Recommended Best Practices For Using Rap In Asphalt Pavements For Costa Rica

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Abstract Utilization of RAP in asphalt pavements has become an important strategy to help offset rising raw material prices and to improve the sustainability of our transportation infrastructure. Even though the use of reclaimed asphalt pavement (RAP) materials in Costa Rica is permitted and specified in the "Standard Specifications for Highway Construction Manual CR-2010" the production of asphalt mixes containing RAP are limited to local agencies. Characteristics of the recycle materials, mix designs, performance and construction practices do not follow any known standard practice. The objective of the proposed document is to identify best practices for specification, design, production, testing, and placement of RAP mixes. The secondary objective is to suggest revisions and refinements to CR specifications, practices, and pavement preservation practices, and develop guidance for using reclaimed asphalt materials in pavements. The proposed document provides guidance for the effective use of reclaimed asphalt pavement (RAP) materials in pavements specifically for Costa Rica. The document includes recommendations on when milling should be considered as part of pavement rehabilitation, best practices for handling and stockpiling RAP, testing the RAP, designing mixes with RAP, production of mixes containing RAP, and quality control practices during production of mixtures containing RAP. The ultimate goal of this guide is to facilitate the most effective utilization of RAP that ensures the greatest economic benefit and the highest quality of recycled asphalt mixtures.

Keywords Reclaimed asphalt pavement, Milling, RAP Characterization, Mix Design, RAP Management

1. Introduction

Increasing the use of RAP in highway construction and rehabilitation projects around the world has become an important strategy to help offset rising costs of raw materials and to improve the sustainability of transportation infrastructures. Even though the use of reclaimed asphalt pavement (RAP) materials in Costa Rica is permitted and specified in the "Standard Specifications for Highway Con-

struction Manual CR-2010" (0010) the production of asphalt mixes containing RAP are limited to local agencies.
By replacing a portion of the virgin materials with RAP, especially in the intermediate and surface layers, where the binder is used to provide tensile strength, protect from moisture and provide a smooth, skid-resistant riding surface, more economical pavements can be built. Khandal and Mallick (1997) estimated that savings of up to 34% could be generated for mixtures containing up to 50% RAP. McDaniel and Nantung (2005) reported on a cost-benefit analysis conducted by the Indiana DOT that estimated savings in materials were nearly $330,000 per year when adding only 5 percent RAP to more than 5 million tons of base and intermediate mixes.

The use of RAP also conserves energy, preserves natural resources and decreases the amount of construction debris placed into landfills. A study prepared for the New York State DOT (NTD, 2009) quantified the energy savings and environmental impacts of using RAP in HMA through several mathematical models that combined the drying/heating, transportation, and processing/calorific energies. In addition, it was estimated that at low RAP content, using RAP in HMA increases CO_2 emission while the opposite is true for high RAP content. However, the reduction of CO_2 emission from using RAP is primarily from the shorter hauling distance for RAP materials.

This document provides guidance for the effective use of reclaimed asphalt pavement materials in pavements for Costa Rica. The document includes recommendations on when milling should be considered as part of pavement rehabilitation, best practices for handling and stockpiling and testing the RAP, designing mixes with RAP, production of mixes containing RAP, and quality control practices during production of mixtures containing RAP.

2. Proposed Practices

2.1 Milling

Recycling of the road surface is one of the main reasons for milling a road surface. When milling is appropriate, the milling depth should be selected to achieve a specific need such as removing distressed pavement layers, correcting cross slope, improving the roadway profile, and/or maintaining the pavement width (West et al, 2013). Information needed to make an informed decision on when to mill and how much to mill include the pavement condition survey, existing cross-slope surveys, cores of the existing asphalt to identify distressed layers and verify layer thicknesses, and an estimate of future traffic loading.

The milling process should be inspected to ensure that the RAP material is not contaminated, the RAP particles are not too large, and that the milled surface is uniform and suitable for use in the overlay. Contaminants could include soil and/or vegetation from shoulders, excessive crack sealant, paving fabric, and roadway debris. The milling process can result in too many oversized particles that would have to be screened and crushed or disposed. Sometimes, milling over poorly bonded layers will result in scabbing of the surface which, if not corrected, will lead to rapid deterioration of the overlay (NAPA, 2007). additionally, an uneven texture could lead to the dragging of mix under the screed and/or issues with variability in density readings. Inspecting the milling process and subsequent brooming operation is recommended to identify problems and take corrective actions. Similarly, the milled surface cross-slope should be consistent across the lane. An irregular cross-slope will result in thickness variations across the mat and impact compaction and density results.

2.2 RAP Management

RAP variability makes it difficult to control the asphalt content, gradation and air voids of the production mixture, especially at higher percentages of RAP (Solaimanian, M. and M. Tahmoressi, 1996). The use of proper techniques for stockpiling and processing RAP may help control RAP variability. These include eliminating contamination, separating RAP stockpiles from different sources, processing (crushing or fractionating) RAP stockpiles, storing the processed RAP using a paved, sloped surface to reduce the moisture content, and characterizing the processed RAP right after the stockpile is being built at its final location, and marking or numbering the stockpile (Zhou et al, 2010).

Minimizing the moisture content in RAP stockpiles is important for quality and plant efficiency. If the RAP material has a high moisture content, the moisture must first be converted to steam before the asphalt binder can be heated enough to be reactivated. This energy consumed in drying the RAP moisture affects the temperature to which the virgin aggregate is heated. To minimize moisture in RAP, stockpiles should be built in a conical shape in areas that drain water away from the base. Other measures, such as covering RAP stockpiles with a roof from an open-sided building may also help minimize moisture content (Copeland, 2011).

It is considered a good practice to include at least 10 results to estimate the statistics for the stockpile. The recommended maximum standard deviation for the asphalt content is 0.5%. The median sieve is the sieve closest to having an average of 50% passing. The recommended maximum standard deviation for the Percent Passing Median Sieve is 5.0% and the recommended maximum standard deviation for the Percent Passing the 0.075 mm Sieve is 1.5% (0).

Further processing of milled material may or may not be necessary to obtain suitable consistency. As a minimum, RAP materials should be screened over a 1.5-inch screen before entering the plant to ensure that larger chunks of RAP do not get through the mixing process. Heat may not thoroughly penetrate through dense particles of RAP larger than 1.5-inches during the mixing process. Tolerances between before and after gradations of the extracted RAP aggregate are ±4% on the No. 8 and ±1% on the No. 200 sieve are recommended (0). Most sources of RAP will be a well-graded coarse aggregate, comparable to, or perhaps slightly finer and more variable than, crushed natural aggregates (Chesner et al, 1998). Asphalt content and gradation tests on the RAP materials used in mix production should be tested at a frequency of one test per 1000 tons of material used (0)

2.3 Designing Mixes with RAP

The overall Superpave mix design process for mixtures incorporating RAP is similar to the mix design for all virgin materials, with the following exceptions (McDaniel, R. and T. Nantung, 2005):

- The RAP aggregate is treated like another stockpile for blending and weighing, but must be heated gently to avoid changing the RAP binder properties;
- The RAP aggregate specific gravity must be estimated;
- The weight of the binder in the RAP must be accounted for when batching aggregates;
- The total asphalt content includes the binder provided by the RAP; and
- A change in virgin binder grade may be needed depending on the amount of RAP, desired final binder grade, and RAP binder stiffness.

In Costa Rica, the virgin binder grade is normally fixed due to economics and availability. However, specifications for a given project may require different PG grades. In these cases, to determine how much RAP can be used with that typical virgin binder grade requires a blending chart to meet the final blended binder properties. Figure 1 shows an example of the selection process of RAP content. For this example, a PG 76 (+22) asphalt binder is required for a project. Knowing the true critical temperatures, a 34% RAP content will meet the specified PG grade.

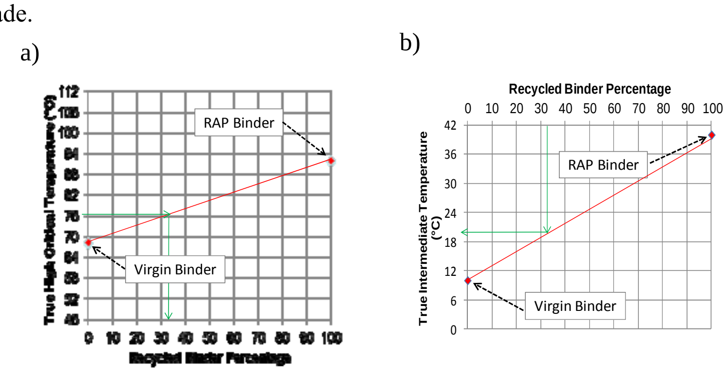

Fig. 1 Example of Blending Chart a) High temperature, b) intermediate temperature

The current AASHTO standard recommends that the virgin binder grade be selected based on the RAP content as percentage by weight of the total mix. Under the recommended guidelines for using RAP in Superpave mixtures, there are three levels of RAP usage. The first level establishes the maximum amount of RAP (15%) that can be used without changing the virgin binder grade. The second level, 15 to 25%, can be used when the virgin grade is decreased by one grade (a 6-degree reduction) on the high temperature grade. The third level is for higher RAP contents (over 25%); for these higher contents, it is necessary to extract, recover, and test the RAP binder and to construct a blending chart.

The solvent extraction method (AASHTO T 164) should be used for determining the asphalt content of RAP samples. The recovered asphalt binder should be tested to determine its performance grade using AASHTO M 320. The gradation of the extracted aggregate from the RAP samples should be determined in accordance with AASHTO T 30. The RAP aggregate's bulk specific gravity should be determined using AASHTO T84 and T 85 for the fine and coarse portions, respectively, of the aggregate recovered from the extraction tests.

Lowering the mix design target air void contents can improve the durability of Superpave mixes and make RAP mixes more resistant to cracking and raveling (0). Lowering the target air void content for mix design and QC/QA by 0.1% for every 5% RAP will result in slightly higher asphalt content for RAP mixes. Reducing the air void content while maintaining VMA will result in an increase in the volume of effective asphalt in RAP mixes which will improve mix compactability and improve resistance to cracking and raveling.

2.4 Tests to Evaluate Binder Performance

The asphalt binder content of RAP typically ranges between 3 and 7 percent by weight. This binder is stiffer than a virgin binder due to aging caused by exposure of the pavement to atmospheric oxygen (oxidation) during use and weathering (Chesner et al, 1998). Therefore, it becomes important to evaluate the resulting binder blend to determine how the aged binder portion may affect overall performance.

There are several tests that have been used as methods to assess asphalt binder performance in Costa Rica. Most of these tests need further development, rigorousness and precision studies, and field validation research before they are suitable for use in specifications.

To characterize the fatigue performance of the bitumen, a repetitive fatigue analysis can be used. The test is performed at the base PG grade intermediate temperature and consists of subjecting the sample to an angular frequency of 10 rad/s, under controlled mode (10 %) following NCHRP 459 recommendations (Bahia et al, 2001).

Due to the environmental conditions and the nature of the local materials, moisture damage potential is of special concern for Costa Rican mixtures. To characterize the moisture susceptibility of the bitumen, a test based on a modification of the Pneumatic Adhesion Tensile Testing Instrument (PATTI) called Bitumen Bond Strength (BBS) test can be used (Morales et al, 2011). This type of analysis is very useful in identifying whether the type of failure that is likely to occur is due to the adhesive interface between the aggregate and the asphalt binder or due to the cohesive strength or the durability of the asphalt binder and the mastic itself. This is basically a pull off tensile strength (POTS) and it is performed under two types of conditioning, 24 hours dry and 96 hours wet (Aguiar-Moya et al, 2013). Additionally, the percent loss in bond strength and the bond strength ratio calculated as $[POTS_{Dry} - POTS_{Wet}]/POTS_{Dry}$ and $POTS_{Wet}/POTS_{Dry}$, respectively can be used as measure of moisture susceptibility.

To characterize the rutting performance of the bitumen, the repetitive creep test can be used. The test is performed at the base PG grade high temperature and consists of subjecting the sample to 300 load cycles with a shear stress of 100 Pa. The defined creep time is 1.0 seconds and the recovery time is 9.0 seconds according to test specifications (Bahia et al, 2001).

2.4.1 Additional Tests to Evaluate Binder Properties

Thermogravimetric analysis (TGA) is a method of thermal analysis in which changes in physical and chemical properties of materials are measured as a function of increasing or decreasing temperature cycles (with constant heating rate), or as a function of time (with constant temperature and/or constant mass loss) (Coats, A. W. & Redfern, J. P., 1963). TGA is commonly used to determine selected characteristics of materials that exhibit either mass loss or gain due to decomposition, oxidation, or loss of volatiles of the asphalt binder. The mass loss of virgin (unaged) binder is greater than the aged binder along the temperature increment. Besides, a lowest temperature of decomposition (beginning of the accelerated rate of weight loss) can be observed for the unaged binder.

Differential Scanning Calorimetry Analysis (DSC) is widely used for determination of thermal transitions brought about by the first order transitions, such as melting and crystallization of crystallizable species (Elsefi et al, 2010). Glass transition, Tg, credited as a second order phenomenon taking place in the amorphous region of the sample, can be also defined by DSC, but it depends largely on the nature of the material and its content of crystallizable fractions. Below the glass transition temperature, asphalt behaves like a glass and appears brittle and affects the fatigue performance of the binder and the mix. Figure 2 shows and example of the DSC test performed on unaged and aged binders. This figure exhibits that higher amount of heat is being introduce into the system in order to produce an endothermic process such as melting. It is also expected to obtain higher glass transition temperatures (Tg) and higher percentage of crystallize fractions for the aged sample which may affect negatively its fatigue performance.

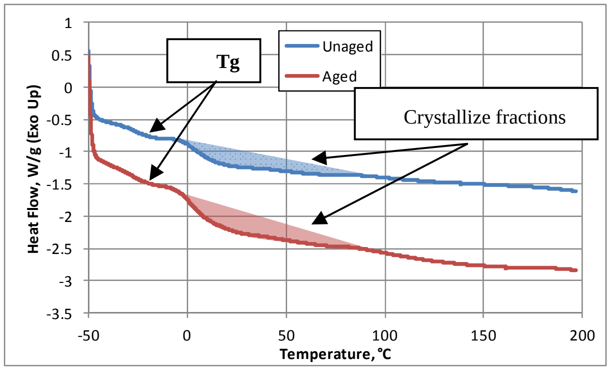

Fig. 2 DSC Example of Tests Results

Fourier Transform Infrared Spectroscopy analysis (FTIR) is a technique used to identify and quantify amounts of known and unknown materials (Marasteanu et al, 2010). In this technique, infrared radiation is passed through a sample; some of this radiation is absorbed by the sample and some of it is passed through (transmitted). The resulting spectrum represents the molecular absorption and transmission, creating a molecular fingerprint of the sample (Daly et al, 2010). The asphalt binder presented physical and chemical changes when subjected to a thermal oxidative process. This can be caused by the loss of volatiles or specimens of low molecular weight, or even by the formation of hydrogen bonds. The groups typically formed asphalt binders upon aging are carboxylic acids (-COOH), ketones (C-CO-C) , sulfoxides (R–SO–R) and anhydrides (C-O-C) (0). These oxidation products form polar groups with strong interaction increasing viscosity and changing flow properties. An increase in the intensity and appearance of different bands from 805 to 1260 cm-1 due to oxidation (aged binders) can be seen in Figure 3.

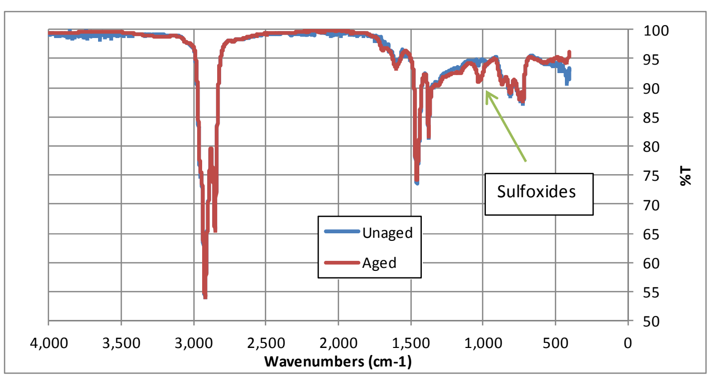

Fig. 3 FTIR Example of Analysis of the aged and unaged binders

There are environmental concerns related to the possible discharge of pollutants from reclaimed asphalt pavement. Naphthalene, butylated hydroxytoluene (BHT) and dibutyl phthalate (DBP) are some of the most dominant semi-volatiles present in RAP (Norin M, Strömvall AM, 2004, Legret et al, 2005). Car exhausts, rubber tires and the asphalt material itself are all probable emission sources, determined from the organic contaminants released from the RAP stockpiles. The previous discussed tests can also help determine the presence of potential hazardous materials and their potential negative effect to the environment.

2.5 Tests to Evaluate Mix Performance

There are an important number of well-known tests that have been used as methods to assess different types of distress in Costa Rica. However, most of these tests need further development, rigorousness and precision studies, and field validation research before they are suitable for use in specifications.

Long-term pavement performance information, though scarce, suggests that RAP mixes may be more susceptible to fatigue cracking. Therefore, identifying a simple fatigue test for evaluating the quality of a RAP mix is essential. Several tests are available for evaluating fatigue behavior of asphalt mixes such as beam fatigue, dynamic modulus, and overlay tester.

The Overlay Tester developed by Texas Transportation Institute has been used successfully as a simple and rapid performance-related test for fatigue cracking. The Overlay Tester test (TEX-248-F) is conducted on trimmed Superpave gyratory compacted specimens or field cores that are glued across the center of a split plate. The test specimens are subjected to very high repeated tensile strains that result in crack initiation and propagation until failure.

The beam fatigue test (AASHTO T 321) has been evaluated by several researchers (Shen et al, 2005, Shu et al, 2007) to assess the fatigue resistance of RAP mixes. Most studies have shown that there is a good correlation with some mixes in the field but none has resulted in a strong correlation between laboratory and field observations for all mixes. Therefore, many researchers use AASHTO T 321 results more for comparison purposes between mixes.

Moisture susceptibility of all mixtures are normally evaluated by determining the diametral tensile strength on dry and wet specimens according to AASHTO T 283. In this test, internal water pressures in the mixtures are produced by vacuum saturation followed by a warm-water conditioning. Moisture damage susceptibility may also be evaluated by the Hamburg Wheel Tracking Device. Most often, the test is conducted in accordance with AASHTO T 324 and specimens are subjected to a loaded steel wheel load while submerged under heated water. In this process, the stripping inflection point is typically used to evaluate moisture damage. Several studies have been conducted to evaluate the appropriateness of using a Hamburg Wheel Tracking Device to rank the stripping potential.

Studies that have used mechanical or fundamental tests to evaluate mixes containing RAP have concluded that RAP increases resistance to rutting (Mohammad et al, 2006, Drescher et al, 1993). The two devices commonly used in the Costa Rica to evaluate rutting are AASHTO TP 63 (Asphalt Pavement Analyzer) and AASHTO T 324 (Hamburg Wheel Tracking Device).

The current Standard Specifications for Highway Construction Manual CR-2010 includes limit criteria that are applicable for conventional asphalt mixtures. Table 1 shows an example of performance based specifications for asphalt mixtures in Costa Rica. No change of these specifications are expected to be applied for RAP mixtures.

Table 1 Performance based specification in Costa Rica (LM-PI-UMP-016-R1, 2013)

Parameter	**Specification**	**Standard Method**
TSR	≥ 85%	AASHTO T 283
Tensile strength (dry)	≥ 700 kPa	AASHTO T 283
APA Permanent Deformation at 8000 cycles at 60°C	≤ 2,5 mm	AASHTO T340
Fatigue repetitions at 20 °C for the following strain levels:		AASHTO T 321
400 E-6 mm/mm	≥ 300 000	
600 E-6 mm/mm	≥ 25 000	

3. Asphalt Mixture Production and Quality Assurance for Mixes Containing RAP

3.1 Mix Temperature

Plant discharge temperatures for mixes containing RAP should be approximately the same or slightly higher than that for virgin mixtures. An increase of 10°F to 15°F in the mix temperature during production may be necessary for higher RAP content mixtures (NAPA, 2007). The mix temperature is typically a decision the contractor makes based on project conditions. Mix temperature measurements should be made on a regular basis during production at a consistent point in the plant to ensure that the mixing temperature is satisfactory and the temperature variability is not too large.

3.2 Making Mix Adjustments

When a mix adjustment is needed during production to control air voids, the first adjustment should be to the composite gradation. Reducing the dust content of the composite mix is the best way to increase the air void content of mixes. In some cases, contractors may find it necessary to waste some of the baghouse fines. This may require reducing the percentage of fine aggregate(s) and/or RAP used in the mixture. Reducing the virgin asphalt content may seem to be a simple solution to adjusting a mix's laboratory air voids, but this will have a negative consequence to contractors' ability to meet the in-place density pay factor. It will also negatively affect the durability of mixes, particularly mixes containing RAP. As with adjustments to virgin aggregate cold feed percentages, RAP percentages should be allowed to be reduced from the mix design by 5% in order to maintain control of mix properties during mix design (0). However, increasing the RAP content above the percentage designated in the mix design should not be permitted.

3.3 Target Air Void Contents for QC/QA Testing

The target air void content for Quality Control and Quality Assurance testing during mix production should also be the same target air void content used in the mix design. If the target air void content for the mix design is lowered, then the lab molded specimens during field production should have the same air void target. The QC/QA tolerance of ±1% for air voids should be applied to the mix design air void target (0).

4. Summary

The recycled asphalt pavement must be properly processed to reduce gradation and asphalt content variability. Random samples should be taken for every 1000 tons of processed RAP to identify the variability of the RAP material properties. In the process of recycling asphalt pavements it is recommended that the maximum aggregate size for should be 1.5 inches. The milling process can affect the size of the particles and result in too many oversized particles that would have to be screened and crushed or disposed. Proper techniques for obtaining, stockpiling, and processing RAP are needed to produce quality mixtures.

The laboratory mixture design should be established using RAP as a component. The asphalt performance grade must be adjusted to take into account the contribution of the recycled asphalt material. For contents less than 15% RAP is not necessary to adjust the PG grade of the virgin binder. For RAP contents between 15% and 25%, reduce on one degree the PG grade of the virgin binder. For more than 25% content the appropriate grade of the virgin asphalt should be obtained by blending charts.

Evaluating mixture performance of the designed asphalt mixture containing RAP, especially high RAP, is recommended. Characterization of the aged binder by means of thermal, chemical and rheological tests is recommended for better understanding of the binder and mix performance. Currently, the Standard Specifications for Highway Construction Manual CR-2010 includes performance based specification for conventional asphalt mixtures. Compliance of the existing asphalt mix specifications should also apply to RAP mixtures.

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