Recycled Concrete as an Aggregate

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Minnesota Concrete Council
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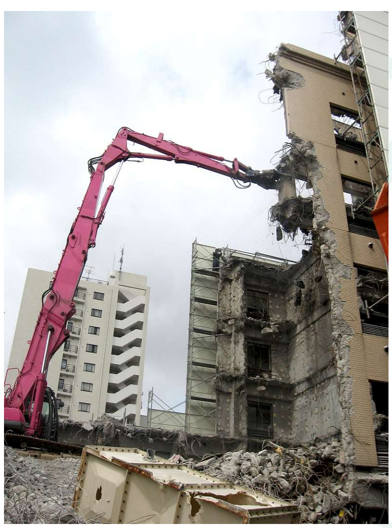
Background

- What is Recycled Concrete Aggregates (RCA)?
- Do Codes, Specifications allow it?
- RCA – Performance in Concrete
- RCA – How to use it?
- Conclusions

What is RCA?

- ACI CCT defines RCA as hardened concrete that has been processed for reuse, usually as aggregate
- AASHTO MP 16-07 defines "Reclaimed concrete aggregate" (RCA) as
  - derived from crushing, processing and classification of hydraulic concrete construction debris recovered from roadways, sidewalks, buildings, bridges, and other sources…

RCA – Building demolition

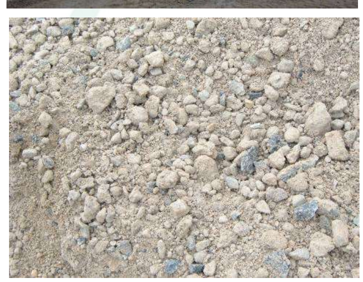


RCA - Pavements



Returned Concrete (CCA)





Reasons for Using RCA

- Dwindling landfills accepting RCA/increasing costs (CP Roadmap, March 2016)
  - 50,000 (1980) vs 5000 (2000)
- Landfill space, material conservation, cost savings, fuel/energy/CO_2 savings
- RCA use in USA since 1940s
- 140 millions tons (2014, CIDRA)

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Is it permitted?

- ASTM C33
  - Aggregate, recycled – granular material that has been diverted, separated, or removed from the solid waste stream, and processed for use in the form of raw materials or products
  - 9.1 Coarse aggregate shall consist of gravel, crushed gravel, crushed stone, air-cooled blast furnace slag, or **crushed hydraulic cement concrete** or other recycled aggregate, or a combination thereof
  - Note 8 – cautions

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Is it permitted?

- ASTM C33
  - 5.1 Fine aggregate shall consist of natural sand, manufactured sand, or other recycled aggregate, or a combination thereof
- ASTM C125
  - Manufactured sand – fine aggregate produced by crushing rock, gravel, iron blast-furnace slag, or **hydraulic cement concrete**

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AASHTO MP 16-07

- Reclaimed Concrete Aggregate for use as Coarse Aggregate in Hydraulic Cement Concrete
- Applications are paving, base courses, sidewalks, barriers, curbings, nonstructural
  - Caution for structural applications

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AASHTO MP 16-07

- Requirements same as for virgin agg
  - Grading – same as M 43 (ASTM C33)
  - LA Abrasion loss – max 50%
  - Soundness
  - Deleterious materials
- Additionally:
  - Resistant to ASR – test by AASHTO T303
  - Resistant to D-cracking – test by T161
  - SG – range < 0.1
  - Absorption – range < 0.8%

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Codes and Standards

- ACI 318, ACI 301, ASTM C94, MasterSpec refer to ASTM C33
- ACI 318-19 likely to state that recycled aggregates or RCA has to be approved by LDP based on performance data

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Japanese Standards

JIS A 5021, 5022 and 5023 (Recycled aggregate for concrete, Recycled Concrete)

	Coarse aggregate		Fine aggregate	
	Density (g/cm³)	Absorption (%)	Density (g/cm³)	Absorption (%)
JIS A5021 (Class H)	2.5 or more	3.0 or less	2.5 or more	3.5 or less
JIS A5022 (Class M)	2.3 or more	5.0 or less	2.2 or more	7.0 or less
JIS A5023 (Class L)	-	7.0 or less	-	13.0 or less

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Dr. Noguchi, U of Tokyo

Applications of Recycled Aggregate

	Scope of application
Class - H	No limitations are put on the type and segment for concrete and structures with a nominal strength of 45MPa or less JIS A 5308 (Ready-mixed concrete) allowing to use Class-H RA for normal strength concrete
Class - M	Members not subjected to drying or freezing-and-thawing action, such as piles, underground beam, and concrete filled in steel tubes
Class - L	Backfill concrete, blinding concrete, and leveling concrete

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Production of RCA

- RCA contains virgin aggregate and old adhered mortar
- Jaw crushers – More coarse RCA but high recycled mortar
- Impact and Cone crushers – Lower coarse RCA but less recycled mortar
- Fine RCA (Minus No. 4) – more mortar

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Characteristics of RCA

Table 1. Comparisons of Some Typical Virgin Aggregate and RCA Properties (Snyder et al 1994)

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 Mass Loss	15% - 30%	20% - 45%
Sodium Sulfate Soundess Mass Loss	7% - 21%	18% - 59%
Magnesium Sulfate Soundess Mass Loss	4% - 7%	1% - 9%
Chloride Content	0 - 2 lb/yd^3 (0 - 1.2 kg/m^3)	1 - 12 lb/yd^3 (0.6 - 7.1 kg/m^3)

Ref: ACPA, Snyder

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Effects on Fresh Properties

Table 4. Effects of RCA on Fresh Concrete Properties and Behavior (after FHWA 2007b, ACI 2001)

Property	Range of expected changes from similar mixtures using virgin aggregates	
	Coarse RCA only	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

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Effects on Hardened Properties

Table 5. Effect of RCA on Physical and Mechanical Properties of Hardened Concrete (after FHWA 2007b, ACI 2001, Hansen 1986)

Property	Range of expected changes from similar mixtures using virgin aggregates	
	Coarse RCA only	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% more	70% to 100% more
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

Slightly lower shear, bond strength

- Adjust mixture proportions to attain performance
- Presence of chlorides

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Effect on Durability

Table 6. Effect of RCA on Concrete Durability (after FHWA 2007b)

Property	Range of expected changes from similar mixtures using virgin aggregates	
	Coarse RCA only	Coarse and Fine RCA
Freeze-thaw durability	Depends upon air void system	Depends upon air void system
Sulfate resistance	Depends upon mixture	Depends upon mixture
ASR	Less susceptible*	Less susceptible*
Carbonization	Up to 65% greater	Up to 65% greater
Corrosion rate	May be faster	May be faster

- FT durability – original RCA air-entrained? Even if not if only using coarse RCA it maybe ok (needs to be tested)
- D cracking can be reduced with crushing < ¾ in.
- ASR, corrosion needs to be mitigated

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Cases of Pavements with RCA

Table 1. Summary of RCA Concrete Pavement Site Locations (Sturtevant, 2007)

Project Location	Route	Site Title	Test Strip Location	Pavement Type
Waterbury, CT	I-84	CT1-1	WB, MP 33.71-33.91	Recycled
		CT1-2	EB, MP 33.94-33.83	Control
Rock Rapids, IA	U.S. 75	IA1-1	n/a	Recycled
		IA1-2	NB, Sta. 1091+00 – 1101+00	Recycled
Effingham, IL	I-57	IL1-1	NB, Sta. 5417+50 – 5427+50	Recycled
		IL1-2	SB, Sta. 5427+50 - 5417+50	Recycled
Johnson Co., KS	K-7	KS1-1	NB, .5 mi. north of 55th St.	Recycled
		KS1-2	SB, 500' from KS River Bridge	Control
Brandon, MN	I-94	MN1-1	WB, MP 90.9-91.1	Recycled
		MN1-2	WB, MP 87.0-87.2	Control
Beaver Creek, MN	I-90	MN2-1	EB, Sta. 89+90 – 100+16	Recycled
		MN2-2	WB, Sta. 100+00 – 90+00	Recycled
Worthington, MN	US 59	MN3	SB, MP 27.00	Recycled
Zumbrota, MN	US 52	MN4-1	NB, Sta. 983+88 – 994+14	Recycled
		MN4-2	NB, Sta. 1035+01 – 1045+27	Control
Menomonie, WI	I-94	WI1-1	EB, MP 39.6-39.8	Recycled
		WI1-2	EB, MP 40.1-40.3	Recycled
Beloit, WI	I-90	WI2-1	WB, MP 176.8-177.0	Recycled
		WI2-2	WB, MP 176.2-176.4	Recycled
Pine Bluffs, WY	I-80	WY1-1	EB, starts 130' ft. east of MP 400	Recycled
		WY1-2	WB, ends 159' W of WY-NE Border	Control

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I10 near Houston, 1995

- RCA used 100% coarse and fine
- Stockpile moisture control
- Lower strength
- TXDOT using fines @ 20% of total fine agg.
- Lower modulus – excellent performance

US59 near Worthington, MN 1980

- Original D cracked agg.
- ¾ in. Top size
- No more D cracking
- Undoweled joints faulted, transverse cracks – lesser aggregate interlock

I80 near Pine Bluff, WY 1985

- Original pavement had severe ASR damage
- RCA from that pavement was used with mitigation
  - Fly ash, blending with natural aggregates
- Some ASR only after 30 years!
- Joint faulting

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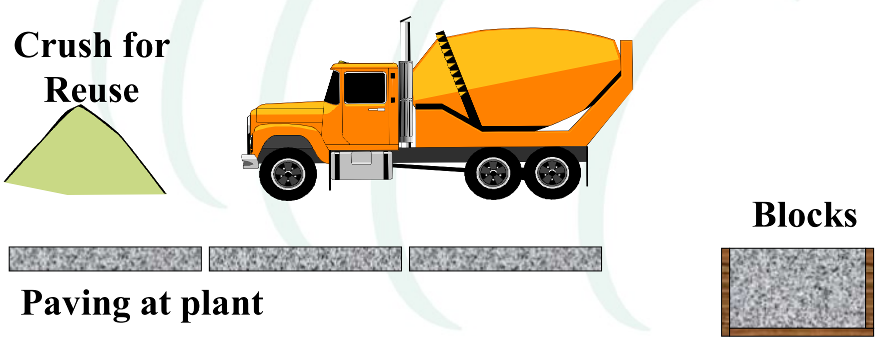
Ready Mixed **Returned** Concrete

- 2017 US RMC production - 350 million yd^3
- Returned Concrete (1 - 5%) ~ 12 million yd^3



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Motivation for Using CCA

- Sustainability – Reduce diversion to landfills
  - 12 million yd^3 = 700 – 10' high foot ball fields/year
- Economic – Costs $100 to $300 Million/yr

Research funded by RMC-REF

- Technical data on concrete containing CCA and evaluate its use in concrete
- Characteristics of CCA
- Effects on Concrete performance
- Guidance on use

- Report published 2007

https://www.nrmca.org/research_engineering/Articles.htm

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CCA - 1000, 3000, 5000 psi Non AE

Aggregate Characterization

Volume of plus No. 4 = 60% to 70%

- Specific Gravity, Absorption
- Sieve Analysis
- Materials Finer than 75-µm (No. 200) Sieve
- Unit Weight and Voids
- LA Abrasion
- Organic Impurities in Fine Aggregates
- Uncompacted Void Content of Fine Aggregate
- Sodium Sulfate Soundness
- Sand Equivalent Value of Soils and Fine Aggregate

Coarse CCA properties

	1000	3000	5000	Control	ASTM C 33
LA Abrasion, %	23.8	26.0	-	13.2	50
Specific Gravity	2.56	2.54	2.58	2.92	NA
Absorption, %	4.40	4.31	4.32	0.86	NA
Minus 200, %	1.13	0.65	0.32	0.37	1 – 1.5
Soundness, %	22.84	8.24	-	0.46	12

- NMSA = 1 to 1.5 in.

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Fine CCA properties

	1000	3000	5000	Control	ASTM C 33
Specific Gravity	2.17	2.25	2.27	2.61	NA
Absorption, %	11.90	10.25	10.03	0.95	NA
Minus 200, %	7.31	9.50	7.64	1.40	5 – 7
Soundness, %	31.19	16.28	-	2.72	10

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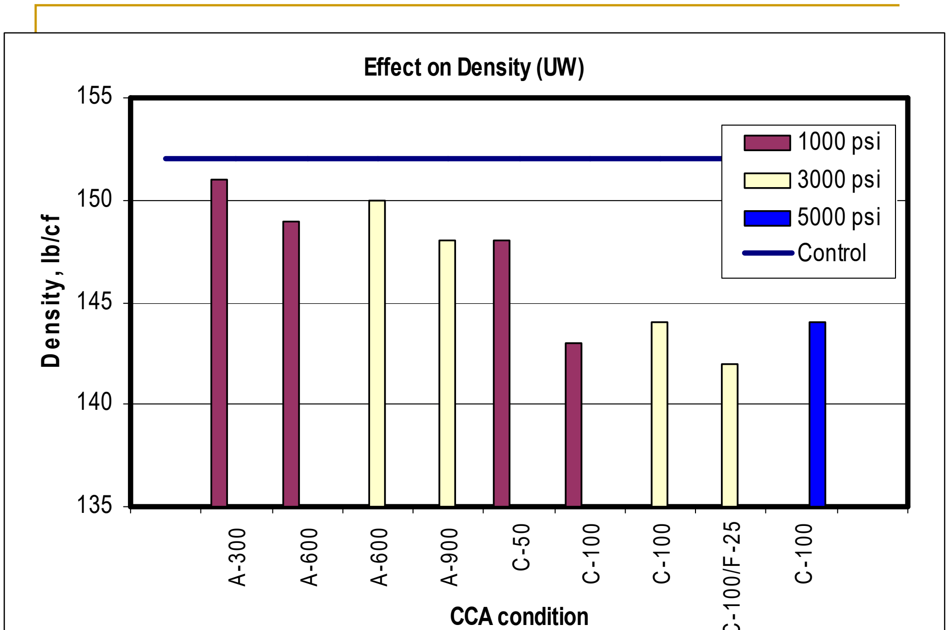
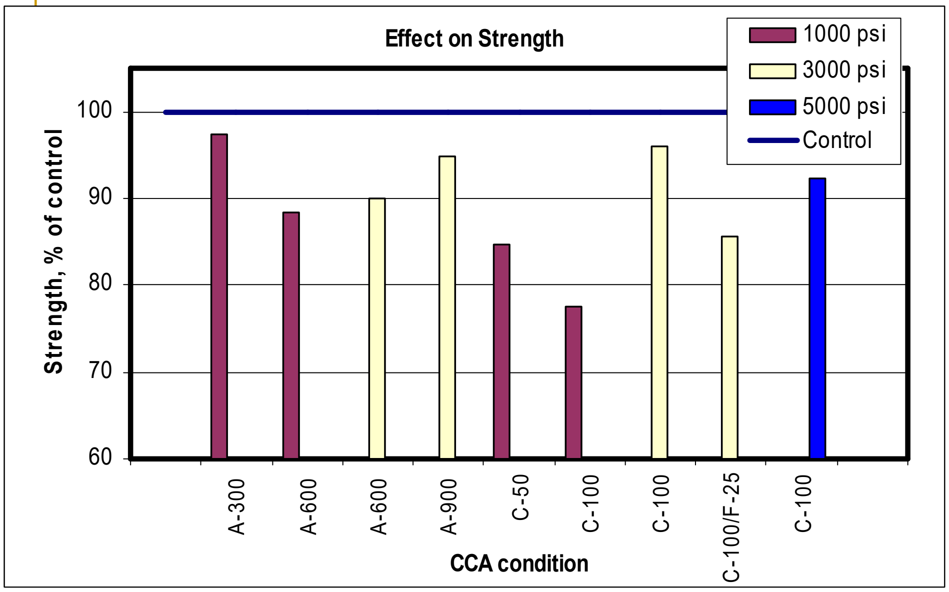
Mixture proportions

- 17 Non-AE mixtures
  - Cement = 500 pcy, slump 5-7 in., w/cm=0.57
  - CCA "as received" – 300, 600, 900 lb/yd^3
  - CCA sieved as "coarse" - 50/100% of virgin
- 4 AE mixtures
  - Cement=564 pcy, slump 6-8 in., w/cm=0.45, HRWR





Control Strength = 4100 psi

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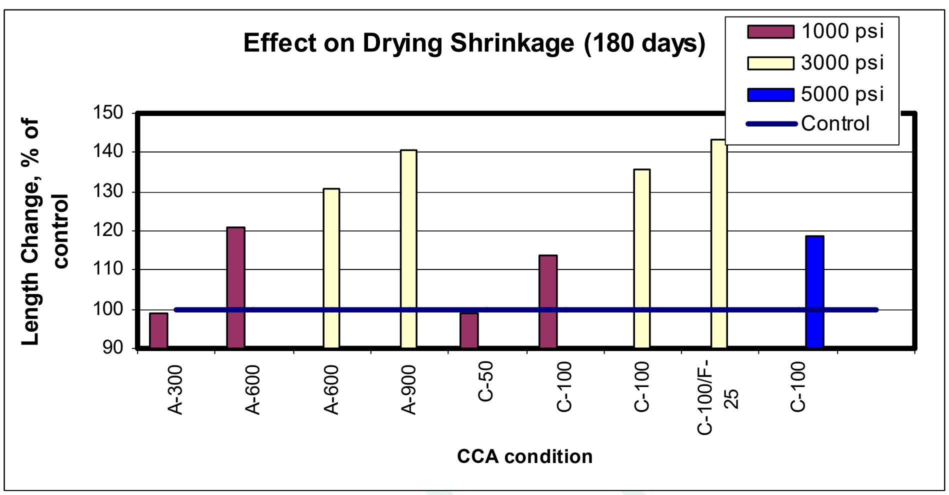

180 day Control Length Change = 0.041%

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Discussions of results

- Similar water demand
- Setting time
  - Accelerated by 30 to 60 min
- Elastic Modulus
  - 'as received" – 6% to 17% (avg. 11%) lower
  - "Coarse CCA" – 6% to 28% (avg. 19%) lower
- RCP (coulombs)
  - 'as received" – negligible change, actually lower
  - "Coarse CCA" – 34% to 105% (avg. 64%)

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Alkali Silica Reactivity (ASTM C1293)

Mix Description	ASTM C1293 Expansion %, 1 yr
No.57 Virgin Coarse + Virgin Crushed Fine	0.022
No.57 Virgin Coarse + 600 lbs/yd^3 CCA + Virgin Crushed Fine	0.027
Coarse 3000 CCA + Virgin Crushed Fine	0.032
No.57 Virgin Coarse + Fine 3000 CCA	0.028

ASTM C1293 "Reactive" > 0.04%

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Freeze Thaw Resistance

	Control	1000 - 600	3000 - 600	3000 – 100% coarse
ASTM C666 Durability Factor, %	92	13*	9	89
ASTM C231 Air Content, %	6.4	4.8	5.6	8.5

- Original CCA made from non AE concrete
- F-T resistance may need evaluation

Slump Retention

	SL-1	SL-2	SL-3	SL-4
CCA Type	0	1000	3000	3000
CCA, lbs/yd^3	0	300	NA	NA
CCA, coarse, %	0	NA	100	100
Slump Retention Study				
Slump, inch				
Slump1	6.50	7.00	7.25	6.75
Slump2 (30 min agitation)	5.75	4.00	6.00	4.50
Slump3 (water added @ 30 min)	6.00	7.00	6.50	7.50
Slump loss, % of slump1	11.5%	42.9%	17.2%	33.3%
Water Adjustment, lbs/yd^3				
Slump2 $\rightarrow$ Slump3	14	17	12	17
Compressive Strength at 14 days, psi				
Sampled with Slump1	4340	4340	4100	3870
Sampled with Slump3	4240	3840	4020	3960

Economics of CCA (Returned RCA)

- Cost of disposal
- Cost of beneficiation
  - Additional crushing, sizing, strength classification
- Aggregate costs
- Performance reduction and costs
- Additional quality costs
- Ability to use CCA

Separate into size fraction vs strength class

Options for Concrete Producer

- No processing
  - 300 lbs/yd^3 (10% of aggregate)
- Divert strength>3000 psi, Do not retemper while discharging; crush after 14 days.
  - 900 lbs/yd^3 (30% of aggregate)
  - Accelerated set, higher shrinkage, F-T resistance
- Step II + Separate into coarse fraction
  - 100% Coarse CCA (1600 lbs/yd^3) (60% of aggregate)
  - Accelerated set, higher shrinkage, higher RCP

RCA at the Concrete Plant

- RCA stockpile
  - Runoff initially has high alkalinity leaching
  - Agglomeration
  - Need to keep wet like light weight aggregate
- More frequent evaluation of aggregate properties
  - absorption, relative density

RCA Mixture Development

- Possibly higher standard deviation
- Coarse aggregate volume same as virgin aggregates

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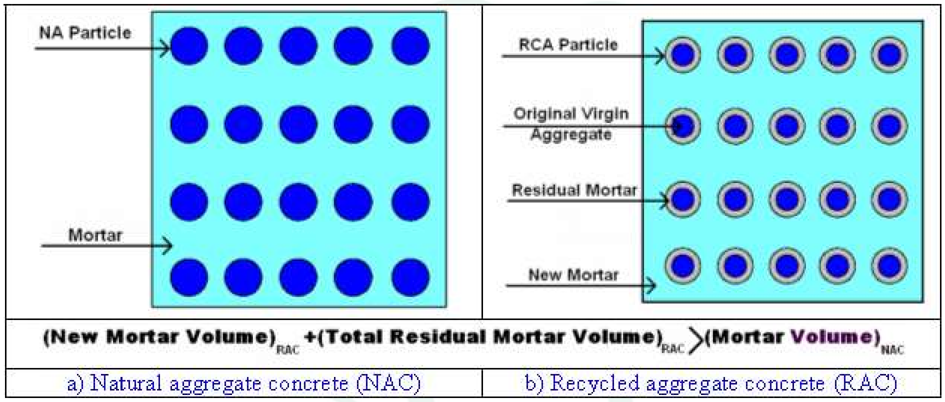
Mixture Proportioning Concept



Fathifazl et. al. Concrete International, March 2010

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International Experiences

- Germany (2000)
  - 90 million tons C&D Waste – 70% reused
  - Concrete aggregate
    - Coarse only @ max 20-45% depending on exposure
    - SG > 2.0; Abs <10%
    - Max Strength class - C30 (4300 psi)

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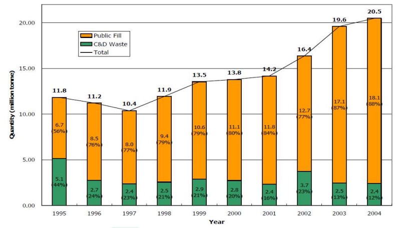
International Experiences

- Hong Kong
  - Most use in fill and base

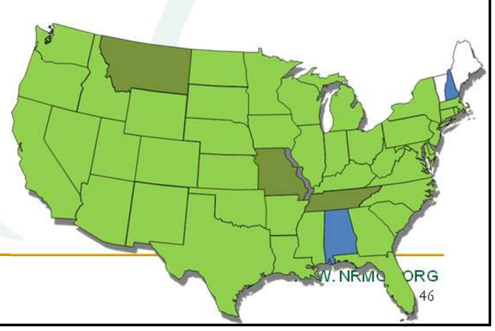


- Netherlands
  - 20 million tons (1.25 per capita)
  - 95% reused
    - 88% fill and base
    - 3% in concrete

FHWA Concrete Recycling Initiative

- Part of FHWA Sustainable Concrete Pavement Program
  - Program Goals: Encourage innovation and extended application of sustainable pavement technologies on projects
- Concrete Recycling Initiative – promote recycling of concrete pavement materials in cost-effective applications while optimizing the triple bottom line (social, environmental, economic)

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



http://www.cptechcenter.org/concrete-recycling/

1) Introduction to Concrete Pavement Recycling

2) Environmental Considerations in Concrete Pavement Recycling

3) Construction Considerations in Concrete Pavement Recycling

4) Case Studies in Concrete Pavement Recycling

New Developments

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Fresh Concrete to Aggregate

Component A

Add bags and mix at high speed for 3 minutes

Component B

Add bags and mix at high speed for 3 to 5 minutes

Courtesy: ARGOS

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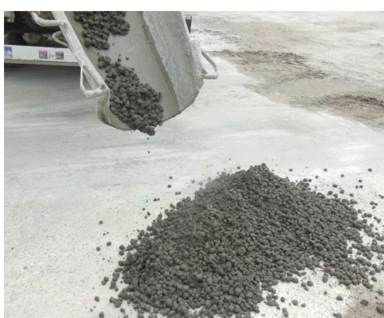
Fresh Concrete to Aggregate



MATERIAL LEFT FOR ~6 HOURS TO SET

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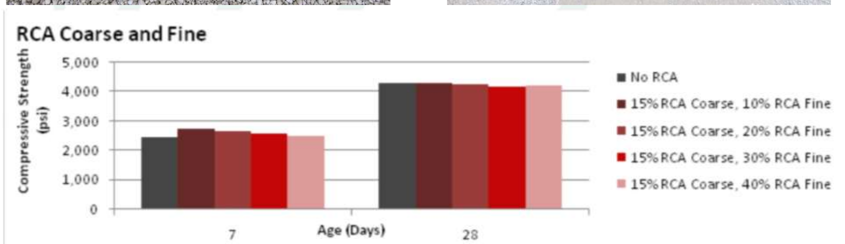
Courtesy: ARGOS

Fresh Concrete to Aggregate



Courtesy: Central Concrete WWW. NRMCA.ORG

ASTM Specification

ASTM C1798-16 – Specification for Returned Fresh Concrete for Use in a New Batch of Ready-Mixed Concrete

fresh concrete not yet discharged from a ready-mixed concrete transportation unit when it is returned to the manufacturer.

- Does not grant permission for use
  - Purchaser shall be notified of use (in C94)
- Does not apply to less than 1000 lb (0.25 yd^3)
- Quantity of returned concrete to nearest
  - 1000 lb or 0.25 yd^3

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ASTM C1798 - Requirements

- If age > 90 min use hydration stabilizing admixture
- Age of returned load (with HSA) less than 8 hours
- Temperature before loading shall be < 100°F
  - Cannot be cooled to get to this temp
- Specified strength of returned load should be equal to or greater than that for new load
- Volume of returned load < 50% of new load

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ASTM C1798 - Reporting

- Quantity of returned concrete in load
- At request of purchaser
  - Time original load batched (of returned load)
  - Info necessary to calculate total mixing water
  - Temperature of returned load before new material added

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Recycled Concrete - Conclusions

- Supports sustainable construction
- Allowed by standards
- Desired performance of concrete with RCA can be attained
  - Improved quality control maybe needed
- Economics – possible cost savings

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Recycled Concrete as an Aggregate

Thank you

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