Life cycle assessment of ultra-high performance concrete bridge deck overlays

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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AP</td>
<td>Acidification potential</td>
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<tr>
<td>CC</td>
<td>Conventional concrete</td>
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<tr>
<td>EOL</td>
<td>End-of-life</td>
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<tr>
<td>EP</td>
<td>Eutrophication potential</td>
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<td>GWP</td>
<td>Global warming potential</td>
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<td>HBS</td>
<td>Hypothetical bridge structure</td>
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<td>LCA</td>
<td>Life cycle assessment</td>
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<td>LMC</td>
<td>Latex modified concrete</td>
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<td>ODP</td>
<td>Ozone depletion potential</td>
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<tr>
<td>SCM</td>
<td>Supplementary cementitious materials</td>
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<td>SCP</td>
<td>Smog creation potential</td>
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<td>UHPC</td>
<td>Ultra-high performance concrete</td>
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Problem Statement

• Conventional concrete or asphalt overlays for bridge deck repairs provide limited service life extension.

• More resilient and durable solutions for bridge deck repairs are sought after.

• Sustainability considerations (economic, environmental, social) are important.

• UHPC presents a promising innovative solution.
What is UHPC?

- Cement-based composite
- Optimized gradation of granular constituents
- Discontinuous pore structure
- High volume of discrete steel microfiber reinforcement
- Post-cracking strain capacity and tensile ductility
Ballpark Properties

• High compressive strength (18 ksi +)
• High tensile strength (0.7 ksi +)
• Tensile ductility, post-cracking strain capacity
• Very low permeability (100x < conventional concrete)
• Resistant to freeze-thaw damage
• Strong bond to existing concrete
• Strong bond to reinforcing bars
• Application-tailored rheology
Use as an Overlay
Use on Signature Structures in the U.S.

Commodore Barry Bridge (New Jersey)

Delaware Memorial Bridge (Delaware)

Newport Bridge (Rhode Island)
Study Goal

- Conduct a preliminary LCA on overlays of HBS.
- Evaluate 3 overlay options:
  1. CC – Conventional Concrete
  2. LMC – Latex Modified Concrete
  3. UHPC – Ultra High Performance Concrete
- Account for performance difference and include life-cycle perspective.
- Involve stakeholders and include primary data.
HBS and overlay details

Functional unit:
The overlay applied to the full deck area of the HBS over a service life of 50 years.

Elevation view of bridge structure

Cross-section and travel lanes

a) pre-overlay
b) CC or LMC overlay
c) UHPC overlay
Product system

CC or LMC
- Cement
- Aggregate
- Admixtures
- SCM
- Equipment
- Batch in volumetric trucks
- Transfer to placement site
- Mixing
- Return to stockpile
- Hydromilling
- Waste transfer to landfill
- Placement
- Finishing
- Grinding

UHPC
- Cement
- Aggregate
- Admixtures
- SCM
- Fibers
- Equipment
- Set up mobile mixer
- Charge and mix
- Transfer to placement site
- Return to mixer
- Hydromilling
- Waste transfer to landfill
- Placement
- Finishing
- Grinding

Legend
- System boundary
- Transport

Bridge exits
Service (year 50)

A1
Raw material production

A2
Transport to jobsite

A3 and A4
Mixing and Transport

A5
Construction

B
Use

C
EOL

Deck overlay in-service
Maintenance events neglected

2 reconstruction events

Deck overlay in-service
Maintenance events neglected

Deck overlay in-service
Maintenance events neglected

Maintenance events neglected

Maintenance events neglected
Main drivers of environmental impacts are: cement, steel fibers (UHPC), admixtures (LMC, UHPC).
Main drivers of environmental impacts are hydromilling and slurry containment.
Results: Life Cycle

- Impacts of UHPC overlay are lower after the first cycle.
- Service life extension of UHPC overlay increases environmental benefits.
• Impacts of materials are the highest, followed by construction.
• Reconstruction (CC, LMC) includes 2 repeated cycles of materials, mixing, and construction.
Conclusions

• UHPC overlays can outperform CC and LMC counterparts in terms of environmental impacts after only one life cycle.

• Benefits are more prominent when service-life extensions are considered.

• Relatively high environmental impacts of UHPC overlay can be attributed to cement, steel fibers, and hydromilling activities.

• Future research efforts include:
  • Additional sustainability metrics (LCCA, stochastic LCA)
  • Service-life modeling of chloride ingress
  • Alternative mixture designs
For More Information

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UHPC

FHWA Sustainable Pavements Website:
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