TechBrief

The Asphalt Pavement Technology Program is an integrated, national effort to improve the long-term performance and cost effectiveness of asphalt pavements. Managed by the Federal Highway Administration through partnerships with state highway agencies, industry and academia the program's primary goals are to reduce congestion, improve safety, and foster technology innovation. The program was established to develop and implement guidelines, methods, procedures and other tools for use in asphalt pavement materials selection, mixture design, testing, construction and quality control.

U.S. Department of Transportation
Federal Highway Administration

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The Use of Recycled Tire Rubber to Modify Asphalt Binder and Mixtures

This Technical Brief provides an overview of the various processes for recycled tire rubber used as a modifier for asphalt binders and as an additive for asphalt mixtures. Considerations for laboratory and field testing, as well as performance, are discussed. Since some aspects of the technology are still evolving, best practices and areas of caution have been included.

Introduction

Recycled tire rubber (RTR), from waste tires (Figure1) has been used in asphalt by the paving industry since the 1960's. RTR has been used as an asphalt binder modifier and asphalt mixture additive in gap-graded and open-graded asphalt mixtures and surface treatments.

Figure 1. Picture of a waste tire pile.

Until recently the routine use of RTR in pavements has been limited to a few states. While performance is generally good, RTR cost has been high when compared to conventional practices. Asphalt binder costs have increased over the past several years due to the rising cost of crude oil. In addition, polymers, such as styrene-butadiene-styrene (SBS), have also seen an increase in cost due to other market demands and fluctuations in availability. In contrast, over this same time period RTR from car and truck tires has experienced a relatively stable market price.

Local, State, and Federal regulations have also created an increase in the availability of recycled tire rubber. This has driven a renewed interest in RTR as an asphalt binder modifier and mixture additive – with the goal of providing a long-life, cost-competitive, environmentally-responsible pavement system.

In 2006 the FHWA Recycled Materials Policy was established and is located at:
http://www.fhwa.dot.gov/legsregs/directives/policy/recmatpolicy.htm

The FHWA policy states:

1. Recycling and reuse can offer engineering, economic and environmental benefits (Figure 2).
2. Recycled materials should get first consideration in materials selection.
3. Determination of the use of recycled materials should include an initial review of engineering and environmental suitability.
4. An assessment of economic benefits should follow in the selection process.
5. Restrictions that prohibit the use of recycled materials without technical basis should be removed from specifications.

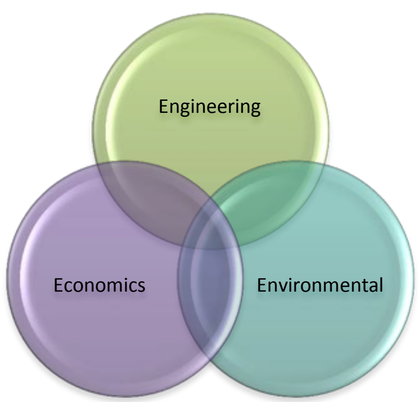


Figure 2. The three key benefits of recycled/reused materials.

This Technical Brief provides background on the various RTR processes used in asphalt pavements and information on how to incorporate RTR into the Superpave design system.

Background

The modern use of RTR in asphalt pavements started in the early 1960's. Charles McDonald, Materials Engineer for the City of Phoenix, Arizona, developed a surface patching material. This was a highly elastic RTR modified binder and aggregate topping. McDonald's work expanded into the application of large surface treatment projects along with other crack relief and open-graded surface courses. In this early work asphalt rubber was field blended at the hot-mix plant and used immediately due to the inherent instability of the product. The developments by the City of Phoenix and subsequently the Arizona DOT led to the initial growth of asphalt rubber (AR) applications, which included surface treatments, interlayers, and AR open-graded friction courses (AR-OGFC).

In 1991, Section §1038(d) of the Intermodal Surface Transportation Efficiency Act (ISTEA) required states to use a minimum amount of crumb rubber from recycled tires in asphalt surfacing placed each year beginning with the 1994 paving season. Although the mandate was lifted in 1995, under Section §205(b) of the NHS Designation Act, a significant number of RTR asphalt pavement sections were placed and national research was fostered. Many States discontinued use of RTR after the mandate was lifted. However Agencies such as Florida, Texas, and Rhode Island continued their use of RTR. In 2005, the State of California Public Resource Code Section §42700-42703 legislated the use of RTR.

The application of RTR modified asphalt binder has evolved with the development of terminal blended AR binders. This development was driven to reduce the need for asphalt mixture production plant modification (needed to incorporate RTR) and to address some performance concerns. A few RTR pavement failures had been linked to poor quality control with field blending practices.

Mix Design Challenges

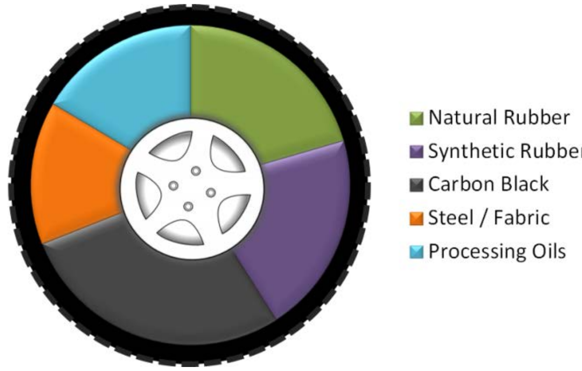
Today, asphalt pavements are primarily designed under the Superpave system, specified under AASHTO standards and procedures. Superpave is a well-documented and proven design system that allows for the specification and development of a wide-range of asphalt binders and mixtures for varied local environmental and traffic conditions. In contrast, RTR has evolved into essentially recipe formulations. Conceptually, the AR recipe should change from one part of the country to another. However, there is currently no widely recognized guidance for adjusting the recipe for varied local traffic or environmental conditions.

Tires

The make-up of tires varies depending on the type, truck or passenger, and manufacture. However, the basic components are about the same and are provided in Table 1 below.

Table 1. Basic Components of Tires

Component	Typical Range
Natural rubber	14 to 27%
Synthetic rubber	14 to 27%
Carbon black	28%
Steel, Fabric	14 to 15%
Processing oils	16 to 17%



Average Percentage Components of Tires

In the past it was believed that different types of tires or different portions of the tires produced better material for blending with asphalt binder. However, with modern tires there is little difference between truck and passenger tires. There are slight variances in the percentage of natural and synthetic rubber, but this is not believed to cause differences in RTR modified binder performance.

Tire Processing

Processing is required to make tires usable as a modifier or additive. The steel and fiber must be removed from the tires and then the remaining tire must be reduced in size to small particles for blending into the asphalt binder or mixture. Several different processes are used to reduce the RTR size for asphalt modification. The two primary processes are ambient grinding and cryogenic fracturing.

Processing the tires using cryogenic fracturing involves cutting up the larger tire pieces into smaller, typically 50 mm particles, using sharp steel cutters. These smaller pieces are then frozen and fractured. The fracturing process produces a large variety of sizes from very small, passing the 75 µm sieve, to larger 4 or 5 mm size particles. The rubber particles produced by cryogenic fracturing have a tendency to be cubical with a smooth surface.

The ambient grinding process starts the same way as the cryogenic process; the tires are cut into smaller pieces with sharp cutting blades. The smaller pieces are then passed through shredders that grind and tear the rubber into smaller particles. Similar to cryogenic fracturing, the ambient grinding produces sizes ranging from small, passing the 75 µm sieve, to larger 4 to 5 mm size particles. The main difference between the two processes is the surface texture of the rubber particles. Ambient grinding produces a rough texture with increased surface area due to the tearing process. Figure 3 below shows the two different types of particles. On the left is the ambient grind with the rough surface texture and on the right is cryogenic fractured with smoother surface texture.

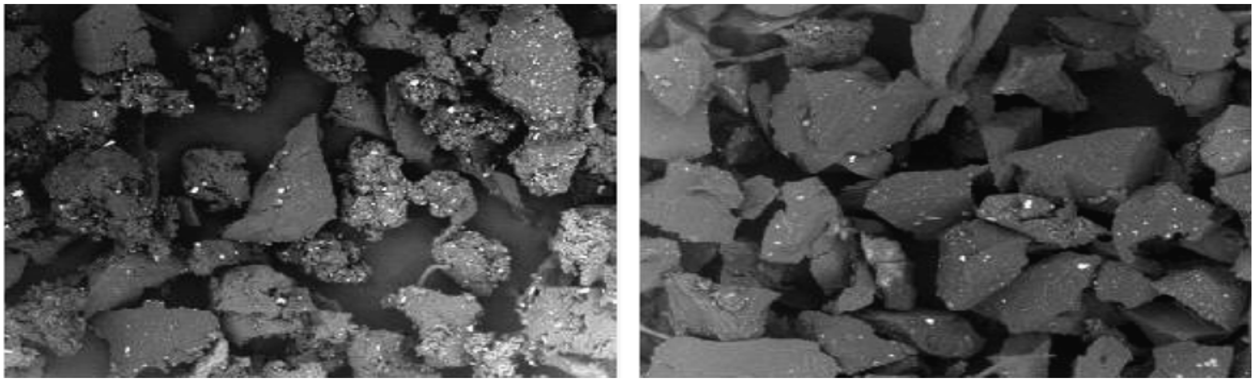


Figure 3. Ambient grind rubber (left) and Cryogenic fractured rubber (right).

The surface area of the rubber particles, in addition to blending temperature, controls how fast the particles will react with asphalt binder where the rubber particles absorb some of the asphalt binder and swell. The greater the surface area the faster the reaction time with asphalt binder. It is critical to know the size of the rubber to control the reaction process. Using a different size in production than used in the mix design may not produce optimal results.

Various Processes for Creating RTR Binders and Mixtures

Figure 4 shows the three general processes used for creating RTR asphalt pavements.

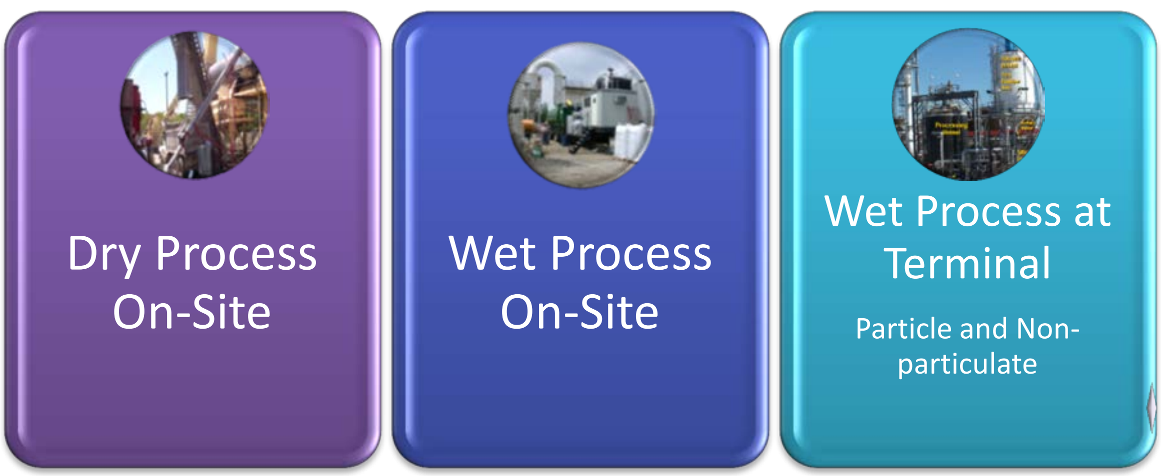


Figure 4. General processes for creating RTR binders and mixtures.

Each of these processes will produce AR pavements with different properties and different performance. Agencies need to understand these differences so they can make a choice on the type of process that will perform best for their desired application. Agencies are encouraged to determine their goals when using RTR so the correct process can be selected for their needs. Further, each of these processes has different risks in terms of success. Agencies need to understand the testing and inspection resources necessary to commit to each of these types of processes to ensure success. Considerable literature is available providing detailed information on each of these processes (see References section at the end of this document) and further guidance is being developed.

Dry Process

RTR used in the dry process is considered to be an aggregate replacement in the mix as opposed to a binder additive. Dry process asphalt rubber is the least commercially significant type of asphalt rubber. Dry RTR is added similar to reclaimed asphalt pavement (RAP) at the mixture production plant. The rubber is typically larger size particles between 4 to 18 mesh or 4.75 to 1.00 mm. Cryogenic rubber is typically used in this process. Gap-graded aggregate mixtures are required to provide space for the rubber particles. Figure 5 shows RTR being auger fed into the RAP collar on the drum of a mixture production plant.

Figure 5. Feed system to add dry RTR into mixture production plant.

Wet Process – On-site Blending

The AR wet process with on-site blending has the longest history of use, Figure 6. The RTR is field blended in a mixing tank and allowed to react with the asphalt binder for a set time. RTR is typically field blended at 350 to 400°F (175 to 200˚C) for 45 to 60 minutes. The temperature and time depends on the base asphalt binder grade, percentage, and particle size of the RTR. During this reaction time the rubber particles absorb some of the light fractions of asphalt binder and swell. This absorption and swelling causes an increase in the viscosity of the AR-asphalt binder blend. With extended reaction times the viscosity will then decrease slightly. This has typically been called “digestion” of the rubber in the asphalt binder.

Figure 6. Wet Process On-site.

The typical RTR addition is 15 to 22 percent by weight of the asphalt and rubber blend. A minimum of 15 percent was initially set to maximize use of recycled tires and has not changed. This initial minimum percentage was not set for performance-related rationale. This is a recipe formulation and may not necessarily produce the optimum performance for traffic or environment at the project. A course graded RTR material, 10 to 14 mesh or 2.0 to 1.4 mm maximum size is used. The larger RTR particle size requires a gap-graded or open-graded aggregate in the mixture to allow room for the rubber particles. If this is not done, compaction is difficult to achieve because the rubber particles push the aggregate particles apart as they are compressed during rolling and expand when the compaction force is removed.

The increase in viscosity that RTR provides to the asphalt binder also requires an appropriate increase in production temperatures for producing and placing mix. Increased temperatures can create unique odors and the potential for smoke. Worker health and safety issues need to be considered. Warm mix asphalt (WMA) technologies have been successfully used to help reduce AR mixture production and placement temperatures.

Best Practice: The City of Phoenix has a small geographic area. By moving field blending of the RTR to a terminal, they have found more consistent quality control.

Best Practice: In California strategically located "depots" exist for just-in-time supply of RTR to small and medium projects. The "depots" have a focus on quality control.

CAUTION: Quality control during field blending is a significant factor that Agencies need to consider. In the past, Agencies have made major changes to their AR program to ensure quality control concerns.

Wet Process - Terminal Blend

Terminal blend RTR modified AR asphalt binder is produced at a supplier's terminal as shown in the left image of Figure 7 and shipped to the mixture production plant similar to standard asphalt binder. RTR used in this process is typically a smaller particle grind, sized to minus 30 mesh or smaller than 0.6 mm. The smaller rubber particles are used to help improve storage stability and minimize RTR particle settlement. In some systems, rubber is completely digested in asphalt with no particulate matter present. The terminal blend RTR binders used alone or with polymers can be formulated to produce Superpave performance graded (PG) binders, typically using 5 to 10 percent RTR by weight of the total binder.

Figure 7. Terminal Blend RTR (left); Mixture production plant with vertical binder storage tanks which allow for better agitation and storage (right).

Smaller RTR particles and polymers are used in a terminal blend to produce an AR binder that is similar to standard polymer modified asphalt binder. It is shipped to the mixture production plant, stored in in the plant's binder storage tanks and mixed with the aggregate, similar to standard asphalt mixture. It may be used in dense-graded mixes with no modification to the job mix formula.

Depending on the technology used, storage stability can be a problem with terminal blend AR binders. If RTR is simply mixed with the binder it will settle with time; because rubber is heavier than asphalt binder. Settlement time will vary depending on the size of the RTR particles and other additives or methods used to reduce separation. To avoid separation transport vehicles and storage tanks with agitation capability may be employed. Even with higher solubility AR binders, cleaning of tanks is recommended. Several patented methods have been developed to reduce separation and newer methods are in development. Continuous agitation in the storage tanks using stirring paddles and recirculation pumps will help reduce separation.

CAUTION: Patented processes may be used with terminal blend AR asphalt binders and may need special consideration for projects receiving federal-aid funding.

Asphalt Binder with RTR Testing

Traditional Physical Property Tests–Viscosity, Ring & Ball

Previous testing practice used a rotational vane viscometer to measure the viscosity of the AR modified asphalt binder, Figure 8. Penetration and ring & ball softening point have also been used to test RTR modified asphalt binders. The rubber particles in the asphalt binder make it difficult to perform viscosity, penetration, and ductility testing. Early methods used larger rubber particles in the 10 to 14 mesh size to blend with the asphalt binder. Currently, the larger particle size prevents performing standard DSR binder tests and will cause high variability in the test results.

Figure 8. Field rotational viscometer.

Current Physical Property Test - Superpave PG System

The introduction of the Superpave system brought new testing equipment and procedures for asphalt binder testing and specification. These new tests were not originally developed to evaluate asphalt modified with particulate matter such as RTR. The Dynamic Shear Rheometer (DSR) test standard limits the maximum particulate size to 250 µm maximum within a 1 mm parallel plate test gap, Figure 9. The test may not measure the bulk properties of the binder if the particles are too large and the test results are influenced by the particle to particle interaction between the DSR parallel plates. This may be offset by increasing the gap between the plates to accommodate larger particle sizes. Many terminal blend RTR modfied binders use 30 mesh rubber or smaller. The typical larger particle sizes would be 600 µm or smaller. Larger particles up to 600 µm might be accomodated by increasing the gap between the plates to 2 mm, although this is still experimental. The test procedure requires a maximum particle size less than one quarter of the gap size. One quarter of a 2 mm gap equals 0.500 mm (500 µm) maximum or 35 mesh particle size. However, the bulk of the rubber particles will be less than 500 µm with only a small percentage of particles larger than 500 µm; typically less than 10%. Increasing the gap between the DSR plates from 1 mm to 2 mm in addition to reducing the RTR particle size to 30 mesh maximum could potentially allow high temperature PG grading of the RTR modified AR binders.

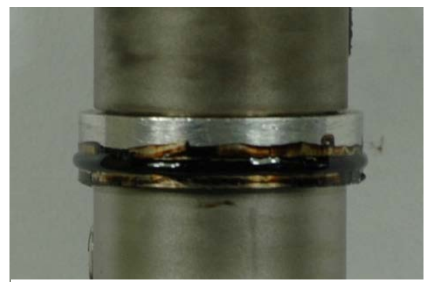


Figure 9. DSR parallel plates with asphalt sample mounted.

CAUTION: Performance grading of terminal blend AR with smaller sized RTR particles and an increased DSR sized opening is still being evaluated.

Figure 10. New DSR geometry to allow testing of larger RTR.

Additionally, work is underway to develop new testing geometries that will allow evaluation of asphalt binders with even larger RTR particle sizes, Figure 10. The cup and bob geometry provides a gap of up to 6.5 mm and will allow for rubber particles up to 1.5 mm or approximately a 14 mesh particle size. Many newer dynamic shear rheometers can accommodate the cup and bob geometry as well as perform typical parallel plate geometry tests. This will allow full PG grading of typical wet process AR with up to a maximum 14 mesh size RTR.

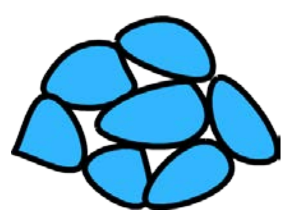
Low temperature binder testing is done using the Bending Beam Rheometer (BBR). The BBR tests a rectangular beam of asphalt binder 6.5mm x 12.5mm x 100mm. This large sample size can accommodate the larger RTR particle sizes allowing PG testing of the low temperature properties of the binder.

Mixture Design Process

There are three general mixture gradation types used with RTR asphalt pavements, Figure 11.

Figure 11. The three aggregate gradation types.

Open-Graded Mixtures

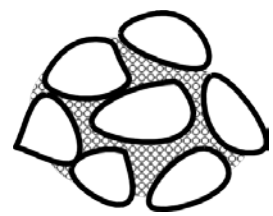


One of the most common uses of wet process RTR modified binder has been in open-graded mixtures. These surface mixtures are used to help drain water from the pavement surface quickly in order to reduce splash and spray and reduce tire-pavement noise. The design process for these mixtures will typically involve using a standard open-graded gradation band and minimum specified asphalt binder content. A drain down test is used to make sure the binder will not flow off the aggregate during production, placement, and compaction. Table 2 shows the gradations bands for typical open-graded mixes placed in Arizona.

Table 2. Arizona gradation specifications for open-graded mixes with and without lime or cement as an anti-stripping admixture.

MIXTURE DESIGN GRADING LIMITS		
Sieve Size	Percent Passing	
	Without Admixture	With Admixture
3/8 inch (9.5 mm)	100	100
No. 4 (4.75 mm)	30 - 45	31 - 46
No. 8 (2.36 mm)	4 - 8	5 9
No. 200 (75 µm)	0 - 2.0	0 - 3.0

Gap-Graded Mixtures



Gap-graded mixtures are used in place of dense-graded mixtures with wet process AR. A portion of the sand size aggregate is removed to allow room for the rubber particles within the gradation. These mixes are designed to have high binder contents in the 6 to 8 percent range. Superpave, Marshall, or Hveem mix design systems have been used for the mixes, but design air voids vary based on agency requirements. Arizona agencies design these mixes for 5% air voids and California designs for 3 to 4 % air voids. The Voids in Mineral Aggregate (VMA) will also be higher because of the high binder contents. Typical gradations that have been used by these two States are shown in Tables 3 and 4.

CAUTION: Typical Superpave mixture test procedures will need to be adjusted when using AR mixtures because of swelling.

Table 3 Arizona DOT gradation specifications for gap-graded mixes with and without the addition of lime or cement as an anti-stripping admixture.

TABLE 413-2 MIXTURE DESIGN GRADING LIMITS		
Sieve Size	Percent Passing	
	Without Admixture	With Admixture
3/4 inch (19 mm)	100	100
1/2 inch (12.5 mm)	80 – 100	80 – 100
3/8 inch (9.5 mm)	65 – 80	65 – 80
No. 4 (4.75 mm)	28 – 42	29 – 43
No. 8 (2.36 mm)	14 – 22	15 – 23
No. 200 (75 µm)	0 - 2.5	0 - 3.5

Table 4. California DOT specification limits for gap-graded mixes.

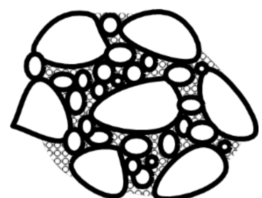
3/4-inch (19.0 mm) Rubber HMA-G

Sieve sizes	TV limits
1" (25.0 mm)	100
3/4" (19.0 mm)	95 – 100
1/2" (12.5 mm)	83 – 87
3/8" (9.5 mm)	65 – 70
No. 4 (4.75 mm)	28 – 42
No. 8 (2.36 mm)	14 – 22
No. 200 (75 µm)	0 – 6.0

1/2-inch (12.5 mm) Rubber HMA-G

Sieve sizes	TV limits
3/4" (19.0 mm)	100
1/2" (12.5 mm)	90 – 100
3/8" (9.5 mm)	83 – 87
No. 4 (4.75 mm)	28 – 42
No. 8 (2.36 mm)	14 – 22
No. 200 (75 µm)	0 – 6.0

Dense-Graded Mixtures



RTR used in dense-graded mixtures will typically be a non-particulate form or a system that uses a very fine particulate rubber. The smaller size, or completely digested RTR particles used in the terminal blending will typically allow for substitution of the AR asphalt binder in place of the standard asphalt binder into the mixture. The supplier should provide information and recommendations on the handling, storage, and mixture production temperatures of the terminal blend AR asphalt binder.

Terminally blended RTR modified asphalt binders may have much higher viscosities than typical polymer modified binders. This may require slightly higher binder contents in the mixture to produce similar air voids in design. Some users have tried slightly reducing the sand portion of the mixture to compensate, however the effect may vary based on the binder, aggregate, and overall gradation. Directly substituting the RTR modified asphalt binder for a polymer modified asphalt binder may not always provide the same mix properties. New mix designs will be needed. Mixture performance testing should be considered to better evaluate the expected performance. While not dealing directly with RTR asphalt mixes, some suggested source materials for analyzing mixture performance are contained in NCHRP Report 673, “A Manual for Design of Hot Mix Asphalt” and FHWA-HIF-13-005, “Asphalt Mixture Performance Tester “.

Performance Challenges

In the United States, the predominate use of RTR asphalt pavements has been in warm climates. This has led some to believe that RTR modified materials will not perform well in cold climates. There have been issues with compaction and raveling of mixes in cold climates, but this has typically been a construction issue with unfamiliarity when working with high viscosity binders and trying to pave in cooler climates.

In recent years RTR has been used in cold climates. One significant property for pavement performance is achieving sufficient compaction on the roadway. Slightly higher binder contents in the RTR modified mixtures may help to achieve sufficient compaction. Warm mix asphalt (WMA) technologies combined with RTR modified AR mixtures may help reduce production temperatures and also improve workability and compaction. This also could potentially reduce the exposure of workers to fumes that would otherwise be produced in greater concentration with higher mixture temperatures.

Tire Rubber Industry Resources

- Rubberized Asphalt Foundation http://www.ra-foundation.org/
- Rubber Pavements Association http://rubberpavements.org/
- Rubber Manufactures Association http://rma.org/

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