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Use of Brick Masonry from Construction and Demolition Waste as Aggregates in Concrete

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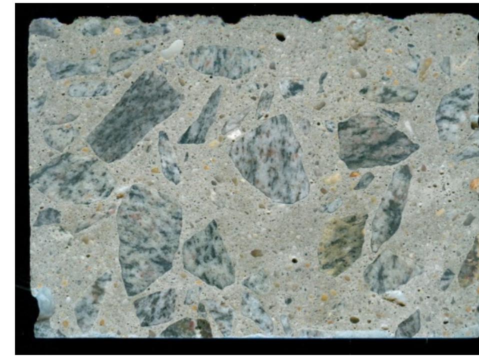
Overview

- Recently there has been increased interest in beneficial reuses of construction and demolition (C&D) waste.
  - Sustainability reasons
    - Reuse of C&D waste can:
      - Reduce landfill input
      - Reduce environmental impact of obtaining, transporting, and using new materials
      - Reduce the embodied energy of built environment
  - Economic reasons
    - Reuse of C&D waste in new construction can:
      - Lower hauling costs
      - Reduce landfill tipping fees paid
      - Provide a cost savings (versus use of new materials)
      - Achieve points in sustainable construction rating systems (LEED)

Overview



- Reuse of C&D waste as aggregates in PCC
  - Advantages
    - 25 billion tons of concrete used worldwide (Schokker 2010)
    - Significant amount of hardscape rubble generated yearly
    - Can be cheaper than virgin natural aggregates
    - Lower embodied energy of PCC
  - Challenges
    - Perceived increased risk to stakeholders
      - Lack of guidance, support, specifications/codes
      - Lack of certification systems for recycled aggregates
      - Relatively few field studies to support existing laboratory studies
  - Forecast for future use
    - Many researchers foresee increased use of recycled aggregate concrete (RAC) as cost of RCA becomes competitive with virgin natural aggregate

Building Materials Reclamation Program

- Grant from the US Department of Energy
- Purpose:
  - Develop innovative and cost-effective ways of diverting construction and demolition (C&D) waste from landfills through recycling and reuse
  - Possibly develop strategies that create small business opportunities
- Research as part of this grant:
  - Reclamation and reuse of structural steel members
  - Use of gypsum wallboard as a soil amendment
  - Use of concrete recycled aggregate in concrete materials
  - Use of recycled brick masonry aggregate (RBMA) in concrete materials
- Case Study:

  Idlewild Elementary

  School (built 1953)

Brick Masonry Aggregate Concrete a lost science?

- Two motivations for use of crushed brick and crushed brick masonry as aggregates in PCC in the past:
  - Disaster
    - World War II (England and Germany)
  - Lack of sources of natural aggregates
    - Regions located on river deltas
      - Unstable relations with neighboring areas that have natural aggregate sources.
      - Economically poor areas unable to afford hauling costs for natural aggregates from other locales
- Brick aggregate has high absorption
  - requires high water content to achieve workability
  - lowers strength and reduces durability performance

Research Objectives

- Characterize recycled brick masonry aggregate (RBMA) obtained from local C&D material
  - crushed at a local waste processing facility with no added processing
- Develop recycled brick masonry aggregate concrete (RBMAC) mixture designs that achieve acceptable strengths (4,000 to 6,000 psi compressive strength at 28 days)
  - utilize an acceptable portland cement content
  - maintaining adequate workability
- Assess mechanical properties and durability performance of RBMAC in a laboratory setting
- Assess the suitability of RBMAC for use in NCDOT pavement applications

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Case Study – Idlewild Elementary School

- Top-down demolition strategy
- From demolition contractor's standpoint, advantageous for several reasons:
  - Concrete slab-on-grade remains in place until remainder of building is cleared from site
    - Ensures that equipment has a sound surface to traverse
  - Concrete slab is used as a sorting pad for other materials

Results in relatively "clean" source-separated materials.

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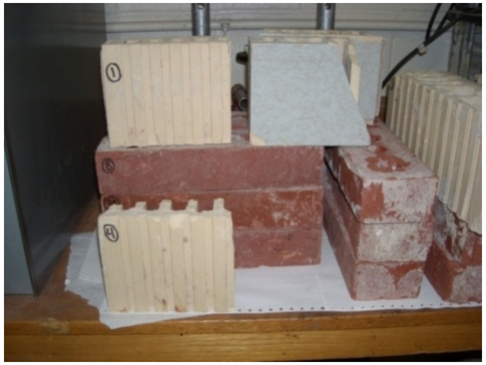
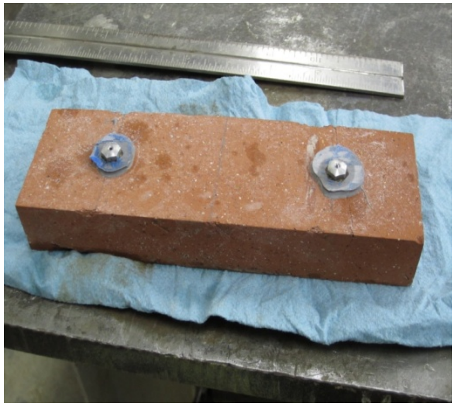
Characterization of Brick, Clay Tile, and Mortar

	Brick	Clay Tile	Mortar
Gross Unit Weight (pcf)	111.6	91.4	---
Net Unit Weight (pcf)	131.9	168.6	---
Compressive Strength (psi)	9,752	11,805	---
Modulus of Rupture (psi)	2,010	1,070	---
Absorption (%) (24-hr soak procedure)	8.5	4.0	---
Suction (g) (gain in weight corrected to basis of 30 in^2)	4.0	0.9	---
Coefficient of Thermal Expansion ($\times 10^{-6}$ in/in/°F)	2.45	---	---
Thermal Conductivity (BTU/(hr·ft·°F))	6.17	10.13	1.18
Heat Capacity (BTU/(lb·°F)	1.13	2.05	6.98





Characterization of Brick, Clay Tile, and Mortar

- Mechanical properties are within expected ranges as published by Brick Institute of America (BIA), American Concrete Institute (ACI), and several other researchers.
  - Compressive strength, suction, modulus of rupture, thermal conductivity
- Coefficient of thermal expansion (CTE) of brick is slightly lower than typical range of 3×10^{-6} and 4×10^{-6} in/in/°F (Klingner 2010)
- Heat capacity of brick and clay tile are higher than values published by ACI. Heat capacity of mortar is much higher than value published by ACI.

Composition of RBMA

Material	% by weight	% by volume
Clay brick	64.5	63.9
Clay tile	2.1	1.9
Mortar	30.1	31.6
Other (rock, porcelain, lightweight debris)	3.3	2.6

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Characterization of RBMA

	Recycled Brick Masonry Aggregate	Manufactured Lightweight Aggregate	Recycled Concrete Aggregate	Quarried Natural Aggregate
	Idlewild Elementary School	Local producer	Idlewild Elementary School	Local quarry
Specific Gravity	2.19	1.53	N/A	2.84
Absorption (%)	12.2	6.0	7.6	0.34
Abrasion Loss (%)	43.1	25 to 28	N/A	17.2
Loose Bulk Density (Unit Weight) (pcf)	60.9	50.0	80.0	95.9

- ASTM C127, "Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregates"
- ASTM C29, "Standard Test Method for Bulk Density (Unit Weight) and Voids in Aggregates"
- ASTM C 131, "Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine"

Flat and Elongated Particles

	Average % Flat and Elongated	
Material	**by particle count (%)**	**by mass (%)**
RBMA (blend)	4.0	3.6
Brick only	9.0	6.7
Mortar only	0.7	0.5
Tile only	8.0	4.8

- ASTM D4791, "Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate"

NCDOT limit (asphalt use only):

maximum percentage 10% flat and elongated

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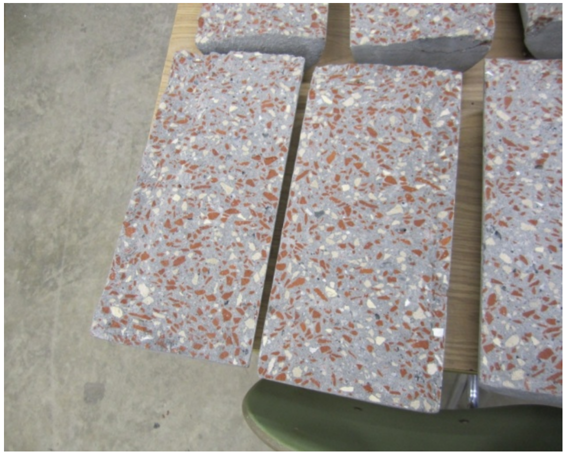
Development of RBMAC Mixture Designs

- Coarse aggregate
  - RBMA as 100% replacement for natural aggregate
  - Batched in saturated surface dry (SSD) condition
- Fine aggregate
  - Natural sand meeting ASTM C33 and AASHTO M6



- Cementitious materials
  - Type I/II portland cement
  - No supplementary cementitious materials
- Admixtures
  - Air entrainment
  - Mid-range and high-range water reducers
- ACI 211.2 Proportioning for Structural Lightweight Concrete
  - ASTM C330 "Standard Specification for Lightweight Aggregates for Structural Concrete" - loose bulk density (shoveling procedure) not to exceed 55 pcf.
  - RBMA is 60 pcf.

Methodology
Properties of Fresh and Hardened Concrete

	Property	Method of Testing
Fresh Properties	Slump	ASTM C143
	Air content	ASTM C173 (Volumetric method)
Mechanical Properties	Unit weight	ASTM C138
	Compressive strength	ASTM C39
	Splitting tensile strength	ASTM C496
	Flexural strength	ASTM C78
	Modulus of elasticity and Poisson's ratio	ASTM C469
	Coefficient of thermal expansion	Methodology similar to AASHTO T336
	Thermal conductivity	TCi apparatus
	Heat capacity	TGA apparatus
Durability Performance	Air and water permeability	Figg Method, ACI 228.2
	Rapid chloride ion permeability	ASTM C1202
	Surface resistivity	AASHTO T XXX-08
	Abrasion resistance	ASTM C944

RBMAC Baseline Mixtures

	BAC 5.0	BAC 6.0	BAC 6.1	BAC 6.2
Coarse Aggregate (pcy)	1178.6	1178.6	1178.6	1178.6
Sand (pcy)	1296.0	1296.0	1356.0	1428.3
Cement (pcy)	675.0	675.0	625.0	575.0
Water (pcy)	292.0	216.0	200.0	183.6
w/c	0.43	0.32	0.32	0.32
Air Entraining Admixture (oz)	13.7	16.4	13.7	13.7
High-Range Water Reducing Admixture (oz)	0	36.5	29.2	29.2
Slump (in)	6.0	5.5	6.0	3.5
Air content (%)	5.50	7.50	8.00	6.50
3-day compressive strength (psi)	2139	4559	3684	4508
7-day compressive strength (psi)	2858	6182	4074	5283
28-day compressive strength (psi)	3675	6497	5307	6450
90-day compressive strength (psi)	3872	6903	5362	7343

Results of Hardened RBMAC Testing

- ACI required overdesign strengths:

  4000 psi → 5200 psi

  5000 psi → 6200 psi

  6000 psi → 7300 psi

- Strengths of baseline mixtures were slightly lower than anticipated, and did not meet the overdesign strengths

- Considering overdesign strengths:

  BAC 6.1 could be considered a 4000 psi mixture

  BAC 6.0 and 6.2 could be considered 5000 psi mixtures

- Overall, RBMAC mixture development was successful

  Acceptable strengths at reasonable cement contents.

  Workability issues overcome using admixtures.

Results of Hardened RBMAC Testing

	BAC 5.0	BAC 6.0	BAC 6.1	BAC 6.2
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90-day compressive strength (psi)	3872	6903	5362	7343
3-day modulus of elasticity (psi)	2,200,000	3,340,000	3,120,000	3,600,000
7-day modulus of elasticity (psi)	2,753,000	3,977,000	3,467,000	3,430,000
28-day modulus of elasticity (psi)	2,783,000	3,840,000	3,563,000	3,903,000
90-day modulus of elasticity (psi)	2,905,000	3,960,000	3,645,000	3,875,000
28-day Poisson's ratio	0.18	0.16	0.17	0.16
90-day Poisson's ratio	0.17	0.18	0.18	0.17
7-day Modulus of Rupture (psi)	519	797	730	716
28-day splitting tensile strength (psi)	320	439	484	387

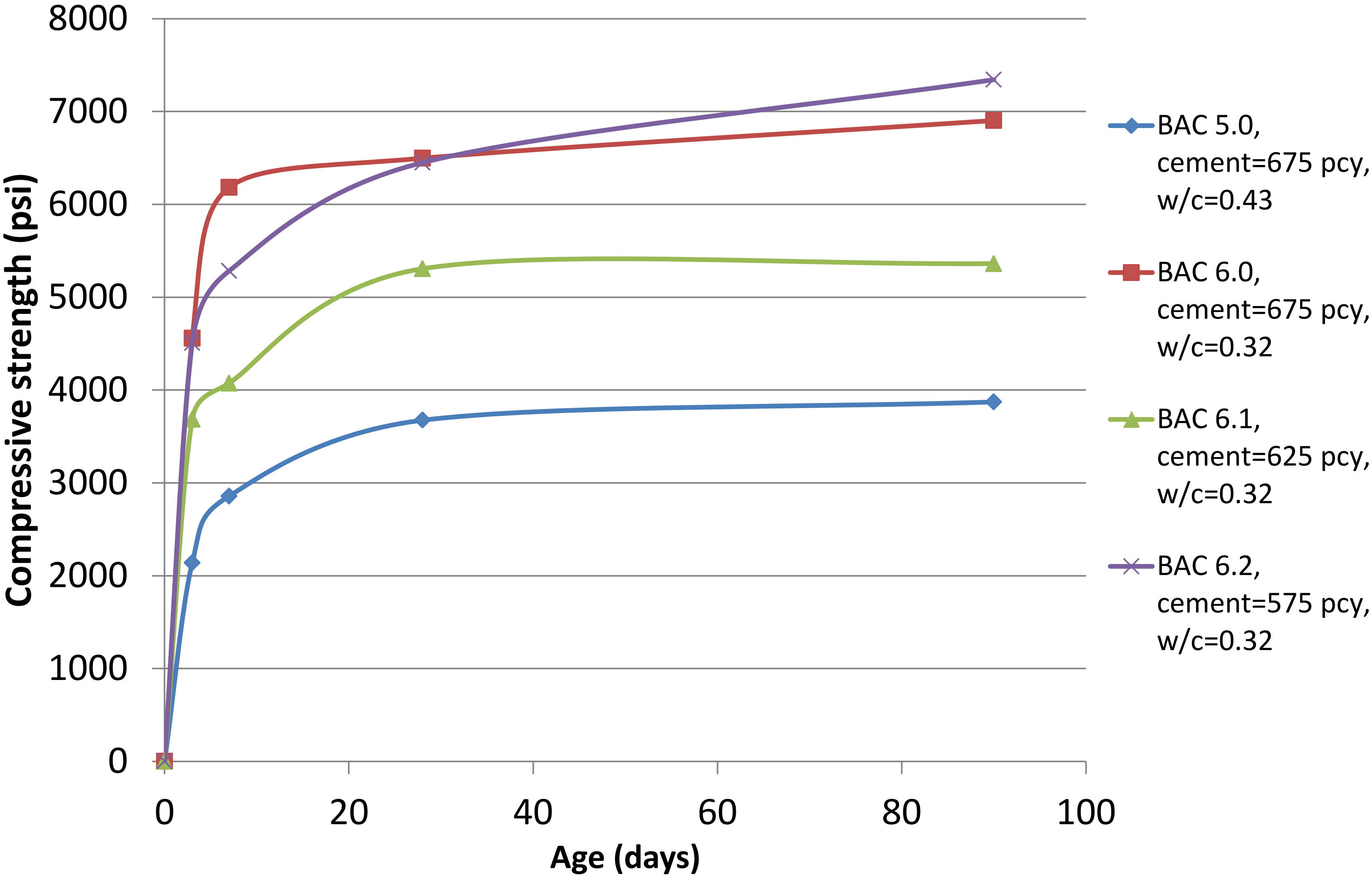
Equilibrium Density

- ASTM C567 test method

	RBMAC Mixture			
	BAC 5.0	BAC 6.0	BAC 6.1	BAC 6.2
Equilibrium density (pcf)	111.8	128.2	127.4	125.5

- ACI 213, “Guide for Structural Lightweight-Aggregate Concrete,” requires an equilibrium density between 70 and 120 pcf.
  - Requires lightweight aggregate to meet ASTM C330 (less than 55 pcf) and a minimum 28-day compressive strength of 2500 psi.
- RBMAC without water-reducing admixture can meet ACI 213 strength and equilibrium density requirements for structural lightweight concrete.
- RBMAC with water-reducing admixture exceeds ACI 213 requirement for equilibrium density.

Variability in RBMA



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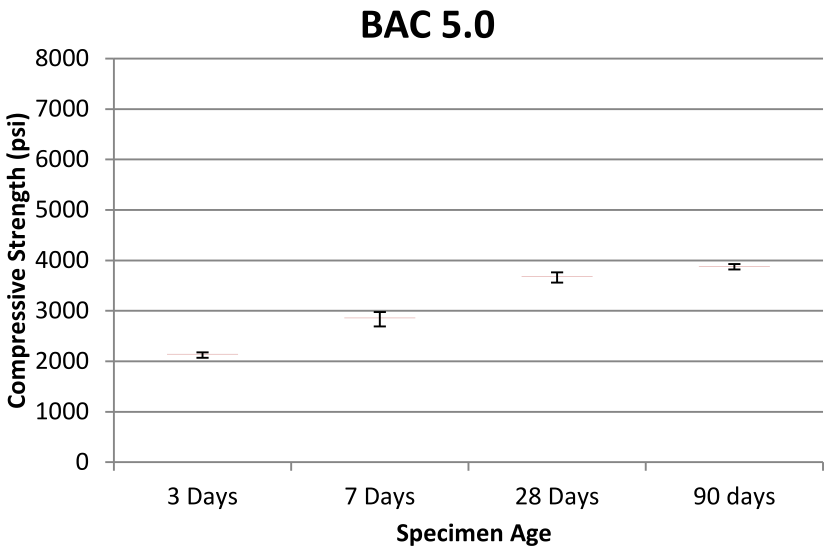

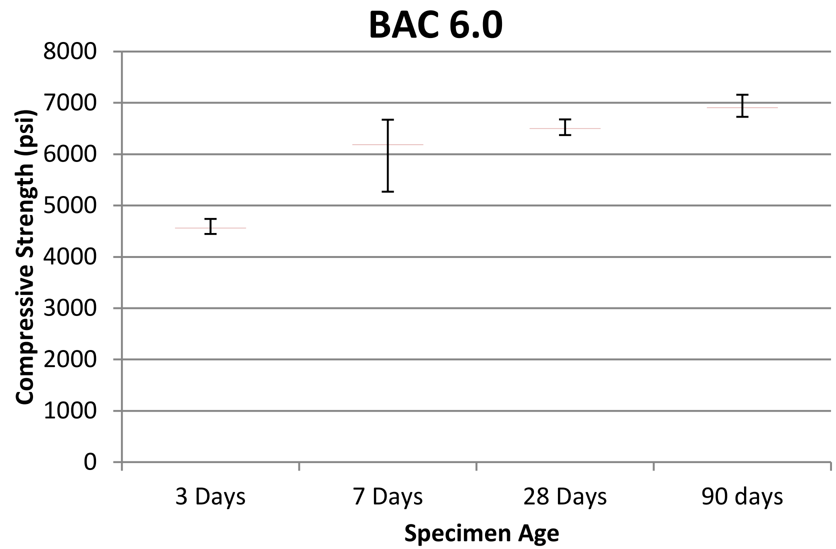

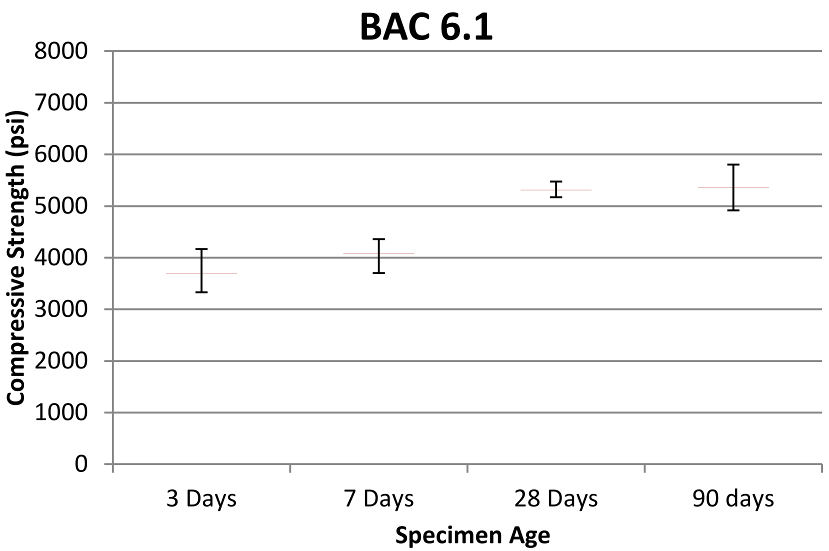

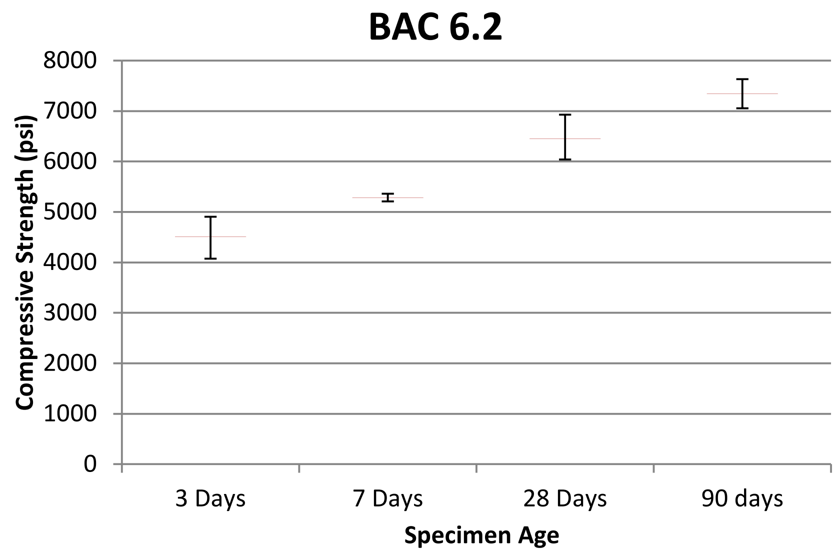

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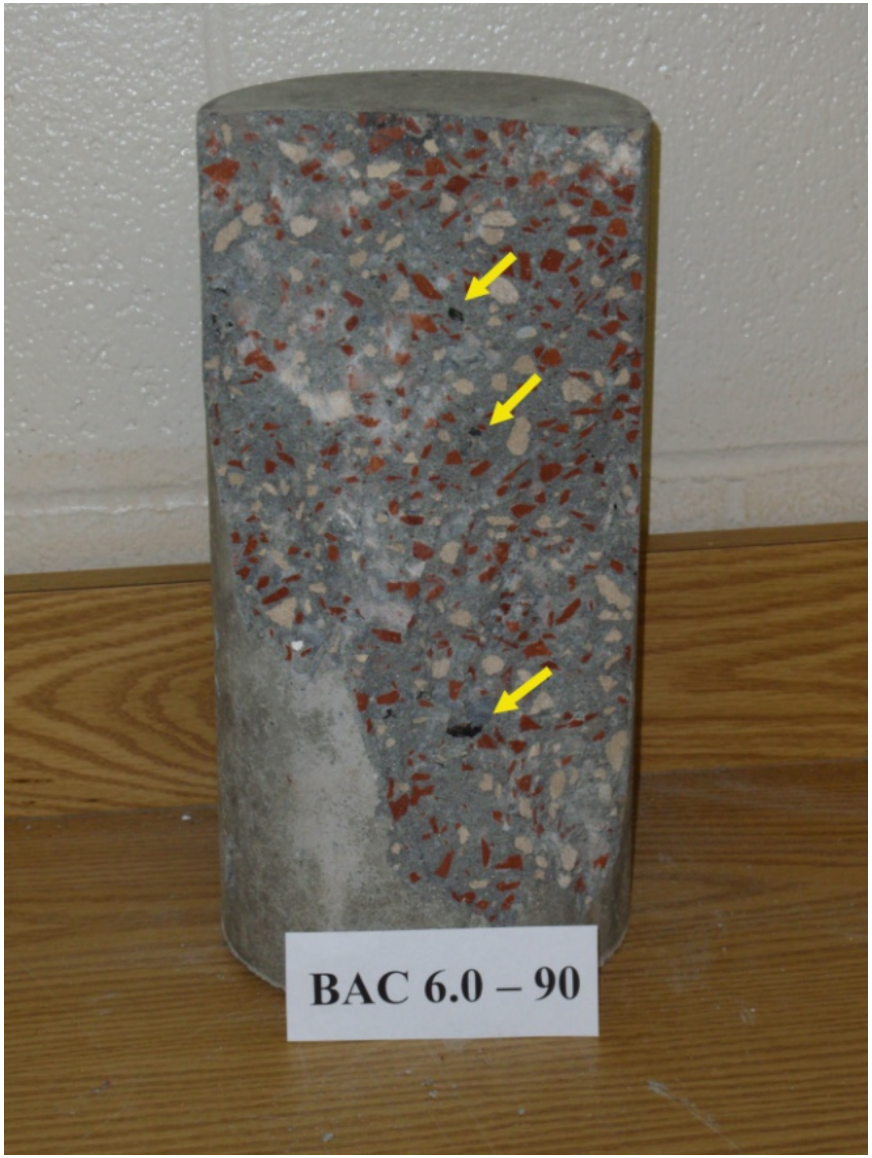

Use of RBMAC in NCDOT Applications

- 2006 NCDOT Standard Specifications
  - no provisions for use of recycled aggregates in any applications.
- 2012 NCDOT Standard Specifications
  - Section 1043, "Aggregate from Crushed Concrete."
    - Crushed concrete from existing structures, return concrete
    - Limits use of aggregate made from crushed concrete to Class B (lower-grade) concrete mixes only.
    - Must meet all approval requirements for conventional aggregate
      - Section 1005, "General Requirements for Aggregate,"
      - Section 1006, "Aggregate Quality Control / Quality Assurance," with a slight increase in deleterious materials content.

Use of RBMAC in NCDOT Applications

- Although prohibited, results of tests on RBMA were compared to NCDOT requirements to assess suitability for use in PCC
  - RBMA can meet 2012 NCDOT Standard Specifications for aggregates used in concrete with the possible exception of abrasion resistance for concrete with specified 28-day design strengths greater than 6,000 psi

- Use of RBMAC in NCDOT <u>pavement</u> applications.
  – Each of RBMAC mixtures that included a water-reducing admixture (w/c = 0.32) meets the current NCDOT requirements for pavement concrete mixtures for:
    - Cement content
    - Maximum w/c ratio
    - Minimum 28-day compressive strength
    - 28-day flexural strength (exceeded at 7 days of age)

Conclusions

- RBMAC mixtures were produced that have acceptable fresh and hardened properties using demolished brick masonry rubble
  - Top-down demolition sequence works
    - Variation in quality of source brick may still be a concern
    - Certification systems and other published guidance may help identify suitable sources of brick masonry

- These mixtures:
  - Include the mortar fraction
    - No additional processing required by C&D waste processing facility
  - Did not require portland cement contents that are higher than those used in conventional concrete mixtures
  - Exhibited acceptable workability with use of chemical admixtures

Conclusions

- 2012 NCDOT Standard Specifications do not allow use of RBMA
  - Test results indicate that it could potentially perform adequately in pavement applications
  - Results of durability tests performed to date indicate suitable performance in many tests (some testing is ongoing)
  - Other potential uses of RMBAC include:
    - Lower lift of two-lift pavements
    - Shoulders
    - Private roadways and parking areas
    - Low-grade concrete applications
    - Precast concrete

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Thank you for your time!

Questions?