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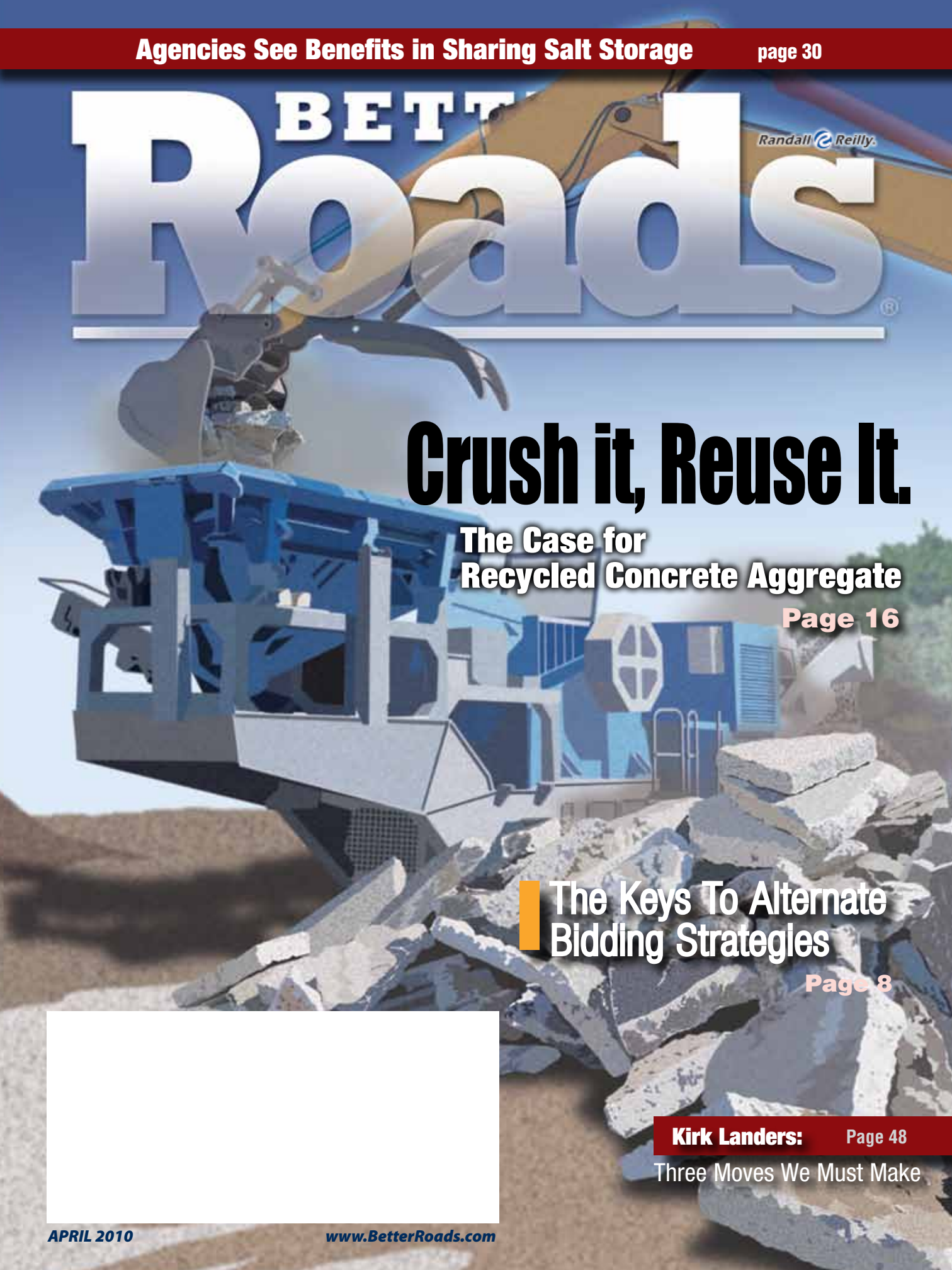

Crush it, Reuse It.

The Case for Recycled Concrete Aggregate

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By Tom Kuennen, Contributing Editor

Two for the Price of One

Recycled concrete aggregate proves its value; but it demands an engineered approach.

Recycled concrete aggregate (RCA) is a valuable resource for road owners and builders, both in terms of lowering costs and in constructing a "green" highway. But RCA needs to be approached as an engineered product, with its production and reuse tailored to fit its composition and ultimate end use in a project.

Fortunately, new guidance is available that will help road owners and builders make decisions on how to use RCA, even as its utilization is growing on vast scales, for example the recently completed reconstruction and widening of I-294, the TriState Tollway in suburban Chicago.

Despite being blessed with extensive virgin aggregate sources, Texas is a strong supporter of RCA. In a September 2008 report, Recycled Concrete Aggregates Make 'Cents', the Texas DOT said, "In today's environment of skyrocketing material and transportation costs encountered in road construction, recycled concrete aggregates (RCA) provide substantial savings to TxDOT and taxpayers."

With RCA, natural resources are conserved, waste disposal is reduced, and air quality is improved due to reduced haul distances and reduced energy consumption, TxDOT said. "In many cases, allowing the use of RCA can be the most cost effective choice for an aggregate source," the DOT said. "This is especially true for those districts that do not have good, native aggregate sources. Using RCA can reduce time and expense of importing aggregates from other parts of the state."

TxDOT has researched and used RCA with good success for about 17 years. In the years 2006-2008, TxDOT saved approximately 1.8 million tons of virgin aggregates by incorporating RCA in cement treated base, flexible base, continuously reinforced concrete pavement (CRCP), filter dams, gabion walls, concrete traffic barriers, flowable fill and select backfill for mechanically stabilized earth walls. "This equates to an estimated savings of $12.6 million from reduced or eliminated landfill and virgin aggregate associated costs. Savings from using RCA has the potential to increase tenfold based on current availability of RCA."

RCA an Engineered Material

But care must be taken in specifying and using RCA in road structures and concrete mixes.

"Concrete pavement recycling is a viable, successful and proven technology," said Mark B. Snyder, Ph.D., P.E., vice-president, Pennsylvania chapter of the American Concrete Pavement Association (ACPA), adjunct professor at the University of Pittsburgh, and 2010 president of the International Society for Concrete Pavements.

"However, RCA must be treated as an engineered material, and not as a straight-up replacement for natural aggregate," Snyder told *Better Roads*. "The properties of recycled concrete aggregate can vary greatly, depending on the original aggregate source, and the production techniques. Therefore it's necessary to characterize the material so it's used properly, and if using in new concrete, appropriate adjustments are made in the structural or mix design."

That's why as an engineered material – like reclaimed asphalt pavement (RAP) – RCA must be tested and analyzed in a lab before being included in a structure or mix. In particular, the physical and mechanical properties of RCA vary with the quality and quantity of reclaimed mortar, which may affect the design of the structure or concrete mixture. These effects can be significant when maximizing reclamation efficiency by including lots of mortar, or minimal when efforts are made to eliminate as much reclaimed mortar as possible.

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Illustration by Edd Hickingbottom

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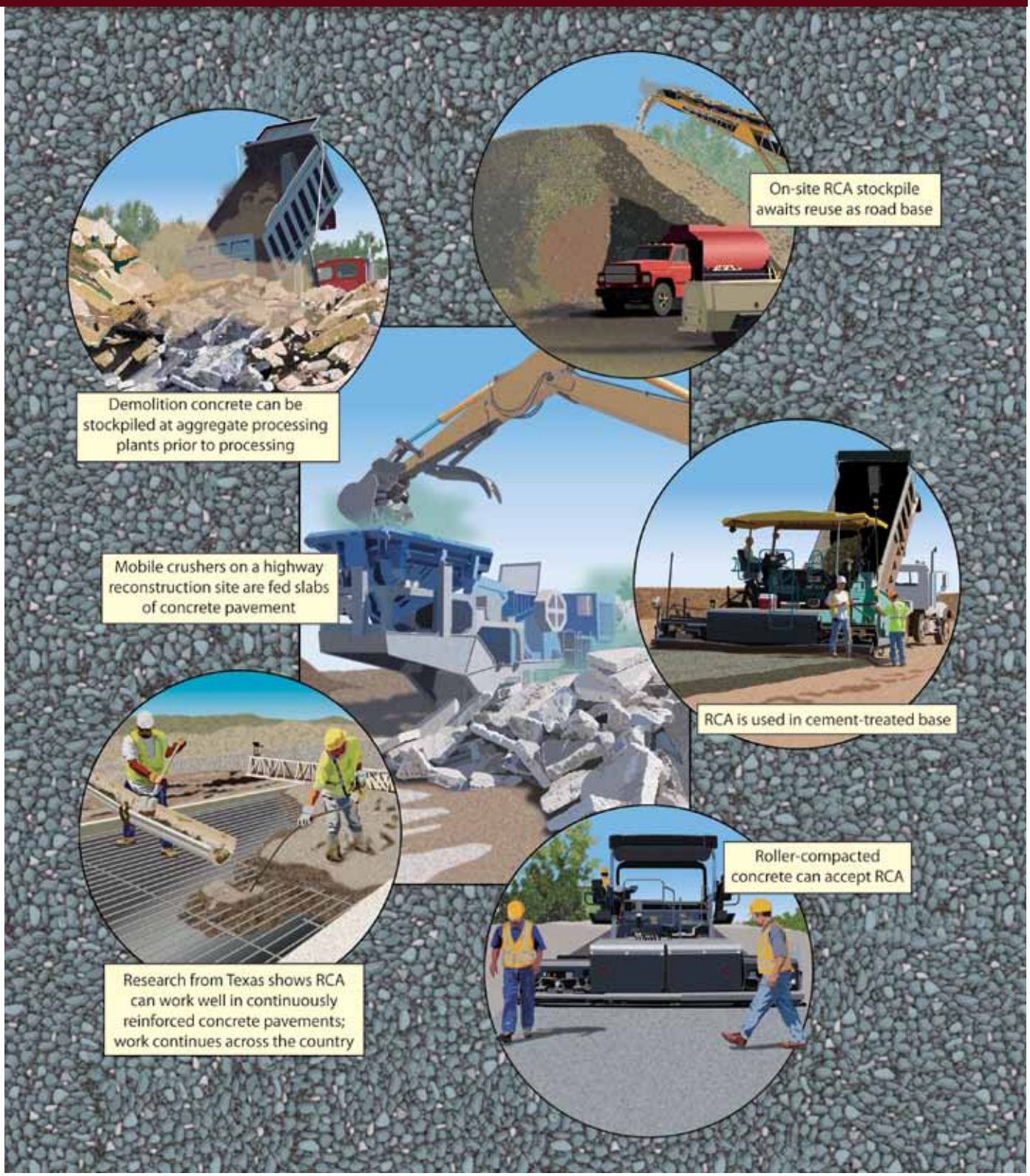
Recycled Concrete Aggregate
Best Used as an Engineered Material



"It's a matter of deciding what your goals are in terms of reclamation, and what the final use of the material will be, and test, test, test and characterize the material accordingly," Snyder said.

Natural "virgin" aggregates and mortar (cement paste, sand, air and admixtures) comprise RCA. The crushing process results in aggregate particles that are often more angular and rough than typical virgin aggregates, and their properties are somewhat different. RCA typically has a higher absorption capacity, lower specific gravity, greater mass loss in tests such as L.A. abrasion and sodium and magnesium sulfate, and higher chloride content than virgin aggregates, reports the American Concrete Pavement Association.

Nonetheless, ACPA says, RCA aggregates typically must (and generally do) meet the same requirements as virgin aggregates for the target application, even if the RCA is produced from a concrete pavement with a materials-related distress such as D-cracking or alkali-silica reactivity (ASR). Other concerns with RCA are precipitate potential in the presence of water, and surface dust and contaminants, which can be addressed during RCA production and pavement design.

RCA's angularity is considered a plus when it's used as a base course. For example, in the 2007 report, *Evaluation of Recycled Portland Cement Concrete Pavements for Base Course and Gravel Cushion Material*, done for the South Dakota DOT and FHWA, the researchers concluded "Strong and stable gravel cushion and aggregate base course layers can be attributed to the gradation, angularity and cleanliness of the RCA materials."

Recycled portland cement concrete pavements have a relatively high level of water absorption, they warned, adding that relatively high level of water absorption could potentially make the proper compaction of gravel cushion and aggregate base course layers variable.

Nonetheless, South Dakota found that "recycled portland cement concrete pavements are a viable option for use in gravel cushion and aggregate base course construction."

▲ ***Reclaimed concrete aggregate*** *is mostly angular and varies in mortar content, which will affect how it performs in its ultimate application.*

Photo courtesy of ACPA

Acceptance of RCA

The last formal survey of RCA use among the states was released in 2004 by the Federal Highway Administration. Its purpose was to capture for technology transfer the most advanced uses of recycled concrete aggregate for use by state highway agencies.

Transportation Applications Of Recycled Concrete Aggregate: FHWA State of the Practice National Review found that concrete routinely is being recycled into the highways of the United States, and its principal application has been as base material.

State transportation agencies were surveyed to determine the current uses of RCA. Forty-one of 50 state DOTs allowed some use of RCA in their specifications, the survey reported. From the results of this survey, five states were identified as being among the highest consumers of RCA in the United States, as well as having large supplies. Their applications were spotlighted in the report, which may be easily located online by "Googling" the title.

"Of those 41 states, 38 were permitting its use in foundation layers, among other applications," Snyder said. "Foundation layers were the most common application. But its use in pavements is increasing as aggregates costs go up, and haul distances to virgin aggregates become greater. The amount of RCA used is increasing and it's already fairly high."

Addressing the need for better guidance, ACPA has articulated guide specifications for use of RCA in road projects, and the American Association of State Highway & Transportation Officials (AASHTO) has a standard specification for use of RCA in foundation layers, and a draft temporary spec for its use in concrete mixes, Snyder said.

The ACPA guide spec is contained in a new publication released in October 2009, *Recycling Concrete Pavements*. The 102-page technical resource describes concrete pavement recycling as a proven technology that offers an alternative aggregate resource that is both economical and sustainable.

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The publication begins with an executive summary and an introduction, and then continues with chapters covering production, properties and characteristics, uses of RCA, and properties, performance, and recommendations for concrete pavement structures containing RCA. Appendices follow, including guidelines for removing and crushing existing concrete; using RCA in unstabilized (granular) subbases: and using RCA in concrete pavement mixtures. Additional appendices include AASHTO and ASTM standards, as well as a glossary of terms.

Mortar Content Key

The mortar content of the final RCA product is key to a successful application. "Crushed concrete will come down to either large-size coarse aggregate particles, or the 'glue' that holds them together, the mortar, which is the cement paste plus sand particles and fly ash or any other admixture,"

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Millions of tons of existing concrete pavement *was recycled on the spot in last year's reconstruction of I-294, the TriState Tollway in suburban Chicago.*

Photo courtesy of ISTHA

Snyder told *Better Roads*.

How much mortar should come off the RCA depends on the ultimate use of the RCA, Snyder said. "It really depends on the application," he said. "RCA needs to be treated as an engineered material. If you want to maximize reclamation efficiency, so you are reclaiming as much mortar as possible to be as 'green' as possible, there are certain types of crushing processes that will remove less mortar. Then you will need to take the presence of that added mortar into account in designing the application."

For example, concrete mix designs may need to be modified to compensate for the higher absorption capacity of the RCA, and base course gradations need to be selected with consideration of the higher abrasion or degradation properties of the material.

"If you are considering the use of high mortar-content RCA in an unbound foundation layer, there may be more potential for leaching of calcium hydroxide, which is a byproduct of the hydration of cement," Snyder said. "This will result in a high-pH runoff at first, and perhaps the collection of calcium carbonate precipitate in your drain pipes or filter fabric. So you will want to reduce RCA mortar content for

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RCA from existing pavement *is placed as base of reconstructed I-294 in suburban Chicago in 2009.*

Photo courtesy of ISTHA

▲ ***RCA is not confined to base applications****; busy I-10 was completely reconstructed in 1995 as a continuously reinforced concrete pavement containing RCA, and is performing superbly after 15 years.*

Photo courtesy of Mark Snyder, P.E.

this application, use a daylighted base instead of pipe drains, or use the material in an undrained layer instead."

If the goal is to reclaim as much mortar as possible, and the high mortar-content RCA is going into a concrete mix, it will result in high absorption and lower specific gravity for the aggregate, Snyder said. "Perhaps there will be higher shrinkage as well," he said. "Thus you may need to shorten up your joint spacing, adjust water content, or use additional fly ash or water reducers to adjust the mix design. You need to test and understand the properties of the RCA so that you can adjust your designs to achieve the performance you want."

The other end of the spectrum is reclaiming less material while producing an RCA that is as close to natural aggregate as possible. "For that you may use an impact crusher, making an effort to remove as much mortar as possible," Snyder said. "The mortar can be recycled separately into an undrained base layer, or stabilization layer. The processed RCA with minimal mortar can be placed into a new mix application, without too many mix design adjustments in that case, as you are essentially reusing existing aggregate."

The production processes might be dictated by the engineer who decides how the material will be used, Snyder said. If the contractor wants to pick the material up and reuse it in the same pavement structure, the selected use of the RCA within that pavement structure will dictate the required handling, crushing and any post-crushing treatments (like washing or air-blowing or other beneficiation) of the material.

Dealing with ASR Concrete

Alkali-silica reactivity, called ASR, is the bane of concrete. Formerly thought to afflict only concrete made with western aggregates, it's now thought that the potential for ASR-prone aggregates exist in every state.

ASR is a chemical reaction that occurs between alkalis contributed primarily by cement, and a reactive form of silica from reactive aggregate, which forms an alkali/silica gel. Under the right conditions – particularly enough available moisture – the gel will expand and produce stresses and damage in the concrete.

Over time, this expanding ASR gel exerts tremendous internal pressure that can lead to cracking of the concrete. This cracking can provide pathways for potentially deleterious materials such as water, sulfates and chlorides to the interior of the concrete matrix, which in turn can lead to serious durability issues such as freeze/thaw damage, sulfate attack or steel corrosion.

It's acknowledged that ASR doesn't destroy concrete per se. Rather, ASR-compromised concrete is weakened so that day-in, day-out wear-and-tear becomes prematurely destructive. Clues to ASR's destructive chemical reactions include map and longitudinal cracking in bridge decks and pavements, and longitudinal cracking in structural columns.

The best way to avoid ASR in new concrete is to take precautions in the mix design. These include testing aggregates for reactivity, consideration of the use of low-alkali cements, use of suitable pozzolans like ASTM C-618 Class F fly ash, use of lithium-based admixtures, and a basic knowledge of the historical performance of all the materials used.

If ASR-afflicted recycled concrete aggregate is reused in a structure, does the potential exists for ASR damage in the new concrete?

Maybe, maybe not. "There are a number of projects, particularly in Wyoming, where they've done large amounts of recycling of badly ASR-distressed pavements, and they've done it successfully, with pavements over 20 years old with no ASR," Snyder said. "But they tested and determined the right combination of fly ash, how much RCA they could use, and how much low-alkali cement was needed to get a good outcome. It worked just fine."

The Wyoming engineers decided to crush the concrete, lose a lot of the mortar, and limit the amount of reclaimed aggregate that could be used. Class F fly ash was specified as it's a known mitigator of ASR.

Drain to Fight D-Cracking

D-cracking is another material-related distress in concrete pavements. It's a concrete deterioration caused by excessive expansion of certain critically saturated coarse aggregate particles during freezing temperatures.

"Many states fight potential recurrent D-cracking by crushing the RCA down to a minus 3/4-in. top size," Snyder said. "They may also choose to design the pavement with drains or other features that keep the pavement relatively dry. Minnesota has had tremendous success doing this. They had a number of pavements that were badly D-cracked, including one on U.S. 59 that was crushed down to a 3/4-in. top size for the concrete paving mixture, and where the pavement structure included a drained foundation so the pavement would not become critically saturated. That pavement has now been in place for nearly 30 years with no evidence of recurrent D-cracking."

The solution is to treat RCA as an engineered material. "Again, to use RCA successfully," Snyder said, "it's a combination of understanding what you've got, understanding the mechanisms involved, and designing so that those undesired mechanisms don't take place, either chemically in the case of ASR, or mechanically via freeze-thaw in the case of D-cracking."

RCA and Transverse Cracking

Transverse cracking is a not uncommon problem with pavements containing RCA, but it's not confined to RCA pavements.

In the 2009 presentation at the Transportation Research Board meeting, *Performance of Rigid Pavements Containing Recycled Concrete Aggregates, 2006 Update*, by Snyder, David L. Gress, Ph. D., P.E., Recycled Materials Resource Center at the University of New Hampshire, and Jeffrey R. Sturtevant, traffic engineer, Whitney Bailey Cox & Magnani, the authors describe excessive transverse cracking in pavements built prior to 1988 and containing RCA, such as I-94 near Brandon, Minn., where the recycled section developed more deteriorated transverse cracks than did the control section (31 percent vs. 0 percent).

"The transverse cracking was not necessarily related to the use of RCA," Snyder said. "The jointed reinforced concrete pavement [JRCP] had longer 27-ft. panels, so they were longer than usual and one would expect them to crack anyway. However, the use of RCA in these long panels may have contributed to the deterioration of those cracks because of the higher shrinkage potential and thermal responses of the RCA concrete mixtures. Where RCA was used in jointed plain concrete pavements, we generally did not find excessive cracking in the RCA pavements we revisited."

Typically, an owner will see a higher coefficient of thermal expansion with RCA, because less natural aggregate is present, and more mortar. "Natural aggregate is a stabilizing influence," Snyder said. "Mortar has a much higher volumetric expansion and contraction, due to moisture shrinkage or thermal properties. When you increase your mortar content by including

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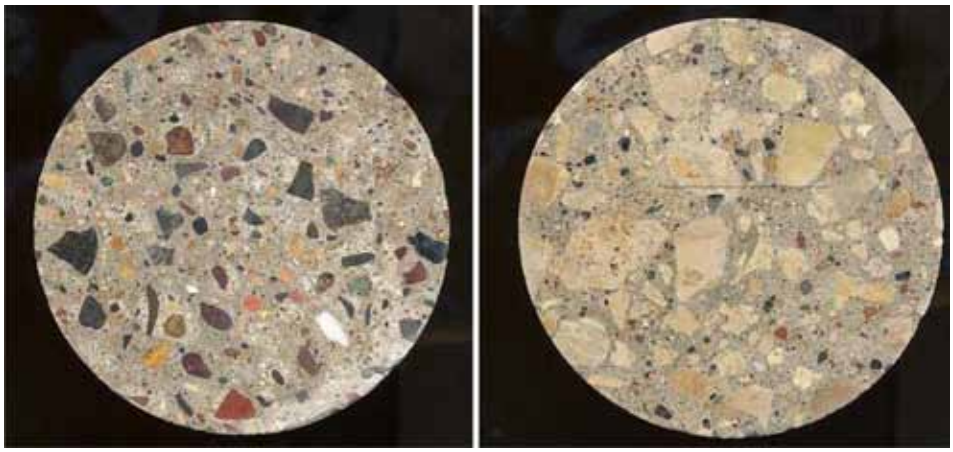

On U.S. 52 in Minnesota, *cores show concrete pavement containing RCA with angular aggregates, some coated with mortar (left), and virgin aggregate control section (right).*

Photo courtesy of Mark Snyder, P.E.

both new and reclaimed mortar, you tend to get a little more shrinkage and thermal responsiveness in the pavement. And when you have a long-panel jointed pavement like I-94, your curling and warping stresses will go up as well. In hindsight, some of the problems found on I-94 and other pavements could have been avoided by using shorter joint spacings and/or higher amounts of reinforcing."

RCA and CRCP

Much of this is moot anyway, as JRCP designs are rarely seen these days, having been replaced by continuous reinforced concrete pavements (CRCP, see *Road Science: The ABCs of Continuously Reinforced Concrete, Better Roads, May 2007*).

"No one builds much JRCP anymore," Snyder said. "It's either continuously reinforced, or short-jointed plain with no reinforcing steel, mostly 15-ft. panels."

Texas has done major work in the field in evaluating the use of RCA with CRCP, and is confident that it works, thanks to the largest application to-date of RCA in CRCP in 1995, a very heavily traveled section of I-10 in Houston between Loop 610 and I-45 involving 10 lanes, including HOV lanes.

Reconstruction of Houston's I-10 (from Loop 610 to I-45) was the first project in the state in which all recycled aggregate was used for pavement concrete, according to TxDOT. Today, crushed concrete is used extensively in state projects in the Houston area and is fairly common in Dallas as well.

"Concrete from existing roadways, pavements, airfields, and buildings can be reused," said Dr. Moon Won, P.E., now with Texas Tech University, who oversaw the I-10 work when with TxDOT.

"The project recycled everything, with nothing but recycled concrete aggregate, both coarse and fine, into the surface layer, and coarse and fine aggregates in the base layer," Snyder said. "It was a huge project, now in place 15 years, and it looks great."

The DOT's objectives of the I-10 study were to evaluate the engineering properties of RCA and portland cement concrete made with RCA, investigate the effect of RCA and PCC properties on CRCP performance, and develop guidelines for the effective use of RCA for CRCP.

There are a number of factors affecting CRCP performance with RCA, TxDOT said. They include adequacy of the pavement structure, material properties, environmental conditions during concrete placement, and construction practices. The study included laboratory evaluation of RCA and PCC material properties, performance evaluation of CRCP with RCA sections in the Houston District, and analysis of information to develop guidelines for the use of RCA in CRCP.

TxDOT found that the CRCP sections utilizing 100 percent recycled coarse and fine aggregates have performed well. No distresses, including spalling, wide cracks, punchouts, or meandering cracks, have taken place. Transverse crack spacing distributions are comparable to those in concrete with natural siliceous river gravel.

The large amount of old mortar in recycled coarse aggregate did not appear to have an adverse effect on CRCP performance, TxDOT said. Moisture control of recycled aggregate was critical in producing consistent and workable concrete. No significant adjustment in paving operations was necessary due to the use of 100 percent recycled coarse and fine aggregate in concrete.

The agency found that RCA in this project did not have a pronounced effect on compressive strength, but that recycled fine aggregates had an adverse effect on flexural strength. The use of both recycled coarse and fine aggregates reduces modulus elasticity significantly, TxDOT said. For the same water/cement ratio, replacing virgin sand with recycled sand did not result in changes in tensile strength.

Echoing Snyder, the state reported that the thermal coefficient of concrete containing 100 percent recycled aggregate is much higher than that of virgin aggregate concrete, and that recycled coarse aggregate has a much higher thermal coefficient than virgin aggregate due to the attached old mortar.

Constructing the I-10 segment was not without complications, TxDOT said. In the beginning of the project, there was a problem producing concrete with consistent workability that met the minimum strength requirement. "The primary reason for inconsistent workability was due to the lack of moisture control of recycled aggregate," TxDOT said "A better sprinkler system was installed later for aggregate

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stockpiles, and moisture of the recycled aggregate was better controlled. This system mitigated the inconsistent workability problem."

Paving operations were closely monitored to identify any variations that might result from using the recycled aggregate. Not much difference was observed.

RCA and TriState Tollway

More recently, in 2009, RCA from the existing pavement was used in the complete reconstruction and widening of the TriState Tollway (I-294) in suburban Chicago, from the Wisconsin to the Indiana border.

The Illinois State Toll Highway Authority (ISTHA) said all existing concrete pavement was crushed on site and reused as base stone under new roadways.

"Recycling the existing road materials not only saved the cost of purchasing new materials for the roadway beds, but also eliminated the cost of hauling the old materials from the work site and disposal in landfills," the authority said.

It resulted in 3.2 million tons of concrete recycled, which is enough concrete to build 4,000 miles of sidewalk, which would equal the distance from Chicago to San Diego and back, ISTHA said.

On the project, excavated concrete was broken up and crushed into smaller pieces – right on the roadway construction site with the use of mobile crushers – to create a high-quality aggregate base for new pavement. Up to 90 percent of each new roadway base consisted of recycled concrete.

But "Bein' Green" means that you need to get recognition of it as well. Thus beginning in October 2009, roadway signs were being installed along the newly reconstructed roadways throughout the 286-mile tollway system to inform drivers that improvements have been made using "green" construction methods and materials.

"We will see much more of this in urban areas," Snyder told *Better Roads*. "The hauling required to remove demolition concrete, and return with virgin aggregate, constitutes an unnecessary added cost. What the Illinois State Toll Highway Authority did was a model for the way highway agencies ought to be doing this in the future."

RCA in Patch Mixes

RCA is going into ready-mixed patch materials, too, being part of the 50 percent recycled material content of Quickcrete Green Concrete Mix. The material's recycled content also includes fly ash or slag cements, or both, the company reports.

Green Concrete Mix diverts material from the waste stream and preserves virgin aggregate resources. As an example, for each 60-lb. bag of the material, there is 0.25 cubic feet of waste diverted from the landfill volume. After an initial launch of the product in the Seattle, Portland, Ore., and northern California markets, Green Concrete Mix is now available in the Denver, Columbus, Salt Lake City and New England markets. ❖