Use of Rubber in Asphalt Pavements: Kansas Experience

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From 1990 to 1992 eight rubber hot bituminous mix projects were constructed on the Kansas Department of Transportation highway system. Four have been dry and four have been of the wet process. Two projects have been administered through normal bid procedures. Six have been constructed through change orders and negotiated prices. Approximately 616 tons of rubber was used in the hot mix overlays. Preliminary conclusions are as follows: (*a*) From the crack survey results, it is apparent that rubber may not inhibit the development of cracks in the higher-density mixes. However, even though the results are still preliminary, the gap-graded mixes show the greatest potential in reducing the amount of cracking. (*b*) Rubber in a gap-graded mix will prevent asphalt draining off the aggregates during construction. This will allow a thicker film thickness on the aggregates. (*c*) None of the rubber projects have rutted, but neither have the asphalt-only control sections. (*d*) On hot recycle projects, rubber addition rates should be based on the weight of dry virgin aggregate and recycled asphalt pavement. (*e*) Rubber absorbs a large portion of an RA-100 in a hot recycle mix. An AC-5 with rubber will reduce the asphalt absorption and improve the aggregate coating.

In response to a request of the state legislature, the Kansas Department of Transportation (KDOT) started to incorporate ground tire rubber into experimental hot mix overlays in 1990. There were three reasons why KDOT was interested in using ground tires in hot mix:

1. To determine whether it would reduce or retard reflective cracking from old portland cement concrete or bituminous pavements,
2. To determine whether it would reduce the amount of pavement rutting, and
3. To address the environmental concerns over what could be done with old tires.

Over a 2-year period (1990 to 1992), a total of eight projects were constructed. Four have been dry and four have been of the wet process. Two projects have been administered through normal bid procedures. Six have been constructed through change orders and negotiated prices. Test sections were planned on six of the eight projects. However, construction problems on two of the projects limited formal crack surveys to only four projects. Most of the projects allowed KDOT to experiment with mix variations. Standard virgin mixes, new gap-graded mixes, and even recycle mixes were tried on the projects.

The primary method of determining the amount of asphalt and rubber has been the Marshall method (*1*). This is the official mix design method for KDOT and the one most familiar to the field personnel.

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Approximately 616 tons of rubber was used in the hot mix experimental overlays. A map of the project locations for the mixes is shown in Figure 1.

HISTORY

KDOT's previous experience with asphalt rubber dates back to five experimental stress-absorbing membrane interlayer (SAMI) projects constructed in 1977, 1978, and 1979. SAMI consists of an asphalt rubber seal coat followed by a hot mix overlay. Stress-absorbing membrane (SAM) is an asphalt rubber seal coat left as the wearing surface. The results of the test sections were variable. On one project the SAMI section had fewer cracks than the control section, on three sections the control section without asphalt rubber performed the best, and one project had nearly the same performance for both sections. The final report stated that none of the projects have an economic justification for the extra cost of using the asphalt rubber.

Sixteen states participated in a pooled fund study conducted by the Texas Transportation Institute (TTI) in 1986. Iowa and Kansas helped finance the study. Numerous asphalt rubber projects constructed throughout the United States were reviewed. A report issued by FHWA in September 1986 (*2*) concluded that the negative performance of some interlayer installations does not appear to be related to fundamental material properties, but to inappropriate use of the materials.

On the basis of the results of our test sections and those of the TTI study, KDOT decided not to construct any more SAM or SAMI test sections, but to continue literature reviews on asphalt rubber. KDOT then decided to construct several asphalt rubber hot mix test sections to determine whether the thicker lifts of asphalt rubber hot mix would perform better than the SAM or SAMI projects.

Two methods are used by KDOT to accomplish the introduction of rubber into the hot mixes. The first is a wet process, and the second is a new dry process.

WET PROCESS

The wet process is the already familiar MacDonald process. Crumb rubber (Type II or III) was shipped in 22.68-kg (50-lb) bags from a tire supplier or the tire grinding facility. The bags were then broken and the rubber conveyed to a mixing tank where hot asphalt at approximately 204°C (400°F) was blended with the ambient temperature rubber. A typical blending ratio of 18 percent rubber and 82 percent AC-5 was used, but a blend ratio of 16/84 was also tried. The combined asphalt-rubber was then pumped to

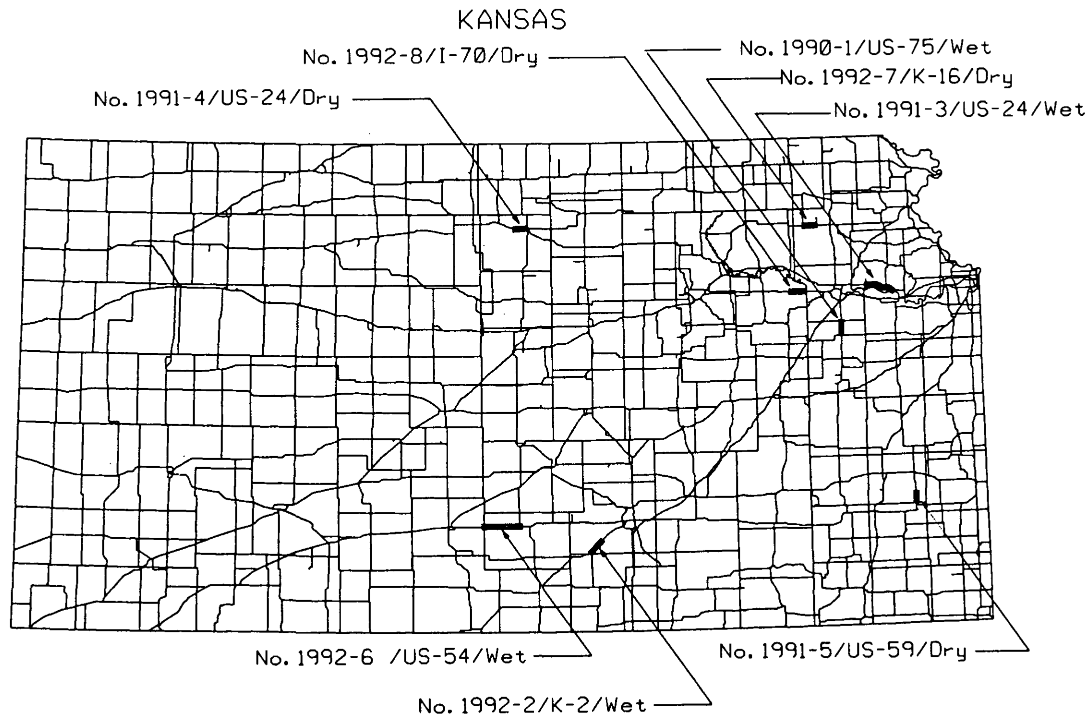


FIGURE 1 KDOT's rubber projects, 1990 to 1992.

another heated tank where the blended material was allowed to "react" for 45 to 90 min at approximately 177°C (350°F).

After the asphalt-rubber had been reacted, the material was metered into the mixing chamber of the asphalt concrete production plant at the percentage required by the job mix formula. Both a batch mix plant and drum-drier mix plant were used in KDOT projects.

Trucks used for hauling the paving mixture were tailgate discharge, dump or moving bottom (horizontal discharge) type and were compatible with the spreading equipment. At no time were bottom dump trucks used on the projects.

Paving was accomplished by a normal self-propelled, mechanical spreading and finishing paver. They were capable of distributing the material to not less than the full width of a traffic lane and to the desired depth.

Compaction equipment conisted of self-propelled rollers equipped with pads and a watering system to prevent sticking of the paving mixture to the steel-tired wheel (drums). At least two rollers were used on the projects. Usually there were three steel rollers available. Pneumatic-tire rollers were hardly ever used because of the increased adhesiveness of the asphalt-rubber binder.

DRY PROCESS

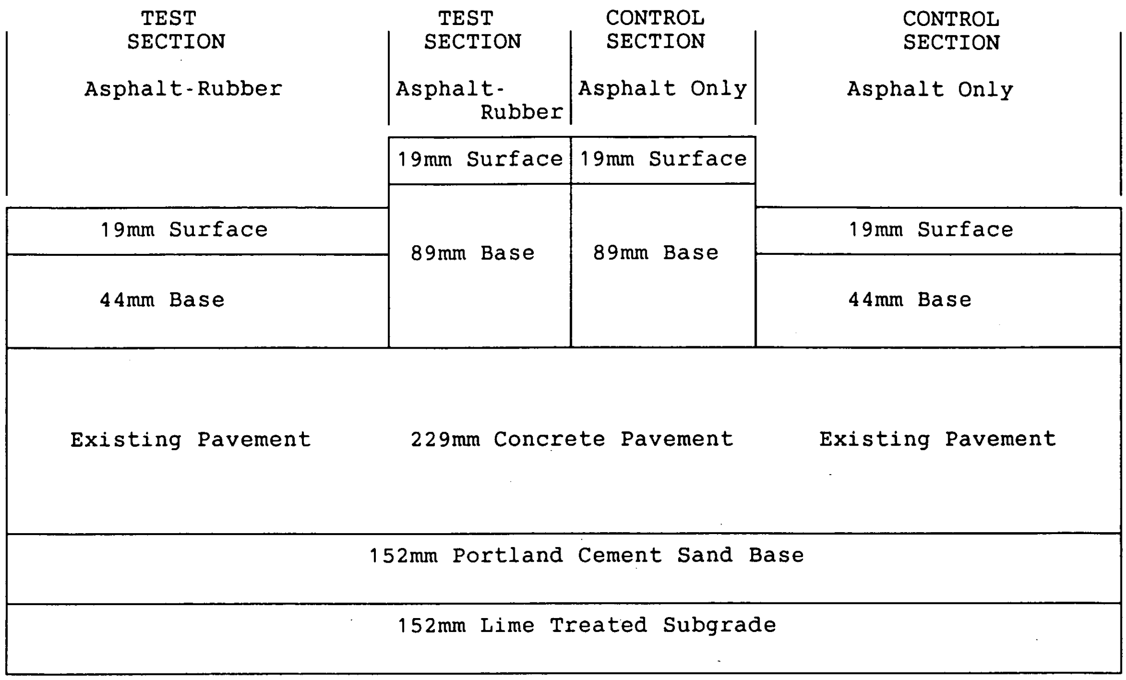
The follow dry process was the only process that KDOT tried as an alternative to the more expensive and previously described MacDonald (wet) process. It is applicable to a double drum plant mixer but was tried later on a drum mixer as well. To date, all of the projects constructed under this process used the UltraFine Rouse rubber or what is commonly referred to as GF-80 rubber.

The process involves the handling of the UltraFine GF-80 rubber in bulk form (versus bags in the wet process) through the use of pressurized truck tankers. The tanker blows the rubber into a storage silo. A gate, located at the bottom of the storage silo, discharges the rubber into a weigh chamber. The weigh chamber continuously measures the weight of the rubber where it can be monitored in the control facility. A vane feeder is also attached to the bottom of the weigh container that will meter the rubber or control the rubber feed rate. The rubber feed rate can be regulated to give the desired rubber mix content at the plant mix production rate. After the vane feeder has metered the ultrafine rubber out of the weigh container, the conveyor or auger system discharges the rubber into the outside mixing chamber of a double drum plant. The rubber is added at the same relative location as the asphalt cement and bag house fines. After hot asphalt is mixed very briefly with the superheated aggregate, the UltraFine GF-80 rubber is fed into the mix. The mix is then completely mixed in the outer barrel of the double drum plant. There is no reaction in that the rubberized asphalt is not held at elevated temperatures for 45 to 90 min.

The mix is discharged from the plant and handled in a manner similar to any other mix operation. Typically, steel rollers are used instead of pneumatic rollers because of the increased potential of rubber in the mat to stick to the rubber tires of the pneumatic rollers.

HOT MIX PROJECTS, 1990

Two 1990 projects were located on US-75 south of Topeka and on K-2 southwest of Wichita. The Topeka project (Figure 1, No. 1990-1) was constructed over an old portland cement concrete pavement, and the Wichita project (Figure 1, No. 1990-2) was



1"=25.4mm

FIGURE 2 Location of test sections, US-75, Osage County (No. 1990-1).

placed over an old bituminous pavement. These were not highly experimental projects involving a great amount of testing. International Surfacing, Inc., of Phoenix, Arizona, was the subcontractor and did the preliminary mix design. The sections were constructed using their guide specifications and appropriate items from KDOT's standard specifications.

No. 1990-1, US-75, Wet

The Topeka project began about 8.1 km (5 mi) south of Topeka and continued south into Osage County. The test and control sections were located in the two northbound lanes and are shown in Figure 2. The two thicker sections were 0.8 km (0.5 mi) long and received two base course lifts of 44-mm (1.75-in.) BM-1B and one lift of a 19-mm (0.75-in.) BM-1T, for a total thickness of 108 mm (4.25 in.) over the old PCCP. The two thinner sections, each 1.61 km (1 mi), received one lift of 44-mm (1.75-in.) BM-1B and one lift of 19-mm (0.75-in.) BM-1T, a total thickness of 64 mm (2.5 in.). The rest of the project was constructed 64 mm (2.5 in.) thick as shown in the thin section. The 1989 traffic count on this four-lane roadway was 6,610 AADT.

The BM-1B base course had gradation limits as given in Table 1. This mix is predominately a crushed limestone mix that has been used for the last 2 years to reduce rutting. Most of the time the mix has been placed approximately 38 mm (1.5 in.) thick. The 19-mm (1.5-in.) BM-1T surface course is normally used for skid resistance on overlay projects for roadways with greater than 5,000 vehicles per day. It contains approximately 50 percent crushed limestone with 40 percent chat for skid resistance. Table 1 presents its gradation limits. The same two mixes were used on the Wichita project. The asphalt-rubber was placed using a drum

TABLE 1 Virgin Mix Gradations

MIX DESIGNATION	PERCENT RETAINED-SQUARE MESH SIEVES									
	19mm	12.5mm	9.5mm	4.75mm	2.36mm	1.18mm	600um	300um	150um	75um
BM-1B	0	0-10	12-26	39-56	60-76	72-87	79-92	84-95	88-98	92-98
BM-1T		0	0-14	39-56	57-72	70-85	78-91	84-94	87-97	92-98
BM-Gap Experimental		0	8-22	71-83	81-91	84-94	87-95	91-97	92-98	94-98
BM-2A	0		6-21	23-40	38-56		61-78			91-97

mix plant, in which the contractor had a new pipe installed in the drum near the existing asphalt supply line.

No. 1990-2, K-2, Wet

On the project located approximately 21 km (13 mi) southwest of Wichita, asphalt-rubber hot mix was placed near Viola. Shown in Figure 3 are the typical sections consisting of 57 mm (2.25 in.) of BM-1B and 19 mm (0.75 in.) of BM-1T, for a total of 76 mm (3.0 in.). The thinner sections consisted of 38 mm (1.5 in.) of BM-1B and 19 mm (0.75 in.) of BM-1T, for a total of 57 mm (2.25 in.).

The existing bituminous pavement had numerous transverse, longitudinal, and block cracks. Many of the transverse cracks had secondary cracks. Generally, there were slight depressions associated with the secondary cracks. Most of the roadways were on a straight alignment and flat grade.

Tables 2 and 3 present the cost data of these short experimental test sections.

HOT MIX PROJECTS, 1991

Because of the high cost of the construction of the 1990 small 2.4-km (1.5-mi) test sections, a larger and complete asphalt-rubber overlay was constructed. The principal idea was to determine whether the volume of material and the normal state competitive bidding procedures would reduce the overall cost.

No. 1991-3, US-24, Wet

The wet process was used and the design was again completed by the subcontractor (International Surfacing, Inc.). The subcontractor also accomplished the blending and reacting of the asphalt-rubber. As in the 1990 projects, a BM-1T mix was used on most of the project. However, two test sections, each 1 mi, were also designed and constructed after the total project had been awarded to the successful bidder. One of the test mixes was gap graded as indicated in Table 1. The aggregate gradation increased the voids in the mineral aggregate, which in turn allowed room for more asphalt-rubber into the mix.

The second test mix on this project was a normal BM-1T but with asphalt-rubber. This mix was also constructed on the rest of the project. A control section was constructed with a BM-1T mix using only asphalt as the binder. The location of the third project is indicated in Figure 1 (No. 1991-3). Table 4 gives a description of the aggregate, binder content, and cost data. Approximately 18.8 km (11.7 mi) of a 25-mm (1-in.) overlay was constructed on US-24 in Jefferson and Douglas counties.

As indicated in Table 4, costs still remain high, and competitive bidding on larger quantities did not appreciably reduce the cost of the overall mix. Therefore, to reduce the cost and still incorporate rubber directly into the mix, a proposal from a contractor was approved to experiment with the use of crumb rubber as an aggregate (dry process). The contractor owned a double drum counterflow hot mix plant, and the rubber could be fed so that it would not blow out with the exhaust. The ultrafine rubber was shipped from Mississippi and stored in a plant silo. When the plant was operating, the rubber was fed through a vane feeder to approximately the same location where recycled asphalt pavement (RAP) would be introduced into the plant.

No. 1991-4, US-24, Dry

Three test sections and one control section were constructed as indicated in Figure 1 (No. 1991-4). This was the fourth crumb rubber project but the first using the new dry method. Even though

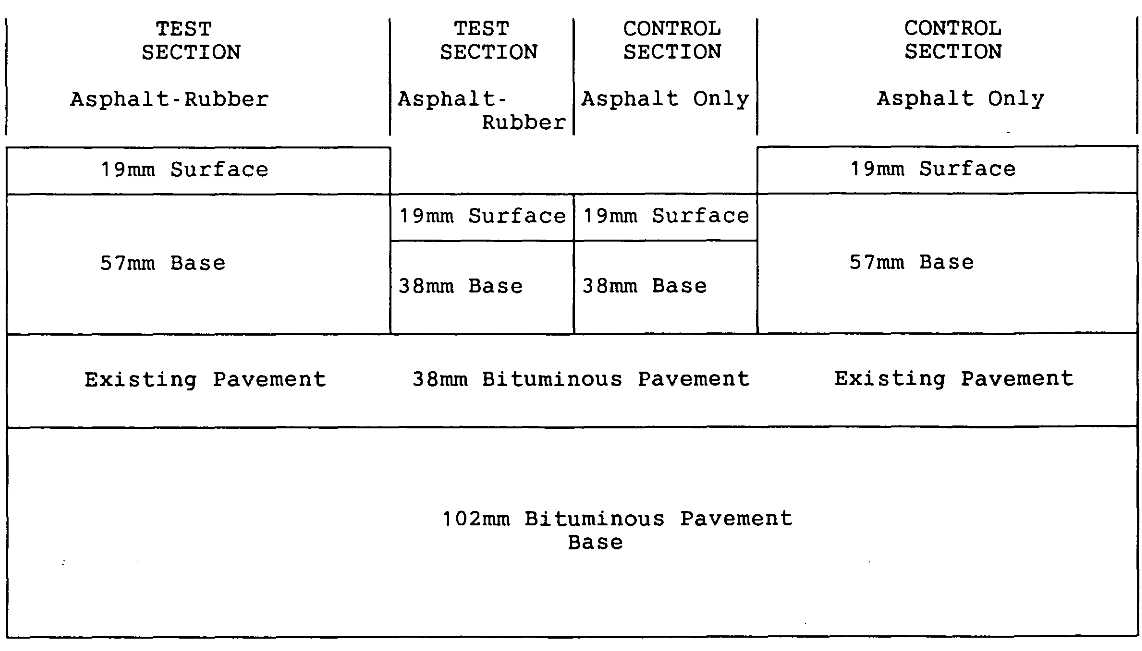


FIGURE 3 Location of test sections, K-2, Sedgwick County (No. 1990-2).

TABLE 2 Mix and Cost Data, US-75, Osage County (No. 1990-1), Wet Process

MIX	DESCRIPTION	BINDER CONTENT (AGGREGATE BASED) (%)	COST DATA (MIX) ($/TON)
BM-1B	Asphalt Only 85% Crushed Limestone 15% Sand	4.75% AC-10	17.09
BM-1B	Asphalt-Rubber 85% Crushed Limestone 15% Sand	6.16% ACR 16% Type III Rubber 84% AC-5	46.18
BM-1T	Asphalt Only 47% Crushed Limestone 40% Chat (Mine Tailings) 13% Sand	5.5% AC-10	19.97
BM-1T	Asphalt-Rubber 47% Crushed Limestone 40% Chat (Mine tailings) 13% Sand	6.3% ACR 16% Type III Rubber 84% AC-5	49.22

TABLE 3 Mix and Cost Data, K-2, Sedgwick County (No. 1990-2), Wet Process

MIX	DESCRIPTION	BINDER CONTENT (AGGREGATE BASED) (%)	COST DATA (MIX) ($/TON)
BM-1B	Asphalt Only 75% Crushed Limestone 25% Sand	5.0% AC-20	17.60
BM-1B	Asphalt-Rubber 75% Crushed Limestone 25% Sand	6.6% ACR 18% Type II Rubber 82% AC-5	44.64
BM-1T	Asphalt Only 36% Crushed Limestone 40% Chat (Mine tailings) 24% Sand	5.75% AC-20	19.64
BM-1T	Asphalt Rubber 36% Crushed Limestone 40% Chat (Mine tailings) 24% Sand	7.4% ACR 18% Type II Rubber 82% AC-5	49.45

TABLE 4 Mix and Cost Data, US-24, Jefferson County (No. 1991-3), Wet Process

MIX	DESCRIPTION	BINDER CONTENT (AGGREGATE BASED) (%)	COST DATA (MIX) ($/TON)
BM-1T	Asphalt Only 45% Crushed Limestone 40% Chat (Mine tailings) 15% Sand	5.25% AC-10	21.05
BM-1T	Asphalt-Rubber 45% Crushed Limestone 40% Chat (Mine tailings) 15% Sand	6.9 18% Type II Rubber 82% AC-5	48.97
BM-Gap Graded	Asphalt-Rubber 60% Crushed Limestone 40% Chat (Mine Tailings)	8.9% AC-10 18% Type II Rubber 82% AC-5	57.71

the rubber was added separately to the mix, it was designed as part of the liquid binder. A 10 percent asphalt-rubber mix was computed as 10 parts rubber (by weight) to 90 parts asphalt.

No major problems were encountered with the rubberized asphalt overlay. The mix was a 51-mm (2-in.) KDOT BM-2A (low traffic surface course) laid over a milled surface.

Table 5 gives the data on the cost of the asphalt mix and three rubberized asphalt mixes, excluding mobilization. Because of the relatively small quantity of rubber used on the project, the mobilization cost was a major expense. If the project had been larger with a greater utilization of rubber, the cost of mobilization would have been less significant. Also, in Table 5, the mix cost excludes

TABLE 5 Mix and Cost Data, US-24, Mitchell County (No. 1991-4), Dry Process

MIX	DESCRIPTION	BINDER CONTENT (AGGREGATE BASED) (%)	COST DATA (MIX) ($/TON)
BM-2A	Asphalt Only 66% Crushed Limestone 34% Sand	5.25% AC-10	20.22
BM-2A (3 Binder Contents)	Asphalt-Rubber 66% Crushed Limestone 34% Sand	5.5% ACR 5% Ultra Fine Rubber 95% AC-10	21.96
		5.5% ACR 7.5% Ultra Fine Rubber 92.5% AC-10	22.70
		5.5% ACR 10% Ultra Fine Rubber 90% AC-10	23.44

all other indirect costs such as tack coats, stripping, and so forth. The effect of these indirect costs would be relatively small.

No. 1991-5, US-59, Dry

The fifth project continued experimentation with the new dry process. The project was a hot mix recycle that was started in 1991 but not finished until 1992 (Figure 1, No. 1991-5). The project was the first attempt to introduce rubber into a hot recycle mix by this process. Previous KDOT products using the fine rubber involved virgin aggregates with a viscosity-graded asphalt cement.

This project was originally set to add the fine rubber to both a 30 percent RAP/70 percent virgin aggregate mix and 50 percent RAP/50 percent virgin aggregate. Both mixes would have control sections where no rubber would be added. The plan was to build a total of five test sections and two control sections.

As in the previous dry process, the rubber was added directly into the mix with no preblending or reacting with the liquid asphalt. The amount of rubber to be added was calculated as a percentage of the total liquid binder (asphalt added plus asphalt in the RAP). This calculation could also be expressed as a blend ratio. A 10 percent asphalt-rubber mix blend ratio was computed as 10 parts rubber (by weight) to 90 parts asphalt. Using this example for the asphalt-rubber recycle mixes, the 90 parts asphalt would include the asphalt added at the plant plus the asphalt in the RAP. If more asphalt was added at the plant, more rubber needed to be added to comply with the overall blend ratio.

The project was complicated further by the fact that two different additives were used for the two different mixes. An AC-5 was used in the 30/70 mix, and an RA-100 asphalt rejuvenator was added to the 50/50 mix.

Construction began during late fall 1991. The existing 3.35-m (11-ft) road was first milled to a depth of 38 mm (1.5 in.). Bituminous shoulders were extended 0.46 m (1.5 ft) at a depth of 114 mm (4-1/2 in.), which widened the total roadway to 9.1 m (30 ft). Cold weather prevented completion of the project, but a 38-mm (1.5-in.) lift of the control and test sections was finished before winter shutdown. Severe raveling occurred on the first lift, but it was uncertain whether this was due to the rubber in the mix or the cool weather at the time of construction. The surface was "smoke coated" with a diluted asphaltic emulsion by state maintenance forces. This was to control the raveling and keep the wheelpaths from "shelling out."

During the winter, a decision was made to increase the binder content to counteract the effects of the raveling. Also, construction would first be completed on other portions of the project so that the top and final lift would be constructed during warmer months of the construction season.

The 30 percent RAP/70 percent virgin test and control sections were constructed without any major problems. The rubber asphalt content was increased beyond what was originally recommended, and this appeared to help reduce the tendency of the mix to ravel. The mix appeared to be tender and was somewhat difficult to compact. The section with 10 percent rubber looked better and had better workability.

Major problems occurred in the 50/50 mix. When the rubber asphalt was increased, the rubber had to be substantially increased to maintain the overall blend ratio. The resulting mix still appeared to be dry and would not adhere to the aggregates. Apparently the additional rubber absorbed the RA-100 and prevented proper coating of the aggregates. Various percentages of additives were tried in the southbound lane, but none proved effective. Finally, a tanker load of AC-5 was ordered and used in the opposite lane the following day. This proved to be much more effective in coating the aggregates. The 50/50 mix had to use an AC-5 instead of an RA-100 to finish the test sections.

If rubber is to be added in a hot recycle project, it should not be tied to the total asphalt content as a blend ratio. It should be based on the weight of RAP and virgin aggregate (i.e., 10 lb rubber per ton of virgin aggregate and RAP). The percentage of new asphalt could then be increased or decreased without affecting the rate of rubber utilization. Estimated quantities would be more accurate and production yield rates would be more manageable.

HOT MIX PROJECTS, 1992

In 1992 the hot recycle project on US-59 in Allen County was completed. Three additional rubber projects were completed, bringing the number of KDOT rubber projects to eight. Initial crack survey results on the 1990 and 1991 projects indicated that the gap-graded mix may prove more beneficial with regard to pavement cracking. Therefore, two more rubber projects were constructed using a gap-graded mix.

No. 1992-6, US-54, Wet

The sixth project used the wet process. Competitive bids were received on a 29.8-km (18.5-mi) project on US-54 in Kingman County (Figure 1, No. 1992-6). This project did not contain any test or control sections. The mix on this project was designed and the binder reacted by International Surfacing, Inc. Costs were still high compared with a normal paving grade asphalt cement.

No. 1992-7, K-16, Dry

The seventh project (Figure 1, No. 1992-7), incorporating a gap-graded mix and a BM-1B mix, used the double-drum dry process. Prices were again negotiated and several test sections built. The method of determining rubber content on this project was changed and based on weight of dry aggregate. The asphalt cement and rubber were varied independently of each other. The three test sections and control section of the BM-1B mix were built with increased amounts of asphalt or rubber.

Three test sections and one control section were also built using the gap gradation as previously described. The 0.8-km (0.5-mi) control section contained asphalt without rubber. Severe problems were encountered with the gap-graded asphalt-only mix. The asphalt would drain down from the aggregates and stick to the truck beds. When rubber was added to the mix this "drain down" problem was substantially reduced. This mix very closely resembled a stone mastic asphalt (SMA) mix gradation. The major difference was that rubber (instead of fibers in an SMA mix) was used to control the amount of binder runoff of the aggregate. This allowed a thick asphalt-rubber film coating of the aggregates. Table 6 gives the mix and cost data of the control and test sections.

TABLE 6 Mix and Cost Data, K-16, Jackson County (No. 1992-7), Dry Process

MIX	DESCRIPTION	BINDER CONTENT (AGGREGATE BASED) (%)	COST DATA (MIX) ($/TON)
BM-1B	Asphalt Only 80% Crushed Limestone 20% Sand	5.5% AC-10	17.67
BM-1B (3 Binder Contents)	Asphalt Rubber 80% Crushed Limestone 20% Sand	5.0% AC-10 1.0% Ultra Fine Rubber	24.27
		6.0% AC-10 1.0% Ultra Fine Rubber	24.79
		7.0% AC-10 1.0% Ultra Fine Rubber	25.29
BM-Gap Graded	Asphalt Only 100% Crushed Limestone	6.0% AC-10	20.55
BM-Gap Graded (3 Binder Contents)	Asphalt-Rubber 100% Crushed Limestone	8.0% AC-10 1.0% Ultra Fine Rubber	28.30
		8.0% AC-10 1.5% Ultra Fine Rubber	31.59
		8.5% AC-10 1.5% Ultra Fine Rubber	31.80

TABLE 7 Crack Survey, US-75, Osage County (No. 1990-1)

SURVEY DATE (Mo/Day/Yr)	TRANSVERSE CRACKING (PERCENT OF ORIGINAL)			
	THIN OVERLAY		THICK OVERLAY	
	CONTROL SECTION (Asphalt Only) 19mm Surface BM-1T 44mm Base BM-1B	TEST SECTION (Asphalt-Rubber) 19mm Surface BM-1T 44mm Base BM-1B	CONTROL SECTION (Asphalt Only) 19mm Surface BM-1T 89mm Base BM-1B	TEST SECTION (Asphalt-Rubber) 19mm Surface BM-1T 89mm Base BM-1B
6-20-1990	0 (Construction)	0 (Construction)	0 (Construction)	0 (Construction)
10- 4-1990	0	0	0	0
1-17-1991	31	47	1	10
5- 2-1991	34	62	5	27
10- 3-1991	31	62	3	25
5-21-1992	50	62.3	4	39
10- 6-1992	39	58.5	3	34
4-16-1993	58	70.7	23	40

1" = 25.4mm

TABLE 8 Crack Survey, K-2, Sedgwick County (No. 1990-2)

SURVEY DATE (Mo/Day/Yr)	TOTAL CRACKING (PERCENT OF ORIGINAL)			
	THIN OVERLAY		THICK OVERLAY	
	CONTROL SECTION (Asphalt Only) 19mm Surface BM-1T 38mm Base BM-1B	TEST SECTION (Asphalt-Rubber) 19mm Surface BM-1T 38mm Base BM-1B	CONTROL SECTION (Asphalt Only) 19mm Surface BM-1T 57mm Base BM-1B	TEST SECTION (Asphalt-Rubber) 19mm Surface BM-1T 57mm Base BM-1B
8-29-1990	0 (Construction)	0 (Construction)	0 (Construction)	0 (Construction)
10-31-1990	0	0	0	0
1-18-1991	0	0	0	.4
10- 2-1991	0	0	0	.2
5- 1-1992	.4	5.6	0	1.6
12- 2-1992	3.4	6.4	.4	2.9
5- 4-1993	28.5	32.1	10.2	24.8

1" = 25.4mm

No. 1992-8, I-70, Dry

The last project was constructed on I-70 in Wabaunsee County (Figure 1, No. 1992-8). The project was built late in the construction season. The contractor was willing to try to use a normal drum mixer instead of a double drum mixer, incorporating the ultrafine rubber into the mix. Rubber was again vane fed out the silo but air blown into a coater placed at the discharge end of a drum mixer. The rubber was not introduced into the mix inside the drum dryer, where the hot gases could remove the fine rubber from the mixing chamber.

PRELIMINARY RESULTS

Even though it is too early to evaluate the final performance of the rubber projects, the following preliminary conclusions are presented:

1. Tables 7 through 10 give the crack survey results to date on several of the projects. From these results it is apparent that rubber may not inhibit the development of cracks in the higher-density mixes. Even though the results are still preliminary, the gap-graded mixes show the greatest potential in reducing the amount of cracking.

TABLE 9 Crack Survey, US-24, Jefferson County (No. 1991-3)

SURVEY DATE (Mo/Day/Yr)	TOTAL CRACKING (PERCENT OF ORIGINAL)		
	CONTROL SECTION 25mm Surface BM-1T (5.25% Asphalt Only)	TEST SECTION 25mm Surface BM-1T (6.9% Asphalt-Rubber)	TEST SECTION 25mm Surface Gap Graded (8.9% Asphalt-Rubber)
5-30-1991	0 (Construction)	0 (Construction)	0 (Construction)
10- 3-1991	.7	0	0
5-21-1992	18.7	3.0	0
10- 6-1992	15.4	2.8	.3
4-19-1993	71.3	30.9	0
10-27-1993	49.2	12.8	0

1" = 25.4mm

TABLE 10 Crack Survey, US-24, Mitchell County (No. 1991-4)

SURVEY DATE Mo/Day/Year	TOTAL CRACKING (PERCENT OF ORIGINAL)			
	CONTROL SECTION (Asphalt Only)	TEST SECTION (95% Asphalt) (5% Fine Rubber)	TEST SECTION (92.5% Asphalt) (7.5% Fine Rubber)	TEST SECTION (90% Asphalt) (10% Fine Rubber)
5-28-1991	0 (Construction)	0 (Construction)	0 (Construction)	0 (Construction)
12- 5-1991	38.5	87.8	70.4	21.3
7-30-1992	47.7	87.4	73.5	41.7
7-19-1993	91.4	131.1	99.6	86.1

1" = 25.4mm

2. Rubber in a gap-graded mix will prevent asphalt draining off the aggregates during construction. This will allow thick film on the aggregates and help retard the tendency of the mix to stick to truck beds, and so forth.

3. None of the rubber projects have rutted, but neither have the asphalt-only control sections.

4. On hot recycle projects using the dry process, rubber addition rates should be based only on the weight of dry virgin aggregates and RAP.

5. Rubber and RA-100 are very reactive in a hot recycle mix. Rubber appears to absorbed most of the RA-100, thereby causing a dryer than normal mix. An AC-5 with rubber will reduce the asphalt absorption and improve aggregate coating.

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