Use, Availability, and Cost-Effectiveness of Asphalt Rubber in Texas

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A study was conducted for the Texas Department of Transportation (DOT) by the Texas Transportation Institute (TTI) to address the following issues: (a) the current extent of use of asphalt rubber by the department, (b) the availability of crumb rubber produced from scrap tires and the availability of asphalt rubber in the state of Texas, and (c) the cost-effectiveness of asphalt rubber compared with conventional paving materials on the basis of existing information and the experience of department personnel. Published information was reviewed, phone interviews with knowledgeable department personnel were conducted, and existing laboratory information was evaluated. The Texas DOT currently uses asphalt rubber in four different applications. Listed in order of their volume of asphalt rubber consumption, these are (a) chip seal or stress-absorbing membrane (SAM) construction, (b) stress-absorbing membrane interlayer (SAMI) construction (c) crack or joint sealing, and (d) hot-mixed asphalt concrete pavement construction (on a very limited experimental basis). These applications of asphalt rubber are described in detail in the body of this paper. Results of this study indicated that the major obstacle for widespread use of asphalt rubber in Texas is its high cost.

Texas Senate Bill 1516 became effective in September 1989 and gave the following mandate (among others) to the Texas DOT:

> (1) If the State Department of Highways and Public Transportation uses rubberized asphalt paving, the Department shall use scrap tires converted to rubberized asphalt paving by a facility in this state if that paving material is available.
> (2) In comparing bids submitted for road construction that require paving, the Department may give a preference to bids, the paving materials portion of which includes the use of rubberized asphalt paving made from scrap tires by a facility in this state if the cost of those materials does not exceed by more than 15 percent the bid cost of alternative paving materials for the same job.

In order to make rational decisions about materials selection based on comparative cost-effectiveness, the department initiated the study described herein (*1*). The objective of this study is to provide the following information to the department: (a) the cost-effectiveness of asphalt rubber compared with more conventional paving materials based on existing information and on the experience of department personnel, (b) the availability of asphalt rubber in Texas, and (c) the current extent of usage of asphalt rubber in Texas.

To meet these objectives, an extensive review of pertinent literature was performed, phone interviews of cognizant department personnel in each district were conducted and other individuals were contacted. Applications of asphalt rubber in chip seals, sometimes called stress-absorbing membranes (SAM), stress-absorbing membrane interlayers (SAMI), crack fillers, and hot-mixed asphalt concrete were addressed. For this study, asphalt rubber is defined as a blend of 17 to 26 percent ground tire rubber by total weight of the blend. The blend is typically formulated at elevated temperatures to promote chemical and physical interaction of the two constituents. Various petroleum distillates are sometimes added to the blend to reduce viscosity and enhance workability.

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AVAILABILITY AND USE OF ASPHALT RUBBER

Governmental agencies including state highway departments and municipal street divisions are under public pressure to use waste materials to the greatest extent possible. Without question, this is the direction in which our society must move. Using waste materials and by-products is logical, sensible, and many times cost-effective. Incentives are sometimes offered by federal and state legislative bodies to promote the use of waste products.

Waste Tire Availability

According to industry figures, there are as many as 2 billion scrap tires currently on the ground in the United States, with approximately 240 million tires being discarded in the United States each year (*2*). Of these, 200,000,000 are passenger car tires and 40,000,000 are truck tires (*3*).

It is estimated that Texas is accumulating scrap tires at a rate of 18 million annually and that there are approximately 150 million located at various storage sites around the state. These figures are based on the number of passenger cars and commercial vehicles registered in the state and an average tire life of 4 years.

A typical worn-out passenger car tire weighs approximately 20 lb and will provide about 60 percent rubber, 20 percent steel, and 20 percent fiber and other reusable products. On the basis of these estimates, Texas drivers are generating each year the following potentially reusable materials: 108,000 tons of rubber, 36,000 tons of steel, and 36,000 tons of fiber. These estimates are conservative because they were computed using an average weight for passenger car tires, and truck tires are much heavier.

Asphalt Usage

Approximately 32 million tons of asphalt were produced in the United States in 1987. Of this, about 27 million tons were used for paving, 4 million tons for roofing, and fewer than 1 million tons for other purposes. At $100/ton (a reasonable average cost), this translates into $2.7 billion worth of asphalt cement per year for paving purposes. Approximately 90 percent of this was used in hot-mixed asphalt concrete (HMAC) and the other 10 percent was used for chip seals and surface treatments. The approximate quantity of HMAC produced in the U.S. was 500 million tons. At an average cost of $30/ton, it is estimated that more than $15 billion dollars were spent on HMAC during 1987. Although these values have varied somewhat, they are reasonably typical of the last 18 years.

In Texas, about 20 million tons (or $0.6 billion worth) of HMAC was produced in 1989 according to the Texas Hot-Mix Association. Just under half of this was purchased by the Texas Department of Transportation (DOT). The remaining went to municipalities, airport authorities, and private buyers.

In fiscal year 1988, the Texas DOT used 1,100,000 tons of asphalt cement, 200,000 tons of emulsified asphalt, and 110,000 tons of cutback asphalt—a total of 1.4 million tons of asphalt products. These figures were obtained from the Materials and Tests Division (D-9) of the Texas DOT.

Potential Tire Use in Asphalt Rubber

If 10 percent of the paving asphalt cement used annually by the State DOT were routinely replaced with asphalt rubber (using Texas tires), this would result in partial recycling of more than one-fifth of all the scrap tires accumulated annually in the state. Recall that only 60 percent of a tire is used in producing asphalt rubber. Therefore, the remaining 40 percent must be either disposed of or used in some other recycling process.

On the basis of information from asphalt rubber suppliers in Texas, it is estimated that the Texas DOT is currently using 12,000 to 14,000 tons of asphalt rubber/year in paving operations. Another 1,200 tons are used as asphalt-rubber crack sealant. Assuming that 20 percent tire rubber was used in the modified binder and that 12 lb of rubber/tire (60 percent of 20 lb) were used, this quantity of asphalt rubber would account for approximately 430,000 scrap tires. However, it should be pointed out that at the time of this study, more than 85 percent of these tires were coming from out of state. Most of the crumb rubber comes from suppliers in California, Indiana, and Ohio.

According to asphalt-rubber suppliers and tire-rubber suppliers to the asphalt-rubber industry, a continuous supply of 1 to 3 million tires annually and about $1 million in capital will be required to open and maintain operations of a profitable facility for grinding tire rubber for use in asphalt. There is one producer of ground tire rubber at this time in Texas and several reports of others going into this business. It is anticipated that there will soon be an adequate supply of crumb rubber produced in Texas to handle the current asphalt-rubber market.

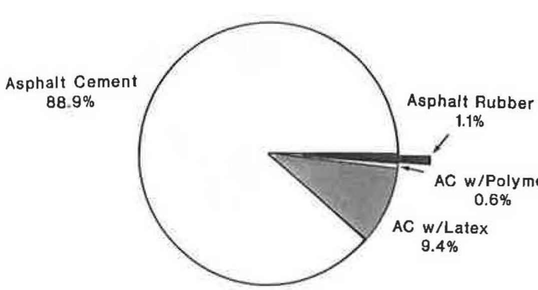

FIGURE 1 Current unmodified asphalt binder use compared with modified binder use.

Use of Asphalt Rubber in Texas

All of the 24 highway districts in Texas have experimented with asphalt rubber as a paving material. As stated previously, the Texas DOT currently uses 12,000 to 14,000 tons of asphalt rubber in paving operations annually. Another 1,200 tons are used as asphalt-rubber crack sealants. The amount of asphalt rubber used as a paving material is compared with other modified binders in Figure 1.

ASPHALT-RUBBER CHIP SEALS (SAMs)

Research on SAMs in Texas

Texas Transportation Institute

A research study (*3*) was conducted by Texas Transportation Institute in 1982 for the Texas DOT on asphalt-rubber membranes. An evaluation of performance was made for 45 separate projects in 13 highway districts. Approximately 850 lane miles of highways were represented by materials constructed as asphalt-rubber chip seals or SAMs. All projects reviewed were constructed between 1976 and 1981. Data on 148 conventional chip seal projects throughout Texas were reviewed and a comparison of performance was made. Some of the more significant conclusions are listed below.

1. Flushing distress occurs more often with asphalt-rubber chip seals than with conventional seals at a ratio of 99 percent of all asphalt-rubber projects and 74 percent of conventional projects.
2. Shrinkage cracking appears in both asphalt-rubber and conventional seals at approximately the same level, occurring in about 50 percent of all projects.
3. With all other environmental factors being equal, alligator cracking appears in conventional seals at approximately twice the frequency it does in asphalt-rubber chip seals.
4. Shelling of the cover stone appears in approximately 44 percent of the conventional seals compared with 17 percent of the asphalt-rubber seals.
5. The improved resistance to alligator cracking and raveling by asphalt-rubber chip seals and poorer flushing performance is not surprising because the typical normal application rate for asphalt rubber is significantly higher than that for conventional chip seals.

6. The present performance of asphalt rubber suggests that improved design methods for these new systems may alleviate the problems described here.

Much of the early research shows that asphalt-rubber chip seals typically exhibit more distress than the conventional asphalt chip seals; however, this distress is attributed to construction practices rather than to the asphalt-rubber material itself. The primary type of distress in asphalt-rubber chip seals is flushing, which is caused by inappropriate quantities of binder and aggregate. It should be noted, however, that flushing on an asphalt-rubber chip seal is not as critical as it is on a conventional asphalt chip seal. Experienced department personnel report that although an asphalt-rubber chip seal can be flushed on the surface, it will still have adequate skid resistance to remain serviceable for a number of years, which is not true for conventional asphalt chip seals. This may be because the rubber particle provides increased skid resistance or the asphalt-rubber binder is much stiffer than an asphalt cement.

District 24: El Paso

District 24 has applied a total of 606 lane miles of asphalt-rubber SAMIs and 1,751 lane miles of asphalt-rubber chip seals or SAMs. The typical practice of District 24 is to use asphalt rubber on their three main highways: I-10, U.S. 90, and U.S. 62/180 from El Paso east to New Mexico. Because of the costs associated with asphalt rubber, it is considered cost-effective only when used on the higher traffic-volume roadways, but "Yes, it is cost-effective," states the district operations engineer. It is reported as lasting twice as long as a conventional seal. In El Paso, a conventional chip seal is reported to last for 7 yr and an asphalt-rubber chip seal is reported to last for 14 yr.

Conclusions about the use of asphalt rubber in SAMs after a number of years of experience in District 24 are as follows:

1. An excellent material for use in a dry, hot area. Some have reservations about use in other climates.
2. Should use only precoated aggregate. Best results will be obtained using ⅜-in. maximum size.
3. Restrict "asphalt (construction) season" to hottest months of the year (e.g., June, July and August).
4. Permits seal application on high traffic volume roads.
5. Most things applicable to conventional seal coats apply to this material—this is a very "forgiving" material.
6. General appearance of asphalt-rubber seal is best after about 3 yr.
7. "This is a significant advancement in asphalt technology."

Texas Highway District Survey

As a part of this study, a telephone survey of all the districts in Texas was conducted. Texas is divided into 24 highway districts, and personnel in each district were queried about their experiences with asphalt rubber.

Although there are a significant number of asphalt-rubber projects in Texas, many of these were built on an experimental basis and the use of asphalt rubber in most districts is not standard practice. These districts are shown shaded in Figure 2. The primary reason cited by most districts for not using asphalt rubber is that it is too expensive. Some of these districts, which have used asphalt rubber in the past but have no future plans, report that there were some performance benefits associated with the material, but the benefits do not offset the additional cost. District 21 tried an asphalt-rubber chip seal 5 yr ago but believes a conventional AC chip seal is just as good.

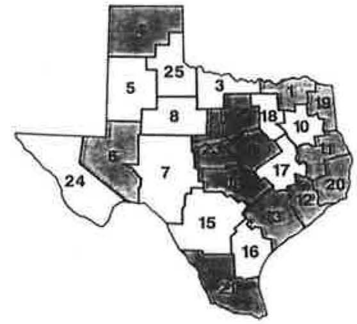

FIGURE 2 Districts with no interest in using asphalt-rubber chip seals in near future.

During the earlier years of asphalt-rubber technology, many of the performance problems that emerged were caused by poor design and construction techniques. Now, asphalt-rubber technology is more advanced and improved. The five districts that are beginning to give asphalt-rubber chip seals another try and those that use asphalt-rubber chip seals on a somewhat regular basis are shown shaded in Figure 3. District 17 uses asphalt rubber regularly. The managing resident engineer in Brenham states: "When the pavement is badly cracked but appears structurally sound, asphalt rubber is the answer." He further stated that he uses asphalt rubber as often as his budget will allow.

Cost-Effectiveness

To determine the cost-effectiveness of an asphalt-rubber chip seal, the life of that seal must be known. There are many variables that affect the life of any pavement surface: environment, traffic, quality of construction and materials, condition of pavement before surfacing, design, and substrate.

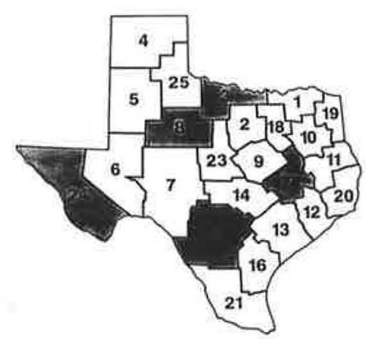

FIGURE 3 Districts currently using asphalt-rubber chip seals.

Even with construction techniques that are backed by many years of experience, such as conventional chip seals, it is difficult to estimate the serviceable life for a given roadway class and condition. For asphalt-rubber chip seals, this task is even more difficult. From Arizona (*4*) comes the report that the life of an asphalt-rubber chip seal is 5 yr on the Interstate, 8 yr on U.S. routes, and 10 yr on state routes. District personnel in El Paso report that, on U.S. highways, the life of an asphalt-rubber chip seal is 14 yr, and a conventional chip seal lasts 7 yr. It must be kept in mind that the climate in both El Paso and Arizona is very arid. In an area of low rainfall, a badly cracked pavement may remain structurally sound longer than it would in a wet region. If a pavement is structurally sound before placement of an asphalt-rubber chip seal, or any type of chip seal, that seal is likely to have a relatively long life.

Because of the many factors influencing the life of any pavement surface, it is difficult to assess the cost-effectiveness of asphalt rubber. Although reports of experience with asphalt rubber in some locations are quite good (*4*), research results from across the United States (*3,5*) do not indicate that there are significant improvements in performance with asphalt-rubber seals over that of conventional seals. However, it must also be kept in mind that much of the research involving asphalt rubber was done at a time when the technology was still in an experimental stage. Many reports of negative performance were related to improper construction and design practices rather than to the material itself. With the present state of the art on asphalt rubber, it is not possible to accurately estimate the life of asphalt-rubber seals under specific climates, traffic conditions, and underlying pavement conditions. For the purposes of this study, an annualized cost evaluation was performed for a range of service lives of an asphalt-rubber chip seal, a conventional chip seal, and a thin overlay. To determine the costs of conventional chip seals and asphalt-rubber chip seals, actual construction bids from 1989 were reviewed. All compared bids were for jobs of more than 2,000,000 yd^2. The following are unit costs for the different pavement surfaces used to calculate annualized costs for different pavement lives:

Conventional AC chip seal,	\$0.47/yd^2.
Asphalt-rubber chip seal,	\$1.14/yd^2.
Thin overlay, 1-in.	\$1.60/yd^2.

The cost of the overlay is based on an in-place cost of \$30/ton of HMAC. The formula for equivalent uniform annual cost used in this analysis is

$$A = \frac{P[i * (1 + i)^n]}{[(1 + i)^n - 1]}$$

where

A = equivalent uniform annual cost
P = initial construction cost
i = interest rate
n = pavement life in years

It must be kept in mind that the annualized cost is based on initial construction cost only with an effective interest rate of 4 percent (interest rate with inflation accounted for). It does not include any user costs or expected maintenance costs.

When comparing a conventional AC chip seal with an asphalt-rubber chip seal, on the basis of this analysis, an asphalt-rubber chip seal would have to last three times longer than a conventional seal to have the same annual cost. Although this may be possible, there is little information to document these service life extensions in the field. As stated earlier, El Paso reports that the asphalt-rubber chip seal lasts twice as long as the conventional seal. Arizona reports a maximum life of 10 years on a state route. It is commonly reported that a conventional chip seal will last about 7 yr in Texas. The asphalt-rubber seal would have to last 21 yr to have an equivalent cost. This seems unlikely. Asphalt rubber is usually only placed on high-volume roads where a conventional chip seal might have a much shorter life of 3 to 4 yr.

Originally, it was intended to compare asphalt-rubber chip seals with polymer-modified chip seals. Most of the districts in Texas, at the present time, use a polymer-modified AC or polymer-modified emulsion for standard chip-seal construction. The addition of a polymer into the binder does not significantly increase the bid price of the chip seal for relatively large jobs. In fact, many bids show an equivalent cost/yard^2 of chip seal. Although there is no doubt that the addition of a polymer into asphalt increases the cost of the binder, this is not evident in the overall cost of the chip seal examined in this study, as shown in Figure 4. There are several factors that enter into the cost of the chip seal: size and location of job, aggregate, traffic control, and mobilization. For the jobs examined herein, the polymer-modified chip seals were not really any more expensive than the conventional AC chip seal. Although those districts that use polymer-modified binders report that there are benefits associated with the material, none are able to identify whether or not there is an increase in the service life. Therefore, the polymer-modified chip seals were not included in the cost analysis because they appear to be similar in cost to a conventional chip seal (on a yard^2 basis), as shown in Figure 4. Furthermore, no information is available about the life of polymer-modified chip seals.

It should be pointed out that an asphalt-rubber chip seal contains more binder than a conventional chip seal. The conventional chip seal used in this analysis contains 0.35 gal of AC/yard^2, whereas the asphalt-rubber chip seal contains 0.55 gal/yard^2. Because of this difference, comparisons with conventional chip seals are not completely valid. Engineers in the department who have experience with asphalt rubber often report that they do not use this material in a location at which a conventional chip seal is a viable option. An asphalt-rubber chip seal is typically used as a rehabilitative measure rather than a preventive measure when a pavement is badly cracked. Therefore, a bigger burden is often placed on an asphalt-rubber chip seal than on a conventional chip seal. Jacobson and Schnormeier (*6*) of the Asphalt Rubber Producer's Group report that asphalt rubber applications have been most successful when the pavement lost 80 to 90 percent of its quality and funds were not available to reconstruct.

Perhaps a more valid performance comparison for an asphalt-rubber chip seal would be with a thin overlay. If an asphalt-rubber chip seal lasted 9 yr, a thin overlay (1-in. thick) would need to last 14 yr to have an equivalent annual cost.

Jacobson and Schnormeier (*6*) stated, "Cost comparisons (of SAMs) are usually based on the direct cost of asphalt rubber versus conventional asphalt. This is O.K. if one is

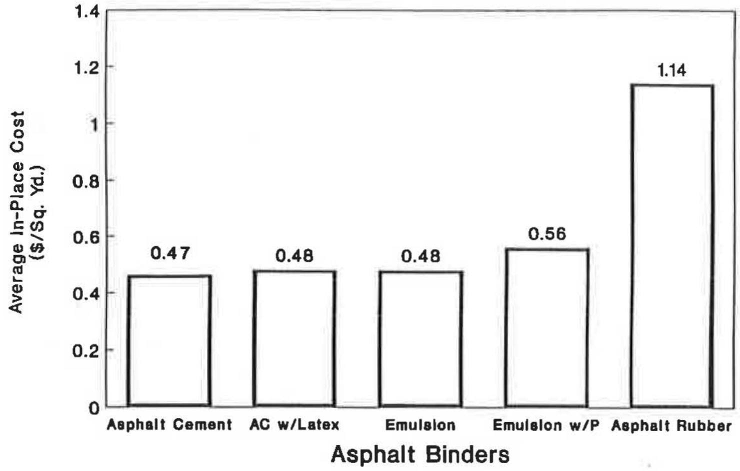

FIGURE 4 Typical in-place costs for chip seals constructed with different binders in 1989.

concerned only with initial cost. It becomes very important that all costs be included today and tomorrow. Initial asphalt-rubber costs are twice as much as a conventional asphalt. This is a disadvantage because the money made available must be used to cover as much as the public can and will accept." Jacobson and Schnormeier conclude, however, that asphalt rubber is cost-effective because less maintenance is required of asphalt-rubber chip seals than of conventional asphalt chip seals.

ASPHALT-RUBBER INTERLAYERS (SAMIs)

SAMI Research in Texas

Texas Transportation Institute

The Texas DOT is sponsoring an ongoing research study with the Texas Transportation Institute (7) to evaluate the performance of asphalt-rubber interlayers. Three full-scale test roads were constructed in 1983 and 1984 near El Paso, Brownsville, and Buffalo, Texas. The Buffalo test road has an overlay thickness of between 4 and 6 in. and is not showing any distress. The Brownsville test road was constructed with excessive interlayer binder application rates and all sections are flushing. However, the El Paso test road has yielded some useful information. Nine different types of asphalt-rubber interlayers were constructed there using different binder application rates, different rubber concentrations, and different ground tire rubber suppliers. The control section contained no interlayer. All of the asphalt-rubber sections are performing better than the control in terms of delaying reflective cracking, with some sections performing significantly better.

District 24: El Paso

District 24 currently has six asphalt-rubber interlayers under observation. These range in age from 1 to 12 yr. Overlay thickness is from 1-1/2 to 3 in. The average binder application rate was 0.55 gal/yard^2. Traffic exceeds 100,000 average daily traffic (ADT) on some of these pavements. El Paso reports that major cracks in the old pavement were sealed with asphalt rubber before application of the SAMIs. Cracks reflected through SAMIs by the second winter, but these were only "hairline" cracks and they tended to heal the following summer. All pavements are still in good to excellent condition. A representative of District 24 stated: "This material provides the best life-cycle cost we have found for rehabilitation of cracked, weathered asphalt surfaces needing minor leveling provided by thin HMAC overlays."

Survey of Texas Highway Districts

Personnel in each highway district were contacted to determine their experiences with asphalt rubber applied as interlayers. The six districts that have constructed asphalt-rubber interlayers are identified in Figure 5. The opinions of department personnel on asphalt rubber used as an interlayer are much more favorable than they are for asphalt rubber used as chip seals. Although the cost of an asphalt-rubber interlayer is still at least twice that of a conventional chip seal interlayer, it is only a small portion of the total overlay system cost. Most of the districts that have used asphalt rubber as

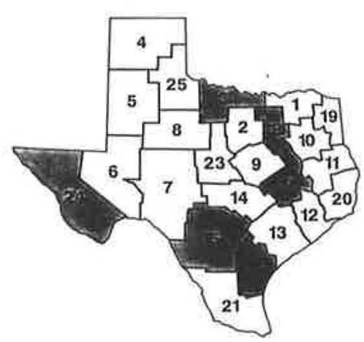

FIGURE 5 Districts currently using asphalt-rubber interlayers.

an interlayer report that it definitely reduces the rate of reflection cracking.

Evidence has been seen of cracks in asphalt-rubber chip seals healing in the summer months. Although this phenomenon can be observed in an asphalt-rubber chip seal, it cannot be viewed in an asphalt-rubber interlayer because it is covered by an overlay. However, if this healing ability exists in an asphalt-rubber interlayer, then the interlayer may function as a waterproofing membrane. Once cracks do develop in the surface layer, the asphalt rubber may prevent, or at least reduce, any water intrusion into the underlying pavement structure.

Cost-Effectiveness

Based on the literature review, research conducted by TTI, and the experience of department personnel, an asphalt-rubber interlayer can produce an improvement in pavement performance. Although it is generally believed that an asphalt-rubber interlayer extends pavement life, it is not accurately known how long. Because the interlayer is not visible on the surface, its effects are difficult to measure. A common method of evaluation is to measure reflective cracking in the surface of the overlay. However, there may be other improvements in pavement performance that are not commonly measured by highway departments, such as roughness. If there are any benefits from "waterproofing" of the underlying structure, this is difficult to measure.

A similar cost analysis as shown in the previous chapter was performed for SAMIs. An annualized cost was determined for a 2-in. overlay and compared with the annualized cost for an asphalt-rubber SAMI with a 2-in. overlay. As in the previous cost analysis, this is based on initial construction cost only and does not include any user or maintenance costs. The following initial construction costs were used for the analysis:

2-in. overlay	$3.20/yd^2.
2-in. overlay with SAMI	$4.25/yd^2.

On the basis of this analysis, a 2-in. overlay with an asphalt-rubber SAMI would need to last approximately 50 percent longer than a 2-in. overlay alone to yield an equivalent annual cost. For example, if a 2-in. overlay lasted 8 yr, a 2-in. overlay with SAMI would need to last 12 yr to be equivalent in cost.

ASPHALT-RUBBER CRACK SEALANTS

One of the most troublesome problems the highway department faces in its effort to provide quality long-lasting pavements is the presence of pavement cracks. In the past, maintenance forces have used many materials as sealants in attempts to seal cracks and effectively extend pavement life. These materials include asphalt cements, cutbacks, emulsions, and latex-modified emulsions. However, during the 1970s and early 1980s, an asphalt-rubber sealing compound containing ground tire rubber emerged as a new and comparatively effective means of crack repair. The compound is composed of approximately 80 percent asphalt and 20 percent ground tire rubber.

At the current time, more than 95 percent of all asphalt-rubber crack sealant that is used in Texas is supplied from Crafco, Inc., in Chandler, Arizona. Crafco has done extensive research in asphalt-rubber formulation, production, and application and has helped the state of Texas in its specification guidelines for asphalt rubber crack sealant. In 1989, Crafco supplied almost 3.5 million lb of material to Texas at an average price of 19 cents/lb, translating to a yearly total of $495,041. This material was used to fill approximately 14 million linear ft of crack and joints. The price has varied slightly during the past several years, with costs ranging from 12 to 15 cents/lb. The department is currently modifying its specifications to accept a slightly wider variety of products that would allow other suppliers to enter the market.

Survey of Texas Highway Districts

On the basis of a telephone survey of district personnel in Texas, Crafco asphalt-rubber sealant is the product of choice. Many of the districts have used other products in the past, and on jobs with very small cracks a polymer emulsion product has proven to be more effective; however, according to one DOT engineer, asphalt rubber continues to "last longer and provide less problems" than other types of sealants.

In talking to each of the districts with crack sealing programs, it was readily apparent that they were pleased with the product. Typical comments were that the rubber is very stable; vehicle tires do not displace it; the rubber provides good elasticity and strength; and it does not seem to weather or oxidize at all.

Almost all of the districts agreed on the material's properties and all independently estimated the typical life of the product to be 3 yr.

Cost-Effectiveness

To be consistent with the rest of this paper it would be beneficial to include a cost-effectiveness comparison with other similar products. However, the extensive use of the asphalt rubber throughout the districts makes this type of comparison difficult. Projects are sometimes encountered that require other special sealants; however, these projects are usually very small and a true performance comparison cannot be established.

RUBBER-MODIFIED ASPHALT CONCRETE MIXTURES

Field Experience in Texas

The 1989 hot-mix asphalt concrete usage within the state of Texas is approximately 8.1 million tons, which is down slightly from the 5-yr average of 9.4 million tons. These high values indicate excellent opportunities for use of asphalt rubber. However, at this time, only two districts in Texas have tried the product. Ten years ago, District 21 experimented with the rubber-modified hot mix but the job was unsuccessful. District maintenance forces applied the hot mix along a 1-mi section on S.H.336 in McAllen. The mix raveled severely and the district was forced to place a chip seal over the mix within 3 months.

In 1989, the Tyler district (District 10) placed a dense-graded, asphalt-rubber hot-mix overlay. The project was located at the intersection of FM 14 and Loop 323 just outside Tyler. Asphalt rubber was chosen for the site in hopes of curing a severe rutting problem caused by large trucks turning onto and off the loop. So far, district personnel are pleased with the project and are interested in using the product again but on a more standard hot-mix job. The cost of the asphalt rubber for this job was approximately \$80/ton. Tyler's district personnel believe that a larger job would help reduce this high material cost.

District 4 in Amarillo constructed 10 lane mi of dense-graded, asphalt-rubber hot mix in the fall of 1990. Bid prices showed an in-place cost of \$52/ton for the asphalt-rubber paving material, which is substantially less than the \$80/ton reported in Tyler but not particularly attractive when compared with the \$30 to \$35/ton most districts were paying for conventional hot-mixed asphalt concrete.

CONCLUSIONS AND RECOMMENDATIONS

Availability and Use

Approximately 150 million scrap tires are currently stored in Texas and another 18 million are being discarded in the state each year. The scrap tires accumulated annually could be used to produce 108,000 tons of rubber suitable for use in asphalt-rubber products. The Texas DOT annually uses more than 1,000,000 tons of asphalt cement. If 10 percent of this paving asphalt cement were routinely replaced with asphalt rubber, more than 20 percent of the annual production of waste tires in Texas would be used. At the present, slightly more than 1 percent of this paving asphalt is asphalt rubber.

Only about 60 weight percent of a tire is consumed in producing asphalt rubber. Remaining products include primarily steel, fiber, and additional rubber.

The Texas DOT is currently using about 13,000 tons/yr of asphalt rubber, which accounts for approximately 430,000 scrap tires. However, most of the waste tires used in this material come from other states. The availability of crumb rubber in Texas is a rapidly changing issue. Findings indicate that next year 7,000,000 to 10,000,000 tires may be recycled in plants in Texas.

Asphalt-Rubber Chip Seals

Asphalt-rubber chip seals have been constructed, at least on an experimental basis, in all parts of Texas. However, there are only 5 out of the 24 highway districts currently constructing asphalt-rubber chip seals with some regularity.

Use of asphalt rubber for chip seals in most highway districts in Texas has historically not been standard practice, and 13 districts have no plans for increasing their use in the future. The primary reason cited for this is that asphalt rubber is too expensive and has not proven to be cost-effective in this application.

An asphalt-rubber chip seal costs two to three times more than a conventional chip seal. Proponents of asphalt-rubber chip seals claim they will last twice as long as a conventional chip seal.

There is not enough available information to accurately determine the cost-effectiveness of asphalt-rubber chip seals. However, an annualized cost analysis performed in this study revealed that an asphalt-rubber chip seal would have to last three times longer than a conventional asphalt chip seal to have an equivalent annual cost.

Districts in Texas that are experienced with asphalt-rubber chip seals do not usually construct them on a pavement where a conventional chip seal is a viable option. Asphalt-rubber chip seals are used successfully as a rehabilitative instead of a preventive measure and they are often placed on high-traffic volume roads. Therefore, perhaps a more valid comparison for asphalt-rubber chip seals might be with a thin overlay or multiple chip seal, in which case the asphalt rubber is much more likely to be cost-effective.

Asphalt-Rubber Interlayers (SAMIs)

Only six Texas highway districts have built SAMIs. Opinions of department personnel on asphalt-rubber interlayers are much more favorable than those on asphalt-rubber chip seals. Most of the districts that have installed SAMIs believe they are effective in delaying reflective cracking. Some also believe SAMIs will reduce intrusion of surface water and thus pumping even after cracking occurs in the surface layer.

An asphalt-rubber SAMI may provide cost-effective improvements in performance of hot-mixed asphalt concrete overlays. On the basis of an annualized cost analysis performed in this study, an overlay with an asphalt-rubber interlayer would need to last approximately 50 percent longer than an overlay constructed without an interlayer to be cost-effective.

Asphalt-Rubber Crack Sealants

Asphalt-rubber crack sealant, which contains 20 percent ground tire rubber, is essentially the only crack sealant used by the Texas DOT. The Texas DOT uses approximately 3.5 million lb of crack sealant annually.

Asphalt-rubber crack sealant is considered by all personnel interviewed in highway districts to be the best product available for sealing cracks in asphalt concrete and portland cement concrete pavements.

Asphalt-Rubber Hot Mix

Asphalt rubber has been used on a very limited basis in Texas for construction of HMAC. The use of crumb rubber in HMAC is gradually gaining popularity across the United States; however, the technology is still in a somewhat experimental stage of development.

General Recommendation

The Texas DOT and the Texas Legislature should not "go overboard" in promoting the use of tire rubber in asphalt because the benefit-cost ratios are not sufficiently high for every application. Offering incentives to use tire rubber (which negate fair competition) or mandating the use of tire rubber in asphalt pavements to solve the waste tire problem does not appear to be in the best interest of the tax-paying public. Sound engineering, not politics, should govern the choice of paving materials used in highway construction. A practical solution to the problem will require more research and engineering to provide self-supporting, cost-effective uses for scrap tires. There may be more economically efficient ways to recycle tires in much greater volumes than in asphalt pavements.

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