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Product (P1) from Project 0-6738: Performance Studies and Future Directions for Mixes Containing RAP and RAS

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Date:	January 25, 2013
Subject: P1 of Project 0-6738	**Best Practices for Using RAP/RAS in HMA/WMA Mixes Including Workshop and Workshop Materials**

Best Practices for Using RAP/RAS in HMA/WMA Mixes Including Workshop and Workshop Materials

In recent years both reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS) have been widely used in asphalt mixes by the asphalt paving industry in Texas. The use of RAP and RAS can save tax payers' money, and it is also good for the environment. Several factors including RAP/RAS processing, mix design, plant production, and field construction are critical to have a durable RAP/RAS mix with good field performance. The researchers at the Texas A&M Transportation Institute (TTI), collaborating with the Texas Department of Transportation (TxDOT), the Texas Asphalt Pavement Association (TxAPA), and contractors, developed best practices for best use of RAP/RAS in asphalt mixes in terms of:

- RAP/RAS handling (processing and stockpile management).
- RAP/RAS mix design.
- RAP/RAS production.
- RAP/RAS construction.

Additionally, the researchers, collaborating with TxDOT and TxAPA organized a RAP/RAS best practice workshop held at the TxAPA headquarter in Buda, Texas, on Jan. 8, 2013. More information about the workshop will be presented in a later part of the product.

RAP PROCESSING AND STOCKPILE MANAGEMENT

RAP processing and stockpile management are key to having high-quality RAP and consistent RAP mixes. The best practices for RAP processing and stockpile management were developed based on field observation and the interactions with TxDOT's personnel and contractors. A six-step RAP processing and stockpile management guideline is presented below:

1. **Eliminate contamination.**

   The first step to control the quality of RAP materials is to eliminate contamination. It is acknowledged that RAP processing/fractionating is a critical step in reducing the RAP variability. RAP fractionation in itself will help. However, it will not solve all the RAP variability and other problem. For example, if you fractionate one contaminated pile of RAP, you will get two contaminated piles of RAP. Both TxDOT and contractors will benefit from keeping deleterious materials out of any RAP stockpile from the beginning.

   Contamination may occur from milled-up paving geosynthetics (fabrics, grid), reflective lane markers (yellow or white), and dumping general road debris with dirt and vegetation on the pile. In some cases, the multiple-source RAP stockpiles were believed to contain construction trash. Figure 1 shows an extreme example in which concrete trash and reinforced steels were mixed with RAP stockpile. Another type of contamination may be due to unstable, unconditioned, sunk earth surface. Any potential contamination to RAP stockpiles should be avoided in order to improve the RAP quality and, accordingly, pavement performance.

Figure 1. Contaminated RAP Stockpile.

2. **Separate RAP stockpiles from different sources.**

   It is always important to separate RAP stockpiles obtained from different sources. In most cases, it is unnecessary to crush or fractionate a single source RAP stockpile with a known source. As shown previously, the separated, unfractionated RAP materials that TxDOT owned have a similar quality to that of crushed RAP. Well-separated stockpiles can save lots of time and cost for crushing or fractionating RAP. In particular, when a large quantity of millings occurs from a single project, it is always worthwhile to keep the milled RAP separate from other RAP stockpiles.

3. **Blend or mix before processing RAP stockpiles.**

   The whole purpose of processing a multiple-source RAP stockpile is to obtain a uniform RAP. One of the observations during the field visits is that the mixing process is rarely carried out before RAP crushing or fractionation. Current practice for processing multiple-source RAP stockpiles is to use a front-end loader or other machines to sequentially dig into the stockpiles to feed into a RAP crushing or fractionating machine. Such operating sequence often makes it difficult to truly meet the purpose of processing the multiple-source RAP stockpiles. Therefore, when the RAP materials are excavated, it is essential to randomly dig into the RAP pile from different angles so that the RAP material feeding into the crusher or fractionating machine at any time gets mixed up.

4. **Process (crush or fractionate) RAP stockpiles.**

   4.1. <u>Crush or Fractionate RAP</u>

   There has been a lot of discussion about fractionating RAP, but the current practice for RAP processing is to crush all RAP materials to a single maximum size, in most cases, either 1/2 in. or 3/8 in. Unlike crushing, fractionating the RAP involves simply screening RAP materials into two or more sizes. The fractionated RAP is often split into coarse and fine fractions. The coarse RAP stockpile will contain only the RAP material retained over a 3/8 in. screen or 1/2 in. screen; the fine RAP stockpile will contain only the RAP material passing the 3/8 in. screen or 1/2 in. screen. In comparing RAP fractionation with simply crushing RAP, there are benefits and some additional costs for fractionation. For example, RAP fractionation can provide designers more flexibility to choose different percentages of the coarse and fine RAP with virgin aggregates to meet both gradation and volumetric requirements. Generally speaking, it is easier to use more total fractionated RAP than crushed RAP.

4.2. Avoid over crushing

Most contractors crush all RAP materials to a single maximum size, such as 1/2 in. or 3/8 in., so that the crushed RAP can be used in, for most cases, asphalt overlay mixes (dense-graded Type C or D). When crushing large aggregate particles in the RAP, it may generate too much fines (or dust passing #200 sieve size). Note that the excess dust often controls the percentage of RAP being used in a new mix during RAP mix design process. Another scenario is to further crush the RAP materials to 1/4 in. size. Theoretically, it is always better to crush RAP materials into finer size so that it is possible to better control the gradation and use more fine RAP with high asphalt binder content. However, crushing RAP to a smaller size often generates more dust that limits the percentage of smaller RAP used in the new mix. The authors of this report have experienced such a scenario when designing RAP mixes for field experimental test sections. Therefore, it is important to avoid excessive crushing of RAP materials.

5. Store the processed RAP using paved, sloped surface.

Another aspect of managing RAP stockpiles is to store the RAP processed using a crusher or fractionation machine. It is a well-known fact that RAP has a tendency to hold water; in many instances, the RAP moisture content limited the percentage of RAP use, reduced the overall production rates, and raised the drying and heating cost for superheating the virgin aggregates. Therefore, it is beneficial and critical to minimize the RAP moisture content. Several measures are proposed to reduce RAP moisture content during stockpiling the processed RAP and are discussed below:

5.1. Conical vs. horizontal stockpiles

As documented in “Recycling Hot-Mix Asphalt Pavements” (NAPA 2007), the RAP in the early days were piled in low, horizontal piles for fear that high, conical stockpiles would cause RAP to pack together with the weight of the pile. However, past experience indicated that this is not the case. Additionally, RAP has a tendency to hold water and the low, horizontal stockpiles often retain higher moisture accumulation than the tall, conical stockpiles. In general, tall, conical stockpiles are preferred.

5.2. Use paved, sloped surface area

While waiting for the contractors, the authors observed that at least one contractor already started using the paved, sloped surface to stockpile RAP materials. Using the paved surface under stockpiles not only can contribute to drainage from RAP stockpiles, but it also provides an even, hard-surfaced area to minimize material loss and contamination of underlying materials. Meanwhile, providing a slope to the paved surface under the stockpile away from the side where the front-end loader moves RAP materials to cold feed bind, as Figure 2 shows, will allow rainwater to drain away, allowing drier RAP materials to go into the plant.

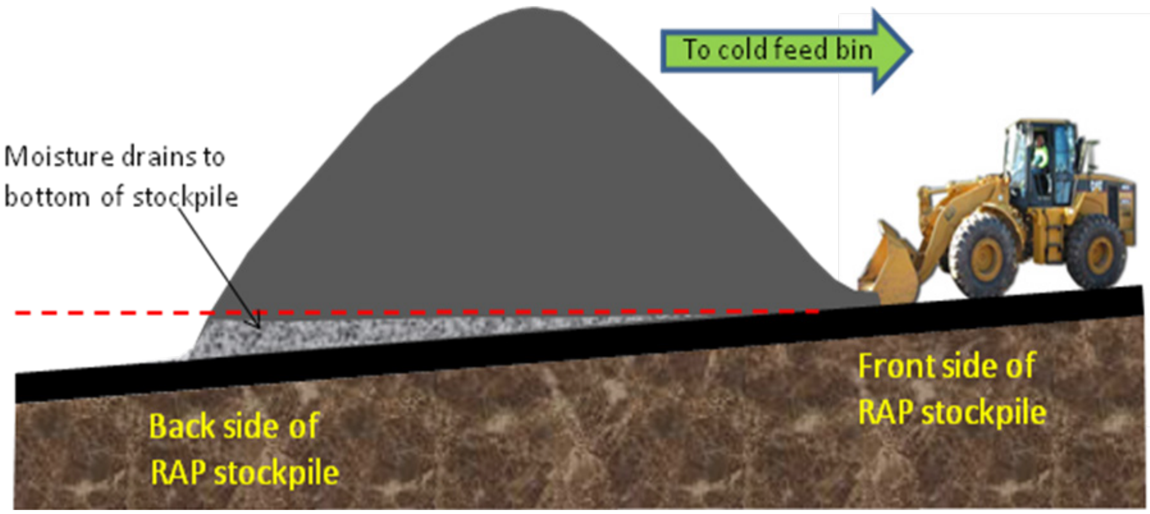

Figure 2. Illustration of Paved, Sloped Surface under RAP Stockpiles.

5.3. Cover RAP stockpiles if necessary

Currently, relatively few contractors cover any of their RAP stockpiles, but covering RAP stockpiles to minimize RAP moisture content is even more economical than covering virgin aggregate stockpiles. RAP should never be covered with a tarp or plastic, however. It is best to store RAP materials under the roof of an open-sided building (see Figure 3). Free air can pass over the RAP, but the RAP is protected from precipitation.

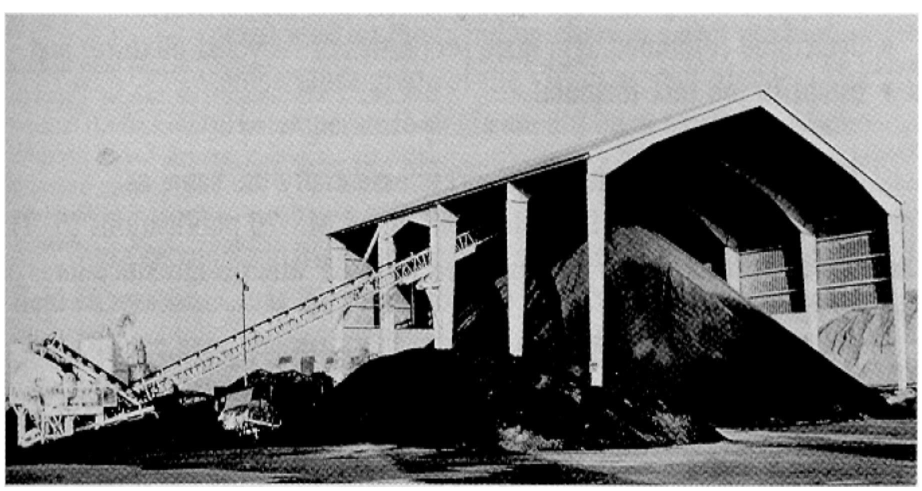

Figure 3. Storing RAP under a Covered Roof (NAPA 2007).

6. **Characterize the processed RAP and mark stockpiles.**

   A good practice some contractors have been adopting is to characterize the processed RAP right after the stockpile has been built at its final location, then marking or numbering the stockpile. A minimum of five RAP samples collected from each RAP stockpile should be obtained and tested before making a mix design. Both average values and associated standard deviations of RAP asphalt content and aggregate gradation should be recorded. To produce a consistent RAP mix the associated standard deviations of the RAP asphalt content and aggregate gradation should be carefully observed. With these measured data including both average values and associated standard deviations of RAP asphalt content and aggregate gradation, contractors can evaluate their RAP processing operations, and consider improving their processing operations.

RAS PROCESSING AND STOCKPILE MANAGEMENT

RAS processing is one of the critical steps for using the RAS in asphalt mixes and producing high quality RAS mixes. There are two types of RAS: manufacture waste asphalt shingles (MWAS) and tear-off asphalt shingles (TOAS). For use in HMA, MWAS has traditionally been preferred over TOAS, primarily because MWAS contains fewer contaminants (Hansen, 2009; Maupin, 2008), plus the asphalt in MWAS is less oxidized (Button et al., 1996). MWAS only requires grinding with little or no sorting, inspection, testing, or separation of undesirable materials. Specifically, there is no need for asbestos testing for MWAS. However, MWAS is geographically significantly more restricted than TOAS, as shingle manufacturing facilities are typically located only in densely populated areas. In contrast, TOAS are more readily available to contractors and recyclers. The main concerns with TOAS are potential asbestos, deleterious materials (including metal, wood, plastic, paper, etc.), and very hard highly oxidized asphalt. Consequently, it becomes more difficult to process the TOAS, and asbestos testing is required in Texas.

Processing RAS basically includes five steps: collecting, sorting, grinding, screening, and storing the processed RAS plus asbestos testing for the TOAS. The research team visited different recyclers and contractors in Texas and reviewed published literature to identify the best practices for each of these steps. Figure 4 shows the best practices identified; detailed explanations and associated guidelines follow.

Step 1: Collecting

Step 2: Asbestos testing for TOAS

Step 3: Sorting

Step 4: Grinding

Step 5: Screening

Step 6: Storing

Figure 4. Proposed RAS Processing Steps.

1. **Collecting**

Quality (cleanness) of RAS and a sustainable supply are two major issues related to collecting RAS. MWAS is relatively clean, but its supply is limited. In contrast, TOAS has relatively more supplies, but its cleanness (or contamination) is a bigger problem. According to Krivit (2007), the two basic types of strategies to develop a clean, secure supply are:

- *Source Separated*—Attracting high quality, separated loads of clean TOAS. The roofing contractor or hauler must first separate the non-shingle debris (e.g., plastic, metal, wood) before tipping at the shingle recycling plant. Source-separated TOAS should be kept separate from other roofing debris at the demolition site before loading and then are loaded separately onto haul units.
- *Mixed Roofing Material*—Attracting mixed loads of TOAS without requiring source separation, such that the shingle recycler conducts most, if not all, of the materials separation. Non-shingle debris is sorted from the tear-off shingles at a recycling facility. TOAS recyclers might instruct their suppliers to load the shingles first, at the bottom of the haul unit. Then, the non-shingle debris, which are placed on top of the shingles layer, can be easily separated when the load is tipped at the recycling plant.

Under either strategy, Krivit (2007) continues, TOAS recyclers must work proactively with suppliers to ensure that no asbestos containing material (ACM) is delivered to the recycling plant. After the TOAS are tipped at the recycling plant, a second stage of quality inspection and sorting occurs. Most facilities use both manual separation (e.g., 'dump and pick,' sorting conveyors) and mechanical equipment (e.g., screens, air classifiers). Shingle recyclers have demonstrated a wide variety of techniques to cost-effectively meet and exceed the minimum waste sampling and asbestos testing requirements. They have recently developed innovations, such as establishing in-house laboratories that use standard detection methods and certified personnel. Such internal laboratories minimize the turnaround time for test results. Together with other in-house personnel training and supplier technical assistance, TOAS recyclers are proactively managing their supplies through upstream quality control and quality assurance.

Hanson (2009) points out that as part of the quality control and acceptance program, shingle recycling operations need an inspection and testing plan for waste shingles delivered to the site, which should include:

- Type and quality of material that is acceptable.
- Criteria for rejecting loads.
- An asbestos management plan.

A list of prohibited materials for TOAS recyclers should include (Krivit, 2007):

- Cementitious shingles, shake shingles, and transite siding that may contain ACM.
- Any type of hazardous waste (e.g., mercury-containing devices such as thermostats, paint, solvents, or other volatile liquids).

- Significant amounts of other debris that are not asphalt shingles (e.g., plastic, paper glass, or metal).
- Significant amounts of trash.

2. Asbestos Testing for TOAS

According to Hansen (2009), the main issue that impedes recycling of TOAS is concern over potential asbestos content. In the past, asbestos was sometimes used in manufacturing asphalt shingles and other shingle installation materials. Asphalt shingle manufacturers generally acknowledged that, between 1963 and the mid-1970s, some manufacturers did use asbestos in the fiber mat in some of their shingle products, but the total asbestos content of those shingles was always less than 1 percent. Other materials used in shingles, such as some tarpapers and some types of asphalt cement, also reportedly contained asbestos. In reality, while asbestos was heretofore used in some asphalt roofing materials, asbestos was rarely used in the shingles themselves.

Since TOAS may contain asbestos, the Texas Department of State health Service (TDSHS) regulates asbestos-containing materials including TOAS. More detailed information on asbestos program can be found at TDSHS' website: http://www.dshs.state.tx.us/asbestos/pubs.shtm. Generally, asbestos testing (Figure 5) involves sampling each layer of roofing material. Details of asbestos testing are described in EPA/600/R-93/116, 'Test Method for the Determination of Asbestos in Building Materials,' July 1993 (Perkins and Harvey, 1993). The complete test method is available at: http://www.rti.org/pubs/Test-Method-for-Determination.pdf. Representative samples must be properly selected, labeled, recorded in a sample log book, and then sent to an accredited asbestos testing laboratory for assay of asbestos content. TOAS recyclers should contact the appropriate state environmental and/or health agency to determine specific requirements for sample collection, analytical procedures, data reporting, and records preservation.

Figure 5. Setup for Asbestos Testing (after Krivit, 2007).

Krivit (2007) advised that shingle recycling operators should attend state-sponsored training courses to become licensed asbestos inspectors. Trained personnel should inspect each load to visually detect possible ACM. This will help increase the awareness of potential asbestos containing materials and allow company personnel to help provide accurate, timely, and state-approved information and related technical assistance to material suppliers and other customers. Shingle recycling operators should contact their state representative for the National Emission Standards for Hazardous Air Pollutants (NESHAP) to explore technical assistance resources, including a listing of organizations providing asbestos inspector training. The website www.shinglerecycling.org is an excellent source of EPA and other regulatory information regarding asbestos, management, and recommended best practices. Specifically, in Texas TCEQ has several regulations that may impact asphalt shingle processors, which can be found using the following links:

- Recycling: http://www.tceq.state.tx.us/permitting/waste_permits/msw_permits/MSW_amIregulatedrecycling.html
- Industrial Storm Water: http://www.tceq.texas.gov/permitting/stormwater/TXR05_AIR.html
- Storm Water from Construction Activities: http://www.tceq.texas.gov/permitting/stormwater/TXR15_AIR.html

3. Sorting

Generally, little sorting work is needed for MWAS. However, substantial sorting work is required for TOAS because various debris (e.g., nails, wood, and insulation) contaminate this type of shingle. Any debris must be removed to prevent equipment damage during size reduction and produce high-quality processed RAS. There is no standard processing equipment to accomplish this task; in most cases, the debris has to be sorted out manually (see Figure 6).

Figure 6. Sorting RAS Manually.

Note that most facilities will recover metal and cardboard (perhaps in baled form) as secondary recyclable products. Trash from such sorting consists of plastic, non-recyclable metal, and paper. Recovery rates of TOAS from mixed waste sorting systems range from 15 to over 90 percent, depending on the feedstock and the efficiency of the separation (Krivit, 2007).

4. Grinding

The vast majority of RAS used in asphalt paving mixes is ground into pieces smaller than ½ inch (13 mm) in size using a shingle grinding or shredding machine consisting of a rotary shredder and/or a high-speed hammer mill. It seems logical that, as shingles are ground finer, more RAS asphalt can be mobilized into the paving mixture.

According to Krivit (2007), each grinder manufacturer uses a unique combination of material handling and size reduction designs. RAS sizing is a key specification and will determine the product's suitability for various applications. For example, the larger particle size (+ ¾ in.) may be more suitable for aggregate supplement. In general, the grinder will include a loading hopper; a grinding chamber that includes cutting teeth, sizing screens, and exit conveyor; and a feeding drum to present the shingles into the grinding chamber. A pulley head magnet at the end of the exit conveyor is standard equipment for removing nails and other ferrous metal. The final RAS product is stacked using a stacking conveyor and/or front-end loader. During visits to recyclers and contractors, the research team noted that it is important and necessary to pick up some debris left in the sorted, clean pile before feeding to the grinder (see Figure 7).

Figure 7. Preparation for Grinding.

To prevent agglomerating during grinding, the material may be passed through the grinding equipment only once to reduce heating, or it is kept cool with water spray at the hammer mill. However, the application of water is not very desirable, since the processed material becomes quite wet and must be dried (thus incurring additional fuel cost) prior to introduction into the HMA (Chesner et al., 1997).

5. **Screening**

Ground shingles may contain oversize pieces that do not meet the specification requirement. To remove the oversize pieces, the operators ideally should screen the processed RAS using a trommel screener (Figure 8). This equipment can help customize the size of processed RAS, thus guaranteeing that the specifications are met. Furthermore, the oversize pieces can be reground to the ideal size. Chesner et al. (1997) contends that scrap shingle greater than ½ inch may not readily disperse in HMA and may function much like aggregate particles; too small particles can release short fibers, which act as a filler substitute. Hansen (2009) adds that several HMA producers have found that grinding to less than ⅜ inch improves blending. Texas DOT specifies 100 percent passing the ½-inch sieve with 95 percent passing the ⅜-inch sieve.

Figure 8. Screening RAS Using Trommel Screen Machine.

6. **Storing**

    Storing the processed RAS is typically conducted similar to that of aggregate or RAP. Because the average gradation of RAS is very small, a stockpile can absorb a large amount of water, which can cause problems during HMA mixing (inadequate coating), compaction (mat tenderness), and performance (higher stripping potential) as well as require more fuel for drying. Ideally, a RAS stockpile should be covered (Figure 9). Additionally, it is important to keep loaders off RAS stockpiles and separate high AC RAS (tear-offs) from low AC RAS (manufacture waste).

    Button et al. (1996) deduced that, during static storage in a stockpile, shredded roofing shingle material can agglomerate. High temperatures and the stickier manufacturing waste shingles can magnify this issue. Significant agglomeration or consolidation of processed roofing material necessitates reprocessing and rescreening prior to introduction into the hot mix plant. To mitigate this problem, processed roofing shingle scrap may be blended with a small amount of less sticky carrier material, such as sand or RAP, to prevent the RAS particles from clumping together.

Figure 9. Covered RAS Storing Facility.

BALANCED RAP/RAS MIX DESIGN FOR PROJECT-SPECIFIC SERVICE CONDITIONS

Since rutting is not a problem for RAP/RAS mixes, and it is well controlled through the Hamburg wheel tracking test, the cracking issue mainly observed in the field should be the main focus when designing mixes containing RAP/RAS. Therefore, the philosophy of developing mix design and performance evaluation procedure is to meet volumetric, compactability/workability, and cracking requirement, meanwhile making sure acceptable rutting and moisture damage resistance. Table 1 lists potential cracking distresses when mixtures containing RAP/RAS is used under different applications.

Table 1. Potential Major Cracking Distresses for Different Applications.

Applications		Main concerns
Asphalt overlay	AC/existing AC/granular base	Reflective cracking, fatigue cracking, or thermal cracking
	AC/existing AC/cement stabilized base	Reflective cracking, thermal cracking
	AC/Jointed PCC	Reflective cracking, thermal cracking
	AC/CRCP	Thermal cracking, reflective cracking
New pavement	Surface layer	Thermal cracking, fatigue cracking (top-down)
	Intermediate layer(s)	
	Bottom layer	Fatigue cracking

Currently, asphalt mix design in Texas is based on volumetric properties of asphalt mixtures plus checking potential rutting and moisture damage. TxDOT already established the rutting/moisture damage requirements for mixes with different binders. For example, rut depth of a mix with PG76-22 binder should be less than 0.5 inch (12.5 mm) after 20,000 passes. However, there is no cracking requirement on dense-graded, Superpave, and SMA mixes in the specification. As clearly observed in the field and discussed previously, it may be difficult to establish a single cracking requirement, because cracking performance of asphalt mixes depends on traffic, climate, pavement structure, and existing pavement conditions for asphalt overlays. Therefore, a balanced RAP/RAS mix design and performance evaluation system for project-specific service conditions, rather than a single cracking requirement, should be developed, and then implemented to ensure the mixes designed with acceptable field performance.

In the last several years, the researchers at TTI have made significant progresses toward that goal—the balanced RAP/RAS mix design and performance evaluation system, as noted below:

- Balanced mix design for overlay mixes developed under Project 0-5123 and documented in Report FHWA/TX-06/0-5123-1.
- Mechanistic-empirical asphalt overlay thickness design and analysis system developed under Project 0-5123 and documented in Report FHWA/TX-09/0-5123-3.
- High RAP mixes design methodology with balanced performance developed under Project 0-6092 and documented in Report FHWA/TX-11/0-6092-2.
- Balanced RAP/RAS mix design and performance evaluation system for project-specific service conditions developed under Project 0-6092 and documented in Report FHWA/TX-12/0-6092-3.

Figure 10 shows the balanced RAP/RAS **overlay** mix design and performance evaluation system for project-specific conditions proposed under Project 0-6092. Basically, the proposed system is an expanded balanced overlay mix design procedure in which cracking performance is evaluated through a simplified asphalt overlay performance analysis system, S-TxACOL, with OT cycles as an input, as shown in Figure 11. If the predicted performance meets the requirements, then the mix design process is done; otherwise one needs change virgin binder, RAP/RAS, or aggregates and repeat the mix design process.

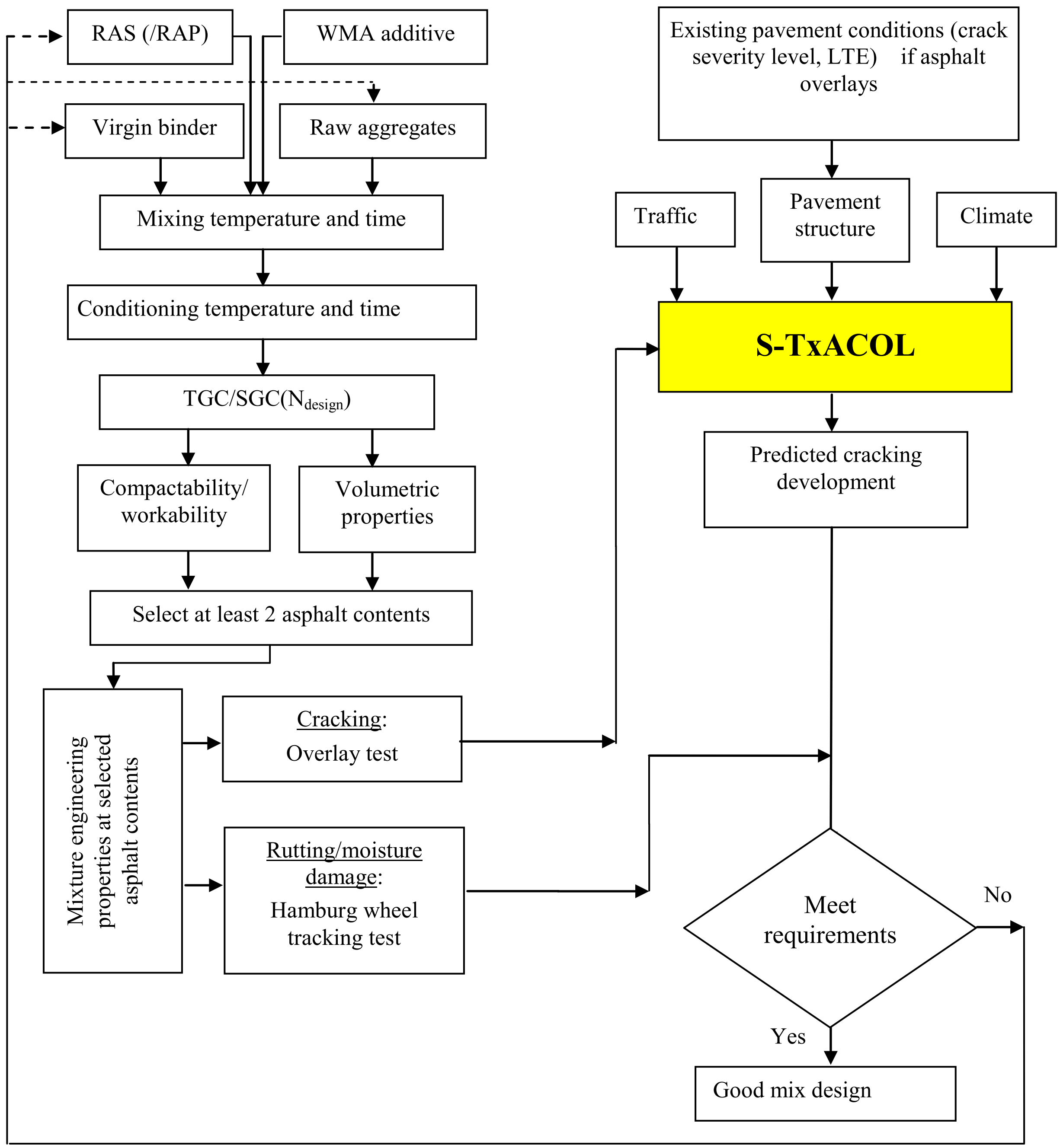

Figure 10. Balanced RAP/RAS Overlay Mix Design and Performance Evaluation System for Project-Specific Service Conditions.

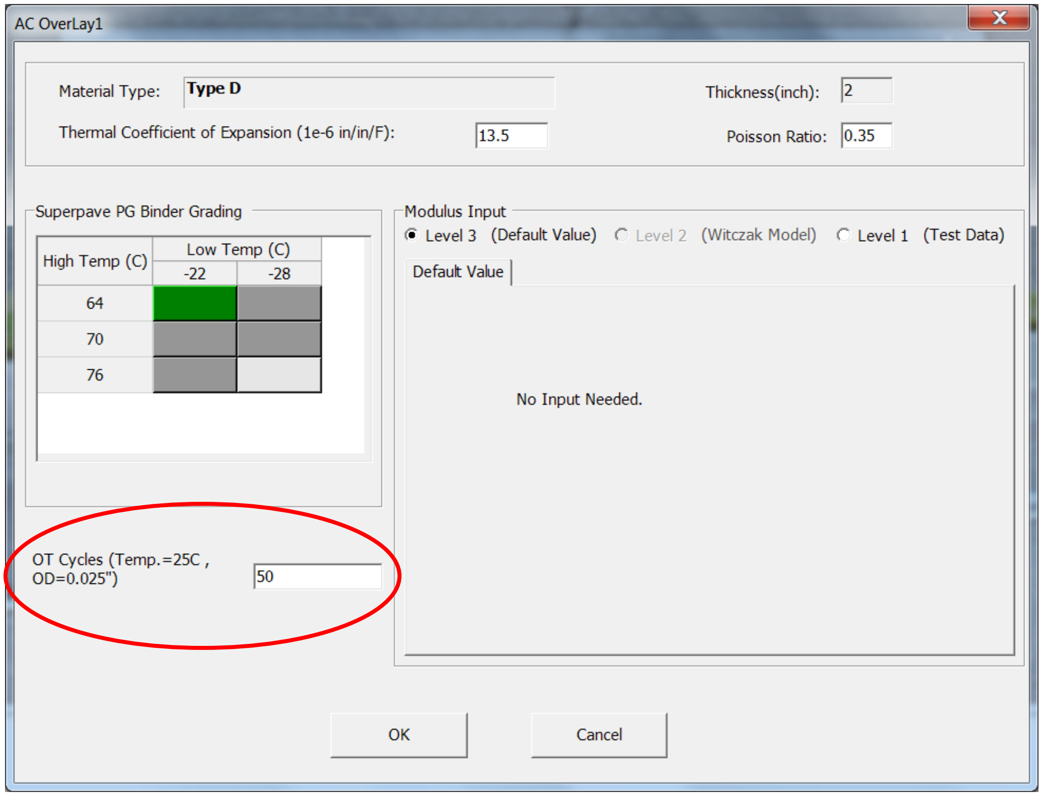

Figure 11. OT Cycles Input Interface for S-TxACOL.

Compared with TxDOT's current mix design procedure, the balanced RAP/RAS overlay mix design and performance evaluation system proposed under Project 0-6092 is a step forward and has four advantages:

- Directly evaluating cracking resistance rather than indirectly through VMA.
- Balancing both rutting/moisture damage and cracking requirements.
- Connecting cracking requirement with project-specific service conditions.
- Integrating mix design with pavement structure design together.

Meanwhile, there are several things listed below, which needs further development.

- Conditioning temperature and time for RAP/RAS/WMA.

  The conditioning temperature and time have significant impact on design asphalt content, rutting (or permanent deformation) resistance, moisture damage, cracking resistance, and dynamic modulus. This issue must be investigated in order to establish a useful mix design system.

- Compactability (or workability) of RAP/RAS/WMA.

  There are some concerns on field compaction issue of RAP/RAS mixes. It is necessary to evaluate this issue during mix design process.

- Fatigue and thermal cracking prediction.

The balanced mix design system shown in Figure 10 is mainly for asphalt overlays. The new pavement construction will be different from asphalt overlays. As noted in Table 6, fatigue cracking rather than reflective cracking needs to be addressed. Additionally, thermal cracking, regardless of overlays or new construction, is another major distress in Texas cold areas (i.e., Pan-handle area). Thus, these two types of cracking should be considered as well.

- Rutting prediction.

  It is assumed that rutting issue is addressed through the Hamburg wheel tracking test and associated specification requirements. There is no rutting prediction involved in the balanced mix design system shown in Figure 10. However, it is necessary to expand it to include rutting prediction through establishing the relationship between the Hamburg wheel tracking test and the repeated load test.

In summary, a balanced RAP/RAS overlay mix design system is available. The proposed mix design and performance evaluation system integrated mix design with pavement structure design together for project-specific service conditions. Meanwhile, the new system needs further development in four areas: 1) conditioning temperature and time for RAP/RAS/WMA, 2) compactability (or workability) of RAP/RAS/WMA mixes, 3) fatigue and thermal cracking prediction, and 4) rutting prediction.

RAP/RAS MIXES PRODUCED WITH WMA TECHNOLOGIES

In last five years, WMA technologies have been widely used in both Texas and the nation. Most recently, they have been combined with RAP/RAS to produce RAP/RAS/WMA mixes. The following subsections discuss different aspects of RAP/RAS/WMA mixes.

WMA Technologies

In Texas WMA is defined as HMA that is produced within a target temperature discharge range of 215°F and 275°F using TxDOT-approved WMA additives or processes. WMA is allowed for use on all projects and is required when shown on plans. The maximum placement or target discharge temperature for WMA may be set at a value less than 275°F when shown on the plans. Also, TxDOT-approved WMA additives or processes may be used to facilitate mixing and compaction of HMA produced at target discharge temperatures greater than 275°F; however, such mixtures will not be defined as WMA.

When WMA technologies were introduced to US in 2004, only a few WMA additives or process were available. There are now (November 2012) over 30 WMA technologies available in the U.S. In Texas only 13 WMA technologies listed in Table 2 are approved by TxDOT. These 13 additives or processes can be further classified into four categories: 1) organic additives (e.g., Sasobit), 2) chemical additives (e.g., Evotherm, Cecabase RT) with typical dosage rate of 0.2 to 0.5 percent of the binder, 3) foaming with additives (e.g., Advera) with typical dosage rate of 0.25 to 0.30 percent by weight of mix, and 4) foaming with water injection systems (e.g., double barrel green, Terex) with typically adding 1 to 2 percent water by weight of binder. The three most common WMA technologies used are 1) foaming with water injection system, 2) Evotherm, and 3) Sasobit.

Table 2. TxDOT Approved WMA Products and Technologies (1/9/2012).

Process Type	WMA Technology	WMA Supplier
Chemical Additive	Astech PER (Hydrogreen)	Meridian Technologies
Chemical Additive	Cecabase RT	Arkema Inc.
Chemical Additive	Evotherm	MeadWestvaco Asphalt Innovations
Chemical Additive	Rediset WMX	AkzoNobel Surface Chemistry
Chemical Additive	Rediset LQ 1106	AkzoNobel Surface Chemistry
Organic Additive	Sasobit	Sasol Wax Americas, Inc.
Chemical Additive	Aspha-Min (Synthetic Zeolite)	Aspha-Min
Chemical Additive	Advera (Synthetic Zeolite)	PQ Corporation
Foaming Process	HydroFoam IEQ	East Texas Asphalt Co., Ltd.
Foaming Process	Double Barrel Green	Astec Industries, Inc.
Foaming Process	Terex	Terex Roadbuilding
Foaming Process	Maxam	Maxam Equipment
Foaming Process	Ultrafoam GX	Gencor Industries

Benefits of RAP/RAS Mixes Produced with WMA Technologies

The original purpose of using WMA was to reduce emissions, especially in non-attainment areas. Additionally, the use of WMA can have the following benefits:

- Reduce fuel sue.
- Reduce binder oxidation during production.
- Improve field compaction especially for late season paving.
- Avoid the bump when overlaying pavements with joint/crack sealants.
- Allow long haul distance.

When combing with RAP/RAS, the WMA technologies can improve the ability to properly coat aggregates and RAP/RAS during production. Again, the lower production temperatures will reduce plant aging of binders, which may allow for increased use of RAP/RAS without grade bumping.

RAP/RAS Mix Production

Producing RAP/RAS mixes is similar to virgin mixes. Normally RAP/RAS is treated like virgin aggregates with a cold bin and is fed into the plant. However, there are some specific issues that are worth watching when producing RAP/RAS mixes:

- Keep RAP and RAS bins separate.
- Keep RAP/RAS bin empty when not in use.
- Use a vibratory scalping screen to help break down or remove clumps that may be in the RAS material before entering the drum (Figure 12).
- Don't superheat the mix; it makes the RAS mix stiffer and more difficult to work with in the field.
- Avoid holding RAS mix in silo overnight.
- Consider the following things when using WMA additives:
    - Plant introduction issues.
    - Anti-strip replacement.
    - Required dosage.
    - Cost.

Figure 12. Vibratory Scalping Screen (after Morton, 2011).

RAP/RAS MIX CONSTRUCTION

No special techniques or equipment are required for placing and then compacting RAP/RAS mixes. Therefore, the existing construction specification (Item 341) for regular HMA/WMA is applicable to RAP/RAS mixes. However, failure to properly address RAP/RAS processing as well as inadequate QC of RAP/RAS will significantly increase the likelihood of problems in placement and compaction of RAP/RAS mixes in the field. Again there are several specific issues to consider during RAP/RAS mix construction:

- Consider the weather.
- Consider the haul distance.
- Consider the trucks that haul the mix.
- Don't let mix set in trucks too long on job site.
- Check RAP/RAS mix temperature when unloading trucks.
- Mix tends to stiffen quicker in trucks than standard hot mix.
- More difficult to hand work.
- Mat can be more sensitive to temperature segregation.
- Consider to use WMA as a compaction aid when needed.

RAP/RAS BEST PRACTICE WORKSHOP

TTI collaborating with TxDOT and TxAPA organized a RAP/RAS best practice workshop, which was held at TxAPA's headquarter in Buda, Texas, on Jan. 8, 2013. The workshop agenda is listed below. The identified best practices for RAP/RAS processing, mix design, production and quality control, and field construction were presented at this workshop. The five presentations are included in the product CD. The overall message to the audience is summarized as follows:

- Process your RAP/RAS following the best practices.
- Know where your RAP/RAS mixes are used; tailoring your mix design for better performance.
- Know your RAP/RAS (check asphalt binder content, aggregate gradation, moisture content DAILY).
- Know your mix design, plant production, and construction and have all three crews to communicate.

RAP/RAS Best Practice Workshop Agenda

- 2:00 p.m.–2:10 p.m.: **Welcome and brief introduction**
  Robert Lee, TxDOT (Dr. German Claros could not make it).
- 2:10 p.m.–2: 40 p.m.: **Balanced RAP/RAS mix design and performance evaluation for project-specific service conditions**
  Fujie Zhou, TTI
- 2:40 p.m.–3:10 p.m.: **TxDOT's new specification on RAP/RAS use in asphalt mixes**
  Robert Lee, TxDOT

- 3:10 p.m.–3:30 p.m.: Break

- 3:30 p.m.–4:00 p.m.: **RAP/RAS/WMA/Rejuvenator**
  David Morton, APAC

- 4:00 p.m.–4:30 p.m.: **Best practices for RAP/RAS mix design and quality control**
  Maghsoud Tahmoressi, Pave-Tex

- 4:30 p.m.–5:00 p.m.: **Best practices for RAP/RAS mix production and field construction**
  Chuck Fuller, Ramming Paving

- 5:00 p.m.–5:30 p.m.: Open Discussion

- 5:30 p.m.: Adjourn

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