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Recycled Wash Water
Crushed Returned Concrete

National Concrete Consortium
March 2012
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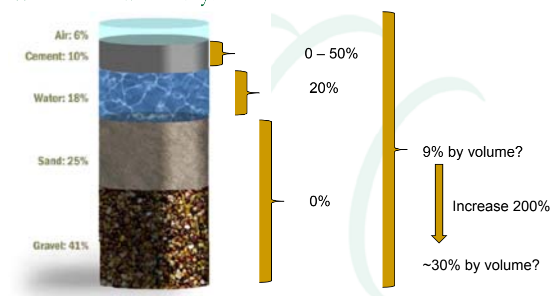
NRMCA Sustainability Initiatives

Key Performance Indicators

- Potable water:
  - 10% reduction by 2020
  - 20% reduction by 2030
- Waste:
  - 30% reduction by 2020
  - 50% reduction by 2030
- **Recycled content:**
  - **200% increase by 2020**
  - **400% increase by 2030**

Recycled Content:
Where are we today?



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NRMCA Sustainability Initiatives

Recycled content:
200% increase by 2020
400% increase by 2030

- Potable water:
  - 10% reduction by 2020
  - 20% reduction by 2030
- Waste:
  - 30% reduction by 2020
  - 50% reduction by 2030

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"Waste" to "Recycled"

- Returned Concrete - estimated 2 - 10% of production
  - 8 to 12 million cubic yards
- Truck and Mixer Washout
  - 50 to 200 gallons per truck
- Need to manage
  - Storm Water
  - Process Water
  - Aggregates and Cement Solids
- Comply with environmental regulations

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1950's: This is Not New!

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The future…

- CO_2 is passé!
- Water – the NEW GOLD

Water & Solids Management

Recycling Water

Challenge: Recycle Water

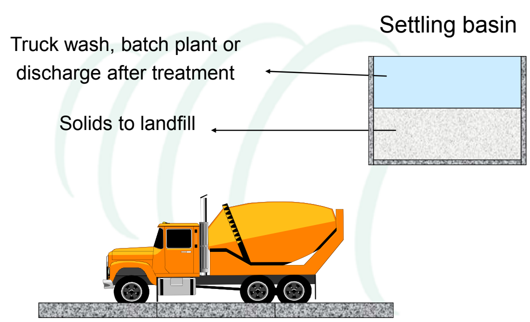
- Specification Clauses
  - Mixing water for use in concrete shall be potable
  - Water used in concrete shall be clean and free oil, salt, acid, alkali, sugar, vegetable or other substances injurious to the finished product

Water and Solids Management

Vary from simple to complex:

1. Pit or sedimentation ponds
2. Recycle clarified water
3. Basic reclaimers
4. Reclaimers - “Zero-discharge”
5. Reclaimers - “100% recycling” system w/HSAs

Typical



Sedimentation (Washout) Basin
w/Water Transfer Capability

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Basic Reclaimer System

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Drying Extracted Solids

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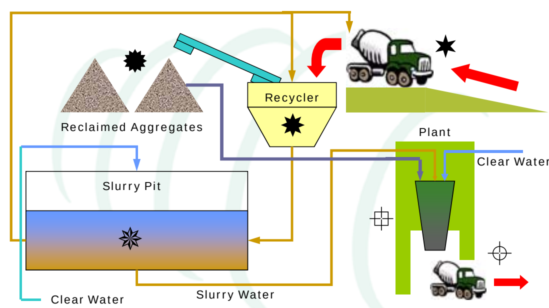
Zero Discharge



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Research – Use of wash water

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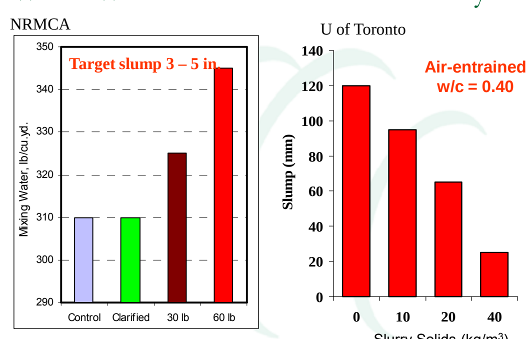
Wash Water: Effect on Consistency



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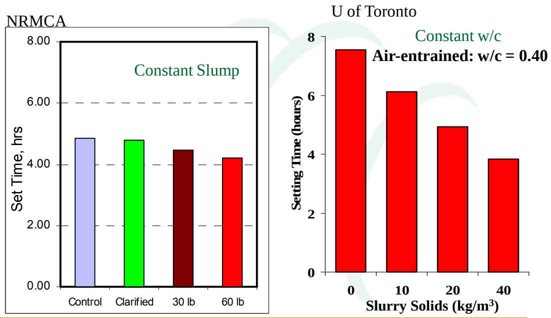
Wash Water: Effect on Setting Time



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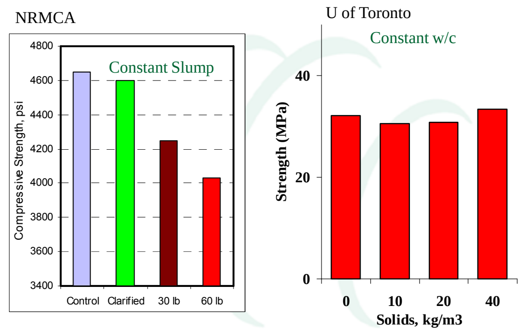
Wash Water: Effect on Strength



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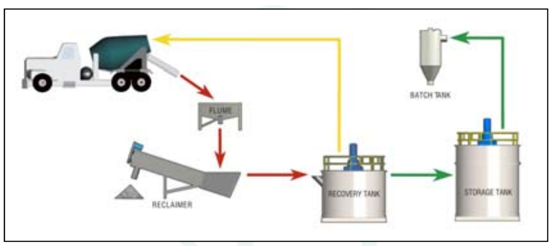
Zero Discharge - HSA



Courtesy: Knelson Concrete Recovery Systems

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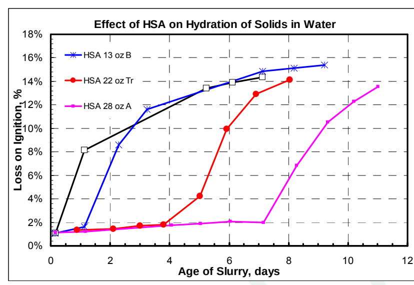
Hydration Stabilizing Admixtures



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Zero Discharge - HSA

Courtesy: Knelson

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Zero Discharge: w/ HSAs

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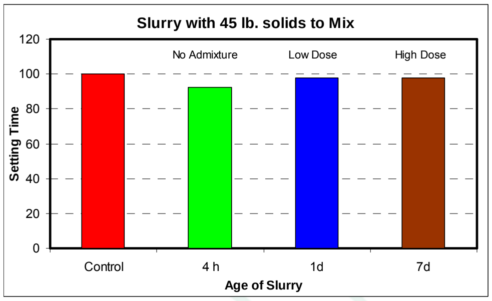
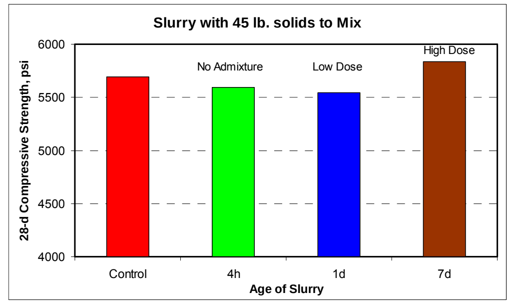
Wash Water/HSA: Effect on Setting Time



Wash Water/HSA: Effect on Strength



Reclaimers w/Gray Water Recycling

Gray Water Recycling

- Monitoring gray water
  - Specific gravity
  - Temperature
  - Age
- Plumbing, back-flush
- Special water meters,
- Maintenance
- QC buy-in
- Commitment and Training!

MIXING WATER SHALL BE POTABLE

ASTM C1602 - Mixing Water

- Types
  - Potable
  - Non-potable
  - Water from ready mixed production
- Qualify for use
  - Strength
  - Setting time
- Optional
  - Chemistry
  - Solids
- Testing Frequency

C 1602 – Qualification of Water

TABLE 1 Concrete Performance Requirements for Mixing Water (Mandatory)

	Limits	Test Methods
Compressive strength, min % control at 7 days [A]	90	C 31/C 31M, C 39/C 39M
Time of set, deviation from control, h: min [A]	From 1:00 early to 1:30 later	C 403/C 403M

[A] Comparisons shall be based on fixed proportions for a concrete mix design representative of questionable water supply and a control mix using 100 % potable water or distilled water. (See Annex A1).

C 1602 – Qualification of Water

TABLE 2 Optional Chemical Limits for Combined Mixing Water (Optional)

Max conc. in combined water	Limits, ppm	Test Methods
Chloride as Cl^-		
prestressed	500	C 114
other reinforced concrete	1000	C 114
Sulfate as SO_4	3000	C 114
Alkalies as (Na_2O + 0.658 K_2O)	600	C 114
Total solids by mass	50,000	C 1603

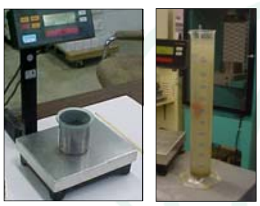
C 1602 – Qualification of Water

Testing Frequencies at Most Critical Condition

Water source	Density	Table 1	Table 2
Potable	No testing		
Non Potable	N/A	3 months /(4)/ annual	6 months
Wash Water (based on density)			
< 1.01	Daily	6 months /(2)/ annual	6 months
1.01 – 1.03	Daily	Monthly /(4)/ 3 months	6 months
>1.03	Daily	Weekly /(8)/ monthly	6 months

Water source has to be tested before first use
Testing frequency can be reduced after number of tests (#) indicate compliance

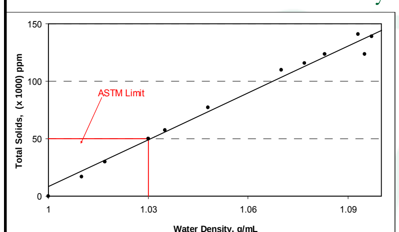
ASTM C 1603 – Density and Solids Content



Density

Solids Content

ASTM C 1603 – Correlation between Density and Solids



D_W – Density of Slurry
D_S – Density of solids (2.6)
S_{ppm} – Solids in slurry, ppm

$$S_{ppm} = \left(\frac{D_W - 1}{D_S - 1}\right) \times \frac{D_S}{D_W} \times 1{,}000{,}000$$

Gray Water Blend Chart

based on specific gravity of gray water

% Gray Water / Tap Water (Based on sp. gr. of Gray Water)

per ASTM C-94 Optional Table 3
(Limit of Total Solids in Mixing Water = 50,000 ppm)
Chart Based on 35 gal. Water/ 500 lb. Cement Mix Design

Gray Water Specific Gravity	% Gray Water	% Tap Water
1.01	100%	0%
1.02	100%	0%
1.03	99%	1%
1.04	79%	21%
1.05	64%	36%
1.06	54%	46%
1.07	46%	54%
1.08	41%	59%
1.09	37%	63%
1.10	33%	67%
1.11	31%	69%
1.12	28%	72%
1.13	26%	74%
1.14	25%	75%
1.15	23%	77%
1.16	22%	78%
1.17	21%	79%
1.18	20%	80%
1.19	19%	81%
1.20	18%	82%

AASHTO T26-79 (2004)

- Acidity and Alkalinity
  - Indicator method
  - Hydrogen ion concentration – pH
- Chloride ion concentration – ASTM D512
- Sulfate ion concentration – ASTM D516
- Total Solids and Inorganic Matter
  - Dried solids and loss on ignition
  - Autoclave expansion – T107
  - Time of setting (cement) – T131
  - Mortar Strength – T106

International Standards

Parameter	EN 1008	ASTM C94	AS 1379
Cl^- content	≤500 mg/L (prestressed concrete/grout) ≤1000 mg/L (reinforced concrete) ≤4500 mg/L (without reinforcement)	Optional requirement: ≤500 ppm (prestressed concrete or bridge decks) ≤1000 mg/L (reinforced concrete)	Specified as a total limit for concrete. Acid-soluble chloride ion content shall not exceed 0.8 kg/m^3
SO_4^{2-} content	≤2000 mg/L (otherwise, water fit for use in certain cases only*)	Optional requirement: Sulfate as SO_4 ≤3000 ppm	Specified as a total limit for concrete. Acid-soluble sulfate-ion content, reported as SO_3, shall not exceed 50 g/kg of cement.
Suspended solid matter	Recommendation: ≤1% of the total amount of aggregate in concrete	Optional requirement: Total solids by mass ≤50,000 ppm	Not specified.
Other impurities and harmful contaminants	Preliminary inspections for oils and fats, detergents, colour, odour, acids and humic matter (see Table 1 of Standard). Alkali as Na_2O_{eq}† ≤ 1500 mg/L* Sugars < 100 mg/L Phosphate, P_2O_5 < 100 mg/L Nitrates, NO_3^- ≤500 mg/L Lead, Pb^{2+} ≤ 100 mg/L Zinc, Zn^{2+} ≤100 mg/L	Optional requirement: Alkalies as Na_2O_{eq} ≤600 ppm. Density as QC tool for combined water.	Sugar < 100 mg/L Oil and grease <50 mg/L pH >5.0
Comparative samples strength	The mean 7-day and 28-day compressive strength of the mortar or concrete samples prepared with wash water must be at least 90% of the mean strength of the control samples (prepared with distilled or tap water)	The mean 7-day compressive strength of the mortar or concrete samples prepared with the water must be at least 90% of the mean strength of the control samples (prepared with distilled or potable water).	7-day and 28-day compressive strength of concrete made with water from a source with no service record must be at least 90% of the mean strength of the control samples (prepared with water from a stable reticulated drinking water supply).
Setting times	Initial set ≥1 h and final set ≤12 h with both not differing by more than 25% from control.	From 1:00 hr earlier to 1½ hrs later than control.	Initial set from 60 min earlier to 90 min later than control sample time.

*ie the final assessment depends on an assessment of each individual case and/or the comparative concrete test
† Na_2O_{eq} is Na_2O+0.658 K_2O

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Suggestion

- State highway specifications need to consider updating standards and permitting the use of non-potable water

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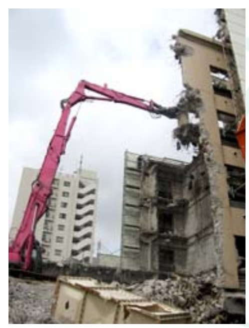
Crushed Concrete Aggregate (CCA)

RCA – Building demolition



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RCA - Pavements


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Returned Concrete (CCA)



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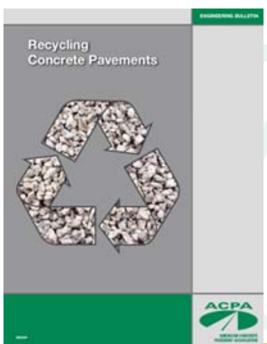
CCA - Aggregate in Concrete

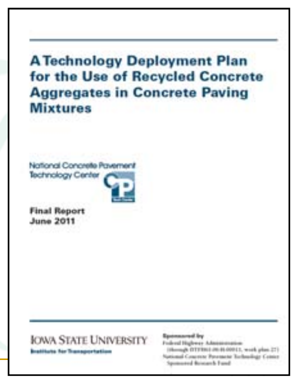
- Sustainability: Reduce landfill burden
  - 15 million yd^3 / year (≈ 845 10'-high foot ball fields)
- Economy: $300 Million/yr

Considerations

- Quality and uniformity
  - Meets specification
- Economics
  - Cost / processing
  - Credit for green construction
- Permitted by project specifications?
- Impact on production
- Impact on concrete properties
- What applications?

Initiatives





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

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	Range of expected changes from similar mixtures using virgin aggregates: 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

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	Range of expected changes from similar mixtures using virgin aggregates: 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

Effect on Durability

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

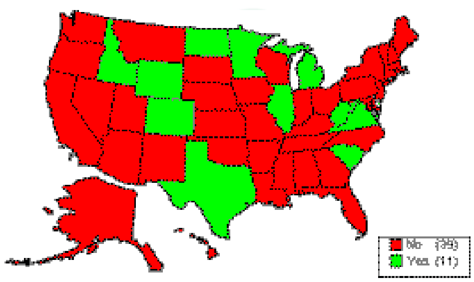
Property	Range of expected changes from similar mixtures using virgin aggregates	
	Coarse RCA only	Coarse and Fine RCA
Freeze-thaw durability	Depends upon air void system	Depends upon air void system
Sulfate resistance	Depends upon mixture	Depends upon mixture
ASR	Less susceptible*	Less susceptible*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

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

States using RCA as aggregate



http://www.fhwa.dot.gov/pavement/recycling/rca.cfm

Is it permitted?

- ASTM C33
  - 9.1 Coarse aggregate shall consist of gravel, crushed gravel, crushed stone, air-cooled blast furnace slag, or **crushed hydraulic cement concrete**
  - Note 6 – cautions.
- ASTM C125
  - Manufactured sand – fine aggregate produced by crushing rock, gravel, iron blast-furnace slag, or **hydraulic cement concrete**

AASHTO MP 16-07

- Reclaimed Concrete Aggregate for use as Coarse Aggregate in Hydraulic Cement Concrete
- "Reclaimed concrete aggregate" (RCA)
  - derived from crushing, processing and classification of hydraulic concrete construction debris recovered from roadways, sidewalks, buildings, bridges, and other sources…

AASHTO MP 16-07

- Grading – same as M 43 (ASTM C33)
- LA Abrasion loss – max 50%
- Soundness
  - Sodium sulfate – 12%
  - Magnesium sulfate – 18%
- Resistant to ASR – test by AASHTO T303
- Resistant to D-cracking – test by T161
- SG – range < 0.1
- Absorption – range < 0.8%

AASHTO MP 16-07

- Deleterious materials
  - Class A (severe), B (moderate), C (negligible)
  - Limits on clay lumps, friables and chert
  - Limit on "other deleterious substances" <0.3%
  - Limit on coal and lignite <0.2%
  - Minus No. 200 < 1.5%
  - Chloride ions <0.6 lb per cubic yard.

Japanese Standards

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

	Coarse aggregate		Fine aggregate	
	Density (g/cm^3)	Absorption (%)	Density (g/cm^3)	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

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

Dr. Noguchi, U of Tokyo

Research funded by RMC - REF

- Technical data on concrete containing CCA and evaluate its use in concrete
- Properties of CCA
  - Revisions to standards? (C 33)
- Concrete performance
- Guidance on use

http://www.nrmca.org/research/eng_articles.asp

NRMCA Research

- CCA - 1000, 3000, 5000 psi Non AE

http://www.nrmca.org/research/eng_articles.asp

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

- No organics

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CCA and ASTM C 33

- Coarse CCA
  - Meets C33 except soundness (1000 psi)
  - Sect 11.3 accepts with concrete performance
- Fine CCA
  - Meets C33 except minus 200, soundness
  - Sect 6.3, 8.3 accepts with concrete performance
- Did not test - clay, friable, coal/lignite, chert
- No aggregate specification revisions required

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Concrete Tests

- Slump, Air, Unit weight, Setting Time
- Compressive strength (7, 28, 90 days)
- Elastic modulus (28 days)
- Shrinkage (7 day moist dry till 180 days)
- Chloride Ion Penetration - RCPT (90 days)
- ASTM C1293 ASR
- ASTM C666 Freeze Thaw Durability

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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 pcy
  - CCA sieved as "coarse" - 50/100% of virgin
  - 3 mixtures repeated
  - Varied mixing and aggregate processing
- 4 AE mixtures
  - Cement=564 pcy, slump 6-8 in., w/cm=0.45, HRWR

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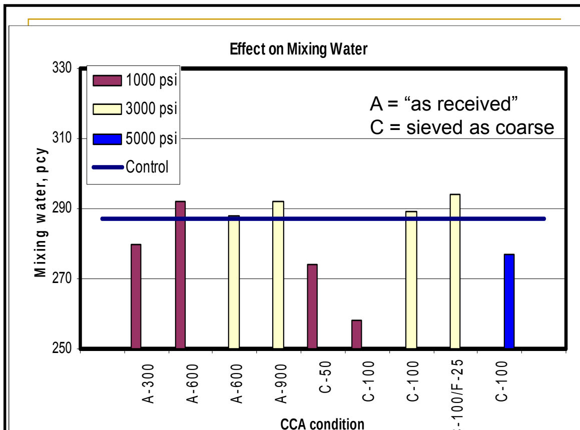

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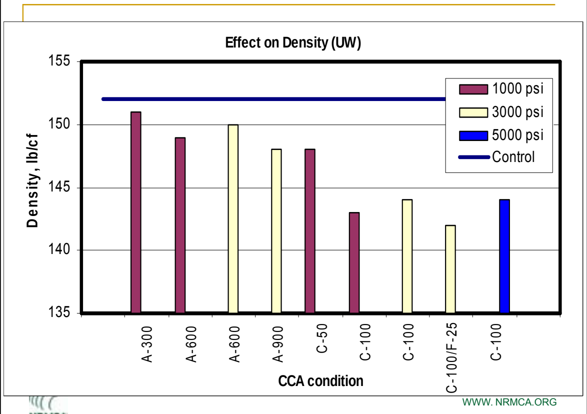
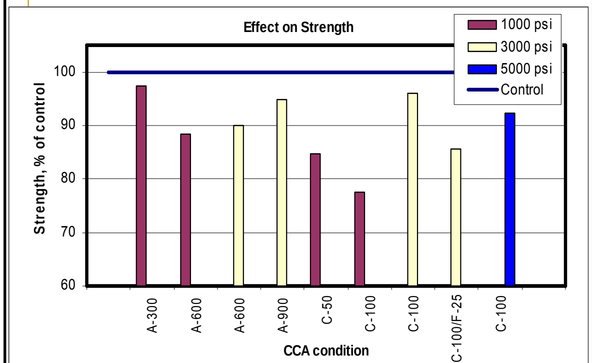
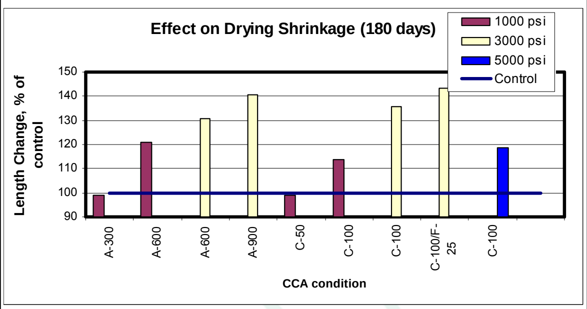




Control Strength = 4100 psi



180 day Control Length Change = 0.041%

Discussions of results

- 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%)

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 Pile1 CCA + Virgin Crushed Fine	0.027
Coarse fraction of 3000 psi CCA + Virgin Crushed Fine	0.032
No.57 Virgin Coarse + Fine fraction of 3000 psi CCA	0.028

Freeze Thaw Resistance

- As is - 1000-600 pcy and 3000-600 pcy failed;
  - Fine fraction of CCA?
- Original CCA made from non AE concrete
- Higher air contents needed for CCA mixes?

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 → 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

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Guidance to Producer

- **Step I** No processing
  - 300 lbs/yd^3
- **Step II** Divert strength>3000 psi, crush after 14 days
  - 900 lbs/yd^3
  - Accelerated set, higher shrinkage, F-T resistance
- **Step III** Step II + Separate into coarse fraction
  - 100% Coarse CCA (1600 lbs/yd^3)
  - Accelerated set, higher shrinkage, higher RCP
- Do not retemper while discharging
- Frequently measure absorption, relative density
- Develop database of concrete properties

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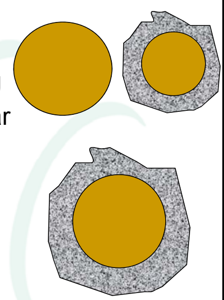
Proportioning mixtures

Equivalent Mortar Method
- Equivalent volume virgin agg
- Old mortar part of new mortar



- Similar performance
  - Fresh
  - Mechanical
  - Durability

Fathifazl et al, Concrete International, March 2010

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What do we need?

Concrete needs to meet
- Quality
- Purchasers requirements
- Specifications

Challenges:
- Economic incentive
- Credit for sustainable construction
- More attention to quality control

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Sustainability will drive the future

Does it make ECONOMIC sense

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Recycled Wash Water
Crushed Returned Concrete

Questions