Durable Concrete in a Low-Ash World

Jerod Gross, PE, LEED AP
Dan King, PE
Representing the CP Tech Center
What’s Coming Up…

A Virtual Better Concrete Conference

Noon webinars

Nov. 4  ACI 301 – Specifications for Concrete Construction
        Michelle Wilson, PCA
Nov. 18 Wet Weather Strategies for Handling Concrete Placements
        Ron Kozikowski, North Starr Concrete Consulting
Dec. 2  The Future of Fly Ash: Dystopia or Hysteria
        Larry Sutter, Michigan Tech University
Dec. 16 Project Bluejay & Krause Gateway Center
        Dan Goldsworth, Mark Stinocher, Jordan Stokes, Nick Aldrich

https://register.gotowebinar.com/register/6780190539906386191
Special Thank you

Dr. Peter Taylor, PE, Ph. D

Director, National Concrete Pavement Technology Center

ptaylor@iastate.edu
Overview

• Introduction
• Controlled mixtures
• Other products
• Impacts in Iowa
• Crystal ball gazing
Introduction

• Fly ash is amazing!
  • Less expensive $
  • More workable
  • Reduces permeability
  • ASR / sulfate / oxychloride resistant
  • Cooler (lower heat of hydration)

• But…
  • There are no fly ash factories
  • Utilities are changing
  • 2020…
Cementitious Materials

Hydraulic cement – reacts with water, creates CH

- Portland Cement
- Slag Cement
- Class C Fly Ash

Pozzolan – reacts with cement and water, consumes CH

- Class F Fly Ash
- Silica Fume

CaO
Al₂O₃
SiO₂

Not to scale
Fly Ash Production

- By-product of combustion of pulverized coal
- During combustion
  - Volatiles & carbon burned off
  - Mineral impurities remain in flue gas
  - Fused materials cool into glass spheres
Fly Ash Contaminants

- Carbon (LOI)
  - Sucks up air entrainers

- Sulfates
  - Expansion

- Moisture
  - Handling, workability

- $\text{C}_3\text{A}$
  - Can contribute to incompatibility
How SCMs Work

Cement + Water → C-S-H

Calcium Hydroxide

- Good for raising pH and protecting steel
- Bad for
  - Oxychloride
  - Solubility
  - Shear strength

CH
How SCMs Work

Cement

Water

SCM

Water

CH

C-S-H

React

React

C-S-H
Introduction

• Can we go back to this?
Introduction

- Review the benefits

Impact of Coal Fly Ash

- Workability/Finish-ability
- Strength (low w or high cm)
- Low Permeability (water or high cm)
- Freeze-Thaw Resistance
- Low Shrinkage
- Lower Materials Cost (low cm)
- Cooler Concrete (low cm)
- Mitigate Alkali-Aggregate Reaction
- Sustainable Carbon Footprint
Workability

• Does workability matter to anybody other than the contractor?
  • “Add 10”
    • Hurts long term performance
  • The right vibration
    • How fast, how long
    • Moves air, water and aggregates
  • Aesthetics
    • Matter to the owner
  • Fly ash and admixtures help
Durability

• Durability is largely governed by permeability / transport
  • Most failure mechanisms involve water

• Getting low permeability
  • Low water/cement (MN history)
  • Appropriate SCM dose
Oxychloride

- MgCl2 and CaCl2
  - React with CaOH to form calcium oxychloride
  - Forms when temperature >32 ºF
  - Expands ~300%
  - Unstable at higher temperatures

- Prevented by using SCMs to reduce
Review

• What do we (really) need from fly ash
  • ASR
  • Oxychloride
  • Permeability
  • Workability
  • Strength
  • Heat
  • Sustainability
  • Cost

Limited alternatives to fly ash

Alternatives available
Controlled mixtures

- Prepare the mixture for the application
  - Use what you need (and no more)
  - From what you have
  - Control the cementitious content

Performance Engineered Mixtures

- Require the things that matter
  - Transport properties (everywhere)
  - Aggregate stability (everywhere)
  - Strength (everywhere)
  - Cold weather resistance (cold locations)
  - Shrinkage (dry locations)
  - Workability (everywhere)
Controlled mixtures

- Use what you need (and no more)
  - It's like balancing the family checkbook

- ASR – depends on the aggregate
- Oxychloride – depends on the cement

- Permeability
- Workability
- Strength
- Heat
- Sustainability

Limited alternatives
Alternatives available
True or False?

- More cement = more strength
- Strength is everything
- Slump indicates quality
- Stronger concrete is more “brittle”
Controlled mixtures

• Control the cementitious content
  • With more cement you need more fly ash

• Excess has a:
  • Negative effect on permeability, shrinkage, cost
  • Small negative effect on strength

• “Optimum” depends on:
  • Aggregate type
  • Gradation
How do we proportion to achieve design goals?

<table>
<thead>
<tr>
<th></th>
<th>Workability</th>
<th>Transport</th>
<th>Strength</th>
<th>Cold weather</th>
<th>Shrinkage</th>
<th>Aggregate stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type, gradation</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>✓</td>
</tr>
<tr>
<td>Paste quality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air, w/cm, SCM type and dose</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Paste quantity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vp/Vv</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Controlled mixtures

- From what you have
  - Class C or F
  - Behave differently
Other Products

- Slag cement
- Metakaolin
- Other minerals like zeolite?
- Microspheres for f/t protection
- IP cements
- But…
But

- Do they do what we need?
- They change mix properties
- Cost
  - Particularly shipping
  - Is it worth it?
- Availability
  - “Free market?”
But

• Education
  • Every product has its own quirks
• Specifications
  • Have to be appropriate
  • AASHTO PP84
  • Iowa
    • DOT: QM-C
    • SUDAS: C-SUD
AASHTO PP84

• Require the things that matter
  • Transport properties (everywhere)
  • Aggregate stability (everywhere)
  • Strength (everywhere)
  • Cold weather resistance (cold locations)
  • Shrinkage (dry locations)

• Workability (everywhere)
AASHTO PP84

- Measure them at the right time
  - Prequalification
  - Process control
  - Acceptance
- A buffet of approaches
  - Prescriptive: w/cm, paste volume
  - Performance: Formation factor
AASHTO PP84

- Allow contractor to develop the mixture to meet requirements
  - w/cm (within limits)
  - SCM dose (within limits)
  - Aggregate gradation
- Iowa’s QM-C and C-SUD mix specs are informed by these principles
Measuring what we need

- ASR
  - Follow AASHTO R80 / ASTM C1778

- Oxychloride
  - LTDSC
  - Expansion at 40°F
Measuring what we need

- Permeability / Transport
  - Resistivity
- Strength
- Heat
  - Calorimetry
- Air void system
  - SAM
Measuring what we need

- Workability
  - VKelly
  - Box

Measure the response to vibration
Fly Ash in Iowa

• Likely to continue seeing reduced fly ash production

• Events in 2020 causing a short-term supply crunch:
  • Mild winter
  • COVID-19

• Other issues
  • Consistency
  • Substitutes are not immediately available
Iowa Specifications

• What can we do right now with our Iowa mixes to maximize durability?
  • Save the fly ash for where you need it
  • The C-SUD mix specification can be used regardless of fly ash content
  • Follow good principles (control the paste):
    • Lower total cementitious content via optimized gradation
    • Appropriate w/cm
    • Good air void system
The Future

• Blended ashes
  • “Good enough for engineering purposes”
  • Coming soon to Iowa?

• Reclaimed ash
  • Quality control
  • Transportation
The Future

- Reclaimed ash
- CP Tech Center September 2020 Tech Brief:
- Fly ash harvesting is being done in PA, SC, and WI, and should continue to expand

Summary and Disclaimers
The purpose of this Tech Brief is to summarize the characteristics of reclaimed or reclaimed fly ash and identify considerations for its use in highway infrastructure. The document is intended for highway agency and contractor engineers.

The contents of this document do not have the force and effect of law and are not meant to bind the public in any way. While this is non-binding guidance, compliance with applicable statutes and regulations cited is required.

Background
Fly ash is amorphous, non-combustible residue that results from coal-fired electric power production. Its use in concrete was first described in 1957 (Elmore et al. 1957), but despite the compelling research presented in that early publication, fly ash was initially used only to replace the most expensive part of a concrete mixture (i.e., the Portland cement) as a less expensive filler, not as a significant constituent material (USDOE).

Over time, largely due to the loss of 50 years, concrete engineers have come to understand how to improve the properties of concrete by including fly ash in a concrete mixture, and fly ash has now become a common component in concrete.

Benefits of Fly Ash in Concrete
- Workability: fly ash, as a normal bias, pozzolanic cement with fly ash, which typically has a lower specific gravity that cement, increases the paste volume of the self-consolidating material mix (Wang et al. 2013) held in concrete. The volume of the concrete mixture typically is corrected by withholding an equal volume of fine aggregate. Increased pozzolan content improves concrete workability.

USE OF RECLAIMED FLY ASH IN HIGHWAY INFRASTRUCTURE

CONTRIBUTORS
Lorrain O. Gutek, Ph.D, P.E. NCDOT
Dana Meitner, Ph.D.

SUMMARY
The use of fly ash in highway infrastructure is a hot topic due to its environmental benefits and cost savings. However, its use is not without challenges, as it requires careful consideration of its properties and integration into the concrete mix. This summary provides an overview of the benefits and challenges associated with using fly ash in highway infrastructure projects.

Intended Audience
This summary is intended for highway agency and contractor engineers who are interested in incorporating fly ash into their projects.

Core Message
Fly ash is a valuable material that can be used in highway infrastructure projects to improve the durability and cost-effectiveness of concrete. However, it is important to consider the specific properties of fly ash and how they affect the overall performance of the concrete mix.

Key Takeaways
- Fly ash can be used in highway infrastructure projects to improve the durability and cost-effectiveness of concrete.
- Careful consideration of fly ash properties is necessary to ensure optimal performance of the concrete mix.
- Fly ash can replace Portland cement in concrete mixes, leading to cost savings and environmental benefits.
- Monitoring and testing of fly ash quality are crucial to ensure consistent performance in highway infrastructure projects.

Learn More
For more information on the use of fly ash in highway infrastructure, please refer to the associated technical report and the references provided in the summary.

Footnotes

National Concrete Pavement Technology Center
2751 South Long Drive, Suite 4106
Ames, IA 50010-5854
contact@ncptc.org

Director: Peter Saltik
peter.saltik@iastate.edu

National Concrete Pavement Technology Center
IOWA STATE UNIVERSITY
Institute for Transportation
The Future

- Local powders
  - Limited availability
  - Testing can be onerous (ASTM C 1709)
- But all help is good help
- Economics may be helping
Philosophical Ramblings

• What about those old pavements?
  • Cements have changed
  • Placement methods have changed
  • Curing!!!!!

• Traffic has changed
• Salting has changed
Philosophical Ramblings

• Life is changing – we have to adapt
• There are solutions
• We have to think
• Quality matters

• Call us if you need help

Dan King
515-963-0606
dking@concretestate.org

Jerod Gross
515-669-7644
jgross@snyder-associates.com