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July 2018

ROAD MAP TRACK 6

PROJECT TITLE

Using Recycled Concrete Aggregate in Pavement Base Products

TECHNICAL WRITER

Mark B. Snyder
Engineering Consultant
717-441-3506
mbsnyder2@yahoo.com

EDITOR

Sabrina Shields-Cook

SPONSORS

Federal Highway Administration
National Concrete Consortium

MORE INFORMATION

Dale Harrington
HCE Services
515-290-4014
dharrington@hceservices.com

The Long-Term Plan for Concrete Pavement Research and Technology (CP Road Map) is a national research plan developed and jointly implemented by the concrete pavement stakeholder community. Publications and other support services are provided by the Operations Support Group and funded by the Federal Highway Administration.

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“Moving Advancements into Practice”

MAP Brief July 2018

Best practices and promising technologies that can be used now to enhance concrete paving

Using Recycled Concrete Aggregate in Pavement Base Products

Introduction

Pavement base applications are the most common uses for recycled concrete aggregate (RCA) produced from concrete pavement slabs (Snyder 2016). The widespread acceptance of RCA in pavement base layer applications is probably because these uses offer some of the greatest environmental benefits at a low cost, while providing the potential for performance that meets or exceeds what can be achieved with natural aggregate.

This MAP Brief describes constructability considerations, qualification testing, and pavement design considerations for both unbound and bound (stabilized) RCA base applications.

Unbound Aggregate Base Applications

Unstabilized (granular) base applications are the most common use of RCA produced from concrete pavements. Figure 1 shows that at least 34 states currently allow the use of RCA in pavement base applications based on a 2012 survey of state materials engineers.

Of the six responding states that did not then allow the use of RCA as an aggregate base, two were considering allowing its use and a third indicated that RCA would be used if requested.

An important benefit to using RCA as an unstabilized base material is that the presence of typical contaminants to the base material (e.g., asphalt concrete, joint sealant materials, and other paving materials) is of relatively little concern. For example, Minnesota allows up to 3% asphalt cement by weight of aggregate and California has no limit on the relative proportions of reclaimed asphalt pavement (RAP) and RCA in their base materials. Requirements like these offer contractors added flexibility in production and construction.

Through process control and blending, contractors can produce RCA material for a broad range of base applications. For example, RCA can be produced to provide excellent free-draining base material that is both permeable and highly stable when angular, rough-textured RCA particles are graded to meet applicable specifications.

Concrete recycling can also produce economical dense-graded base materials that include higher proportions of crushed concrete particles of all sizes. Dense-graded RCA bases are highly effective because the angular, rough-textured particles provide excellent stability, while the secondary hydration of RCA fines often results in further strengthening of the base layer (ACPA 2009).

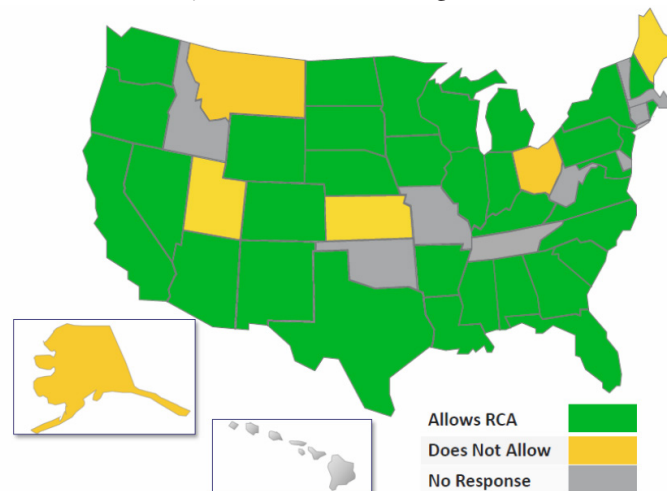


Figure 1. Responses to 2012 survey of RCA use for unbound bases

Performance Considerations

Structural Matters

RCA has been widely and successfully used in unbound base layer applications. The available literature yielded no reports of pavement performance problems related to structural deficiencies in any properly designed and constructed RCA foundation layer. In fact, some agency engineers believe RCA outperforms natural aggregate in unbound base applications (FHWA 2004).

While there are anecdotal reports of possible frost- and/or moisture-heave in some more densely graded RCA base materials in Michigan and Minnesota, these problems seem to disappear with more open gradations (e.g., permeability greater than ~300 ft/day), which can be achieved by removing 15% to 25% of the fines (whether recycled or not) or by limiting the percent passing through the No. 200 sieve to 6% or less. An alternate approach is to stabilize the RCA with cement or asphalt to bind the fines that would otherwise be susceptible to frost- or moisture-heave.

Drainage Issues

RCA has been used with great success in most pavement base applications, especially in dense-graded, undrained foundation layers and fill applications. The use of RCA in unbound applications that are exposed to drainable water (e.g., free-draining base layers, drain pipe backfill material, and dense-graded base layers that provide significant flow or runoff to pavement drainage systems) has been associated with the deposit of crushed concrete dust and leachate (calcium carbonate precipitate or “calcareous tufa”) in drainage pipes and on filter fabric.

Although these products can clog the fabrics and form deposits in drainage pipes, thereby inhibiting the function of the drainage system, they typically do not affect the performance of the foundation system. However, in extreme cases, they can cause water to be retained in the pavement structure for longer periods.

Accumulations of precipitate and residue in drainage pipes can be significant and can reduce discharge capacity, but rarely (if ever) completely prevent drainage flow. The accumulation of these materials typically takes place early in the pavement life and dissipates as the dust and soluble calcium hydroxide are removed from the RCA surface.

The mechanism of precipitate formation was explained by Bruinsma et al. (1997). The authors described the dissolution of calcium hydroxide (a by-product of cement hydration) into water from freshly exposed crushed concrete surfaces and the subsequent precipitation of calcium carbonate as the dissolved calcium hydroxide reacts with atmospheric carbon dioxide. Therefore, all recycled concrete aggregates that are exposed to water have the potential to produce precipitate, regardless of the product gradation.

The amount of precipitate that will be produced is directly related to the amount of freshly exposed cement paste surface (i.e., increased quantities of cement paste fines), the amount of water flowing over the aggregate surfaces, and the amount of time that the water is exposed to atmospheric conditions. The potential for precipitation decreases with time as the available calcium hydroxide is depleted. Additional possible mechanisms include evaporation and temperature changes that result in supersaturation of the calcium hydroxide-infused solution, resulting in precipitate formation.

Bruinsma (1995) and Tamirisa (1993) also determined that as much as 50% of the material deposited in drainage structures and on associated filter fabrics may be dust and insoluble residue produced by crushing operations. Washing RCA prior to use reduces the presence of this material (Bruinsma 1995).

Snyder (1995) and Snyder and Bruinsma (1996) summarized several laboratory and field studies to characterize and identify solutions to the potential problems of accumulated precipitate and dust/insoluble residue from crushing. The following techniques have been suggested and can often be used in various combinations to prevent problems with pavement drainage systems when using unbound RCA base materials in drainable layers:

- *Production and stockpiling*—Carefully select the crusher type for the aggregate gradation being produced to reduce the generation of fines and the need for mitigation measures. Good stockpile and material management practices can also reduce RCA degradation, which produces fines.
- *Washing*—Wash the RCA or use other dust removal techniques (such as air blowing) prior to placement in the base to minimize the contribution of “crusher dust” to drainage system problems. While washing is effective for controlling crusher dust, it is not believed to significantly reduce the potential for precipitate formation.
- *Avoid using fine RCA*—Selectively grade the RCA to eliminate the inclusion of fine RCA particles (i.e., material passing the No. 4 sieve, which has the greatest surface area per unit weight of material), which will significantly reduce inclusion of crusher dust and potential for precipitate formation. Use unbound fine RCA in layers that do not transport water to the pavement drainage system.
- *Blend with virgin aggregate*—Use virgin aggregate to partially replace the RCA (particularly for small particle sizes) to reduce inclusion of crusher dust and the potential for precipitate formation.
- *Use high-permittivity filter fabrics*—Use filter fabrics with initial permittivity values that are at least double the minimum required so that adequate flow will be maintained even if some clogging takes place (Snyder 1995).
- *Use effective drainage design features*—Design the drainage system to allow residual crusher dust to settle in a granular filter layer at the bottom of the trench rather than allowing direct entry to the pipe. This can be accomplished by placing the pipe (with slots oriented to the bottom) on the filter layer rather than directly at the bottom of the trench. Also,

wrap the drain pipe trench (rather than wrapping the pipe) to prevent fines from the subgrade and foreslope from clogging the trench backfill material (see Figure 2).

- *Use daylighted base designs*—Consider using daylighted base designs, where a drainable base layer is extended across the shoulder to the face of the foreslope and drains directly to the ditch rather than to a pipe underdrain system. Daylighted base designs are described in the American Concrete Pavement Association's (ACPA's) Engineering Bulletin EB204P (ACPA 2007).
- *Stabilize the base*—Stabilize the base layer with cement or asphalt. This is an effective strategy for reducing dust and leachate concerns.

Qualification Testing

General

Many highway agencies require only gradation control when recycling pavements from their own networks (i.e., known sources), while demanding more extensive testing only for the processing of materials from other sources. When additional testing is called for, RCA materials are generally required to meet the same quality requirements as conventional aggregate base materials, with the exception of sulfate soundness testing (as is discussed later).

RCA materials may be subject to some qualification tests not generally applied to natural aggregates (e.g., limits on certain potentially deleterious substances, such as asphalt concrete, brick, plaster, gypsum board, and hazardous materials). Most of these substances (other than asphalt concrete) are found in RCA obtained from building demolition and are not common in RCA from pavement sources. Limitations on pavement-related material inclusions, such as asphalt concrete and soils, are discussed later in this MAP Brief.

A detailed specification concerning the use of RCA for unbound soil-aggregate base courses can be found in AASHTO M 319-02 (2015). This document covers the possible recycling of concrete from any source, including building and demolition debris, pavements, etc. Further guidelines specific to the use of crushed concrete from existing pavements are available in Appendix B of the ACPA publication Recycling Concrete Pavements (ACPA 2009). The following sections discuss some

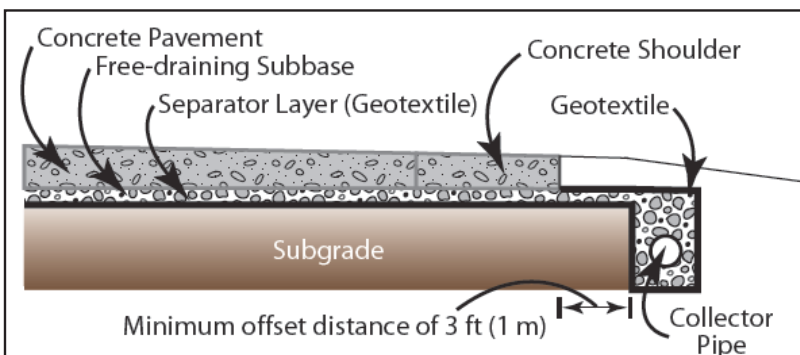


Figure 2. Typical drainage system for use of free-draining RCA base (©ACPA, used with permission)

key qualification testing issues from these documents and others related to the use of RCA in unbound base applications.

Gradation

Unbound RCA base materials are typically required to meet the same grading requirements (e.g., AASHTO M 147 [2017], ASTM D2940/D2940M, or local requirements) that are applied to conventional unbound base materials to ensure stability (for both the pavement structure and the paving equipment) and the desired degree of drainability. The aggregate top size should not exceed 1/3 of the layer thickness, and base layers thicker than 6 in. are not economical or recommended in most cases.

Regardless of the size(s) produced, the grading bands should be adjusted to provide suitable gradations for the intended application (e.g., free-draining vs. dense-graded) and to minimize production of materials that cannot be used. In addition, good dense-graded unbound base materials typically have a plasticity index (PI) of 6.0 or less, with no more than 12% to 15% passing through the No. 200 sieve (ACPA 2007, ASTM 2015).

Guidance on specific gradations to achieve unstabilized base materials that provide good stability with varying degrees of permeability (free drainage capacity) can be found in the ACPA's Engineering Bulletin EB204P (ACPA 2007).

Other Physical Requirements

Los Angeles (LA) abrasion test (AASHTO T 96) requirements for RCA are typically the same as for natural aggregate materials (i.e., loss of not more than 50%). RCA usually meets this requirement without difficulty but generally exhibits higher losses than most conventional aggregate types. This can be a concern in construction, where compaction efforts result in an effective change in gradation.

Soundness testing of RCA is sometimes required but cannot be performed with conventional sodium or magnesium sulfate soundness tests (AASHTO T 104) because RCA is susceptible to sulfate attack, which produces unusual mass loss values that are not representative of the actual durability of the RCA. Therefore, soundness testing of RCA is often waived (particularly for unbound base applications). For similar reasons, unbound RCA bases should not be used in areas with high-sulfate soils.

AASHTO M 319 describes alternative soundness testing approaches, including AASHTO T 103 (a freeze-thaw procedure conducted in water with 25 cycles of freezing and thawing and a maximum allowable loss of 20%). Other listed alternates are the New York State Department of Transportation Test Method NY 703-08 and Ontario Ministry of Transportation Test Method LS-614, both of which involve freeze-thaw cycles in a sodium chloride brine solution with a maximum allowable mass loss of 20%.

Limits on deleterious materials are often applied because, while RCA is primarily comprised of crushed concrete material and natural aggregate particles, it is not uncommon to find that some natural soils, asphalt concrete (from shoulder, base, or repair materials), and other potentially deleterious materials have been included. These materials should be limited as follows:

- Bituminous concrete materials are limited to 5% or less, by mass, of the RCA in AASHTO M 319, with a note that validation testing should be performed to justify the use of higher percentages. Appendix X4 of that specification describes the use of the California bearing ratio test (AASHTO T 193) and the resilient modulus test (AASHTO T 307) for validation. The specification also describes validation by field application (construction of a test strip or historical data to show that higher percentages of asphalt concrete will not adversely affect the performance of the granular base). As a result, many agencies allow significantly more than 5% asphalt material in their unbound RCA base materials.
- AASHTO M 319 limits the inclusion of plastic soils such that the liquid limit (AASHTO T 89) of materials passing the No. 40 sieve is 30 or less and the plasticity index (AASHTO T 90) of the same material is less than 4. Alternatively, the sand equivalent test (AASHTO T 176) value of the same material must be a minimum of 25%.
- RCA should be free of all materials that can be considered solid waste or hazardous materials, as defined locally.
- RCA should also be “substantially free” (i.e., each less than 0.1% by mass) of other potentially deleterious materials such as wood, gypsum, metals, or plaster. These limits can be adjusted if it is determined that the adjustments will not have a negative impact on the performance of the base course.

Application-Based Requirements

The final report for the National Cooperative Highway Research Program (NCHRP) Project 4-31 (Saeed 2008) identified several properties of recycled aggregate base materials that influence the performance of the overlying pavement: aggregate toughness, frost susceptibility, shear strength, and stiffness.

Saeed and Hammons (2008) provided recommendations or critical values for each of these tests to ensure good RCA base performance in specific traffic, moisture, and temperature conditions. While these tests and criteria have not been widely adopted, they may offer useful guidance for assuring good performance potential with the RCA base under various service conditions.

Base Design and Construction Considerations

Design of unbound RCA base layers should be performed with the same tools used for conventional unbound aggregate base layers and should result in layers of similar thickness.

Thicknesses commonly range from a minimum of 4 in. (a typical minimum value for constructability and stability of the construction platform) to a maximum of 6 in. A further reason

compaction efforts for thicker layers may result in increased fines through abrasion and particle fracture.

Thicker base layers may be used for other reasons, such as added frost protection for local soils. Blending with virgin aggregate may be necessary when the designed base thickness exceeds the amount of properly graded material that can be produced from the original pavement.

In many cases, more RCA base material is produced from the original pavement than is required for the new base layer (e.g., when a 12 in. concrete pavement is recycled to produce material for a 4 in. base layer). The use of RCA base across the full pavement cross-section (including the shoulders) is often recommended to minimize hauling or waste of the RCA base material.

RCA bases can be placed using standard equipment and techniques. Excessive handling and movement of the RCA during placement and compaction should be avoided because these activities can produce additional fine material through abrasion, particle fracture, and other mechanisms.

RCA (and blends of RCA and natural aggregate) should be placed at close to the optimum moisture content to ensure that compaction efforts are efficient. Optimum moisture content for RCA generally is significantly higher than for natural aggregate because of the higher absorption capacity of typical RCA.

Placement at sub-optimal moisture contents requires additional compaction effort, which may result in unnecessary degradation of the RCA and the creation of fines that change the drainage and stability characteristics of the material. Additional fines from RCA degradation also increase the potential for precipitate formation.

Compaction density control is typically accomplished by performing a standard proctor test (AASHTO T 99 or ASTM D698) and requiring a minimum in-place density of no less than 95% of standard proctor. If the RCA is to be free-draining (i.e., a target permeability of 150 to 350 ft/day), it may be difficult to achieve the desired density without crushing the material during compaction. In such cases, it may be preferable to relax the compaction requirement slightly and/or adopt a procedural standard of compaction (i.e., require a specified number of compaction passes to achieve adequate density, based on agency experience).

Appendix X1 of AASHTO M 319 provides a detailed description of an alternative field control method that involves the use of variable acceptance criteria for compaction based on testing performed on each designated lot and subplot on the project.

Regardless of the compaction control method selected, construction specifications must be appropriately written and enforced to ensure compaction is achieved. It is critical that no significant densification of the compacted base material occurs due to service traffic loadings.

The noise and dust associated with breaking and crushing operations have raised concerns with on-site concrete pavement recycling in urban areas. Noise must be controlled in accordance with local requirements, often through limitations on the times when noisy operations can be conducted. These limitations can affect production schedules. Dust abatement procedures (e.g., dust collection hoods and/or water sprays at the crushing and screening stations, as shown in Figure 3) are less problematic, but do add cost to the process.

Concrete Pavement Design Considerations

There is little evidence, either anecdotally or in the literature, to indicate that any agency has significantly modified their pavement thickness, panel size, or panel reinforcing designs to date to address long-term RCA base stiffening due to secondary cementing. Further, there is no evidence to suggest that concrete pavements built on unbound RCA foundations have performed poorly due to a failure to adjust panel length, thickness, or reinforcing design. Thus, there are no concrete pavement design implications associated with the use of RCA in unbound base layers.

Environmental Considerations

Water percolating through RCA foundation layers can result in effluent that is initially highly alkaline, often with pH values of 11 or 12. This is an effect that generally diminishes with time in service as the calcium hydroxide near the exposed RCA surfaces is dissolved and removed from the system. Furthermore, this high pH effluent is generally not considered an environmental hazard, because it is effectively diluted with much greater quantities of surface runoff at a very short distance from the drain outlet (Sadecki et al. 1996, Reiner 2008).

It is not uncommon, however, to see very small regions of vegetation kill in the immediate area of the drain outlet. Awareness of the sensitivity of local soils, surface waters, and groundwater to the presence of alkaline effluent may necessitate setting limits on the proximity of RCA placement to sensitive areas. This same effluent may also cause or accelerate corrosion of exposed metals in culverts and other appurtenant structures, so those types of exposure should be avoided.

The gradation and washing recommendations previously provided to prevent precipitate formation are generally effective



Figure 3. Water spray dust suppression system on concrete crusher (photo courtesy of Duit Construction)

in reducing initial pH levels in RCA base drainage effluent (Snyder and Bruinsma 1996). Chapter 7 of Snyder et al. (2018) offers additional information and guidance on mitigating the presence of elevated pH effluent and other environmental concerns associated with concrete recycling.

Example Projects

Edens Expressway, Chicago, Illinois—1978 (ACPA 2009)

The 1978 Edens Expressway project (I-94 through the northern suburbs of Chicago) was the first major US urban freeway completely reconstructed and also the largest highway project on which concrete recycling had been used up to that time (Dierkes 1981, Krueger 1981).

The Illinois Department of Transportation (IDOT) permitted the use of RCA in base layers and fill applications on this project. While there were adequate supplies of acceptable virgin base aggregate approximately 18 miles from the project site, the haul from the source to the job site would have required a 3-hour round trip during daytime traffic conditions, so on-site recycling was selected (Darter et al. 1998). The crushing plant was set up in an interchange cloverleaf area (see Figure 4).

The area was heavily populated, so noise was a serious concern. Crushing operations were suspended from midnight until 6 a.m. every day, and some modifications to typical operational procedures were instituted (such as truck drivers not being allowed to bang their tailgates to help discharge materials from their truck beds).

Nearly 350,000 tons of the old pavement were crushed at this site, with about 85% of the RCA produced being used in fill areas, while the remaining 15% was used as a 3-in. unbound aggregate base. An asphalt-treated base and 10-in. continuously reinforced concrete pavement (CRCP) were placed over the RCA base. It was estimated that recycling the old concrete pavement saved 200,000 gallons of fuel that would otherwise have been consumed in disposing of demolished concrete and hauling virgin aggregate to the job site (Darter et al. 1998).

This pavement provided excellent service for nearly 40 years under extremely heavy traffic (up to 170,000 vehicles per day in 2007) and demonstrated the feasibility (and economy) of



Figure 4. Concrete recycling operation set up inside of Edens Expressway cloverleaf interchange (photo from NHI 1998,

completely recycling and reconstructing a high-volume urban concrete expressway.

Other Projects

RCA has been successfully used as unbound aggregate base in hundreds of projects since the 1978 IDOT Eden's Expressway project. Recent well-documented example projects are described in Chapter 2 of Snyder et al. (2018). These include: the Illinois State Toll Highway Authority use of RCA in base materials between 2006 and 2016, resulting in a savings of more than \$61 million (2016 dollars); a 1981 18-mile two-lane recycling project in Minnesota that saved 150,000 gallons of fuel and 27 percent of project costs; and a 2015 1.5-mile Wisconsin Interstate project that was projected to save more than \$250,000 over the project life.

Bound (Stabilized) Base Applications

Lean Concrete Base and Cement-Stabilized Base

The physical and mechanical properties of RCA (particularly the absorption characteristics) must be considered in the design and production of lean concrete base (LCB) and cement-stabilized base (CSB) materials, similar to their consideration in concrete production using RCA. Chapter 5 of Snyder et al. (2018) provides detailed information and guidance on the design and production of concrete mixtures using RCA; the concepts presented there are also generally applicable to the production of cement-stabilized RCA base materials.

Coating or embedding the RCA in fresh cement paste or mortar prevents the migration of crusher fines and the dissolution and transport of significant amounts of calcium hydroxide, which can otherwise form calcium carbonate precipitate in drain pipes. Thus, the LCB or CSB layers can be constructed without risk of serious drainage or runoff concerns.

Asphalt Concrete and Asphalt-Stabilized Base

RCA has been used successfully in new asphalt concrete and asphalt-stabilized base applications at replacement rates of up to 75%. Typical RCA particle angularity and rough texture provide excellent potential for stability and surface friction, and the use of asphalt to encapsulate RCA particles effectively eliminates the potential for drainage and runoff concerns in base applications.

The more absorptive nature of typical RCA particles significantly increases asphalt demand, which may increase costs. However, it is worth noting that the U.S. Geological Survey (USGS 2000) determined that about 10% of all RCA produced at that time was being used in asphalt concrete mixtures.

Performance Concerns

No known pavement performance concerns are specifically related to the use of RCA in bound base layers for either asphalt or concrete pavements.

Qualification Testing

As noted in the discussion of unbound RCA base applications, highway agencies typically require only gradation control when recycling concrete pavements from their own networks. When additional testing is called for, RCA materials must typically meet the same quality requirements as conventional aggregate materials intended for use in the same application, with the exception of sulfate soundness testing (which often yields misleading results for RCA).

When produced for use in cement-bound base applications, it is particularly important to limit the inclusion of gypsum and organic materials that would affect the base strength and set time. Guidelines specific to the use of crushed concrete in concrete mixtures are available in Appendix C of *Recycling Concrete Pavements* (ACPA 2009). These guidelines are generally applicable to RCA use in cement-treated bases as well.

Base Design and Construction Considerations

Design of bound RCA base layers should be performed using the same tools used for conventional bound aggregate base layers and should result in layers of similar thickness.

RCA bases of all types can be placed using standard equipment and techniques. Excessive handling and movement of the RCA during placement and compaction should be avoided because these activities can produce additional fine material through abrasion, particle fracture, and other mechanisms.

Overall Pavement Design Considerations

The physical and mechanical properties of bound RCA base layers are very similar to those of bound conventional aggregate base layers, so there is no need to modify any aspect of the design of the overlying pavement (either asphalt or concrete).

Environmental Considerations

Binding the RCA in cementitious or asphaltic material effectively coats the RCA and prevents the leaching of calcium hydroxide that would lead to high-pH drainage effluent and/or crusher dust and calcium carbonate precipitate that can be deposited in drainage systems. Without those potential negative impacts, the use of RCA in bound base layers is generally considered to have a highly favorable environmental impact.

Example Projects

Hartsfield-Jackson Atlanta International Airport (ATL)

RCA was successfully produced on-site at ATL using pavement slabs from construction in the 1980s, some of which had alkali-silica reactivity. RCA was allowed for use (at the contractor's option) as both fill and cement-treated base materials at the airport.

The primary reason for RCA use was the saving of landfill

costs in disposing of existing concrete. When used as fill, the RCA complied with the Georgia Department of Transportation (GDOT) specifications for graded aggregate bases.

However, RCA at ATL was required to exceed GDOT virgin aggregate standard specifications for Sections 800 (Coarse Aggregate) and 815 (Graded Aggregate). This resulted in a 1.5-in. top size material with 4% to 11% passing the No. 200 sieve, LA abrasion maximum mass loss of 51% to 65%, and a sand equivalent test result of at least 28%.

Construction of RCA CSB at ATL was accomplished using conventional equipment. There was concern that the RCA would degrade during compaction, but no evidence of degradation was observed. It was reported that the RCA fill and cement-stabilized bases have performed adequately (Saeed et al. 2006).

Figure 5 shows locations at ATL where RCA has been used as a cement-stabilized base. In addition, it has also been used successfully under flexible (asphalt) pavement at the Southeast Navigation, Lighting, and Visual Aid Road (not shown).

Michigan DOT Experience (Van Dam et al. 2011)

The Michigan Department of Transportation (MDOT) has constructed a few projects under Special Provision 03CT303(A140): Open-Graded Drainage Course, Modified (Portland Cement-Treated Permeable Base Using Crushed Concrete). This was done, at least in part, due to issues related to excessive flow of precipitate from unbound open-graded RCA drainage courses.

The special provision requires that all RCA used for the cement-treated permeable base (CTPB) be obtained from the pavement that is being reconstructed (unless otherwise approved). Physical requirements for the RCA are presented in Table 1.

The CTPB mixture is proportioned with 250 lbs of cement and 100 to 120 lbs of water per cubic yard, with adjustments allowed to achieve compressive strengths between 200 and 700 psi at 7 days. At the time of this MAP Brief, the pavements constructed on an RCA CTPB are “performing very well” (personal communication with Dan DeGraaf, Michigan Concrete Association).

Summary

RCA is commonly used with great success in pavement base and fill applications. Reasons for the wide acceptance in these applications include the following:

- The stable nature of the typically angular, rough-textured particles
- Added stability often provided by secondary cementation
- Relative insensitivity of the material to the presence of minor amounts of asphalt, metals, and other typical materials found in the pavement environment
- Economics associated with reduced hauling costs and tipping fees for disposal
- Environmental benefits of resource conservation and reductions in processing and hauling energy
- Excellent performance potential

RCA generally meets all of the same quality and physical requirements used for natural base aggregate. An exception is that sulfate soundness testing is not indicative of RCA durability, so other durability tests must be used.

Structural issues due to frost heave, moisture swelling, or sulfate attack have been present in a very few cases. These rare instances can be avoided through selective RCA gradation to minimize exposure to and retention of moisture.

The flow of water over and through RCA can result in highly alkaline effluent—at least initially—and the depositing of crusher dust and calcareous tufa in drainage systems. Several techniques have been used successfully to mitigate these issues.

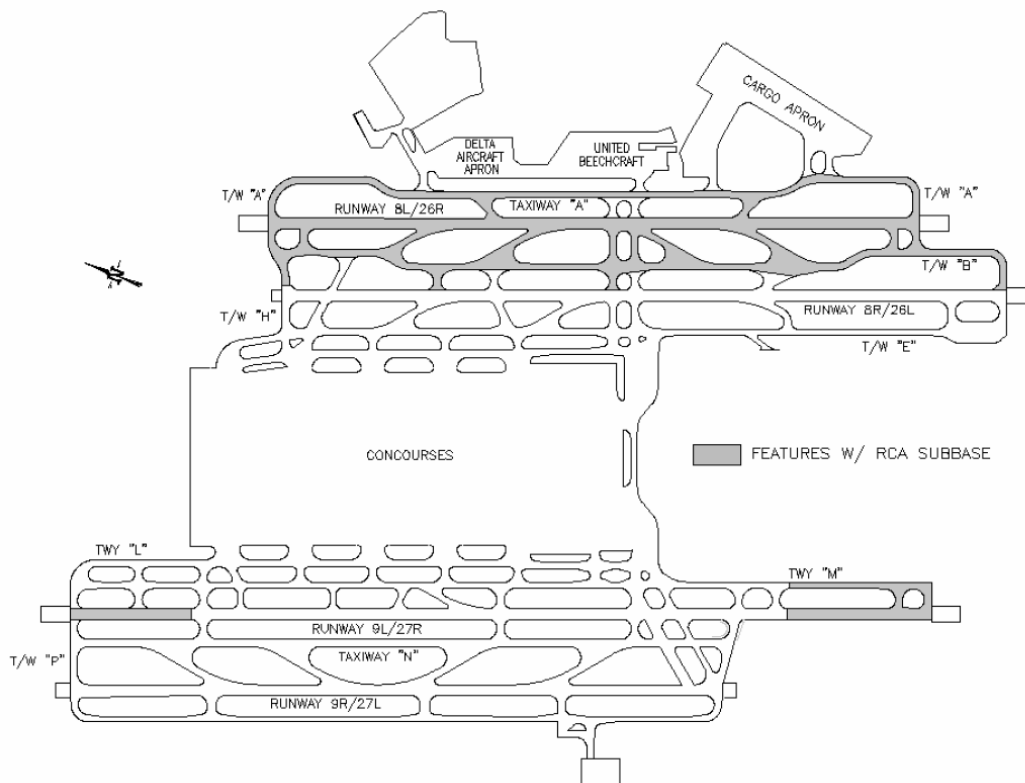


Figure 5. Airfield pavement layout at Hartsfield-Jackson Atlanta airport showing features with RCA base (photo courtesy of Innovative Pavement Research Foundation)

Table 1. MDOT requirements for RCA use in cement-treated permeable base

Sieve Analysis (MTM 109)							
Sieve Size	1 1/2 in.	1 in.	3/4 in.	1/2 in.	No. 4	No. 8	No. 200*
Percent Passing	100	90-100	--	25-65	0-20	0-8	5 max.
Additional Physical Requirements							
Crushed Material, % Min (MTM 100, 117)				90**			
Loss, % max, Los Angeles Abrasion (MTM 102)				45			

*Loss by washing (MTM 108)

**The percent crushed material will be determined on that portion of the sample retained on all sieves down to and including the 3/8 inch

Source: Michigan DOT via Applied Pavement Technology, Inc.

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