Fifteen-Year Pavement Condition History of Asphalt-Rubber Membranes in Phoenix, Arizona

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Phoenix began its placement of asphalt rubber in 1967, and since that time has applied more than 600 lane miles (970 km). Based on this experience with asphalt rubber, it is believed that this material provides an economically competitive alternative to conventional asphalt pavement with superior engineering properties, such as a remarkable retention of viscosity, as emphasized in the paper. Reduction of the volume changes in the subgrade due to moisture changes. The reduction of maintenance that results with the use of asphalt rubber is observed in the survey of streets and roads treated 15 years ago. The survey in this paper follows similar papers by the author in 1975, 1979, and 1981, and should provide insight into the type of performance that might be expected from asphalt rubber under various conditions of usage.

In the past 15 years, tremendous advances have been made in the use of asphalt rubber. With the introduction of asphalt rubber in the late 1960s came a new terminology, new equipment, and the challenge of a new product for asphalt producers. Since that time, application equipment has been refined, new compositions have been developed and introduced, specifications for product quality control and construction control have been established and improved, and—perhaps most important—new concepts for the use of asphalt rubber have come into being.

Phoenix has used asphalt rubber in a variety of ways since its introduction—for pavement seal coats, stress absorbing membranes (SAM), stress absorbing membrane interlayers (SAMI), subgrade seals, lake liners, joint and crack fillers, roofing, and airport runway surface covers. Since 1974 the city has placed approximately 117 mi (188 km) of asphalt rubber on its major streets, which is 15.6 percent of the Phoenix major street system.

In this paper observations are made of asphalt rubber placed between 1969 and 1974 in Phoenix. Similar papers were presented by the author in 1975, 1979, and 1981 (1–3). It is hoped that the author’s numerous experiences in the use of asphalt rubber under a variety of conditions will be helpful in developing future applications of this versatile material.

DEFINITIONS

- Asphalt rubber: Two concepts have been and still are being used: (a) the McDonald Process—hot asphalt cement mixed with 25 percent ground tire rubber to establish a reaction and diluted with kerosene for easy application (beginning in 1968); and (b) the Arizona Refinery Process—hot asphalt cement mixed with 18 to 22 percent ground rubber to establish a reaction and diluted with an oil extender for ease of application (beginning in 1975).

- Asphalt-rubber chip seal: Application of hot asphalt rubber followed by an application of hot precoated 1/4-in. (6.3-mm) nominal, or 3/8-in. (9.5-mm) nominal, aggregate.

- Standard or conventional chip seal: Application of hot asphalt cement (AC-20 or AC-40) followed by an application of hot precoated 1/4- or 3/8-in. nominal aggregate.

- Flush seal: Application of emulsified asphalt mixed 50-50 with water and applied at 0.1 to 0.2 gal/yd$^2$ (0.45 to 0.91 L/m$^2$).

- Specification: A statement of particulars; available on request.

- SAM: The application of hot asphalt-rubber chip seal to a stressed surface.

- SAMI: The application of a hot asphalt-rubber chip seal to a stressed surface followed by an asphaltic concrete overlay.

- Mini SAMI: The application of a hot asphalt-rubber chip seal to a surface followed by the application of a conventional chip seal.

- Texture: The exposure of the aggregate to develop skid resistance.

- Reflective crack: Any crack that has developed in the pavement or subgrade, and has passed through the asphalt-rubber seal.

APPLICATION BACKGROUND AND COMMENTS

The detailed data on the four inspections over the 15-yr period, which covered the work street by street and project by project, are far too voluminous for this paper. However, they are available from the author on request. For brevity, only the application background and comments on the survey are included here.

It should be emphasized that the initial use of asphalt rubber was for severe pavement conditions with high or potentially high maintenance. The pavements were in the last stages of disrepair. Generally, the asphalt rubber was used where reconstruction was indicated, but funds were not available.

In 1972, asphalt rubber was used on new construction for inexpensive residential streets, as discussed in this paper. Also, at this time asphalt rubber was used on new and old asphaltic concrete at Sky Harbor International Airport.

The largest category of treatment in this study is where asphalt-rubber chip seals were placed on existing high maintenance pavements, referred to previously. One of the earliest

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such applications was placed on the I-17 frontage road and exit at Van Buren Street in December 1968. This pavement has held well for 17 years; however, it is now due for reconstruction. The application method is known as SAM. Since 1970, this treatment has been applied to more than 360 lane miles (579 km) in Phoenix, in addition to the main runway at Sky Harbor International Airport.

The principal problem encountered early in the asphalt-rubber construction using a SAM was the chip loss in low or nontraffic areas. This was followed by some initial bleeding, or loss of the asphalt rubber, or both. This problem has been solved by increasing the asphalt-rubber application and by applying a flush coat to the seal in a timely manner. A flush coat is recommended when 3/8-in. chip seals are used.

The main advantage of the asphalt rubber in the early treatments (SAM) has been virtually complete cessation of surface maintenance (this cessation does not include utility cuts). The prime reason for the application of the SAM was the high maintenance. These streets were due for reconstruction. They were in such poor condition that maintenance could not be afforded until reconstruction. Often, cracks had not reflected through the seal for 8 years, and in some cases for as many as 12 years. Reflection of alligator cracking on treated areas is only occasional, and when such cracking does occur, there is no spalling and deterioration into potholes (see Figures 1-4). It should be noted that asphalt-rubber seals will not bridge cracks in excess of approximately 3/4 in. (0.64 cm) in the original pavement. In several cases in the survey, SAM seals were removed for reconstruction. Although reconstruction was needed (as pointed out here) the reconstruction was delayed due to the SAM. In all of the instances, no maintenance was required on the streets until the time of reconstruction.

Where chip loss occurred after placement, for various reasons, the early SAM seals were resealed with the standard asphalt cement chip seal—a process that has been designated as mini SAMI. This process has extended the pavement life, as demonstrated in the survey. A regular SAMI consists of an
asphaltic concrete overlay on an asphalt-rubber seal. One common reason for applying an asphaltic concrete overlay was to improve ride quality. The SAMI has also proven successful in the past 5 years.

A second use of asphalt rubber is in inexpensive residential street design (2). One method involved the placement of an asphalt-rubber seal directly on a primed soil cement. Although this method was effective in stopping soil cement shrinkage crack reflection, the asphalt-rubber seal did not bond well to the soil cement. The design lasted 9 years before reconstruction (refer to Survey on Double Tree Ranch Road, available from the author).

Another residential design was tried in 1972, 1973, and 1974, using 41/2 in. (11.4 cm) of soil cement under 11/2 in. (3.8 cm) of asphaltic concrete followed by a SAM. In early use the pavement developed slippage of the asphaltic concrete on the soil cement. By 1979 the areas of slippage were either removed or healed by use. The major problems, as reported in the survey, are the low tensile strength that exists in 1/2-in. (3.8-cm) asphaltic concrete and the poor bond between the asphalt and the soil cement. Slippage problems proved to be troublesome where a loose layer existed between the soil cement and the asphaltic concrete. These problems were not the result of any faults in the asphalt rubber. This 5-year design has lasted 15 years.

As reported in the 11-year study for this design, “after seven years no reflected cracks have been shown through the asphalt-rubber seal” (2). The 1985 survey indicates that reflective cracks have shown largely in nontraffic areas and that the asphalt rubber did not retard the crack reflection after 8 to 10 years. Some of the residential streets have received resells (mini SAMI), as indicated in the survey, and are in good condition.

At the time of the 11-year study, it was believed that if the asphalt rubber had been placed on the soil cement followed by 2 in. (5.1 cm) of asphaltic concrete, much of the slippage could have been avoided. This has now been tried in the 1985 construction work as a SAMI and will be evaluated.

A third use of asphalt rubber, as reported in the 1975 TRB special report on low-volume roads, is application on an untreated soil (7). In 1970, asphalt rubber was applied to a compacted native soil for a temporary widening of the street (on 55th Avenue). The 1985 survey indicates alligator cracking on the south end. After 15 years of use, and some additions for new development, the pavement is beginning to fail because of the lack of subgrade support. The surface received a chip seal in 1976 (mini SAMI). Sidewalks, driveways, and utility cuts have altered the pavement condition over the years; however, the rubber has molded to the changes and has stood without maintenance for several years. This procedure definitely holds promise for low-volume streets and roads. Reference to the survey and original 1975 report indicates that there is only 1/2 in. (1.3 cm) of asphalt and asphalt rubber with chips on a loam soil (performance index = 18; 80 percent passing No. 200 sieve).

In 1974, the Deer Valley Airport was designed and constructed by the city. The soil condition indicated a swelling material in the subgrade with volume changes of 8 percent occurring with moisture variations. Two designs were used for the two parallel runways; each design was intended to control volume changes by retaining a constant moisture value in the subgrade.

The first design consisted of full-depth asphaltic concrete on native soil. The second design employed an asphalt-rubber membrane between the aggregate base and the subgrade, followed by asphaltic concrete over the aggregate base. Both designs have been checked periodically for moisture conditions in the subgrade. For each design, the moisture has remained 3 to 4 percent below optimum for 11 years, yet the design incorporating asphalt rubber has saved about 10 percent on construction costs for materials. Before these applications, volume changes in the subgrade created high maintenance costs. Since the application of these methods, maintenance has been reduced by 90 percent.

Over the past 15 years of evaluating asphalt rubber, perhaps the most significant and surprising property noted is its ability to seal the pavement surface. In the evaluation study of the main runway of the Sky Harbor International Airport there was an opportunity to observe the aging of asphaltic cement in asphaltic concrete. The project built in 1972—which was observed in the survey in 1972, 1976, 1979, 1981, and 1985—has asphaltic concrete placed on the main runway and the adjacent taxiway. Both asphalt concretes were identical except that the main runway received the asphalt-rubber seal (SAM) with 1/4-in. chips and the taxiway went untreated. This surface was placed in June 1972. Since that time, neither the runway nor the taxiway has had maintenance repairs. The runway has had the rubber tire skid buildup removed 10 times by high-pressure water.

In 1972 the city used an 85-100 penetration asphalt cement on this project with a known absolute viscosity of 1000 ± 200 poises at 140°F (60°C). Since 1972 cores of asphaltic concrete have been periodically extracted from the main runway and the taxiway within 500 ft of one another. The absolute viscosities at 140°F (60°C) of the asphalt cement were measured by using the abson recovery procedure Arizona Method 511 to extract the asphalt. Refer to Table 1 for the viscosity data.

The tests show a viscosity more than 20 times higher in the nonsealed taxiway than in the main runway. This indicates that the asphalt-rubber seal preserved the asphalt cement in the underlying mix in its nearly pristine condition, while the unprotected mix from the untreated area suffered more than 20 times as much hardening and embrittlement from oxidation and weathering. This discovery alone justified the original place-

### TABLE 1 ABSOLUTE VISCOSITIES FOR ASPHALT CEMENT AT SKY HARBOR AIRPORT

<table>
<thead>
<tr>
<th>Year</th>
<th>Absolute Viscosity (poises) at 140°F</th>
<th>No. of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972 (initial)</td>
<td>1 000 ± 200</td>
<td>Not applicable</td>
</tr>
<tr>
<td>1975</td>
<td>1 620</td>
<td>3</td>
</tr>
<tr>
<td>1977</td>
<td>1 700</td>
<td>3</td>
</tr>
<tr>
<td>1981</td>
<td>1 980</td>
<td>1</td>
</tr>
<tr>
<td>1985a</td>
<td>2 000 000+</td>
<td>2</td>
</tr>
<tr>
<td>1985b</td>
<td>2 125</td>
<td>7</td>
</tr>
</tbody>
</table>

Note: For 1975–1985 measurements ASTM D2171–81 was used.

*aOnly top lift used.

*bAverage of all lifts.
ment of the asphalt-rubber seal; moreover, crack reflection was prevented and surface maintenance was eliminated for 13 years.

**VISCOSITY–TIME RELATIONSHIP COMMENTS**

Because of the limited data taken, a conclusive relationship between asphalt viscosity (both rubberized and nonrubberized) and time cannot be determined. The asphalt viscosity graph (Figure 5) shows the apparent trend for the two asphalts based on the averages of five samplings made over the 13-yr study period. The literature indicates that a logarithmic relationship exists between viscosity and time for nonrubberized asphalt (4). The viscosity should approach an upper limit as oxidation progresses and its volatiles are removed. Such a trend is observed in the data before 1985, followed by a large increase in the 1985 viscosity value. In explaining this discrepancy, the number of samples used before 1985 must be considered. Further sampling might fill in a smooth curve to the 1985 value. A second possibility is that some type of sealant was applied around 1974. Although no record of this exists, it could explain the observed behavior if additional data had agreed with those already taken.

Although the hardening of regular asphalt with time is well documented, the hardening, or rather lack thereof, of asphalt-rubber sealed asphalt is the important result of this study. The asphalt-rubber sealed asphalt has shown no appreciable increase in viscosity after 13 years. During the same period, the nonrubberized asphalt has increased in viscosity more than 20-fold. With such well-maintained viscosity, the durability of the surface is no doubt greatly increased. An extended study into how asphalt rubber ages past 13 years should be of interest for two reasons:

- It would indicate whether a significant increase in viscosity does actually occur at a later time, as well as the rate of this increase; and
- It might point to weaknesses in the association between viscosity and surface durability, for example, a low-viscosity rubberized sample at 15 years might be in worse condition than

![Figure 5](image-url)
a 5-yr-old nonrubberized sample with a much higher viscosity. This could give insight into the chemical and physical nature of the hardening process in asphalt.

Of secondary interest is the relationship between viscosity and sample depth. Data are presented in Table 2 for the 1985 test (the only one in which deeper cores were taken and divided). Each lift was approximately 3 in. (7.6 cm) deep. The data in Table 2 agree with the general relationship expected from the literature (4); viscosity decreases as the distance from the surface increases.

### ECONOMICS OF ASPHALT RUBBER

In 1971, 3 miles of conventional chip seals could be placed for every mile of asphalt rubber based on initial cost. Today only 2 miles of conventional chip seals can be placed for every mile of asphalt rubber. Cost comparisons were made in Phoenix, but these may not be applicable in other parts of the world.

Since 1971 the costs of asphalt rubber (SAM) have increased 2 percent annually. The cost of the conventional chip seal coat has increased 3 percent annually. The cost of the primary ingredient other than the aggregate, asphalt cement, has fluctuated over the past 15 years. This fluctuation has caused asphalt-rubber costs to change as well (3).

After installing and observing asphalt-rubber applications for the past 15 years, it is the author’s conclusion that 10 to 12 years of maintenance-free life can be expected from an asphalt-rubber seal. Normal life expectancy using a conventional chip seal is 6 to 8 years with some maintenance. Therefore, by doubling the life and reducing the maintenance, the asphalt-rubber costs will equal the conventional chip costs over a 12-yr period. The survey has indicated pavement life expectancy beyond 12 years by timely applications of standard chip seals or, better, a resealing of the pavement with asphalt rubber.

### CONCLUSIONS

**Asphalt-Rubber over 1½ in. (3.8 cm) of Asphaltic Concrete over 4½ in. (11.4 cm) of Soil Cement**

Where traffic was light, the soil cement shrinkage cracks did reflect through after 8 to 10 years. The unrelated problem of slippage of the asphaltic concrete over the soil cement could probably have been prevented by placing the asphalt rubber as the intervening layer (SAMI). This might also have been more effective in preventing crack reflection, provided that the soil cement cracking was not more than ¼ in. Where cracks have reflected in this construction method there has been no raveling at the crack edges, which has stopped spalling and secondary cracking that lead to potholes.

**Chip Loss**

The most common defect noted early in the survey was a loss of cover aggregate generally in the nontraffic areas such as the center and shoulder portion of the pavement. It is important to use proper applications of asphalt rubber just as it is for conventional asphalt. The application rate should fit the condition. The loss of aggregates can be stopped at the onset by a timely flush coat of approximately 0.1 or 0.2 gal/yr² (0.45 to 0.91 L/m²) of diluted emulsified asphalt. It is critical that a ½ in. (9.5-mm) aggregate be 50 percent embedded via one or all methods available. Some variables that can be used to control embedment are application rate, viscosity, rolling, timing, and flush coat.

**Crack Reflection Caused by Fatigue**

Cracking caused by fatigue-type failure, characterized by alligator pattern cracking followed by pitting in the original pavement, has not generally reflected through the asphalt rubber except in areas in which there is little or no traffic. Asphalt rubber performs optimally with large volumes of traffic. The surface needs to be kneaded to retain its best qualities. The important result here is that maintenance costs attributable to fatigue-type failures have been completely eliminated.

Asphalt rubber cannot bridge wide cracks that move laterally, and cannot prevent their reflection through the asphalt rubber, but it will reduce their width and prevent spalling at the edges (see Figures 3 and 4). When wide cracks exist before the seal coat or the pavement has failed as evidenced by potholes, the pavement should be pre-prepared. Asphalt rubber can be used in filling cracks over ¼ in. and potholes. Slurry seal has been used to fill cracks where it becomes impractical to use asphalt rubber.

**Mini SAMI and Double Application**

The mini SAMI is formed when an asphalt-rubber seal is covered with a conventional chip seal. This type of treatment was applied after 8 to 10 years to the asphalt-rubber seal and was used on a number of the early projects that suffered early chip losses for reasons previously given. It has proven to be an excellent rehabilitative measure.

The most effective treatment on an 8- to 10-year-old asphalt-rubber seal is another asphalt-rubber seal, as indicated in the survey on 52nd Street from Van Buren to McDowell Road. As a method of eliminating intervening surface maintenance costs, this double application has proven to be impressive.

### TABLE 2 VARIATION OF VISCOSITY WITH SAMPLE DEPTH FOR ASPHALT CEMENT AT SKY HARBOR AIRPORT

<table>
<thead>
<tr>
<th>1985 Lifts</th>
<th>Absolute Viscosity (poises) at 140°F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With Rubber</td>
</tr>
<tr>
<td>Top Lift</td>
<td>1411</td>
</tr>
<tr>
<td>Second from top</td>
<td>975</td>
</tr>
<tr>
<td>Third from top</td>
<td>964</td>
</tr>
<tr>
<td>Fourth from top</td>
<td>1184</td>
</tr>
</tbody>
</table>
Effect of Asphalt-Rubber Seal on the Aging Phenomenon

From the evaluation of the two pavement types placed in 1972 on Sky Harbor International Airport, the effects of the asphalt-rubber seal on the aging phenomenon became apparent. The asphalt-rubber layer acted as a sealant, preventing the loss and reaction of the more volatile components of the asphalt. This sealing action preserved the viscosity of the pavement and maintained much of the flexibility of the young surface. The pavement that did not include asphalt rubber has suffered the normal large loss in viscosity over time. With its flexibility intact, the asphalt-rubber treated surface has avoided cracking. On the other hand, the nontreated area has become brittle and cracked.

Asphalt rubber has given the engineer property values that can be shown to be economically advantageous:

1. Stops reflective cracking in paving materials with less than 0.25-in. (0.64-cm) cracks for 8 to 12 years.
2. Stops spalling of asphaltic concrete around potholes and larger cracks.
3. Waterproofs the structure to obtain maximum stability.
4. Preserves the original quality of the asphalt cement and seals the asphaltic concrete into the pavement.
5. Eliminates maintenance because of all of the preceding points.
6. Seals the subgrade to minimize the volume changes that take place because of moisture changes.
7. Serves as a stress-absorbing interlayer to reduce future maintenance.
8. Offers a flexible property to be considered for use on low-volume streets and roads.
9. Is an excellent crack-filling material and joint sealer.

SUMMARY

After 15 years, Phoenix is still using asphalt rubber as SAM and SAMI applications at the rate of 15 to 25 mi (24 to 40 km) per year. The costs over the 15-yr period have been competitive and the product has greatly reduced the maintenance problem. Asphalt rubber must be used with careful consideration of the pavement structural condition, its absorption properties, the size of cracks, and its intended use. Although asphalt rubber absorbs pavement stresses and seals, it does not stop cracking or failures in the existing pavement or subgrade. However, although the cracks are still present, they do not come to the surface to cause problems.

The engineer must consider the economics when deciding on whether to apply asphalt rubber. The cost of asphalt rubber in 1971 was three times that of a conventional chip seal. Today, the initial cost is approximately two times that of a conventional chip seal. Asphalt-rubber chip seals have performed well in Phoenix for 15 years over severely cracked pavements, whereas the conventional chip seal usually lasts about 1 to 2 yr over such pavements and 6 to 8 yr over reasonably sound pavements. Asphalt rubber has virtually stopped maintenance costs, whereas the conventional chip seal has only reduced them. Thus a real value of the asphalt-rubber application is that it can eliminate maintenance costs while providing the traveling public with a reasonably good road surface at reduced costs until a major construction program can be developed.

The use of asphalt rubber will continue because of sound engineering properties, economic advantages, and its success as a surface for streets, highways, and airports.

REFERENCES


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