Concrete Pavement Recycling: Improved Guidance to Support Practitioners

Tara L. Cavalline, PhD, PE
University of North Carolina at Charlotte

Mark B. Snyder, PhD, PE
Pavement Engineering and Research Consultants (PERC), LLC

Peter C. Taylor, PhD, PE
National Concrete Pavement Technology Center
Iowa State University

RCA Increases Pavement Sustainability

- RCA can be used in bound and unbound applications in concrete paving projects
- Increased use of RCA will address several challenges:
  - dwindling landfill space and increased disposal costs
  - increased demand for aggregates
  - reduced availability and longer hauls for virgin aggregates
- Use of RCA reduces environmental impacts due to:
  - conservation of materials
  - reduced emissions associated with production of virgin aggregates and hauling
  - reduced construction traffic
- Use of RCA can reduce project cost and schedule
- RCA can potentially improve pavement performance

Source: Phillip Lamoureux, FHWA Western Federal Lands

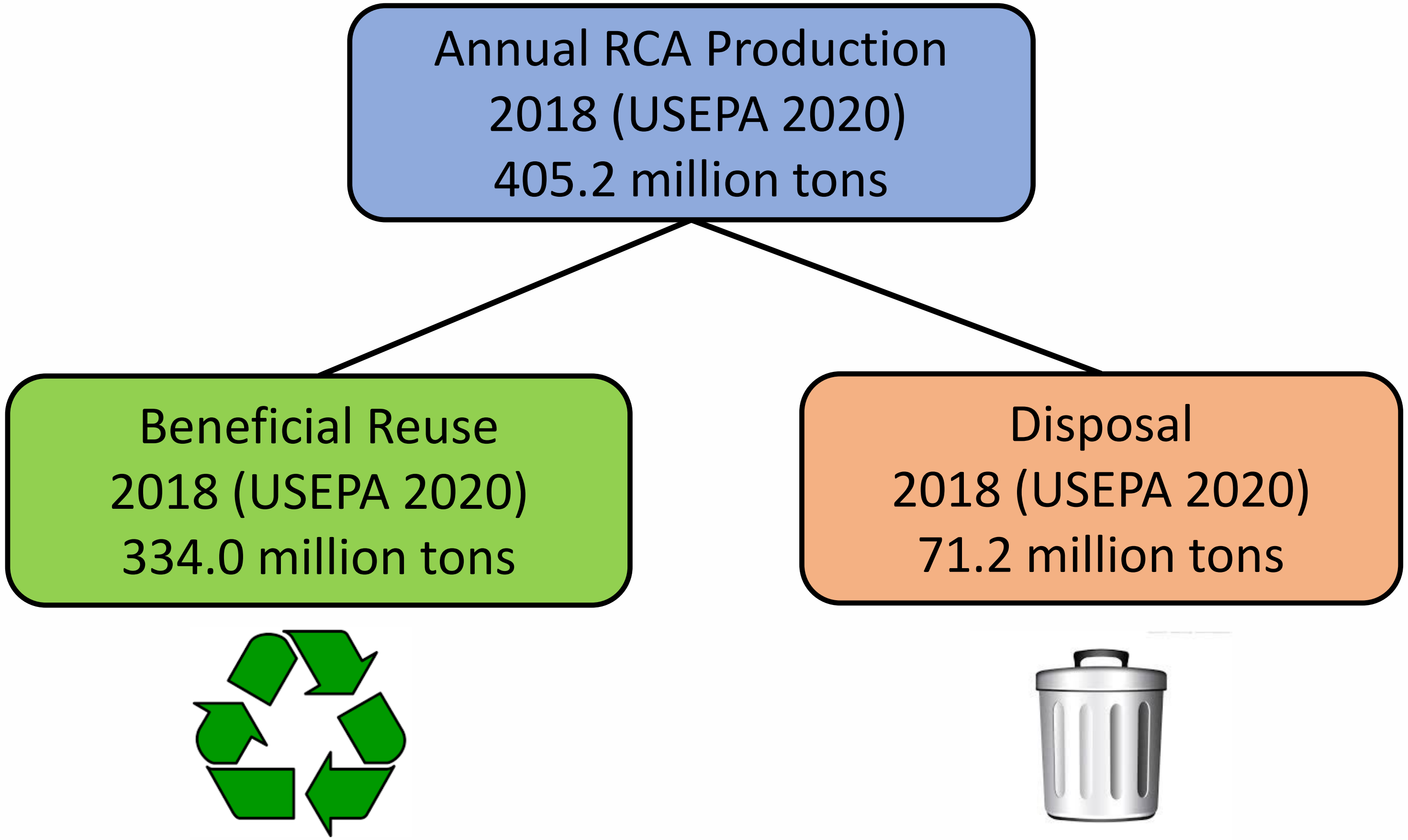
Properties of RCA

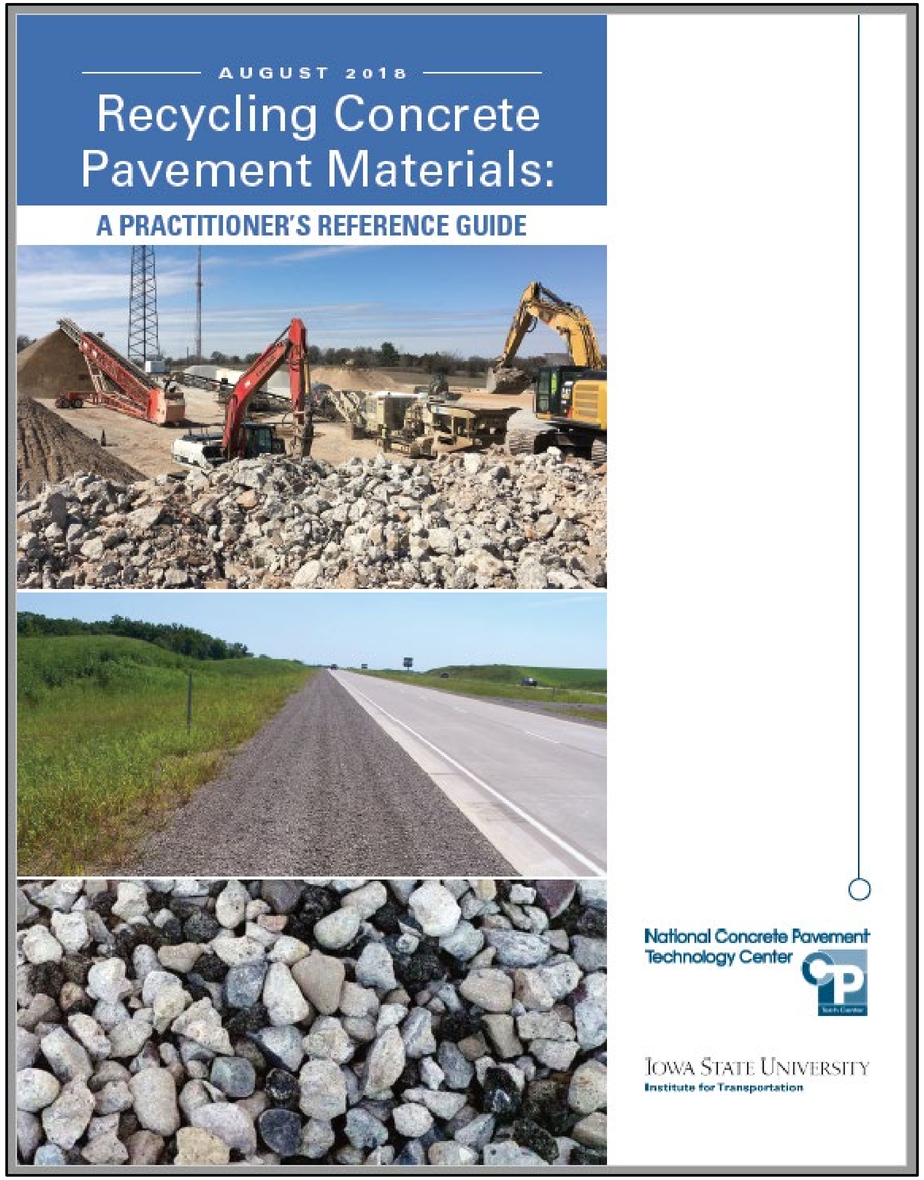
Property	Virgin Aggregate	RCA
Shape and Texture	Well–rounded; smooth to angular/rough	Angular with rough surface
Absorption Capacity	0.8% – 3.7%	3.7% – 8.7%
Specific Gravity	2.4 – 2.9	2.1 – 2.4
L.A Abrasion	15% – 30%	20% – 45%
Sodium Sulfate	7% – 21%	18% – 59%
Magnesium Sulfate	4% – 7%	1% – 9%
Chloride Content	0 – 2 lb/yd^3	1 – 12 lb/yd^3

Source: ACPA EB043P

Uses of Recycled Concrete Aggregate in Pavement Applications

- Concrete pavement
  - Conventional or 2-lift
- Asphalt pavement
- Aggregate shoulder
- Subbase
  - Unbound or stabilized
- Drainage layer
- Filter material
- Fill material





Recycling Concrete Pavement Materials: A Practitioner's Reference Guide (2018)

https://intrans.iastate.edu/app/uploads/2018/09/RCA_practioner_guide_w_cvr.pdf

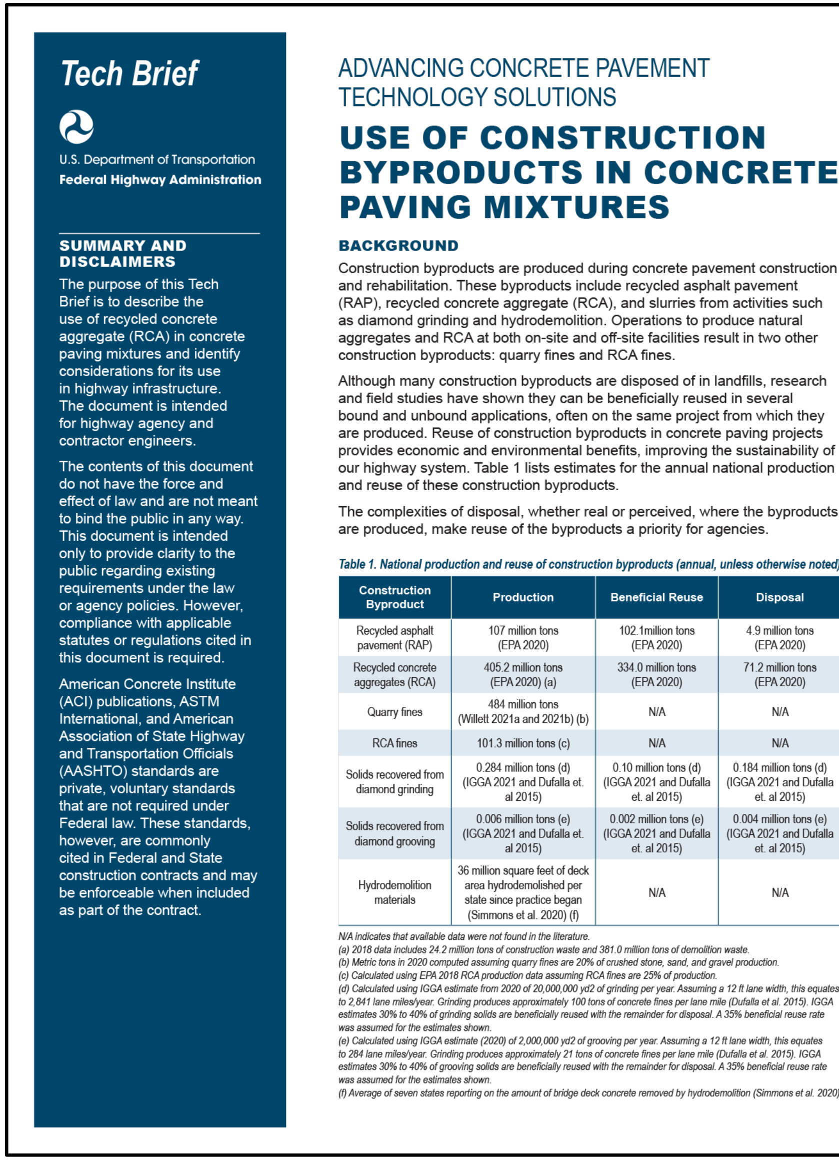
Ch. 1: Introduction to Concrete Pavement Recycling
Ch. 2: Economics and Sustainability
Ch. 3: Project Selection and Scoping
Ch. 4: Using RCA in Pavement Base Products
Ch. 5: Using RCA in Unbound Aggregate Shoulders
Ch. 6: Using RCA in Concrete Paving Mixtures
Ch. 7: Mitigating Environmental Concerns

92 pages of useful technical information,
many case studies, and
up-to-date implementation guidance

Tech Brief - Characterization

- Characteristics of byproducts
- Handling and processing needed for reuse
- Evaluate construction byproducts for reuse in bound and unbound applications
- Potential impacts of reusing each byproduct in specific applications
- Protocol for characterizing and assessing byproducts for reuse
- Qualification-, preconstruction- and construction-phase tests for the byproduct materials and applications (bound/unbound bases, fills, concrete mixtures)

- Describes design and construction considerations and ways to protect the environment



Tech Brief

U.S. Department of Transportation
Federal Highway Administration

SUMMARY AND DISCLAIMERS

The purpose of this Tech Brief is to describe the use of recycled concrete aggregate (RCA) in concrete paving mixtures and identify considerations for its use in highway infrastructure. The document is intended for highway agency and contractor engineers.

The contents of this document do not have the force and effect of law and are not meant to bind the public in any way. This document is intended only to provide clarity to the public regarding existing requirements under the law or agency policies. However, compliance with applicable statutes or regulations cited in this document is required.

American Concrete Institute (ACI) publications, ASTM International, and American Association of State Highway and Transportation Officials (AASHTO) standards are private, voluntary standards that are not required under Federal law. These standards, however, are commonly cited in Federal and State construction contracts and may be enforceable when included as part of the contract.

ADVANCING CONCRETE PAVEMENT TECHNOLOGY SOLUTIONS

USE OF CONSTRUCTION BYPRODUCTS IN CONCRETE PAVING MIXTURES

BACKGROUND

Construction byproducts are produced during concrete pavement construction and rehabilitation. These byproducts include recycled asphalt pavement (RAP), recycled concrete aggregate (RCA), and slurries from activities such as diamond grinding and hydrodemolition. Operations to produce natural aggregates and RCA at both on-site and off-site facilities result in two other construction byproducts: quarry fines and RCA fines.

Although many construction byproducts are disposed of in landfills, research and field studies have shown they can be beneficially reused in several bound and unbound applications, often on the same project from which they are produced. Reuse of construction byproducts in concrete paving projects provides economic and environmental benefits, improving the sustainability of our highway system. Table 1 lists estimates for the annual national production and reuse of these construction byproducts.

The complexities of disposal, whether real or perceived, where the byproducts are produced, make reuse of the byproducts a priority for agencies.

Table 1. National production and reuse of construction byproducts (annual, unless otherwise noted)

Construction Byproduct	Production	Beneficial Reuse	Disposal
Recycled asphalt pavement (RAP)	107 million tons (EPA 2020)	102.1million tons (EPA 2020)	4.9 million tons (EPA 2020)
Recycled concrete aggregates (RCA)	405.2 million tons (EPA 2020) (a)	334.0 million tons (EPA 2020)	71.2 million tons (EPA 2020)
Quarry fines	484 million tons (Willett 2021a and 2021b) (b)	N/A	N/A
RCA fines	101.3 million tons (c)	N/A	N/A
Solids recovered from diamond grinding	0.284 million tons (d) (IGGA 2021 and Dufalla et. al 2015)	0.10 million tons (d) (IGGA 2021 and Dufalla et. al 2015)	0.184 million tons (d) (IGGA 2021 and Dufalla et. al 2015)
Solids recovered from diamond grooving	0.006 million tons (e) (IGGA 2021 and Dufalla et. al 2015)	0.002 million tons (e) (IGGA 2021 and Dufalla et. al 2015)	0.004 million tons (e) (IGGA 2021 and Dufalla et. al 2015)
Hydrodemolition materials	36 million square feet of deck area hydrodemolished per state since practice began (Simmons et al. 2020) (f)	N/A	N/A

N/A indicates that available data were not found in the literature.
(a) 2018 data includes 24.2 million tons of construction waste and 381.0 million tons of demolition waste.
(b) Metric tons in 2020 computed assuming quarry fines are 20% of crushed stone, sand, and gravel production.
(c) Calculated using EPA 2018 RCA production data assuming RCA fines are 25% of production.
(d) Calculated using IGGA estimate from 2020 of 20,000,000 yd2 of grinding per year. Assuming a 12 ft lane width, this equates to 2,841 lane miles/year. Grinding produces approximately 100 tons of concrete fines per lane mile (Dufalla et al. 2015). IGGA estimates 30% to 40% of grinding solids are beneficially reused with the remainder for disposal. A 35% beneficial reuse rate was assumed for the estimates shown.
(e) Calculated using IGGA estimate (2020) of 2,000,000 yd2 of grooving per year. Assuming a 12 ft lane width, this equates to 284 lane miles/year. Grinding produces approximately 21 tons of concrete fines per lane mile (Dufalla et al. 2015). IGGA estimates 30% to 40% of grooving solids are beneficially reused with the remainder for disposal. A 35% beneficial reuse rate was assumed for the estimates shown.
(f) Average of seven states reporting on the amount of bridge deck concrete removed by hydrodemolition (Simmons et al. 2020)

Unstabilized Bases/Backfill

- Most common application for RCA in U.S. (Cackler 2018)
- Application used by 38+ of 44 states using RCA in U.S. (FHWA 2002, Cackler 2018)
  - Some believe it outperforms virgin aggregate as an unstabilized subbase!
- Some level of contaminants is tolerable.

- On-grade recycling reduces time, cost, and hauling impacts (fuel, traffic)

Photo: Gary Fick, Transtec

RCA in Unbound Base Applications

- Performance concerns
  - Structural issues
  - Drainage issues
- Qualification testing
  - General
  - Gradation
  - Other tests (abrasion, soundness, etc.)
- Subbase design and construction considerations
- Concrete pavement design considerations
- Environmental considerations

Photo: Manatt's

Using RCA in Unbound Aggregate Shoulders

- Constructability considerations
  - particle degradation during roll-down
  - moisture-density control
  - other concerns
- Qualification testing
  - gradation
  - absorption
  - LA abrasion/MicroDeval
  - unconfined compression
  - other tests
- Examples and Case Studies

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.

Photos: Andy Naranjo, TxDOT (top), CP Tech Center (bottom)

Fresh Properties of Concrete Containing RCA

Property	Coarse RCA	Coarse and Fine RCA
Workability	Similar to slightly lower	Slightly to significantly lower
Finishability	Similar to more difficult	More difficult
Water bleeding	Slightly less	Less
Water demand	Greater	Much greater
Air content	Slightly higher	Slightly higher

Source: ACPA EB043P

Tech Brief – RCA in Concrete Mixtures

Tech Brief

U.S. Department of Transportation
Federal Highway Administration

ADVANCING CONCRETE PAVEMENT TECHNOLOGY SOLUTIONS

USE OF RECYCLED CONCRETE AGGREGATE IN CONCRETE PAVING MIXTURES

SUMMARY AND DISCLAIMERS

The purpose of this Tech Brief is to describe the use of recycled concrete aggregate (RCA) in concrete paving mixtures and identify considerations for its use in highway infrastructure. The document is intended for highway agency and contractor engineers.

The contents of this document do not have the force and effect of law and are not meant to bind the public in any way. This document is intended only to provide clarity to the public regarding existing requirements under the law or agency policies. However, compliance with applicable statutes or regulations cited in this document is required.

American Concrete Institute (ACI) publications, ASTM International, and American Association of State Highway and Transportation Officials (AASHTO) standards are private, voluntary standards that are not required under Federal law. These standards, however, are commonly cited in Federal and State construction contracts and may be enforceable when included as part of the contract.

INTRODUCTION

Recycled concrete aggregate (RCA) is produced by removing, crushing, and processing hardened concrete. It can be substituted for virgin aggregate in a variety of both bound and unbound uses. Concrete pavement is an excellent source of RCA, because it is generally comprised of high-quality source materials that have previously met state agency specifications.

As virgin aggregate sources and landfill space become limited, use of RCA is becoming increasingly attractive for both environmental and economic reasons (Cackler 2018). While RCA is often utilized in unbound applications, RCA has also been successfully used in new concrete paving mixtures in both laboratory studies and in new pavement construction projects.

Over the past several decades, more than 100 pavement projects have been constructed in the United States using RCA as either a full or partial replacement for coarse aggregate, fine aggregate, or both in concrete paving mixtures (Snyder et al. 1994, Reza and Wilde 2017). Most of these pavements have exhibited satisfactory performance over several decades, and a number of these pavements are still in service today.

In addition, several projects have served to identify limitations with use of RCA and have guided advancements in design and construction processes to improve performance. Overall, when RCA is properly evaluated and considered in mixture design and proportioning, RCA concrete has been found to provide durable performance with accompanying sustainability benefits (Reza and Wilde 2017).

The fundamental principles guiding design and batching of a durable RCA mixture that meets the agency's specifications do not differ from those utilized for conventional concrete mixtures. However, some additional considerations may be needed to ensure suitable performance, and differences in RCA and RCA concrete properties should be considered during the mixture design and development processes. The performance of a pavement should not be compromised when aiming to improve sustainability (FHWA 2007).

This Tech Brief provides information about the effective use of RCA in new concrete mixtures, including characterization of RCA, the expected impacts of RCA on concrete properties and durability performance, and current procedures for proportioning concrete pavement mixtures using RCA. After that, this Tech Brief presents information about pavement design using RCA, along with considerations for RCA production and use. Finally, this Tech Brief briefly describes example projects that illustrate the successful use of RCA in new concrete pavements.

CURRENT USE OF RCA IN CONCRETE MIXTURES

In 2016, a two-part benchmarking survey on the use of RCA was conducted (Cackler 2018). Information regarding the current use of RCA, as well as barriers and challenges to increased use, was solicited from state highway agencies (SHAs) and industry stakeholders. Findings indicated that production of RCA was common on most projects when existing concrete pavement was removed, and opportunities existed to use larger volumes of RCA.

- Updated guidance to build upon 2018 Practitioner's Reference Guide
- Guidance for:
  - Characterizing RCA
  - Influence of RCA on concrete properties
  - Mixture design approaches
  - Production and use considerations
  - Example projects
- https://www.fhwa.dot.gov/pavement/concrete/pubs/hif22020.pd

Influence of RCA on Hardened Properties of Concrete

Property	RCA used as Coarse Aggregate	RCA used as Coarse and Fine Aggregate	Potential Adjustments
Compressive strength	0% to 24% less	15% to 40% less	Reduce w/cm ratio
Tensile strength	0% to 10% less	10% to 20% less	Reduce w/cm ratio
Strength variation	Slightly greater	[illegible]	Increase average strength compared to specified strength
Modulus of elasticity	10% to 33% less	[illegible]	This may be considered a benefit with regard to cracking of slabs on grade
Specific gravity	0% to 10% lower	[illegible]	None recommended
CTE	0% to 30% greater	[illegible]	Reduce panel sizes
Drying shrinkage	20% to 50% greater	[illegible]	Reduce panel sizes
Creep	30% to 60% greater	30% to 60% greater	Typically not an issue in pavement applications
Bond strength	Similar to conventional concrete, or slightly less		None recommended
Permeability	0% to 500% greater	0% to 500% greater	Reduce w/cm ratio

Guidance in text on how to accomplish this, supporting references and studies

Source: Modified from ACPA EB043P

Mixture Design Using RCA

- Qualification testing
  - Agencies report success when ensuring RCA meets same requirements as virgin aggregates
  - Contaminant limits (ACPA 2009):
    - Asphalt concrete: < 1% by volume (although 30% or more ahs been successfully used in lower lift of 2-lift paving applications)
    - Gypsum: < 0.5% by weight
    - Glass: 0%
    - Chlorides 0.6 lb/cy
  - Waive magnesium and sodium sulfate soundness tests since RCA results are unreliable - reaction between cement paste and test solutions

Mixture Proportioning Using RCA

- Proportioning does not differ significantly from procedures from conventional concrete
- ACI 211 and similar approaches have been successfully used for decades
  - Adequate characterization of RCA is key
  - Trial batching and testing is a must
- Lower w/cm is often needed to meet concrete property targets
- Use of SCMs improves performance of RCA concrete by supporting enhanced hydration → helps compensate for relatively weak interfacial transition zone (ITZ) of RCA
- Use of Class F fly ash, slag, or lithium nitrate admixtures should also be used if the potential for ASR exists.

Tips and Tricks for Mixture Proportioning

- Workability
  - Increase the paste content (particularly if fine RCA is to be used in the mixture) while holding w/cm constant (rather than simply increasing water content) (ACPA 2009, ACI 2001)
- Aggregate proportioning
  - Use a combined approach for fine and coarse aggregates
    - Tarantula Curve, Shilstone workability-coarseness chart, or gradation envelope (used by Illinois Tollway)
  - Success generally achieved with 100% coarse aggregate replacement
    - If RCA is susceptible to ASR or D-cracking, reduce replacement rate (Snyder et al. 1994)
  - ACPA (2009) recommends limiting fine aggregate replacement to 30%

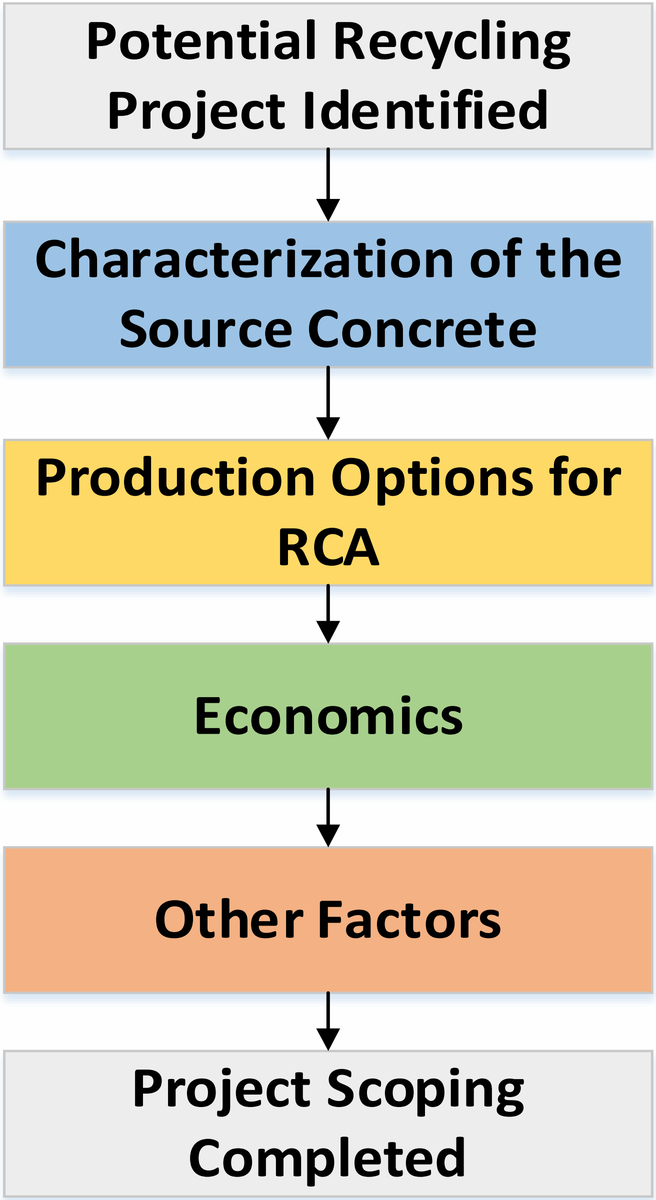
Considerations for Pavement Design Using RCA Concrete

Input Type	Input	RCA used as Coarse Aggregate	RCA used as Coarse and Fine Aggregate	Recommended Test Proto and/or Additional Guidar
PCC	Poisson's ratio	Similar to mixture with virgin aggregates		ASTM C469
	Thickness	Select based on user preferences		
	Unit weight	0% to 10% lower	5% to 15% lower	AASHTO T 121
PCC Thermal	CTE	0% to 30% greater	0% to 30% greater	AASHTO T 336
	Thermal conductivity	0% to 40% lower (Bravo et al. 2017)		ASTM E1952
	Heat capacity	Somewhat higher (Damdelen et al. 2014)		ASTM D2766
PCC Mixture	Aggregate type	Select based on actual or expected aggregate source		
	Cementitious material content	Select based on actual or expected concrete mixture design		
	Cement type	Select based on actual or expected cement source		
	w/cm ratio	Select based on actual or expected concrete mixture design		
	Curing method	Select based on agency recommendations and practices		
	Reversible shrinkage (%)	Estimate using agency historical data or select M-EPDG defaults		
	Time to develop 50% of ultimate shrinkage	Estimate using agency historical data or select M-EPDG defaults		
Strength and Modulus	Elastic modulus	10% to 33% lower than mixture with virgin aggregates	25% to 40% less than mixture with virgin aggregates	ASTM C469
	Flexural strength	Mixture can be designed to meet specified strength with reduced w/cm ratio		AASHTO T 97
	Indirect tensile strength (CRCP only)	Mixture can be designed to meet specified strength with reduced w/cm ratio		AASHTO T 198

Source: Modified from ACPA EB2

Considerations for Pavement Design Using RCA Concrete

- Proper use of RCA in concrete pavements should not adversely impact the performance of the pavement (FHWA 2007)
- Since trial batching is typically not performed prior to design, estimates of RCA concrete material properties should be used in design.
- Lower strength and modulus of elasticity may result in a slightly increased design thickness
- For CRCPs, reinforcement requirements may also change (Snyder et al. 2018)
- Increased shrinkage may result in greater warping stresses and larger joint movements
    - May need shorter panel dimensions or more extensible joint sealants
- Incorporate adequate drainage provisions



Project Selection and Scoping

Structured around a flowchart showing typical project selection and scoping process

- Includes checklist of considerations for use of RCA in different applications
  - Materials considerations ✓
  - Production considerations
  - Other considerations

Practical Considerations

- Availability
  - Project-specific (project-produced byproducts)
  - Proximity to a producer (e.g. quarry, C&D waste recycling facility)
  - Phasing should be considered
    - Immediate need, handling/storage capacity, ways to maximize use
- Consistency
  - Function of quality of the source material, processing/handling techniques
  - Characterization of materials is essential to understand properties and consistency
- Economic factors
  - Difference in cost between using byproduct vs. using virgin material

Project Selection and Scoping

Checklist of considerations for use of RCA in different applications

RCA use	Materials considerations	Production Considerations	Other considerations
New RCA concrete and stabilized base materials Unbound bases and drainage layers Filter material around drainage structures Fill (beneficial reuse of fines) not in pavement structure	• Sources • Specifications	• Processing options • Hauling • Crusher types • Production rates/storage • QA/QC • Residuals management	• Project staging • Costs • Environmental considerations • Permitting • Public perception

! Highly simplified table shown here !
See Reference Guide for all details…

Mitigating Environmental Concerns

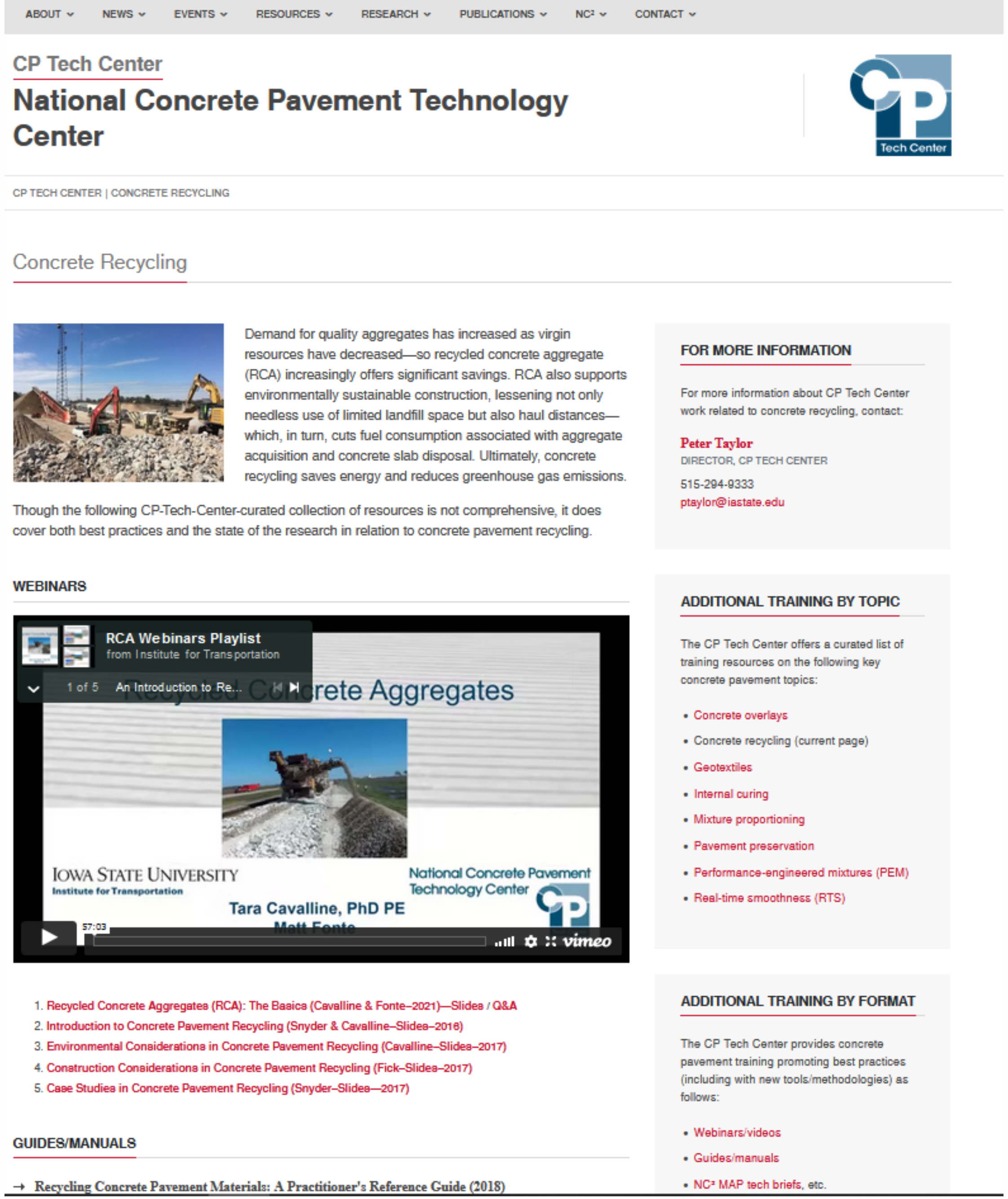
- Legislative and regulatory considerations
- Overview of potential environmental concerns
  - water quality
  - air quality
  - noise/local impacts
  - waste generation

Mitigating environmental concerns <u>during project planning and design</u>

- Focus on water quality issues

Mitigating environmental concerns <u>during construction</u>

- Strategies for mitigating issues on-site


ABOUT NEWS EVENTS RESOURCES RESEARCH PUBLICATIONS NC² CONTACT

CP Tech Center

National Concrete Pavement Technology Center

CP TECH CENTER | CONCRETE RECYCLING

Concrete Recycling

Demand for quality aggregates has increased as virgin resources have decreased—so recycled concrete aggregate (RCA) increasingly offers significant savings. RCA also supports environmentally sustainable construction, lessening not only needless use of limited landfill space but also haul distances—which, in turn, cuts fuel consumption associated with aggregate acquisition and concrete slab disposal. Ultimately, concrete recycling saves energy and reduces greenhouse gas emissions.

Though the following CP-Tech-Center-curated collection of resources is not comprehensive, it does cover both best practices and the state of the research in relation to concrete pavement recycling.

WEBINARS

RCA Webinars Playlist
from Institute for Transportation
1 of 5 An Introduction to Re...
Recycled Concrete Aggregates
IOWA STATE UNIVERSITY
Institute for Transportation
National Concrete Pavement Technology Center
Tara Cavalline, PhD PE
Matt Fonte
57:03
vimeo

1. Recycled Concrete Aggregates (RCA): The Basics (Cavalline & Fonte–2021)—Slides / Q&A
2. Introduction to Concrete Pavement Recycling (Snyder & Cavalline–Slides–2018)
3. Environmental Considerations in Concrete Pavement Recycling (Cavalline–Slides–2017)
4. Construction Considerations in Concrete Pavement Recycling (Fick–Slides–2017)
5. Case Studies in Concrete Pavement Recycling (Snyder–Slides—2017)

GUIDES/MANUALS

→ Recycling Concrete Pavement Materials: A Practitioner's Reference Guide (2018)

FOR MORE INFORMATION

For more information about CP Tech Center work related to concrete recycling, contact:

Peter Taylor
DIRECTOR, CP TECH CENTER
515-294-9333
ptaylor@iastate.edu

ADDITIONAL TRAINING BY TOPIC

The CP Tech Center offers a curated list of training resources on the following key concrete pavement topics:

- Concrete overlays
- Concrete recycling (current page)
- Geotextiles
- Internal curing
- Mixture proportioning
- Pavement preservation
- Performance-engineered mixtures (PEM)
- Real-time smoothness (RTS)

ADDITIONAL TRAINING BY FORMAT

The CP Tech Center provides concrete pavement training promoting best practices (including with new tools/methodologies) as follows:

- Webinars/videos
- Guides/manuals
- NC² MAP tech briefs, etc.

Resources

- CP Tech Center has a concrete recycling website with links to many resources
- https://cptechcenter.org/concrete-recycling/

Use of RCA in Interstate Concrete Shoulders

- Georgia DOT I-16 project – 56 miles
- Truck lane replacement plus new inside and outside shoulder construction
- Existing 10-inch slab crushed at nearby stationary facility
- Trial batches used 100% RCA as fine and coarse aggregate but were too sticky
- Final mixture blended some natural sand to improve workability

- Final mixture 81.1% RCA and 18.9% natural sand
- Approach allowed recycling of 100% of removed concrete
- GDOT gained confidence in use of RCA for shoulders

Source: Georgene Geary, GG

Use of RCA in Lean Concrete Bases

- Caltrans I-710 project in Los Angeles
- Rehabilitation of 3.5-mile stretch with 5 lanes in each direction
- Existing JPCP removed and mostly replaced with rapid strength JPCP
  - 700-foot section of rapid-strength CRCP constructed, weekend closure schedule
- Existing pavement crushed and combined with existing aggregate base
  - 75-80% RCA plus 20-25% original aggregate base

- This blend was used as 100% of the coarse and fine aggregate in the new lean concrete base mixture
- Also used in new permeable base

Use of RCA in Lean Concrete Bases

- Use of all old pavement resulted in a "Zero Concrete Waste" project
- Completed in 2020
- Constructed over 55 hours of extended weekend closures
- Demonstrated that RCA mixtures can be used in projects with short time frames

Source: Caltrans

Use of RCA in Concrete Pavement

- Colorado State Highway 470 (C-470) – SW portion of Denver's beltway
- 100,000 vehicles per day expected to increase 40% by 2035
- 12.5 miles – addition of 3 express lanes + full reconstruction of existing pavement
- All existing pavement removed used to produce RCA on-site
- 86,000 tons of 1½-inch nominal max coarse RCA used in concrete mixture for 926,000 SY of pavement

Source: Castle Rock Construction Company

Use of RCA in Concrete Pavement

- Coarse RCA used as 38% replacement for natural aggregate
- Other RCA used in unbound base for the pavement
- Benefits
  - Cost savings to owner on price of material
  - Reduced hauling of existing material off-site and hauling new material on-site
- Contractor's experience:
  - Make sure material is prewetted before adding to the mixer
  - Log washers have been successfully used to prewet RCA prior to mixing

Acknowledgments

- Tom Cackler – Woodland Consulting, Inc.
- Gary Fick – Transtec
- Dale Harrington – Snyder & Associates
- Georgene Geary – GGfGA
- Jiong Hu and Miras Mamirov – University of Nebraska-Lincoln

- American Concrete Pavement Association
- Federal Highway Administration
- Caltrans – Dulce Rufino Feldman
- Castle Rock Construction – Amy Brooks and Matt Fonte
- Flatiron – Michael Roe
- Southwest ACPA – Charles Stewart

References

- ACPA. (2007) Subgrades and Subbases for Concrete Pavements. Engineering Bulletin EP204P. American Concrete Pavement Association, Skokie, IL.
- ACPA. (2009). Recycling Concrete Pavements. Engineering Bulletin EB043. American Concrete Pavement Association, Skokie, IL.
- Cackler, T. (2018). Recycled Concrete Aggregate Usage in the US. National Concrete Pavement Technology Center. Ames, IA.
- FHWA. (2002). Formal Policy on the Use of Recycled Materials. Federal Highway Administration, Washington, DC. https://www.fhwa.dot.gov/legsregs/directives/policy/recmatmemo.htm