Concrete Recycling in Pavement Applications

Update on the FHWA Concrete Recycling Initiative

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FHWA Concrete Recycling Initiative

• Part of FHWA Sustainable Concrete Pavement Program
  – Program Goals: Encourage innovation and extended application of sustainable pavement technologies on projects

• *Concrete Recycling Initiative* – promote recycling of concrete pavement materials in cost-effective applications while optimizing the triple bottom line (social, environmental, economic)

44 of 50 states allow use of RCA in various applications
(FHWA, 2004 + new info)
Acknowledgments

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• Moon Won, Texas DOT and University of Texas
• Todd Hanson, Iowa Department of Transportation
Overview

• Motivation for concrete recycling
• Use of RCA in pavement applications
  – Lower grade applications
  – Concrete mixtures
• Performance history of selected RCA concrete pavements in service
• Properties of RCA and concrete with RCA
• Recommendations for using RCA
• Sustainability considerations in concrete recycling
• Resources:
  – Available now and coming soon
Reasons for Concrete Recycling

• Dwindling landfill space and increasing disposal costs
  – 50000 U.S. landfills accepting PCC in 1980
  – 5000 U.S. landfills accepting PCC in 2000

• Rapidly increasing demand for aggregates with limited resources

• Sustainability
  – Conservation of materials
  – Potential reduced environmental impact due to reduced construction traffic, reduced landfill
  – Cost savings
  – Potential for improved pavement performance

• A proven technology – it works!
Recycling can save **money**!

- TH 59 near Worthington, MN
- 16-mile two-lane D-cracked PCCP recycled in 1980
  - Coarse RCA for new 8-inch PCCP
  - Fine RCA for 1-in lift on subbase
- Estimated 27% total project cost savings and 150,000 gallons of fuel (MnDOT estimates)

2006 Photo (after 2000 DBR and Grind)
Uses of Recycled Concrete Aggregate in Pavement Applications

- PCC pavement
  - Single and Two-Lift
- HMA pavement
- Subbase
  - Unbound
  - Stabilized
- Fill material
- Filter material
- Drainage layer
Unstabilized Subbases/Backfill

• Most common application for RCA in U.S.
• Application used by 38+ of 44 states using RCA in U.S.
  – Some believe it outperforms virgin aggregate as an unstabilized subbase!
• Some level of contaminants is tolerable.
Cement-stabilized and Lean Concrete Subbases

- Stabilization helps to prevent migration of crusher fines, mitigates high pH runoff

- Physical and mechanical properties of the RCA must be considered in the design and production of cement-stabilized subbases
Concrete Mixtures

• RCA can be (and has been) incorporated as the primary or sole aggregate source in new concrete pavements.

• Used in the U.S. concrete mixtures since the 1940s
  – Roadway surfaces, shoulders, median barriers, sidewalks, curbs and gutters, building/bridge foundations and even structural concrete.

• Common in the lower lift of two-lift concrete pavements in Europe.
RCA in Two-Lift Construction

- **Iowa US 75 Reconstruction (1976)**
  - 60-40 RCA and RAP in 7-in lower lift; 23 ft wide
  - All virgin in 4-in top lift; 24 ft wide
  - Provided **more than 40 years of service!**

- **Austrian Standard Practice since late 1980s**
  - A-1 (Vienna-Salzburg)
  - 19-cm (7.5-in) lower lift (RCA and RAP), 3-cm (1.5-in) upper lift fines to stabilize foundation (**100 percent PCC recycled**)  
  - **Overall project savings >10 percent**

- Using recycled materials, particularly in lower lift, is now standard
Paving with RCA Concrete Mixtures

• Batching, mixing, delivery, placement and finishing techniques can be similar to those used for virgin aggregate concrete mixtures.

• Concerns with water demand and premature stiffening:
  – Limiting or eliminate fine RCA
  – Presoak RCA
  – Chemical and mineral admixtures

• Contaminants can lead to air entrainment problems.

• Fresh and hardened properties of RCA PCC might be different from virgin aggregate PCC.
Performance of Pavements Constructed using RCA

There have been a few notable (and well-publicized) failures ....

• Deterioration of mid-panel cracks in JRCP
• Design issues (undoweled joints, panel length, foundation type, etc.)

.... but performance has generally been very good!
Texas Interstate 10

- 1995 Rehab Project in Houston, Texas
- I-10 between I-45 & Loop 610 West
- Project Length: 9.3 km
- Existing CRCP: 1968 construction
- 10 Lanes + HOV

No Virgin Aggregates Used for New Concrete:

**100% RCA (Coarse & Fine)**
Texas I-10 Pavement Structures

Original

Reconstruct and Unbonded Overlay

- 8” CRCP
- 6” CSB
- 14” CRCP
- 3” ASB
- 6” LTS
- 11” CRCP
- 1” BB
2007 Photo of Texas I-10

<table>
<thead>
<tr>
<th>Property</th>
<th>I-10 RCA concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>28-Day compressive strength</td>
<td>4,615 psi (31.8 MPa)</td>
</tr>
<tr>
<td>28-Day elastic modulus</td>
<td>2.58 x 10^6 psi (17.8 MPa)</td>
</tr>
<tr>
<td>Coefficient of thermal expansion and contraction (CTE)</td>
<td>4.7 to 5.3 με/°F (8.5 to 9.5 με/°C)</td>
</tr>
<tr>
<td>Permeability (ASTM C1202/AASHTO T277)</td>
<td>466 coulombs (very low permeability)</td>
</tr>
</tbody>
</table>
Interstate 80 (Pine Bluffs, Wyoming):

- Extensive alkali-aggregate (ASR) damage
- Much pre-design testing
Interstate 80 (Pine Bluffs, Wyoming):

• 1985: Original 8-in pavement recycled into new 10-in pavement
  • 65% coarse RCA, 22% fine RCA
  • Low-alkali (<0.5%) cement, 30% Class F flyash, w/c = 0.44
  • Skewed joints (14, 16, 13, 12 ft panels)
  • No dowels
  • 4400 ADT in 1985 (30 - 40% heavy)

• Rehabilitated in 2004
  • Dowel bar retrofit, diamond grinding, joint reseal
  • 2006 ADT: 8000 vpd (30-40% heavy)
  • No significant evidence of recurring ASR until recently.

30+ year service life...
Conclusions of 2006 Field Study of RCA Pavements in Service

• Need to treat RCA as “engineered material” and modify mix and structural designs accordingly
  • Reduce w/c
  • ASR mitigation
  • Reduced panel lengths
  • Other modifications as needed

• Mortar contents are generally higher for RCA
  • Varied with aggregate type, crushing process
  • Higher mortar contents often had more distress – may need to control reclaimed mortar content
PROPERTIES OF RCA AND CONCRETE WITH RCA
Production of RCA

• Typical steps:
  – Evaluation of source concrete
    • quality, contaminants
  – Pavement preparation
  – Pavement breaking and removal
  – Removal of embedded steel
  – Crushing and sizing
  – Beneficiation
  – Stockpiling

• Off-site material?
Pavement Breaking and Removal

- Use of front-end loaders and dump trucks for removal and transport to off-site processing (left)

or

- On-site processing using back hoe and mobile crushing equipment (below).
In-Place Concrete Recycling

• When RCA is to be used in a subbase layer of the roadway and/or shoulders, production can be accomplished using an in-place concrete recycling train.

ON-SITE recycling often maximizes cost savings + environmental benefits
## Properties of RCA

<table>
<thead>
<tr>
<th>Property</th>
<th>Virgin Aggregate</th>
<th>RCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape and Texture</td>
<td>Well-rounded; smooth to angular/rough</td>
<td>Angular with rough surface</td>
</tr>
<tr>
<td>Absorption Capacity</td>
<td>0.8% – 3.7%</td>
<td>3.7% – 8.7%</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>2.4 – 2.9</td>
<td>2.1 – 2.4</td>
</tr>
<tr>
<td>L.A Abrasion</td>
<td>15% – 30%</td>
<td>20% – 45%</td>
</tr>
<tr>
<td>Sodium Sulfate</td>
<td>7% – 21%</td>
<td>18% – 59%</td>
</tr>
<tr>
<td>Magnesium Sulfate</td>
<td>4% – 7%</td>
<td>1% – 9%</td>
</tr>
<tr>
<td>Chloride Content</td>
<td>0 – 2 lb/yd³</td>
<td>1 – 12 lb/yd³</td>
</tr>
</tbody>
</table>
Properties of Concrete with RCA
(Hint: it’s all about the mortar ...)

MN 4-1 (Recycled)  MN 4-2 (Control)
# Fresh (Plastic) Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Coarse RCA</th>
<th>Coarse and Fine RCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workability</td>
<td>Similar to slightly lower</td>
<td>Slightly to significantly lower</td>
</tr>
<tr>
<td>Finishability</td>
<td>Similar to more difficult</td>
<td>More difficult</td>
</tr>
<tr>
<td>Water bleeding</td>
<td>Slightly less</td>
<td>Less</td>
</tr>
<tr>
<td>Water demand</td>
<td>Greater</td>
<td>Much greater</td>
</tr>
<tr>
<td>Air content</td>
<td>Slightly higher</td>
<td>Slightly higher</td>
</tr>
</tbody>
</table>
# Hardened Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Coarse RCA</th>
<th>Coarse and Fine RCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength</td>
<td>0% to 24% less</td>
<td>15% to 40% less</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>0% to 10% less</td>
<td>10% to 20% less</td>
</tr>
<tr>
<td>Strength variation</td>
<td>Slightly greater</td>
<td>Slightly greater</td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td>10% to 33% less</td>
<td>25% to 40% less</td>
</tr>
<tr>
<td>CTE</td>
<td>0% to 30% greater</td>
<td>0% to 30% greater</td>
</tr>
<tr>
<td>Drying shrinkage</td>
<td>20% to 50% greater</td>
<td>70% to 100% greater</td>
</tr>
<tr>
<td>Creep</td>
<td>30% to 60% greater</td>
<td>30% to 60% greater</td>
</tr>
<tr>
<td>Permeability</td>
<td>0% to 500% greater</td>
<td>0% to 500% greater</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>0% to 10% lower</td>
<td>5% to 15% lower</td>
</tr>
</tbody>
</table>
# Durability and Other Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Coarse RCA</th>
<th>Coarse and Fine RCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeze-thaw durability</td>
<td>Depends on air voids</td>
<td>Depends on air voids</td>
</tr>
<tr>
<td>Sulfate resistance</td>
<td>Depends on mixture</td>
<td>Depends on mixture</td>
</tr>
<tr>
<td>ASR</td>
<td>Less susceptible</td>
<td>Less susceptible</td>
</tr>
<tr>
<td>Carbonization</td>
<td>Up to 65% greater</td>
<td>Up to 65% greater</td>
</tr>
<tr>
<td>Corrosion rate</td>
<td>May be faster</td>
<td>May be faster</td>
</tr>
</tbody>
</table>
RECOMMENDATIONS FOR USING RCA
RCA Production Considerations

• Consider RCA an “engineered material”; test thoroughly.
• Determine material properties and quality (before recycling, if possible)

• Consider product type/quality requirements
  – Gradation requirements will determine crushing equipment selection
  – Maximize reclamation?
  – Minimize reclaimed mortar?

• Give contractor options for determining the most cost-effective point for recycling
• Stockpile management plan (contamination, moisture)
Recommendations: Pavement Structural Design

- **RCA Subbase:**
  - Consider possible stiffening of RCA subbase
  - Adjust thickness as required

- **RCA Slab:**
  - Consider CTE and shrinkage
    - Adjust panel length
    - Adjust sealant reservoir dimensions and sealant materials
    - Higher reinforcing quantities (CRCP, JRCP)?
  - Reduced aggregate interlock potential
    - Dowels
  - Evaluate abrasion resistance (surface friction and wear)
Recommendations: RCA in Mixture Design

- AASHTO MP16-13 provides guidance

- Consider specific gravity and absorption

- Consider higher strength variability
  - To maintain workability, add 5 – 15% water
  OR
  - Use admixtures (chemical and/or mineral)

- Verify air content requirements (adjust for air in reclaimed mortar)

Trial mixtures are essential
SUSTAINABILITY CONSIDERATIONS IN CONCRETE RECYCLING
Sustainability Benefits

Concrete recycling addresses sustainability “Triple Bottom Line”:

• **Environmental benefits**
  – Conservation of aggregates
  – Reduction of landfill use
  – Reduction of greenhouse gases, sequestration of carbon

• **Economic benefits**
  – Metals recovery
  – Fuel savings due to reduced haul distances
  – Reduced disposal costs
  – Extension of landfill life
  – Potential tax credits, other incentives

• **Societal benefits**
  – Reduced land use and reduced impact to landscape
Quantifying Sustainability Benefits

- **Environmental** and **societal** benefits of concrete recycling are well documented.
- **Economic** benefits are not as readily evident, or can be at equivalent cost.

Decisions made based on initial cost can eliminate options that include recycling.

- **Quantification** of sustainability benefits (particularly **environmental** and **societal**) benefits support choice of recycling.
Quantifying Sustainability Benefits

Measurement tools can be used to quantify sustainability benefits, weigh alternatives and facilitate decision-making.

• **Economic Analysis**
  – Life Cycle Cost Analysis, LCCA

• **Environmental Assessment**
  – Life Cycle Assessment, LCA

• **Rating Systems**
  – INVEST
  – Greenroads
  – Envision
  – Others

Incorporate recycling activities into these tools to quantify sustainability benefits.
Life Cycle Assessment (LCA)

- Lifecycle Assessment (LCA) quantifies impact of a product or process on the environment over the life cycle.
- Level of detail required makes LCA project-specific
- Comparisons are only possible with equivalent bounding assumptions.

NEW from FHWA:

Pavement Life Cycle Assessment Framework
Quantifying Sustainability

• Beltline Highway – Madison, WI
  – 1.5 mile segment reconstructed with variety of recycled materials
  – RCA used in base course or embankment fill
  – 9,870 CY of RCA produced from onsite material, crushed and graded onsite
  – Additional RCA sourced from offsite

• LCCA indicated cost savings of approx. $130,000 at initial construction from use of RCA

• LCA quantified lifetime environmental impact reductions:
  - Energy use (13% reduction)
  - Water consumption (12% reduction)
  - CO₂ emissions (13% reduction)
  - Hazardous waste (9% reduction)
  (Bloom et al. 2016)
Quantifying Sustainability – LCCA and LCA

• Illinois Tollway
  – Move Illinois: 15-year, $12.1B program started 2011
  – Extensive use of recycled materials
  – LCCA used to identify $50M in savings (through 2014) by use of recycled concrete rather than virgin aggregate in pavement bases.
  – Modified version of INVEST rating system developed to adapt to Tollway needs, used to score (and compare) over 15 projects

  – Tools for LCA for pavements developed and are in proof-testing stages (early 2016)
  – Plans to integrate LCA with LCCA software and INVEST rating system

(Gillen et al. 2015 and Gillen and Vavrik 2016)
Environmental Impacts

Recycling is inherently a beneficial practice, but must mitigate potential adverse environmental impacts

- **Water quality**
  - Contaminants in runoff and drainage
  - Alkalinity, chemical contaminants, other
  - Transported sediments

- **Air quality**
  - Equipment emissions
  - Fugitive dust

- **Noise**
  - Additional processing, handling

- **Waste generation and disposition**
  - Solids, wastewater, slurries, residuals

Often identified as key concern by state agencies
CONCRETE RECYLCING RESOURCES:
AVAILABLE NOW AND COMING SOON
ACPA EB043P: Recycling Concrete Pavements

- RCA Production
- Properties and Characteristics of RCA
- Uses of RCA
- Properties of Concrete Containing RCA
- Performance of Concrete Pavements Constructed Using RCA
- Recommendations for Using RCA
- Appendices:
  - Guidelines for Removing and Crushing Existing Concrete Pavement
  - Guidelines for Using RCA in Unstabilized (Granular) Subbases
  - Guidelines for Using RCA in Concrete Paving Mixtures
  - Relevant AASHTO/ASTM Standards
  - Glossary of Terms and Index
CP Tech Center Deployment Plan

A Technology Deployment Plan for the Use of Recycled Concrete Aggregates in Concrete Paving Mixtures

National Concrete Pavement Technology Center

Final Report
June 2011

IOWA STATE UNIVERSITY
Institute for Transportation

Sponsored by
Federal Highway Administration
(through DTFH61-06-H-00011, work plan 27)
National Concrete Pavement Technology Center
Sponsored Research Fund

• Report outlines barriers to implementation (perceptions, lack of experience, risk, etc.) and recommends approaches to overcoming them.

• Also: FHWA Technical Advisory TT 5040.37: Use of Recycled Concrete Pavement as Aggregate in Hydraulic-Cement Concrete Pavement
Resources from the FHWA Concrete Recycling Initiative

WEBINARS

Available Now:

– Introduction to Recycling of Concrete Pavements
  • Offered 5 times during 2016, recorded version available

Coming in 2017:

– Environmental Considerations in Concrete Pavement Recycling
– Construction Considerations in Concrete Pavement Recycling
– Case Study Experiences in Concrete Pavement Recycling
Resources from the FHWA Concrete Recycling Initiative

TECH BRIEFS

Available Now:

– Introduction to Concrete Recycling
– Quantifying the Sustainability Benefits of Concrete Pavement Recycling

Coming Soon:

– Project Selection, Scoping, and Economics
– RCA in Unbound Aggregate Shoulders
– RCA in Concrete Paving Mixtures
– Residual Material Management
– Mitigating Environmental Concerns

WANT THESE RIGHT NOW???

Email me: tcavalline@uncc.edu
Coming soon from the FHWA Concrete Recycling Initiative...

Recycling Concrete Pavement Materials - Practitioner’s Reference Guide

- Economics and Sustainability
- Project Selection and Scoping
- Using RCA in Pavement Base
- Using RCA in Concrete Paving Mixtures
- Using RCA in Unbound Aggregate Shoulders
- Residual Material Management

ACI 555: Concrete with Recycled Materials
ACI 555R-01: Removal and Reuse of Hardened Concrete

Questions?