Recycled Concrete Aggregates:
Current Practice, Implementation Challenges and New Guidance

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Fostering a Circular Economy and
Carbon Sequestration for Construction Materials
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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 provides reduced 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 improved pavement performance

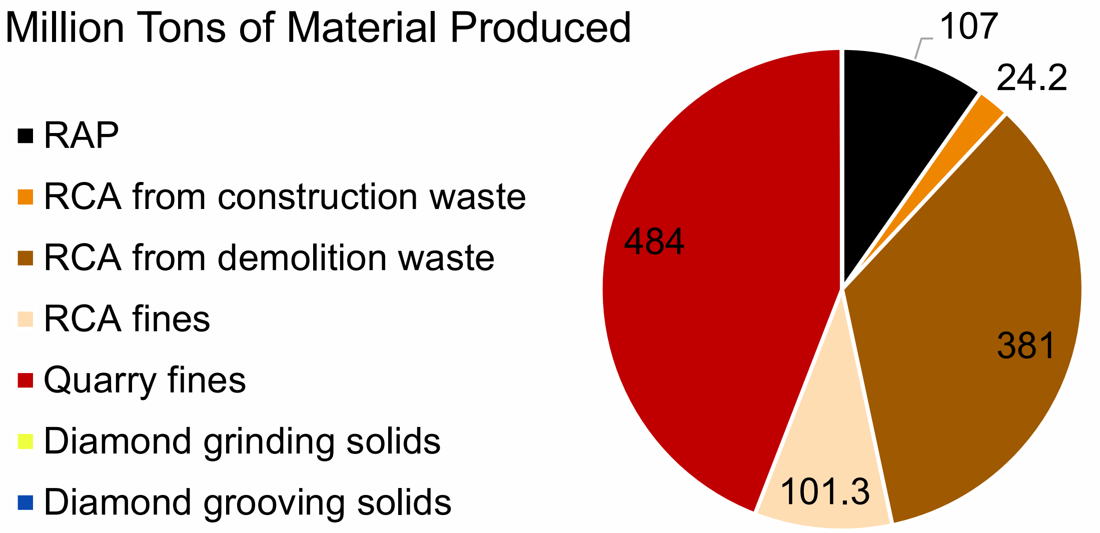
Source: Phillip Lamoureux,
FHWA Western Federal Lands

Production and Reuse of RCA

National production and reuse (annual, unless noted)

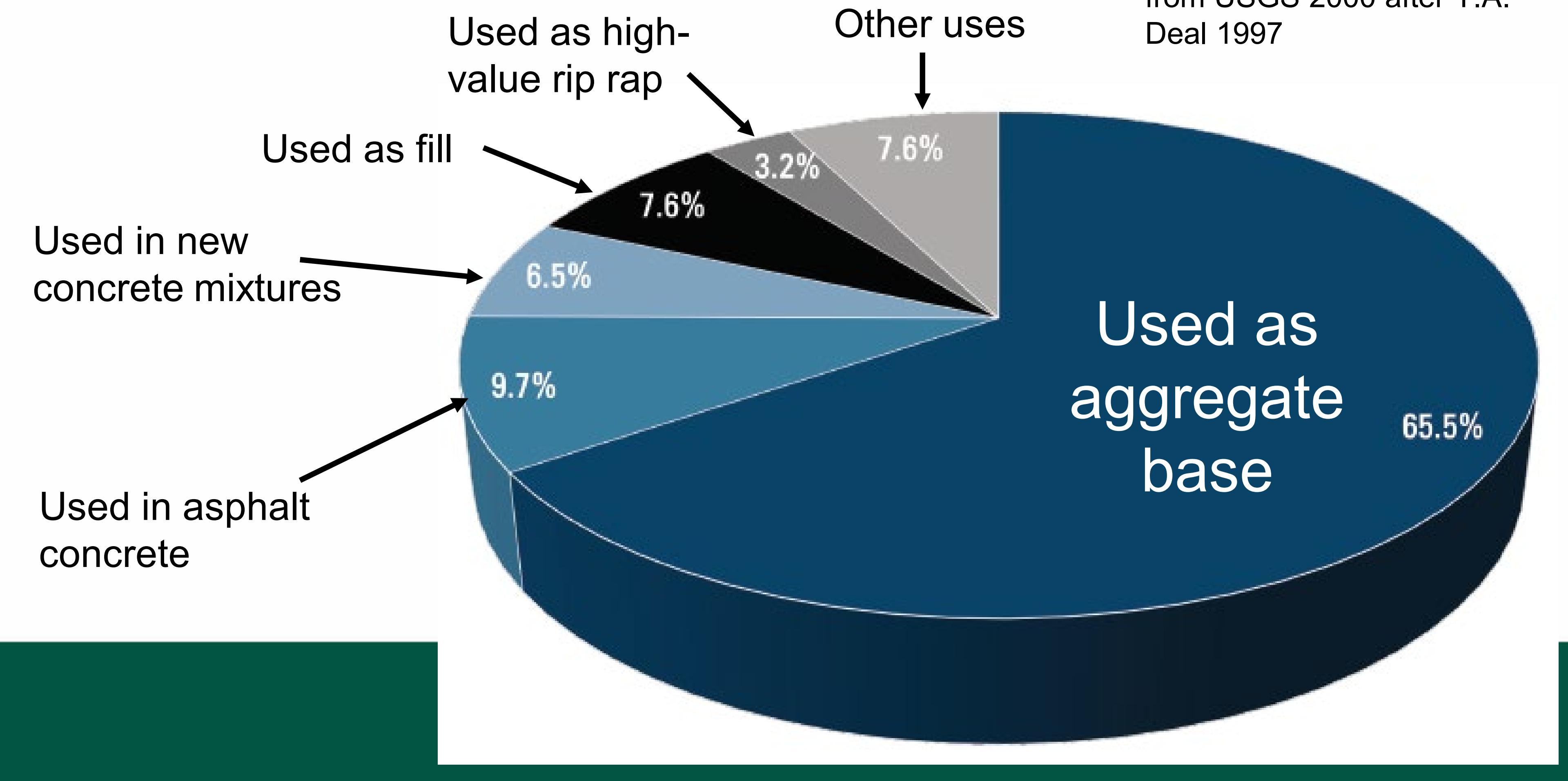
Construction Byproduct	Production	Beneficial Reuse	Disposal
Recycled asphalt pavement (RAP)	107 million tons	102.1 million tons	4.9 million tons
	(EPA 2020)		
Recycled concrete aggregates (RCA)	405.2 million tons 24.2 (6%) – construction waste 381.0 (94%) – demolition waste	334.0 million tons	71.2 million tons
	(EPA 2020)		
Quarry fines	484 million tons	N/A	N/A
	(Willet 2021a and 2021b)		
RCA fines	101.3 million tons	N/A	N/A
	(EPA 2018 data @ 25% fines production estimate)		
Solids recovered from diamond grinding	0.284 million tons	0.10 million tons	0.184 million tons
	(IGGA 2021 and Dufalla et al. 2015, IGGA 2020 annual grinding estimate @ 100 tons fines/lane mi with 35% beneficial reuse rate)		
Solids recovered from diamond grooving	0.006 million tons	0.002 million tons	0.004 million tons
	(IGGA 2021 and Dufalla et al. 2015)		
Hydrodemolition materials	36 million square feet of deck area hydrodemolished per state since practices began	N/A	N/A
	(Simmons et al. 2020)		

National production and reuse



End uses for crushed concrete

After Van Dam et al. 2015, from USGS 2000 after T.A. Deal 1997



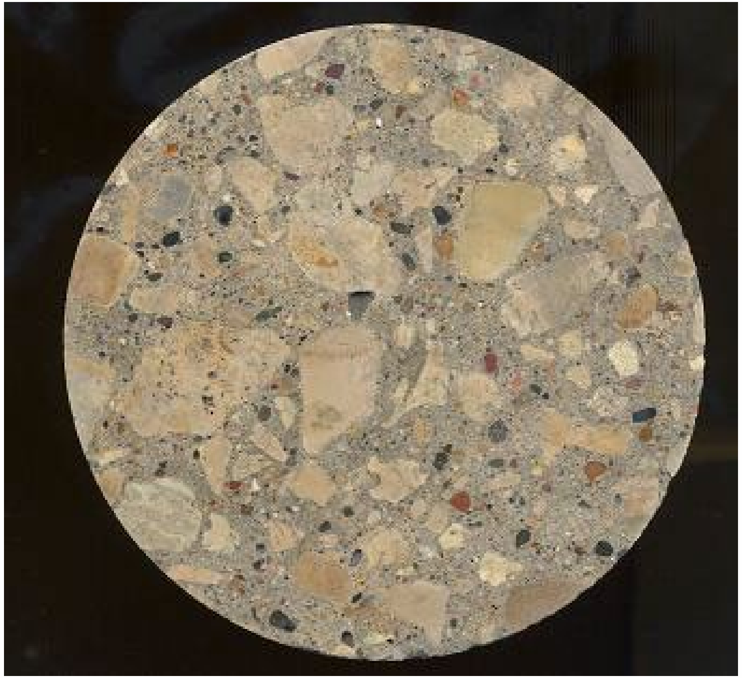
Characteristics of RCA and RCA Concrete

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

Properties of Concrete with RCA

MN 4-1 (Recycled)



MN 4-2 (Control)

Photos from Mark Snyder, PERC

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

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	Slightly greater	Increase average strength compared to specified strength
Modulus of elasticity	10% to 33% less	25% to 40% less	This may be considered a benefit with regard to cracking of slabs on grade
Specific gravity	0% to 10% lower	5% to 15% lower	None recommended
CTE	0% to 30% greater	0% to 30% greater	Reduce panel sizes
Drying shrinkage	20% to 50% greater	70% to 100% greater	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

Bound and Unbound Uses of RCA

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.

Photo: Gary Fick, Transtec

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

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

Use of RCA in Lean Concrete Bases

- Caltrans - 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 timeframes

Source: Caltrans

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)

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)
  - <u>Overall project savings >10 percent</u>

  - Using recycled materials, particularly in lower lift, is now standard

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

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

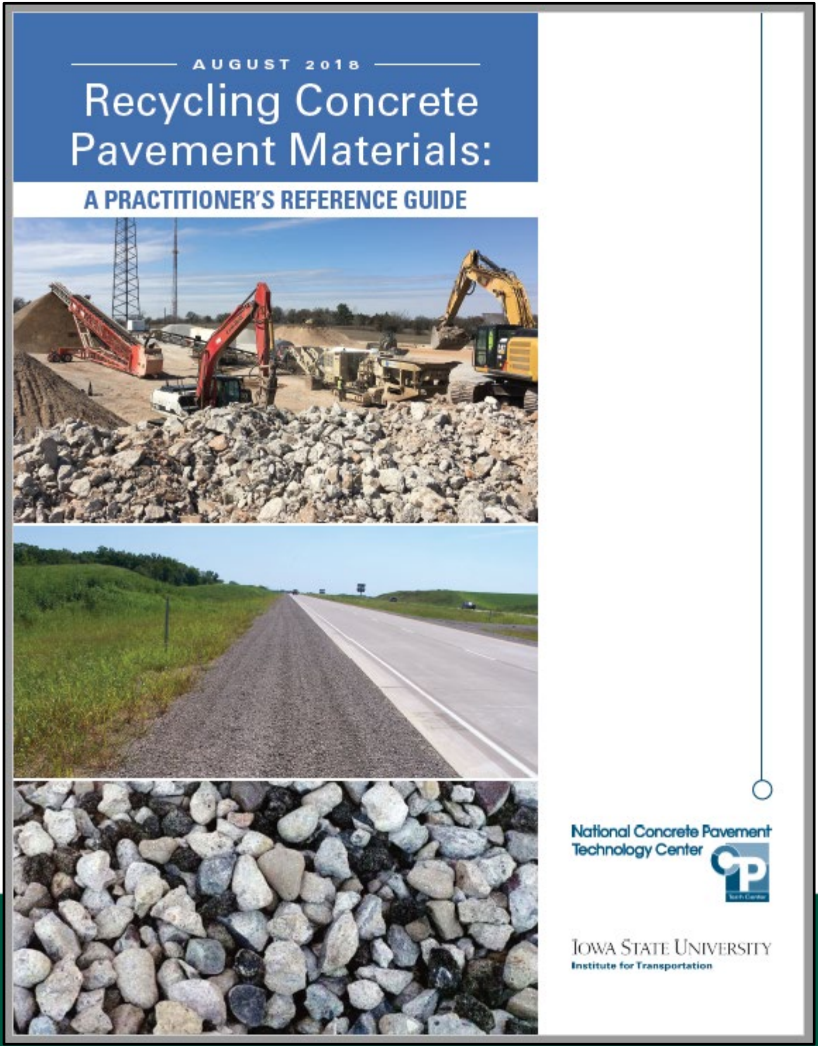
- Mortar contents are generally higher for RCA
  - Varied with aggregate type, crushing process
  - Higher mortar contents often had more distress – may need to control reclaimed mortar content

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.*

User must understand the RCA that will be used…. Characterization is key!

Guidance for Use of RCA



Guidance on Use of RCA prepared as part of Concrete Recycling Initiative (2018)

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: Use of RCA in Concrete Paving Mixtures

- Prepared as part of FHWA Cooperative Agreement with CP Tech Center
- 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

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.

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ADVANCING CONCRETE PAVEMENT TECHNOLOGY SOLUTIONS

USE OF RECYCLED CONCRETE AGGREGATE IN CONCRETE PAVING MIXTURES

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.

Tech Brief

- Characteristics of byproducts
- Provides information on handling and processing needed for reuse
- Recommends how to evaluate construction byproducts for reuse in bound and unbound applications
- Describes potential impacts of reusing each byproduct in specific applications
- Presents a protocol for characterizing and assessing byproducts for reuse
- Provides recommendations for 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

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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.

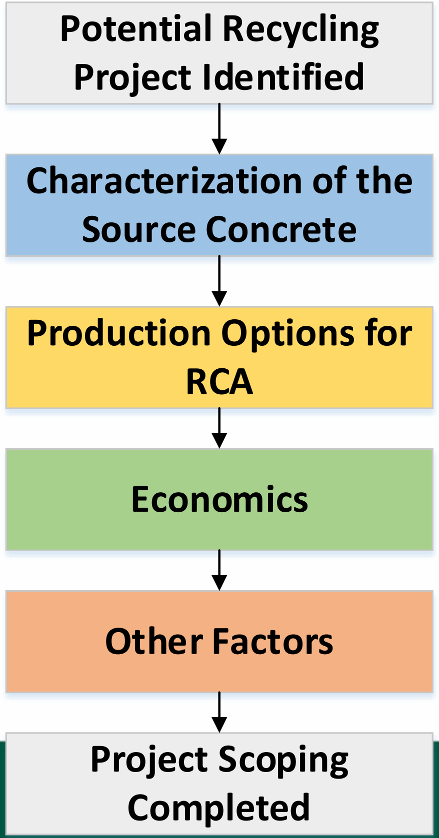
Table 1. National production and reuse of construction byproducts (annual, unless otherwise noted)

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).

Planning, Scoping,
and Construction Considerations

Project Selection and Scoping



Structured around a <u>flowchart</u> showing typical project selection and scoping process

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

Project Selection and Scoping

Checklist of considerations for use of RCA in different applications

<table>
<tr><th>RCA use</th><th>Materials considerations</th><th>Production Considerations</th><th>Other considerations</th></tr>
<tr><td>New RCA concrete and stabilized base materials</td><td rowspan="4">Sources
Specifications</td><td rowspan="4">Processing options
Hauling
Crusher types
Production rates/storage
QA/QC
Residuals management</td><td rowspan="4">Project staging
Costs
Environmental considerations
Permitting
Public perception</td></tr>
<tr><td>Unbound bases and drainage layers</td></tr>
<tr><td>Filter material around drainage structures</td></tr>
<tr><td>Fill (beneficial reuse of fines) not in pavement structure</td></tr>
</table>

! 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

Photo: Dwayne Stenlund, MnDOT

Mitigating environmental concerns during project planning and design

- Focus on water quality issues

Mitigating environmental concerns during construction

- Strategies for mitigating issues on-site

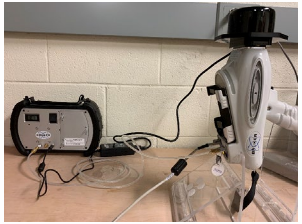
Evaluation for Use

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

Recent Advancements in RCA Characterization

- ACI CRC 2019 P0027:
  Effective Characterization of RCA for Concrete Applications
  (PI – Jiong Hu, UNL, Co-PI Tara Cavalline, UNC Charlotte)
- Improved existing tests and developed new tests:
  - Modified residual mortar content (RMC) test
    - improved thermal shock method
  - Modified Aggregate crushing value (ACV) test
    - strength characterization
  - Aggregate freeze-thaw test
    - able to differentiate the air-entrainment level of parent concrete
  - Portable handheld XRF
    - can be used for chemical characterization and residual mortar determination



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.

Recent Developments in RCA Mixture Proportioning

- **NJIT Method** (Adams and Jayasuriya 2019)
  - Statistical study using data from more than 100 peer-reviewed studies of RCA concrete
  - Linked RCA properties and mixture characteristics to RCA concrete mechanical properties (compressive/flexural strength, elastic modulus)
  - Developed a new RCA concrete mixture design procedure based on models developed as part of this study, along with recommendations from ACI 302.

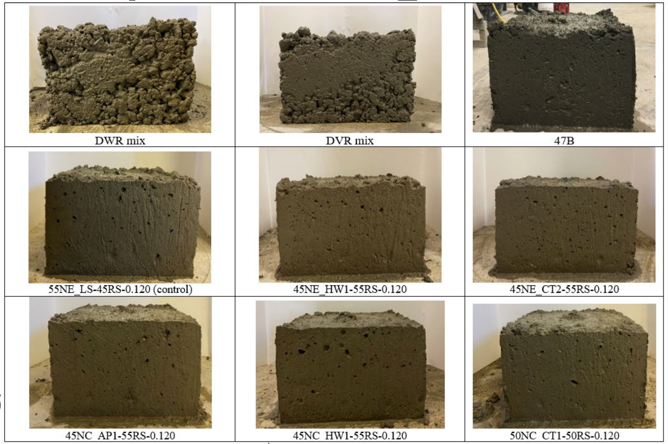
New Jersey Institute of Technology

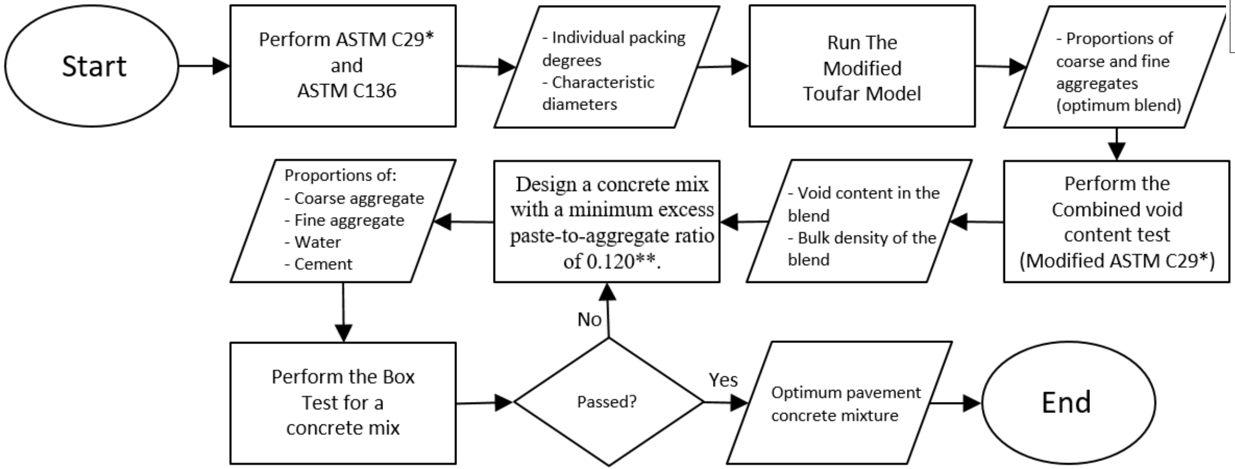
Overview of NJIT
RCA Mixture Proportioning Method

- Step 1 – Approximate effective w/cm ratio
- Step 2 – Approximate RCA replacement level
- Step 3 – Determine aggregate-to-cement ratio
- Step 4 – Finalize material ratios
- Step 5 – Select aggregate size
- Step 6 – Select minimum requirements for cement contents
- Step 7 – Determine mixture proportions for concrete materials

Recent Developments in RCA Mixture Proportioning

- UN-L Method
  - Mamirov 2021, and Hu et al. 2022
  - Based on particle packing and excess paste theory
  - ACI CRC Project 2019 P0027: Effective Characterization of RCA for Concrete Applications





*- the test is performed by means of the vibration plus pressure compaction method

**- increase the excess paste-to-aggregate ratio after each failure of the mix to pass the Box Test (if needed)

UNIVERSITY OF Nebraska Lincoln

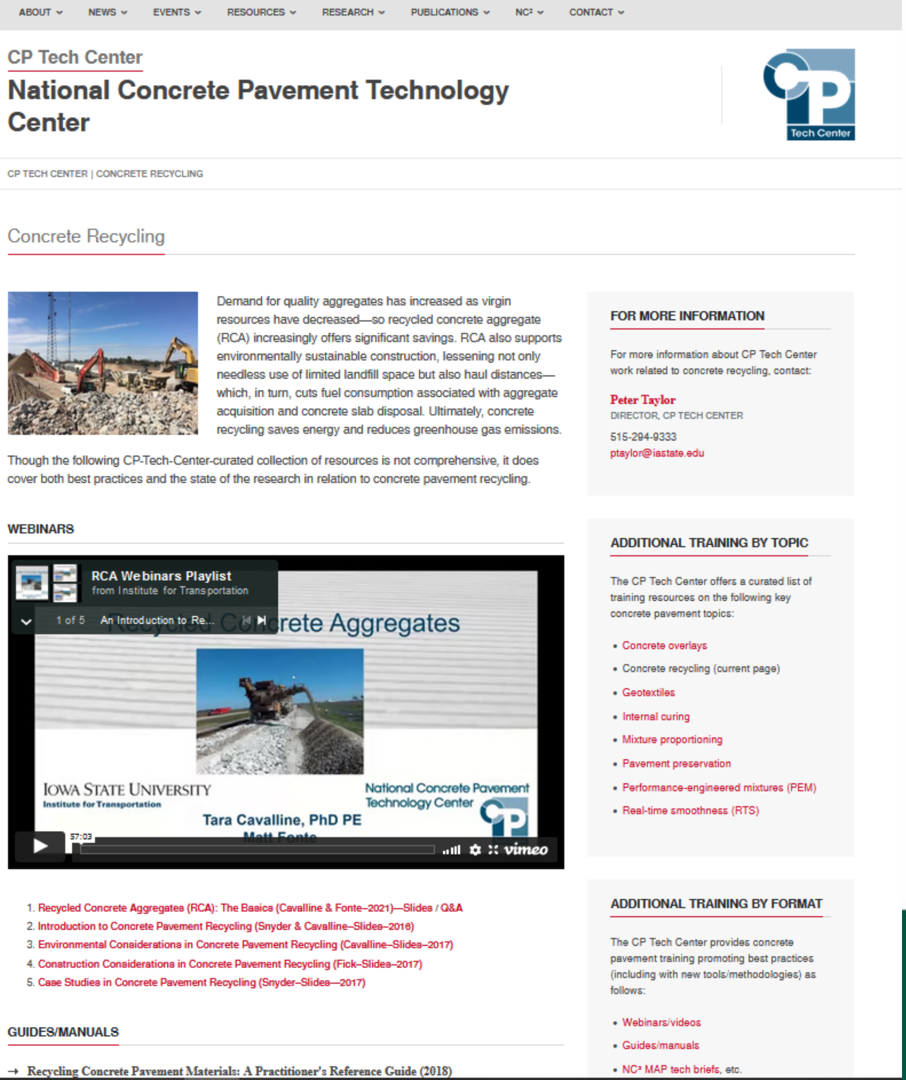
UNIVERSITY OF NORTH CAROLINA CHARLOTTE | THE WILLIAM STATES LEE COLLEGE OF ENGINEERING

Considerations for Pavement Design Using RCA Concrete

Input Type	Input	RCA used as Coarse Aggregate	RCA used as Coarse and Fine Aggregate	Recommended Test Protocol and/or Additional Guidance
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

Resources

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



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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

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:

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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.

Acknowledgements

- Peter Taylor – Director, CP Tech Center at Iowa State University
- Mark Snyder – PERC
- Gary Fick - Transtec
- Jiong Hu and Miras Mamirov – University of Nebraska-Lincoln
- Arindam Dey – UNC Charlotte
- Castle Rock Construction – Amy Brooks and Matt Fonte
- Georgene Geary – GGfGA
- Caltrans – Dulce Rufino Feldman
- Flatiron – Michael Roe
- Southwest ACPA – Charles Stewart

Extra slides

Using RCA in Pavement Base Products

Unbound aggregate 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

Bound (stabilized) base applications

- Lean concrete subbase and cement-stabilized subbase
- Asphalt concrete and asphalt-stabilized subbase

Includes example projects for each application

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

Using RCA in Paving Mixtures

- Constructability considerations
    - Fresh properties

- Pavement design considerations
    - Hardened properties

- Developing concrete mixture designs using RCA
    - Qualification Testing
    - Proportioning

- Examples and Case Studies
    - D-cracking aggregate
    - ASR
    - Continuously reinforced concrete pavement

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

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

Source: Castle Rock Construction Company

Log Washer

Developed in 1890s –
Used in the mining industry to remove clay from gravel, ores, crushed stone to improve the quality of the material feed

Source: Matt Fonte, Castle Rock Construction Company

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, GGfGA

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

Source: Caltrans

- 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

Factors to consider when comparing costs

Cost of the Virgin Material	Cost of the Construction Byproduct
• Material costs (either virgin aggregate or binder) • Cost to haul to site • Cost to place and compact (for unbound uses) • Cost to handle/store/manage (for bound uses) • Cost to haul away existing or unsuitable materials • Cost of existing or unsuitable material disposal	• Cost to take material to a crushing facility (if produced on site) • Cost of hauling material to the site (if produced off site) • Cost of blending material and hauling (if applicable) • Cost of crushing and screening a material produced on site (if applicable) • Cost of placement and compaction of the material (for unbound uses)

- Production costs for lower-grade applications (unbound base/fill) may be lower than production costs for higher-grade applications (bound bases/new concrete)
- Key to cost savings:
    - Consider use of byproducts early in project bidding or delivery phases
        - Challenges can be addressed/cost savings potentially passed on
    - Allow contractor flexibility in establishing operations

Flowchart! Characterization and Assessment for Use

Recommended Tests for Qualification/Preconstruction Stage

Tests of Byproduct Material

Byproduct used as Aggregate

Tests to Support Use in Base or Fill

- ❑ Gradation (AASHTO T 27)
- ❑ Contaminants (visual, or per AASHTO M 319)
- ❑ Uniformity should be evaluated by reviewing the variability of the characterization test results. The agency should determine the sampling frequency and allowable variability that provides confidence in the uniformity.
- ❑ Optimum moisture and maximum dry density (AASHTO T 134)

Tests to Support Use in Concrete

- ❑ Gradation (AASHTO T 27)
- ❑ Contaminants (visual, or per AASHTO M 319)
- ❑ Uniformity should be evaluated by reviewing the variability of the characterization test results. The agency should determine the sampling frequency and allowable variability that provides confidence in the uniformity.

Byproduct used as SCM

Tests to Support Use in Base or Fill

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Tests to Support Use in Concrete

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Flowchart! Characterization and Assessment for Use

Recommended Tests for Qualification/Preconstruction Stage

Tests of Application Containing Byproduct Material

Byproduct used as Aggregate

Tests to Support Use in Base or Fill

- ❑ Resilient modulus (AASHTO T 307)
- ❑ Shear strength (static triaxial and repeated triaxial loading, at optimal moisture content and saturated conditions)

Tests to Support Use in Concrete

- ❑ Assess the potential for Alkali-Aggregate Reactivity using AASHTO R 80
- ❑ Assess the susceptibility of the material to D-cracking using ASTM C666 (only if by-product material was not previously assessed using AASHTO T 103 or the hydraulic fracture test).

Byproduct used as SCM

Tests to Support Use in Base or Fill

- ❑ Compressive strength (ASTM C593 and/or D1632)
- ❑ Freeze-thaw durability (ASTM C593 and/or D560)
- ❑ Maximum dry density and optimum moisture content (ASTM D698 or D1557)
- ❑ Compacted density (ASTM D1556 and/or D3877)
- ❑ Volumetric stability (ASTM D3877)
- ❑ Resilient modulus (AASHTO T 307)

Tests to Support Use in Concrete

- ❑ Strength development (AASHTO T 22 / T 97)
- ❑ Unrestrained volume change (AASHTO T 160 or T 334) or restrained volume change (AASHTO T 363)

Flowchart! Characterization and Assessment for Use

Recommended Tests for Delivery or Construction

Tests of Byproduct Material

Byproduct used as Aggregate

Tests to Support Use in Base or Fill

- Resilient modulus (AASHTO T 307)
- Shear strength (static triaxial and repeated triaxial loading, at optimal moisture content and saturated conditions)

Tests to Support Use in Concrete

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Flowchart! Characterization and Assessment for Use

Recommended Tests for Delivery or Construction

Tests of Application Containing Byproduct Material

Byproduct used as <u>Aggregate</u>

Tests to Support Use in <u>Base</u> or <u>Fill</u>

- ❑ Compacted density (AASHTO T 310, AASHTO T 191, ASTM D2167)

Tests to Support Use in <u>Concrete</u>

- ❑ Workability (AASHTO T 119 / TP 129 / TP 137)
- ❑ Air content (AASHTO T 152 or T 196)
- ❑ SAM number (AASHTO TP 118)
- ❑ Strength (AASHTO T 22 / T97)

Byproduct used as <u>SCM</u>

Tests to Support Use in <u>Base</u> or <u>Fill</u>

- ❑ Optimum moisture and maximum dry density (AASHTO T 134)
- ❑ Compacted density (AASHTO T 310, AASHTO T 191, ASTM D2167)

Tests to Support Use in <u>Concrete</u>

- ❑ Workability (AASHTO T 119 / TP 129 / TP 137)
- ❑ Air content (AASHTO T 152 or T 196)
- ❑ SAM number (AASHTO TP 118)
- ❑ Strength (AASHTO T 22 / T97)

Environmental Impacts

- Consider during Qualification/Preconstruction
    - Review agency regulations, specifications, permitting
    - Identify and address any environmental considerations
- Many byproducts contain small amounts of heavy metals and contaminant materials
- Water quality should be protected on and near the site

- RAP and RCA can produce high-pH runoff, leachate with contaminants

- Although levels can be greater than those acceptable in drinking water, research has shown runoff or leachate can be readily diluted, mitigated, or captured in nearby environmental systems (bioswales) or typical stormwater BMPs
    - RAP - Cosentino et al. 2003, Townsend and Brantley 1998, Brantley and Townsend 1999
    - RCA - Snyder et al. 2018

Photo: Dwayne Stenlund, MnDOT

Processing, Handling, and Storage

- Typically use equipment and methods like (or the same as) conventional materials
- Stockpile management
    - Appropriate stockpile management to ensure contaminants are not introduced
        - RCA - limiting stockpiles to a single source of material to support consistency
            - Guidance in Snyder et al. (2018)
        - RAP – processes and techniques exist to support blending of material from multiple sources to achieve uniform composition (Hoppe et al. 2015).
            - Sampling and testing of RAP in West (2015).

- Mitigate environmental impacts
    - Manage high pH runoff (BMPs, setbacks from receiving waters)
    - Snyder et al. (2018) provides strategies for protecting air, water quality, reducing noise

Photo: Tom Cackler