International Forum: Hot Recycling Technologies: Experiences and New Challenges in Costa Rica and Central America

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ABSTRACT. The use of recycled pavement technologies presents a new, economical and environmentally efficient alternative for road maintenance and construction. For this reason, the implementation of recycled pavement technologies has become a necessity worldwide. Recently, hot recycling technologies have been actively implemented and promoted in Central America. The main applications consist of reclaimed asphalt pavement (RAP), stabilization of base courses with foamed asphalt and/or asphalt emulsion, and warm mix asphalts.

Recognizing the existence of diverse recycled pavement techniques that look to comply with different environmental goals, generating economic benefits, and promoting improvements in quality of life of the local citizens, to date Nicaragua, Guatemala, El Salvador and Costa Rica have been researching and implementing some of these technologies. Furthermore, the National Laboratory of Materials and Structural Models of Costa Rica established a group of researchers dedicated to the implementation of sustainability in the development of road infrastructure. Their main purpose is to achieve the Carbon Neutrality goal that Costa Rica set for 2021 (bicentennial celebration of independence).

The document presents an overview of projects constructed in Central America by applying environmentally friendly technologies, as well as R&D from Costa Rica promoting the implementation of these techniques.

KEYWORDS: recycling, reclaimed, stabilization, sustainability

1.0 Introduction

Preservation of road infrastructure is a fundamental aspect for the economy of a country, given the amount of resources it demands and the impact it generates. Due to the required maintenance budget, and possible environmental issues, the search for new techniques that allow resource optimization in the required investments and reduction of the environmental impact are currently under implementation.

Sustainability, as per the National Asphalt Pavement Association (NAPA), can be defined as *the development that satisfies the needs of the present, without compromising the capacity of the future generations to satisfy their own needs*. Newer generations have been concerned with the innovation and implementation of technologies suitable with this definition. Miller and Bahia (2009), and later Teodoro and Paucar (2013), contextualize this concept in terms of pavement infrastructure as pavements that reduce to the minimum the environmental impacts through reduced energy consumption, natural resources and associated emissions, while still complying with all operational standards. The use of recycled materials is an ideal tool for meeting the previous requirements.

As a consequence of the depletion of natural resources, there is a tendency towards the development of legislations to preserve the environment, making more difficult the extraction of raw materials and increasing the costs and transportation requirements. The previous is especially critical in urban areas. On the other hand, discarding materials extracted from a deteriorated pavement structure is counterproductive from a technical viewpoint, since the materials still retain a good part of their original qualities, even if they are deteriorated or aged.

Based on the previous preamble, the implementation of recycled pavement technologies becomes a necessity. Conscious of the existence of diverse recycled pavement techniques that intend to comply with the mission of being environmentally friendly, generating economic savings and promoting improvements in quality of life of the local citizens, the following document intends to show the advancements and applications of pavement recycling technologies in Costa Rica and Central America.

Recently, the National Laboratory of Materials and Structural Models of Costa Rica established a group of researchers dedicated to the implementation of sustainability in the development of road infrastructure. The group intends to analyze and evaluate three main topics: life cycle assessment (LCA), life cycle cost analysis (LCCA), and classification systems (carbon footprint, risk transfer, wildlife crossings, socialization, recycled materials, mobility, energy balance, climate change, and others).

In Costa Rica, the National Laboratory of Material and Structural Models has developed stabilized materials design methodologies with asphalt emulsions and foamed asphalt, which have been specifically designed accounting for the materials in the region, which ensures the durability of the application of these technologies in the field. Central American countries like Nicaragua and El Salvador have the required technology to rehabilitate roads through said techniques of stabilization with foamed asphalt and emulsions. Additionally, Guatemala is currently a regional leader in the use of warm mixes.

2.0 Hot Recycling Technologies

According to the Asphalt Recycling and Reclaiming Association (ARRA, 2001), asphalt recycling is not a new concept. Cold recycling and rehabilitation of roadways with asphalt binders dates to the early 1900's. The first documented case of asphalt recycling, in the form of hot in-place recycling (HIR), was reported in the literature of the 1930's. However, only moderate advancements in asphalt recycling technology and equipment occurred until the mid 1970's.

The focus on the implementation of recycled asphalt technologies is summarized in the diagram shown in Figure 1.

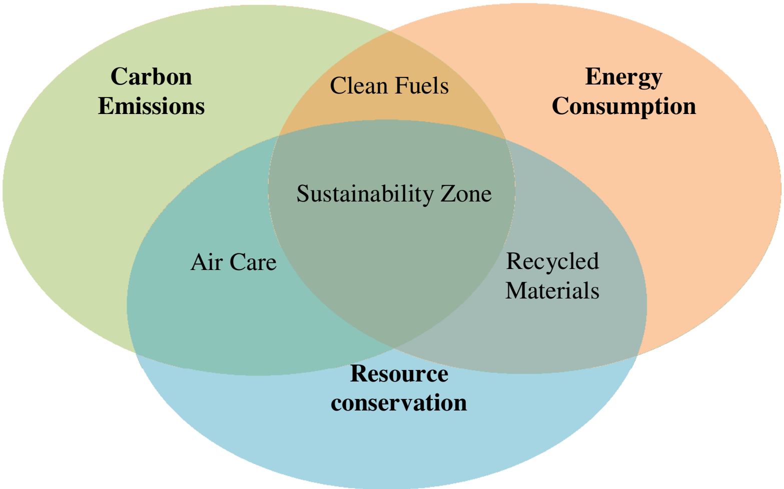

Figure 1. *Sustainability diagram (Miller and Bahia, 2009; Teodoro and Pacuar, 2013).*

The conservation of resources, in addition to the reduction of emissions and energy consumption, are currently the point of focus in pavement engineering and material design. In economic terms, a World Bank study indicates that each $1.00 expended on pavement structures that have a 40% reduction in quality will result in a savings of $3.00 to $4.00 compared to the expenditure which would be required if the road is rehabilitated after an 80% loss in capacity (ARRA, 2001) (See Figure 2). In this sense, innovation is required in order to do more with less. Asphalt recycling technologies are one way of optimizing the effectiveness of existing budgets to maintain, preserve, rehabilitate and reconstruct more kilometers of roadway.

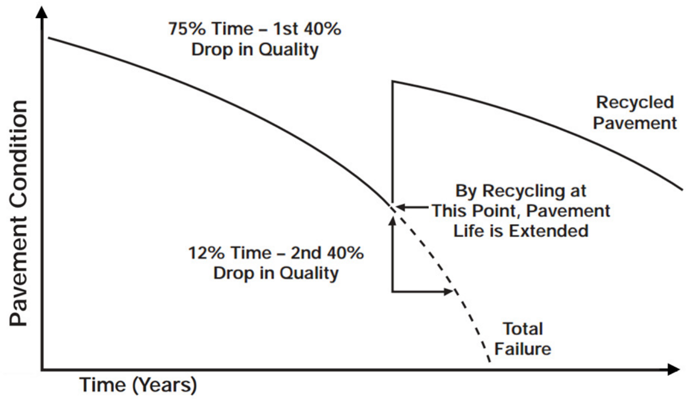

Figure 2. *Pavement deterioration and recycling rehabilitation vs. time (ARRA, 2001).*

The technologies that incorporate elements from the previous figure that have been actively implemented and promoted in Central America and regionally, using asphaltic materials, are:

- Reclaimed asphalt pavement
- Stabilization of base courses with foamed asphalt or asphalt emulsion
- Warm mix asphalt (WMA)

These techniques can be implemented simultaneously, which can potentiate the benefits of the applications. The following section presents a review of the most important factors associated to these technologies.

2.1 Reclaimed Asphalt Pavement

Reclaimed asphalt materials offer saving in costs associated to material, energy and labor. Furthermore, some regions of United States such as California, Oregon, Wisconsin, Florida, Kansas, Minnesota, Illinois, and others require the use in every asphalt mixture produced (Corrigan, 2016). This is due to a continued increase in the cost of high-quality aggregates, asphalt binder and energy required for production; a decline in the availability of aggregates meeting specification; strict project-specific requirements; and an overall increase in awareness of the environmental impact of inadequate storage and disposal of materials generated when reconstructing asphalt pavements. Costa Rica and Central America are not the exception. Furthermore, cost saving considerations and the incorporation of WMA technologies are other influencing factors that are contributing to increased use of RAP. Due the benefits of the technique, FHWA has developed policy guidance on the use of recycled materials: recycled materials should be considered first when selecting materials (Colorado Asphalt Pavement Association, 2011).

The methods used to reclaim asphalt pavements, according to the Asphalt Recycling and Reclaiming Association, (ARRA, 2001) follow:

- Hot recycling
- Cold recycling
- Cold planing (CP)
- Hot in-place recycling (HIR)
- Full depth reclamation (FDR)

It is important to recognize that even though asphalt recycling technology and methods have advanced, not all roadways are appropriate candidates for asphalt recycling.

2.2 Asphalt Stabilized Materials

Compared to an untreated granular base, a bitumen stabilized materials (BMS) base increases the stiffness of base course layer, resulting in a more efficient load distribution (Li and Liu, 2010). Stabilization also improves durability and flexibility of the structure.

Original **BSM Foam** **BSM Emulsion**

Figure 3. *Asphalt stabilized materials.*

Asphalt is a versatile binder that is used in pavement layers in many ways. However, since bitumen is highly viscous and relatively unworkable at ambient temperatures, viscosity must be reduced to handle the material. In general, there are three methods for doing so (Wirtgen, 2012):

- Increasing the temperature of bitumen and aggregate.
- Emulsifying in water to form bitumen emulsion.
- Creating foamed bitumen in a temporary state of low viscosity.

Based on the Cold Recycling Manual (Wirtgen, 2012), the following table compares the treatment process for hot mix asphalt with those for a stabilized material with different types of asphalt applications.

Table 1. *Comparison between different types of asphalt treatments (Wirtgen, 2012).*

Factor	Stabilization process BMS Emulsion	 BMS Foam	Hot Mix Asphalt
Aggregate types applicable	Crushed rock Natural Gravel RAP stabilized	Crushed rock Natural Gravel RAP stabilized Marginal (sands)	Crushed rock 0% to 50% RAP
Bitumen mixing temperature	20°C to 70°C	160°C to 180°C (before foaming)	140°C to 180°C
Aggregate temperature during mixing	Ambient (> 10°C)	Ambient (> 15°C)	Hot only (140°C to 200°C)
Moisture content during mixing	Optimum Moisture Content plus 1% minus emulsion addition	70% to 90% of Optimum Moisture Content	Dry
Type of coating of aggregate	Coating of finer particles Increased cohesion from the asphalt/fines mortar	Coating of finest particles only Increased cohesion from the asphalt/fines mortar	Coating of all aggregate particles with controlled film thickness
Construction and compaction temperature	Ambient (> 5°C)	Ambient (> 10°C)	140°C to 160°C
Air Voids	10% to 15%	10% to 15%	3% to 7%
Rate of initial strength gain	Slow (Moisture loss)	Medium (Moisture loss)	Fast (cooling)
Modification of Asphalt	Yes	No (Modifiers are generally anti-foamants)	Yes
Important Asphalt Parameters	Emulsion type Residual Asphalt Breaking Time	Foaming properties: Expansion Ratio Half-time	Penetration Softening point Viscosity

Depending on the site conditions, two different asphalt stabilizations can be identified in Central America: materials stabilized with emulsified asphalt and materials stabilized with foamed asphalt. Materials need to be appropriately selected for each design. The treatment design can require changing material proportions, blending of aggregates or use of a bitumen or active filler to finally obtain the specific performance required for the project.

According to the Asphalt Academy (2009), the benefits of using BMS are:

- Significant increase in cohesion related to the parent material. The friction angle of the treated material is typically the same as for the untreated material.
- This material acquires flexural strength because of the combined effect of the visco-elastic properties of the dispersed asphalt droplets.
- The material performs well when cohesive strength is optimized through appropriate mix design. Since the asphalt is dispersed only within the finer aggregate particles, the fines are encapsulated and immobilized. This improves the moisture sensitivity and durability of the treated materials.

2.2.1 Classification of Bitumen Stabilized Materials

According to the Asphalt Academy (2009), there are three kinds of bitumen stabilized materials (BSM):

- BSM1: This material has high shear strength, and is typically used as a base layer for design traffic applications of more than 6 million equivalent standard axles (MESALs). For this class of material, the source material is typically a well graded crushed stone or reclaimed asphalt.
- BSM2: This material has moderately high shear strength, and would typically be used as a base layer for design traffic applications of less than 6 MESALs. For this class of material, the source material is typically a graded natural gravel or reclaimed asphalt.
- BSM3: This material is typically a soil-gravel and/or sand, stabilized with higher bitumen contents. As a base layer, the material is only suitable for design traffic applications of less than 1 MESALs.

*2.*3 ***Warm Mix Asphalt***

In general, asphalts mixtures can be classified by their production (mixing) temperature ranges, from cold asphalt mixes to hot asphalt mixes (Ulloa, 2011), as per Figure 4. Typical examples are the following:

- Cold mix: Usually mixed at ambient temperature using emulsions or foamed asphalts.
- Half-warm asphalt: Produced at temperatures under the water evaporation temperature (100°C).
- Warm mix asphalt: Produced typically at a range of temperatures between 120°C to 140°C.
- Hot mix asphalt: Produced typically at a range of temperatures between 150°C to 180°C, according to the used asphalt binder.

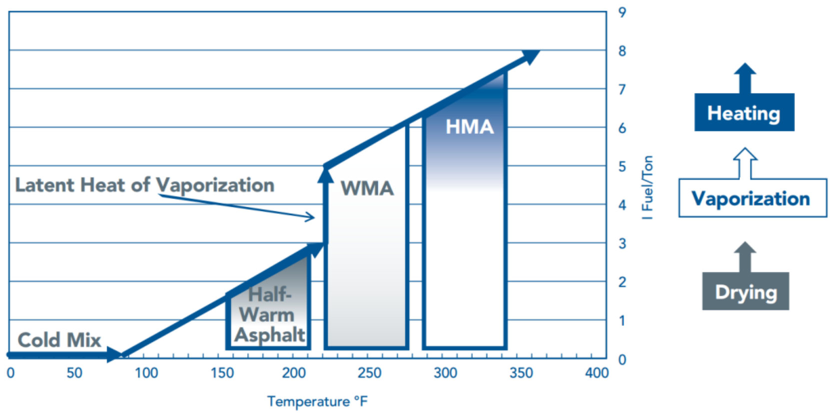

Figure 4. *Asphalt mixture classification by temperature range (D'Angelo et al., 2008).*

Based on Corrigan (2016), Warm Mix Asphalt (WMA) is the generic term for a variety of technologies that allow producers of hot mix asphalt (HMA) to lower temperatures for production, transportation and placement in the field. The main benefits associated to WMA are:

- Emissions are significantly reduced: typical expected reductions are 30 to 40% of carbon dioxide (CO_2) and sulfur dioxide (SO_2), 50% volatile organic compounds (VOC), 10 to 30% carbon monoxide (CO), 60 to 70% nitrous oxides (NO_x), and 20 to 25% dust. (D'Angelo et al., 2008)
- Fuel savings, typically burner fuel is reduced in range from 11 to 35% (D'Angelo et al., 2008).
- Paving benefits related to the improved compaction and workability (less effort required), ability to pave in cooler temperatures at the density desired, ability to haul the mix longer distances, and ability to incorporate higher percentages of reclaimed materials.

2.3.1 Better Working Conditions

In addition to the environmental benefits, WMA improves working conditions at the production plant and on the paving site by reducing exposure to fuel emissions, fumes and odors (Figure 5).

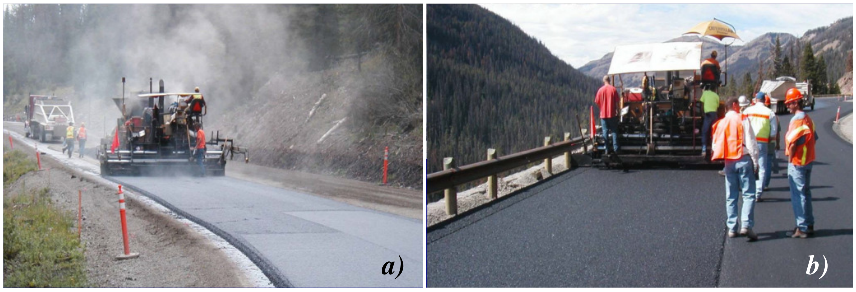

Figure 5. *Working conditions in a) HMA and b) WMA.*

3.0 Applications in Costa Rica

3.1 Past Research

3.1.1 Design Methodology for Base Stabilization with Asphalt Emulsions

Improving low quality or recycled materials for use in road rehabilitations is increasingly taking importance because of environmental and economic reasons, and the reduction in readily available quality raw materials.

Costa Rican authorities have recently assessed the use of asphalt emulsions as stabilizing agent for granular materials and recycled asphalt layers as an alternative for road maintenance and rehabilitation. One of the challenges for the successful implementation of this technique was to develop a design methodology and specifications for quality assurance that accurately discriminate materials that result in adequate behavior versus those that do not, taking into account climatic conditions particular to the country: high relative humidity and precipitation.

The design methodology defined in LanammeUCR project LM-PI-UMP-054-R2 (Ulloa et al., 2016) proposes the following steps.

3.1.1.1 Preliminary Testing. Corresponding to the characterization of the source base material, with the objective of determining if asphalt emulsion stabilization is the ideal technique for the material.

3.1.1.2 Pre-Treatment of the Material. This procedure involves the pre-treatment of the materials to be stabilized using hydrated lime, which is added two hours before the incorporation of the asphalt emulsion. This procedure is required to determine the minimum content of lime that guarantees an acidity in the mix equal to or greater than 12.4.

3.1.1.3 Mineral Filler Selection. This step verifies the need of incorporating active mineral fillers by preparing mixes under three different conditions: 0% mineral filler, 1% lime, and 1% portland cement, all with the same residual asphalt content. The test is used to determine the condition that guarantees a tensile strength ratio (TSR) greater than 65%.

3.1.1.4 Asphalt Content Determination. The procedure for the selection of optimum asphalt content defines three levels as a function of the design traffic. The previous is consistent with international requirements. (Wirtgen, 2012; Asphalt Academy, 2009):

- For Level 1, the indirect tensile strength (ITS) test is performed on specimens 100 mm in diameter and 63 mm in height, compacted by means of the Marshall methodology: 75 blows on each side and conditioned at 40°C for 72 hours. Level 1 allows the determination of the optimum residual asphalt content for pavements with low traffic levels (values less than 3 MESALs).
- For Level 2, the ITS test is performed on specimens 150 mm in diameter and 95 mm in height, compacted at the optimum asphalt content and conditioned at 30°C for the first 24 hours, followed by a conditioning step at 40°C for an additional 48 hours. Level 2 allows the determination of the optimum residual asphalt content with a higher confidence level, so that it can be implemented for the design in pavements for medium traffic volumes, corresponding to a range of values between 3 and 6 MESALs.
- For Level 3, a static triaxial test is performed on specimens 150 mm in diameter and 300 mm in height, compacted at the optimum asphalt content and conditioned to 30°C for the first 24 hours, and then at 40°C for the next 48 hours. This test allows the evaluation of shear resistance for a stabilized material. Level 3 ensures high reliability and is therefore recommended for use on roads with traffic levels higher than 6 MESALs.

3.1.2 Material Requirements for Stabilization with Foamed Asphalt

The technology of foamed asphalt is applicable to crushed rock, natural gravel and marginal or reclaimed granular materials as shown in Table 1. However, certain fundamental requirements must be verified before the design to guarantee the effectiveness of the technique. For this purpose, LanammeUCR developed a project beginning with a literature review of the state of the practice, to finally propose a design methodology applicable to local conditions.

The main requirements for the implementation of the foamed asphalt technique for material stabilization are (Ulloa et al, 2015):

- Fines content. To guarantee the dispersion of asphalt particles, a percentage equal to or higher than 5% particles 0.075 mm or less in size is required. A low percentage of fines will produce large filaments (agglomerations of materials with asphalt), which will cause the mix to act as a lubricant and produce a reduction in resistance and stability in the material.
- Gradation. A continuous gradation is required for the aggregates under 2 mm in size to improve the dispersion of foamed asphalt and to facilitate compaction, while also ensuring the impermeability of the mixture. In case this condition is not satisfied, the addition of a filler is possible.
- Active filler. The resistance requirement for moisture susceptibility in Costa Rican materials can be achieved by adding fine materials such as lime (up to 1.5%) and portland cement (up to 1%).

3.1.2.1 Resilient Modulus in Foamed Asphalt Stabilized Materials. With the objective of evaluating the performance of bases stabilized with foamed asphalt, the resilient modulus test was performed in accordance to the test procedure suggested by NCHRP Report 01-28A. Figure 6 shows the process that was used in preparing the resilient modulus samples.

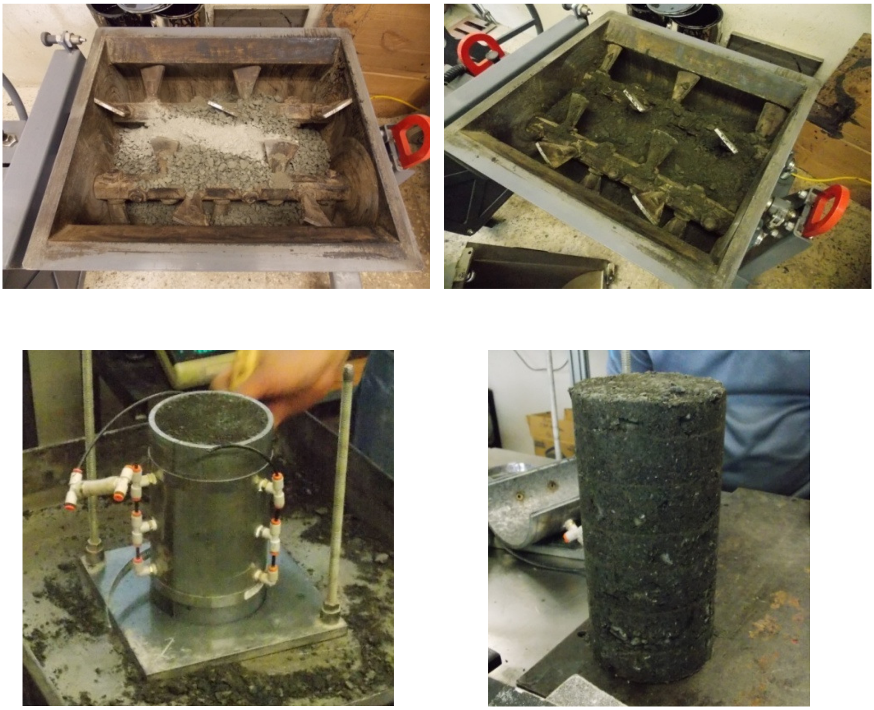

Figure 6. *Foamed asphalt sample preparation for resilient modulus testing.*

Figure 7 shows an example of typical test results for an asphalt stabilized base when compared to an untreated sample. A significant increase in capacity after the stabilization process can be observed.

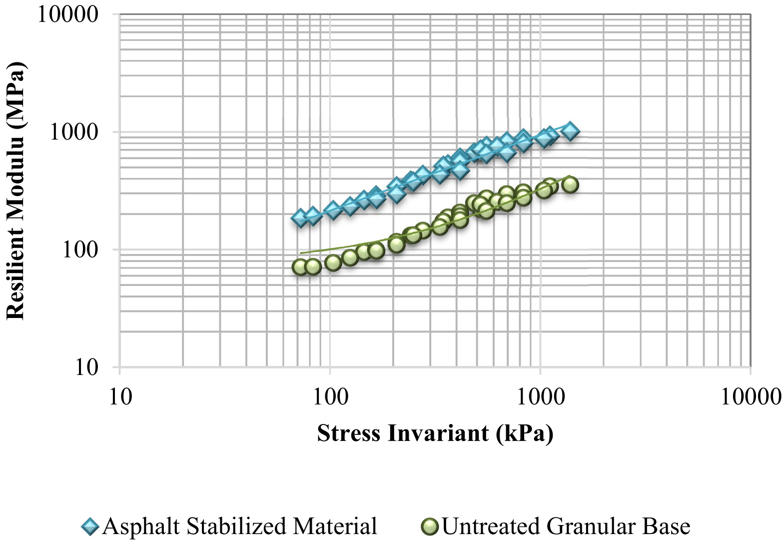

Figure 7. *Resilient modulus test results.*

3.1.2 Simulation of Reclaimed Asphalt Mixtures in Laboratory and Evaluation of Performance

The objective of the research consisted in the evaluation of the mechanical properties and performance of mixes and asphalt mortars with different simulated RAP contents. Additionally, a complete characterization of the asphalt binder, recovered from the simulated RAP, was performed with the purpose of correlating the behavior of the three phases: asphalt binder, mortar and asphalt mix. The procedure for the simulations of RAP was done in accordance to the NCHRP project 09-54 recommendations (Kim et al., 2013).

To evaluate the existence of possible side effects due to the use of RAP in an asphalt mix, the following performance tests were performed: dynamic modulus test, modified Lottman test to measure moisture susceptibility and flexural fatigue tests to find fatigue life. All of them were evaluated for 0, 15, 30, 50 and 100% of simulated RAP (Zamora, 2016). The results from the dynamic modulus test for all five conditions are shown in Figure 8. An effect in the mechanical performance of the material can be identified for simulated RAP contents above 30%, where the curves shift upwards evidencing higher material stiffness: direct effect on fatigue resistance.

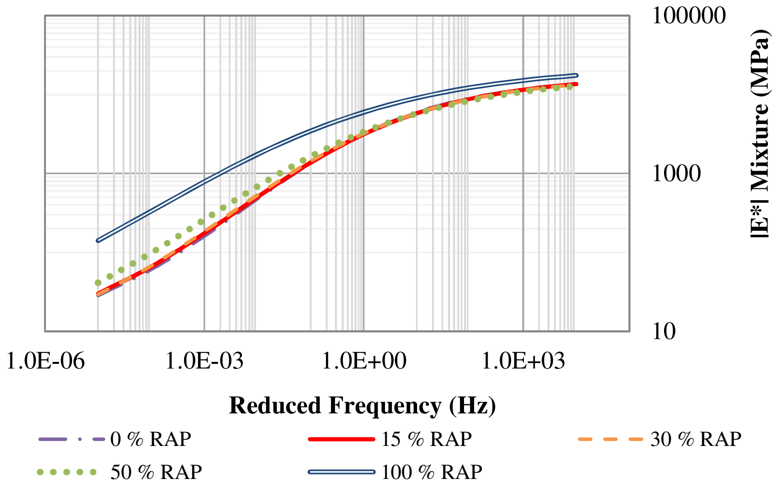

Figure 8. |*E**| *Mixture master curves using different RAP contents.*

With the purpose of separating the effect of aging in each of the asphalt mixture components, the properties of the asphalt binder were analyzed by means of rheological testing. From the obtained results, the relation between shear dynamic modulus (|G*|) of the asphalt binder and the dynamic modulus (|E*|) of the asphalt mix for each RAP content is shown in Figure 9.

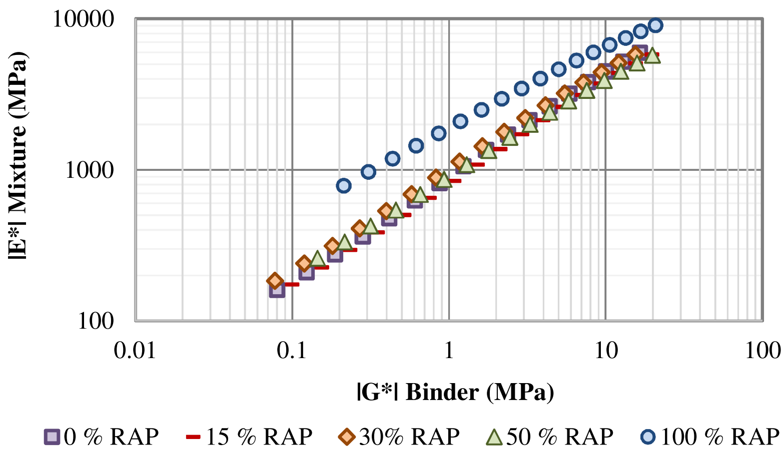

Figure 9. *Relationship between mixture* |*E**| *and asphalt binder* |*G**|.

For each RAP content, a specific relationship was obtained, allowing for correlation between the |E*| modulus of the mixture and the |G*| modulus of the binder. The identified relationships follow:

$$|E^*|_{0\%\ RAP} = 907\ |G^*|^{0.695} \quad [1]$$

$$|E^*|_{15\%\ RAP} = 811\ |G^*|^{0.679} \quad [2]$$

$$|E^*|_{30\%\ RAP} = 1006\ |G^*|^{0.666} \quad [3]$$

$$|E^*|_{50\%\ RAP} = 905\ |G^*|^{0.639} \quad [4]$$

$$|E^*|_{100\%\ RAP} = 1886\ |G^*|^{0.538} \quad [5]$$

As per the equations, the addition of higher RAP contents causes the progressive decrease in the exponential term in the model, evidencing that the effect of stiffening due to addition of RAP is greater at the asphalt binder level.

On the other hand, the components analysis allows obtaining, for each condition, a relation between the magnitudes of mix (|E*|), mortar (|G*|) and asphalt binder (|G*|) moduli. Figure 10 shows the relationship between the original mix condition and Figure 11 shows the comparison with the 100% RAP mix.

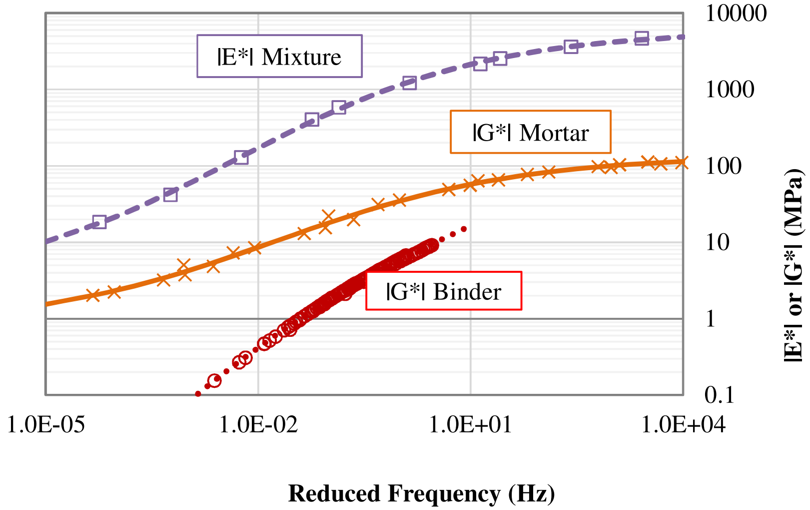

Figure 10. *Relationship between mixture |E*|, mortar |G*| and binder |G*| in control mix.*

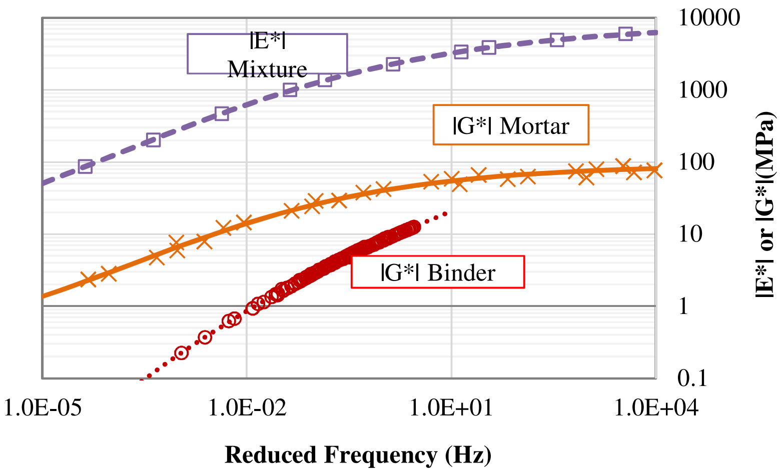

Figure 11. *Relationship between mixture |E*|, mortar |G*| and binder |G*| with 100% RAP.*

3.1.3 Mechanical Properties of Asphalt Mixes using RAP

The study analyzes the use of recovered materials on a Costa Rican national route. The material was divided in two fractions, where an asphalt content of 3.3% was obtained for the coarse fraction (retained material on the No. 4 sieve) and 6.5% for the fine fraction. Figure 12 shows the RAP material that was used.

Figure 12. *RAP handling in the laboratory.*

Based on the performed analysis, it was determined with a confidence level of 90% that there are significant differences in the fatigue performance of mixes including more than 30% RAP. This has aided in establishing a maximum RAP content to be initially allowed in the country to ensure that material failures are minimized.

3.2 Field Tests

3.2.1 Experimental Section: National Route No.224.

The analysis of failed projects in Costa Rica´s road infrastructure is generally performed by LanammeUCR. Therefore, in coordination with private companies, the project "*Evaluating the performance of bases stabilized with foamed asphalts in experimental sections*" was developed and implemented on the National Route No. 224 (Ujarrás – Cachí Dam) (Badilla et al., 2011) The primary objective of the project consisted in assessing the effects of foamed asphalts as a stabilizing additive on the mechanical properties, as well as the durability, of the stabilized material in an experimental section that was built on National Route No. 224.

With the purpose of determining the initial condition of the section, the following test procedures were performed:

- Falling weight deflectometer (FWD)
- Photographic survey by means of Geo3D
- Mechanical capacity by means of the dynamic cone penetration test
- Visual survey

Figure 13 shows pictures of the section and its issues. Currently, the project is in operation and under continuous monitoring.

3.2.2 Experimental Section: National Route No. 39

This study is focused on the feasibility analysis for the application of the foamed asphalt technique on National Route 39. This road is the main loop around San José, where heavy vehicle traffic has very high concentrations (Ulloa et al., 2015). The project has a length of 8 km of asphalt concrete, in which nine homogeneous sections were determined with very variable compositions. The analysis was performed by means of FWD and trenching to extract materials.

The design of the nine sections indicated that for specification compliance, the entire section required an asphalt content of 3.2% and 1% lime as an adhesion promoter. While it is true that the laboratory results evidence an improvement in the property of the materials, it was concluded that the project was not feasible from an economic standpoint.

Figure 14 and Figure 15 show pictures of the construction process of a test track built in 2015.

Figure 13. *Stabilized section with foamed asphalt in National Route 244 in Costa Rica.*

Figure 14. *Stabilized section with foamed asphalt in National Route 39 in Costa Rica.*

Figure 15. *Equipment used in stabilization process in Route 39 in Costa Rica.*

3.3 Additional Efforts

3.3.1 Environmental Campaign: Green Pavements

The campaign "Pavimentos Verdes" (Green Pavements) aims to spread the concepts related to the diverse techniques in pavements that are more environmentally friendly. It focuses on the topics of warm mix asphalts, asphaltic emulsions, foamed asphalts, asphalt improvement through modification with polymers and pavement recycling; all while considering the elements of pavement durability, permeability, reduction in application temperature and gas emissions during the construction, economic impact, among others.

Figure 16. *"Pavimentos Verdes" campaign.*

The initiative has as an objective to inform the department of transportation as well as contractors in construction projects and road preservation about new efficient technologies from an environmental and economic standpoint.

3.4 Applications in Central America

3.4.1 Nicaragua: Rehabilitation of Nandaime–Rivas–Peñas Blancas Corridor.

The rehabilitation project on the Nandaime–Rivas–Peñas Blancas road was developed using foamed asphalts for base stabilization. The total length of the project is greater than 50 km on Nicaragua's National Route, channeling most international heavy traffic (inbound and outbound from Costa Rica). Figure 17 shows the state of the road previous to intervention.

Figure 17. *Route conditions before the intervention.*

The intervention consisted in the profiling and cold recovery of 8 cm of an existing asphalt layer. The stabilization of the material was done through foamed asphalt techniques, followed by the placement of a 5-cm reinforcement layer as shown in Figure 18. Figure 19 shows the rehabilitation process.

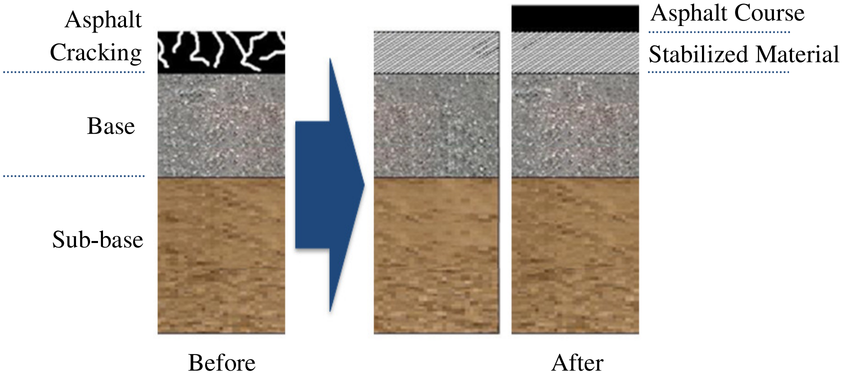

Figure 18. *Project structural profile.*

Figure 19. *Rehabilitation process for the Nandaime–Rivas–Peñas Blancas corridor (Chávez, 2013).*

3.4.2 El Salvador: Boulevard del Ejército: Soyapango Overpass – San Bartolo Intersection

The length of the project is approximately 57.8 km, where important works with recycled pavements were done. The rehabilitation of the road is important as it is a strategic corridor for the capital and is key for the operation of the San Salvador Metropolitan Area Integrated Transport System (SITRAMSS) (Martinez, 2013). Figure 20 shows the rehabilitation process.

Figure 20. *Rehabilitation process for the boulevard (Chávez, 2013).*

3.4.3 El Salvador: Jiquilisco – Puerto El Triunfo Road

The project has a length of 31.67 km and connects the towns of Jiquilisco and Puerto El Triunfo, both in the Usulután Department. The improvement of this road consisted in the construction of a two-way road with a width of 6 m plus 1 m shoulders on both sides using RAP and existing material stabilization with asphaltic emulsions. Additionally, in coordination with FOVIAL's Technical Management, and due to monitoring of the recovered materials during routine maintenance, close to 35 km of non-paved roads were rehabilitated across the country using RAP.

4.0 Sustainability in Road Projects

The main purpose of the project is to promote the implementation of sustainability in road infrastructure through a multicriteria approach (environmental, economic and social). The previous ensures the efficient use of resources and conservation of the environment. The main research lines are the following:

- Life cycle assessment (LCA)
- Carbon footprint estimation
- Life cycle cost analysis (LCCA)
- Risk analysis and transfer
- Wildlife crossings
- Reclaimed materials
- Energy balance
- Climate change
- Noise reduction
- Effect on International Roughness Index

The project started with LCA research because the country currently requires a methodology that allows estimation of performance indicators to aid in road infrastructure evaluation and decision making at the project and network levels. The next goal consists of generating a methodology that will unify each of the identified issues and encompass them under the central topic – sustainability – following a multicriteria (environmental, economic and social) approach. Furthermore, software will be developed to predict the selected sustainability indicators for future investment by the administration.

This project is a part of the commitment the country has made to achieve carbon neutrality by the year 2021 (bicentennial celebration of independence), as well to comply with international agreements (e.g., Kyoto Protocol, Paris Agreement). Finally, it is necessary to provide measurement and analysis tools enabling the administration to comply with its commitment in matters related to road infrastructure. The software will then be free access and can be applied in the planning of infrastructure projects ensuring efficiency and quality, based on sustainability indicators. The project's objectives and goals are summarized in Figure 21.

Figure 21. *Schema of sustainability (Aguiar et al. 2017).*

5.0 Conclusions

The use of recycled pavement technologies represents a new, economically and environmentally efficient alternative. Furthermore, the use of recycling techniques, such as use of reclaimed materials for stabilization processes with asphaltic materials or warm mixes, can increase the benefits.

This document presents an overview of some of the applications of recycled pavement techniques and its advancements and implementations in Costa Rica and Central America in general. From an academic viewpoint, LanammeUCR has aided in developing design tools and has promoted the implementation of new recycled pavement technologies, as well as setting the requirements and specifications associated with stabilized materials.

At an implementation level, important national routes like the Nandaime–Rivas–Peñas Blancas corridor in Nicaragua by FOVIAL (Road Conservation Fund) or the Boulevard del Ejercito in El Salvador by SITRAMSS have been intervened using recycling techniques and foamed asphalt. The document evidences the importance of performing feasibility studies and material characterizations prior to the application of these techniques, with the objective of optimizing resources in function of the existing conditions and materials.

Finally, the commitment of the road industry in Costa Rica towards achieving the carbon neutrality goal by 2021 is driven by the sustainability in road infrastructure projects program, which will generate a valuable tool for LCA analysis that may be applied by the administration.

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7.0 Discussion

ARLIS KADRMAS: Very good presentation. I wanted to bring something up because you had talked about a lot of moisture and a lot of rain that you get in Costa Roca and the failure of a hot in-place recycling project. But it was interesting that you're doing a lot with base stabilization foamed asphalt or basically cold in-place recycling or full-depth reclamation. Those are high air void systems. Basically, you probably see 9 to 13% air voids, I'm guessing, in that range. And it just kind of goes contradictory with what people tend to think of these systems. We know they perform well in the United States, but people often think, "Well, how can they possibly perform when you have those high air voids in these systems?" And we really need to think about looking at systems and why they're performing well. And I think you give a perfect example of something that's contradictory to what a lot of people probably in here have thought about in the past on how you need lower air voids. That kind of water should just tear apart those systems, and yet they're performing well. I just wanted to point that out. I think it's very good.

LUIS LORIA-SALAZAR: Thank you.

AAPT/ISAP International Forum: Discussions

1.0 Discussion – Martin Hugener

SIMON HESP: So, I have a question about vegetable oil. I have seen some very good data on 100% recycling of vegetable oils, and I'm worried about the microbes eating the vegetable oil. Do you have any comments on that? And the other issue is physical hardening at low temperatures. When you leave them there, do they phase separate from any of these rejuvenating agents?

MARTIN HUGENER: So, what is the exact question?

SIMON HESP: Do you have any comments on vegetable oils being biodegradable? Bugs getting to them and in four or five years it falls apart.

MARTIN HUGENER: I have some doubts that it would be degraded because it's quite well mixed with bitumen. And if it's fully dispersed in bitumen, I don't think that the bugs have still access to this vegetable oil.

SIMON HESP: I don't know. I'm just asking. And the other question with physical hardening at low temperature do they phase separate from the oxidized components? Or have you done any experimental work on that?

MARTIN HUGENER: My presentation is not about results from my own work, but intended to to show what is happening in Europe.

BOB FRANK: Martin, early in your presentation you had a Black space diagram by Martin Rattenburg showing the failure of the rejuvenated mixes to come back to the virgin binder properties. Can you confirm whether those rejuvenated binders were aged or unaged for the specimens that were used for that Black space?

MARTIN HUGENER: I'm not sure what you…

BOB FRANK: Right there. So, you commented how the rejuvenation wasn't able to bring those binders back up to the blue zone of fresh binders.

MARTIN HUGENER: Yes.

BOB FRANK: It looks to me like those are plots of aged rejuvenated recycled binders rather than just a Black space diagram of the rejuvenated binder.

MARTIN HUGENER: If I have read the paper correctly, I think it's not aged. They represent mixtures of a recovered RAP binder with different rejuvenators but identical viscosity in terms of softening point ring and balL. No additional aging has been done.

BOB FRANK: Thank you very much.

GEOFFREY ROWE: When we've been looking at rejuvenating binders with some of my clients in the US, we've been looking at a plot of the R value versus the crossover frequency on both the original binder and the rejuvenated product, trying to make sure they line up. Are you following any particular protocols like that in terms of the way you're looking at rejuvenating?

MARTIN HUGENER: For the moment, we don’t have that kind of protocol. Actually, I did present some work which has been done in Europe, and if you refer to the intended work in the RILEM TG3, I have to say that we haven’t decided yet which protocol we are using or at which parameter we are looking.

GEOFFREY ROWE: I know some folks in the UK are looking at the VET concept along with the aging index with certain rejuvenating oils. And it may be that that approach is not too dissimilar to some of the approaches we’re looking at over here. It might be that that type of approach could be used, but certainly we can discuss that later.

MARTIN HUGENER: Yes. Thank you.

ELIE FINI: What an interesting discussion when you are actually finished what we call a rejuvenator or how we can… We should make sure we don’t destroy the reputation of it in the future because if you use the wrong term and they don’t behave the way we think, then it could damage the reputation of rejuvenator as a whole. So, I guess in that term, we should go back and say what we call rejuvenator and what we expect. So far, there is a lot of controversy as to what is a rejuvenator. We have Glover-Rowe parameter that is doing a relatively good job in differentiating rejuvenated versus softened asphalt. But we still don’t have a full picture of it. So, if you're talking about, and one other question was referring to aging and what happens if it’s a vegetable oil or whatever. I just want to add a comment that when you have a real rejuvenator, you restore the properties and it doesn’t mean that the rejuvenator is just floating there and it aged by itself and so forth. We presented a paper in TRB that we look at the molecular interaction and what a rejuvenator can do in terms of restoring properties. So maybe some of this material should be called biomodifier or modifier before we can really know what rejuvenation is.

MARTIN HUGENER: Yes, I think there is no definition what a rejuvenator is, so we are really struggling to have some quality properties for these rejuvenators.

2.0 Discussion – Shigeru Shimeno

GABRIELE TEBALDI: I have a quick question. You are talking about repeated recycling. Do you have a maximum amount of secondary recycling, so the material is recycled for two times? Is there a limit or does it depend on the wear and the condition?

SHIGERU SHIMENO: No. As I said, we have no exact data on how much is repeated and how many times repeated. Currently, the maximum amount is around 50% and the amount is actually the same in the repeated uses. We are studying how the property of the asphalt mixture is going on when they use it repeatedly. We’re studying now.

BECKY McDANIEL: My question isn't about recycling per se, but you mentioned that 80% of the expressway has a coarse asphalt surface, and I wondered what the motivation for that is. Is it noise or safety?

SHIGERU SHIMENO: For expressways, safety is a priority. So, to assure the safety, porous asphalt pavement was introduced.

BECKY McDANIEL: Great. Thank you very much.

JEAN-PASCAL PLANCHE: Thank you for presentation. If I understand the Japanese market well enough, I think a lot of the bitumen that you use is polymer modified, so the binders that are recycled are most of them, I guess, polymer modified to a great extent.

SHIGERU SHIMENO: As I said, we use much polymer-modified asphalt. That's the reason why the penetration grade gets smaller. I think nowadays 15% to 20% is modified asphalt. The amount is increasing.

JEAN-PASCAL PLANCHE: Do you see some benefit from the old polymer-modified asphalt? When it's recycled, are there still some polymer properties in these products?

SHIGERU SHIMENO: In the ordinary plant, we cannot identify which is modified asphalt mixtures and which is straight asphalt mixtures in the stock yards. So that we needed to evaluate asphalt mixtures including polymer-modified asphalt and introduced the Bituminous Tenacity Index. We can evaluate the property of asphalt mixture including modified asphalt.

3.0 Discussion – Shih-Hsien Yang

EDGAR HITTI: In your presentation, you mentioned about if the pen is greater than 15 and viscosity around 50,000, you allow 30-40%. That's quite a significant amount of viscosity comparing to let's say a 70/50 pen material which typically is 2000. So, you're giving around 15-20%; 20 times more tolerance for the RAP. And the other thing about the residual value, you're comparing it to the aggregate. And here really the value of the RAP is what binder is still in it, so you're giving 60-70% of the aggregate value. I mean, aggregate is going to be way too expensive. That doesn't give a lot of incentive for the use of RAP if it's going to compare to the aggregate value.

SHIH-HSIEN YANG: To quickly respond. Like I say, ____ especially like ____of using the RAP and also the binder aging level, they don't really have serious research about how to link those. They are more based on their experience. Like I say, in the first ten years, it's okay. So, based on that experience, they set the rules, but they don't really look seriously about this performance, mechanical properties stuff. And in the second ten years, things failed. The second part about the residual value. Right now, the situation is nobody wants the RAP, no one. Not a contractor, not an agency. Nobody wants it. So, I understand you saying they do have value, but it’s more that the agency tries to give incentives, saying, “Hey, you know, you can use it and it’s actually usable.” So, they try to first, again, establish the normal process. I don’t know if they raise the price later, but that’s so far, their plan. Yes, their plan is like this.

EDGAR HITTI: Thanks. But for that, there’s no incentive at all. Which is fine, from a binder supplier. Anyway, thank you.

NIMA ROOHI: Green Asphalt. Nice presentation. I have two questions. Do you guys have any problem with the mineral part of your RAP? Because I imagine you're milling and milling it again?

SHIH-HSIEN YANG: Yes.

NIMA ROOHI: If you don’t have quality aggregate sand and stone, you're going to create a lot of problems in your milling in your second and third rounds. And in the first part of your presentation, you mentioned that you have a lot of limitation on mining quality sand and stone.

SHIH-HSIEN YANG: Yes.

NIMA ROOHI: So, is that a problem or no?

SHIH-HSIEN YANG: If you are talking about the mineral part of it.

NIMA ROOHI: No. I’m talking about the sand and the stone, the actual mineral structure of your mix. Most of your discussion was about the liquid asphalt part, like how that ages and how the recycling period is three to ten years. I’m just wondering about the mineral part.

SHIH-HSIEN YANG: It is. For example, I think the common intuitive thinking is if you have more RAP, you should have good rutting resistance. But actually, in a lot of cases, when you add RAP, they have bad rutting resistance. And that comes from two things. One is during the multiple recycling of the RAP, the durability of rut actually degrades. And in order to pass the specification, they add something soft in there. The nicer guy will add AC5, which is a low-viscosity binder. The not very nice guy will add maybe a lubricant. But they will cheat the system and go on. So, we do. But we are not allowed to permit land mining, but we can also get river gravel. We have a lot of river gravel.

NIMA ROOHI: The second question, do the producers utilize screening for the millings at all or not? Do you use the black sand and the black stone?

SHIH-HSIEN YANG: They do. From the factory that participates in the program, they do. That’s what I can answer. For those who are not participants, I doubt. Yeah.

4.0 Discussion – Paul Marsac

NIMA ROOHI: Nice presentation. I just wanted to make a comment. You have on one of your slides the average RAP needed in the US to be utilized in a mix, which was, I think, 21%.

PAUL MARSAC: Yes.

NIMA ROOHI: I just wanted to say that the standard deviation for that is pretty large in the United States because you have very densely populated areas with a lot of RAP generation. It's very tough to truck them to other areas that don't have a lot of RAP, so you need technologies to be able to go way over that 20%. So I just wanted to make this comment.

PAUL MARSAC: That's true. But that's what I wanted to show. If you have a broad scope, you have about 20%. But if you reduce the scope, for example, to Netherland, that can go to 60%. It depends on the availability of RAP you have. So, then you need to have high-truck recycling and sometimes you don't. I cannot say. Some should go to 100% recycling, but some not.

NIMA ROOHI: Exactly. I just wanted to mention the experience in the New York area. We generate a lot of RAP in New York City. And then upstate New York doesn't have a lot of RAP. Right now, with all the economics around the oil prices and sand and stone, people truck or barge RAP from New York City to upstate, a couple hundred miles away, to utilize that RAP up there. So, it's a problem really in our area. We're densely populated. We have tons of RAP to be utilized. So, if there are technologies to go way over that 20%, they're more than welcome.

PAUL MARSAC: Yes, of course. But we had a trial of life cycle software, and we found, at least in France, if your transport distance is more than 150 km from the RAP stock to the plant, you're losing all the benefit of your recycling. So, if you recycle RAP for more than 150 km, it's not a good idea. So, plants should be near the RAP stock.