AMERICAN ENGINEERING TESTING, INC.

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MCC Recycled Aggregate Research

Literature Review

ACI Literature

Amorim, P., de Brito, J., and Evangelista, L., "Concrete Made with Coarse Concrete Aggregate: Influence of Curing on Durability", *ACI Materials Journal*, March-April 2012, pp. 195-204

- Recycled concrete aggregate (RCA) concrete behaves like normal concrete in response to curing
- Water absorption is not affected by aggregate type
- RCA concretes are slightly more sensitive in dry environments
- Longer curing times in dry conditions may be more detrimental to RCA concretes
- Short curing in dry conditions is offset by internal curing supplied by excess water in the RCA
    - Long curing times may use up the excess water and then hydration may be interrupted by the RCA's high porosity
- 20% replacement of natural aggregate with RCA seems to have no impact

Fathifazl, G. and Razaqpur, A.G., "Creep Rheological Models for Recycled Aggregate Concrete", *ACI Materials Journal*, March-April 2013, pp. 115-126

- Modifications to models to include the effect of old mortar
- Conventional ACI method can be used with inclusion of "RCA coefficient"
- RCA adds both fines and air to the concrete which impacts creep
- RCA creep is a function of residual mortar content
- Modified mix design method of Equivalent Mortar Volume (EMV) results in less creep for RCA concretes
- No comparison of creep behavior between concretes, only an evaluation of the model
- EMV mix design method adjusts aggregate content to maintain overall mortar volume

Lee, S.T., et al., "Sulfate Attack of Mortars Containing Recycled Fine Aggregate", *ACI Materials Journal*, July-August 2005, pp. 224-230

- Up to 50% replacement of fine aggregate with RCA reduced expansion but greater replacement levels cause more deterioration
- Increased ITZ in RCA concrete may cause the excess deterioration

Limbachiya, M., Meddah, M.S., and Ouchagour, Y., "Performance of Portland/Silica Fume Cement Concrete Produced with Recycled Concrete Aggregate", *ACI Materials Journal*, January-February 2012, pp. 91-100

- Up to 30% replacement without impact on strength
- RCA needs lower w/c and higher cement content
- The higher the RCA content, the more substantial the shrinkage
- Addition of silica fume reduces shrinkage
- Carbonation increases with porosity, therefore RCA can increase carbonation rate
- Use of RCA increases sulfate attack expansion

Purushothaman, R. and Mani, S., "Studies on Fresh and Hardened Properties of Recycled Aggregate Concrete with Quarry Dust", *ACI Materials Journal*, May-June 2014, pp. 283-290

- Fine aggregate replaced with quarry dust for concretes made with natural aggregate and RCA
- Studied fresh and hardened properties
- 50-60% quarry dust with coarse RCA was stronger than 100% natural aggregate
- Quarry dust decreased the workability of fresh concrete
- Together, quarry dust and RCA had lower splitting tensile strength at all levels of fine aggregate replacement along with higher flexural strength at high replacement levels

Salem, R. M., Burdette, E. G., and Jackson, N.M., "Resistance to Freezing and Thawing of Recycled Aggregate Concrete", *ACI Materials Journal*, May-June 2003, pp. 216-221

- Comparison of RCA and natural aggregate mixes at different w/c ratios along with the addition of an air entrainer
- With air entrainer, RCA concrete can behave like natural aggregate concrete
- RCA pores may hold onto lots of water during the freeze-thaw test cycle which gives poor performance without air entrainer
- Air entrainer is just as effective for RCA as it is for natural aggregate
- Aggregate saturation during freeze-thaw test greatly reduces durability without air entrainment

Salem, R.H., and Burdette, E.G., "Role of Chemical and Mineral Admixtures on Physical Properties and Frost Resistance of Recycled Aggregate Concrete", *ACI Materials Journal*, September-October 1998, pp. 558-563

- Similar study to article by Salem, R. M., Burdette, E. G., and Jackson, N.M.
- 3 mixes with fly ash studied: control, additional fly ash, air entrained mix
- All RCA mixes had lower modulus of elasticity ad modulus of rupture than comparable natural aggregate mix
- Higher fly ash dosage increased durability but RCA concrete still failed
- Air entrainer gave durability to both aggregate types

Surya, M., Kanta Rao, V.V.L., and Lakshmy, P., "Mechanical, Durability, and Time-Dependent Properties of Recycled Aggregate Concrete with Fly Ash", *ACI Materials Journal*, September-October 2015, pp. 653-662

- Study of durability, short term creep and shrinkage
- Shrinkage increased 24-41% and creep increased 10-15% for RCA concrete
- Utilized a modified mix design method involving specific gravity ratios to calculate natural aggregate replacement volumes
    - EMV method used elsewhere was problematic
- Creep was conducted for 90 days only
- Lower modulus for RCA, possibly due to microcracks in aggregate
- Chloride permeability increases with RCA content
    - 100% RCA negated a 20% addition of fly ash
- RCA concrete with fly ash had higher creep at early age but was equivalent to natural aggregate concrete without fly ash by 90 days

- RCA concrete had only 71% of the modulus of natural aggregate concrete but still had similar creep

Tavakoli, M., and Soroushian, P., "Strengths of Recycled Aggregate Concrete Made Using Field-Demolished Concrete as Aggregate", *ACI Materials Journal*, March-April 1996, pp. 178-181

- If the strength of the original concrete used for aggregate is greater than the design strength of the control concrete, then the strength of RCA concrete will be greater than the control concrete
- Higher absorption or LA abrasion loss gives poor performance
- RCA doesn't necessarily have a negative impact on tensile strength
- Knowledge of the original mix designs of the concrete used as aggregate helpful in predicting behavior of RCA concrete
- Qualities of original concrete restrict RCA concrete properties but variation makes it difficult to predict
- Strength trends are similar for the aggregate types

Ulloa, V. A., et al., "New Views on Effect of Recycled Aggregates on Concrete Compressive Strength", *ACI Materials Journal*, November-December 2013, pp. 687-696

- Study of the effect of RCA properties, w/c ratios and replacement ratio on compressive strength
- Predictive equations developed
- RCA properties impact how much w/c and replacement ratio are key factors in the final RCA concrete
- Asphalt and/or clay masonry particles in RCA decrease strength variability
- Mortar content critical to absorption and density of RCA

Yang, K-H., Chung, H-S., Ashour, A.F., "Influence of Type and Replacement Level of Recycled Aggregates on Concrete Properties", *ACI Materials Journal*, May-June 2008, pp. 289-296

- Higher absorption of RCA decreases the performance of concrete
  - Lower strength
  - Lower modulus of elasticity
  - Higher shrinkage after 10 days
- Find lower absorption concrete sources

<u>Minnesota Department of Transportation Standard Specifications for Construction (2016)</u>

- 3137.2 B (5)
  - Permits use of recycled aggregate in portland cement concrete
- 3138.2 C
  - Permits use of recycled aggregate in surface and base course in accordance to Table 3138-2
- 3149.2 A.2
  - Permits use of recycled aggregate as a granular material

Possible Research Topics

- Methods to decrease variability in performance
  - RCA composition/uniformity
  - RCA sourcing
  - High quality RCA production
  - Mix design method
- Limiting shrinkage
- Relationship between modulus of elasticity and creep
- Methods to reduce creep
- Durability of “ideal” blend
  - Freeze-thaw
  - Scaling
- Life cycle analysis of RCA concrete
  - Initial chloride content
  - Not a raw material
  - Embedded carbon of RCA mortar
- Internal curing potential
- Field performance
- Incorporation of fine recycled aggregates