Sustainability – An On-Ramp for Concrete Pavements

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Suddenly, Sustainability Is All The Rage

• Politicians come and go, but scientific facts remain
  – The Arctic continues to melt and sea levels are rising
  – Global temperatures continue to rise

• The Biden administration is emphasizing climate change and social equity
  – Climate change is a focal point in the new infrastructure bill

• Sustainable solutions are of increasing interest to governmental agencies and industry

• Sustainability is important to you in Iowa’s concrete pavement industry
Climate Change

• Changes in global climate from human activities are occurring
  – Supported by historical observation and climate modeling

• Optimistic models predict substantial climate change over the next century
  – Rate of change depends on what we do
  – Long life of emitted heat-trapping, greenhouse gases and slow feedback functions of atmospheric systems drive climate change
Certainty

“It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred”


Uncertainty

The degree of change is uncertain as many variables are important and as yet, undefined
Changes in Global Surface Temperatures Relative to 1850-1900 (IPCC 2021)

Warming is unprecedented in more than 2000 years

Warmest multi-century period in more than 100,000 years

Global Surface Temperature Increases Compared to 1850-1900

Projected Sea Level Rise

Low-likelihood, high-impact storyline, including ice sheet instability processes, under SSP5-8.5

Sustainable practices are simply good engineering and not just GHG emissions or environmental impacts.
Sustainable Solutions Require Life-Cycle Thinking

- Long-life design
- Optimized design
- Recycling
- Carbonation
- Keep smooth pavements smooth
- Focus is on vehicle fuel consumption – dominate effect

- Reduced energy
- Blended cements
- Alternative cements

- Efficiency
- CaCO₃ mineralization

Materials Processing → Design → Reconstruction and Recycling → Preservation and Rehabilitation → Construction → Operations
Challenges In Front of Us

• Change is difficult
  – Must ween ourselves from business as usual
• Traditional cement and concrete are carbon intensive
• Designs and materials are dictated by past experience and “conservatism” in codes and specifications

DON’T BE SAD – INNOVATE!
There is Hope!

- New policies and initiatives are focused on sustainability
  - New infrastructure bill
  - State and local initiatives
- The cement and concrete industry is focused on change
  - PCA’s Net Zero by 2050
  - ACI, ASTM and others
- Organizations and associations are responding to the need to innovate
  - ACPA, APWA, ASCE, etc.
  - Others (e.g., Breakthrough Energy)
What Can We Do? A LOT!

- Stay educated – This is really important
- Adopt life cycle thinking
- Wise use of materials
- Consider the use phase
- Verification
Hydraulic Cement and Concrete Mixtures

• Hydraulic cement concrete is humankind’s most used material after water
  – Approximately 2.2 yd$^3$/person/year
  – Civilization is built on it – This is no exaggeration
  – 5%-8% of global GHG emissions

• Massive economic, environmental, and social impacts
  – 90 million metric tons of cement manufactured in the U.S. in 2020 (4.1 billion worldwide)
  – In 2018, linked to 0.6% of US GHG emissions
GHG Emissions Associated With Concrete at the Gate

- ~1.5% from acquiring and processing raw materials
- ~89% from cement manufacturing
  - ~37% from burning fuel
  - ~46% from calcination
- ~9.5% from making concrete

Net result: for every pound (kg) of U.S. made typical ASTM C150 Type I cement, roughly 0.94 lbs (kg) of GHG emissions are released.
Total GHG Emissions Embodied in Concrete

- Cement
- Gravel
- Sand
- Water

Typical concrete at the gate:
- 0.26 tons CO₂ /yd³ concrete
- 0.23 tons CO₂ from portland cement
Elements of PCA’s Net Zero by 2050

- Clinker optimization
  - Production enhancements
  - Sequestration
- Cement optimization
  - Blended portland cements
  - Alternative cements
- Concrete optimization
  - Reduced cementitious materials content
  - Longevity
- In-service and end-of-life carbonation
  - For structural concrete, small but still significant
Clinker Optimization

• Reduce GHG emissions during production including
  – Make kilns super efficient
  – High efficiency grinding mills
  – Fuels including waste fuels and plasma

• Carbon dioxide sequestration
  – Kiln flue gas has high CO$_2$ concentration...typically about 25 mol% vs 14% for coal-fired power plant vs 0.033% in atmosphere
  – A “target-rich environment” for sequestering CO$_2$
Cement Optimization

- Replace clinker with supplementary cementitious materials (SCMs)
  - Obtained as blended cement (ASTM C595)
  - Blend at concrete plant
- Replace clinker with ground limestone
  - ASTM C595 Type IL blended cement can have up to 15% limestone
  - On-going work to look at higher limestone content
Traditional Supplementary Cementitious Materials (SCMs)

• Fly ash
  – Collected from flue gases of coal burning power plant

• Slag cement
  – From iron blast furnace

• Natural pozzolan
  – Calcined clay, volcanic ash, ground pumice, etc.
Alternative SCMs

- Reclaimed coal ash
  - From landfills and ponds
  - Mix of fly ash and bottom ash
  - Almost always requires processing

- Ground glass pozzolan

- SCM produced from carbon dioxide sequestration

- Importantly, ASTM is working to develop standards based on reactivity
ASTM C595 Blended Cements

- Produced by cement manufacturers
- Type IP(X), Type IS(X), and Type IT (X)(Y)
  - Blended with pozzolan, slag cement, limestone or ternary blend
- Type IL will reduce carbon footprint by 8 to 10 percent with little impact on behavior
- Can be designated as moderate sulfate resistance (MS), high sulfate resistance (HS), moderate heat (MH), or low heat (LH)
Alternative Cementitious Materials

- Non-traditional blended hydraulic cements
  - LC3
- Alkali-activated hydraulic cements
  - Alkali activator – liquid or powder
  - Precursor containing calcium and alumino-silica minerals
    - E.g., Class C fly ash, slag cement
- Geopolymers
  - Alkali-activated non-hydraulic reaction based on low calcium alumino-silica minerals
  - Dissolution and polymerization process

Fig. 1.2 Classification of AAMs, with comparisons to OPC and calcium sulfoaluminate binder chemistry. Shading indicates approximate alkali content; darker shading corresponds to higher concentrations of Na and/or K (Diagram courtesy of I. Beleta)
LC3 Cement

LC³ is a family of cements, the figure refers to the **clinker** content.

- 50% less clinker
- 40% less CO₂
- Similar strength
- Better chloride resistance
- Resistant to alkali silica reaction

K. Scrivener, 2020
Reduce Cementitious Content in Concrete

- Maximize aggregate content through use of optimized aggregate grading
Dispelling A Common Fallacy: Increasing Cement Content Increases Strength

Based on Taylor and Wilson
Real Data from Project NEON in Las Vegas

3-Day Average Flexural Strength

- 500 pcy
- 611 pcy
Project NEON Concrete

28-Day Average Flexural Strength

- 500 pcy
- 611 pcy
Reducing GHG Emissions by Minimizing Cement Content and Increasing SCMs
What About CO₂ Sequestration Through Carbonation?

• It is a real thing
• Paper quantifies uptake of CO₂ by concrete through carbonation
  – Ca(OH)₂ + CO₂ → CaCO₃ + H₂O
  – Calcium silicate hydrate also undergoes carbonation
  – Uses Fick’s law
How Much Carbonation Occurs in Typical U.S. Concrete?

- Depends on exposure and quality of concrete
  - Is climate wet or dry? Is it exposed to rain?
- Quality of concrete
  - In the paper, is related to strength, but it is permeability that matters
  - Related to \( w/cm \)
- In general, dry concrete that is permeable (low strength) will have a higher degree of carbonation than wet concrete that has low permeability (high strength)
Applying This to a Typical U.S. Pavement

- Assume 564 lbs/yd$^3$ portland cement mix with a compressive strength of 4000 psi that is exposed to rain
  - Note that less carbonation would occur if less cement and/or SCMs were used
- The amount of CO$_2$ sequestered through carbonation is calculated to be between 0.2-0.3 lbs/ft$^2$ of surface area in 50 years
  - Roughly 14,000-20,000 lbs per lane-mile, or equivalent to 700 to 1000 gallons of fuel consumed
Pounds CO$_2$ Sequestered Over Time per Lane-Mile

\[ F'_c = 3,600-5,100 \text{ psi} \]

\[ F'_c = > 5,100 \text{ psi} \]
Preservation Through Diamond Grinding Increases Carbonation

- Rate of carbonation decreases with time
  - Roughly 45% of carbonation over 50 years occurs by Year 10
- Diamond grinding creates a “fresh” surface with more surface area for carbonation
- Grinding every 10 years will more than double the amount of sequestered CO$_2$
- Overlaying concrete with asphalt will shut out atmospheric CO$_2$ and terminate sequestration
Pounds CO$_2$ Sequestered Over Time per Lane-Mile

Range with grinding every 10 years

Range without grinding
Diamond Grinding has Close to Net Zero GHG Emissions

- Diamond grinding every 10 years results in 17,400 to 25,300 lbs of additional CO$_2$ being sequestered over 50 years per lane-mile
  - This is equivalent to 870 to 1,270 gallons of diesel fuel consumed over 50 years
- Four diamond grindings consumes between 1,000 and 1,600 gallons of diesel
  - 250-400 gallons per lane-mile of grinding
- In addition, increased vehicle fuel efficiency due to improved smoothness results in greater than net zero GHG emissions
Assessing Sustainability

• Use of unbiased, factually-based tools/resources to assess life cycle impacts are essential
  – There is A LOT of greenwashing going on
  – Only through standardized assessment can we know if we are doing the right thing

• A life cycle assessment (LCA) meeting ISO standards is the best way to assess environmental impact
  – Request environmental product declarations (EPDs) based on approved product category rules (PCR)
  – Stay informed
  – Seek help as needed
VERIFY!

- Assessment tools should be used to evaluate the economic, environmental, and social impacts of alternatives over the life cycle
- Tools for environmental impact assessment are currently under development
  - Environmental product declarations
  - FHWA LCA tool
  - eLCAP in California
  - Athena Pavement LCA

“Trust, but verify”
Current Initiative: MnROAD Reduced GHG Emission Test Site

• A test site is under development at MnROAD to evaluate strategies to reduce GHG emission in concrete paving

• 16 test cells
  – 1 control cell
  – 3 carbon mineralization cells
  – 1 optimized concrete
  – 6 alternative SCM cells
  – 5 alkali-activated cements

• Construction scheduled for summer 2022
Current Initiative – Breakthrough Energy Foundation

- BTE Foundation is focused on reducing global GHG emissions and fighting climate change
- Identification and elimination of barriers restricting carbon reduction strategies in concrete construction
  - Tracking the follow of clinker through the U.S. and Canadian economies
  - Evaluating codes, specifications, and standards dictating use
  - Identifying barriers and developing strategies to overcome barriers
Summary

- Sustainable concrete pavement practices are available for all phases of life.
- Sustainable solutions require a life cycle perspective.
  - Evaluating cradle to construction only will result in short-sighted decisions.
- Strive to optimize your cement and concrete.
- Use rigorous verification to avoid “greenwashing.”
- As an industry, the future is bright.
Questions?

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