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Conversion factors used in this paper are

°F = 32 + 18°C
1 inch = 25.4 mm
1 lbm = 0.45 kg
1 lbf = 4.44 N
1 pcf = 16.03 kg/m^3
1 psi = 6.89 kPa
1 gal/yd^2 = 4.53 L/m^2
1 lbm/yd^2 = 4.88 kg/m^2

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Field Performance of Rubber-Modified Asphalt Paving Materials

T. S. SHULER, R. D. PAVLOVICH, and J. A. EPPS

ABSTRACT

Six types of paving systems containing ground tire rubber are evaluated. Asphalt-rubber seal coats and interlayers are the construction applications in which most ground rubber has been used, and, therefore, most of the results of this study relate to these two paving processes. Asphalt-rubber interlayers studied in this research do not appear to always improve performance of overlays compared with control sections. However, the negative performance of some installations does not appear to be related to fundamental material properties but to inappropriate use of some interlayers. It is believed that improved performance of such systems can be demonstrated if use is limited to specified modes of pavement distress. Asphalt-rubber seal coat performance also indicates some unfavorable performance compared with control sections. However, this adverse performance can be related directly to a high incidence of flushing distress. A recommendation is given for design of asphalt-rubber seal coats similar to conventional seal coats. A lack of rational design procedure for determining material quantities is cited as the primary cause of some detrimental asphalt-rubber seal coat performance in the past. Four other rubber-modified paving processes were investigated; however, because of the relatively few projects involved, specific conclusions regarding these types of applications are difficult to assess. Further study is recommended as more projects of this type are constructed.

Ground tire rubber has been used as an additive in various types of asphalt pavement construction in recent years. The use of rubber is of interest to the paving industry because of the additional elasticity imparted to the binder. However, additional benefits such as resource recovery have also been gained by creating a use for some of the 240 million waste tires generated annually (1).

Adding ground tires to asphalt has been practiced on a routine basis in recent years by several companies, each of which supplies a proprietary product based on variations of this concept. However, acceptance of these products has been primarily regional, depending somewhat on favorable experience gained during experimental stages of use. As a result, information about performance of such systems has been fragmented and difficult to assess.

INTRODUCTION

A purpose of this research is to evaluate numerous installations in the contiguous 48 states where ground tire rubber has been used in pavement construction. Sixteen state highway departments pooled research funds to enable such a task to be undertaken. Administered by the Federal Highway Administration, this research presents the overall performance of six types of paving materials containing ground tire rubber.

Background

A blend of ground tire rubber and asphalt cement is used as a binder in various types of pavement construction. This blend is called asphalt-rubber and consists of 18 to 26 percent ground tire rubber by total weight of the blend. The blend is formulated at elevated temperatures to promote chemical and physical bonding of the two constituents. Various petroleum distillates are sometimes added to the blend to reduce viscosity and promote workability.

Asphalt-rubber is used as a binder in chip seal and dense- and open-graded asphalt concrete construction. An asphalt-rubber chip seal, or seal coat, applied beneath an asphalt concrete overlay is called an asphalt-rubber interlayer. This treatment has been used in an attempt to reduce reflection cracking in overlays. When an asphalt-rubber binder is used to fabricate hot-mixed asphalt concrete, the result is either an asphalt-rubber friction course or open-graded mixes.

The term asphalt-rubber in this paper indicates that a chemical and physical change has occurred in the two constituents that compose blended asphalt-rubber. These changes allow a distinction to be made between asphalt-rubber and a simple mixture of asphalt cement and solid ground tire rubber.

Other types of paving materials were studied as part of this research. These materials consisted of asphalt concrete, both dense and open graded, to which ground tire rubber was added as part of the aggregate component. These mixtures will not be considered asphalt-rubber in this study because rubber is not blended with the asphalt cement before mixing with mineral aggregates. Instead rubber is mixed dry with mineral aggregates before mixing with asphalt cement. The rubber and mineral aggregates are mixed with asphalt cement in an asphalt plant like conventional asphalt concrete. These materials are called "asphalt concrete rubber filled" for dense-graded mixes, and "friction course rubber filled" for open-graded mixes.

Project Scope

Field performance was judged for six types of paving materials containing ground tire rubber. These materials are classified on the basis of the purpose ground tire rubber serves in the material. These six material types are as follows:

1. Asphalt-rubber seal coat,
2. Asphalt-rubber interlayer,
3. Asphalt-rubber concrete,
4. Asphalt-rubber friction course,
5. Asphalt concrete rubber filled, and
6. Friction course rubber filled.

In all, 219 test sections containing these materials were evaluated for relative field performance compared to comparable control sections.

The asphalt-rubber projects evaluated in this study were constructed between 1977 and 1984. Rubber filled projects were constructed between 1977 and 1984. During these periods, various changes in fabrication equipment and construction procedures were introduced by contractors building with ground tire rubber paving materials. A portion of this research is dedicated to descriptions of recommended practices that have evolved since the earlier periods of rubber-modified paving material use.

Research Approach

The subject of this paper is a review of the performance of pavement sections containing ground tire rubber. Selection of sites for review was important to the success of the evaluation process; therefore, specific requirements were desirable before a site was considered for review. Criteria for site selection were based on the following by order of importance:

1. Quality of preconstruction data available,
2. Quality of experiment design,
3. Variety of application types,
4. Climate, and
5. Access.

Performance of test sections was measured in terms of the occurrence of specific distress types. Although crack reduction is the primary objective of asphalt-rubber systems, other distress modes such as flushing were evaluated as well. This is because, although asphalt-rubber may reduce reflection cracking, if the reason for success in crack reduction is severe flushing, the overall benefit may not be positive.

Determination of crack reduction potential was accomplished by judging differences between control and test sections when crack surveys were available. All field installations were judged on the basis of relative performance of adjacent control sections when control sections were present.

FIELD PERFORMANCE

Research Approach

Pavement installations containing ground tire rubber were evaluated to determine if service performance was enhanced compared with that of control sections without rubber. Performance was judged on the basis of varying levels and amounts of specific distress types:

1. Rutting,
2. Raveling,
3. Flushing,
4. Corrugations,
5. Alligator cracking,
6. Longitudinal cracking,
7. Transverse cracking, and
8. Patching.

Each test section was evaluated on the basis of the quantity and severity of each distress type. An objective method for rating pavements described by Epps et al. (2) was used to rate each section using a deduction point system. This system assigns various deduction points to specific distress types depending on level of distress and amount.

Additional information was collected for seal coats. These pavements were also rated according to aggregate embedment and retention. A point system based on percentage of embedment and retention was used and an additional score obtained.

The objective of this work was to evaluate projects so that an analysis could be made of the effect of rubber on each pavement system evaluated. The wide variety of projects evaluated made direct comparison between project locations impractical because variables such as traffic, substrate pavement, climate, and construction techniques differed on all projects. To provide an objective means of comparison, a system for evaluating all projects on an equal basis was devised. This system compares test sections with control sections. The performance of the two are judged on the basis of relative performance at each site. An improvement rating scale (IRS) from -3 to +3 was developed as shown in Figure 1. Positive numbers indicate that experimental sections provided improvement over control sections. Negative numbers indicate the opposite trend. Relative IRS values provide an indication of how improved or detrimental a particular treatment was compared to a corresponding control section. Values for IRS are assigned to sections depending on degree of improvement over control sections. This value also depends on project climate, traffic, pavement type, and age of facility. These variables are then included in the IRS so that comparison of performance between material suppliers and climatic regions is possible.

An example of how this system was used follows:

Experimental treatment	Asphalt-rubber interlayer Asphalt concrete/interlayer/4-in. asphalt concrete
Pavement section	1 1/2 in/I/4-in. AC
Construction date	1978
Survey date	1983
Climate	Southeast
Traffic, vehicles per day per lane	9,000
Trucks (%)	15-20
Soils (unified system)	CH
Pavement rating scale (PRS) (test section)	88
PRS (control)	78
Condition of original pavement	Moderate to severe transverse cracks at 8 to 20 ft intervals. Moderate alligator cracking over 30 percent of area. PRS = 51.
Reason for difference in PRS	Higher percentage reflected transverse cracking in control. No reflected alligator cracking in test section.
IRS	+2

Each section of pavement surveyed was evaluated for performance and rated by assigning IRS values to each. A simple comparison of PRS ratings was not always possible to determine IRS values. This is because the PRS system places various rating values on different distress types and severity levels. For example, if, in the example, the test section had displayed flushing distress and the control had displayed transverse cracking distress, this might have been the reason for less cracking in the test section. Therefore it could be possible for the IRS rating to be zero even though the PRS of the experimental section is higher than is that of the control.

Regions

Climate may be a factor in considering performance of paving materials containing rubber. Therefore seven climatic regions have been defined to help describe the operating environment for all projects evaluated. The distribution of projects in the country, however, is not uniform; therefore only major trends in performance between regions will allow description of a regional effect.

Applications

Six types of paving applications were studied. These applications can be broadly categorized as materials in which asphalt-rubber serves as the binder and material to which ground rubber has been added as an aggregate or filler.

Asphalt-rubber binders, as previously described, are used to produce seal coats, interlayers, asphalt

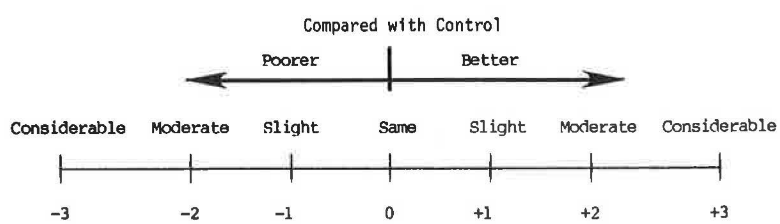

FIGURE 1 Improved rating scale (IRS). This scale was developed to quantify performance difference between pavement sections containing rubber and control sections. Positive numbers indicate that sections containing rubber provide improved performance compared to control sections. Negative numbers indicate that sections containing rubber provide poor performance relative to control sections.

concrete, and open-graded friction courses. In this paper use of the term "asphalt-rubber" as a prefix implies that a modified asphalt has been used as the binder in the paving application. However, unless rubber and asphalt have been blended at elevated temperatures and over an extended time to cause chemical changes in the asphalt, the term asphalt-rubber does not apply. Therefore, applications where rubber has been added to mineral aggregates and mixed with asphalt in a pugmill or similar mixer will not be considered asphalt-rubber. The rubber in these mixtures will be considered as an elastic aggregate or filler, depending on rubber size. Applications of this type will contain the suffix "rubber filled." Asphalt-rubber systems represent 74 percent of all sections surveyed. Rubber filled sections represent 26 percent.

Suppliers

Five suppliers are represented for all materials studied. These suppliers will be abbreviated as A, S, P, PF, and O for convenience. Ninety percent of all asphalt-rubber applications studied were constructed by suppliers A and S. The other 10 percent were constructed by supplier O. Three proprietary products represent approximately 15 percent of the rubber filled projects, and state agencies or various local contractors constructed the remaining 85 percent.

Paving fabrics were present at five sites and were evaluated as interlayers with the asphalt-rubber systems at these sites.

Results of Field Survey

Each test section within a project was evaluated for relative performance compared to an appropriate control section at the same location under equal service conditions. The rating system described earlier was used to score the performance of each test section. These data have been categorized so comparative performance can be seen more easily. Bar graphs have been made for various data presentations to relate improvement rating score and project frequency. This method of data presentation makes performance trends more easily distinguishable.

Subdivisions have been made for comparison purposes. First, the project test sections were clarified by the six application types described under Project Scope.

All data for these six pavement types have been prepared in bar graph form. Figure 2 shows the performance of each treatment type relative to control sections. Inspection of Figure 1 indicates a nearly normal distribution of performance for interlayers. Performance is skewed slightly negative for asphalt-rubber seal coats and friction course-rubber filled systems, and slightly positive for asphalt concrete-rubber filled systems. Judgment of performance qualities for asphalt-rubber concrete and asphalt-rubber friction course applications are inconclusive because there were few projects of this type; however, a normal to slightly negative trend appears for these projects as well. The performance of fabric interlayers is not contained in the Figure 2 interlayer bar graph so that comparison of asphalt-rubber systems could be made without confusion.

Figure 3 shows data for interlayers only and compares performance of each material supplier. Suppliers A and S show no clear positive or negative trend in interlayer performance. Supplier A has three projects with +1 or +2 and 14 projects with -1 performance. Supplier S has twelve +1 or +2 projects and eleven projects rated -1 through -3.

The negative trend in asphalt-rubber seal coat performance cannot be attributed to either Supplier A or S. Both suppliers have skewed negative performance distributions for asphalt-rubber seal coats, as shown in Figure 4.

Asphalt concrete rubber filled performance is positively skewed for both Suppliers O and P as shown in Figure 5. However, most test sections monitored were short sections with minimal preconstruction data available, and many sections were in service for short periods with little or no distress present.

Few data were collected for remaining application types; therefore, conclusive results are difficult to establish. No clear trends appear in this data, although for friction course-rubber filled applications the trend appears negative, as shown in Figure 6.

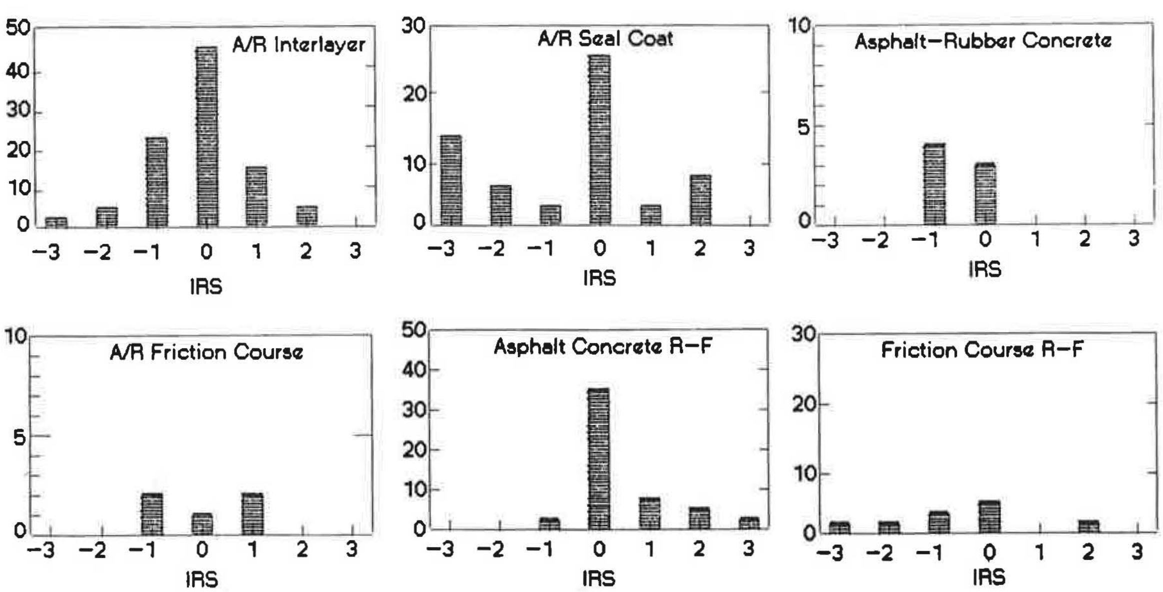

FIGURE 2 Performance by application type.

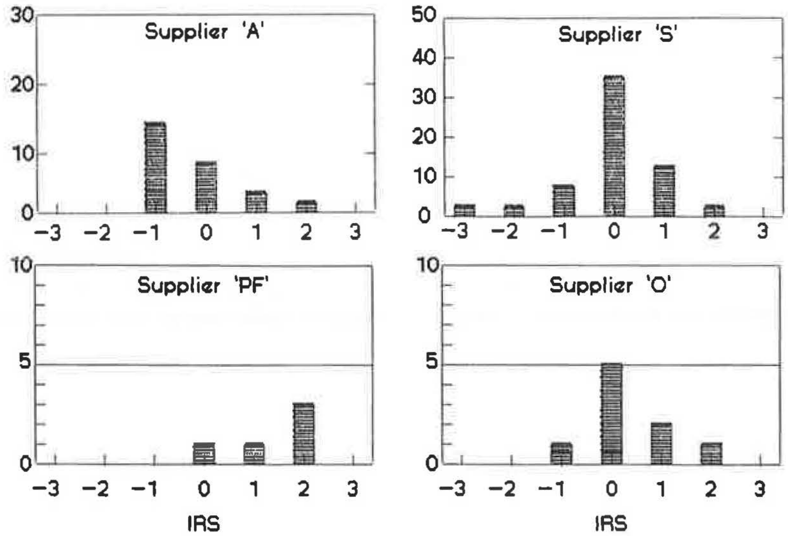

FIGURE 3 Interlayer performance.

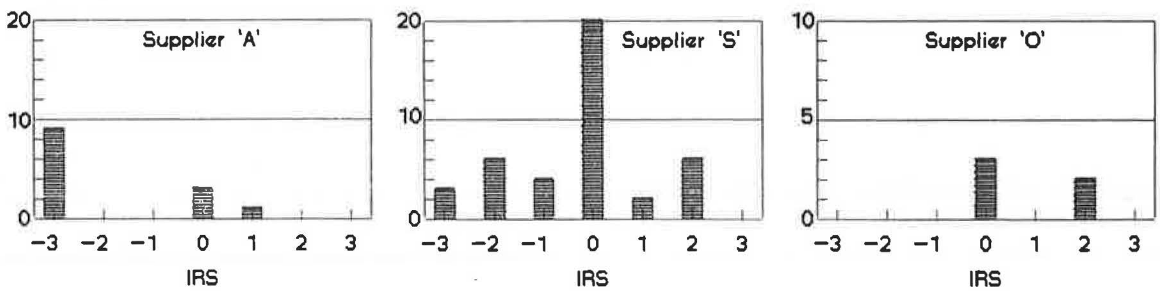

FIGURE 4 Asphalt-rubber seal coat performance.

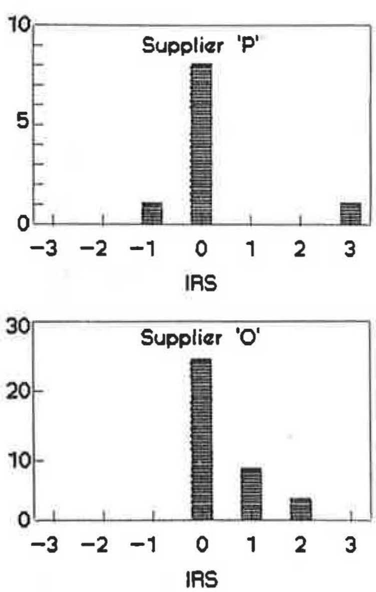

FIGURE 5 Asphalt concrete rubber filled performance.

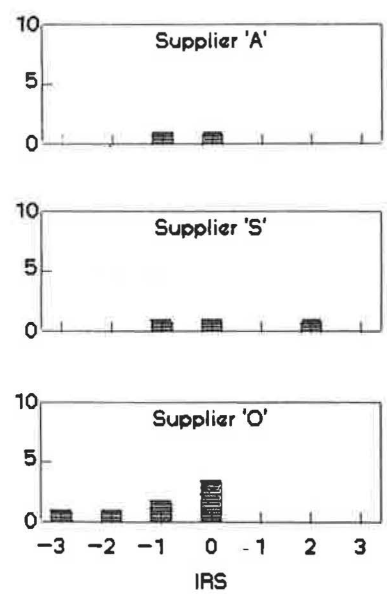

FIGURE 6 Friction course rubber filled performance.

Application types were also subdivided by climatic region. This was done to determine if performance is affected by climate. However, not enough projects were located in each of the seven regions for an objective analysis to be made of climatic effect.

CONCLUSIONS

Interlayers

1. Performance of asphalt-rubber interlayers appears to follow a normal distribution with a slight

skew to negative or detrimental performance compared to control sections.

2. Negative performance of interlayers does not appear related to inadequate material properties but rather to inappropriate construction practice or intended use.

3. The detrimental performance on the two -3 rated sections shown in Figure 2 was caused by severe rutting and flushing of the overlay. The interlayer was sandwiched between new asphalt concrete beneath and open-graded friction course above. Investigators believe this structure allows the friction course to be embedded in the interlayer creating excess binder at the pavement surface (3).

4. The three -2 and two -1 sections were constructed over portland cement concrete or in cold climates where joints or thermal shrinkage cracks existed in the original pavements. In both situations in which high strains develop at the pavement joint or thermal crack, these strains apparently cannot be attenuated by interlayer systems.

5. Many of the interlayers with negative performance were constructed before 1979. This may be significant for two reasons. First, there may be a learning process appearing in the analysis. Projects constructed during development of asphalt-rubber technology may reflect this learning process as negative performance. Second, preblending of asphalt-rubber became routine during the summer of 1979. This preblending improves workability of the blended asphalt-rubber allowing less clogging of distributor nozzles and more uniformity during application.

6. Successful performance of +1 and +2 interlayers shows that, when asphalt-rubber interlayers are used for appropriate pavement distress and constructed properly, improved overlay performance can be achieved.

7. No significant difference in performance between Supplies A and S was observed.

Asphalt-Rubber Seal Coats

1. Asphalt-rubber seal coat performance displays an approximately normal statistical distribution but with a negative skew.

2. The negative performance of asphalt-rubber seal coat does not appear related to fundamental material characteristics but rather to construction practices.

3. Flushing distress is the primary cause for negative performance of asphalt-rubber seal coats.

4. Flushing distress occurs because of inappropriate application quantities of binder and aggregates.

5. When sections displaying flushing distress are removed from the analysis, a shift from negative to positive performance occurs for asphalt-rubber seal coats.

6. If seal coats displaying flushing distress had been designed to eliminate flushing it is likely that these sections would have demonstrated improved performance compared with controls. The resulting overall performance of asphalt-rubber seal coats would have been significantly better than that of corresponding control sections.

7. No significant difference in performance for asphalt-rubber seal coats was observed among suppliers.

Asphalt Concrete Rubber Filled

1. Performance of these systems is improved compared with control sections. The majority of projects indicating improved performance contained finely ground rubber at 1 percent by total mix weight. Projects with approximately 3 percent 1/4-in. minus ground rubber indicated no improvement on most sections where long-term performance data have not been generated. In one case, however, these materials reduced onset of reflective cracking better than did a control section and an adjoining section that used a fabric interlayer.

2. Two projects were observed that displayed poor performance that contained 1/4-in. minus rubber. Poor performance was characterized by a delamination of the treatment from the substrate pavement. Poor performance on one of the two projects is suspected to have been caused by inadequate fine aggregate in the mixture. Although reviewed, this project was not included in the summary of performance because it is believed that materials failed to meet job specification requirements. Inadequate fine aggregate is thought to be the cause of the pavement distress witnessed; therefore, blame is not attributed to inherent material deficiencies.

Friction Course Rubber Filled, Asphalt-Rubber Concrete, and Asphalt-Rubber Friction Course

1. Few of these types of applications were observed; therefore general conclusions regarding performance are not possible.

2. Performance of the few projects observed indicates a balanced, normal distribution.

3. Certain applications of friction course rubber filled systems appear to perform significantly worse than others. Two such sections contained 2.5 percent by total mix long strand rubber. Both sections failed significantly earlier than control sections or sections containing crumb rubber.

RECOMMENDATIONS

Asphalt-Rubber Seal Coats

1. On many of the interlayer and seal coat projects surveyed, it was common to specify a fixed rate of asphalt-rubber binder and a variable rate of aggregate cover material. This resulted in high quantities of stone loss and flushing in many cases. The practice of selecting binder quantity before aggregate quantity should be abandoned.

2. Asphalt-rubber seal coats should be designed following a procedure that provides for embedment of one layer of aggregate per application. The quantity of aggregate required to accomplish this can be determined by design. After aggregate quantity is determined, the design quantity of asphalt-rubber binder can be calculated on the basis of voids and desired embedment depth. A design procedure proposed for seal coats and interlayers is outlined in detail elsewhere (4).

3. Asphalt-rubber seal coats appear to be more effective in the following situations:

- Maintenance of pavements displaying alligator cracks or random transverse and longitudinal cracking at less than 8-ft intervals.
- Maintenance of low-volume facilities in conditions under which conventional seal coat would oxidize and crack due to lack of use.
- Facilities where conventional seal coat could not withstand high traffic volume. In this situation, in which aggregate loss is potentially the greatest threat, precoated aggregate should be used, and proper asphalt-rubber seal coat design is critical.

Interlayers

1. Interlayer design should be modified from seal coat design to allow slightly higher initial embedment (5). Initial embedment depth will vary depending on the length of time the interlayer serves as a seal coat. Care must be taken to avoid producing a low shear strength layer between old and new pavement layers. However, embedment of aggregate needs to be high enough to avoid keying of interlayer aggregates and overlay. It is believed that, if keying occurs between interlayer aggregates and overlay asphalt concrete, reflection cracking may be accelerated.

2. Adequate curing time should be provided after interlayer construction. Certain diluents used in asphalt-rubber binders may cause softening of overlay asphalt concrete if overlay is applied too soon after interlayer. No general time interval can be specified between interlayer and overlay construction because many variables affect the rate at which volatiles escape asphalt-rubber binders.

3. Interlayer systems with dense-graded asphalt concrete overlays are not recommended for reflection crack control on pavements with transverse cracks or joints appearing at regular intervals of more than 15 ft. Pavements of this type include but are not limited to jointed portland cement concrete and asphalt concrete over cement or lime-treated subbases and subgrades.

Specifications

A recommended guide specification for construction of asphalt-rubber seal coats and interlayers has been prepared by the authors but is too lengthy to include here (5,6). Although intended as a guide, this specification should be useful as a platform for developing working specifications.

Future Experimentation

1. Future field experiments should be statistically designed such that results can be analytically measured. Many results presented by this research are subjective. This was necessary because every pavement section evaluated was unique. Unless future field test experiments are designed so that objective comparisons can be made both within and between projects, the results of these experiments will be limited to subjective analysis.

2. In future statistical experiments, limit variables to a maximum of three. Statistical design requires at least one replication; therefore, a three-factor experiment includes six test sections. The length of each section should be such that materials placed are representative. This results in asphalt concrete test sections constructed from several transport loads and seal coat sections constructed using at least one distributor load. The length of such sections makes investigation of more than three variables impractical.

3. Adopt a standard method for evaluation of pavement condition. This should include precondition survey information that, as a minimum, documents existing cracks. Crack maps should be detailed enough that subsequent surveys verify previous surveys. Using a system of this type allows determination of crack rate as well as information on "healing" of cracks. Automated photologging equipment, which can accurately record the pavement condition, has been developed. This type of system also has the advantage of allowing crack measurement in the office at the convenience of evaluation personnel.

4. Embedment depths recommended for seal coats and interlayers in this paper are based on observations of many and varied field projects. A controlled experiment is necessary to determine objectively what embedment depths are necessary to provide optimum performance for both seal coats and interlayers.

5. Positive trends in performance of rubber filled systems suggest that a greater research effort aimed at these materials is warranted. Sites of this type included in this study tended to be short sections with little or no precondition data available, were not designed to be experiments, or were not in service long enough to display significant performance features. It is recommended that proper experimentation be planned so that meaningful data on the potential contribution of these systems can be generated.

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