Role of Cementitious Materials in the Next Decade

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CESTiCC, RE-CAST and ACI Alaska Chapter Webinar
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9:00-10:00 AM Alaska Time; 12:00-1:00 PM Missouri Time
8:00-9:00 PM Italian Time
Hypotheses

Sustainability will fuel the growth of concrete use worldwide given:

a. binders complementing portland cement
b. additives that transform fresh/hardened properties
c. non-corrosive reinforcement (concrete w/o chloride limits)
d. saltwater and recycled/alternative aggregates

Other technologies (nano-materials, ultra-high performance concrete, self-healing concrete, engineered cementitious composites and 3-D printing) not addressed as impact felt in following decades.
Hypotheses (cont.)

Resilience will fuel the growth of concrete use worldwide given:

a. climate change and population growth exacerbate disastrous event outcomes

b. different approach for how we build and what we build with our homes, schools and commercial structures

c. cement-based materials play a critical role in the repair, rehabilitation and upgrade of the existing building stock (e.g., improve performance of unreinforced masonry) and infrastructure
Outline

- Binders
- Non-corrosive reinforcement
- Saltwater and recycled/alternative aggregates
- Brittle matrix composites for repair
- Conclusions

Item of emphasis
Outline

• Binders
• Non-corrosive reinforcement
• Saltwater and recycled/alternative aggregates
• Brittle matrix composites for repair
• Conclusions
• Concrete plays remarkable socio-economic role in the world
• More than 18B tones of concrete produced every year requiring large amounts of natural resources
• Produced in almost every country because cheap and abundant
Primary objective cut the CO$_2$ content in cement production
No breakthrough technologies foreseen in portland cement manufacturing to significantly reduce thermal energy consumption
Promising research in alternative binders to complement and partially replace portland cement (cement of tomorrow as diverse as society today!)

Some with many years of experience:
- fly ash
- ground granulated blast furnace slag
- silica fume
Others being subject of more recent work:

- **lime-pozzolana cements** combines naturally occurring pozzolanic materials (e.g., volcanic ash) with slaked lime to produce concrete that can hydraulically set. Lime content affects microstructure and performance of the fresh and hardened paste. Disadvantage is slow strength development during room temperature curing (fixed by thermal or chemical activation).

- **limestone calcined clay cements** (LC3) have excellent durability and mechanical properties, but workability issues due to high water demand of the clay.
- **Calcium aluminates cements (CAC)** contain mainly monocalcium aluminate. They offer rapid strength gain, durability to sulfates and resistance to abrasion and alkali-silica reaction. Combination of CAC with supplementary binders and admixtures results in lower costs and eliminates formation of metastable hydrates.

- **Calcium sulfoaluminate (CSA) cements** contain 30–70% C₄A₃S. Produced, used and standardized in China and known for their low CO₂ emissions. Rapid strength gain, ability to bind heavy metals, and high resistance to freeze-thaw and against chemical attack by sulfates, chlorides, magnesium and ammonium salts. Less known is long-term durability.
Binders (cont.)

- **Geopolymers** made by activating with alkaline solutions by-product materials (e.g., fly ash, slag, or metakaolin). Strength, durability and low environmental impact are known. Effects of raw materials on reaction kinetics and reaction product development are not fully understood. Carbonation problematic (no reserve of calcium to provide a pH buffer).

- **Supersulfated cements** comprised of blast furnace slag, calcium sulfate and alkaline activator (often Portland cement). Very low heat of hydration and good durability in chemically aggressive environments. Carbonation problematic when curing is not sufficient. A European standard is now available.
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Non-corrosive reinforcement

Impact of Corrosion

Chloride-induced corrosion occurs in RC and PC structures exposed to seawater or de-icing salts (once steel depassivates, corrosion attack progresses rapidly)

Cost of Corrosion (done in 2002 by NACE)

  - $8,790 Billion
- Annual Cost of Corrosion in Infrastructure
  - $22.6 Billion

Non-corrosive reinforcement (cont.)

Impact of Corrosion: Florida as Example

Transportation- 12% of Florida’s Budget

• Large integrated investment in state bridges.
  ~6,000 bridges.

  1/2 in aggressive marine service.

• ~ $300 million per year spent on bridge construction. Additional yearly costs for maintenance.

• 75-year design life - potential huge cost in life reduction due to corrosion.

• Need to improve design to control corrosion, develop tools to assess future performance to decide on best design and rehab alternatives, and assess need for future maintenance.

Source of slide:
Non-corrosive reinforcement (cont.)

Motivation

• To solve the problem of corrosion of carbon steel reinforcement, we have mainly looked at making concrete better. A more logical answer could be replacing carbon steel with non-corrosive reinforcement where it makes sense.
• Concrete with new binder systems may not offer the alkalinity necessary to passivate carbon steel.
• We need to find a way to replace, at least partially, natural aggregates and fresh water (mixing and curing). Chloride contamination is unavoidable.
Non-corrosive reinforcement (cont.)

To prevent risk of premature degradation of traditional and new concretes non-corrosive reinforcement in the form of composites (fiber reinforced polymer = FRPs) CAN BE adopted.

Technology developed over the last two decades has made available FRPs to replace carbon steel reinforcement when the durability of a structure is of concern.
Fate Bridge Construction and Monitoring

**Motivation**
- Implementation Glass FRP bars
- Less labor due to GFRP light weight
- Serving as an educational test-bed by monitoring

**Instrumentation**
- Vibrating wire strain gauges to monitor concrete, GFRP, and steel behavior

**Concrete Test**
- Cylinders prepared on-site
- Tests performed in the lab

**Monitoring**
- Data acquisition mounted under the bridge
- Load tests scheduled for long-term monitoring under service loads
Innovation Bridge (cont.)
Innovation Bridge (cont.)
SEACON: Sustainable concrete using seawater, salt-contaminated aggregate and non-corrosive reinforcement
Demo in **Citrus County, Florida**

Replace functionally obsolete **Halls River Bridge** to increase capacity and improve safety.

New bridge total length is **56.5 m** consisting of five **11.3 m** simply supported spans (two 3.6-m traffic lanes with 2.4 m outside shoulders, 1.5-m wide sidewalk with standard traffic barrier and bridge pedestrian/bicycle railing on each side).
Halls River Bridge Replacement
Typical FDOT Bridge Components with possible FRP
Super- and sub-structure classified as extremely aggressive due to chloride concentrations in water and close proximity of superstructure to water.

Non-corrosive bars and stirrups address long-term durability of cast-in-place concrete bulkhead caps, pile caps, wing-walls, back-walls, deck and approach slabs.

Provisions being made for collection of samples from the bulkhead cap over time as shown in figure.
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Saltwater and recycled/alternative aggregates

Approximately 1.5 trillion liters of freshwater are used annually in concrete production for mixing, curing and equipment cleaning.

Recycled concrete aggregate (RCA) and recycled asphalt pavement (RAP) are abundant.

Worldwide, construction and demolition wastes make about 30% of total. In the US, annual construction waste ranges from 250 to 300M tons.
Saltwater and recycled/alternative aggregates (Cont.)

Some technical results discussed at SCMT4 in paper: “SEACON: Redefining Sustainable Concrete”

Compressive Strength

- Outdoor
- Seawater
- Tidal zone
- Mix A: benchmark mix
- Mix B: as mix A w/seawater
- Mix C: as Mix B w/RCA

Age (days)

Compressive Strength (Mpa)
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Brittle matrix composites for repair

Fabric Reinforced Cementitious Matrix (FRCM) and Steel Reinforced Grout (SRG)

• Concrete and masonry repair industry a multi-million dollar enterprise
• Externally bonded FRP systems lead strengthening technology conceived and fully deployed in the last three decades
• New strengthening tools based on cementitious matrix are coming of age
• FRCM and SRG consist of a sequence of one or more layers of cement or hydraulic lime matrix reinforced with fabrics in the form of open grids.
• **FRCM**: fabric of strands made of aramid, AR-glass, carbon, basalt or PBO

• **SRG**: fabric of woven cords of twisted micro steel wires (twisting provides an interlocking mechanism with mortar)
Several papers on this topic at SCMT4
Concrete Application
Masonry application
### SRG

The ultra high strength steel fabric (galvanized)

<table>
<thead>
<tr>
<th>Steel wire</th>
<th>SI</th>
<th>US</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength</td>
<td>&gt;2.9 GPa</td>
<td>&gt;420 ksi</td>
</tr>
<tr>
<td>Elastic modulus</td>
<td>&gt;205 GPa</td>
<td>&gt;29.7 msi</td>
</tr>
<tr>
<td>Ultimate strain</td>
<td></td>
<td>&gt;1.4%</td>
</tr>
<tr>
<td>Wire area</td>
<td>0.108 mm$^2$</td>
<td>0.000167 sq.in</td>
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</tbody>
</table>
SRG (cont.)

Concrete application
Masonry application
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Conclusions

• Addressing challenges of sustainability and resilience and transforming them into opportunities makes concrete and its derivatives more ubiquitous

• Concrete benefits from transformational research complementing portland cement with other binders of smaller CO$_2$ footprint

• Advances in supplementary materials and additives chemistry transform fresh properties of concrete (SCC)
Conclusions (Cont.)

• FRP composites as internal reinforcement remove limit in concrete chloride content and open to use of seawater, unwashed offshore aggregates and RCA

• Concrete technology as response to challenges of resilience implies transformation of current construction practices

• Cement-based brittle-matrix strengthening systems can play an important role in the repair and rehabilitation of buildings and civil infrastructure (seismic upgrade of unreinforced masonry)
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