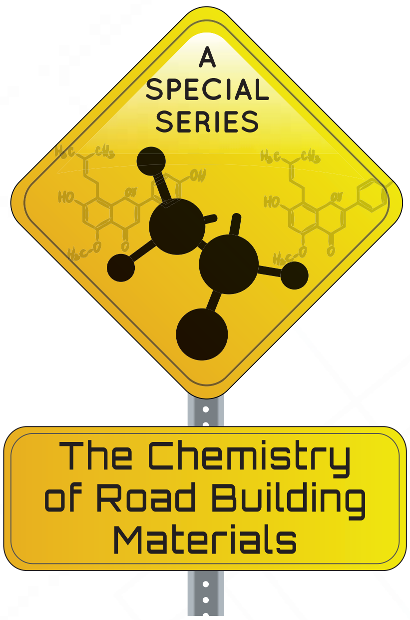
by Tom Kuennen, *Contributing Editor*



The Second Time Around

Recycled materials need analysis, characterization

There is no stopping the growth of recycled and reclaimed materials in pavements.

The use of reclaimed asphalt pavement (RAP), reclaimed asphalt shingles (RAS), recycled concrete aggregate (RCA), and recycled granulated tire rubber (GTR) in pavement mixes and structures is growing dramatically as states accept them more and more in their specs.

But because RAP, RCA, RAS and GTR come from a variety of sources, they must be physio-chemically characterized prior to use in mixes.

• For RAP, which virgin aggregates does it contain? Do deleterious materials exist? How much residual asphalt remains after years of exposure to the elements and oxidation? How much liquid binder will the residual asphalt replace when reused in fresh asphalt mixes?

• For RCA, what is the extent and composition of the mortar or residual cement/sand blend? Were its virgin aggregates prone to alkali-silica reactivity (ASR) or is ASR present and in what degree? Are other deleterious materials present? Is the resulting RCA "good" enough to be used as aggregate in fresh asphalt or portland cement mixes, or is it going to be destined for road base, a much more common use?

• For RAS, the processed post-consumer ("tear-off") shingle feed will come from a supplier that certifies the material meets state specs. The supplier will have sorted, ground and tested the RAS to make sure it does not contain asbestos, wood scraps or metal and is kept separate from pre-consumer (manufacturer waste) shingles (more on this below). Likewise, GTR will come from a supplier that maintains consistency.

Thus, physio-chemical analysis of beneficiated RAP, RCA, RAS and GTR by in-plant or supplier labs is essential for their continued usage. Because their source composition varies tremendously, these reclaimed materials must be chemically characterized and cataloged; then, blended stockpiles may be managed over time with more or less material added to maintain consistency.

Use of RAP and RCA as road base or fill is a less-critical application so a detailed analysis is not essential; here the research emphasis is on the possibility of leached pollutants finding their way into ground water, and long-term performance.

Processing Adds Value to RAP

Ideally the raw, stockpiled RAP or RCA will have been crushed and screened, or "beneficiated," or screened or "fractionated" into homogenous stockpiles. While this costs the mix producer or contractor additional money, it adds value to the raw materials as they now are consistently sized.

Fractionation is the act of processing and separating raw RAP into at least two sizes, typically a coarse fraction (plus-1/2 or plus-3/8 inch) and a fine fraction (minus-1/2 or minus-3/8 inch), reports the Federal Highway Administration (FHWA) in its April 2011 publication, *Reclaimed Asphalt Pavement in Asphalt Mixtures: State-of-the-Practice*, by Audrey Copeland, formerly materials research engineer at FHWA, now vice president, engineering, research and technology at the National Asphalt Pavement Association.

"States allow higher amounts of RAP if it has been fractionated," Copeland writes. "For example, in the Texas specification, unfractionated RAP is limited to 10, 20, and 30 percent by surface, intermediate and base

April	May	June	July	August	September	October
THE CHEMISTRY OF ASPHALT MODIFIERS	THE CHEMISTRY OF CONCRETE ADMIXTURES	THE CHEMISTRY OF ASPHALT EMULSIONS	THE CHEMISTRY OF AGGREGATES	THE CHEMISTRY OF LOW-ENERGY MIXES	**THE CHEMISTRY OF RECYCLED/ RECLAIMED MATERIALS**	THE CHEMISTRY OF PAVEMENT FORENSICS

layers, respectively. However, by special provision, fractionated RAP is allowed at up to 20, 30 and 40 percent in those same layers."

Separately, RAP has to be chemically analyzed or characterized to determine its properties (below). That beneficiation or fractionation of RAP that's been chemically characterized can permit significantly higher levels of RAP in Superpave mixes is borne out in a paper from the 2012 Transportation Research Board meeting, *Fractionation of High Recycled Asphalt Pavement Content in Asphalt Mixtures for Superpave Mix Design Compliance*, by Cory Shannon, E.I.T.; Yongjoo Kim, Ph. D.; Thomas Glueckert and Hosin "David" Lee, Ph.D., P.E., Department of Civil and Environmental Engineering University of Iowa-Iowa City.

In Wisconsin, pavement demolition concrete is crushed next to a construction site. The resulting RCA will go back as base material below concrete pavement.

Photo courtesy of Tom Kuennen

"Due to the increased amount of fines created during the milling process and the corresponding increased surface area, high RAP content mixes have great difficulty in meeting the volumetric requirements of the Iowa DOT," they write. "The fractionation method for this study focused on physical removal of RAP material below a certain sieve size to limit fine aggregate contribution."

Current Iowa DOT specifications limit contractors to a maximum of 30-percent virgin asphalt binder replacement by RAP materials in the surface course for any state-regulated project, the authors write. "The main objective of this study is to develop quality standards for the inclusion of RAP contents higher than 30 percent in asphalt mixtures," they write. "First a sieve analysis was performed on the recovered aggregate materials from ignition oven burn-off testing to determine the aggregate and asphalt binder composition of the RAP materials. To remove excessive fine materials a fractionated RAP stockpile was produced by removing RAP materials passing the No. 30 (0.60 mm) sieve."

The Superpave mix design was then performed with RAP inclusion levels of 30, 40 and 50 percent, based on virgin asphalt binder replacement for RAP materials randomly selected from the bulk stockpile (traditional RAP) and RAP materials from the fractionated stockpile consisting of materials retained at No. 30 sieve and larger (fractionated RAP).

The fractionated RAP materials produced a lower surface area requiring lower virgin asphalt content, they say, resulting in the increased asphalt film thickness on aggregates. The fractionated RAP mixtures also exhibited higher indirect tensile strength than traditional RAP mixtures for all levels of inclusion.

"It was determined that the use of the fractionation method to remove fine recovered aggregates contributed by the RAP materials is an effective method for improving mix design criteria compliance while also reducing the requirement of virgin asphalt for asphalt surface mixtures with a high RAP inclusion level up to 50 percent," they conclude.

Determining AC Content

Lab testing requirements and testing frequency for binder (AC) content vary according to the category of RAP and the amount of RAP used in a mixture, Copeland writes in *Reclaimed Asphalt Pavement in Asphalt Mixtures* (download a copy by Googling "FHWA-HRT-11-021").

RAP from multiple sources may be subject to more rigorous testing than RAP from a single source, she writes. For all RAP stockpiles, the asphalt binder content and aggregate gradation must be determined. The asphalt binder content may be determined according to AASHTO T308 or AASHTO T164.

The most common method for determining the AC in a sample of RAP is to use the ignition oven method specified in AASHTO T308. A Colorado DOT survey compiled in January 2008 includes responses from 29 state DOTs, and shows that almost half of them used the ignition oven to determine the AC of the RAP fraction for mix design purposes. About 30 percent of the respondents used solvent or chemical extraction, while three out of the 29 states used both solvent extraction and the ignition oven, reported FHWA in *Reclaimed Asphalt Pavement in Asphalt Mixtures*.

The oven can predict future performance of RAP mixes as well. Use of a lab oven for long-term aging or oxidation of various-content RAP mixes found that as RAP content increased, HMA mixes would stiffen at a slower rate than virgin mixes say Sean Tarbox, and Jo Sias Daniel, Department of Civil Engineering, University of New Hampshire, in their 2012 TRB paper, *Effects of Long-Term Oven Aging on RAP Mixtures*.

"Asphalt concrete mixtures undergo aging while in place during their service lives," the authors state. "The aging process stiffens the asphalt, changing its mechanical properties and resulting performance under traffic loading. The major factor contributing to the increase in stiffness of asphalt concrete mixtures over time is the oxidation of the asphalt binder at the molecular level."

In this study, four plant-produced mixtures containing zero, 20, 30 and 40 percent RAP were long-term oven-aged in the laboratory to three levels. The dynamic modulus was measured for each aging level and was compared to unaged values to determine if there was a statistical difference. It was found that as RAP content increased, aging had less of an effect on stiffness.

Long-term oven aging to simulate aging in the field can be used to evaluate stiffness changes over time, they say. The impact of the measured increases in stiffness on the fatigue performance of the pavement has been shown to be influenced by the binder type, as well as the pavement structure. Aging has also been shown to reduce the stress relaxation capacity of the binder. The authors found the stiffening effect of long term oven aging on RAP mixtures is less than that of virgin mixtures. This could be due to the inclusion of already aged binder in the RAP mixtures that does not age further under laboratory conditioning.

Spectroscopic Evaluation of RAP

The ignition oven is not the only way to determine the content and chemical condition of residual binder in RAP. Spectroscopic analysis offers the chance of moving the analysis from the lab into the field.

The ongoing Second Strategic Highway Research Program (SHRP-2) project titled *Evaluating Applications of Field Spectroscopy Devices to Fingerprint Commonly Used Construction Materials* targets, among the other objectives, evaluation of oxidation in RAP, say Iliya Yut and Adam Zofka, Ph.D., University of Connecticut, in their 2012 TRB paper, *Spectroscopic Evaluation of Recycled Asphalt Pavement Materials*.

The study investigates the effect of the RAP content on the concentration of oxidized components of asphalt by using advanced, yet portable, easily interpretable spectroscopic methods. Two types of samples are prepared in the laboratory: binder blends containing 15 to 40 percent weight RAP-binder, and loose HMA samples modified by up to 80 percent weight RAP.

> **"Spectroscopic investigation of the oxidization age hardening in asphalt products has been the focus of pavement research for more than three decades."**
>
> *-Yut and Zofka*

Spectroscopic measurements were performed using a portable attenuated total reflection Fourier transform infrared (ATR FT-IR) spectrometer. Quantitative analysis of the ATR spectra indicates that an increase in RAP content is highly associated with concentration of ketones and sulfoxides in RAP binder. It's also possible to determine RAP content based on the analysis of extracted RAP binder, the authors write.

"Spectroscopic investigation of the oxidation age hardening in asphalt products has been focus of pavement research for more than three decades," Yut and Zofka write. Earlier research employed spectroscopy to study long-term aging in asphalt binders. The researchers recognized three major products of oxidation, i.e., benzylic ketones, sulfoxides and free hydroxyl radicals that may interact with ketones and form carboxylic acids. Later studies confirmed that an increase in viscosity of aged binders is related to an increase in their carbonyl content, they write.

They found that a portable ATR spectrometer is capable of detecting main chemical components usually present in both binders and HMAs, namely aliphatic and aromatic hydrocarbons and mineral aggregates, thus allowing timely field tests of pavements.

RCA Needs Analysis

Recycled concrete aggregate (RCA), like RAP, must be crushed, screened and tested, and stored in blended stockpiles to ensure consistency. It should consist of mineral aggregates bonded by a hardened cementitious paste; residual mortar causes processed RCA to have a rougher surface texture, lower specific gravity and higher water absorption than similar virgin aggregates, says FHWA

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, 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 making reclamation simpler by including lots of mortar, or minimal when efforts are made to eliminate as much reclaimed mortar as possible.

Late last year, the Michigan DOT produced a definitive guide for use of RCA. Prepared by Applied Pavement Technology of Urbana, Ill., for the Michigan Tech Transportation Institute, *Using Recycled Concrete in MDOT's Transportation Infrastructure: Manual of Practice* (download by Googling the title) is an essential guide.

Michigan refers to RCA, the most widely used term, as crushed concrete aggregate (CCA), and observes how it's different from virgin aggregates. "CCA has different properties than natural aggregate, largely because the resultant crushed material is composed of both the original natural aggregate and reclaimed mortar, which significantly affects the properties and behavior of materials produced with CCA unless specific steps are taken to account for it in the design and construction process," the report says. "Moreover, the composition of CCA can be highly variable, and in addition to aggregates and reclaimed mortar may contain contaminates such as soil and clay balls, joint sealant, and asphalt or other construction waste."

Freshly processed RCA/CCA also is highly alkaline and may contain chlorides that may limit is use or applicability, Michigan DOT says "Nevertheless, when its characteristics are properly considered and accounted for, CCA can be used effectively in a number of transportation infrastructure applications."

Data collected from 2009 indicate that concrete pavements are recycled for transportation infrastructure applications in at least 41 states; moreover, about 140 million tons of CCA are produced in the United States per year, according to the American Concrete Pavement Association. "The material has been used in applications ranging from placement in various paving layers (surface, base, subbase) and as fill and embankment material," MDOT says.

A major concern regarding the use of CCA in base layer applications is related to leachates, MDOT says. "CCA contains calcium hydroxide from the original cement hydration reaction," according to the manual. "It is water-soluble, and when water flows through a CCA base, some calcium hydroxide will dissolve into the water. Subsequently, it interacts with atmospheric carbon dioxide to form calcium carbonate, precipitating out of solution and leaving deposits where the water flows. This is problematic if the precipitate clogs up elements of a pavement drainage system, such as filter fabrics, drainage pipes, and outlets."

Residual mortar causes processed RCA to have a rougher surface texture, lower specific gravity and higher water absorption than similar virgin aggregates *– FHWA*

Some environmental concerns exist regarding the use of RCA/CCA as base material, primarily because of its alkalinity. However, the alkalinity rapidly decreases with time, and is not considered a major concern although some vegetation may be destroyed where runoff is discharged directly from a CCA base.

CCA contaminants may be encountered during the recycling process, including HMA overlays and patches, joint sealant, reinforcing steel, dowel and tie bars, and soils and foundation materials, the manual states. "Other contaminants may be present within the concrete itself, such as alkalis and chlorides from deicing salts. Efforts should be made to minimize the potential for introducing contaminants, especially if the CCA is to be considered for use in new concrete."

RCA/CCA will exhibit lower specific gravity, which decreases with increasing amount of reclaimed mortar; higher absorption, which increases with increasing amount of reclaimed mortar; greater angularity; and increased abrasion loss, which increases with increasing amount of reclaimed mortar.

"In addition, CCA may contain unhydrated cement, which may alter its behavior and complicate stockpiling, especially the fine material," according to the 2011 manual. "Finally, the fines produced during the crushing operation (those passing the No. 4 sieve) are coarse and angular, which tend to make CCA concrete mixtures very harsh and difficult to work."

Photo courtesy of Tom Kuennen

In central Texas, crushed recycled asphalt shingles (RAS) are conveyed to an asphalt drum

RCA/CCA in Pavements

RCA/CCA can be used with confidence in asphalt pavements. "Although not common, CCA can be used as an aggregate in asphalt paving layers," the DOT says. "As with the application in base courses, CCA can produce a stable mixture because of its high angularity. And, because the asphalt cement forms a film around the aggregate, leaching and other complications from water interacting with the CCA are minimized."

For this purpose, deleterious materials such as soil, ash, or other fine organic materials should be limited, as they will increase demand for liquid asphalt and decrease overall quality.

"Soundness, abrasion resistance and volume stability should also be tested to ensure the CCA is a suitable aggregate for asphalt mixtures," the report says. "Specific gravity and absorption are generally the properties in which CCA varies the most from natural aggregate, and should be thoroughly evaluated and properly accounted for in the mix design ... due to the crushing process, CCA is generally very angular and therefore would contribute to good asphalt mixture stability. And CCA should meet the requirements for flat and elongated particles, as excessive amounts of these can lead to a weak aggregate matrix and weak asphalt mixtures. Even if ASR or D-cracking was observed in the source concrete, it is not a concern if the CCA is used as aggregate in an asphalt mixture."

In the modern permutation of high-service concrete pavements – continuously reinforced concrete pavement (CRCP) – 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.

Today, crushed concrete is used extensively in state projects in the Houston area and is fairly common in Dallas as well. There are a number of factors affecting CRCP performance with RCA, including adequacy of pavement structure, material properties, environmental conditions during concrete placement, and construction practices.

TxDOT found that the CRCP sections using 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.

And Now, Shingles

Because of their asphalt, fiber and mineral content, abundant, processed recycled asphalt shingles (RAS) are finding their way into hot, warm and cold asphalt mixes. Typical addition rates for RAS into hot mix asphalt can range from 3 to 6 percent by mass, reports FHWA.

RAS provides similar or enhanced properties to conventional asphalt pavements, with reductions in requirements for virgin asphalt cement by 0.5 to 1.5 percent. In most instances, raw shingles are collected by a recycling firm, and cleaned and crushed into fine aggregate.

Currently a national pooled-fund study involving multiple state DOTs – *Performance of Recycled Asphalt Shingles* (RAS) in Hot *Mix Asphalt* [TPF-5(213)] – is under way. Research in different states includes mix performance comparisons, beam fatigue testing, dynamic modulus, flow number and binder property test results.

"The use of reclaimed asphalt shingles (RAS) in asphalt paving mixtures is not a new concept," say NAPA's Kent Hansen and Dave Newcomb, in NAPA Information Series No. 138: *Asphalt Pavement Mix Production Survey*. "The combination of a high asphalt binder content, high-quality fine aggregate, mineral filler, and fibers makes roofing shingles very compatible with asphalt pavement mixtures," they say.

The fact that the asphalt cement in shingles is generally harder than that employed in paving mixtures, and that the other ingredients impact the volumetric properties of the final mix, generally limits its incorporation in asphalt mixtures to 5 percent or less, they add.

Crumb rubber increases asphalt binder viscosity as it's blended in ranges of 18 to 25 percent rubber, reacting to produce an asphalt-rubber binder

"However, even at a relatively lower RAS content, there is somewhere on the order of 15- to 20-percent binder replacement in the final paving mixture," Hansen and Newcomb say. "Currently, 12 states allow the use of manufacturers' waste in asphalt mix and 10 states allow either manufacturers' waste or roofing tear-offs in their mixtures. It is estimated that there are 10 million tons of tear-off waste and 1 million tons of manufacturer waste available on an annual basis. If all these could be incorporated into asphalt paving mixtures, it would amount to approximately 1.8 million tons of asphalt binder replacement. Thus, there is great interest in utilizing waste asphalt roofing shingles in asphalt paving mixtures."

Rubber as Performance Modifier

Rubber from recycled tires is a common additive to asphalt on a regional basis, either as an asphalt modifier (wet process) – where it reacts with the liquid asphalt – or as a fine aggregate substitute (dry process).

As a modifier, crumb rubber increases asphalt binder viscosity as it's blended in ranges of 18 to 25 percent rubber, reacting to produce an asphalt-rubber binder.

Asphalt mixes in which ground rubber particles are added as fine aggregate are referred to as rubberized asphalt for open-graded mixes.

The road to universal acceptance of granulated tire rubber (GTR) as an alternative to conventional polymer modifiers is long, and has been paved with doubts created by premature failures from technologies of the 1990s that were not well understood, or required too many challenges to implement, says Doug Carlson, vice president of asphalt products for Liberty Tire Recycling.

"Two more decades of research and development have dramatically changed the landscape by generating materials and process advancements that definitively position rubberized asphalt as a viable alternative to polymer-modified asphalt in terms of performance and cost," Carlson says.

Asphalt-rubber (A-R) is defined by the American Society for Testing and Materials (ASTM) Standard D6114 as "a blend of paving grade asphalt cement, ground recycled tire (that is, vulcanized) rubber and other additives, as needed, for use as binder in pavement construction. The rubber should be blended and interacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles prior to use."

Asphalt-rubber binder is field-blended (at a hot mix plant) – requiring mobile mixing equipment to produce – or as a terminal blend. The typical rubber content for asphalt rubber ranges from 18 to 22 percent. Granulated tire rubber used in asphalt rubber is in the 10-to-16 mesh range for maximum particle size. This binder is best suited for very thin overlays and heavy duty surface treatments to prevent cracking.

"New technologies have emerged that allow GTR to be used as the primary modifier in performance-graded (PG) asphalt," Carlson says. "These binders are manufactured with 8 to 12 percent rubber content and may include a small amount of virgin polymer or other additives. The rubber particles have a 30-minus maximum size, but are small enough to fit into PG tests. They can be made onsite or delivered by an asphalt supplier. Mechanical or chemical suspension is needed for the binders that retain GTR particles. These binders can directly replace polymer modified materials in dense graded mixes and chip seals."

Rubber enables the use of more recycled asphalt pavement (RAP). Emerging technologies researched by Louay N. Mohammad and Samuel B. Cooper Jr. at the Department of Civil Engineering and Louisiana Transportation Research Center at Louisiana State University have shown that rubber mixes with up to 40 percent of RAP can perform as well as regular mixes with only 25 percent RAP, Carlson says. ❖