Concrete Innovations

Lionel Lemay, PE, SE, LEED AP
Donn C. Thompson, AIA, LEED AP BD+C
About the Course

Learning Units

• AIA-CES (1 LU/HSW - 1 PDH)

Learning Objectives

• Understand new technologies used in concrete manufacturing.

• Discover how innovative concrete products can improve project performance.

• Learn how to implement the latest concrete innovations in building and infrastructure projects.

• Demonstrate the importance of incorporating new technologies to enhance resilience and sustainability in the built environment.
The Problem
The Reality

- Every year
  - 6.13 billion square meters of buildings are constructed.
  - 3729 million metric tons CO₂ per year.
- By 2050
  - embodied carbon emissions and operational carbon emissions will be roughly equivalent.

Total Carbon Emissions of Global New Construction from 2020-2050
Business as Usual Projection

<table>
<thead>
<tr>
<th>Year</th>
<th>Embodied Carbon</th>
<th>Operational Carbon</th>
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</thead>
<tbody>
<tr>
<td>2020</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>2025</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>2030</td>
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<td>2050</td>
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Data Sources: UN Environment Global Status Report 2017; EIA International Energy Outlook 2017
The Challenge

- Embodied carbon from the building materials produces 11% of annual global GHG emissions.
- Concrete, iron, and steel alone produce ~9% of annual global GHG emissions.
- Likely will need to build with more robust materials like concrete.
- How do we minimize environmental impacts?

Annual Global CO₂ Emissions

- Building Operations: 28%
- Building Materials and Construction: 11%
- Transportation: 22%
- Industry: 30%
- Other: 9%

Source: UN Environment Global Status Report 2017
Data Source: IEA (2017); World Energy Statistics and Balances
Concrete Innovations

• More efficient concrete mixtures
• Admixtures
• Blended cements
• Supplementary cementitious Materials
• Carbon capture technologies
• High-performance concretes
What do these buildings have in common?

The Jubilee Church

Pantheon
Both Used Innovative Concrete

Pantheon, Rome 27 B.C.
- Roman Concrete
- Volcanic ash (pozzolana)
- Aggregate (rock, crushed tile, brick)

Jubilee Church, Rome 2003 A.D.
- Photocatalytic Concrete
- Self cleaning
Conventional (Modern) Concrete

- Portland Cement (invented in 1824)
- Quarried aggregate
- Water

- Not always synonymous with innovation

- But most concrete used today uses some form of innovation
More Efficient Concrete Mixtures

• Performance-based Specifications
  – No limitations on materials and quantities

• Qualified Producers
  – NRMCA qualified plants and technicians

• Qualified Laboratories
  – ASTM Qualified testing labs
  – ACI Qualified technicians

• TIP: Guide Spec from www.nrmca.org

• TIP: Register for Specifying Sustainable Concrete webinar www.buildwithstrength.com/education
Admixtures

- **Water reducing**
  - Decreases water demand
  - Decreases cement demand
- **Viscosity Modifying**
  - Improves workability
- **Set accelerating**
  - Can compensate for high SCMs
- **TIP: Permit all admixture types**
  - See guide spec and upcoming webinar
**Blended Cements**

### ASTM C 595

<table>
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<tr>
<th>Cement Type</th>
<th>Description</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Type IL (X)</td>
<td>Portland-Limestone Cement</td>
<td>5% and 15% percent interground limestone</td>
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<tr>
<td>Type IS (X)</td>
<td>Portland-Slag Cement</td>
<td>up to 70% slag cement</td>
</tr>
<tr>
<td>Type IP (X)</td>
<td>Portland-Pozzolan Cement</td>
<td>up to 40% pozzolan. Fly ash is the most common.</td>
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<tr>
<td>Type IT (X)(X)</td>
<td>Ternary Blended Cement</td>
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- (X) identifies the percentage of portland cement replacement

- TIP: Permit ASTM C 595 hydraulic cements
- TIP: Permit ASTM C 1157 hydraulic cements
Supplementary Cementitious Materials

- **Slag Cement**
  - A latent hydraulic material
  - Minimal pozzolanic behavior

- **Pozzolan – fly ash, natural pozzolans, silica fume**
  - Siliceous or siliceous and aluminous material
  - Little or no cementitious value
  - With moisture reacts with calcium hydroxide
  - Fine form
Hydraulic cement

- Cement reacts with water to form cementitious compounds
- Can set and harden under water

\[
\text{Cement + Water} \rightarrow \text{C-S-H + CH}
\]

- the good stuff
- not so good stuff
Hydration and SCMs

Cement + Water $\rightarrow$ C-S-H + CH  

Pozzolan + CH $\rightarrow$ C-S-H  

Slag + Water $\rightarrow$ C-S-H (no CH)  

Slag + CH $\rightarrow$ C-S-H

Hydraulic  
Pozzolanic  
Hydraulic  
Pozzolanic
Case Study: Trump Tower, Chicago

- 92 stories, made entirely out of reinforced concrete
- 194,000 cubic yards of concrete
- Columns and walls required 12,000 psi at 90 days
- Lateral resisting elements up to 16,000 psi
- SCC was specified for many structural elements because of reinforcement congestion
- High volume SCMs to reduce heat of hydration for the mat foundation
- Combination of slag cement, fly ash and silica fume
- Reinforced concrete system helped minimize floor thickness creating higher ceilings
- Open spans up to 30 feet without spandrel beams
- Panoramic vistas of Chicago and Lake Michigan
Fly Ash Beneficiation

- Over 1.5 billion tons of coal ash in landfills
- Some is fly ash
- Several companies have begun to recover fly ash from landfills
- Treat it using a process called beneficiation to meet construction standards
  - Reduce amount of unburned carbon
  - Reduce ammonia
  - Adjust particle size
Case Study: 102 Rivonia Road

- Designed with sustainability in mind
- 50% more sustainable than the average office building
- 4-star Green Star SA (South Africa) rating
- Use of fly ash reduced the overall concrete footprint by 30%
Geopolymer Concrete

- Uses fly ash and/or slag and chemical activators to form hardened binder
- Activators include sodium hydroxide or potassium hydroxide
- Properties similar to portland cement concrete:
  - 3,500 psi or higher at 24 hours
  - 8,000 to 10,000 psi at 28 days
  - Lower drying shrinkage
  - Lower heat of hydration
  - Improved chloride permeability
  - More resistant to acids
  - More fire resistance
Geopolymer Concrete cont’d

- High cost to produce the chemical activator
- Handling a highly alkaline solution
- Need temperature control during the curing process
- Rice University
  - Optimal balance of calcium-rich fly ash, nanosilica and calcium oxide
  - Less than 5% of the traditional sodium-based activator
Case Study: Global Change Institute, Brisbane, Australia

- Australia’s first carbon neutral building
- One of the first Living Building Challenge projects
- First building to include structural geopolymer precast concrete
- Significantly reducing the carbon footprint of construction materials
Carbon Capture

• Carbonation: carbon dioxide (CO$_2$) penetrates the surface of hardened concrete and chemically reacts with cement hydration products to form carbonates

• For in-service concrete, slow process

• Given enough time and ideal conditions
  – all of the CO$_2$ emitted from calcination could be sequestered via carbonation.
  – Real world conditions are usually far from ideal.
• CO₂ uptake are greatest when the surface-to-volume ratio is high
• When concrete has been crushed and exposed to air.
• Article “Substantial Global Carbon Uptake by Cement Carbonation,” Nature Geoscience
  – Estimates cumulative CO₂ sequestered in concrete is 4.5 Gt 1930-2013
  – 43% of the CO₂ emissions from production of cement
  – Carbonation of cement products represents a substantial carbon sink.
Natural Carbonation

• Enhance carbonation at end-of-life and second-life
• Crushed concrete can absorb more CO₂ over short period
• Leave crushed concrete exposed to air for 1-2 years before re-use
Enhanced Carbonation

- Inject CO$_2$ into concrete
- Creates artificial limestone
- Sequesters small amount of CO$_2$
- Enhances compressive strength
- Reduces cement content
725 Ponce, Atlanta

- 360,000 square feet of office space
- 48,000 cubic yards of carbonated concrete
- Concrete sequestered 680 metric tons of CO₂
- The amount of CO₂ absorbed by 800 acres of U.S. forest each year
Enhanced Carbonation

- Specially formulated cement
- Significantly reduces CO$_2$ emissions
- Uses less limestone, fired at lower temperatures
- Produces 30% less greenhouse gases
- Concrete cures in contact with a CO$_2$ atmosphere in curing chamber
- Sequesters CO$_2$ equal to 5% of its weight
- Claims concrete’s carbon footprint is reduced by 70%
**Enhanced Carbonation**

CO₂ treated fly ash (or other SCM)
- Infuse CO₂ under pressure
- Combines to make carbonates
- Increases compressive strength by 32%
  - Reduces cement demand
- Reduces chloride permeability
  - Increased durability
- Eliminates between 50 to 250 kg of CO₂ per metric ton of product
- Does not have any impact on air entrainment
Enhanced Carbonation

- Combine industrial CO₂ emissions with metal oxides
- CO₂ absorbed construction aggregate (limestone)
- 44% by mass permanently eliminated CO₂
- Substrate is small rock particles or recycled concrete
- Carbon-negative concrete is achievable
  - 1 yd³ of concrete contains 3,000 lbs of aggregate
  - Roughly 1,320 lbs of sequestered CO₂
  - Offsets considerably more than the amount of CO₂ generated during cement production (roughly 600 lbs per yd³)
High Performance Concrete

- High strength
- High modulus
- Increased durability
- Increased life
- Reduce steel reinforcing
- Improves performance
Self-Cleaning Concrete

- TiO\textsubscript{2} breaks down harmful pollutants
- Reaction catalyzed by light...photocatalysis
- Nitrous dioxide (NO\textsubscript{2}) produced by burning fuels in cars and trucks.
- Responsible for acid rain, smog, respiratory problems and staining
- Sunlight converts NO\textsubscript{2} to NO\textsubscript{3}
- A harmless salt which is dissolved by water
Case Study: The Jubilee Church, Rome

- Three large concrete shells meant to represent the Holy Trinity.
- Their appearance is an absolute priority.
- Used “self-cleaning” photocatalytic concrete
- Completed in 2003
- The shells have remained clean and white
- Performing constant self-maintenance
Bendable Concrete

- Tiny fibers disbursed throughout
- Applications
  - Paved surfaces with repeated loading of heavy vehicles
  - Viaduct dampers
  - Earthquake resistance in tall buildings
- Self-healing capabilities
  - Keeps cracks relatively small
  - Natural reactions through carbon mineralization
  - Repairs the cracks and restores the durability

- 300-500 times more tensile strain capacity than normal concrete
Ultra High Performance Concrete (UHPC)

- Manufacturer distributes the premix powder, fibers and admixtures to partners
- Can use high carbon metallic fibers, stainless fibers, poly-vinyl alcohol (PVA) fibers or glass fibers
- Improves strength and ductility
- Less porous than conventional concrete
- Resistant to chlorides, acids, and sulfates
- Has self-healing properties
Case Study: Perez Art Museum, Miami

- 200,000 sq ft of indoor and outdoor exhibits
- Built on Biscayne Bay
- Subject to sea air and salt
- Risk of tropical storms and hurricanes
- Bendable/UHPC was used for 100 16-foot-long mullions
- World’s largest impact resistant window
- Concrete mullions are thin, maximizing visibility
- Meets Florida code for hurricane resistance
Fiber Reinforced Concrete

• Fiber reinforced concrete is not new
• Many companies supply fibers
• Improving strength and durability
• Fibers made of steel, glass or plastics
• Plastic fibers are primarily used to combat plastic and drying shrinkage
• Steel fibers are being used in structural applications
• Reduce or eliminate traditional steel reinforcing bars
• Saving time and labor
Case Study: 42 Broad, Fleetwood, New York

- 16-story mixed-use development
- Insulating Concrete Form (ICF)
- Thousands of projects built in the U.S.
- Still considered innovative by many
- ICFs sandwich a reinforced concrete wall between forms made of rigid polystyrene insulation
- Stay in place after the concrete hardens
- 16 stories is tallest ICF in the U.S. (several taller in Canada)
Case Study: 42 Broad, Fleetwood, New York

- Real innovation on this project is panelizing the ICF blocks
- Steel fiber reinforcement
- ICFs assembled off-site
- Custom panels up to 50 feet long
- Labor and time savings
- Owner can occupy the building earlier
- Steel fibers replace the horizontal reinforcing steel
- Eliminates costly horizontal rebar slices
Graphene Concrete

- Graphene is single layer of carbon atoms from Graphite
- Commonly used in pencils and lubricants
- Over 100 times stronger than steel
- Graphene concrete is made with flakes of graphene
- Inexpensive, compatible with large scale manufacturing
- Improves strength and permeability
- Requires less cement to make concrete
Self-Consolidating Concrete

- SCC is highly flowable concrete
- Non-segregating
- Combines high proportion of fine aggregate and admixtures called superplasticizers and viscosity-modifiers
- Can be placed faster than regular concrete
  - Less finishing
  - No mechanical vibration
  - Improves uniformity
  - Smoother surfaces
Case Study: 432 Park Avenue, New York

- Tallest residential structure in the U.S. when completed
- Exposed white concrete columns
- Very thin for its height, 94 feet wide by 1,396 feet high
- Heavily reinforced structural system
- Stiffer concrete with higher compressive strength
- Enhanced durability by minimizing the ratio of water to cementitious materials to as low as 0.25
- Pumpable, self-consolidating, and low heat of hydration
- Maintain appearance of the exposed elements
What’s The Future of Concrete?

- No one single solution...
- Combining technologies
  - Blended cements
  - SCMs
  - Fibers
  - Geopolymers
  - Carbon Capture
- Could sequester more CO$_2$ than is emitted during manufacturing
• Structural system recommendations
• Cost comparisons
• Specification review
• Design/construction team collaboration
www.buildwithstrength.com/education

- Concrete Innovations (On-demand)
- Specifying Sustainable Concrete (On-demand)
- Pathway to Resilience (On-demand)
- Zero Energy Schools (On-demand)
- The Business Case for Building Multifamily Buildings with Concrete (On-demand)
- Life Cycle Assessment of Concrete Buildings (On-demand)
- The Balanced Design Approach to Fire Safety (On-demand)
- The Environmental Impacts of Building Materials (On-demand)
- A New Generation of Tilt-up Buildings (On-demand)
- Achieving Resilience with ICF Construction (On-demand)
- Economical Design of Insulating Concrete Forms (On-demand)
Thank you