Development of Improved Mix and Construction Guidelines for Rubber-Modified Asphalt Pavements

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Rubber-modified asphalt pavement mixtures have been used in Sweden and the United States since the 1970s. In these applications ground, recycled tire particles (1/4 in. minus) are added to a gap-graded aggregate and then mixed with hot asphalt cement. The benefits of adding rubber to the mix include increased skid resistance under icy conditions, improved flexibility and crack resistance, elimination of a solid waste, and reduced traffic noise. The major disadvantage of these rubber-modified mixtures is their high initial cost compared with conventional asphaltic concrete pavements. One such rubber-modified asphalt mixture used in the United States is described. The mix ingredients and typical properties are first presented. The requirements for adding and controlling one additional ingredient and for producing an unusual aggregate gradation (gap-graded aggregate) have resulted in construction problems on some projects. These problems can be avoided by proper specifications, controls, and inspection. In the last section of the paper guidelines for use of rubber-modified asphalt mixtures in cold, moderate, and hot environments are presented.

Ground tire rubber has been used as an additive in various types of asphalt pavement construction in recent years (*1*). The use of rubber is of interest to the paving industry because of the additional elasticity imparted to the binder. Resource recycling is an additional benefit of creating a use for waste tires. Each year the United States disposes of about 200 million passenger vehicle tires and 40 million truck tires (*2*). This represents a total of 4 million tons of scrap waste tires. Although a limited number of these 4 million tons of waste tires are used for resource and energy recovery, the vast majority go to landfills or are disposed of in an environmentally unacceptable manner (*2*).

In recent years, rubber-modified asphalt has come to the attention of Congress as a way of solving the ecological problems of disposing of discarded tires. Congress, to stimulate the use of recycled materials, requested the Environmental Protection Agency and the Federal Highway Administration to issue procurement guidelines. In response to the request, the February 20, 1986, issue of the *Federal Register* contains a proposed ruling by the Environmental Protection Agency for Federal Procurement of Asphalt Materials Containing Ground Tire Rubber for Construction and Rehabilitation of Paved Surfaces (*3*). The impact of this proposed guideline remains to be seen. However, many municipalities are currently evaluating the use of discarded tires to modify hot-mix asphalts for road surfacing (*4–8*).

Two different methods of incorporating ground tire rubber into paving mixes have been developed. The method of adding rubber to asphalt mixtures, which will be discussed in this paper, was originally developed in late 1960 in Sweden and patented under the trade names of "PlusRide" in the United States and "Rubit" in Sweden. In this system, rubber-asphalt mixtures are prepared by a process that typically uses 3 to 4 percent by weight relatively large (1/16-in. to 1/4-in.) rubber particles to replace some of the aggregate in the mixture (Figure 1). The benefits of adding rubber to the mix, besides elimination of rubber tire waste, are increased flexibility, resistance to studded tires, increased fatigue life, reduced noise, and crack reflection control. In addition, the increased elastic response of this material also reportedly causes ice formed on the pavement during freezing weather to break under transient vehicle loadings.

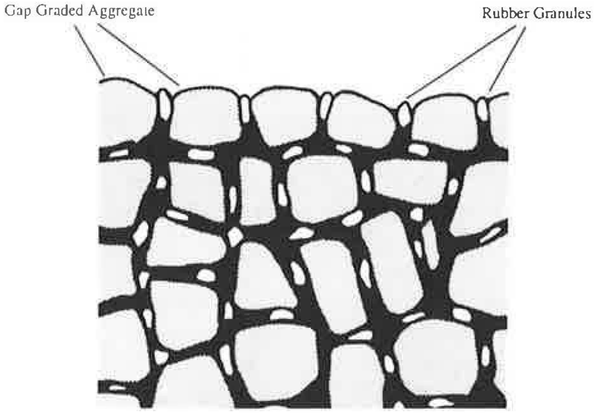

FIGURE 1 Illustration of rubber-modified asphalt (rubber granules are white).

The second type of rubber modification (not discussed here) uses finely ground rubber tire "buffings" that are mixed into the hot asphalt to create a "rubberized asphalt" binder, which is then added to a normal paving aggregate.

The purposes of this paper are to evaluate the use of one type of rubber-modified asphalt paving mixture in road construction and to develop guidelines that indicate how these mixes can best be used in U.S. road systems.

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CURRENT MIX AND CONSTRUCTION GUIDELINES

The rubber-modified asphalt mixture evaluated in this paper is prepared by a process that typically uses 3 percent by weight granulated coarse and fine rubber particles to replace some of the aggregate in the mixture. On the basis of experience in Alaska and Sweden, three different aggregate gradation bands have been recommended for different layer thicknesses to serve different traffic levels (Table 1).

TABLE 1 RECOMMENDED SPECIFICATIONS FOR RUBBER-ASPHALT PAVING MIXTURES FOR DIFFERENT LEVELS OF TRAFFIC (*9*)

	Mix Designation		
	A	B	C
Average daily traffic	2,500	2,500–10,000	10,000
Minimum thickness (in.)	1.0	1.5	1.75
Sieve size (% aggregate passing)			
3/4 in.			100
5/8 in.		100	
1/2 in.			
3/8 in.	100	60–80	50–62
1/4 in.	60–80	30–44	30–44
No. 10	23–38	19–32	19–32
No. 30	15–27	13–25	12–23
No. 200	8–12	8–12	7–11
1/4-in. to No. 10 size fraction		12 max	12 max
Preliminary mix design criteria			
Rubber, % of total mix by			
Weight	3.0	3.0	3.0
Volume (approx.)	6.7	6.7	6.7
Asphalt (% of total mix by weight)	8–9.5	7.5–9.0	7.5–9.0
Maximum voids (%)	2.0	2.0	4.0

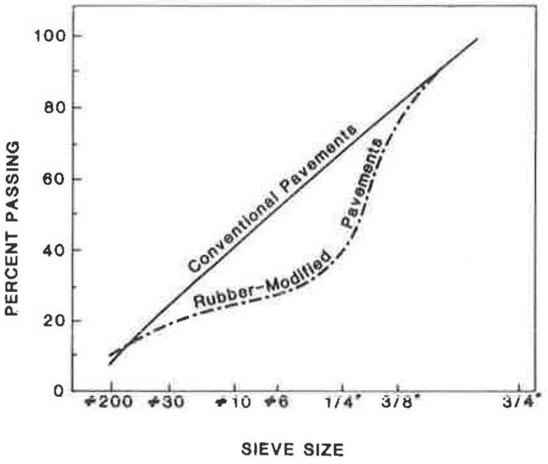

FIGURE 2 Comparative aggregate gradation curves for conventional and rubber-modified asphalt pavements.

TABLE 2 PARTICLE SIZE SPECIFICATION FOR RUBBER (*9*)

	Percentage Passing		
Sieve Size	Coarse Rubber	Fine Rubber	80/20 Rubber Blend[a]
1/4 in.	100		100
No. 4	70–90		76–92
No. 10	10–20	100	28–36
No. 20	0–5	50–100	10–24

[a] The 80/20 is 80 percent coarse and 20 percent fine rubber in combination.

A review of aggregate grading specifications reveals some significant differences between these modified and conventional paving mixtures. The most important difference is indicated by the comparative shapes of the aggregate gradation curves (Figure 2). To provide space for the rubber particles, it is necessary to create a "gap" in the gradation curve of the aggregates, primarily in the 1/8- to 1/4-in. size range. The rubber particles replace a portion of the rock particles that normally occupy this size range.

The rubber particles used in these mixes are specified to be produced in "roughly cubical form" by grinding waste tires, which have first had the steel wires in the tire bead area removed. The rubber may include some tire cord and steel fibers from tire belts and must meet the gradation specifications given in Table 2.

The paving grade asphalt is the same for the rubber-asphalt mixture as for conventional mix. However, rubber-asphalt mix typically requires from 1 1/2 to 2 percent more asphalt than does conventional mix.

Mix Design Considerations

Mix designs for rubber-modified asphalt mixtures are normally arrived at by using the Marshall or Hveem method; however, the criteria for selecting the asphalt content are different for conventional hot-mix asphaltic concrete and rubber-modified asphalt pavements. Most engineers use Marshall stability, flow, cohesion, air voids, and density as criteria for designing conventional hot-mix asphaltic concrete pavements. However, stability values for rubber-asphalt mixes are lower than values obtained for typical asphalt mixes. The flow values for rubber-modified mixes are generally greater than the maximum allowable in asphalt mix design criteria (*10*). Consequently, stability and flow values for rubber-modified mixes may give guidance only in terms of their relative position on design curves, and different criteria should be developed as performance indicators for rubber-modified mixtures.

Experience has shown that the critical factor for successful rubber-modified asphalt installations has been a low percentage of voids in the total mix (*10*). For example, pavements placed in Alaska with low void contents (approximately 4.6 percent) and exhibiting satisfactory performance had stabilities as low as 350 lb and flows of up to 0.19 in. (*10*). In general, the laboratory air voids are recommended to range from 0 to 4 percent maximum depending on the traffic level of the facility being designed (*10*):

- Low traffic—2 to 3 percent,
- Medium traffic—3 percent maximum, and
- High traffic—4 percent maximum.

This required void content is achieved by increasing both the mineral filler and the asphalt cement content until the target value is reached (*10*).

Construction Considerations

Aggregate Production

The most common problems with project batching of acceptable rubber-modified asphalt mixes have been achieving the proper gap in the grading curve and obtaining sufficient fines (No. 200 minus) to serve as a void filler. The lack of mineral filler in the mix causes high air voids and this is of concern to the road agency. Contractors can achieve the (No. 200 minus) requirement by adding baghouse fines or introducing filler such as Cottrell flour, fly ash, limestone dust, or one of several other types of mineral filler (*11*). The percentage by weight of total aggregate for the additional filler material has varied from 2 to 9 percent with an average of 5.3 percent as determined from 15 project summaries (*11*).

Mix Production

Batch, continuous, and drum-dryer plants have been used for mix production (*12, 13*). The experience of the Alaska Department of Transportation and Public Facilities (DOT&PF) indicates that a batch mixing plant is preferable because the required quantities of rubber, asphalt, and aggregates can be measured exactly and added separately to the pug mill or mixing chamber. In this type of plant, preweighed and sacked rubber can be used to advantage, with quantity control by bag count. However, both continuous mix and drum-dryer mix asphalt paving plants have been used without difficulty. In these plants the mixing operation goes on continuously instead of in batches, and the rubber must be added from a separate bin with a belt feed to maintain uniformity. Control in this type of feeding is less accurate. Two additional disadvantages of drum-dryer plants have also been reported. The first problem is the potential for producing smoke, noted on the Lemon Road project in Juneau, Alaska, on a single-entry drum mixer. On this project the flame heat shield had been removed from the drum. Drum mixers set up for the production of recycled mix have generally proven satisfactory. The best drum plants are the double (mid) entry type that allow the rubber to be added in the center of the mixing drum. The second problem occurred when a contractor decided to lower the mixing temperature from 325°F to 305°F. At the lower temperature, asphalt mix began sticking to the flights, which caused the trunnion to slip with the increased load. The slippage was also due to some rubber granules blowing from the feeder belt onto the trunnion. The problem was corrected by cleaning the trunnions and elevating the mix temperature back to 325°F.

Laydown

The laydown of the hot mix must be performed by paving machines equipped with full-width vibratory screens to aid in compaction (*12*). The laydown machinery used includes both hopper and pickup types (*12–14*). Alaska DOT&PF also made one attempt to place the mix by using a motor patrol after end dumping the material (*12*). The mix placed by the grader was too sticky to be easily leveled.

Handwork (such as raking longitudinal joints and placing radii) for the rubber-modified asphalt mixes is affected by the mix gradation and temperatures. According to contractors, the best result of handwork was observed when the mix was at normal laydown temperatures (300°F to 320°F) (*11*).

Compaction

Conventional compaction equipment has been used to roll the rubber-modified asphalt mix. The breakdown rollers are typically 10- to 12-ton vibratory steel drum units (*12–14*). The intermediate and finish rollers are also steel drum units; but they are not always required to be vibratory, nor are they as heavy. Rubber-tired rollers are not recommended according to Swedish engineers. However, experience with rubber-modified asphalt placed in Vancouver, British Columbia, and Anchorage, Alaska, in 1981 indicates that significant surface tightening might be achieved by use of rubber-tired rollers after the mix has cooled below 140°F (*10*).

Current practice is to avoid use of rubber-tired rollers because rutting and pickup problems can occur too easily. Rubber-modified asphalt mix being picked up by the rollers has been reported by several agencies (*12, 13*). The methods used by contractors to prevent or reduce pickup are (*6, 12, 13*)

- Removing rubber-tired rollers from the rolling pattern;
- Making sure all water nozzles are fully operational;
- Using liquid detergent in the drum water; and
- Using a specialty wetting agent, Dewko wetting concentrate, in the drum water.

The most successful method appears to be a combination of making sure that the wetting system is fully operational and including some liquid soap with the drum water (*11*).

REVIEW OF PRIOR PROJECTS

From 1979 to 1987 this process was used in approximately 52 applications throughout the United States. Table 3 gives a summary of the number of tons of rubber-modified asphalt mix placed in the United States.

TABLE 3 SUMMARY OF RUBBER-MODIFIED ASPHALT PROJECTS IN THE UNITED STATES

Year	No. of Projects	Tons of Mix
1979	1	90
1980	1	1,700
1981	4	3,000
1982	8	5,867
1983	6	15,886
1984	7	18,883
1985	14	20,315
1986	11	38,370
Total	52	104,111

As part of the study for Alaska DOT&PF, a survey questionnaire on the performance of these mixes (*15*) was sent to various transportation agencies that had used the rubber-modified asphalt mixes. The questionnaire was designed to obtain the following key items of information from these agencies:

1. Project location and agency in charge;
2. General data, including tons mixed and thickness of paving;
3. Rubber and asphalt content;
4. Construction data and problems encountered;
5. Overall performance and any problems noted;
6. Reasons for using rubberized asphalt; and
7. Project's condition (1987).

A total of 20 experimental projects constructed between 1979 and 1986 were evaluated using the survey questionnaire. Tables 4–6 give summaries of the results of these surveys. As noted, almost all of these projects encountered some difficulties in the construction or performance, or both, of the mix. Many of the performance problems appeared to be related, at least indirectly, to the construction methods used. In a few cases construction was reportedly hampered by "sticky" mixes, which can be attributed to the added rubber. The stickiness appeared to make joint construction difficult. This may have led to reduced rolling and high voids and contributed to early mix raveling. Other possible causes of performance problems included (a) incomplete mixing, (b) excess or insufficient asphalt, (c) high voids, (d) low p-200 content, and (e) erratic rubber content of mix.

TABLE 4 SUMMARY OF MIX DESIGN SURVEY QUESTIONNAIRE

	Average	Range
Asphalt content (%)	7.7	5.0–9.5
Rubber content (%)	3.0	2.5–4.0
Mix temperature (°F)	330	285–360
Total mix time (sec)	30	14–45
Compaction temperature (°F)	320	200–300
Voids in mix (%)	4.8	0.5–12.0

TABLE 5 SUMMARY OF PAVEMENT PERFORMANCE SURVEY QUESTIONNAIRE: PRESENT CONDITION OF RUBBER-MODIFIED ASPHALT MIXES (eight agencies reporting)

	Pavement Condition		
	Severe	Moderate	None
Raveling	1	1	6
Bleeding	0	2	6
Potholing	0	3	5
Wheel track rutting	0	0	8
Cracking	0	0	8

Deicing benefits have been reported by several agencies including the Alaska and Minnesota departments of transportation. Finally, stopping distance tests by the Alaska DOT&PF Research Section showed an average reduction in icy-road stopping distance of 25 percent on rubber-modified pavements for 23 test days over a 3-year period in the Fairbanks area, and a 19 percent reduction in the Anchorage area.

TABLE 6 SUMMARY OF PAVEMENT PERFORMANCE SURVEY QUESTIONNAIRE: OTHER PAVEMENT PERFORMANCE OBSERVATIONS (eight agencies reporting)

Pavement Performance	Noted	Not Noted	Not Evaluated
Ice control	1	6	2
Noise control	4	4	0
Reflective crack control	4	1	3
Skid resistance	3	2	3
Fatigue resistance	3	3	2

EVALUATION OF MIX PROPERTIES

A laboratory study was performed to evaluate the effect of mix variations on properties of rubber-asphalt mixes. The asphalt cement (AC-5 produced by Chevron, USA's Richmond Beach Refinery, primarily from Alaskan North Slope crude) and aggregate (crushed river gravel from Juneau, Alaska) used in this study were obtained from Alaska DOT&PF (Table 7). The recycled rubber was provided by Rubber Granulators in Everett, Washington.

TABLE 7 AGGREGATE GRADATION AND CORRESPONDING SPECIFICATION FOR B MIX

	Percentage Passing		
Sieve Size	Gap Graded	Dense Graded	Specification for B Mix
3/4 in.		10	
5/8 in.	100		100
3/8 in.	70	76	60–80
1/4 in.	37		30–44
No. 4		55	
No. 10	26	36	19–32
No. 30	18		13–25
No. 40		22	
No. 200	10	7	8–12

The two general types of tests used in this study were mix design tests and mix properties tests. The Marshall mix design procedure was used to determine optimum asphalt contents for the different mix combinations. When the optimum asphalt contents had been determined for the different mix combinations, the resilient modulus and fatigue life tests were used to evaluate mix properties.

Mix Design Results

The laboratory mix design results show that the asphalt content required to reach a certain minimum voids level for rubber-modified mixes depends on aggregate gradation, rubber gradation, and rubber content (Table 8). Coarse rubber is defined as rubber particles from ambient-temperature grinding of old tires, of which 80 to 90 percent is in a sieve size range from No. 10 to 1/4 in. The remaining rubber content is tire buffings, primarily in a sieve size range from No. 40 to No. 10. The laboratory results show that the mixture with gap-graded aggregate and 3 percent coarse rubber required the highest design asphalt content (9.3 percent) based on dry aggregate weights. Reducing the rubber content to 2 percent resulted in a reduction in the optimum asphalt content to 8.0 percent. The mixtures with 3 percent coarse rubber and dense aggregate grading required 7.5 percent, and conventional asphalt mix (no rubber) had the lowest design asphalt content (5.5 percent). The design asphalt contents reported were the asphalt contents required to reach the 2 percent air voids level (*16*).

TABLE 8 RECOMMENDED ASPHALT CONTENT AND MIX PROPERTIES AT 2 PERCENT AIR VOIDS (*13*)

Aggregate Gradation	Rubber Content (%)	Rubber Gradation (% coarse/ % fine)	Design Asphalt Content (%)	Marshall Stability (lb)	Flow (0.01 in.)
Gap graded	2	0/000	7.0	920	15
		60/40	7.2	690	21
		80/20	8.0	665	23
	3	0/100	7.5	600	19
		60/40	7.5	650	22
		80/20	9.3	436	33
Dense graded	0	No rubber	5.5	1,500	8
	3	80/20	7.5	550	22

Modulus and Fatigue Results

To evaluate the effect of mix variations on the behavior of rubber-modified asphalt, 20 different mix combinations (Table 9) were tested for diametral modulus (ASTM D 4123) and fatigue at two different temperatures (+10°C and –6°C) (*13*). The mix variables included two void contents, two rubber contents, three rubber gradations, two mix temperatures, two cure times, and use of surcharge. The test results on mix properties show that the modulus and fatigue of rubber-modified asphalt mixes depend on rubber gradation, aggregate gradation, and rubber content.

A summary of the resilient modulus and fatigue life test results at –6°C is given in Table 10. The mix properties test results show that the mixtures with the finer rubber gradations had higher resilient modulus (MR) and lower fatigue life (N_f) values than did mixtures with coarser rubber gradations. In addition, the aggregate gradation affects the mixture properties. The dense-graded aggregate has a higher modulus value. The effect of fatigue on aggregate gradation at two different temperatures (+10°C and –6°C) was reversed. At –6°C the fatigue life was less for mixes with gap-graded aggregate than for mixes with dense-graded aggregate. This unusual performance is mainly due to behavior of rubber particles in the mixture. At +10°C the rubber particles act more as elastic aggregate. However, at –6°C the rubber particles lose some of their elasticity and may work as weak aggregate in the gap-graded mixture. Reducing the rubber content to 2 percent also resulted in higher resilient modulus and lower fatigue life values compared with mixes with 3 percent rubber content.

The findings of this study indicated that rubber gradation, rubber content, and aggregate gradation have a considerable effect on mix design asphalt content, fatigue life, and modulus value. The study also showed that the rubber-modified mixes had a much greater fatigue life than a conventional asphalt concrete mix (*16*).

Creep Behavior

To evaluate the effect of mix variables such as aggregate gradation and rubber gradation on creep behavior, the regression lines for all five mix combinations were compared (Figure 3). In general, the slope of the regression lines for mixes containing rubber are sharper than those for mixes with no

TABLE 9 SPECIMEN IDENTIFICATION (*16*)

Specimen	Rubber Content (%)	Rubber Blend (% fine/ % coarse)	Mixing/ Compaction Temperature (°F)	Asphalt Content (%)	Aggregate Gradation	Cure Time (hr)	Surcharge (lb)
A	3	80/20	375/265	9.3	Gap	0	0
B	3	80/20	375/265	9.3	Gap	2	0
C	3	80/20	375/265	9.3	Gap	0	5
D	3	80/20	425/265	9.3	Gap	0	0
E	3	80/20	425/265	9.3	Gap	2	0
F	3	80/20	425/265	9.3	Gap	0	5
G	3	80/20	375/210	9.3	Gap	0	0
H	3	60/40	375/265	7.5	Gap	0	0
I	3	0/100	375/265	7.5	Gap	0	0
J	3	80/20	425/210	9.3	Gap	0	0
K	2	80/20	375/265	8.0	Gap	0	0
L	2	60/40	375/265	7.2	Gap	0	0
M	2	0/100	375/265	7.0	Gap	0	0
N	3	80/20	375/265	7.5	Dense	0	0
O	3	80/20	375/265	7.5	Dense	2	0
P	3	80/20	375/265	7.5	Dense	0	5
Q	3	80/20	425/265	7.5	Dense	0	0
R	3	80/20	425/265	7.5	Dense	0	0
S	3	80/20	375/210	7.5	Dense	0	0
T	0	No rubber	375/265	5.5	Dense	0	0
U	3	0/100	375/265	7.0	Dense	0	0

TABLE 10 SUMMARY OF RESILIENT MODULUS AND FATIGUE LIFE (*16*)

Mix	No. of Samples Used in Calculations	Average Value of Air Voids		Average Value of MR		N_f	
		Percentage	SD	ksi	SD	Average Value	SD
A	3	2.17	0.06	1,872	27	29,237	3,629
B	3	2.19	0.12	2,044	128	29,736	2,991
C	3	2.18	0.08	2,084	83	25,070	7,600
D	3	2.14	0.08	2,165	18	22,515	1,504
E	3	2.09	0.03	2,149	52	24,174	1,996
F	4	2.13	0.12	2,047	58	20,768	3,887
G	3	4.08	0.27	1,713	194	46,751	20,326
H	3	2.05	0.08	2,356	175	47,990	256
I	4	2.24	0.09	2,149	74	41,194	5,471
J	3	4.02	0.17	1,787	113	43,271	4,617
K	3	2.12	0.07	2,351	50	89,062	7,012
L	3	2.22	0.05	2,488	127	75,325	4,920
M	2	2.33	0.16	2,588	34	41,788	2,075
N	3	2.22	0.19	2,414	212	118,186	15,670
O	3	2.15	0.24	2,592	161	97,032	18,825
P	3	2.21	0.09	2,225	100	84,153	5,007
Q	3	2.12	0.05	2,116	94	93,651	4,198
R	3	2.02	0.11	1,939	133	81,141	8,354
S	3	4.50	0.23	1,443	177	127,682	24,996
T	3	2.25	0.13	3,163	133	15,536	2,562

NOTE: SD = standard deviation. Specimen U was not tested for MR and N_f. Test temperature was −6°C; strain level was 100 microstrain.

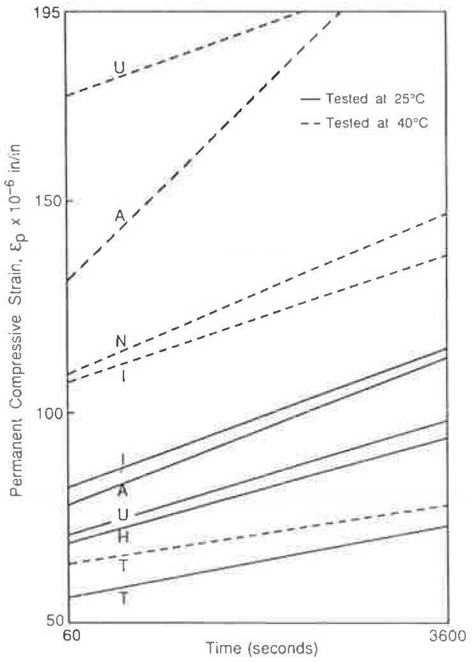

FIGURE 3 Creep behavior of rubber-asphalt mixes.

rubber. Also the intercepts for all rubber-asphalt mixes are at higher values than for mixes with no rubber at both temperatures. These results indicate that the rubber-asphalt mixes have lower creep resistance than the mixes with no rubber.

Among rubber-asphalt mixes, the mix with gap-graded aggregate and coarse rubber (80/20) has the steepest slope, and the dense-graded mix with fine rubber (0/100) has the flattest slope at 40°C. This indicates that the fine rubber improves the creep resistance of rubber-asphalt mixtures. However, there are slight differences among the slopes of all rubber-asphalt mixes, which indicate that the rubber-asphalt mixes have high elasticity.

Permanent Deformation Results

Permanent deformation rates were determined for five different mix combinations. Specimens were tested by cyclic load testing at 100 microstrain (0.01 percent) in a controlled environment at 15°C. Total vertical deformation was measured using a dial gauge accurate to 10^{-3} in.

The test results indicate that the control mix (mix with no rubber) has the steepest slope and the gap-graded mix with 3 percent coarse rubber (80/20) has the lowest slope. In general, all rubber-asphalt mixes have flatter slopes than the control mix (Figure 4). This indicates that the rubber-asphalt mixes have highly elastic behavior.

GUIDELINES FOR USE OF RUBBER-MODIFIED MIXES

On the basis of the results of this study and work by Monismith (*17*), the following guidelines are suggested for use with rubber-modified mixes.

Mix Design Guideline for Hot Climates

For pavements in hot climates (maximum ambient temperature greater than 100°F) that are subjected to large numbers of heavy vehicles or vehicles operating at high tire pressures, or both, rutting may be a controlling factor in mix design. Suggested steps in the mix design process to mitigate rutting are

1. Use rubber-modified asphalt as a thin overlay layer not as a structural layer.

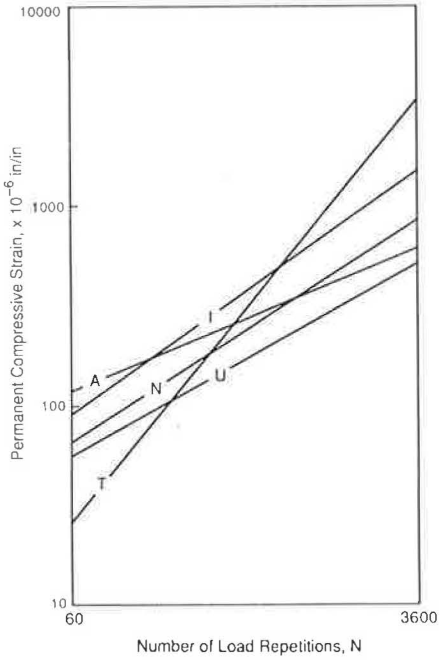

FIGURE 4 Relation between number of load repetitions and vertical strain.

2. The minimum rubber-asphalt layer thickness should not be less than 1 in.
3. Use the same grade of asphalt as is used in conventional cement asphalt pavements.
4. Use rough texture aggregate and Mix A (Table 1) gradation with maximum 9 percent No. 200 filler.
5. Use 3 percent medium rubber (60 percent coarse/40 percent fine, Table 2).
6. Mixing temperatures in the range of 350°F to 375°F and compaction temperatures of from 300°F to 285°F are desirable.
7. Mix the rubber with the aggregate before adding the asphalt.
8. Cure the rubber-asphalt mixture before compaction in an oven (375°F to 350°F) for 1 hr.
9. A preliminary design asphalt content should be selected on the basis of air voids (note that the mix should have an air void content of approximately 3 percent).
10. Determine stiffness of mix at short times of loading (0.1 sec) for expected range in temperatures. Stiffness values should not be less than 300,000 psi at 77°F and 0.1-sec loading time.
11. Perform creep tests on representative specimens to define stiffness of mix as a function of time at 25°C (77°F) and 40°C (100°F). Use 0.5 in. as the criterion for rutting analysis.
12. If the analysis indicates that rutting is at an undesirable level for the expected conditions, the mix must be redesigned and the analysis repeated. The use of fine rubber (0 percent coarse/100 percent fine) can be considered.
13. If the mix is considered suitable, its fatigue performance should be checked.

Mix Design Guidelines for Moderate Climates

For pavements in moderate (maximum ambient temperature of 100°F) climates that are subjected to large numbers of heavy vehicles, fatigue may be a controlling factor in mix design. The following steps represent an approach that can be taken:

1. The minimum rubber-asphalt layer thickness should not be less than 1.5 in.
2. Use the same grade of asphalt as is used in conventional asphalt pavement.
3. Use gap-graded aggregate Mix B (Table 1).
4. Use 3 percent coarse rubber (80 percent coarse/20 percent fine).
5. Mixing temperatures in the range of 320°F to 350°F and compaction temperatures of 300°F to 320°F are desirable.
6. Determine stiffness of mix at short times of loading (0.1 sec) for expected temperatures. Stiffness values should not be less than 250,000 psi at 77°F and 0.1-sec loading time.
7. A preliminary design asphalt content should be selected on the basis of air voids (note that the mix should have an air void content of approximately 3 percent).
8. For all expected traffic and temperature conditions, and for the anticipated range of stiffness (and aging) characteristics of the other rubber or aggregate gradations, perform a fatigue analysis.

Mix Design Guidelines for Cold Climates

In cold climates (minimum ambient temperature of 0°F), low-temperature response will govern the initial selection of mix characteristics. The following steps are suggested for cold climates:

1. The minimum ruber-asphalt layer thickness should not be less than 1.5 in.
2. The rubber-asphalt mixture can be used as an overlay as well as a structural layer.
3. Use the same grade of asphalt cement as is used in conventional asphalt pavement.
4. Use gap-graded aggregate (Mix B or Mix C, Table 1).
5. Use 3 percent coarse rubber (80 percent coarse/20 percent fine) (Table 2).
6. Mixing temperatures in the range of 300°F to 330°F and compaction temperature of 265°F to 300°F are desirable.
7. A preliminary asphalt content should be selected on the basis of air voids (note that the mix should have an air void content of approximately 3 percent).
8. Determine stiffness of mix at short times of loading (0.1 sec) for the expected range of temperatures. Stiffness values should be less than 180,000 psi at 77°F and 0.1-sec loading time.

CONCLUSIONS

On the basis of the results of a laboratory study at Oregon State University and evaluation of the field performance of the pavements made with rubber-modified asphalt mixes, the following conclusions appear warranted:

1. The field survey indicated that most rubber-modified pavements placed to date have not failed in fatigue. Where performance problems have been reported, they have generally been early raveling, or bleeding attributed to excessive voids variation resulting from poor compaction or low or high asphalt contents, or both.

2. Rubber-modified asphalt mixture is more susceptible than conventional mixtures to problems in preparation and compaction because of the need to add and control a third ingredient that has a major effect on overall mix properties and performance. Added plant inspection and increased compaction control efforts are necessary to assure a consistent product. Overall, placement is similar to conventional mixture placement.

3. The laboratory mix design results show that the asphalt content required to reach a certain minimum voids level for rubber-modified mixes depends on rubber and aggregate gradation and rubber content. The asphalt demand of these mixes is much more sensitive to rubber content variations than it is to variation in aggregate size.

4. The increased laboratory fatigue life of these mixes should be further evaluated by comparative field evaluations of underdesigned or overloaded pavement structures.

5. Finally, on the basis of the results of laboratory and field performance of rubber-modified mixes, mix design guidelines for use of these materials in hot, moderate, and cold climates were developed.

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