Entrainment/ Hardened Concrete

• Better freeze-thaw resistance
• Increased watertightness
• Reduced concrete weight
Water Reducing Admixtures
Water Reducing Admixtures

What Are They?

- Admixtures that either increase slump of freshly-mixed mortar or concrete without increasing water content or maintain slump with a reduced amount of water, the effect being due to factors other than air entrainment.

(ACI 116.R-2)
Water Reducer Chemical Action

Cement Flocculation

Water Molecule

Cement
Quality Control
Quality Control is an Active Process

• Tests provide information
  – to better understand material
  – to verify production as compared to target and set points
  – to make adjustments
Quality Control Charts

- Economical method based on statistics and probability
- Provide a method to assess on a continuous basis
- Graphical Representation

Required Average Strength $f'_{cr} = f'_c + ts$
Proper QC Helps to Avoid Big Surprises in QA

- Here we see samples tested by the contractor in “their schedule”
  - mean - 762 psi
  - std dev – 49 psi
- When the agency tested
  - mean - 752 psi
  - std dev – 45 psi
What Are the Practical Implications of Having Tighter Quality Control

• We cannot design structures based on the mean measured strength but we will use it for designing the mixture.

• Assumption: 1/1000 tests are below the design strength ($f'_r=570$ psi)

• Consider two contractors with measured variation:
  
  - Contractor 1: $X = 680$ psi, $\sigma = 45$ psi
  - Contractor 2: $X = 810$ psi, $\sigma = 100$ psi
What Does Improving the Quality Control Mean in Real Life

Minimum Quality Level $f'_{r} = 570$ psi

<table>
<thead>
<tr>
<th>Quality Control</th>
<th>Flexural Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>1</td>
</tr>
<tr>
<td>Good</td>
<td>2</td>
</tr>
</tbody>
</table>

Target Strength for Poor Quality Control

Good Quality Control

Minimum Flexural Strength

Target Strength for Poor Quality Control

Target Strength for Good Quality Control
Research – New Frontiers, Problem Solving
Premature Joint Deterioration
Premature Joint Deterioration
Premature Joint Deterioration
Premature Joint Deterioration

- Air voids filled with hydration products (secondary products)
- Secondary product (ettringite) in air entrained small bubbles
“Drying of Concrete

Spragg et al. submitted 2010
Slab – Silver Nitrate

No Sealer – 4 different Soaking Solutions (56 Days).
NaCl most penetrated, CaCl₂ Damaged Surface, and Water Shows No Penetration.
Freeze-Thaw Durability

• Concrete can experience significant damage due to freezing and thawing

• ASTM C666
  – procedure A (freeze and thaw in water)

• Monitor change in dynamic elastic modulus and mass
Freeze-Thaw Durability

Plain  SME-PS Dose 1  SME-PS Dose 2  SBS
Additional Research Efforts

- Internal Curing of Concrete
- Using Recycled Crushed Concrete as Coarse Aggregate in Concrete
- Investigation of Deicing Chemicals Interaction with Concrete
- Use of Slag Aggregates & Slag Cements in Concrete – Impact on Durability Performance
- 30+ SACs/on going projects
Questions?

Information:
Mike Byers
Indiana Chapter ACPA
mbyers@pavement.com
www.indianaconcretepavement.com