Concrete Recycling

2013 Arizona

Pavement/Materials Conference

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What is Concrete Recycling?

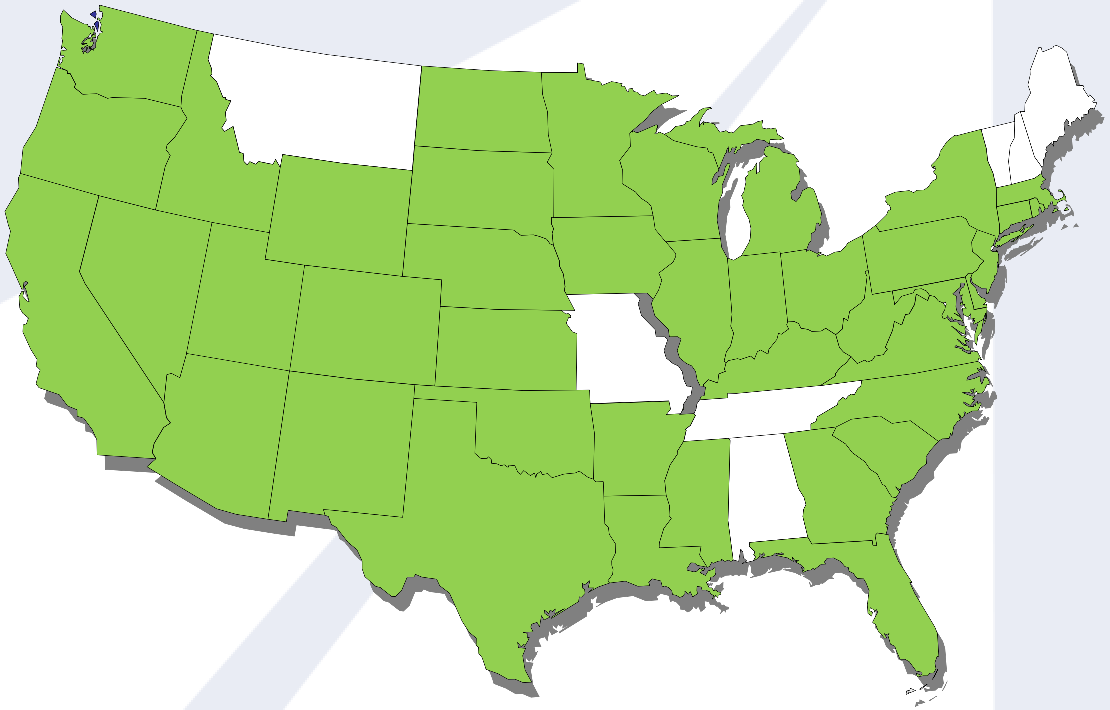
- Breaking, removing and crushing hardened concrete from an acceptable source.
- Old concrete pavements often are excellent sources of material for producing RCA.
- ***<u>Concrete pavements are 100% recyclable!</u>***

Reasons for Concrete Recycling

- **Dwindling landfill space/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**
- **Conservation of materials**
- **Cost Savings**
  - Aggregate = 20-30% of pavement costs, 10-15% of project costs
  - Savings vary - up to 60% of virgin aggregate cost
- **Sustainability**
- **Potential for improved pavement performance**
- **A proven technology – it works!**

Concrete Recycling:
A Proven Technology!

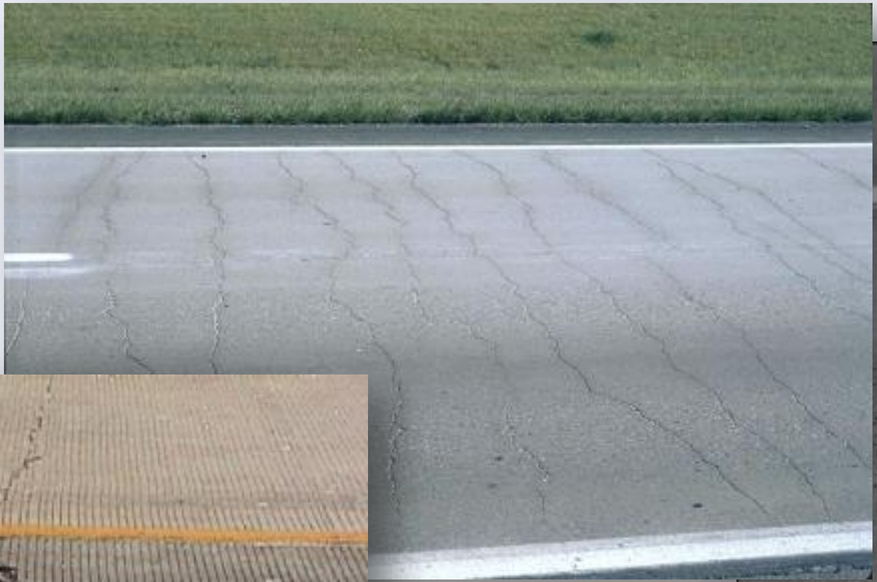
41 of 50 states allow use of RCA in various applications (FHWA, 2004)

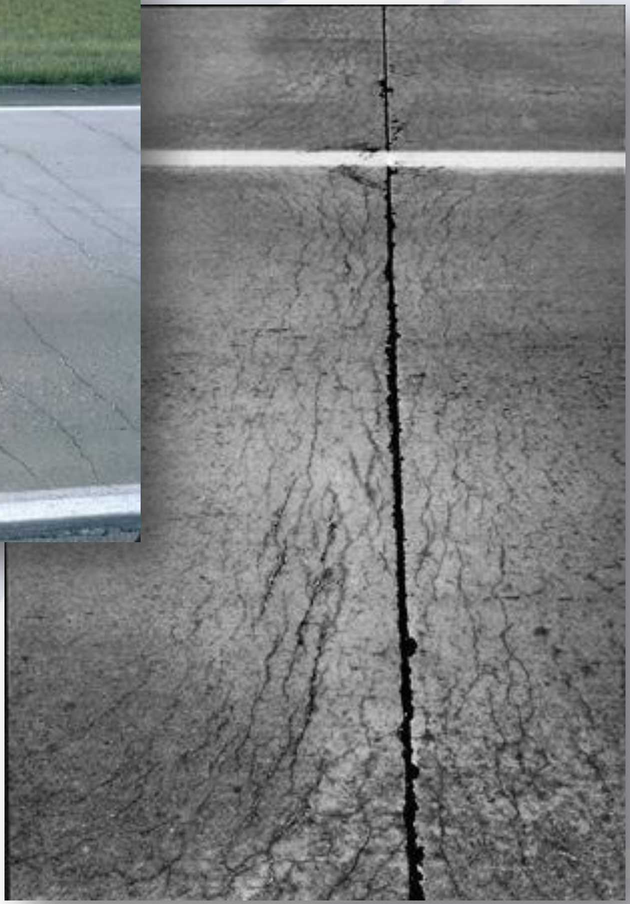


Production of RCA

- Typical steps:
  - Evaluation of source concrete.
  - Pavement preparation.
  - Pavement breaking and removal.
  - Removal of embedded steel.
  - Crushing and sizing.
  - Beneficiation.
  - Stockpiling.

Evaluation of Source Concrete





Pavement Preparation

- How will RCA be used? RCA for concrete mixtures might require more pavement preparation than for other uses.

- Asphalt patches, overlays and shoulders may or may not need to be removed;
  - Illinois Tollway and some European countries allow RAP in new concrete paving mixtures (two-lift construction).

Pavement Breaking and Removal

1,000+ yd²/hr

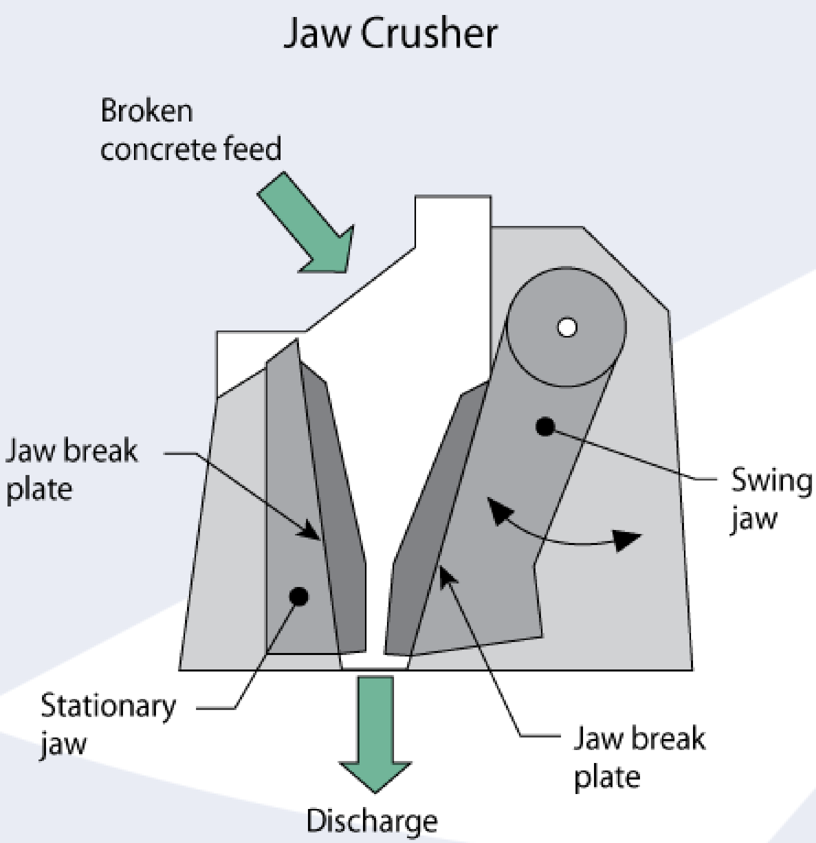
Removal of Embedded Steel

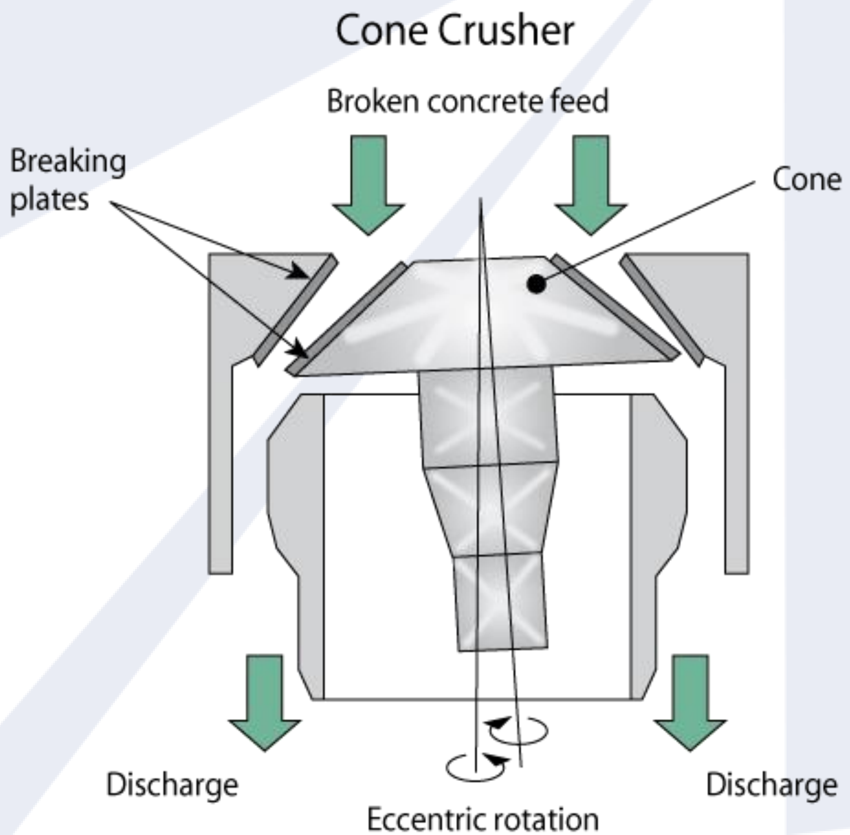
- Can also follow crushing operations
  - Electromagnets
  - Manual removal

Crushing and Sizing

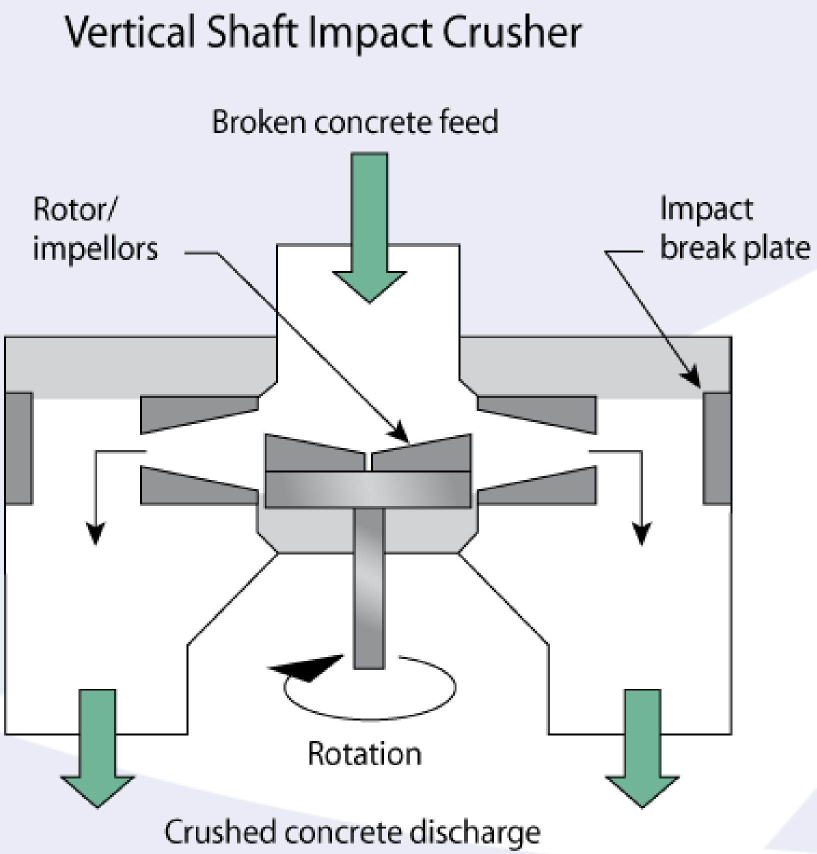
- Same basic equipment used to processes virgin aggregates
- Primary crusher reduces to 3” to 4”; material then screened and anything larger than 3/8” fed to secondary crusher, which breaks to the desired RCA top size.
- Yield depends on many factors but loss of material can be as high as 10% and may approach 0%.

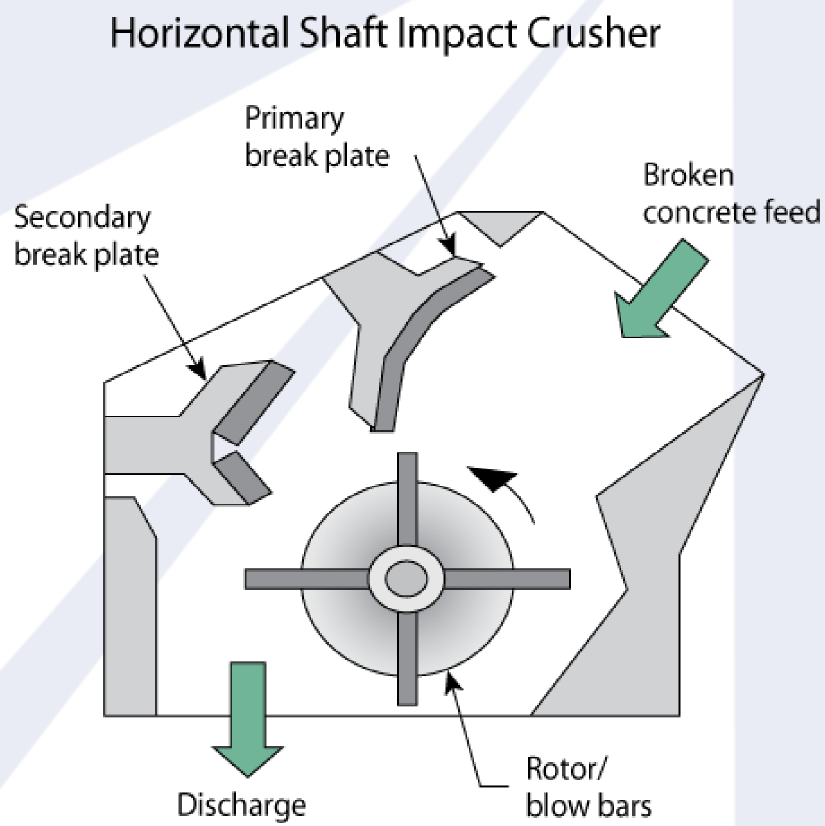
Crushing and Sizing



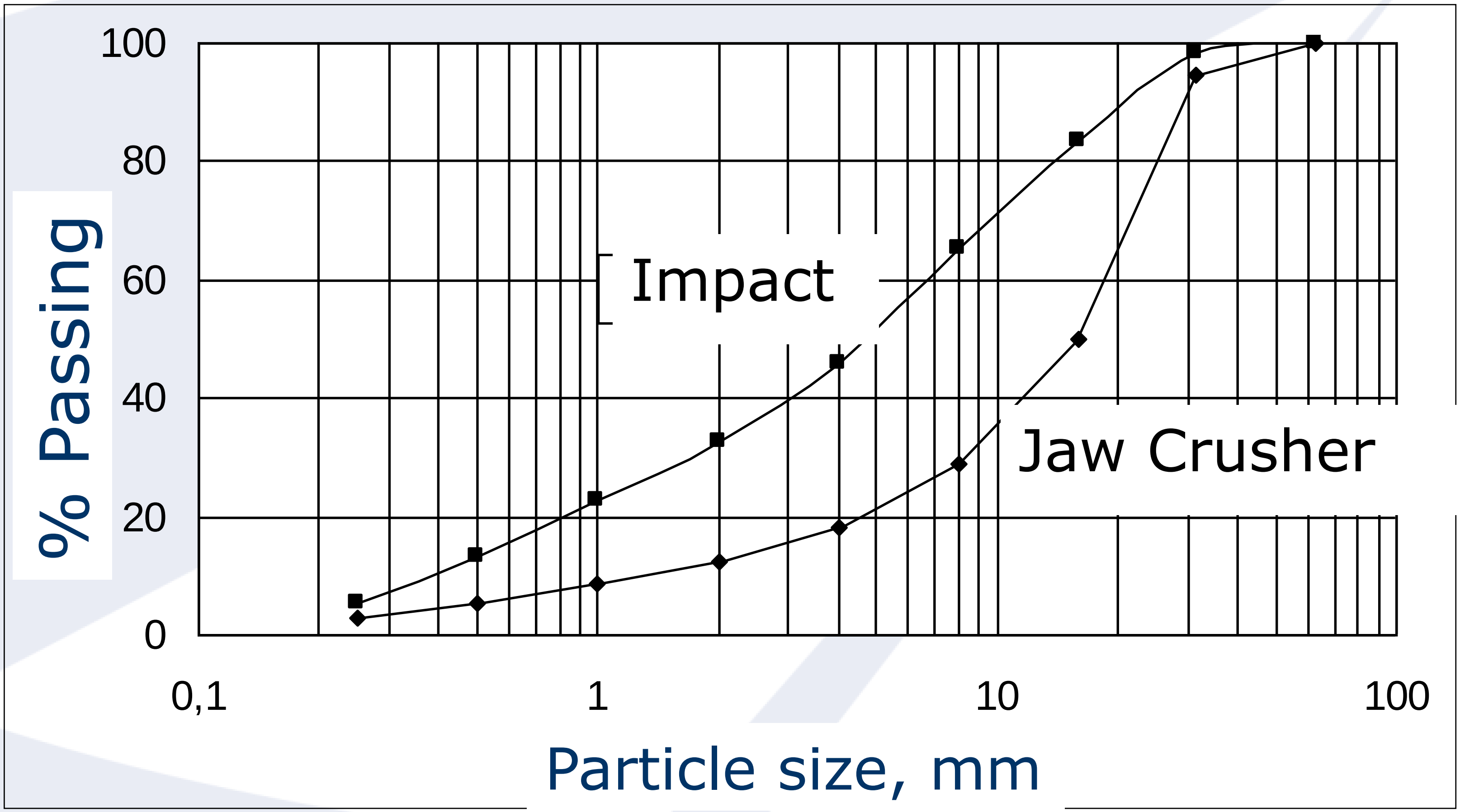


Crushing and Sizing





Effect of Crushing Process on RCA Particle Size Distribution



Effects of Crushing Technique and Natural Aggregate Type on RCA Reclamation Efficiency

Process	Reclamation Efficiency		
	RCA Type		
	Limestone	Gravel	Granite
Jaw-Jaw-Roller	71	73	**87**
Jaw-Cone	73	80	76
Impact-Impact	**44**	63	53

Effect of Crushing Technique on Reclaimed Mortar

Process	Average Reclaimed Mortar (%)		
	RCA Type		
	Limestone	Gravel	Granite
Jaw-Jaw-Roller	55	54	52
Jaw-Cone	**56**	51	48
Impact-Impact	51	43	**39**

Stockpiling

- Coarse RCA can be stockpiled using the same techniques and equipment as are used with virgin coarse aggregate materials.

Stockpiling (cont.)

- Protect fine RCA stockpiles from moisture
  - Secondary cementing.
- RCA stockpile runoff is initially highly alkaline
  - Leaching of calcium hydroxide
  - Runoff alkalinity rapidly decreases
    - Any negative environmental effects are temporary and do not significantly offset positive environmental effects (reduced use of virgin aggregate and landfills).

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.

Recycling Concrete Aggregate

PROPERTIES OF RCA

Properties of RCA

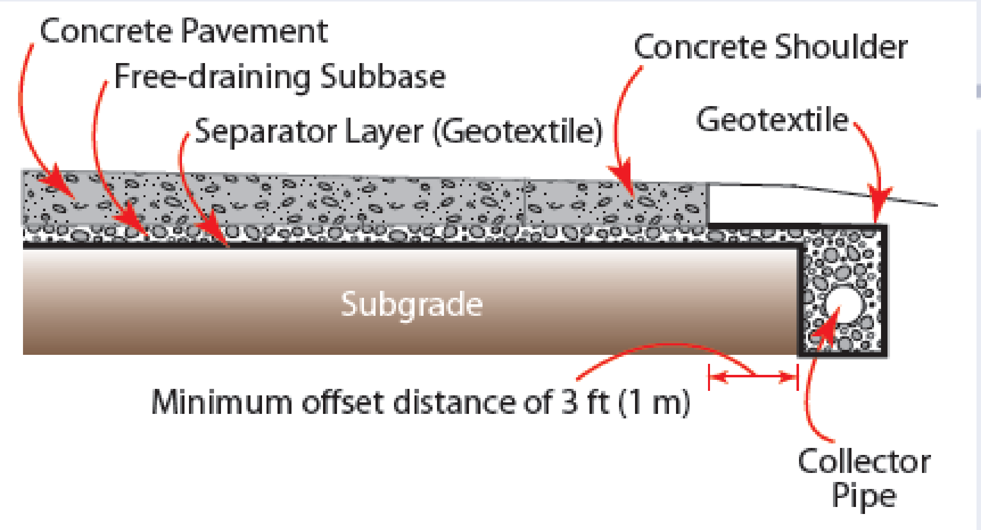
Property	Virgin Agg.	RCA
Shape and Texture	Well–rounded; smooth to angular/rough	Angular with rough surface
Absorption Capacity	0.8% – 3.7%	3.7% – 8.7%
Specific Gravity	2.4 – 2.9	2.1 – 2.4
L.A Abrasion	15% – 30%	20% – 45%
Sodium Sulfate	7% – 21%	18% – 59%
Magnesium Sulfate	4% – 7%	1% – 9%
Chloride Content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

Effect of Particle Size on RCA Properties (after Fergus, 1980)

Sieve size	Percent retained	Bulk specific gravity	Percent Absorption
1.0 in. (25 mm)	2	2.52	2.54
¾ in. (19 mm)	22	2.36	3.98
½ in. (12.5 mm)	33	2.34	4.50
⅜ in. (9.5 mm)	18	2.29	5.34
No. 4 (4.75 mm)	25	2.23	6.50
Weighted average	100	2.31	5.00

Recycled Concrete Aggregate

USES OF RCA



- 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 41 states using RCA in U.S.
  - Some believe it outperforms virgin aggregate as an unstabilized subbase!
- Some level of contaminants is tolerable.

Recommendations: Use in Subbases

- AASHTO M319
- Quality requirements (Saeed and Hammons, 2008)
- Grade according to subbase function
  - Free-draining
  - Dense-graded
  - See ACPA EB204P

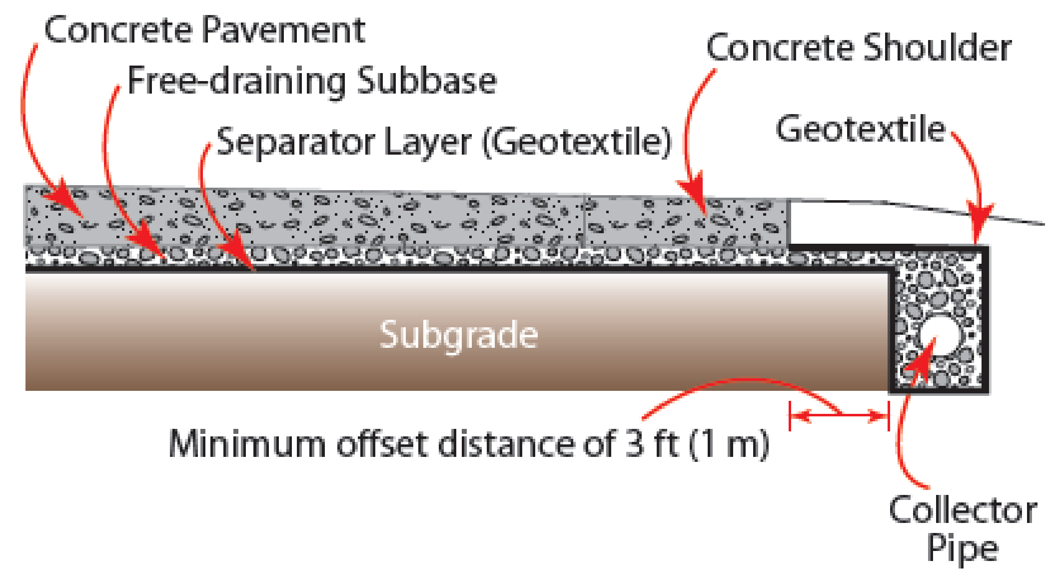
Test Criteria for RCA Unbound Subbase Applications (after Saeed and Hammons, 2008)

<table>
<tr><th rowspan="3">Tests and Test Parameters</th><th>Traffic</th><th colspan="2">High</th><th colspan="2">Med.</th><th colspan="2">High</th><th colspan="2">Low</th><th>Med.</th><th>Low</th></tr>
<tr><th>Moisture</th><th>High</th><th>Low</th><th>High</th><th>Low</th><th>High</th><th colspan="2">Low</th><th colspan="2">High</th><th>Low</th></tr>
<tr><th>Climate</th><th colspan="4">Freeze</th><th colspan="2">Nonfreeze</th><th>Freeze</th><th colspan="3">Nonfreeze</th></tr>
<tr><td colspan="2">Micro-Deval Test (percent loss)</td><td colspan="3">< 5 percent</td><td colspan="4">< 15 percent</td><td colspan="2">< 30 percent</td><td>< 45 percent</td></tr>
<tr><td colspan="2">Tube Suction Test (dielectric constant)</td><td colspan="3">≤ 7</td><td colspan="4">≤ 10</td><td colspan="2">≤ 15</td><td>≤ 20</td></tr>
<tr><td rowspan="2">Static Triaxial Test (Max. Deviator Stress)</td><td>OMC, σ_c = 5 psi (35 kPA)</td><td colspan="3">> 100 psi (0.7 MPa)</td><td colspan="4">> 60 psi (0.4 MPa)</td><td colspan="2">> 25 psi (170 kPa)</td><td>Not required</td></tr>
<tr><td>Sat., σ_c = 15 psi (103 kPA)</td><td colspan="3">≥ 180 psi (1.2 MPa)</td><td colspan="4">≥ 135 psi (0.9 MPa)</td><td colspan="2">≥ 60 psi (410 kPa)</td><td>Not required</td></tr>
<tr><td rowspan="2">Repeated Load Test (Failure Deviator Stress)</td><td>OMC, σ_c = 15 psi (103 kPA)</td><td colspan="3">≥ 180 psi (1.2 MPa)</td><td colspan="4">≥ 160 psi (1.1 MPa)</td><td colspan="2">≥ 90 psi (620 kPa)</td><td>Not required</td></tr>
<tr><td>Sat., σ_c = 15 psi (103 kPA)</td><td colspan="3">≥ 180 psi (1.2 MPa)</td><td colspan="4">≥ 160 psi (1.1 MPa)</td><td colspan="2">≥ 60 psi (410 kPa)</td><td>Not required</td></tr>
<tr><td colspan="2">Stiffness Test (Resilient Modulus)</td><td colspan="3">≥ 60 ksi (0.4 MPa)</td><td colspan="4">≥ 40 ksi (275 kPa)</td><td colspan="2">≥ 25 ksi (170 MPa)</td><td>Not required</td></tr>
</table>

Note: Low traffic: < 100,000 ESALs/year; Medium traffic: 100,000 to 1,000,000 ESALs/year; High traffic: 1,000,000 ESALs/year.

Preventing Drainage Structure Clogging

- Minimize use of RCA fines.
- Crush to eliminate reclaimed mortar
- Blend RCA and virgin materials
- Use largest practical RCA particle sizes.
- Wash RCA to reduce ISR deposits.
- Use high-permittivity fabric
- Wrap trench, not pipe
- Consider daylighted subbase



Cement-stabilized and Lean Concrete Subbases

- Stabilization helps to prevent migration of crusher fines, dissolution and transport of significant amounts of calcium hydroxide.
- 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.

Concrete Mixtures (cont.)

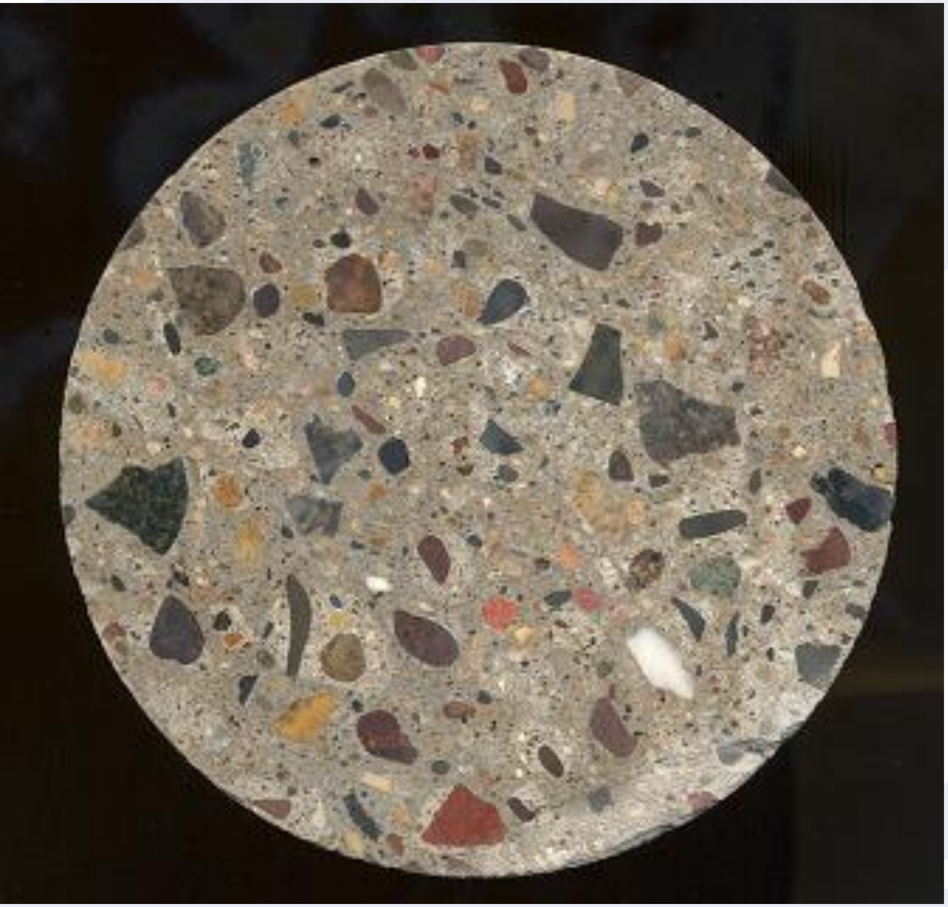
- Concerns with water demand and premature stiffening:
  - Limit or eliminate fine RCA
  - Presoak RCA
  - Use chemical and mineral admixtures.
- *Fresh and hardened properties of RCA PCC might be different from virgin aggregate PCC.*

RCA in Two-Lift Construction

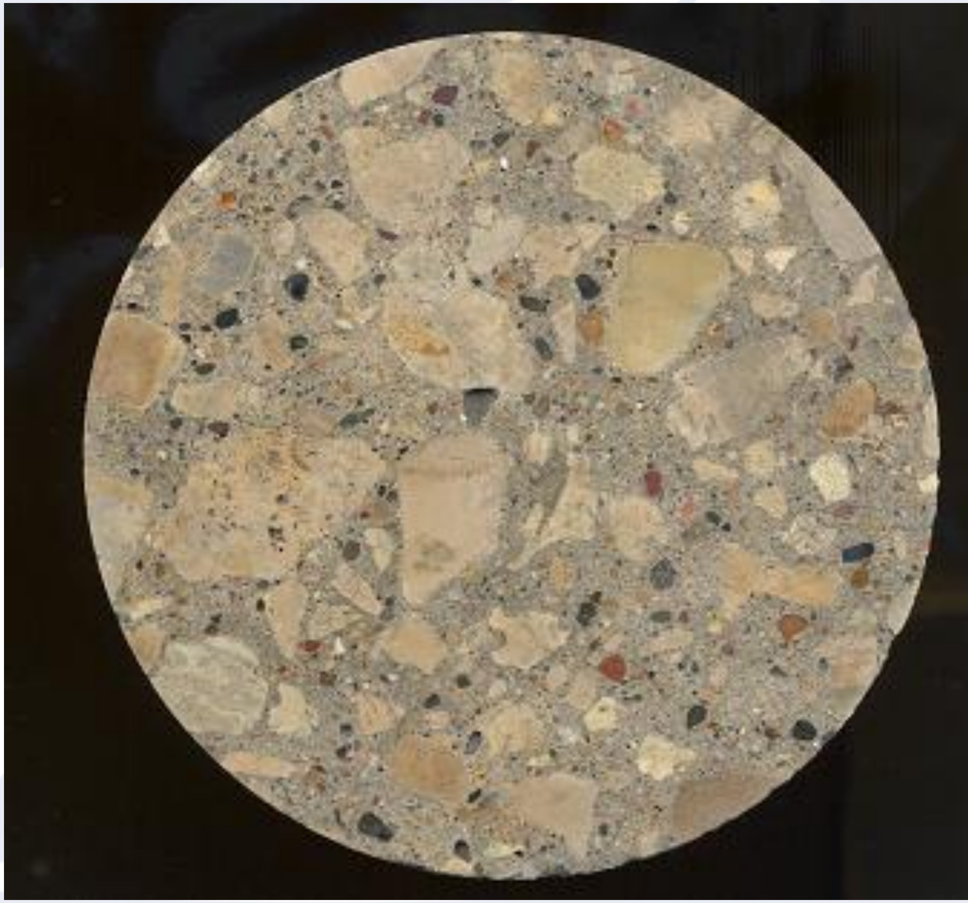
- Iowa US 75 Reconstruction (1976)
  - 60-40 RCA and RAP in 23cm lower lift; 7.0m wide
  - All virgin in 10cm top lift; 7.3m wide
  - Still in service today!
- Austrian Standard Practice since late 1980s
  - A-1 (Vienna-Salzburg): 19-cm lower lift (RCA and RAP), 3-cm upper lift (exposed virgin aggregate), fines to stabilize foundation (100 percent PCC recycled)
  - Overall project savings >10 percent
  - More than 75km between 1991 and 1994; two-lift construction using recycled materials is now standard

Properties of Concrete containing Recycled Concrete Aggregate

It's all about the mortar ...



MN 4-1 (Recycled)

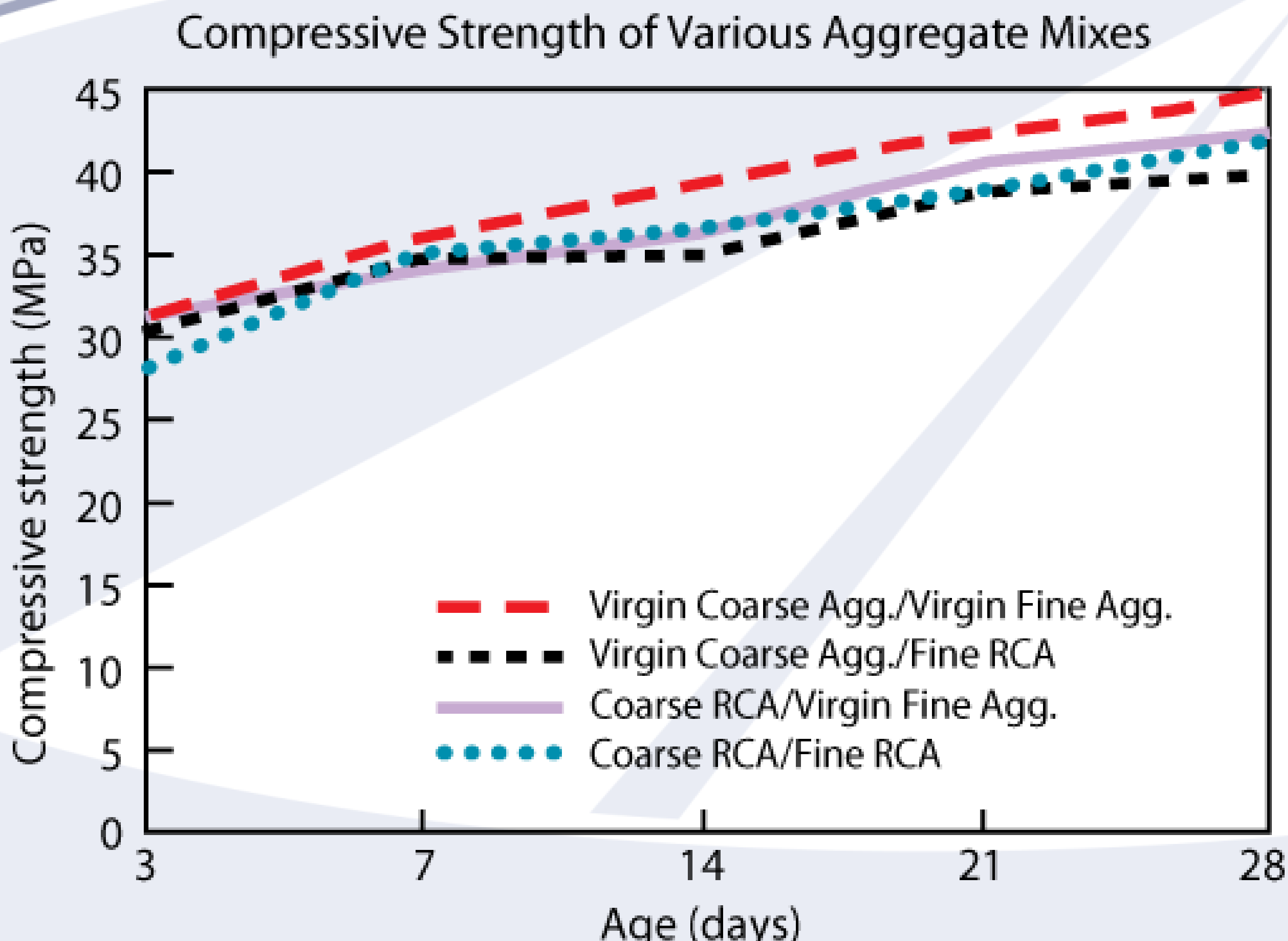


MN 4-2 (Control)

Fresh (Plastic) Properties

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

Hardened Properties



Hardened Properties

Property	Coarse RCA	Coarse and Fine RCA
Compressive strength	0% to 24% less	15% to 40% less
Tensile strength	0% to 10% less	10% to 20% less
Strength variation	Slightly greater	Slightly greater
Modulus of elasticity	10% to 33% less	25% to 40% less
CTE	0% to 30% greater	0% to 30% greater
Drying shrinkage	20% to 50% greater	70% to 100% greater
Creep	30% to 60% greater	30% to 60% greater
Permeability	0% to 500% greater	0% to 500% greater
Specific gravity	0% to 10% lower	5% to 15% lower

Effects of RCA and Mix Design on Strength and Thermal Properties

Project	CT		KS		MN1		WY		MN4	
Section	Rec	Con	Rec	Con	Rec	Con	Rec	Con	Rec	Con
w/(c+p)	**0.40**	**0.45**	0.41	0.41	0.47	N/A	**0.38**	**0.44**	**0.44**	**0.47**
%RFA	0	0	**25**	**0**	0	0	**22**	0	0	0
f'c (ksi)	**5.7**	**5.1**	6.9	6.3	6.9	6.7	**7.1**	**6.5**	**6.2**	**6.9**
E (Mpsi)	4.6	4.8	5.1	5.2	5.2	5.9	5.1	5.3	5.1	6.1
α (10^{-6}/^{o}F)	6.4	5.9	**5.8**	**5.2**	6.2	6.3	**7.4**	**6.0**	**6.4**	**6.2**

Performance of RCA Pavement

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

…. *<u>but performance has generally been very good!</u>*

2007 Photo of Texas I-10
(1995-built RCA-CRCP – no virgin aggregate!)

Property	I-10 RCA concrete
28-Day compressive strength	4,615 psi (31.8 MPa)
28-Day elastic modulus	2.58×10^6 psi (17.8 MPa)
Coefficient of thermal expansion and contraction (CTE)	4.7 to 5.3 $\mu\epsilon$/°F (8.5 to 9.5 $\mu\epsilon$/°C)
Permeability (ASTM C1202/AASHTO T277)	466 coulombs (very low permeability)

US 59 Worthington MN – 1980 Construction
1st Major Recycle of D-Cracked PCC
2000 Rehab for DBR, Grind
No Recurrent D-cracking! (2006 photo)


US 59 Worthington MN – 1980 Construction
1st Major Recycle of D-Cracked PCC
2000 Rehab for DBR, Grind
No Recurrent D-cracking! (2006 photo)

Interstate 80
Pine Bluff, WY
Extensive ASR
1985 Reconstruct:
- 65% Coarse RCA
- 22% Fine RCA
- Low-alkali cement, F ash

2004 DBR and Grind
Isolated Recurrent ASR
(2006 Photo)

2006 Study Conclusions

- 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

Recommendations: RCA in Mixture Design

- AASHTO MP16-07
- Quality Requirements and Properties
  - Generally the same as for PCC with virgin aggregate
  - Exception: sulfate soundness (unreliable for RCA)
- Materials-Related Distress
  - Alkali-silica reactivity
    - Lithium
    - Class F fly ash and/or slag cement
    - Limit RCA fines
    - Reduce water access (joint sealing, drains, etc.)
  - D-cracking
    - Reduce coarse aggregate top size
    - Reduce moisture exposure
  - Test effectiveness of all treatments before construction!

Recommendations:
RCA in Mixture Design Proportioning

- Consider Specific Gravity and Absorption Capacity
- 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

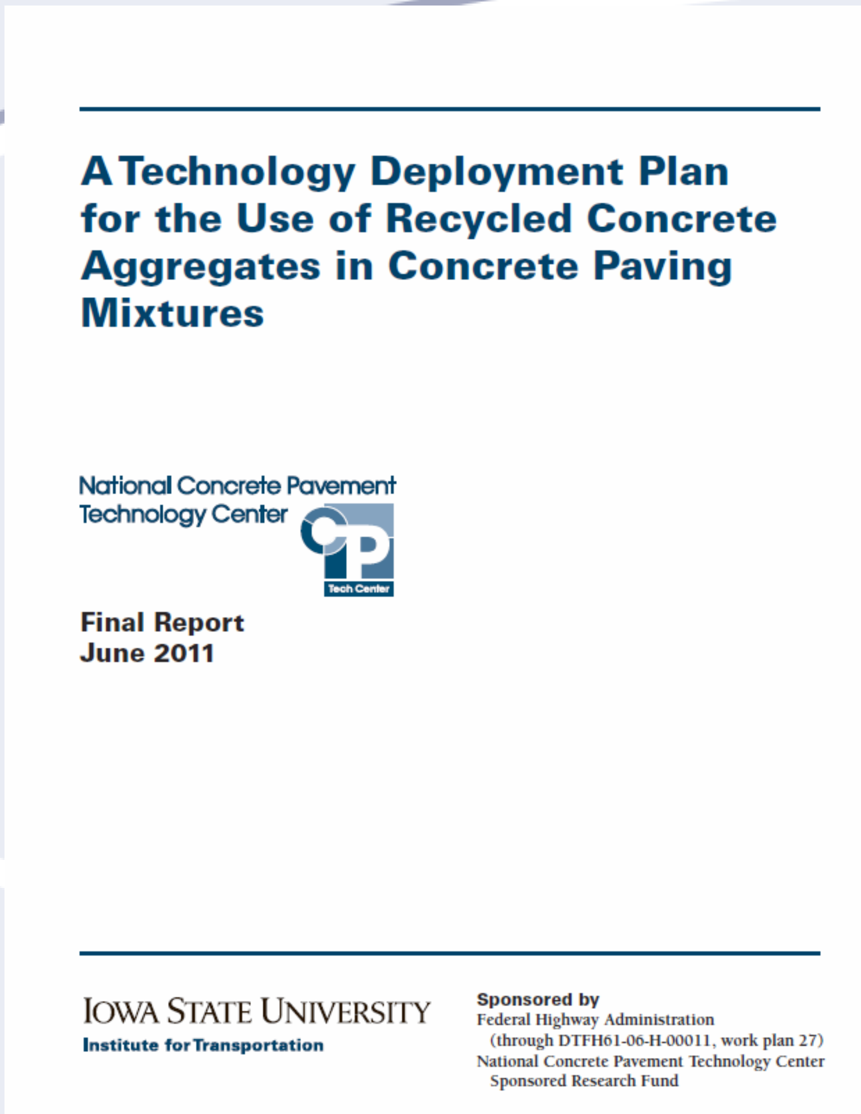
Summary

- Recycling is becoming an increasingly cost-effective alternative due to scarcity of virgin aggregate
- Requires adjustment to mix design and pavement design
- Good performance has been reported
- No specialized techniques or equipment

… also included in EB043P…

- 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

Current Implementation Efforts



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

National Concrete Pavement Technology Center

Tech 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

- Use of RCA in concrete mixtures is not common, but implementation efforts are underway.
- Report outlines barriers to implementation (perceptions, lack of experience, risk, etc.) and recommends approaches to overcoming them.
- Report available at: http://www.intrans.iastate.edu/reports/RCA%20Draft%20Report_final-ssc.pdf

- **FHWA Technical Advisory TT 5040.37: Use of Recycled Concrete Pavement as Aggregate in Hydraulic-Cement Concrete Pavement**

Acknowledgments

- American Concrete Pavement Association
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- Jeff Roesler, University of Illinois at Urbana-Champaign
- Nancy Whiting, Jan Olek, and Kho Pin of Purdue University

Questions?

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Pavements 4life

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