Recycled Wash Water
Crushed Returned Concrete
National Concrete Consortium
March 2012
Colin Lobo, Ph.D., P.E.

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?

Recycled Content:
Where are we today?

“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

1950’s: This is Not New!
The future…

- CO₂ 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

- Truck wash, batch plant or discharge after treatment
- Settling basin
- Solids to landfill
Sedimentation (Washout) Basin
w/Water Transfer Capability

Basic Reclaimer System

Drying Extracted Solids

Zero Discharge

Research – Use of wash water

Wash Water: Effect on Consistency
Wash Water/HSA: Effect on Setting Time

<table>
<thead>
<tr>
<th>Slurry with 45 lb. solids to Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Admixture</td>
</tr>
<tr>
<td>Control</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Setting of Slurry</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Admixture</td>
<td>Low Dose</td>
</tr>
<tr>
<td>Control</td>
<td>4h</td>
</tr>
</tbody>
</table>

Wash Water/HSA: Effect on Strength

<table>
<thead>
<tr>
<th>Slurry with 45 lb. solids to Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Admixture</td>
</tr>
<tr>
<td>Control</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strength, psi</th>
<th>No Admixture</th>
<th>Low Dose</th>
<th>High Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>4h</td>
<td>1d</td>
<td>7d</td>
</tr>
</tbody>
</table>

Reclaimers w/Gray Water Recycling

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

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>
<thead>
<tr>
<th>TABLE 1 Concrete Performance Requirements for Mixing Water (Mandatory)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limits</td>
</tr>
<tr>
<td>Compressive strength, min % control at 7 days ^</td>
</tr>
<tr>
<td>Time of set, deviation from control, h: min ^</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Max conc. in combined water</th>
<th>Limits, ppm</th>
<th>Test Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride as Cl(^{-}) prestressed other reinforced concrete</td>
<td>500</td>
<td>C 114</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>Sulfate as SO(_4^{2-})</td>
<td>3000</td>
<td>C 114</td>
</tr>
<tr>
<td>Alkalies as (Na(_2)O + 0.658 K(_2)O)</td>
<td>600</td>
<td>C 114</td>
</tr>
<tr>
<td>Total solids by mass</td>
<td>50,000</td>
<td>C 1603</td>
</tr>
</tbody>
</table>

**Testing Frequencies at Most Critical Condition**

<table>
<thead>
<tr>
<th>Water source</th>
<th>Density</th>
<th>Table 1</th>
<th>Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potable</td>
<td>No testing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non Potable</td>
<td>N/A</td>
<td>3 months (4)/ annual</td>
<td>6 months</td>
</tr>
<tr>
<td>Wash Water (based on density)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 1.01</td>
<td>Daily</td>
<td>6 months (2)/ annual</td>
<td>6 months</td>
</tr>
<tr>
<td>1.01 – 1.03</td>
<td>Monthly (4)/ 3 months</td>
<td>Weekly (6)/ monthly</td>
<td></td>
</tr>
<tr>
<td>&gt;1.03</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

**ASTM C 1603 – Density and Solids Content**

Density

Solids Content

**Gray Water Blend Chart based on specific gravity of gray water**

**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

Suggestion

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

Crushed Concrete Aggregate (CCA)

RCA – Building demolition

RCA - Pavements

Returned Concrete (CCA)
CCA - Aggregate in Concrete

- Sustainability: Reduce landfill burden
  - 15 million yd³ / 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

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

Characteristics of RCA

<table>
<thead>
<tr>
<th>Property</th>
<th>Virgin Aggregate</th>
<th>RCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape and Texture</td>
<td>Well-rounded &amp; smooth to angular &amp; rough</td>
<td>Angular with rough surface</td>
</tr>
<tr>
<td>Absorption Capacity</td>
<td>0% – 3.5%</td>
<td>1% – 3.5%</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>2.4 – 2.9</td>
<td>2.1 – 2.6</td>
</tr>
<tr>
<td>L.A. Abrasion Loss</td>
<td>15% – 30%</td>
<td>20% – 40%</td>
</tr>
<tr>
<td>Sodium Sulfate Soundness Loss</td>
<td>7% – 21%</td>
<td>18% – 35%</td>
</tr>
<tr>
<td>Sulfate Soundness Loss</td>
<td>0% – 7%</td>
<td>0% – 7%</td>
</tr>
<tr>
<td>Chloride Content</td>
<td>0 – 2% (lb/yd³)</td>
<td>1 – 12 (lb/yd³)</td>
</tr>
</tbody>
</table>

Ref: ACPA, Snyder

Effects on Fresh Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Range of expected change from similar mixture using virgin aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workability</td>
<td>Similar to similar lower</td>
</tr>
<tr>
<td>Freshability</td>
<td>Similar to more difficult</td>
</tr>
<tr>
<td>Workability</td>
<td>Greater</td>
</tr>
<tr>
<td>Water demand</td>
<td>Greater</td>
</tr>
<tr>
<td>Air content</td>
<td>Slightly higher</td>
</tr>
</tbody>
</table>

Effects on Hardened Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Range of expected change from similar mixture using virgin aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength</td>
<td>5% to 20% lower</td>
</tr>
<tr>
<td>Tenacity strength</td>
<td>5% to 15% less</td>
</tr>
<tr>
<td>Sound absorption</td>
<td>Slowly, greater</td>
</tr>
<tr>
<td>Moisture absorptivity</td>
<td>10% to 50% less</td>
</tr>
<tr>
<td>CTE</td>
<td>0% to 10% greater</td>
</tr>
<tr>
<td>Drying shrinkage</td>
<td>10% to 15% more</td>
</tr>
<tr>
<td>Creep</td>
<td>30% to 60% greater</td>
</tr>
<tr>
<td>Permanency</td>
<td>0% to 50% greater</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>0% to 10% lower</td>
</tr>
</tbody>
</table>
Effect on Durability

<table>
<thead>
<tr>
<th>Property</th>
<th>Coarse RCA (no mix)</th>
<th>Coarse RCA 60/70</th>
<th>Basalt gravel</th>
<th>Basalt gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse aggregate durability</td>
<td>Depends upon mix</td>
<td>Depends upon mix</td>
<td>Depends upon mix</td>
<td>Depends upon mix</td>
</tr>
<tr>
<td>Sulfate resistence</td>
<td>Depends upon mixture</td>
<td>Depends upon mixture</td>
<td>Depends upon mixture</td>
<td>Depends upon mixture</td>
</tr>
<tr>
<td>ASR</td>
<td>Less susceptible</td>
<td>Less susceptible</td>
<td>Less susceptible</td>
<td>Less susceptible</td>
</tr>
<tr>
<td>Graduation</td>
<td>Up to 65% greater</td>
<td>Up to 65% greater</td>
<td>Up to 65% greater</td>
<td>Up to 65% greater</td>
</tr>
<tr>
<td>Coarseness ratio</td>
<td>May be flatter</td>
<td>May be flatter</td>
<td>May be flatter</td>
<td>May be flatter</td>
</tr>
</tbody>
</table>

Cases of Pavements with RCA

<table>
<thead>
<tr>
<th>States using RCA as Aggregate</th>
<th>Is it permitted?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ASTM C33</td>
</tr>
<tr>
<td></td>
<td>9.1 Coarse aggregate shall consist of gravel, crushed gravel, crushed stone, air-cooled blast furnace slag, or crushed hydraulic cement concrete</td>
</tr>
<tr>
<td></td>
<td>Note 6 — cautions.</td>
</tr>
<tr>
<td></td>
<td>ASTM C125</td>
</tr>
<tr>
<td></td>
<td>Manufactured sand – fine aggregate produced by crushing rock, gravel, iron blast-furnace slag, or hydraulic cement concrete</td>
</tr>
</tbody>
</table>

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

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)

<table>
<thead>
<tr>
<th>Coarse aggregate</th>
<th>Fine aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>Absorption (%)</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>Absorption (%)</td>
</tr>
<tr>
<td>JIS A5021 (Class H)</td>
<td>2.3 or more</td>
</tr>
<tr>
<td>JIS A5022 (Class M)</td>
<td>2.3 or more</td>
</tr>
<tr>
<td>JIS A5023 (Class L)</td>
<td>-</td>
</tr>
</tbody>
</table>

Applications of Recycled Aggregate

<table>
<thead>
<tr>
<th>Scope of application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class - H (No limitations are put on the type and segment for concrete and structures with a nominal strength of 45MPa or less. Revisions to standards? (C 33) Allowing to use Class-H RA for normal strength concrete)</td>
</tr>
<tr>
<td>Class - M (Members not subjected to drying or freezing-and-thawing action, such as piles, underground beam, and concrete filled in steel tubes)</td>
</tr>
<tr>
<td>Class - L (Backfill concrete, blinding concrete, and leveling concrete)</td>
</tr>
</tbody>
</table>

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

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

http://www.nrmca.org/research/eng_articles.asp
### Coarse CCA properties

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

- NMSA = 1 to 1.5 in.

### Fine CCA properties

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

- No organics

### 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

### 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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### 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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### Effect on Mixing Water

![Effect on Mixing Water](chart.png)

- A = “as received”
- C = sieved as coarse

### Notes

- No aggregate specification revisions required
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 26% (avg.=19%) lower
- RCP (coulombs)
  - ‘as received’ – negligible change, actually lower
  - “Coarse CCA” – 34% to 105% (avg.=64%)

Alkali Silica Reactivity (ASTM C1293)

<table>
<thead>
<tr>
<th>Mix Description</th>
<th>ASTM C1293 Expansion %, 1 yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.57 Virgin Coarse + Virgin Crushed Fine</td>
<td>0.022</td>
</tr>
<tr>
<td>No.57 Virgin Coarse + 600 lbs/yd! Pile1 CCA + Virgin Crushed Fine</td>
<td>0.027</td>
</tr>
<tr>
<td>Coarse fraction of 3000 psi CCA + Virgin Crushed Fine</td>
<td>0.032</td>
</tr>
<tr>
<td>No.57 Virgin Coarse + Fine fraction of 3000 psi CCA</td>
<td>0.028</td>
</tr>
</tbody>
</table>

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**

<table>
<thead>
<tr>
<th>CCA Type</th>
<th>SL-1</th>
<th>SL-2</th>
<th>SL-3</th>
<th>SL-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCA, lbs/yd³</td>
<td>0</td>
<td>1000</td>
<td>3000</td>
<td>3000</td>
</tr>
<tr>
<td>CCA, coarse, %</td>
<td>0</td>
<td>NA</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

**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/yd³**
  - 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/yd³
- **Step II**
  - Divert strength >3000 psi, crush after 14 days
  - 900 lbs/yd³
  - Accelerated set, higher shrinkage, F-T resistance
- **Step III**
  - Step II + Separate into coarse fraction
  - 100% Coarse CCA (1600 lbs/yd³)
  - Accelerated set, higher shrinkage, higher RCP
  - Do not retemper while discharging
  - Frequently measure absorption, relative density
  - Develop database of concrete properties

---

**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

---

**Sustainability will drive the future**

**Does it make ECONOMIC sense**

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**Recycled Wash Water**

Crushed Returned Concrete

---

**Questions**