Use of Construction Byproducts in Concrete Paving Projects

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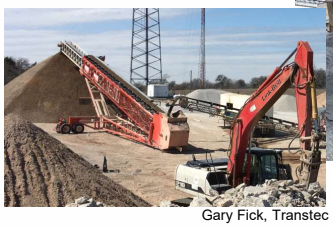

Gary Fick, Transtec

Carter Dold, Vulcan

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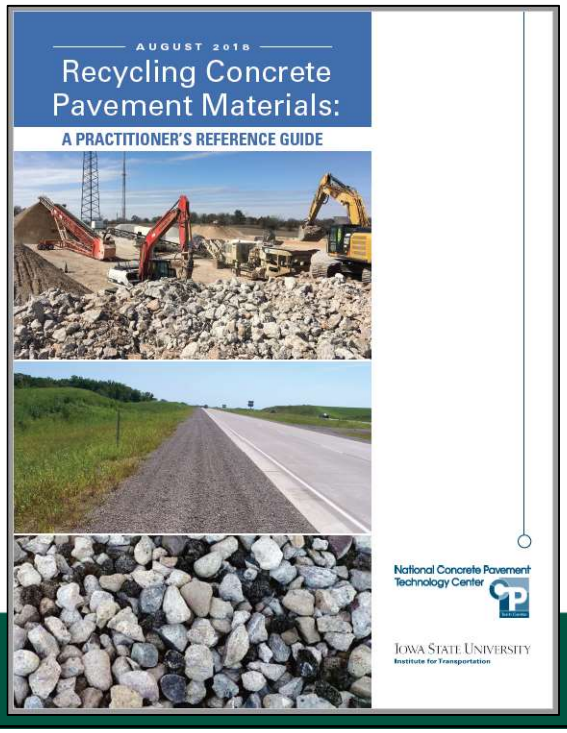

Guidance on Use of RCA prepared as part of Concrete Recycling Initiative

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

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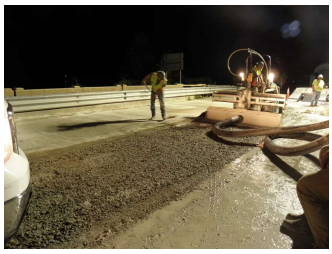
Construction Byproducts

- Produced during concrete pavement construction and rehabilitation

- Recycled concrete aggregate (RCA)
- Recycled asphalt pavement (RAP)
- Slurries
  - Grinding/grooving
  - Hydrodemolition
- Fines
  - Quarry fines
  - RCA fines

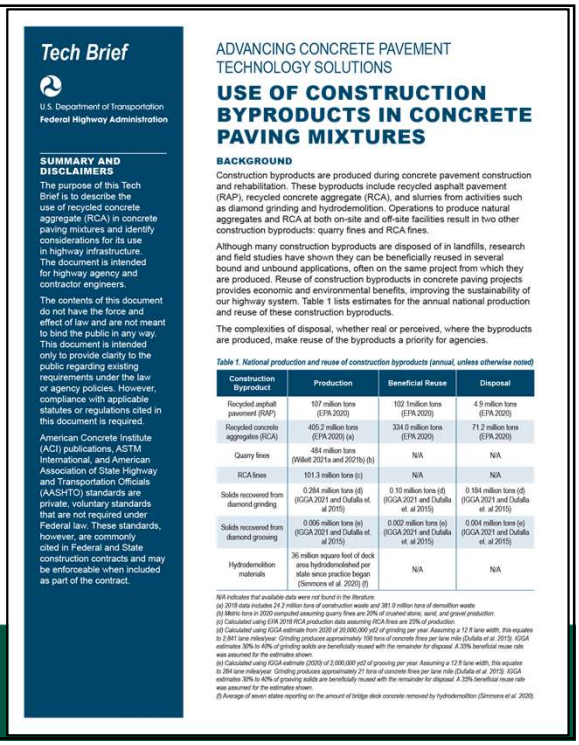
Alex Brand, Virginia Tech



Carter Dold, Vulcan Materials

Tech Brief

- Describes byproducts, provides characteristics
- 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



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)

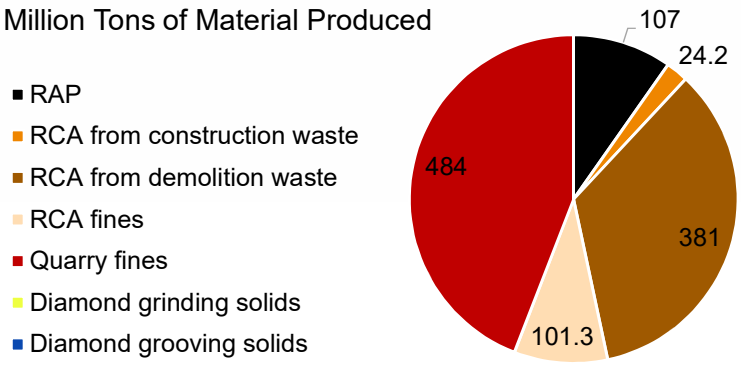
Construction Byproduct	Production	Beneficial Reuse	Disposal
Recycled asphalt pavement (RAP)	107 million tons (EPA 2020)	102.1million tons (EPA 2020)	4.9 million tons (EPA 2020)
Recycled concrete aggregates (RCA)	405.2 million tons (EPA 2020) (a)	334.0 million tons (EPA 2020)	71.2 million tons (EPA 2020)
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).

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 (annual, unless noted)



Characteristics of Construction Byproducts Reused in Concrete Paving Projects

Typical Properties of Construction Byproduct Aggregates

Property	Natural Aggregate	RAP	RCA
Shape and texture	Well-rounded, smooth (gravel) to angular and rough (crushed rock)	Rounded to angular, smooth to rough surface	Angular with rough surface
Absorption capacity (%)	0.8 – 3.7	1.78 – 2.79 (coarse) (Mukhopadhyay and Shi 2019)	3.7 – 8.7
Specific gravity	2.4 – 2.9	2.1 – 2.7 (coarse) 1.8 – 2.5 (fine)	2.1 – 2.4
LA abrasion test mass loss (%)	15 – 30	27 – 29 (grading of sample not provided, Settari et al. 2015)	20 – 45
Sodium sulfate soundness test mass loss (%)	7 – 21	Not found in the literature	18 – 59
Magnesium sulfate soundness test mass loss (%)	4 – 7		1 – 9
Chloride content (pcy)	---		1 - 12
Sample particle sizes		Tends to be fractionated to sizes of ¼ to ½ inch and smaller (Griffiths and Krstulovich 2002)	Depends on types, sizes, sequencing of crushing equipment

Data for natural aggregate and RCA for both fine/coarse material as-produced, from Snyder et al. 1994 and Chesner et al. 2008

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Typical Properties of Construction Byproduct Fines

Property	Quarry Fines*	RCA Fines**
Plastic limit (PL)	9 – 34	Non-plastic
Liquid limit (LL)	6 – 62	<40
Plasticity index (PI)	5 – 16	Non-plastic
Soils classification	AASHTO A-2-4, A-4, A-6	Silty sand
Specific gravity	2.65 (Puppala et al. 2008)	2.10 – 2.38
Fineness modulus	2.86 – 4.05	---
Sample grain size distributions	Tutumluer et al. 2015 Puppala et al. 2012	Lim et al. 2003
Passing No. 200 sieve (%)	7 – 15	1 – 26
Sample chemical compositions	Satvati et al. 2020 Tutumluer et al. 2015	Lim et al. 2003

* Quarry fines in studies by Puppala et al. (2008, 2012) and Tutumluer et al. (2015) were materials finer than 5 mm
** RCA fines in study by Lim et al. (2003) were materials passing No. 4 sieve, all Texas sources

Typical Properties of Construction Byproduct Slurries

Property	Diamond Grinding and Grooving Slurry	Hydrodemolition Slurry
pH	10 – 12.5	11 – 12.5
Particle sizes 0.2 to 2.0 mm (%)	15 – 35	Varies by pressure used and source concrete quality Typically larger sizes than diamond grinding and grooving slurry
Particle sizes 0.02 to 0.2 mm (%)	20 – 30	
Particle sizes 0.002 to 0.02 mm (%)	45 – 60	
Sample grain size distributions	DeSutter et al. 2011a	
Sample chemical compositions	IGGA 2011 Townsend et al. 2016	Line et al. 2017

Sources: Townsend et al. 2016, Winkler 2014, and Line et al. 2017

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Applications for Use

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Unbound Applications for Use of Construction Byproducts

Application	Potential Byproducts
Land application	• Diamond grinding slurry • Diamond grooving slurry
Soil stabilization and working platforms to bridge unsuitable soils	• Quarry fines • RCA fines • Diamond grinding/grooving residual solids
Capping layer on pavement base	• Quarry fines • RCA fines • Diamond grinding/grooving residual solids
Fill material	• RAP • RCA • RCA fines • Quarry fines • Diamond grinding/grooving residual solids • Hydrodemolition residual solids
Base material	• RAP • RCA • RCA fines • Quarry fines
Shoulders	• RAP • RCA • RCA fines • Quarry fines

Land Application

Slurry from diamond grinding and grooving can be used as a soil amendment in some areas

- Approved locations or on other public/private lands
- Permitting is often required (Tymvios et al. 2019)
- Not to be performed near sensitive waterways

- Contaminants possible
- Present in limited amounts - residuals from diamond grinding/grooving and hydrodemolition do not need to be treated as hazardous waste (IGGA 1990, DeSutter et al. 2011, Line and Smyth 2014, Townsend et al. 2016)

- IGGA has BMPs for grinding/grooving slurry handling (IGGA 2013)
- ICRI has BMPS for handling of hydrodemolition residuals (Winkler 2014)

IGGA (top and bottom)

Soil Stabilization and Working Platforms to Bridge Unsuitable Soils

Chemical composition of some quarry fines, RCA fines, residual solids from grinding/grooving and hydrodemolition make them favorable for soil stabilization

- Can improve shear strength, compressive strength, deformation properties (particularly for clayey soils)
- Binding properties are affected by:
  - Chemical composition
  - Particle shape and gradation

- Higher alumina contents and higher plasticity index (PI) materials show improved binding characteristics (Satvati et al. 2020)
- Quantity required to stabilize soil will also vary
- Tests should be performed to determine strength, modulus, and deformation characteristics of soils stabilized with byproduct materials

IGGA (top and bottom)

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Base Material

- RAP and RCA have been successfully used as the primary aggregate in unbound base layers
- RCA fines and quarry fines have been used as a component of unbound base layers
  - together with virgin aggregates or RCA, or
  - as a cap layer for other densely graded base materials.
- Can offer advantages of cost savings (particularly for on-site recycling) and improved performance (RCA) (Snyder et al. 2018)

- Most important material/layer characteristics affecting performance (Tutumluer 2013):
  - Mineralogy
  - Particle size distribution (gradation) fines content, and types of fines (plastic or non-plastic)
  - Particle shape, surface texture, and angularity
  - Durability (soundness, abrasion resistance)
  - Degree of compaction/moisture content

Iowa DOT

Tech Brief includes:
- Guidance for use of RAP and RCA in base materials
- Case studies detailing performance of various materials in bases
- Some examples of cost savings

Shoulders

- RAP and RCA have been successfully used in shoulder applications
  - Material often required to meet specifications for virgin material in unbound base applications
  - Blending byproducts with virgin materials can help achieve desired performance
  - Guidance for use of RCA in shoulders is in Snyder et al. 2018
  - RAP has been used in shoulders in at least 2 states, but the potential for long-term load-related deformation has resulted in some states prohibiting use (Hoppe et al. 2015)

50% RCA aggregate shoulder, Iowa DOT

- Quarry fines and RCA fines are often allowed in unbound shoulders to some extent
  - Iowa DOT specs allow up to 6% of material to be finer than No. 200 sieve
  - Also allow up to 30% and 50% recycled material - RCA, RAP or a composite of the two materials (Iowa DOT 2021)

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Bound Applications for Use of Construction Byproducts

Gary Fick, Transtec

Application	Potential Byproducts
New Concrete • **Single-lift pavement** • **Two-lift pavement** • **Asphalt shoulders**	• RAP • RCA • Quarry fines (limited to a low % by weight) • RCA fines (limited to a low % by weight)
Treated base layers • **Cement-treated base layers** • **Asphalt-treated base layers**	• RAP • RCA • RCA fines • Quarry fines • Diamond grinding slurry • Diamond grooving slurry

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Treated Base Layers

Bound applications –
any potential harmful components are mostly encapsulated by binder!

- RCA – lean concrete bases, cement-stabilized bases, asphalt concrete, asphalt-stabilized base layers
- RCA should meet agency specifications for conventional aggregate
  - Increased absorption of RCA should be accounted for in mixture design (Snyder et al. 2018)
- RAP – cement-treated, cement-fly ash-treated, and self-cementing fly ash-treated bases –
  - Results have been mixed
  - Unconfined compressive strength ↓ as binder content ↑
  - Cement treated bases with RAP and quarry fines exhibited satisfactory strength and stiffness (LaHucik et al. 2016)

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Treated Base Layers

- Quarry fines show acceptable performance in treated base layers (Puppala et al. 2008 and 2012)
  - Recent work by Tutumluer et al. show promising performance of stabilized bases including quarry fines paired with RCA or RAP (Qamhia et al. 2018, 2019a/b)
  - Test sections of quarry fines and primary crusher-run rock in 2-10.5 inch lifts

Qamhia et al. 2018

New Concrete

Single-lift pavements, two-lift pavements, shoulders

- RCA has ben successfully used as a complete or partial replacement for virgin aggregates
  - Mixture design and proportioning approach typically does not differ from conventional mixtures
  - Determine RCA properties/characteristics, account for them in mixture design
  - Typically appropriate to limit RCA fines in concrete mixtures, but guidance in Dufalla et al. (2015)
- RAP has been studied in concrete mixtures in the lab and field
  - Concrete with up to 50% virgin aggregate replacement with RAP has been shown to meet paving application requirements (Brand et al. 2012).
  - Illinois Tollway has constructed several pavement sections that have performed successfully, including lower lift of 2-lift pavement (Gillen et al. 2012, Gillen 2013).
- Quarry fines studied as partial replacement for sand in conventional concrete (Lohani et al. 2012) and SCC (Naik et al. 2005), as well as CLSMs (Halman and Shah 2015)
  - In conventional concrete, strength increased at fines contents up to 30%, then decreased

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

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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

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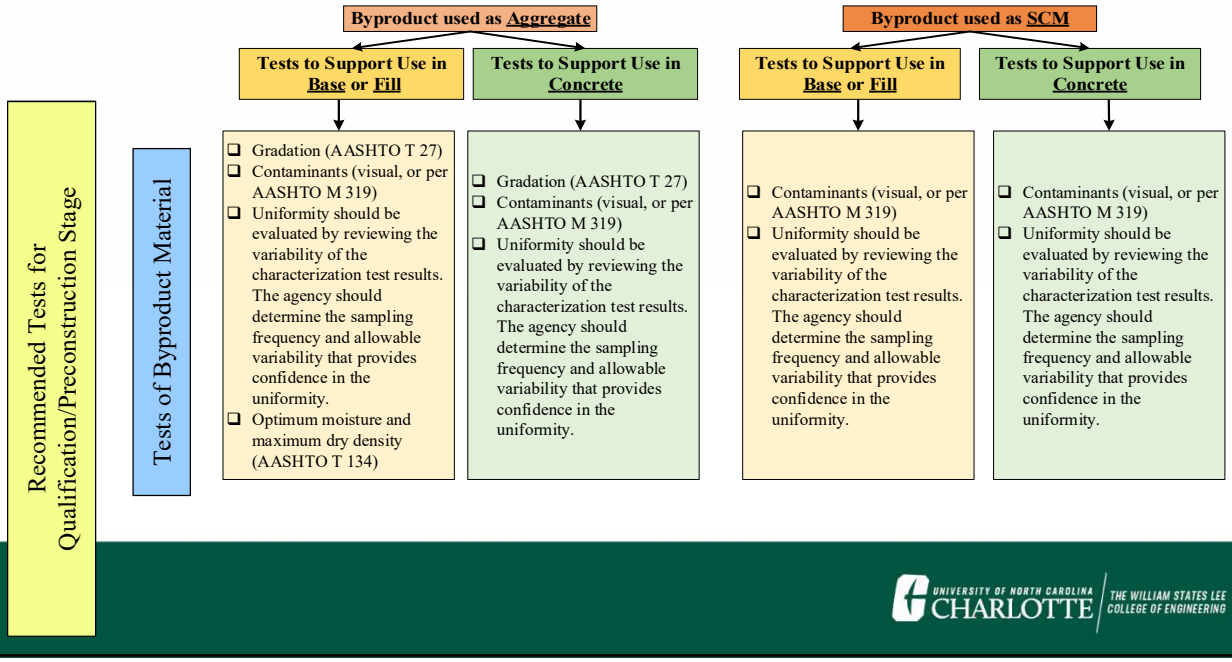
Flowchart! Characterization and Assessment for Use



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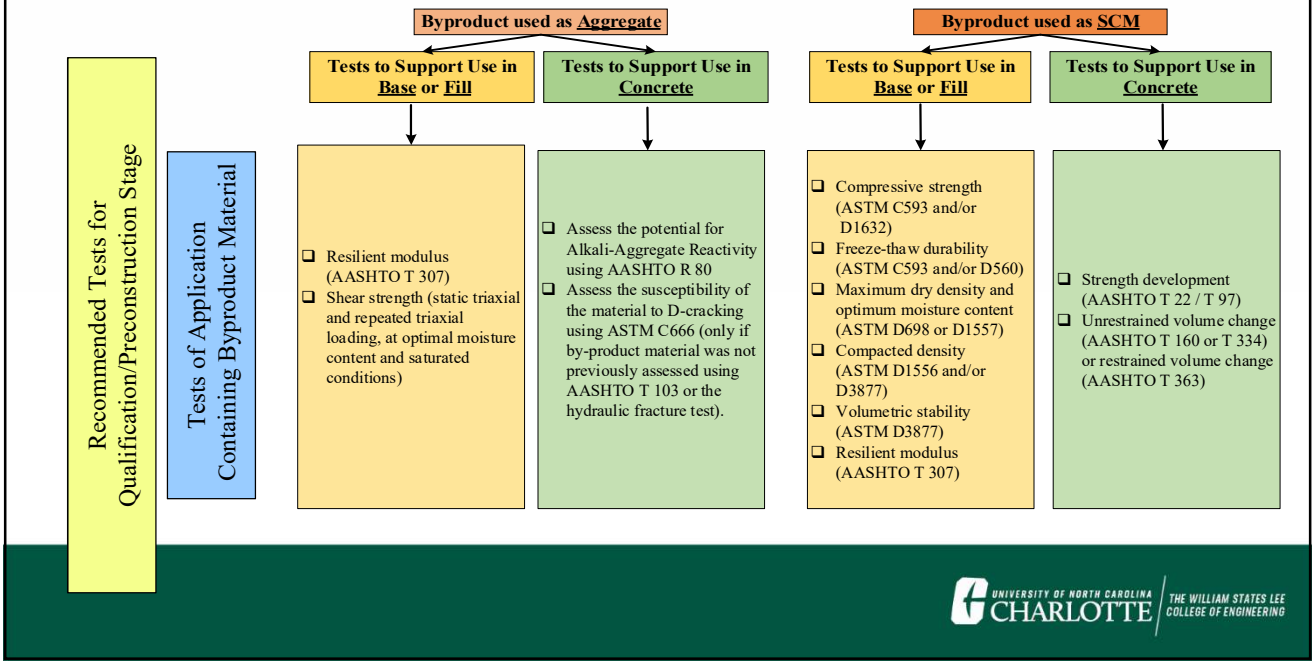

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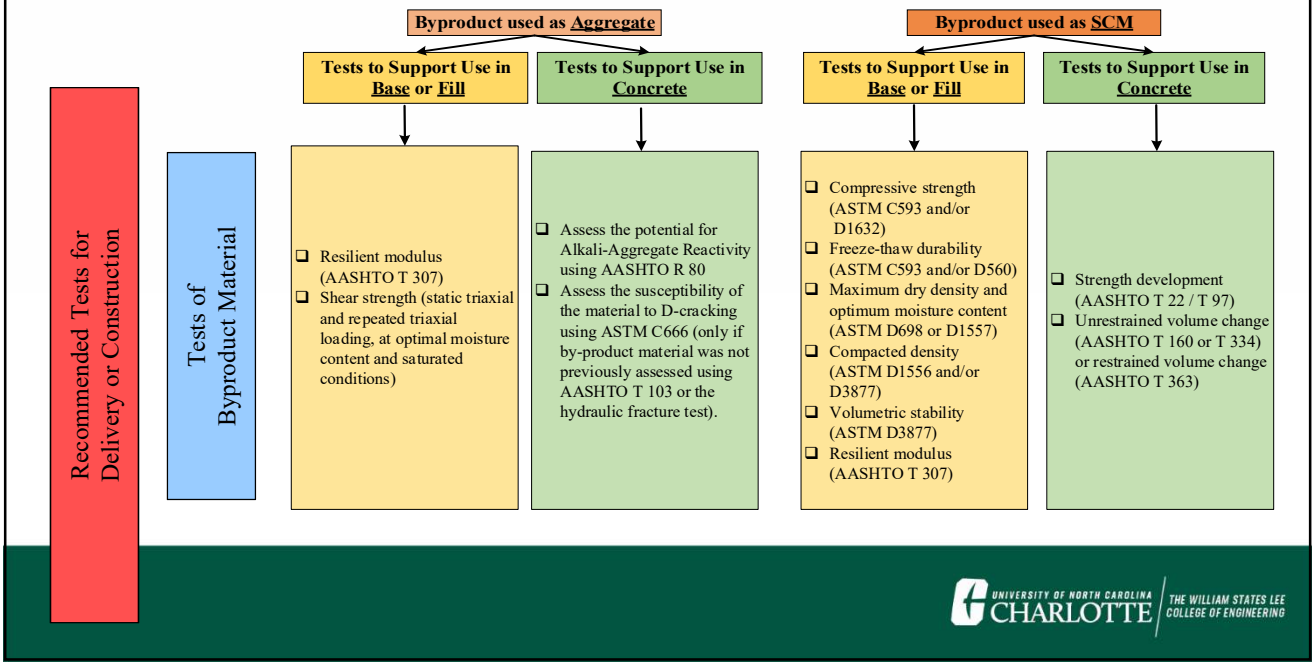

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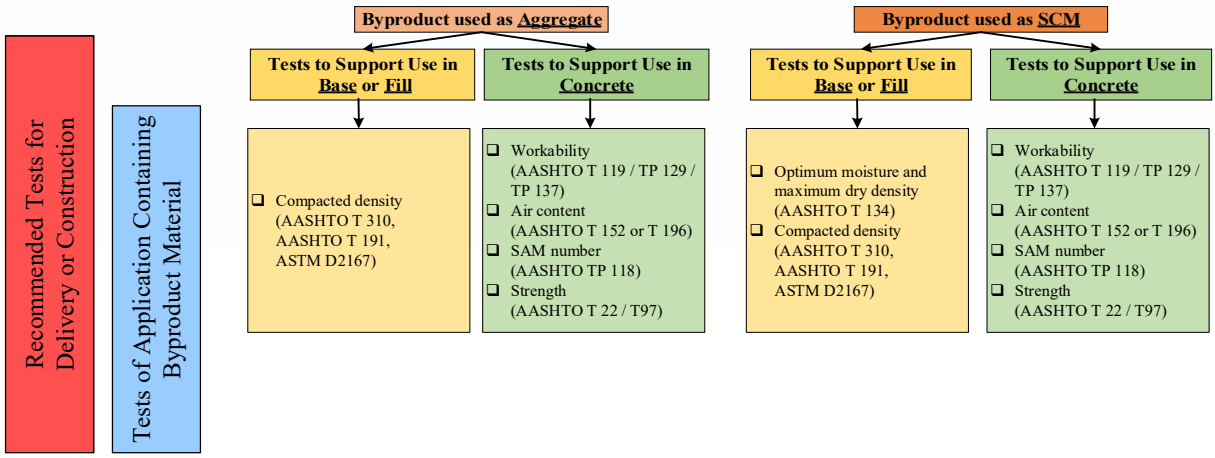

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Environmental Impacts

- 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

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Construction Considerations

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

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Processing, Handling, and Storage of Slurries

- Diamond Grinding
  - IGGA provides recommended practices for handling, reuse, and disposal (IGGA 2013)
  - Practices include:
    - Deposition/spreading of slurries on vegetated slopes
    - Collection of slurry and placement into settlement ponds or tanks
    - Pond decanting
    - pH control

- Hydrodemolition
  - Slurries tend to have larger solids but more liquid than grinding/grooving slurry
  - ICRI provides BMPs for handling and disposal or reuse of hydrodemolition slurries (Winkler 2014)
  - Practices include:
    - Treatment to remove suspended solids using a settling area or tank
    - pH adjustment of liquids

Summary of practices for residuals management along with agency allowed practices is in Tymvios et al. (2019)

Compaction of Unbound Bases and Fill

- Excessive hauling movement and compaction can result in additional fines generated
  - Use compaction equipment with rubber tires (not steel contact surfaces)
  - Use magnets or mechanical means to remove steel during processing

- Compaction density control based on Standard Proctor Test
  - Place materials at moisture state close to optimal
  - If difficult to meet density requirements without adverse crushing/degradation:
    - Relax compaction requirement slightly
    - Require a specific number of compaction passes to achieve adequate density based on agency experience (Snyder et al. 2018)
    - Appendix A1 of AASHTO M 319 provides an alternate field control method that includes use of variable acceptance criteria for compaction test based on designated lots/sublots

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Conclusions

- Several types of beneficial reuse applications exist for construction byproducts
  - Unbound fills and bases
  - Stabilized bases
  - New concrete
- Benefits include:
  - Reducing environmental impacts, conservation of natural resources/landfill space
  - Cost savings
- Agencies should:
  - Provide clear practices for handling, treatment, and allowable end uses
  - Promote beneficial reuse options

Particularly when byproducts are reused on site!

- Beneficial reuse byproducts should be considered as early as possible!
  - Allows for planning, confidence in measures and methods needed to perform the necessary operations
  - May allow cost savings to be passed on at time of bidding

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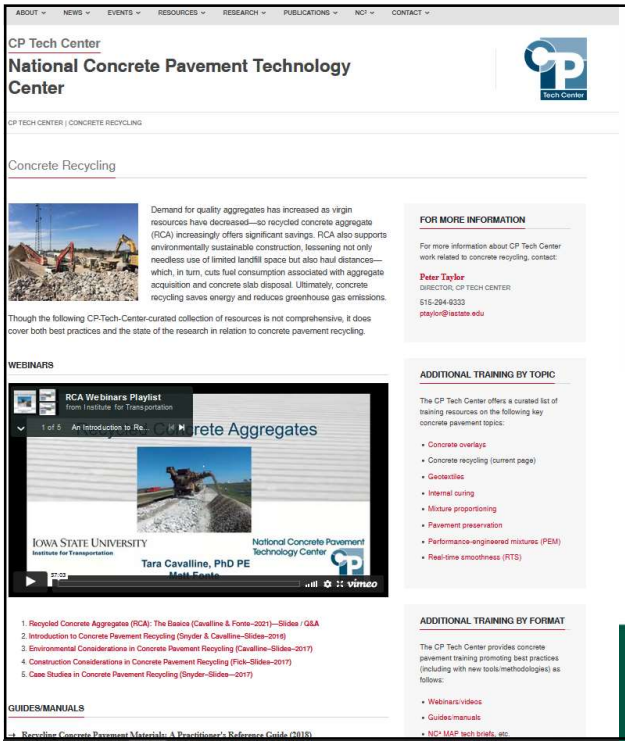

Resources

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

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