“Reduced Thickness Asphalt Rubber Concrete Leads to Cost Effective Pavement Rehabilitation”

By
Jack Van Kirk
Director of Asphalt Technology
Basic Resources Inc.
3050 Beacon Blvd. Suite 205
West Sacramento, CA 95691
(916) 373-1279

Glynn Holleran,
Vice President
Technical and International Operations
VSS Asphalt Technologies
3050 Beacon Blvd. Suite 205
West Sacramento, CA 95691
(916) 373-1500

1st International Conference World of Pavements
Sydney, Australia
February 20-24, 2000
By
Jack Van Kirk, Basic Resources Inc. and
Glynn Holleran, VSS Asphalt Technologies

Between 1980 and 1992 California Department of Transportation (Caltrans) conducted research comparing asphalt rubber concrete to conventional asphalt concrete (AC) in field evaluations. During this time cities and counties in California also experimented with asphalt rubber pavements. It was determined through these field evaluations that the asphalt rubber pavements could be significantly reduced in thickness and provide the same service life as thicker conventional AC pavements. This led to the development of a Reduced Thickness Design Guide by Caltrans for asphalt rubber pavements. The reduced thickness approach (up to 50%) was substantiated by research in South Africa (1994) in field installations using the Heavy Vehicle Simulator (HVS), by the University of California, Berkeley (1994) in the laboratory and by the University of Alaska, Fairbanks (1995) in the laboratory. In 1999 research was conducted to determine the cost-effectiveness of rehabilitation and maintenance strategies using asphalt rubber pavements. It was determined that asphalt rubber rehabilitation and maintenance strategies are more cost-effective when compared to conventional AC strategies. This has led to more wide spread usage of asphalt rubber rehabilitation and maintenance strategies in California and other states in the USA.
Introduction

Asphalt rubber is a term that has been misused for many years. To some it means one type of binder, but to others it can define a whole list of materials. However, “asphalt rubber” as first developed in the early 1960’s is a specific type of binder. It uses a certain type and grading of crumb rubber and it is produced in the field at the job site with specialized equipment. It has over 30 years of proven performance history. The development path that asphalt rubber has traveled has been a very difficult and controversial one. When new products are developed contractors and agencies go through a learning phase. During this time there are successful and unsuccessful test projects. This was also the case for asphalt rubber. Any new product must first prove itself before the user (or agency) accepts it. Asphalt rubber has accomplished this task. Agencies that have recognized the advantages of asphalt rubber are now benefiting from their decision to use it. In states such as California and Arizona, which have extensive experience with asphalt rubber, it has been shown to be a very cost-effective binder for pavement maintenance and rehabilitation strategies when properly produced and constructed (1).

The California Department of Transportation (Caltrans) conducted research between 1980 and 1992, which compared asphalt rubber concrete to conventional asphalt concrete (AC) in field evaluations. During this time cities and counties also experimented with asphalt rubber pavements. It was determined through these field evaluations that the asphalt rubber pavements could be significantly reduced in thickness and provide the same service life as thicker conventional AC pavements. This led to the development of a “Reduced Thickness Design Guide” by Caltrans in 1992 for asphalt rubber pavements. This was the same year that Caltrans began routine use of asphalt rubber pavements. The reduced thickness approach (up to 50%) was substantiated by research in South Africa in 1994 (2) in field installations using the Heavy Vehicle Simulator (HVS), by the University of California, Berkeley in 1994 (2) in the laboratory and by the University of Alaska, Fairbanks in 1995 (3) in the laboratory. Asphalt rubber has been successfully used in chip seals, stress absorbing membrane interlayers (SAMI), hot mix (dense, gap and open graded), and especially in multi-layer systems. The advantages of using asphalt rubber strategies have been validated by many research efforts. Recently the cost-effectiveness of asphalt rubber strategies has been validated in a Life Cycle Cost Analysis research effort (4).

Background

Overall, Caltrans rehabilitation program has proved quite successful. However, in the snow regions where tire chains are used, the design life was not being achieved when using conventional dense graded asphalt concrete (DGAC), thereby resulting in increased maintenance costs. In 1978, in its quest to find a more durable mix for the snow region, Caltrans began experimenting with crumb rubber in AC mixes. The first field trial using asphalt rubber was in 1980. Later laboratory research indicated that crumb rubber modified (RAC) mixes were more abrasion resistant when compared to conventional DGAC. Field permeability testing also showed that RAC mixes had extremely low permeability’s. It was felt that these low permeability’s would reduce the infiltration of water into the mat and therefore cut down on the freeze-thaw damage. The low permeability’s should also reduce oxidation and thereby lower the aging rate. Because of the success in the snow region Caltrans began to broaden its use of RAC mixes. These mixes included adding the crumb rubber in a wet and dry process. In the dry process the crumb rubber is added to the aggregate before the asphalt is added. In the wet process the crumb rubber is first blended and reacted with the asphalt, to form “asphalt rubber” binder, before being added to the aggregate. Caltrans experience with the dry
process was unsuccessful. The wet process has proved to be the most cost effective use of crumb rubber in asphalt concrete.

**Successful Asphalt Rubber Pavement Strategies**

Asphalt rubber was first used as a binder in chip seals. On these projects asphalt rubber exhibited one of its most positive advantages and that is to resist reflective cracking. One of the significant differences with asphalt rubber is the application rate of the binder. Using 12.5 mm maximum size aggregate the following example application rates would apply. For conventional emulsions the application rate is about 1.4 – 1.8 liters per square meter and for polymer modified hot applied binders it is about 2.0 – 2.5 liters per square meter. The application rate for asphalt rubber binder is about 2.5 – 3.0 liters per square meter and this gives it a significant advantage in not only sealing the pavement surface, but also in resisting reflecting cracking. This high application rate helps relieve the stresses that are transmitted to the pavement surface. The application rate along with the improved binder properties makes it a superior binder for chip seals.

Asphalt rubber chip seals also have been used as a stress absorbing membrane interlayer (SAMI). As mentioned above, because asphalt rubber has the ability to significantly relieve the stresses at the pavement surface, it can also provide these similar properties when used as a SAMI. It can significantly extend the life of an overlay when it comes to retarding reflective cracking regardless of the type of binder used in the overlay. However, SAMI’s using asphalt rubber binder coupled with asphalt rubber hot mix as the overlay can provide improved performance resulting in significant cost savings to the user.

Asphalt rubber chip seals have also been used in cape seal applications. A cape seal is simply a chip seal followed by an application of a slurry seal as the final surfacing. It results in a thin pavement surfacing that provides improved resistance to reflective cracking. This strategy can provide significant cost savings when compared to conventional overlay strategies.

Asphalt rubber was first used in hot mix in open graded asphalt concrete (OGAC). The binder content was increased without resulting in binder drain-down during construction or significant loss of drainage capacity on the pavement surface. However, it did result in a wearing surface with increased durability and improved crack resistance. Since this early use it has also been found that the asphalt rubber binder content can be further increased to provide a high binder content open graded friction coarse (OGFC). The binder content has been increased to a range of 9-10 percent (by total mass) which has resulted in a mix that can be placed in very thin lifts and provide a more durable longer life wearing surface. When placed at these high binder contents it loses its ability to provide the normal drainage that occurs when using conventional OGAC. These high binder content mixes are used as wearing coarses rather than drainage coarses. If surface water drainage is desirable, the lower binder content asphalt rubber OGAC should be used. These high binder content OGFC mixes have been used successfully on not only AC pavements, but also on portland cement concrete (PCC) pavements (5). This particular mix is gaining in popularity as an improved wearing surface because of its desirable properties. These properties include high binder content, resistance to oxidation and reflective cracking, excellent skid resistance, and noise reduction.

Early use of asphalt rubber in dense graded asphalt concrete (DGAC) was very successful in California. Caltrans used a construction evaluated research (CER) approach for asphalt rubber mixes. Asphalt rubber went through an extensive evaluation program that lasted more than ten years. On the asphalt rubber projects constructed by Caltrans prior to 1983, the asphalt rubber mixes
were compared to equal thickness of conventional DGAC. However, in 1983 a project was constructed (on RT. 395 in northeastern California) (6,7) using various overlay strategies including three test sections of reduced thickness asphalt rubber mix (when compared to the conventional DGAC overlay design thickness). Also placed on the project were various thickness of conventional DGAC. This project, though not realized at the time, later became the turning point for Caltrans rehabilitation strategies involving asphalt rubber mixes. For a while after 1983, Caltrans continued to construct and compare equal thickness of asphalt rubber mixes and conventional DGAC on other projects, while reviewing and accumulating data on the RT 395 project. By 1987, it became evident that substantially thinner overlays using asphalt rubber, when compared to conventional DGAC, could provide a longer service life at a reduced cost. At this point in time, Caltrans strategy for asphalt test section overlays changed. It was decided that all subsequent projects if appropriate would involve asphalt rubber overlays that were thinner than those required if conventional DGAC were used. Projects utilizing reduced thickness continued until 1992. At that time it became very evident that asphalt rubber mixes could be reduced in thickness when compared to the conventional pavement design thickness and achieve equal or greater service life. Finally in 1992 Caltrans began routine use of reduced thickness asphalt rubber pavements (8,9). This reduced thickness design approach (up to 50 %) when using asphalt rubber binder was validated on many other field projects and also in a research effort (2,10). The research effort indicated that the reduction in thickness recommended by Caltrans was conservative. To date there has been over 750 successful reduced thickness projects in California.

During the late 1980’s Arizona began to use asphalt rubber gap graded mixes. These gap graded mixes resulted in a significant increase in binder content over dense graded mixes. These mixes proved to be very successful in Arizona and subsequently gained popularity in California. At the same time, Caltrans was developing their reduced thickness design guide for asphalt rubber mixes. Caltrans chose to use asphalt rubber hot mix-gap graded (ARHM-GG) mix as the standard in their reduced thickness design guide. They felt it would provide added confidence and be more conservative, because of the higher binder content (when compared to using a dense graded aggregate). Today ARHM-GG is the most popular asphalt rubber mix used by agencies in the United States.

Asphalt rubber mixes have proven to be very cost-effective. However, multi-layer systems using asphalt rubber binder have proven to be the most cost-effective. Asphalt rubber SAMI’s, ARHM-GG mixes and high binder content OGFC mixes used in combination have provided superior field performance. Three layer systems using a conventional AC leveling coarse, an asphalt rubber SAMI and finally an ARHM-GG mix as a surface coarse have provided significant cost savings to California agencies while providing superior performance. Combinations using conventional AC as a base coarse, ARHM-GG mix as a second coarse and finally high binder content OGFC as a wearing coarse have provided superior performance in Arizona (5). These systems in most cases have provided lower initial costs and have also provided reduced long-term maintenance costs.

Asphalt Rubber Experience

Caltrans has used asphalt rubber mixes in many parts of the state and in different climate regions. These regions have included the snow country, the coast, the valley, and low and high desert. Many of the early projects were placed to resolve specific problems such as abrasion resistance, OGAC night placement, thin flexible bridge overlays, and desert AC pavement rehabilitation. Generally, control sections containing conventional DGAC were placed on the early projects so that direct comparisons could be made.
Since the early projects proved successful, asphalt rubber mixes have been used in a wide variety of applications. These have included bridge decks, roadside rests, parking lots, ramps, sharp curves, grades, and low, medium and high volume roadways. Over the years asphalt rubber mixes have proved to provide cost effective performance in all regions of the State.

**Reduced Thickness Design Guide**

In 1992, Caltrans presented a proposal to the Federal Highway Administration (FHWA) to allow the use of reduced thickness asphalt rubber overlays as an approved strategy on federally funded rehabilitation projects. This proposal was approved based primarily on the successful field experience of reduced thickness asphalt rubber projects which included the project on Rt. 395 near Ravendale mentioned earlier. Caltrans uses a deflection-based design procedure for rehabilitation of flexible pavements. This procedure is also used for asphalt rubber overlays. Caltrans developed the reduced thickness design guide in the form of an easy to use table. The guide is titled “Asphalt Rubber Hot Mix-Gap Graded Thickness Determination Guide”. To determine the thickness needed for an asphalt rubber overlay a conventional AC design thickness is first determined. The designer simply enters the table (a portion of the table is shown below) and finds the thickness for the conventional design thickness in the column under DGAC (example-75 mm) and then moves horizontally across to the right to find the equivalent thickness for the ARHM-GG with (45 mm) or without a SAMI (30 mm). There are two tables, one for structural equivalencies and one for reflection crack retardation equivalencies.

| Structural Equivalencies Thickness (mm) |
|-----------------|-----------------|-----------------|
| DGAC            | ARHM-GG         | ARHM-GG on a SAMI |
| 45              | 30              | --              |
| 60              | 30              | --              |
| 75              | 45              | 30              |
| 90              | 45              | 45              |

**Field Validation of the Reduced Thickness Design Guide**

In 1993 Caltrans conducted research to validate the data supporting the reduced thickness design guide (2). The work was conducted by the University of California, Berkeley (UCB), Dynatest Consulting and the Council for Scientific and Industrial Research (CSIR). The work involved the use of the South African Heavy Vehicle Simulator (HVS). The HVS is an Accelerated Pavement Testing (APT) machine designed to test pavement sections in the field. The machine has a truck wheel (single or dual tire) mounted on an I-beam frame that is hydraulically loaded and moves back and forth across the pavement. It is designed to simulate actual traffic on the pavement section. One of the objectives of the study was to test conventional AC and reduced thickness ARHM-GG pavement sections. The results of the study were quite surprising. Laboratory testing by UCB (10) also supported the field test results. The table below shows the results of the HVS testing on the various pavement sections.
The test results show that the conventional AC section failed at 200,000 repetitions. The 38 mm ARHM-GG section showed no cracking at 175,000 repetitions, so the load was increased to 80kN and still no cracking up to 237,000 repetitions. The temperature was then lowered to −5 degrees Celsius and only one half the section cracked at 250,000 repetitions. The 25mm ARHM-GG section showed no cracking at 175,000 repetitions, so the load was increased to 80kN and the section finally showed fine cracks at 200,000 repetitions. The section completely cracked at 237,000 repetitions. These test results show that 25mm of ARHM-GG outperformed the 75 mm section of conventional AC in regards to fatigue. This is a 3:1 reduction in thickness. This not only validates the reduced thickness design being used by Caltrans, but it indicates that it may be conservative.

**Advantages of Asphalt Rubber Binder in Pavement Strategies**

Asphalt rubber binder can provide significant advantages over conventional asphalt (11) and even polymer modified asphalt binders. These advantages include:
- Can use large size crumb rubber (2.0 mm)
- Can use a high percentage of crumb rubber (20 +/- 2 %)
- Adds anti-oxidants to the binder
- Significantly increases viscosity and visco-elastic properties of the binder
- Allows for significantly higher binder contents
- Provides thicker film thickness on aggregates
- Reduced aging of the binder
- Increased softening point of the binder
- Reduced temperature susceptibility of the binder
- Improved low temperature properties of the binder.

The advantages in binder properties lead to advantages in the field performance of the mixes in which asphalt rubber is used (8,12). These advantages include:
- Improved abrasion resistance, especially in snow regions
Reduced oxidation
Increased durability
Increased fatigue life
Increased resistance to reflective cracking
Increased resistance to rutting
Reduced noise
Can reduce pavement thickness
Reduced construction time
Improved safety during construction
Savings in energy and natural resources
Lower maintenance costs.

Asphalt rubber mixes contain significantly higher binder contents than AC mixes using conventional and polymer modified binders. In open and dense graded mixes the binder contents are about 20% higher, in gap graded mixes the binder contents are about 40-50% higher, and in high binder content open graded mixes the binder content is about 50-60% higher. A typical binder content for an ARHM-GG mix using asphalt rubber is about 7.4% (by total mass). A typical binder content for a high binder content OGFC mix using asphalt rubber is about 9.0% (by total mass). With these high binder contents it is easy to understand why these mixes provide improved field performance.

Cost Analysis: Initial Cost vs Life Cycle Cost

The cost per tonne of asphalt rubber binder is more than twice that of conventional asphalt cement and can be slightly more per tonne than that for polymer modified asphalt. This initial higher cost is a result of the need to blend the binder at the project site prior to use. Asphalt rubber cannot be terminal blended because of the size and amount of crumb rubber required in the binder. Some suppliers are marketing products that contain a finer grind crumb rubber and a smaller percentage of crumb rubber by total mass. These binders are not “asphalt rubber”, but they are being marketed as equivalent binders. They do not have a long proven performance history like asphalt rubber.

Based on the initial cost asphalt rubber mixes can cost 30-80% more per tonne of hot mix when compared to conventional mixes. However, when the asphalt rubber mixes are reduced in thickness as compared to the conventional design thickness, the overall cost of the project is usually less. When the life cycle costs of the asphalt rubber mixes are compared to those of conventional AC mixes a significant savings is realized. Asphalt rubber is the only modified binder in which the cost-effectiveness has been validated by actual field performance (4).

Multi-layer systems using asphalt rubber strategies can provide significant cost savings when compared to conventional AC pavement strategies. This is especially true when reconstruction is the recommended strategy for the conventional design. In California many cities and counties have realized savings of hundreds of thousands of dollars on a single project. One example is a project in Hemet, CA, where reconstruction was the recommended strategy on the project. The following shows the cost estimate for the alternatives recommended by the design engineer for the project, which was based on pavement deflections:
The City of Hemet chose the asphalt rubber alternative and realized a savings on this single project of $124,000 when compared to Alternate 1 and $382,000 when compared to Alternate 2. However, on this project the city could not choose Alternate 1 because there was curb and gutter on the project and the thick overlay would have caused grade problems. So, the actual savings to the city was $382,000. These are substantial savings and the city used the extra money to rehabilitate additional streets. Hemet is a very small city and the reason for choosing this example is that a savings of this magnitude is especially important to a small city with a small budget.

This is only one example, but there are many agencies that have realized savings of 1/2 to 2/3 the cost of reconstruction. Many times thick AC overlays cannot be used because of grade control, so the designer has to choose full reconstruction as the required alternative. These types of savings are real and many cities and counties are using thin asphalt rubber strategies to stretch their road budgets.

**Asphalt Rubber vs Crumb Rubber Terminal Blend and Dry Process**

Asphalt rubber has a long and successful history. This has been pointed out in this paper a number of times. The cost of the binder has always been an issue. In the early years asphalt rubber was a patented process and was also very expensive. Since the patents expired in the late 1980’s the cost has dropped dramatically. This has helped the material gain wider acceptance. However, there are many agencies today that still only look at initial cost. The old saying “You can pay me now or pay me later at a higher cost” is especially true when considering asphalt rubber mixes. Many times agencies find that the lower initial cost is not always the best choice. Mixes containing terminal blend crumb rubber modified binder usually have lower initial costs. There are two reasons for the lower initial cost. The first is that they are blended at the refinery at a lower cost and second they require significantly less binder in the hot mix. The lower binder content is a disadvantage with these binders. These binders do not have a proven long-term performance history and have not been validated to perform at reduced thickness, as has asphalt rubber. On one example project the binder content for the ARHM-GG mix using asphalt rubber was 7.7 % (by total mass). On the same project the same mix (aggregate and aggregate grading) using terminal blend crumb rubber modified binder was 6.1 % (by total mass). This is a reduction in binder content of 1.6 %, yet some suppliers marketing these products claim that these binders can provide equal performance. Most research does not support this claim; in fact the research indicates that these binders provide lower fatigue resistance when used in the same type of aggregate grading (3). It is difficult to understand why some agencies believe that mixes containing significantly less binder can provide the same performance. Agencies are accepting significant risks when using these binders as an alternative to asphalt rubber at reduced thickness.
The crumb rubber dry process has been used by many agencies across the United States (13). Suppliers have marketed it as an alternative to the wet process asphalt rubber. However, the performance history of the dry process has been the same in almost all cases. The performance has been inconsistent at best and poor for most agencies. This process has been tried again and again by different agencies since the late 1970’s mainly because of lower cost when compared to the wet process. Today it is an accepted fact that crumb rubber cannot be successfully added dry to asphalt concrete and consistently achieve long-term performance. There are two main reasons for the inconsistent and poor performance. First it is very difficult to achieve uniform distribution of the crumb rubber throughout the mix when adding it dry as a filler. The resulting distress has been early cracking, raveling or most frequently the development of potholes. Second there is not enough time for a reaction or interaction to take place between the asphalt cement and the crumb rubber. When there is no significant reaction between the crumb rubber and the asphalt cement there is no significant modification of the resulting binder. This has also contributed to the early distress with the dry process. These observations led to the elimination of the process in the life cycle cost analysis mentioned earlier (4).

Specifications: Recipe vs Performance Related (End Result)

Asphalt rubber has always been specified using a recipe approach. This has resulted in proven long-term performance. Some agencies are beginning to use the new Strategic Highway Research Program (SHRP) performance grade (PG) specification as an added requirement for the asphalt cement used in asphalt rubber. This approach utilizes the dynamic shear rheometer (DSR) for some of the required properties of the asphalt cement. However, these agencies are also continuing to use the recipe specification for the binder. This approach basically sets certain materials and production requirements for the binder supplier, but also requires the final product to meet certain climatic requirements. This allows the supplier to choose the materials that are necessary to meet the final product requirements. However, it also guarantees that the binder has a certain percentage and type of crumb rubber.

In California Caltrans is working on an end result or performance based asphalt rubber binder specification. It is referred to as the rubber modified binder (RMB) specification. It uses the DSR as the test device for acceptance of the binder. It also uses a modified SHRP testing protocol for the DSR, which has never been used previously for binder acceptance (cup and plate). There have been major problems pointed out with this new approach (14). The main problem with the new RMB specification is that the end result requirements do not always correlate with field performance. In fact, one of the best performing asphalt rubber binders in California is consistently rejected by this new specification even though it has been used successfully on over 400 projects. This contradicts the end result performance basis of the new specification. Another major drawback of the specification is that it does not require any specific amount or type of crumb rubber. This allows new unproven binders to be accepted, which are not asphalt rubber. These binders are polymer modified and utilize a finer grading and a smaller amount of crumb rubber. This creates a risk to the agency when using the binder on reduced thickness projects. These binders have not been validated as an equal to asphalt rubber especially when these unproven binders are used in reduced thickness. Based on the work to date it is evident that more research is needed to validate this new approach. However, work is continuing on the development of a performance based specification for asphalt rubber.
Why Should an Agency Choose Asphalt Rubber Strategies

There are many reasons why an agency should choose asphalt rubber for use in their pavement maintenance and rehabilitation strategies. This paper has pointed out the advantages of using asphalt rubber. It has been used successfully in hot mix and in chip seals and in multi-layer systems. The following provides a summary of the reasons why an agency should choose asphalt rubber strategies:

- Has a long term successful field performance history (over 30 years)
- Over 750 successful reduced thickness projects
- Allows for higher binder contents
- Greater film thickness leads to improved durability and longer life
- Can be used in reduced thickness
- Easy to use reduced thickness design guide
- Reduced construction time leads to increased safety
- Proven alternative to costly reconstruction
- Reduced maintenance costs
- Saves energy and natural resources
- Established life cycle cost-effectiveness.

It has determined that asphalt rubber rehabilitation and maintenance strategies are more cost-effective when compared to conventional asphalt strategies. This has led to more wide spread usage of asphalt rubber rehabilitation and maintenance strategies in California and other states in the USA.

References


