PennDOT RECYCLING MATERIAL BRIEF

Recycled Concrete Aggregate Fact Sheet

Introduction and Background

From 2006-2008 the Pennsylvania Department of Transportation awarded nearly $2 billion in highway and bridge contracts each year. Even with the yearly budgets nearing $2 billion, the Transportation Funding and Reform Commission estimated in 2006 that Pennsylvania needs to invest approximately $1.7 billion a year MORE in its transportation systems to keep them functioning in a state of good repair. With growing stress on our transportation systems juxtaposed with rising costs of materials and disposal necessary to carry out these projects, the need for creative solutions to help offset the cost of highway and bridge repairs are extremely important. One solution that is gaining momentum throughout the United States is the use of recycled Portland cement concrete pavement (RPCC) in construction applications.

According to the National Cooperative Highway Research Program (NCHRP) 350-400 million tons of industrial wastes are generated in the U.S. each year. Construction and demolition debris constitutes approximately 25 million tons of this waste per year and removed concrete pavement generates approximately 3 million tons per year. This otherwise waste material can potentially supply the highway construction industry with a vast resource of cost effective aggregate material.

The process of recycling Portland Cement Concrete (PCC) Pavement creates an aggregate derived from elements of roads, runways, buildings and other structures (i.e. sidewalks, utility excavations, demolition operations, and cleanup operations associated with natural disasters, structural failures, etc). Laboratory studies conducted by several state departments of transportation (DOTs), as well as federal agencies, have found that the use of recycled aggregate will produce strong durable concrete suitable for PCC pavements in all areas of the United States. According to these studies the mixture produced by utilizing coarse aggregate has no significant effect on mixture proportions or workability when compared with control mixtures made with conventional aggregates. Although there are limitations to using recycled fine aggregates, these drawbacks can be generally overcome by limiting a mixture to less than 30 percent of fine RPCC aggregate. Recycled aggregates have exhibited good particle shape, high absorptions and low specific gravity compared with conventional mineral aggregates. In addition, a number of agencies have found through their research that recycled aggregate has shown an increase in freeze-thaw resistance and improved durability.

As of 2007 several major urban freeways have been constructed using RPCC. Such projects have enlisted the use of RPCC in concrete aggregates, sub-base materials, rip-rap or slope protection, embankment burrow and aggregate base coarse. Cost savings as high as 65%+ have been realized.

This fact sheet provides information on the recycling of Portland cement concrete pavement including the resultant aggregate properties, engineering parameters, and applications for the Pennsylvania Department of Transportation (PennDOT) use in civil engineering applications. The fact sheet is divided into the following sections:

- **Material Properties** – describes the physical properties and engineering parameters of recycled PCC pavement.
- **Applications** – describes recycled PCC applications.
- **Specifications** – present existing PennDOT specifications.
- **Conclusions** – presents conclusions and discusses implementation issues.

Material Properties

Test	Parameter	Coarse Findings	Fine Findings
Specific Gravity *Coarse:* ASTM C127, AASHTO T85 *Fine:* ASTM C128, AASHTO T84	Gs (-)	2.2 to 2.5	2.0 to 2.3
Density *Coarse:* ASTM C127, AASHTO T85 *Fine:* ASTM C128, AASHTO T84	Kg/m3	2,430 to 2,490 kg/m3	2,310 to 2,340 kg/m3
Absorption Coarse: ASTM C127, AASHTO T85 Fine: ASTM C128, AASHTO T84	(%)	2 to 6	4 to 8
LA Abrasion ASTM C131, ASTM C33, AASHTO T96-681	Wear (%)	20 to 45	N/A
Magnesium Sulfate Soundness Loss *Coarse:* ASTM C88, ASTM C33 *Fine:* AASHTO T104	Weight Loss (%)	≤ 4	< 9
California Bearing Ratio PTM 106	Resistance (%)	94 to 148	N/A
Alkali-Silica or Alkali-Carbonate Reactivity ASTM C856, AASHTO T303, ASTM C289	--	N/A	N/A
Use of Fine Aggregate (75 AASHTO M80	% of mixture	N/A	Limit to 1% of Mixture
Deleterious Materials ASTM C40, ASTM 295, ASTM C142 ASTM D2419	% By Mass	Limit to nor more than .3 percent (by mass)	N/A
Durability (Freeze/Thaw Testing) ASTM C666 Method B	Loss (%)	1.285	N/A

- Shape will be primarily influenced by the source of the aggregate. Crushed RPCC aggregates are typically more coarse and angular in shape than conventional aggregates.

- Fines (AASHTO M80) is a classification that refers to the gradation of the material. Fine RPCC aggregates are classified as 4 to 8 mm and coarse RPCC aggregates are classified as 16 to 32 mm. It is recommended that a RPCC concrete mix is not made up of more than 1.0 percent of aggregate finer than 75 µm (No. 200 sieve).

- Deleterious Components (ASTM C40, ASTM 295, ASTM C142 ASTM D2419) can affect a materials chemical stability, weathering resistance or volumetric stability. Examples include clay lumps, shales or other friable particles. Like conventional material, RPCC aggregate should be relatively free of potential deleterious materials. RPCC aggregates should be limited to no more than 0.3 percent (by mass) of deleterious materials. Coarse particles mixed with natural sand are able to achieve this best. Fine aggregates should be substituted with natural sand.

- Specific Gravity (Coarse Particles: ASTM C127, AASHTO T85; Fine Particles: ASTM C128, AASHTO T84) is a measure of a material's density and affects the unit weight of porous media. RPCC aggregates typically have a lower specific gravity than conventional aggregates due to mortar adhesion. Specific gravity values for coarse RPCC particles typically range from 2.2 to 2.5. Specific gravity values for fine RPCC particles typically range from 2.0 to 2.3.

- Density (Coarse Particles: ASTM C127, AASHTO T85; Fine Particles: ASTM C128, AASHTO T84) is a measure of an objects mass per unit volume. RPCC has been shown to exhibit lower densities than conventional aggregates due to mortar adhesion. Testing to determine the saturated surface dry (s.s.d.) density is recommended for aggregates that are intended for use in new concrete mixes.

- Absorption (Coarse Particles: ASTM C127, AASHTO T85; Fine Particles: ASTM C128, AASHTO T84) describes the percentage of one substance taken up by another. RPCC aggregates have notably higher water absorption than conventional aggregates due to mortar adhesion. High absorption characteristics generally preclude the use of fine RPCC aggregates in new concrete applications. Presoaking or saturation by sprinkling before mixing in new applications may help to overcome high water absorption properties.

- Los Angeles Abrasion Test (ASTM C131, ASTM C33, AASHTO T96-681, ASTM C535) is used to measure the resistance to abrasion of coarse aggregates. Durability is a material classification property that affects its suitability for roadway base course and fills under fluctuating loads. On average, LA abrasion loss percentage ranges from 25% to 45% for RPCC aggregates. Natural aggregates typically have wear values in the range of 20% to 25%. The RPCC wear value range is within AASHTO TP33 limits for concrete aggregates used in Portland cement concrete for highway applications.

- Sulfate Soundness (*Coarse:* ASTM C88, ASTM C33, *Fine:* AASHTO T104) describes the durability of aggregates by measuring freeze-thaw resistance. This test involves exposing an aggregate to five cycles of alternate soaking and drying in aqueous sulfate or magnesium sulfate solution to establish weight loss limits to the aggregate. The average weight loss for RPCC coarse aggregates soaked in magnesium sulfate was approximately 4%. For fine RPCC weight loss was noted at 9% or less when soaked in magnesium sulfate. Both coarse and fine RPCC aggregates meet ASTM T104 standards. The use of sulfate solutions may increase the likelihood of freeze/thaw degradation due to sulfate attack. Testing may help determine susceptibility.

- Alkali-Silica or Alkali-Carbonate Reactivity (AASHTO T299, AASHTO T303, ASTM C295, ASTM 289, ASTM C342, ASTM C441, ASTM C589, ASTM C666 and ASTM C856) measures the potential for certain aggregate types to react with the alkali components present in Portland cement. Generally, alkali-silica and alkali-carbonate reactivity form expansive compounds and manifest in the form of D-cracking. Testing is recommended where standards exist for conventional aggregates or Type II cement can be used to limit or mitigate reactivity in new concrete applications.

- D-Cracking (ASTM C 666) is a form of pavement distress caused by poor-quality aggregates. D-cracking in concrete pavements is typically promoted by the presence of sulfate ions, chlorine ions and alkali components, all of which can be controlled. New concrete made with RPCC aggregate has exhibited substantial improvement in D-cracking resistance.

- Chloride Content specifically looks at chloride ion entrainment from RPCC aggregates. Chloride ions can induce corrosion of steel. Maximum permissible values of chloride content for RPCC aggregate are 0.5 lb/cu yd and 0.6 lb/cu yd (derived from NY and CT DOT agencies). The chloride content of leachate produced by RPCC stockpiles has been tested. Findings indicate chloride content is within the EPA drinking water standards.

- Alkalinity or an elevated pH can occur in RPCC aggregates due to the old mortar component. An elevated pH can induce corrosion of aluminum or galvanized steel pipes. pH levels should be especially taken into account when placed in direct contact with aluminum or galvanized piping. The pH of leachate produced from RPCC stockpiles is within the EPA drinking water standards.

- Tufa formations refer to the deposition of carbonate deposits associated with alkaline discharge. Tufa deposits have the potential to block openings to drainage systems. To reduce Tufa formation, the use of fine RPCC aggregates (especially those rich in calcium salts and calcium hydroxides) should be limited in RPCC applications.

- Compressive strength (ASTM C39) is influenced by the strength of the original concrete, the composition of RPCC aggregates in the new concrete, the properties of RPCC aggregates and the water-cement ratio. Studies have shown that replacing fine RPCC aggregates with natural sand greatly improves strength to where it can exceed that of conventional aggregate.

- Flexural and tensile strength measure the resistance of unreinforced concrete to failure in bending. There is little difference in flexural strength between RPCC and conventional concrete. Tensile strength of RPCC concrete is slightly lower (10%-20%) than conventional concrete.

- The modulus of elasticity (E) is a measure of the inherent rigidity or stiffness of a material. Mortar adhesion may cause a reduction in (E). Therefore, reducing use of fine aggregate is recommended. Combining coarse RPCC aggregates with natural fine aggregates results in only a slight reduction of E (10%-30%).

- Durability is primarily influenced by concrete permeability. By controlling the RPCC concrete's water-cement ratio and RCC aggregate fractions, durability is comparable to concrete made with conventional aggregates. Freeze-thaw resistance of concrete will also influence durability. Concrete made from RPCC aggregates has been found to exceed the freeze/thaw resistance of concrete made with conventional aggregates.

- Gradation is defined as (grain-size distribution) proportions by mass of a soil or fragmented rock distributed in specified particle-size ranges. Gradation can affect engineering properties such as compaction, permeability, filtration and shear strength. Most states have stipulated that the same gradation requirements for natural materials can be used for RPCC aggregates.

- Miscellaneous Considerations (Placement, Mixing, Stockpiling)-Quality control procedures used for conventional concretes are recommended. The slump, air content and temperature should all be considered during placement.

The mix design should be based on the measured density of RPCC aggregates. The same sand to aggregate ratio used for conventional mixes applies to RPCC aggregates. If fine aggregates are used they should be limited to 30% of the sand portion. RPCC Water content should be monitored during the mixing process.

When stockpiling RPCC stone, in process segregation should be avoided. This will help when blending operations are considered. Stockpile moisture content should be monitored. Sprinkling RPCC stockpiles may help minimize the potential of RPCC aggregate to absorb moisture from the concrete mix. Finally, location is a particularly important due to pH considerations. Storage locations that minimize impact to stormwater runoff should be selected.

Applications

Concrete produced from RPCC aggregates has good particle shape, high absorptions, and low specific gravity. Improvements in freeze-thaw resistance, durability and D-cracking have been observed in RPCC applications. Substandard geometrics, subgrade conditions, vertical clearance at bridges and drainage are also reportedly improved when PCC pavements are recycled. As these above characteristics suggest, RPCC aggregates are a good candidate for use in highway construction. Potential aggregate applications for RPCC concrete include:

- Rip-rap or Rock Lining
- Gabion Applications
- Drainage Applications
- Flowable Backfill/Controlled Low Strength Material

Specifications

Currently the Pennsylvania Department of Transportation uses RPCC from reclaimed concrete pavement in sub-base materials.

- Item 9850-XXXX RPCC Aggregate for Rock-Lining and Use Guidelines;
- Item 9613-XXXX RPCC Aggregate for Miscellaneous Drainage and Use Guidelines;
- Item 9626-XXXX Corrosion Resistant Gabions, Type B, Using RPCC Aggregates and Use Guidelines;

Conclusions

From a chemical and physical standpoint, RPCC aggregate is not significantly different from conventional aggregates. The use of RPCC concretes is a potentially emerging market as it is offers many benefits such as cost effectiveness, diversion of non-recyclable products from disposal in landfills and materials conservation. Additionally RPCC aggregates offer improvements in freeze-thaw resistance and D-cracking.

RPCC concretes have been used in numerous roadway construction projects throughout the U.S. The use of RPCC aggregate has shown significant costs savings and has demonstrated performance comparable to conventional concretes. Limitations of RPCC aggregate, such as decreased workability, Tufa formations and the presence of deleterious materials can be reduced by limiting the use of fine aggregates.