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# Characteristics and Performance of Asphalt-Rubber Material Containing a Blend of Reclaim and Crumb Rubber

**B.J. HUFF AND B.A. VALLERGA**

**Asphalt cement, rubber extender oil, and a mixture of ground reclaim and crumb rubber, blended together at an elevated temperature in specific proportions and sequences, form a tough, durable, and adhesive membrane when hot-spray-applied to a surface and allowed to cool to ambient temperatures. This cast-in-place asphalt-rubber membrane has been found to be suitable for use in the construction of surface treatments for existing pavements (chip seals), stress-absorbing membrane interlayers (SAMIs) in the placing of asphalt concrete overlays, and waterproofing membranes for bridge decks and hydraulic linings (ponds, canals, and reservoirs). When hot-poured into pavement joints and cracks and allowed to cool, it also serves as an effective joint and crack filler. The concepts and proportions of the formulation and preparation of this material are presented together with information and data on its properties and applications. A discussion is presented of the results of two analytic studies on the applicability of asphalt-rubber membranes (a) in minimizing reflection cracking when used as a SAMI and (b) in producing a "multilayered aggregate structure" when used as a single-pass chip seal. A summary of the field performance observed to date on a number of installations of the asphalt-rubber material in its various applications is also included, together with observations on the efficacy of the material as a membrane and as a filler.**

Many attempts have been made to impart the desirable elastic and resilient properties of rubber to asphalt. The earliest of these involved the use of natural rubber and were relatively successful. However, because of the rapid buildup in viscosity of the blend as the percentage of rubber was increased, one could use only small percentages and still maintain a workable material. Obviously, this limited the benefit that could be added by the rubber.

In addition, the virgin polymers were susceptible to oxidation by the elements, and their beneficial properties dissipated rather rapidly with time. Their instability in relation to heat also created problems with their use. Overheating converted the rubber to an oil, which only served to soften the asphalt. This severely limited the production of the rubberized asphalt to jacketed kettles or as a latex in asphalt emulsions.

With the advent of synthetic rubber, the same exercises were repeated with essentially the same results. The synthetic rubber was somewhat cheaper than the natural rubber, but it also lacked some of the elasticity and tackiness of the natural rubber.

As the use of rubber increased, the growing pile of scrap tires was eyed as a cheap source of rubber for preparing rubberized asphalt. Early experiments showed that these tires could be ground and mixed with hot asphalt in large percentages to produce a material that had properties superior to those of the base asphalt. Since the rubber in these tires

was synthetically compounded and vulcanized to resist heat and weathering, the problems encountered with the virgin polymers were eliminated.

The synthetic vulcanized rubber, however, lacked the solubility of the virgin polymers. The only solubility observed was a drawing of the oils out of the asphalt by the rubber to produce swollen rubber particles with gellike surfaces. With time, this swelling would progress to the point that the swollen rubber particles would knit together within the asphalt matrix to form an asphalt-rubber sheet that was more resistant to the stresses that produce fracture in pavements than the asphalt itself.

This was a simple way to improve the asphalt, but it was not without its shortcomings. The drawing of the oils into the rubber particle adversely affected the cohesive and adhesive properties of the asphalt phase, thereby reducing its ability to bond to pavement surfaces or to bind together aggregate particles. The loss in bond strength, which occurred primarily in the early stages of service on the road when the rubber-asphalt matrix was being formed, could be counteracted to some degree by the use of a very soft asphalt rich in oils, but the resulting blend would remain somewhat soft and tender.

In addition, it was found that large quantities of rubber (in excess of 20 percent) were required to produce the desired effect--i.e., to form a matrix (1). The resulting mass had a viscosity much too high for most conventional asphalt applications. To counter this problem, kerosene was added and the material was applied as a cutback. This was quite successful but did create some problems with tenderness before curing and, for the most part, limited the use of the material to chip seals.

As this development was taking place, experiments were in progress to combine a reclaim scrap rubber, generally referred to as "devulcanized", with asphalt. This devulcanized scrap rubber is produced by a process of treating vulcanized scrap rubber with heat and oils, which, in effect, replasticizes it and makes it more soluble in asphalt. It offered advantages over the vulcanized scrap rubber in that it dispersed and dissolved in the asphalt to a greater degree and improved the binder properties (i.e., cohesion and adhesion) of the asphalt. Because of the greater dispersion, less rubber is required, which eliminates the need for solvents. Although it had some advantages, the devulcanized asphalt-rubber blends appeared to lack some of the toughness and resilience ultimately achieved with the vulcanized asphalt-rubber blends.

The "drying-up" effect previously noted with the vulcanized rubber was investigated, and it was found that asphalts that were low in aromatic oils had low-solubility effects on rubber and produced an asphalt-rubber that had poor adhesive properties (2). In going back to earlier work, it was realized that natural rubber contributed greater elasticity and adhesion to asphalt than did synthetic rubber. However, since the use of the virgin polymer still remained undesirable because of its instability and cost, vulcanized natural rubber available in certain scrap rubbers, especially those from truck tires, was tried and found to be highly suitable. When this high-natural-rubber scrap is added to hot asphalt, it is reconverted to the sticky, elastic material. Since the rubber is vulcanized, this conversion proceeds more slowly and thus allows for a greater heat stability than if the virgin polymer were used.

In addition to the rubberlike properties contributed by the scrap rubber, there are valuable components in this compound that are often overlooked but might well contribute to the improvement of the asphalt. Examples of these are the following:

1. Carbon black--Scrap rubber contains more than 20 percent carbon black, an element that has been shown to add reinforcing properties to asphalt (3,4).
2. Antioxidants--For the tire to survive weathering, it is necessary that antioxidants be added to the rubber compound. It is believed that these chemicals contribute an additional measure of durability to the asphalt-rubber.
3. Amines--Although they are added to the rubber compounds for other reasons, particularly during the devulcanizing process, amines are closely related to the antistrip compounds and current laboratory studies indicate that they do aid in resistance to stripping.
4. Aromatic oils--Aromatic oils are the same oils that are used in recycling to rejuvenate the old asphalt and in emulsion form to restore oxidized asphalt pavements. By their presence, these oils will prolong the life of the asphalt-rubber material.

By using the foregoing knowledge of the behavior of combinations of various types of ground rubber and asphalt based on both laboratory and field experiments and observations, a formulation of asphalt, extender oil, and scrap rubber was developed that produced an asphalt-rubber material found to be particularly useful in forming a tough, durable, and adhesive membrane when hot-sprayed or hot-poured and allowed to cool. As a hot-spray application, it is suitable for use in the construction of surface treatments for existing pavements (chip seals), stress-absorbing-membrane interlayers (SAMIs) in the placing of asphalt concrete overlays, and waterproofing membranes for bridge decks and for hydraulic linings in ponds, canals, and reservoirs. As a hot-pour application, it serves as an effective joint and crack filler.

## COMPOSITION OF ASPHALT-RUBBER MATERIAL

The asphalt-rubber material used in the work described in this paper is the product ARM-R-SHIELD produced by Arizona Refining Company. The product is designed to combine the desired properties of the various types of rubbers and react this rubber blend with an asphalt that has been modified with extender oil to improve its quality and its compatibility with the rubber. The ARM-R-SHIELD material is described in detail in U.S. Patent 4,068,023 (5).

The asphalt proposed for use is tested first to determine its compatibility with rubber, which is an indicator of its relative aromatic content. If the asphalt appears to be deficient in aromatic oil, a small amount (2-6 percent) of a highly aromatic rubber extender oil (lube extract) is blended with the asphalt. The modified asphalt is then mixed at 350°-400°F with 20 ± 2 percent of a blend of rubber that contains 40 percent powdered devulcanized rubber and 60 percent powdered vulcanized rubber high in natural rubber (30 percent minimum). By this process, the flexibility and solubility of the devulcanized rubber, the elasticity, toughness, and adhesion of the natural rubber, and the resilience of the insoluble synthetic rubber are incorporated into the asphalt-rubber blend.

Figure 1 shows schematically the composition and formulation of the asphalt-rubber material. The combining of the ingredients and the mixing at elevated temperature are straightforward and can be done readily by a batching process in any tank in which adequate provision is made for (a) mixing by recirculation, stirring, air agitation, or other appropriate means; and (b) heating by appropriate heat-exchanging and temperature-control devices. A conventional distributor truck can serve this purpose if care has been taken to maintain it in good

**Figure 1. Composition of asphalt-rubber-membrane system.**

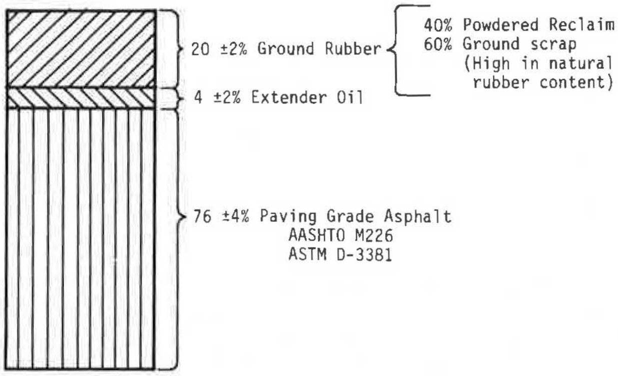



**Table 1. Consistency-temperature characteristics of asphalt-rubber material compared with base asphalt.**

| Property | Test Method | AR-4000 Asphalt | Asphalt-Rubber Material[a] |
|---|---|---|---|
| Penetration | ASTM D-4 | | |
| 39.2°F | | 9 | 17 |
| 77.0°F | | 76 | 101 |
| Softening point (ring and ball) (°F) | ASTM D-36 | 120 | 132 |
| Dynamic viscosity at 140°F (poises) | ASTM D-2171 | 1800 | 7580 |
| Kinematic viscosity (cSt) | Brookfield | | |
| 165°F | | - | 165 000 |
| 170°F | | 45 600 | - |
| 190°F | | 6 200 | - |
| 212°F | | 1 984 | - |
| 230°F | | 860 | - |
| 250°F | | 450 | - |
| 265°F | | - | 3 400 |
| 277°F | | 194 | - |
| 310°F | | 82 | - |
| 330°F | | 58 | - |
| 350°F | | 42 | 912 |
| 400°F | | - | 720 |

[a]Contains 78.4 percent AR-4000 asphalt, 1.6 percent extender oil, and 20 percent rubber blend.

operating condition and the heating system can be adequately controlled.

CHEMICAL AND PHYSICAL PROPERTIES

Determining the chemical properties of a blend of asphalt, extender oil, and ground rubber particles is extremely difficult. Most of the conventional tests are not readily adaptable to the material. Research is currently under way at several government and private laboratories, and it is expected that progress will be reported in the literature in due course.

From the standpoint of chemical properties, composition can be analyzed and the solubility characteristics of the separate ingredients can be measured (6, ASTM D-297, and ASTM D-2007). However, once the ingredients are combined and formed into a product, the interactions among the asphalt, extender oil, and rubber particles are complex and dependent on both time and temperature. Moreover, a method of determining the chemical state of the blend is not available. For example, the fraction of rubber dissolved into the asphalt at any time would seem to be a significant factor, but reliable laboratory procedures and techniques for making this determination are not yet available.

From the standpoint of physical properties, the situation is more favorable although by no means satisfactory. The main physical properties of interest and applicability are consistency, durability, and adhesion. With appropriate modifications to account for the small particles of rubber dispersed in the asphalt, the various viscosity-measuring devices can be used as well as various tests for bonding and resistance to weathering.

Consistency

Table 1 gives data on consistency versus temperature for an AR-4000 asphalt and the same AR-4000 blended with extender oil and ground rubber in accordance with the formulation presented above. The tabulated results are typical of the change in viscosity characteristics of an asphalt when the extender oil and rubber blend are incorporated into the asphalt at an elevated temperature in the manner and sequence specified (5). Figure 2 shows a plot of these data on a special asphalt consistency versus temperature chart that provides for plotting together test data from the various test methods commonly used for determining the flow characteristics of asphalt.

The consistency versus temperature data show that the influence of the rubber on the base asphalt is to decrease its susceptibility to temperature. In the high temperature range particularly, the improvement in viscosity is substantial: There is approximately a 15-fold increase in viscosity at 140°F and above. Improvement of cold-weather properties is also indicated by the significant increase in penetration value at 39.2°F.

Durability

The resistance to weathering of the asphalt-rubber material was measured by exposing various blends to direct sunlight in the Phoenix, Arizona, climate for a two-year period. Specimens 0.25 in thick and 4 in in diameter were cased in metal pans and placed on the roof of the laboratory. Kinematic viscosity was measured at 140°F before and after exposure. Table 2 gives the results obtained.

The data indicate that the ratio of viscosity after exposure to original viscosity was lower when extender oil was included in the blend. This improvement is considered significant and attests to the benefit of incorporating the oil extender in the asphalt-rubber material.

More sophisticated durability testing, including comparisons with other materials of known durability characteristics, is currently under way. These results will be published when they are available.

Adhesion

Preliminary evaluation of the adhesion characteristics of the asphalt-rubber material was performed in a cold-bond test. In this case, a comparison was made with the base asphalt used in making the asphalt-rubber material.

The cold-bond test was run in a specially modified ductility tester designed to pull a specimen with 1x1-in cross section and 2-in length between two brass blocks. The specimens were cast (hot-poured) in a mold so that the two ends adhered to the brass blocks. After a specimen is conditioned in a refrigerated alcohol bath for 10 min, it is quickly transferred to the modified ductility tester and elongated 0.5 in (i.e., 25 percent) at a standard rate. The specimen is removed from the ductility apparatus and again brought to temperature in the alcohol bath and stretched 0.5 in to half again its original length. This step is repeated until the specimen has been elongated a full 2 in, or twice its original length.

Figure 2. Effect of addition of reclaim and crumb-rubber blend on consistency-temperature relation of AR-4000 asphalt.

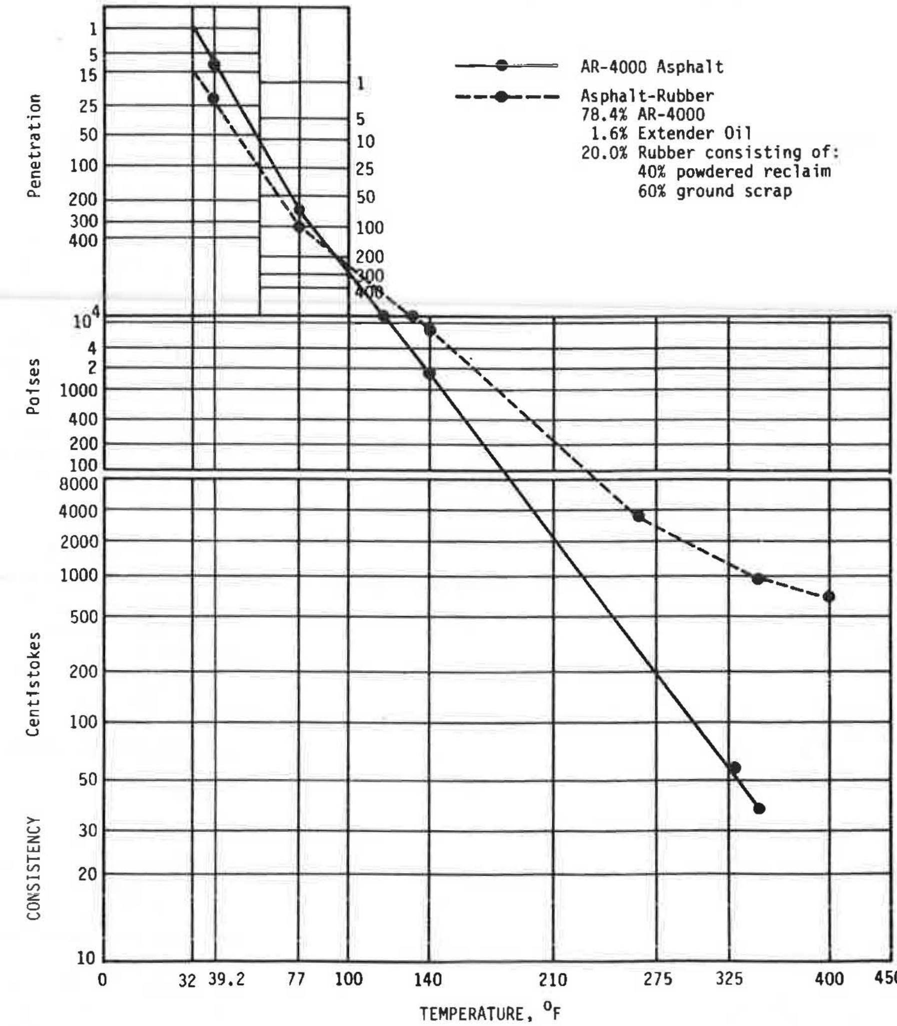



Table 2. Results of durability study of asphalt-rubber blends.

| Test No. | Composition of Blend (%) Asphalt | Extender Oil[a] | Ground Rubber[b] | Exposure Time (months) | Viscosity at 140°F (poises) Before | After | Viscosity Ratio |
|---|---|---|---|---|---|---|---|
| 1 | 80[c] | -- | 20 | 15 | 5704 | 18 034 | 3.16 |
| 2 | 78.4[c] | 1.6 | 20 | 15 | 5204 | 12 341 | 2.37 |
| 3 | 72.6[d] | 7.4 | 20 | 15 | 5978 | 15 759 | 2.64 |

[a]Shell Dutrex 739.
[b]U.S. Rubber Reclaiming Company G-274, consisting of 40 percent powdered reclaim (i.e., devulcanized) rubber and 60 percent crumb (i.e., ground scrap) rubber high in natural rubber content.
[c]AR-4000.
[d]AR-8000.

Table 3 gives the results of this test for adhesion characteristics. Observations were made of adhesion, cohesion, and reduction in cross-sectional area. After 100 percent elongation, the specimens were cut free from one of the blocks and returned to the low-temperature bath, and measurements were made of recovery in elongation at time intervals of 1 and 10 min. Test series were run on separate specimens at 40° and 60°F.

From a study of these data, it can be seen that the asphalt-rubber maintains its ductility at the lower temperature and has the ability to recover elastically about half of the elongation imparted to the specimen whereas the asphalt has essentially no ductility at the lower temperature and no elastic recovery. The asphalt-rubber also exhibited less reduction in cross-sectional area during testing than the base asphalt under the same conditions of temperature and elongation.

CHARACTERIZATION OF ASPHALT-RUBBER

Since the asphalt-rubber material is being widely used as an SAMI in pavement resurfacing operations and therefore becomes an integral part of the structural section of a pavement system, it became necessary to determine the stiffness characteristics of the asphalt-rubber membrane in terms of a stiffness modulus. This was done in a creep mode of loading.

The procedure used in this "tensile creep test" was to cast test specimens in a mold that consisted of the end pieces of the ASTM D-113 ductility test

**Table 3. Results of tests for adhesive and cohesive characteristics of asphalt-rubber material.**

| Material | Test Temperature (°F) | Characteristic | Test Observations at Elongation of 25% | 50% | 75% | 100% | Recovery Time 1 min | 10 min |
|---|---|---|---|---|---|---|---|---|
| AR-4000 asphalt | 40 | Adhesion | Pass | – | – | – | | |
| | | Cohesion | Fail | (brittle fracture) | | – | | |
| | | Reduction in cross-sectional area (%) | 0 | – | – | – | | |
| | | Recovery (%) | | | | | 0 | 0 |
| | 60 | Adhesion | Pass | Pass | Pass | Pass | | |
| | | Cohesion | Pass | Pass | Pass | Pass | | |
| | | Reduction in cross-sectional area (%) | 9 | 22 | 30 | 35 | | |
| | | Recovery (%) | | | | | 0 | 0 |
| Asphalt-rubber[a] | 40 | Adhesion | Pass | Pass | Pass | Pass | | |
| | | Cohesion | Pass | Pass | Pass | Pass | | |
| | | Reduction in cross-sectional area (%) | 14 | 14 | 24 | 33 | | |
| | | Recovery (%) | | | | | 30 | 55 |
| | 60 | Adhesion | Pass | Pass | Pass | Pass | | |
| | | Cohesion | Pass | Pass | Pass | Pass | | |
| | | Reduction in cross-sectional area (%) | 5 | 14 | 19 | 24 | | |
| | | Recovery (%) | | | | | 45 | 55 |

[a]Contains 78.4 percent AR-4000 asphalt, 1.6 percent extender oil, and 20 percent rubber blend.

mold and 5.8-in long, straight side pieces in place of the conventional wedge-shaped ones. The side pieces were coated with a release agent of glycerine and kaolin to facilitate removal. The restricted portion of the test specimen cast in this mold had parallel straight sides 6.2 in long and a uniform cross section of 0.3 in². Gage marks were placed 4 in apart on the center section of the restricted length.

The specimens were then subjected to creep loading in tension under various constant loads at temperatures of 40°, 70°, and 100°F by placing them in a constant-temperature ductility bath modified so that one end of each specimen was fixed while the other end was supported by a floating "raft" made of wood and polystyrene foam. A hanging weight was used to apply the load to the specimen through a thread that passed over essentially frictionless pulleys and was attached to the raft. During the test, the 4-in distance between the gage marks on the specimen was followed with dividers, and readings were taken at 1-min intervals. Each specimen was temperature-conditioned by placing it in the constant-temperature bath for at least 90 min before the start of the test. Figure 3 shows the test setup and a measurement being taken with calipers between the gage marks.

A separate specimen was creep-tested in tension at each temperature, and various loads were applied sequentially, in increasing order, to a single specimen. For each loading, stress and elongation were calculated on the basis of the length and cross-sectioned area at the time of application of that particular load (see Table 4).

An analysis of the test results given in Table 4 was made in connection with an analytic study of the effects of the asphalt-rubber material, when used as an SAMI, in the distribution of stress and strain in an asphalt concrete overlay (7). Assuming that 70°F is a representative temperature for the asphalt-rubber membrane layer, the stiffness for the asphalt-rubber material at times of loading of 0.02-0.05 s, considered representative of moving traffic, was estimated to range from 7500 to 3600 lbf/in². In their analytic study, Coetzee and Monismith (9) chose to use a stiffness modulus of 5000 lbf/in².

## APPLICATION CONSIDERATIONS

Immediately after mixing, the asphalt-rubber material described above is generally ready for application by either hot spray or hot pouring within a temperature range of 375°-425°F. If a delay occurs when the material is ready to be applied, the heat is turned off until the job resumes.

The material may also be allowed to stand overnight and be applied the following day, provided the heat is turned off and restarted at a time interval prior to application sufficient to ensure that the application temperature is again within the range of 375°-425°F. Mixing by recirculation or stirring, or combinations thereof, must be maintained during reheating to obtain uniformity of temperature and to avoid localized overheating, which will damage the asphalt-rubber material.

## USES OF ASPHALT-RUBBER MATERIAL

The principal uses of the asphalt-rubber material described above are in connection with membrane systems designed for pavement maintenance and rehabilitation. The four asphalt-rubber membrane systems most widely used are the following:

1. Surface treatment--A hot-spray, cast-in-place asphalt-rubber membrane into which clean, dry rock chips are embedded (i.e., chip seal);
2. SAMI--A hot-spray, cast-in-place asphalt-rubber membrane placed on an existing asphalt or portland cement concrete (PCC) pavement before resurfacing to reduce the transfer of stresses to the resurfacing layer from the underlying pavement structure and hence minimize reflection cracking (clean, dry chips or sand particles are spread on the membrane while it is hot to provide a working surface for placing the overlay);
3. Waterproofing membrane--A hot-spray, cast-in-place asphalt-rubber membrane used on such structures as bridge decks and hydraulic linings to prevent passage of water to the underlying regions; and
4. Joint and crack filling--A hot pour of asphalt-rubber into joints and cracks to serve as a

Figure 3. Test setup for tensile creep test of asphalt-rubber material: (top) overall view of equipment with pulley system and (bottom) calipers used to measure total strain over gage length.

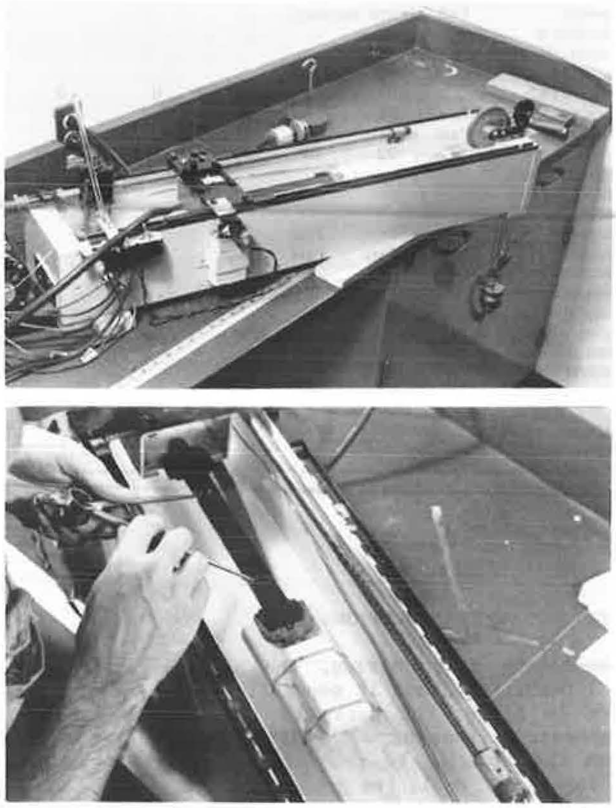


Table 4. Results of tensile creep test on asphalt-rubber material.

| Temperature (°F) | Cross-Sectional Area ($cm^2$) Initial | Final | Load (g) | Elongation at 1000 s (%) | Stress ($g/cm^2$) |
|---|---|---|---|---|---|
| 40 | 2.0 | 1.89 | 300 | 6.03 | 150 |
| | 1.89 | 1.79 | 400 | 5.21 | 212 |
| | 1.79 | 1.64 | 600 | 9.46 | 335 |
| | 1.64 | 1.36 | 1000 | 20.2 | 611 |
| 70 | 2.0 | 1.73 | 20 | 15.4 | 10 |
| | 1.73 | 1.20 | 40 | 38.4 | 23 |
| | 1.20 | 1.03 | 60 | 16.2[a] | 50 |
| 100 | 2.0 | 1.68 | 2 | 18.9[a] | 1.0 |
| | 1.68 | 1.00 | 4 | 69.0[a] | 2.4 |

Notes: 1 $cm^2$ = 0.155 $in^2$; 1 g = 0.0022 lb; and 1 $g/cm^2$ = 0.0064 $lbf/in^2$.
Asphalt-rubber material contains 78.4 percent AR = 2000 asphalt, 1.6 percent extender oil, and 20 percent rubber blend.
Metric units were used because U.S. customary units were too large to give meaningful measurements.
[a]Percentage elongation at 240 s.

seal against the intrusion of water and debris.

Other uses may evolve in time in any case where the unique properties of the asphalt-rubber material may prove to be beneficial. One such case is the use of asphalt-rubber as a binder with open-graded asphalt concrete to impart better adhesion and cohesion characteristics over a wider range of climatic conditions.

PERFORMANCE CHARACTERISTICS

Since the first experimental installations in the 1975 construction season, the asphalt-rubber material has been incorporated into many and varied projects throughout the United States under the auspices of various user agencies. A chronological listing of these projects has been maintained together with data sheets that record construction details for use in subsequent evaluations of condition and performance. Periodically, condition surveys have also been made and the results have been recorded on forms specifically designed for the purpose. These are filed with the original construction data sheets.

Based on evaluations of the data obtained so far from field construction records and from surveys of present condition, the following general observations are made:

1. The handling characteristics of the asphalt-rubber material from blending to application are uncomplicated. Mixing of the ingredients and application of the finished blend can be successfully accomplished in any tank that has adequate means for mixing and temperature control. For example, a conventional pressure-distributor truck is suitable for the purpose if it is in good operating condition and equipped with appropriate heating equipment and good temperature-control devices.
2. The resulting asphalt-oil-rubber blend is smooth in texture and uniform in consistency. It is free of clusters of undispersed rubber particles or of nonuniformly blended ingredients.
3. Hot-spray applications are readily performed with conventional spray equipment, within the temperature range of 375°-425°F. Hot-pour applications are similarly easy to make by using any of the standard pouring devices within the same range of application temperatures.
4. When the asphalt-rubber is hot-sprayed or hot-poured, it is sufficiently adhesive so that the application of a tack coat is generally not required, provided the surface is broomed clean of loose debris.
5. The general performance of surface treatments made with the asphalt-rubber material has been exceptionally good. Some very early problems with soft binder and loss of aggregate have been corrected by making several small modifications in product formulation and avoiding completely the use of wet or dirty aggregate chips. It is essential that, as a minimum requirement, the aggregate be clean and dry. Although the use of hot, precoated aggregates is ideal, it has not been found to be necessary with this material. Of particular interest in connection with asphalt-rubber-membrane surface treatments is the observation that this type of construction is not limited by the "one layer of chips" concept associated with conventional asphalt-seal test construction. Field trials have shown that one can successfully construct a "multilayered chip seal" with a single heavy application of the asphalt-rubber material (as much as 1 $gal/yd^2$ or more) if sufficient aggregate is applied to embed in the membrane and still produce a textured aggregate surface (8).
6. The general performance of SAMIs made with this asphalt-rubber material has been most promising. Results from various field installations have been reported in the literature (9).
7. The general performance of bridge-deck waterproofing membranes made with this material appears to be promising although the installations have not yet been fully tested. Time will tell whether or not the asphalt-rubber membrane will provide sufficient waterproofing to protect the underlying concrete decks from the intrusion of water. It should be noted that the bridge-deck membranes must be covered with a protective sheet, such as asphalt-

impregnated fiber mats, to provide a working surface for placing the overlay.

8. The general performance of joints and cracks filled with hot-poured asphalt-rubber material has been exceptionally good, especially where the joints and cracks are air-blown clean and free of debris. However, a well-designed control experiment with other types of fillers is needed in order to compare the performance of the asphalt-rubber with that of materials that have service records in this kind of use.

As a consequence of the above evaluations of field experience with the asphalt-rubber material, a series of guide specifications has been initiated to delineate the materials and procedures to be followed for achieving the desired results. The first of these is a material specification (10) to cover the preparation of the asphalt-rubber material itself from selected ingredients that must be blended together under carefully controlled conditions in the manner, proportions, and sequence given to ensure uniformity in properties and behavior. This specification is basic to all systems that use the asphalt-rubber material, whether hot-sprayed or hot-poured.

Besides the material specification, two construction specifications have been developed to cover the placement of an asphalt-rubber-membrane surface treatment (11) and an asphalt-rubber SAMI (12). Both of these specifications are considered to reflect the best practice from experience accumulated to date.

## ANALYTIC STUDIES

In conjunction with the evaluation program, two special analytic studies were undertaken to develop a better understanding of the behavior of the asphalt-rubber-membrane systems. The first of these was a study of how to design an asphalt-rubber surface treatment based on a multilayer chip concept. The second was a study of how an asphalt-rubber SAMI functions to minimize reflection cracking in asphalt concrete overlays.

### Design of Asphalt-Rubber Surface Treatment

The study related to the design of an asphalt-rubber surface treatment with a multilayered aggregate structure consisted of conducting a field audit of an experimental project on Van Buren Road in Phoenix in which the quantities of asphalt-rubber material and aggregate chips were varied from section to section and all sections produced a highly satisfactory surface treatment in all respects over more than five years of field service. In the audit, the range of asphalt-rubber was found to vary from 0.4 to 1.95 $gal/yd^2$ and the range of aggregate chips retained ranged from 22 to 68 $lb/yd^2$. The thickness of the surface treatment was also measured for each section. Details of this study are described in Specification M-101 of Arizona Refining Company (11), which also presents a nomograph for use in designing chip-seal surface treatments with a multilayered aggregate structure.

### Effects of Asphalt-Rubber Interlayer on Reflection Cracking

The analytic study of the effect of applying a thin (0.25- to 0.375-in) asphalt-rubber membrane of low stiffness and high deformability at the interface between the underlying and overlay pavements on minimizing reflection cracking in asphalt concrete overlays consisted of finite-element analyses of pavement overlay systems with and without the asphalt-rubber interlayer. This study was undertaken at the University of California, Berkeley, and a report was issued in June 1978 (7).

Conventional methods of overlay design, whether empirical or theoretically based, generally give thickness requirements that are adequate to provide the needed structural strength to accommodate anticipated traffic volumes and loadings for a projected design life. However, these overlays, although structurally functional, are susceptible to the development of cracks caused by the "reflection" of cracking patterns that exist in the underlying pavement. The mechanism for the development of these reflection cracks is not fully understood but is believed to be directly related to the transfer of high stresses to the underside of the overlay at discontinuities in the underlying pavement.

A two-dimensional finite-element model of the pavement system, with and without the SAMI present, was used in this study to analyze the pavement structure for response to traffic loads. The mesh used in the analysis had elements as small as 0.06x0.015 in at the crack tip because of the very high stress and strain gradients encountered at this location.

The results obtained from the finite-element analysis are presented as contours of effective stress distribution that show the concentration of high stresses at the crack tip. For the specific case of a 2-in asphalt concrete overlay on an 8-in PCC pavement, a 0.25-in-thick asphalt-rubber SAMI with a stiffness modulus of 5000 $lbf/in^2$ reduces the maximum stress at the crack tip from about 600 to about 100 $lbf/in^2$, a sixfold decrease. The corresponding contours of shear-strain distribution for the same case show that the shear strain is reduced approximately fourfold, from about $30x10^{-3}$ to $7x10^{-3}$ in/in.

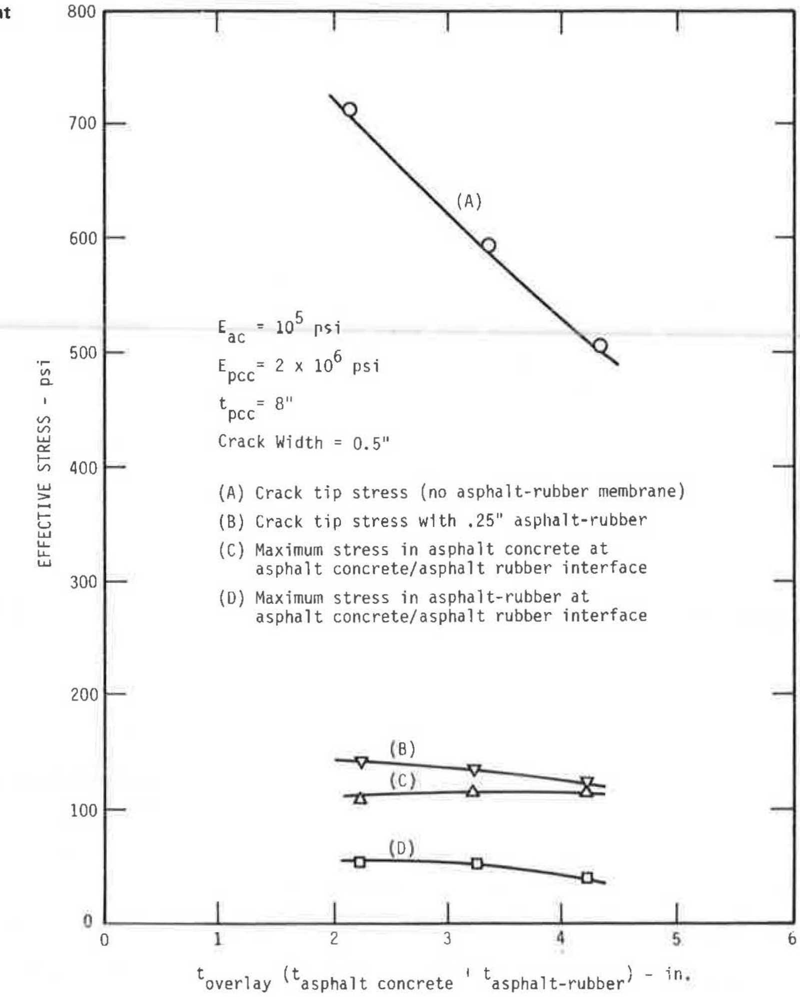
Various studies were made on the effects of varying such parameters as the stiffness moduli of the asphalt-rubber (1000-20 000 $lbf/in^2$), subgrade (5000-10 000 $lbf/in^2$), asphalt concrete (100 000-1 500 000 $lbf/in^2$), and PCC (1 000 000-4 000 000 $lbf/in^2$) as well as cross-sectional dimensions of the pavement overlay system and the crack width. Figure 4 is most interesting because it clearly demonstrates that, although the effect of overlay thickness is to reduce crack-tip stress when the asphalt-rubber SAMI is not present, it has little effect when the asphalt-rubber SAMI is present. For this case, the asphalt-rubber appears by extrapolation to be equivalent to a 9-in asphalt concrete overlay. However, further study is needed to determine whether such an equivalency relation exists.

As part of this analytic study, a limited analysis was also conducted to estimate stresses in the pavement overlay system, with and without the asphalt-rubber SAMI, resulting from temperature change. For a temperature drop of 40°F, with and without the asphalt-rubber SAMI layer, a 30-fold drop in horizontal shear at the crack tip, from about 3000 to 100 $lbf/in^2$, is obtained. For this analysis, the temperature change was attenuated with depth and the stiffness modulus of the asphalt concrete was held constant. Since the modulus is a time-dependent parameter, it is likely that the stress difference in the two cases may not be as large as that stated. Nevertheless, there is indication of a substantial reduction in thermally induced stresses as a result of the use of the asphalt-rubber SAMI.

## CONCLUSIONS

The general concept of combining a blend of 40 percent powdered reclaim rubber--i.e., devulcanized

Figure 4. Effect of thickness of overlay on effective stress at crack tip with and without asphalt-rubber SAMI and on maximum stress in asphalt concrete and SAMI.




scrap--and 60 percent powdered vulcanized scrap rubber high in natural rubber content with a paving-grade asphalt supplemented with rubber extender oil to produce an asphalt-rubber material with the desirable properties of both the asphalt and the rubber is valid. Laboratory experiments, analytic studies, and field experience to date support the following conclusions:

1. The asphalt-rubber material is easily prepared from its three basic ingredients with the equipment and know-how currently available in the field of asphalt construction.
2. The resulting asphalt-rubber product is smooth in texture and uniform in consistency and can be readily spray-applied or poured within a temperature range of 375°-425°F by using conventional asphalt spreading or pouring equipment.
3. When hot-sprayed on a surface and allowed to cool, the material forms a tough, durable, and adhesive asphalt-rubber membrane of low stiffness and high deformability that makes it useful for the construction of (a) surface treatments with a multilayered aggregate structure, (b) SAMIs, and (c) waterproofing membranes for bridge decks and hydraulic linings.
4. When hot-poured into clean and debris-free pavement joints and cracks and allowed to cool, the material forms an effective filler that resists the intrusion of water and debris but still has the low stiffness and high deformability to accommodate displacements associated with loading and thermal stresses.

Although there has been much development work with this asphalt-rubber material since its inception in 1975, further studies are needed at both the laboratory and field stages to develop better methods of determining its properties, characterizing its behavior, and documenting its performance in each of its many applications.

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# Modification of Paving Asphalts by Digestion with Scrap Rubber

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**The service performance of sprayed surface treatments laid where traffic-induced stress is severe or where the existing pavement is cracked can be significantly improved if comminuted scrap rubber is digested in the asphaltic cement before spraying. Work performed to identify the factors that are of importance in optimizing asphalt performance is reported. Measurement of the deformation response of the rubber digestions to sinusoidal loading indicated that the modified binder had improved response under the loading produced by traffic at high pavement temperatures and that produced by thermal contraction at low pavement temperatures. A simple and rapid test procedure was developed to measure the response under loading conditions similar to these. The procedure is to subject a prism of the binder at 60°C to a shear strain of 1.0-in creep and then determine the elastic recovery when the stress is removed. The most important factor affecting elastic recovery was found to be the morphology of the rubber particles as determined by the comminution process used in their manufacture. A simple bulk-density test was used to characterize this morphology. Digestions of natural (truck-tire) rubber are generally superior to those that incorporate synthetic (car-tire) rubber but are more affected by changes in the time or temperature of digestion. Where a cryogenic comminution process had been used, only digestions of natural-rubber particles produced a significant improvement in asphalt properties. Elastic recovery of strain is linearly related to rubber concentration.**

Rubber modifiers have been used in bituminous materials for many years. They have usually been specially prepared natural and synthetic rubbers, and their concentration has been limited to less than 5 percent by mass of the asphaltic cement because greater concentrations have caused problems in handling (pumping and spraying) and because of their high cost. At these concentrations, the improvement in binder performance obtained in pavement service has been marginal unless a satisfactory polymer network has been formed in the asphalt.

A major improvement in this situation occurred as a result of the work of McDonald (1) and Morris and McDonald (2), who introduced the use of digestions of scrap rubber in asphalt that contained up to 25 percent by mass of comminuted tire-tread rubber. A sprayed layer of this material has been widely used in the United States to prevent cracks in the substrate from being reflected through overlays. It is normally applied as either a chip-seal surface treatment with approximately 20 percent rubber added to the asphalt, commonly known as a stress-absorbing membrane, or as an interlayer of rubber-asphalt binder and aggregate (stress-absorbing membrane interlayer) overlaid by a thin course of asphaltic concrete.

In Australia, the main use of the scrap rubber-asphalt digestions has been in sprayed surface treatments where the advantages are considered to be

1. The sealing of cracked pavements to prevent, or delay the onset of, reflection cracking, and
2. The retention of chips in hot weather under severe traffic stress conditions (such conditions occur when seals are used to provide surface texture on high-speed roads where a conventional asphalt seal is unable to provide satisfactory stone retention at bends or in acceleration and deceleration areas).

## DEFORMATION TESTING OF RUBBER-MODIFIED ASPHALTS

### Sinusoidal Loading

A useful means of evaluating the deformation behavior of asphalts and rubber-modified asphalts is by their response to sinusoidal loading in simple shear. This provides basic information on the behavior of the materials, but specialized equipment is required and testing is slow. The sinusoidal loading procedure was therefore used only to determine the appropriate test conditions (temperature, rate of strain, etc.) for the rubber-asphalt digestions, and a simpler apparatus, operated near the required conditions, was then used for routine testing.

In the sinusoidal loading procedure, a force applied to the material produces a sinusoidal displacement that lags behind the force (see Figure 1). The magnitude of the phase-angle difference between the force and the displacement ($\phi$) is an indication of the partitioning of the response between viscous and elastic behavior. The phase angle is zero for purely elastic behavior and 90° for purely viscous behavior. The ratio of the maximum value of the force to the maximum value of the displacement is proportional to the complex