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Using Ground Tire Rubber in Hot Mix Asphalt Pavements

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16. Abstract
This report documents the construction and performance of the research study which was initiated to address section 1038(d) of the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA).

The project selected to demonstrate the crumb rubber process was located on Platt Canyon (SH 75) from Bowles to C470 in the Denver Metropolitan area. The project was a low volume roadway and quantities of crumb introduced into the mix was minimal. This was to reduce risk in terms of premature failure and Colorado's experience with crumb rubber was limited.

Because of this limited experience the "dry" process was selected because with this process it is easier to control the mixing and less complicated for the contractor. The project contained four different mix designs. A mix containing 1% (20lbs/ton) crumb rubber, a mix containing 1lb/ton, a mix containing 3lb/ton and a mix which contained no rubber were placed on the project

The overall performance of the different evaluation sections was not dramatic and no excessive distress was apparent at the conclusion of the study. However before Colorado would incorporate crumb rubber into their mixes more extensive research would need to be conducted.

Implementation

It is recommended until the addition of larger quantities of crumb rubber in Hot Bituminous Pavement (HBP) is shown to be cost effective in addition to enhancing the long term performance of the pavement that crumb rubber usage be limited to research applications. However CDOT has no further plans to pursue the use of crumb rubber in HBP. At this time CDOT is implementing Superpave performance graded (PG) binders and currently there is a national study that is evaluating the use of crumb rubber as a PG binder modifier.

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by

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EXECUTIVE SUMMARY

This report documents the construction and performance of the research study which was initiated to address section 1038(d) of the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA).

In December 1991, ISTEA was signed into law. Section 1038(d) of this legislation required states to use a minimum amount of crumb rubber from recycled tires in asphalt surfacing placed each year beginning with the 1994 paving season. The percentage of recycled crumb rubber in the asphalt paving was to begin at 5% and increase by 5% each year until 1997 when the percentage would be 20%. It was to remain at 20% each year thereafter. Noncompliance with this legislation would result in severe Federal funding reduction.

In October 1993, the House and Senate imposed a one-year moratorium on Section 1038(d) of ISTEA. In September 1994, the House and Senate passed the FY95 Department of Transportation Appropriations Bill (HR 4556). This bill extended the moratorium on the Federal Highway Administration's enforcement of the crumb rubber minimum utilization requirements in Section 1038(d) of ISTEA.

In 1994, Colorado initiated a research project to incorporate crumb rubber into their pavements to identify construction, environmental and other potential problems. Colorado chose to begin first with the "dry" process because with this process it is easier to control the mixing and less complicated for the contractor.

Project No. C 0751-002 was selected for evaluation. This project was located in the Denver Metropolitan Area on SH 75, between West Bowles Avenue and C470 in Littleton. The project contained 4 different mix designs: one containing 1% (20 lbs./ton) crumb rubber, one containing 3 lbs./ton, one containing 1 lb./ton and one mix design containing no crumb rubber. Four 1000 foot test sections were established. One evaluation section was established for each of the mixes containing crumb rubber in

addition to one in the section containing no crumb rubber.

The NHS Designation Act of 1995 amended Section 1038(d) of the ISTEA legislation by eliminating the crumb rubber mandate and all associated penalties. Although states were no longer required to use crumb rubber in asphalt paving, this research study was already inplace and evaluations continued as originally planned.

Although following the five-year evaluation, the use of small quantities of crumb rubber in Hot Bituminous Pavement (HBP) proved to be feasible, it was not, however, an economical method for recycling waste tires. In this study the cost-per-ton of the mix was increased by 21% when the higher percentage (20 lbs./ton) of crumb rubber was used. This would be a significant cost increase if higher percentages of crumb rubber were used.

Implementation

Until the addition of larger quantities of crumb rubber in HBP is shown to be cost effective in addition to enhancing the long term performance of the pavement, it is recommended that crumb rubber usage be limited to research applications. However the Colorado Department of Transportation has no plans to pursue the use of crumb rubber in HBP.

TABLE OF CONTENTS

1.0 BACKGROUND....1
1.1 Federal Legislation....1
1.2 Colorado Legislation....2
2.0 COLORADO'S HISTORY USING CRUMB RUBBER....4
3.0 COLORADO'S CRUMB RUBBER PROJECT....6
3.1 Development of mixes....6
3.2 Selection of Crumb Rubber Hot Bituminous Pavement Mix....8
4.0 CONSTRUCTION....10
4.1 Project Description....10
4.2 Project Plans....10
4.3 Evaluation Section....10
4.4 Pre-Construction Evaluation....11
4.5 Plant Description....11
4.6 Laydown Operations....12
4.7 Crumb Rubber Supplier....13
4.8 Additional Costs With Crumb Rubber....13
5.0 EVALUATION....19
5.1 Field Verification Test Results....19
5.2 Asphalt Content Stability, Field Compaction and Volumetrics....20
5.3 Testing in French Rutting Tester....20
5.4 Field Evaluation....21
6.0 CONCLUSIONS AND RECOMMENDATIONS....26
6.1 Conclusion....26
6.2 Recommendations....27
7.0 COLORADO'S WASTE TIRE RECYCLING PROGRAM....28
REFERENCES....29
APPENDIX A....A-1
APPENDIX B....B-1
APPENDIX C....C-1

LIST OF FIGURES

1. Location of project 9
2. Location of crumb Rubber Section 15
3. Typical distress found in existing pavement prior to construction 16
4. Crumb Rubber was supplied in 2000 lb bags 17
5. An overview of the crumb rubber system 17
6. An auger was used to transport the crumb rubber to the RAP collar 18
7. An overview of the crumb rubber system 18
8. Photograph of surface of 1% section at final evaluation August 1999 (five year old pavement) 24
9. Surface of the 1lb/ton. Notice the rubber particles on the surface 25
10. Surface of the 20 lb/ton. Notice the rubber particles on the surface 25

LIST OF TABLES

1. Crumb Rubber Mix Design 7
2. Bid cost of Crumb Rubber and Hot Mix Asphalt Mixes 13
3. Crumb Rubber Gradation Results 19
4. Asphalt Content, Stability, Field Compaction and Volumetrics Test Results 20
5. French Rut Tests 21

1.0 BACKGROUND

A large number of used tires are discarded each year in the United States. In 1990, it was estimated that 242 million scrap tires were generated, an average of one tire per person. (1) Based on the 1990 census for Colorado, this figure calculated to approximately 3.3 million tires. In addition, it was estimated that there were more than 30 million scrap tires in Colorado that had not been properly disposed of or recycled. Throughout the United States the management of these scrap tires has become a major concern. Whole tires are very difficult to dispose of and consequently landfills have become full of tires. These scrap tires impose health, environmental and aesthetic problems. In 1990 the number of stockpiled tires in the United States was estimated between 2 and 3 billion. (1) Although no one knows the exact number of stockpiled tires in the United States, the 2 to 3 billion that was estimated in 1990 was thought to be high. With additional information available in 1994 the number of stockpiled tires in the United States was estimated to be closer to 800 million. (2)

In 1991, Congress enacted Section 1038(d) of the Intermodal surface Transportation Efficiency Act (ISTEA) legislation to help reduce the number of scrap tires.

1.1 Federal Legislation

In December 1991, the Intermodal Surface Transportation Efficiency Act (ISTEA) was signed into law. Section 1038(d) of this legislation required states to use a minimum amount of crumb rubber from recycled tires in asphalt surfacing placed each year beginning with the 1994 paving season. The percentage of recycled crumb rubber in the asphalt paving was to begin at 5% and increase by 5% each year until 1997 when the percentage would be 20%. It was to remain at 20% each year thereafter. Noncompliance with this legislation would result in severe Federal funding reduction. Appendix A contains a copy of Section 1038(d) of ISTEA.

In October of 1993, the House and Senate imposed a one-year moratorium on Section 1038(d) of ISTEA. At this time FHWA advised the department that in effect, this moratorium deleted the 5% utilization requirement for 1994; however, beginning in 1995 the department would be required to meet the 10% utilization mandate.

In September of 1994, the House and Senate passed the FY95 Department of Transportation Appropriations Bill (HR 4556). This bill extended the moratorium on the Federal Highway Administration's enforcement of the crumb rubber minimum utilization requirements in Section 1038(d) of ISTEA.

The NHS Designation Act of 1995 amended Section 1038 of the ISTEA legislation by eliminating the crumb rubber mandate and all associated penalties. States were no longer required to use crumb rubber in asphalt paving.

Although the crumb rubber mandate was eliminated, the FHWA initiated three Crumb Rubber Modifier (CRM) research contracts. The first contract addressed workers' health-related issues and the other two addressed engineering aspects related to the use of crumb rubber as an asphalt binder modifier. (3)

In addition to the contracted research, FHWA initiated an in-house research project to establish the performance of a chemically modified crumb rubber modifier (CMCRM). The CMCRM was developed by a FHWA researcher in an effort to improve the overall performance of an asphalt binder. (3)

FHWA coordinated with the National Cooperative Highway Research Program (NCHRP) and is currently reviewing a proposal submitted by the researchers on NCHRP 9-10 "Superpave Protocols for Modified Binders" to establish Superpave asphalt binder protocols for CRM asphalt. If approved, the NCHRP 9-10 on modified binders will be expanded to include CRM and CMCRM. (3)

1.2 Colorado Legislation

In an effort to promote recycling, Colorado House Bill 93-1318 went into effect on June 12, 1993 creating the Colorado Waste Tire Program. Beginning January 1, 1994, Section

25-17-202 C.R.S. (created by H.B. 93-1318) required a $1.00 "Recycling Development Fee" be collected by the retailer from the purchaser for each old tire collected when purchasing new tire replacements. Until 1995 the revenues generated from this assessment fee were available for loan under the "Recycling Economic Development Loan Program administered by the Colorado Housing And Finance Authority (CHFA). Any Colorado business could apply for these funds as long as recycling or waste diversion was a component in their business. (4)

In 1995, the Colorado General Assembly passed legislation (House Bill 95-1238, or C.R.S. 24-32-114). This legislation provided funds for counties to help clean up illegally disposed waste tires. This program was managed by the Department of Local Affairs.

In 1998, the Colorado General Assemble expanded the Colorado Waste Tire Program by passing legislation (Senate Bill 98-198, C.R.S. 24-32-114). This legislation provided recycling incentives to local and state agencies by providing funds to purchase products using recycled or reused waste tires for use on projects. In addition, this legislation provided funds to the Colorado Advanced Technology Research Institute (CATI) to evaluate potential uses for recycled material from waste tires. These programs are managed by the Department of Local Affairs. (4)

Also in 1998, House Bill 98-1176 (C.R.S. 25-17-202) provided for partial reimbursements to waste tire processors and end users by reimbursing up to $20 per ton for approved use of processed waste tire material. This program is also managed by the Department of Local Affairs. (4)

Today, 50% of the $1.00 "Recycling Development Fee" is managed by the CHFA and the other 50% is divided among the four programs managed by the Department of Local Affairs.

2.0 COLORADO'S HISTORY USING CRUMB RUBBER

Colorado's experience with crumb rubber is limited. The state's first use of crumb rubber started in the late 1970's with crumb rubber crack fillers, crumb rubber stress absorbing membrane interlayers (SAMI) and stress absorbing membranes (SAM) or chip seal coats.

Five SAMI projects and four SAM projects were constructed and evaluated by the Research Section with the results that neither treatment was found to be cost-effective compared to available standard treatments. (5 & 6)

SAMI's were more expensive than reflection cracking fabric interlayer with comparable results. Additionally, the chips required as part of these treatments caused numerous problems with broken windshields on high-speed, high-volume roads. These chips also caused problems in urban areas when traffic threw them up on sidewalks.

Chip seal coats (SAM's) using crumb rubber modified asphalt did not perform any better than seal coats with standard binders (RC-800 rubberized). The cost of the crumb rubber modified binder was approximately three times the cost of the standard binders. Additionally, this binder was quite susceptible to snow plow damage on highways where packed snow and ice are routine, so these seals would not be recommended in the mountains. (7&8)

In the winter of 1985-1986, the CDOT Flexible Pavement Unit performed a mix design using a dry process (Plus Ride) using local asphalts and aggregates. This design was performed using the Hveem design method. The Plus Ride system picks optimum asphalt content at 2% voids, while with the Hveem system, an optimum asphalt content is picked near 4% void content, providing other properties such as stability and moisture resistance are met. The Plus Ride design using the Hveem Method appeared to have a very low stability and strength coefficient. The design performed yielded what appeared to be a very unstable mix. The Immersion/Compression test for moisture resistance had passing strength ratios, but the compressive strengths were extremely low, approximately one-half of the standard mix from the same aggregate source. This data coupled, with the variable performance of similar pavements in our area, resulted in Colorado not building a dry process crumb rubber project (Plus Ride). (9)

The Plus Ride projects in Arvada and Aurora, as well as the Plus Ride project in New Mexico, showed early distress in the form of raveling from the surface down into the mat, while a project at the Lamar Airport has performed well.

From 1981 to 1994 crumb rubber was only used in crumb rubber modified crack filler throughout the state with moderate success.

In 1994 Colorado initiated a research project to incorporate crumb rubber into their pavements to identify construction, environmental and other problems which may be encountered. Colorado chose to begin first with the "dry" process because with this process it is easier to control the mixing and less complicated for the contractor.

3.0 COLORADO'S CRUMB RUBBER PROJECT

The project selected to conduct the research was located on Platte Canyon (SH 75) from Bowles to C470 in the Denver Metropolitan area. The location of the project can be seen in Figure 1. The project was constructed in August 1994.

3.1 Development of Mixes

Prior to the selection of the project mixes, mixes containing varying amounts of crumb rubber were designed in the Staff Materials Laboratory.

Crumb rubber can be incorporated into the Hot Bituminous Pavement (HBP) in two ways. In the first method the crumb rubber is blended into an asphalt binder prior to the addition of the heated aggregates. This process is commonly referred to as the "wet" method. In the second method the crumb rubber is added directly to the heated aggregates. This process is commonly referred to as the "dry" method.

In the laboratory the "dry process was selected. Four "dribble" mixes were designed with no changes to the gradation of the aggregate, and no special treatment during mixing and compaction. A "dribble" mix is a small amount of crumb rubber uniformly added to a mix. The idea of a "dribble" mix is that a large amount of crumb rubber could be used without special mix designs or special handling. The crumb rubber was added to the original mix design and then lab testing proceeded in the normal manner. Sinclair AC-10 (PG 58 –22) was used in this design.

Following is a summary of the test results from using the "dribble" mix at varying rubber contents.

Table 1. Crumb Rubber Mix Design.

	TEXAS GYRATORY COMPACTIVE EFFORT					
	20-50-2500			30-100-2500		
% Crumb Rubber	Hveem Stability	Optimum % AC	Cohesion	Hveem Stability	Optimum % AC	Cohesion
0%	38	5.4	137	38	4.9	149
0.05% (1 lb./ton)	36	5.3	142	36	4.9	169
0.15% (3 lb./ton)	32	5.6	98	36	5.4	110
0.25% (5 lbs./ton)	30	5.7	95	34	5.5	104

Note: The Texas Gyratory Compactive Efforts of 50 and 100 correspond to the Superpave Ndesigns of 76 and 96 respectively.

Table 1 shows that the addition of crumb rubber at the 1 lb./ton rate had very little effect on the original mix. Additions of crumb rubber above the 1 lb./ton rate had a tendency to increase the asphalt demand and lower the stability. At the 5 lbs./ton rate these changes would not be acceptable without taking the volume of crumb rubber into consideration in the gradation.

In order to make room for the rubber in the mix, the gradation of the aggregate was changed by eliminating 3% of the minus #4 sieve fraction for each 1% crumb rubber added. The mix was then treated like an absorptive mix. After mixing the rubber and aggregate with the asphalt cement, the mix was aged for four hours at compaction temperature to give the asphalt and rubber a chance to react.

A five-pound weight was placed on the top of the molded samples until they cooled. This procedure was an additional change to the standard design procedure. Once the samples cooled they were removed from the molds and tested for Hveem stability, bulk specific gravity, etc. The five-pound weight is recommended to control swell of the crumb rubber mix. This technique accomplishes the control of swell in the same way that rolling in the field is continued until the mat cools to 60°C (140°F).

The Lottman (AASHTO T283) samples from this mix were also treated after cooling with a five-pound weight on the molds. The Tensile Strength Retained (TSR) results for the mix containing 1% crumb rubber was 89%.

The addition of 1% crumb rubber dramatically increased the asphalt demand and as noted in the manual from the crumb rubber modified workshop: the Hveem stabilities are about half of normal. (10)

3.2 Selection of Crumb Rubber Hot Bituminous Pavement Mix

Upon completion of the testing by the Staff Materials Laboratory, it was decided that on the first construction project, three different percentages of crumb rubber would be evaluated. The design mixes included 1 lb./ton, 3 lbs./ton, and a 1% (20 lbs./ton) mixture. The design mixes can be found in Appendix B. In addition to these mixes a mix containing no crumb rubber was placed on the project for evaluation purposes. The specifications for this project can be found in Appendix C.

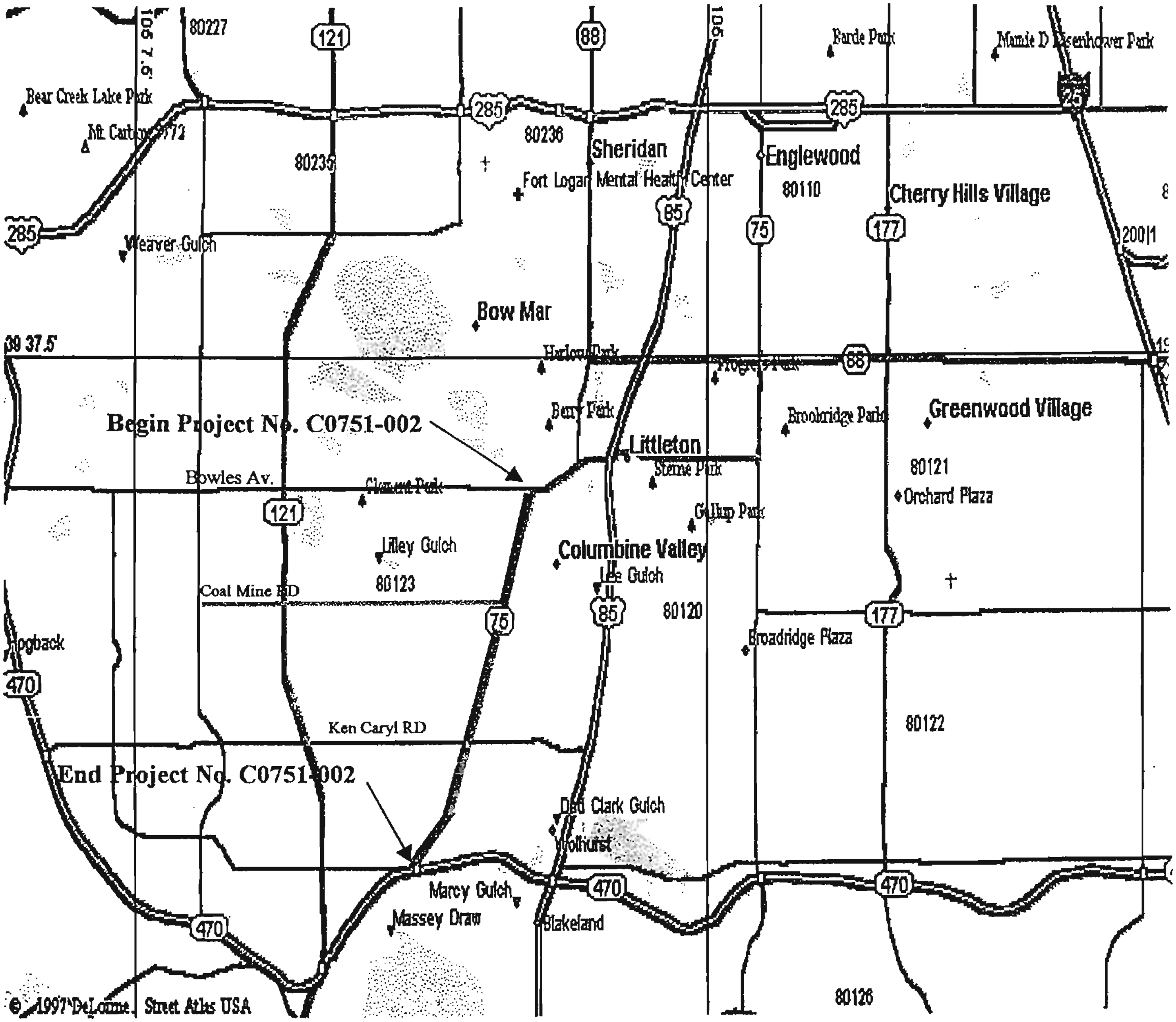

Figure 1. Location of project.

4.0 CONSTRUCTION

4.1 Project Description

Project No. C 0751-002, selected for evaluation, was located in Region 6 (Denver Metropolitan Area) on SH 75 (Platte Canyon Road) between West Bowles Avenue and C470 in Littleton. The 1993 average daily traffic between Ken Caryl Avenue and Bowles Avenue ranged from 8,500 to 14,600 vehicles with 2% trucks. The project was designed using 10-year 18K ESAL of 332,000. The project contained 4 different mix designs. Approximately 9000 tons of HBP, 500 tons contained 1 % (20 lbs./ton) crumb rubber and 500 tons contained 3 lbs./ton of crumb rubber. The remaining 8000 tons contained 1 lb./ton. In addition 500 tons of HBP containing no rubber was placed. The location of the placement of the specific crumb rubber mixes is shown in Figure 2. The project was constructed in August 1994.

4.2 Project Plans

The original plans called for a 2" HBP overlay. Prior to the overlay the entire length of the project was to be milled and paving fabric installed as directed by the Engineer. However, upon inspection of the project, it was determined that in some areas the depth of the existing pavement was only 2 to 3 inches thick which was too shallow to allow milling. Milling was eliminated except in areas that contained curb and gutter.

Construction plans were changed to include paving fabric the entire length of the project and the depth of the HBP was increased from 2" to 2-1/2".

4.3 Evaluation Sections

Prior to construction, four 1000-foot evaluation sections were established. One evaluation section was established for each of the mixes containing crumb rubber plus one in the section containing no crumb rubber. These sections were located in the northbound lane between Ken Caryl and Bowles. Figure 2 shows the location of the evaluation sections.

4.4 Pre-Construction Evaluation

Prior to construction an evaluation was performed on these sections. This evaluation included crack mapping, rut depth measurements, photographs and a visual inspection.

The existing pavement was severely distressed. Block and alligator cracking was found throughout the evaluation sections. The cracks had not been filled and averaged about 25 mm (1 inch) wide. There were several areas in the evaluation sections that had raveled out, creating large holes in the mat. The rut measurements throughout the project averaged 12 mm (0.5 inch). The pre-construction condition of the pavement can be seen in Figure 3.

4.5 Plant Description

The drum mixer plant was located 2 miles from the south end of the project. The mix discharge temperature was between 140°C (285°F) and 149°C (300°F). A baghouse was used for emission control. During production the baghouse was checked for crumb rubber particles. No crumb rubber was found in the baghouse. The mix was delivered to the site by tandems and end dumps. The mix temperature behind the paver ranged from 127°C (260°F) to 135°C (275°F).

Although stack emissions at the plant during production were not measured, it appeared that the 1 lb./ton or the 3 lbs./ton did not make a significant difference in the smoke stack opacity. The quantity of the 1 % crumb rubber mix produced was quite small and any effect that this percentage of crumb rubber had on the emission was difficult to determine. It is recommended that emissions of the plant during production be monitored if crumb rubber mixes are used in the future.

The crumb rubber was conveyed through a grain auger and added at the recycled asphalt pavement (RAP) collar. The amount of crumb rubber being added was controlled by the speed of the auger. The Colorado Department of Transportation (CDOT) did not monitor the addition of the rubber. Although the contractor did not have problems adding the crumb rubber they thought the 2000 lb. bags were difficult to handle. However, if the addition of crumb rubber became a standard practice, the plant could be equipped to handle this more efficiently. Because the diameter of the grain auger was only six inches, the production at the plant was slowed down to accommodate the 1 % mix. This resulted in a higher production temperature. If crumb rubber mixes are used in the future a more precise method for adding the crumb rubber will need to be developed.

Photographs showing the addition of the crumb rubber at the plant are shown in Figure 4. 5, 6, and 7.

4.6 Laydown Operations

Because of the possible pick up by pneumatic rollers on mats containing rubber, the specifications did not allow pneumatic rollers on rubber mixes unless directed by the engineer. The pneumatic roller was not permitted the first day of paving. The 1 lb./ton was placed on the first day. As a result of the mix being tender, the mat placed on the first day developed hairline cracks. A pneumatic roller was used after the first day to seal these tiny cracks. The hairline cracks were eliminated and the use of the pneumatic roller was continued with minor pick up.

Three rollers were used for the majority of the paving. A Hyster 350D was use for breakdown. A Hyster C530A pneumatic roller was used as the intermediate roller. A Hyster C766B was used for the finish roller. Density was easily obtained in all the mixes containing crumb rubber and in the section containing the standard mix. The final density in the evaluation sections ranged from 92.3% in the 3 lbs./ton mix to 94.5 % in the 1 % crumb rubber mix.

Hours for paving on this project were limited. The contractor was not allowed to start placing pavement until 9:00 am and was required to be off the roadway by 3:30 p.m. Because traffic is not normally allowed on the paved section until the mat temperature is 65°C (150°F) or below, a water truck was used to spray the mat on several occasions to drop the mat temperature. Because the crumb rubber specification requires the contractor to continue rolling the mat until the surface temperature is 60°C (140°F), a time restriction for opening a section of roadway to traffic became more critical. The restricted time element needs to be considered if the entire project is under the 60°C (140°F) rolling specification because it will limit the contractor on the amount of pavement that can be placed daily.

4.7 Crumb Rubber Supplier

At the time of construction, Colorado did not have a crumb rubber supplier. The crumb rubber used on this project came from a supplier in Dayton, Ohio.

4.8 Additional Costs With Crumb Rubber

The contractor's bid for the crumb rubber mixes is shown in Table 2 along with the standard mix bid price.

Table 2. Bid Costs of Crumb Rubber and Hot Mix Asphalt Mixes.

TYPE OF MIX	CONTRACTOR'S BID
Grading C 3 lb./ton 500 tons	$30.00
Grading C 1 lb./ton 8075 tons	$30.00
Grading C (20 lbs./ton) 500 tons	$35.00
Grading C No Rubber 500 tons	$29.00

The difference in the contractor's bid between the Grading C without rubber and the Grading C with the 1% (20 lbs./ton) was $6.00 per ton of Hot Bituminous Pavement (HBP). The rubber in this project increased the total cost of the HBP by 4%.

It was expected that there would be a significant increase in the cost of the HBP when the rubber was added because of the small amount of rubber incorporated into the project, the contractor being unfamiliar with the rubber, and because the contractor had to adapt their plants to incorporate the rubber. The contractor was also limited to suppliers of the material. However the crumb rubber only increased the overall cost of the HBP by 4%. The crumb rubber in the 20 lbs./ton mix increased the cost per ton of the mix by 21%, which would be a significant cost increase if mixes containing higher percentages of crumb rubber are used on project. Based on the way the legislation was originally written, the quantity of crumb rubber usage would have to be significantly increased to meet the ISTEA requirement.

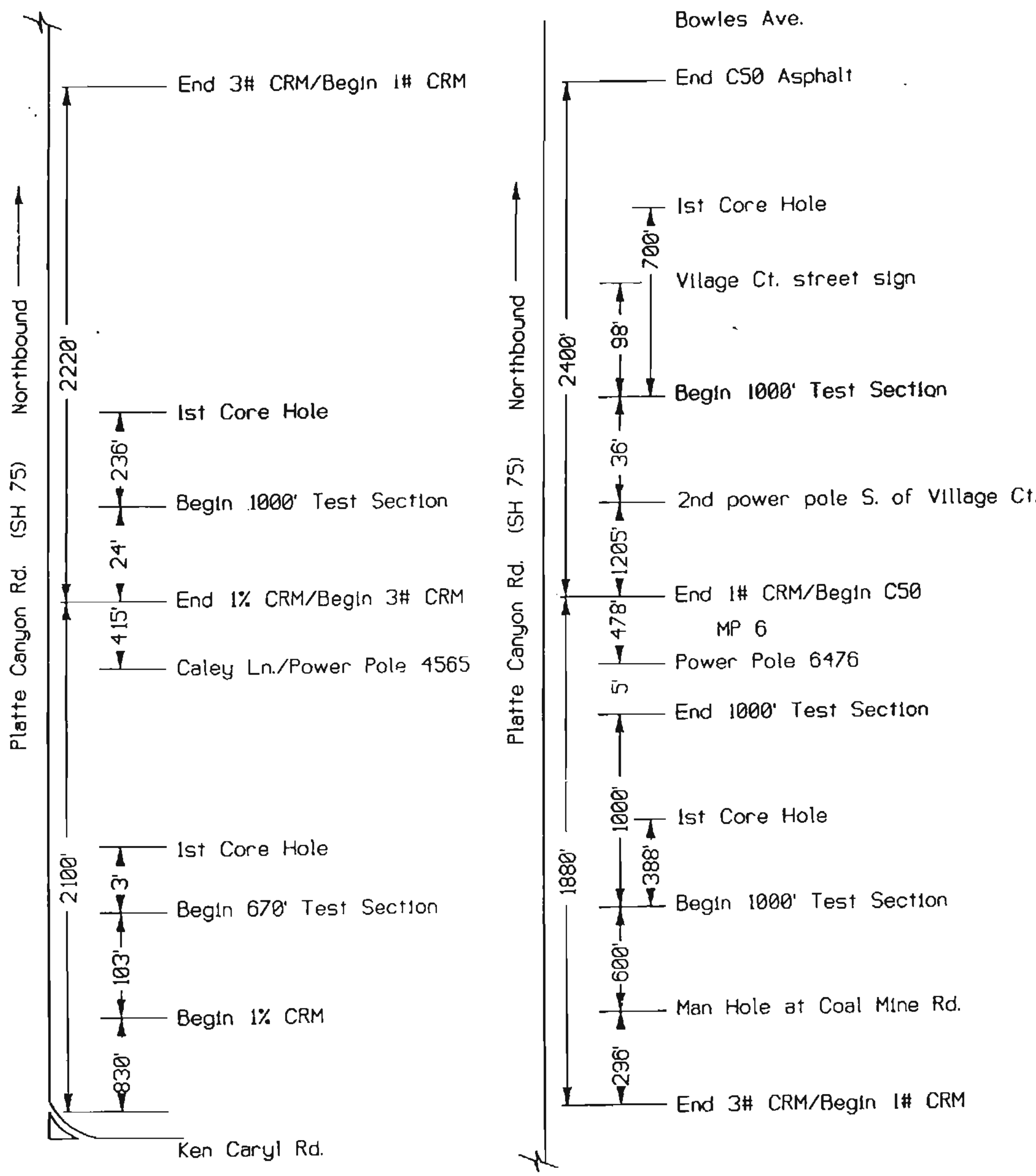

Figure 2. Location of Crumb Rubber Sections.

Figure 3. Typical distress found in existing pavement prior to construction.

Figure 4. Crumb Rubber was supplied in 2000 lb bags.

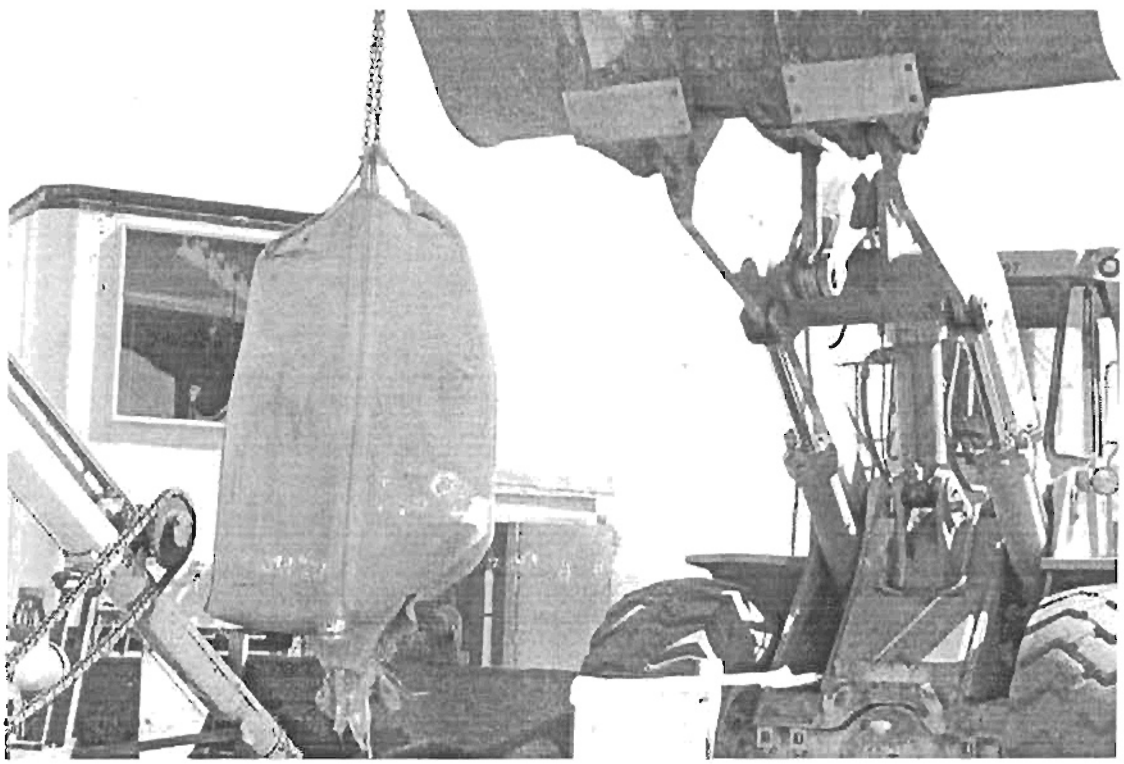

Figure 5. An overview of the crumb rubber system.

Figure 6. An auger was used to transport the crumb rubber to the RAP collar.

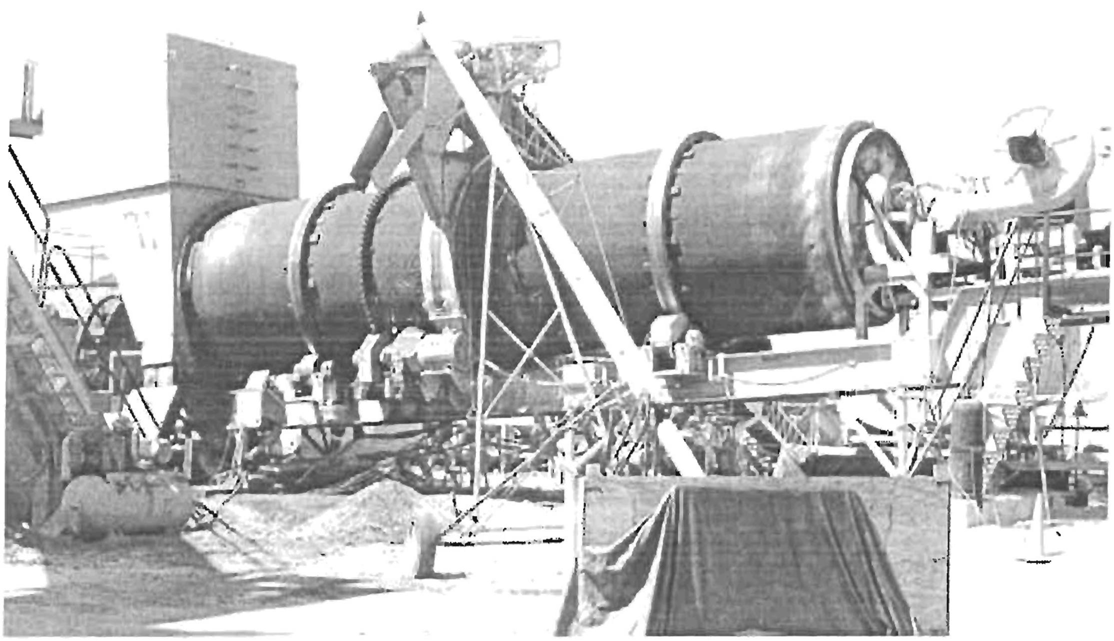

Figure 7. An overview of the crumb rubber system.

5.0 EVALUATION

5.1 Field Verification Test Results

Crumb Rubber Gradation

Only one crumb rubber gradation sample was verified during the paving of this project. The gradation specification and the gradation results for the project are shown in Table 3.

Table 3. Crumb Rubber Gradation Results.

SIEVE SIZE	PERCENT BY WEIGHT PASSING SQUARE MESH SIEVES	
	Specification	Test Results
4.75 mm (No. 4)	100	
2.36 mm (No. 8)	80 – 100	100
1.18 mm (No. 16)	40 – 70	71
600 µm (No. 30)	0 – 20	1.1
300 µm (No. 50)		.4
150 µm (No. 100)		.3
75 µm (No. 200)		0.1

`Note – Gradation was tested in accordance with ASTM C 136 using a 50-gram sample. All crumb rubber modifiers retained on the 2.36 mm (No. 8) sieve shall be cubical in shape and individual particles shall have a flatness or elongation ratio no greater than 2:1.

The gradation results shows that the crumb rubber used on this project was slightly finer on the 2.36 mm sieve than the specification allows.

5.2 Asphalt Content Stability, Field Compaction and Volumetrics

Table 4. Asphalt Content, Stability, Field Compaction and Volumetrics Test Results

% CRUMB RUBBER	% ASPHALT CONTENT	HVEEM STABILITY	% OF MAXIMUM DENSITY	% VOIDS	TSR	% VMA
0% No Crumb Rubber	4.9 (4.9)	36 (37)	93.2 (92.0)	2.4 (3.88)	♦ 99	13.2
0.05% 1 lb./ton	4.8 (4.9) 4.8 (4.9)	38 (39) 37 (39)	93.4 (92.0)	2.4 (4.02) 3.6 (4.02)	101 (98) 106 (98)	13.1 13.9
0.15% 3 lbs./ton	5.0 (4.9)	34 (36)	92.3 (92.0)	3.4 (4.25)	99 (100)	14.6
1.0% 20 lbs./ton	5.4 (6.1)	31 (24)	94.5 (92.0)	1.5 (3.89)	92 (93)	13.9

() These denote values at optimum AC content for each specified percentages of crumb rubber.

♦ Data unavailable

Only one sample was taken from each evaluation section. The voids in the field mix were significantly lower in all the sections. There was only one gradation sample taken and it was slightly finer on the 2.36-mm sieve than the specification allowed.

5.3 Testing in French Rutting Tester

Normally, for the Denver area, a mix would be tested on the French rut tester at 45°C or 50°C (11), however, this project is located on a roadway with relatively low traffic loading, and hence a low compactive effort mix design was used.

The testing on the French rut tester was performed at 45°C in order to determine if there was a difference in the rutting potential between the standard mix and the same mix containing various percentages of crumb rubber.

The specification for rutting is a maximum of 10% rut depth after 30,000 passes. As can be seen in Table 5, at a temperature of 45°C, the mix containing no crumb rubber and 1 lb./ton passed the rutting test; the mix containing 3 lbs./ton barely failed the requirements; and the mix with 1% crumb rubber also failed.

The mixes with no crumb rubber, 1 lb./ton, and 3 lbs./ton all were constructed at the same asphalt content, (4.9% AC). From the rutting data, the rubber, which is an aggregate substitute in the dry process, does not appear to have provided any aggregate interlock so the more crumb rubber added, the greater the rutting potential. With the small amounts added 1 lb./ton and 3 lbs./ton, the effect was minor and rutting results were similar.

In the case of the 1 % crumb rubber mix, the design asphalt content was 6.1% and the RAP was removed in order to provide room for the crumb rubber. This mix was rich in asphalt cement and did not provide the rut resistance needed under these traffic and environmental conditions.

Table 5. French Rut Tests

Temperature	NO CRUMB RUBBER	1 LB CRUMB RUBBER	3 LB CRUMB RUBBER	1% (20 LBS) CRUMB RUBBER
40°C	----	---	3.6%	6.6%
45°C	6.3%	8.4%	10.8%	16.5%
50°C	13.6%	---	---	---

--- Samples not tested

5.4 Field Evaluation

Cores

Cores were taken between the wheel paths in the evaluation sections, immediately following construction and during each evaluation. The cores were used to determine in-place voids. This data was used to determine if the addition of crumb rubber in the mixes affected the performance of the different mixes.

The results of the cores suggested that the addition of crumb rubber into the mix did not make a difference in the ability to achieve density during construction, nor did it effect the long-term performance characteristics of the pavement.

Rutting

Rutting measurements were taken during each evaluation. Measurements were taken with a six-foot straight edge. Rutting measurements taken during the final evaluation, August 1999, when the pavement was in place five years in all evaluation sections, had similar rut measurements of less than 12 mm (0.5 inch).

Cracking

Cracking did not appear in any section until Spring 1996. During the 1996 evaluation it was noted there was minimal transverse cracking; however no longitudinal cracking was apparent. During the final evaluation in August 1999 no evidence of longitudinal cracking was noted and transverse cracking was more evident, however, not severe. Figure 8 shows the condition of the pavement at the five-year-old final evaluation.

Skid Testing

Skid testing was done in Spring 1995. From these initial measurements it does not appear that the addition of the crumb rubber in the mix changed the skid resistance measurement of the pavement. No additional skid testing was performed.

Smoothness Testing

Typically in urban areas smoothness is measured on percent improvement from initial to final inches/mile measurement. However, this project did not include a smoothness specification; initial data was not obtained prior to construction. Following construction, in May 1995, an Ames profilograph was used to measure the smoothness of all the evaluation sections. Measurements were taken in each wheel path. These measurements ranged from 13 inches/miles to 31 inches/mile both measurements were taken in the left wheel path. These are typical values found in urban areas following construction.

Visual

There was no visual performance difference in the test and control sections. All the surfaces were uniform in appearance. No roller marks, no segregation and no flushing were noted in any of the evaluation sections. In the crumb rubber sections it was observed that small particles of crumb rubber were visible on the surface. Figure 9 and 10 shows the small crumb rubber particles on the surface.

Figure 8. Photograph of surface of 1% section at final evaluation August 1999 (five year old pavement).

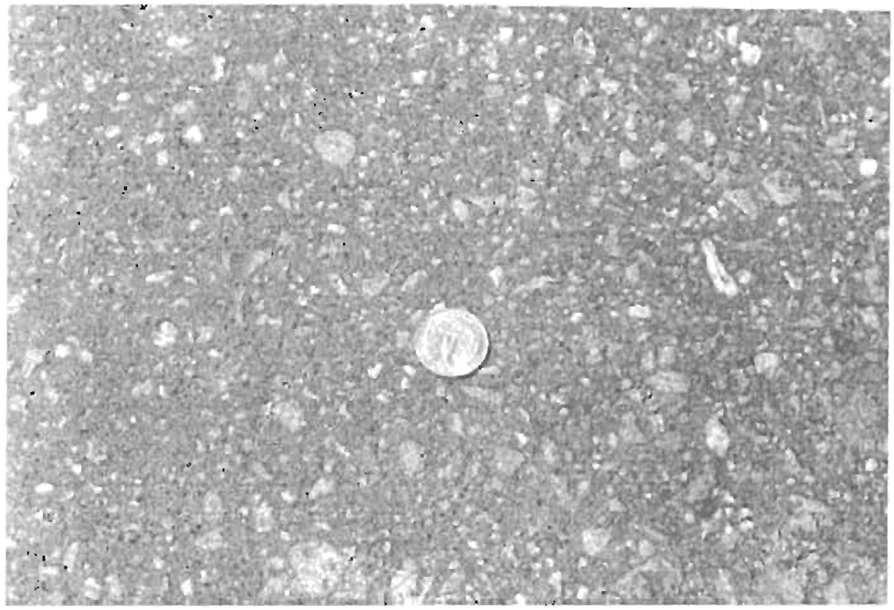

Figure 9. Surface of the 1lb/ton. Notice the rubber particles on the surface.

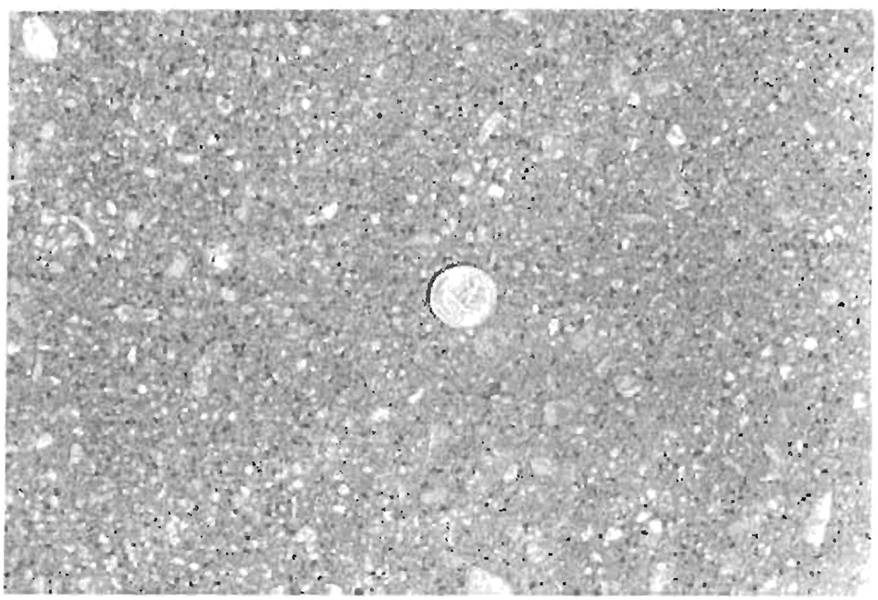

Figure 10. Surface of the 20 lb/ton. Notice the rubber particles on the surface.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The project selected to demonstrate the crumb rubber process was a low volume roadway and quantities of crumb rubber introduced into the mix were minimal. This was to reduce risk in terms of premature failure. However, because of the minimal quantities of crumb rubber introduced on this project, performance of the different evaluation sections was not dramatic.

6.1 Conclusions

Conclusions that can be drawn from this study include:

- There were no apparent constructibility problems on the Platte Canyon project.

- The contractor did not experience any problems at the plant with the introduction of crumb rubber or plant operations. However, the production was reduced during the addition of the 1 % (20 lb./ton) crumb rubber. This problem was attributed to the contractor's method of introducing the crumb rubber.

- The contractor initially had a concern with environmental issues because of the crumb rubber. This concern was never realized during this project as the amount of crumb rubber being introduced was not enough to effect emissions.

- Compaction efforts between the control and evaluation sections were comparable and no additional effort was required for the crumb rubber sections.

- The performance data collected on this project indicate the performance of the non-crumb rubber section as compared to all the crumb rubber sections performed equally.

- Although the crumb rubber gradation was finer on the 2.36 mm sieve than what the specifications allowed, it not have an adverse effect on the pavement performance.

- The visual appearance of the small particles of crumb rubber noted on the surface did not have a detrimental effect on the performance of the pavement.

Although the use of small amounts of crumb rubber in HBP has proven to be feasible, it is not, however, an economical method for recycling waste tires. In this study the cost-per-ton of the mix was increased by 21% when the higher percentage (20 lbs./ton) of crumb rubber was used. This would be a significant cost increase if higher percentages of crumb rubber were used.

6.2 Recommendations

It is recommended until the addition of larger quantities of crumb rubber in Hot Bituminous Pavement (HBP) is shown to be cost effective in addition to enhancing the long term performance of the pavement that crumb rubber usage be limited to research applications. However CDOT has no further plans to pursue the use of crumb rubber in HBP. At this time CDOT is implementing Superpave performance graded (PG) binders and currently there is a national study that is evaluating the use of crumb rubber as a PG binder modifier.

7.0 COLORADO'S WASTE TIRE RECYCLING PROGRAM

Since the initiation of the ISTEA legislation, Colorado has made a major effort through the Waste Tire Program to help combat and control the waste tire issue. Colorado provides financial opportunity through grants to encourage the recycling and reuse of waste tires and to help clean up illegally disposed tires.

The Waste Tire Grant Program is administered by the Division of Local Government in the Colorado Department of Local Affairs. The program has the following four components:

1. Tire Cleanup Grants – This program is for counties only. The purpose is to clean up illegally disposed waste tires.

2. Purchasing Incentives - This program is for local governments and state agencies. The purpose is to encourage the purchase of materials made from recycled tires in public projects.

3. End User Reimbursements – This program is for waste tire processors and end users that demonstrate the use of recycled tires. The purpose is to encourage the use of recycled tires by providing up to $20 per ton in reimbursements to end users of processed tire material.

4. Research Grants – This program is for faculty and researchers at Colorado colleges and universities, in partnership with businesses. The purpose is to stimulate research into feasibility of uses for recycled waste tires.

REFERENCES

1. Environmental Protection Agency, "Markets for Scrap Tires." EPA/530-SW-90-074A October 1991.

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3. Federal Highway Administration, "Crumb Rubber Modifier," June 7, 1999,http://www.fhwa.dot.gov/infrastructure/pavement/CrmbRubr.htm,(August 27, 1999).

4. Colorado Waste Tire Program, Colorado Department of Local Affairs, November 1, 1999, Written by Belsten, Laura.

5. Donnelly, Denis E., LaForce, Robert F. and Swanson, Herbert N. "Reflection Cracking Evaluation, Kannah Creek, Colorado Project FC 050-1(8)" Colorado Department of Transportation, CDH-DTD-R-80-10, June 1980.

6. Donnelly, Denis E., LaForce, Robert F. and Swanson, Herbert N. "Reflection Cracking Treatments -- Alameda Avenue, Project MU 026(2)," Colorado Department of Transportation, CDH-DTD-R-80-11, October 1980.

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8. LaForce, Robert F. " Crumb Rubber Chip Seal East of Pumpkin Center," Colorado Department of Transportation, CDOH-DTD-R-86-3, March 1986.

9. LaForce, Robert F. " Rubber Modified Asphalt Concrete," Colorado Department of Transportation, CDOH-SMB-R-87-15, December 1987.

10. Crumb Rubber Modifier Workshop Design Procedures and Construction Practices, Stouffer Hotel Denver Colorado, March 1 – 2, 1993.

11. Aschenbrener, Timothy. " Comparison of Results Obtained from the French Rutting Tester with Pavements of Known Field Performance," Colorado Department of Transportation, CDOT-DTD-R-92-11, October 1992.

APPENDIX A

Section 1038(d) of the ISTEA Legislation

for nonrail purposes; and

''(ii) will not use any funds or assets from high-speed rail operations for purposes other than high-speed rail purposes,''; and

(B) by inserting ''or high-speed rail services'' after ''provide rail services''; and

(4) by adding at the end the following new subsection:

''(n) Definitions.-As used in this section, the term 'high-speed rail' means all forms of nonhighway ground transportation that run on rails providing transportation service which is-

''(1) reasonably expected to reach sustained speeds of more than 125 miles per hour; and

''(2) made available to members of the general public as passengers.

Such term does not include rapid transit operations within an urban area that are not connected to the general rail system of transportation.''.

(f) General Accounting Office Study.-The Comptroller General, within 2 years after the date of the enactment of this Act, and annually thereafter, shall analyze the effectiveness of the application of section 511 of the Railroad Revitalization and Regulatory Reform Act of 1976 to high-speed rail facilities and equipment, and report the results of such analysis to the Committee on Energy and Commerce of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate.

SEC. 1037. RAILROAD RELOCATION DEMONSTRATION PROGRAM.

Section 163(p) of the Federal-Aid Highway Act of 1973 (23 U.S.C. 130 note) is amended by striking ''and 1991,'' and inserting ''1991, 1992, 1993, and 1994,''.

SEC. 1038. USE OF RECYCLED PAVING MATERIAL.

(a) Asphalt Pavement Containing Recycled Rubber Demonstration Program.-Notwithstanding any other provision of title 23, United States Code, or regulation or policy of the Department of Transportation, the Secretary (or a State acting as the Department's agent) may not disapprove a highway project under chapter 1 of title 23, United States Code, on the ground that the project includes the use of asphalt pavement containing recycled rubber. Under this subsection, a patented application process for recycled rubber shall be eligible for approval under the same conditions that an unpatented process is eligible for approval.

(b) Studies.-

(1) In general.-The Secretary and the Administrator of the Environmental Protection Agency shall coordinate and conduct, in cooperation with the States, a study to determine-

(A) the threat to human health and the environment associated with the production and use of asphalt pavement containing recycled rubber;

(B) the degree to which asphalt pavement containing recycled rubber can be recycled; and

(C) the performance of the asphalt pavement containing recycled rubber under various climate and use conditions.

(2) Division of responsibilities.-The Administrator shall conduct the part of the study relating to paragraph (1)(A) and the Secretary shall conduct the part of the study relating to paragraph (1)(C). The Administrator and the Secretary shall jointly conduct the study relating to paragraph (1)(B).

(3) Additional study.-The Secretary and the Administrator, in cooperation with the States, shall jointly conduct a study to determine the economic savings, technical performance qualities, threats to human health and the environment, and environmental benefits of using recycled materials in highway devices and appurtenances and highway projects, including asphalt containing over 80 percent reclaimed asphalt, asphalt containing recycled glass, and asphalt containing recycled plastic.

(4) Additional elements.-In conducting the study under paragraph (3), the Secretary and the Administrator shall examine utilization of various technologies by States and shall examine the current practices of all States relating to the reuse and disposal of materials used in federally assisted highway projects.

(5) Report.-Not later than 18 months after the date of the enactment of this Act, the Secretary and the Administrator shall transmit to Congress a report on the results of the studies conducted under this subsection, including a detailed analysis of the economic savings and technical performance qualities of using such recycled materials in federally assisted highway projects and the environmental benefits of using such recycled materials in such highway projects in terms of reducing air emissions, conserving natural resources, and reducing disposal of the materials in landfills.

(c) DOT Guidance.-

(1) Information gathering and distribution.-The Secretary shall gather information and recommendations concerning the use of asphalt containing recycled rubber in highway projects from those States that have extensively evaluated and experimented with the use of such asphalt and implemented such projects and shall make available such information and recommendations on the use of such

asphalt to those States which indicate an interest in the use of such asphalt.

(2) Encouragement of use.-The Secretary should encourage the use of recycled materials determined to be appropriate by the studies pursuant to subsection (b) in federally assisted highway projects. Procuring agencies shall comply with all applicable guidelines or regulations issued by the Administrator of the Environmental Protection Agency.

(d) Use of Asphalt Pavement Containing Recycled Rubber.-

(1) State certification.-Beginning on January 1, 1995, and annually thereafter, each State shall certify to the Secretary that such State has satisfied the minimum utilization requirement for asphalt pavement containing recycled rubber established by this section. The minimum utilization requirement for asphalt pavement containing recycled rubber as a percentage of the total tons of asphalt laid in such State and financed in whole or part by any assistance pursuant to title 23, United States Code, shall be-

(A) 5 percent for the year 1994;

(B) 10 percent for the year 1995;

(C) 15 percent for the year 1996; and

(D) 20 percent for the year 1997 and each year thereafter.

(2) Other materials.-Any recycled material or materials determined to be appropriate by the studies under subsection (b) may be substituted for recycled rubber under the minimum utilization requirement of paragraph (1) up to 5 percent.

(3) Increase.-The Secretary may increase the minimum utilization requirement of paragraph (1) for asphalt pavement containing recycled rubber to be used in federally assisted highway projects to the extent it is technologically and economically feasible to do so and if an increase is appropriate to assure markets for the reuse and recycling of scrap tires. The minimum utilization requirement for asphalt pavement containing recycled rubber may not be met by any use or technique found to be unsuitable for use in highway projects by the studies under subsection (b).

(4) Penalty.-The Secretary shall withhold from any State that fails to make a certification under paragraph (1) for any fiscal year, a percentage of the apportionments under section 104 (other than subsection (b)(5)(A)) of title 23, United States Code, that would otherwise be apportioned to such State for such fiscal year under such section equal to the percentage utilization requirement established by paragraph (1) for such fiscal year.

(5) Secretarial waiver.-The Secretary may set aside the provisions of this subsection for any 3-year period on a determination, made

in concurrence with the Administrator of the Environmental Protection Agency with respect to subparagraphs (A) and (B) of this paragraph, that there is reliable evidence indicating-

(A) that manufacture, application, or use of asphalt pavement containing recycled rubber substantially increases the threat to human health or the environment as compared to the threats associated with conventional pavement;

(B) that asphalt pavement containing recycled rubber cannot be recycled to substantially the same degree as conventional pavement; or

(C) that asphalt pavement containing recycled rubber does not perform adequately as a material for the construction or surfacing of highways and roads.

The Secretary shall consider the results of the study under subsection (b)(1) in determining whether a 3-year set-aside is appropriate.

(6) Renewal of waiver.-Any determination made to set aside the requirements of this section may be renewed for an additional 3-year period by the Secretary, with the concurrence of the Administrator with respect to the determinations made under paragraphs (5)(A) and (5)(B). Any determination made with respect to paragraph (5)(C) may be made for specific States or regions considering climate, geography, and other factors that may be unique to the State or region and that would prevent the adequate performance of asphalt pavement containing recycled rubber.

(7) Individual state reduction.-The Secretary shall establish a minimum utilization requirement for asphalt pavement containing recycled rubber less than the minimum utilization requirement otherwise required by paragraph (1) in a particular State, upon the request of such State and if the Secretary, with the concurrence of the Administrator of the Environmental Protection Agency, determines that there is not a sufficient quantity of scrap tires available in the State prior to disposal to meet the minimum utilization requirement established under paragraph (1) as the result of recycling and processing uses (in that State or another State), including retreading or energy recovery.

(e) Definitions.-For purpose of this section-

(1) the term ''asphalt pavement containing recycled rubber'' means any hot mix or spray applied binder in asphalt paving mixture that contains rubber from whole scrap tires which is used for asphalt pavement base, surface course or interlayer, or other road and highway related uses and-

(A) is a mixture of not less than 20 pounds of recycled rubber per ton of hot mix or 300 pounds of recycled rubber per ton of spray applied binder; or

(B) is any mixture of asphalt pavement and recycled rubber that is certified by a State and is approved by the Secretary, provided that the total amount of recycled rubber from whole scrap tires utilized in any year in such State shall be not less than the amount that would be utilized if all asphalt pavement containing recycled rubber laid in such State met the specifications of subparagraph (A) and subsection (d)(1); and

(2) the term ''recycled rubber'' is any crumb rubber derived from processing whole scrap tires or shredded tire material taken from automobiles, trucks, or other equipment owned and operated in the United States.

SEC. 1039. HIGHWAY TIMBER BRIDGE RESEARCH AND DEMONSTRATION PROGRAM.

(a) Research Grants.-The Secretary may make grants to other Federal agencies, universities, private businesses, nonprofit organizations, and any research or engineering entity to carry out research on 1 or more of the following:

(1) Development of new, economical highway timber bridge systems.

(2) Development of engineering design criteria for structural wood products for use in highway bridges in order to improve methods for characterizing lumber design properties.

(3) Preservative systems for use in highway timber bridges which demonstrate new alternatives and current treatment processes and procedures and which are environmentally sound with respect to application, use, and disposal of treated wood.

(4) Alternative transportation system timber structures which demonstrate the development of applications for railing, sign, and lighting supports, sound barriers, culverts, and retaining walls in highway applications.

(5) Rehabilitation measures which demonstrate effective, safe, and reliable methods for rehabilitating existing highway timber structures.

(b) Technology and Information Transfer.-The Secretary shall take such action as may be necessary to ensure that the information and technology resulting from research conducted under subsection (a) is made available to State and local transportation departments and other interested persons.

(c) Construction Grants.-

(1) Authority.-The Secretary shall make grants to States for construction of highway timber bridges on rural Federal-aid highways.

(2) Applications.-A State interested in receiving a grant under

APPENDIX B

Project Design Mixes

Division of Transportation
State of Colorado
Form DOH 429 Flex 2.00

Project No: C 0751-002
Location: SH 75,Bowles to C470
District # 6 Subaccount: 10154
Lab # 496x-500x

Date Received 06/22/94

Field Sample # 64227 (combination 3)

LABORATORY DESIGN for HOT BITUMINOUS PAVEMENT - CONSTRUCTION

Item 403 Grading C Sinclair AC-10, 20-50-2500
Pit name: KWC Contractor/Supplier: Kiewit

SIEVE ANALYSIS: T11 & T27, sampled by CP30

Test No.->	496x	497x	498x	499x	500x	Hyd	As Used		Job Mix
% used-->	18.0	15.0	41.0	10.0	15.0	1.0			
1 1/2	100	100	100	100	100	100	100	1 1/2	
1	100	100	100	100	100	100	100	1	
3/4	99	100	100	100	100	100	100	3/4	100
5/8	40	100	100	100	100	100	89	5/8	
1/2	19	98	100	100	98	100	85	1/2	85
3/8	4	60	100	100	93	100	76	3/8	76
4	2	4	98	100	71	100	63	4	63
8	2	3	72	100	53	100	49	8	49
16	2	2	48	71	39	100	34	16	
30	2	2	32	39	29	100	23	30	30
50	2	2	20	12	21	100	14	50	
100	1	1	13	3	14	98	9	100	
200	1.2	1.1	9.5	2.5	9.8	97.0	6.9	200	6.9
%AC in aggr.	0.00	0.00	0.00	0.00	5.86	0.00	0.88		

Combined Aggregate: Bulk SpG: 2.608 Sand Equivalency:

TEST RESULTS				
Percent bitumen	4.5	5.0	5.5	6.0
Max Sp. Gr. T209	2.461	2.442	2.423	2.404
Bulk Sp. Gr. T166	2.339	2.354	2.359	2.364
% Voids CPL 5105	5.0	3.6	2.6	1.7
Stability CPL 5105	39	36	34	23
Modulus CPL 5110				
Strength coefficient	0.44	0.44	0.44	0.44
VMA (effective)	15.3	15.2	15.3	15.6
VMA (bulk)	14.4	14.3	14.5	14.8
% of bulk VMA filled	65	74	82	88
Dust / AC ratio	1.48	1.32	1.20	1.09

IMMERSION-COMPRESSION CPL 5104
% bitumen
PSI Wet
PSI Dry
% Absorption
% Swell
% Ret. Strength
% Additive used
Asphalt additive type

LOTTMAN CPL 5109
% bitumen
Wet D.T.St
Dry D.T.St
% Voids
% Saturation
% T.S.Ret.
% Additive

Optimum asphalt content 4.9
Stability at Optimum A.C. 37
Lab Max. SpG at Optimum 2.446
% Voids at Optimum A.C. 3.88
Asphalt film thickness at Optimum A.C.: 7.7 microns

"C" w/o Rubber

Robert LaForce 757-9724
Flexible Pavement Engineer

Date Reported 8/2/94

Division of Transportation
State of Colorado
Form DOH 429 Flex 2.00

Date Received 06/22/94

Project No: C 0751-002
Location: SH 75,Bowles to C470
District # 6 Subaccount: 10154
Lab # 496x-500x
Field Sample # 64227 (combination 1)

LABORATORY DESIGN for HOT BITUMINOUS PAVEMENT - CONSTRUCTION

Item 403 Grading C 1lb/Ton Crumb Rubber, 20-50-2500
Pit name: KWC Contractor/Supplier: Kiewit

SIEVE ANALYSIS: T11 & T27, sampled by CP30

Test No.->	496x	497x	498x	499x	500x	Hyd	As Used		Job Mix
% used-->	18.0	15.0	41.0	10.0	15.0	1.0			
1 1/2	100	100	100	100	100	100	100	1 1/2	
1	100	100	100	100	100	100	100	1	
3/4	99	100	100	100	100	100	100	3/4	100
5/8	40	100	100	100	100	100	89	5/8	
1/2	19	98	100	100	98	100	85	1/2	85
3/8	4	60	100	100	93	100	76	3/8	76
4	2	4	98	100	71	100	63	4	63
8	2	3	72	100	53	100	49	8	49
16	2	2	48	71	39	100	34	16	
30	2	2	32	39	29	100	23	30	23
50	2	2	20	12	21	100	14	50	
100	1	1	13	3	14	98	9	100	
200	1.2	1.1	9.5	2.5	9.8	97.0	6.9	200	6.9
%AC in aggr.	0.00	0.00	0.00	0.00	5.86	0.00	0.88		

Combined Aggregate: Bulk SpG: 2.608 Sand Equivalency:

TEST RESULTS						
Percent bitumen	5.5	6.0	6.5	7.0	4.5	5.0
Max Sp. Gr. T209	2.422	2.403	2.384	2.365	2.460	2.441
Bulk Sp. Gr. T166	2.370	2.370	2.366	2.359	2.319	2.354
% Voids CPL 5105	2.1	1.4	0.8	0.3	5.7	3.6
Stability CPL 5105	46	23	21	10	38	40
Modulus CPL 5110	713	534	359	264	549	775
Strength coefficient	0.44	0.44	0.40	0.25	0.44	0.44
VMA (effective)	14.9	15.3	15.8	16.5	16.0	15.1
VMA (bulk)	14.1	14.6	15.2	15.9	15.1	14.3
% of bulk VMA filled	85	90	95	98	62	75
Dust / AC ratio	1.20	1.09	1.00	0.93	1.48	1.32
Cohesiometer	225.1	228.8	221.0	199.3	259.7	223.6

IMMERSION-COMPRESSION CPL 5104		LOTTMAN CPL 5109	
% bitumen		4.9	% bitumen
PSI Wet		58	Wet D.T.St
PSI Dry		59	Dry D.T.St
% Absorption		6.89	% Voids
% Swell		69	% Saturation
% Ret. Strength		98	% T.S.Ret.
% Additive used		0.0	% Additive
Asphalt additive type			

Optimum asphalt content 4.9
Stability at Optimum A.C. 39
Asphalt film thickness at Optimum A.C.: 7.7 microns

Lab Max. SpG at Optimum 2.445
% Voids at Optimum A.C. 4.02

Date Reported 8/2/94

Robert LaForce 757-9724
Flexible Pavement Engineer

Division of Transportation Project No: C 0751-002

Division of Transportation
State of Colorado
Form DOH 429 Flex 2.00

Date Received 06/22/94

Project No: C 0751-002
Location: SH 75,Bowles to C470
District # 6 Subaccount: 10154
Lab # 496x-500x
Field Sample # 64227 (combination 2)

LABORATORY DESIGN for HOT BITUMINOUS PAVEMENT - CONSTRUCTION

Item 403 Grading C 3lb/Ton Crumb Rubber, 20-50-2500
Pit name: KWC Contractor/Supplier: Kiewit

SIEVE ANALYSIS: T11 & T27, sampled by CP30

Test No.->	496x	497x	498x	499x	500x	Hyd	As Used		Job Mix
% used-->	18.0	15.0	41.0	10.0	15.0	1.0			
1 1/2	100	100	100	100	100	100	100	1 1/2	
1	100	100	100	100	100	100	100	1	
3/4	99	100	100	100	100	100	100	3/4	100
5/8	40	100	100	100	100	100	89	5/8	
1/2	19	98	100	100	98	100	85	1/2	85
3/8	4	60	100	100	93	100	76	3/8	76
4	2	4	98	100	71	100	63	4	63
8	2	3	72	100	53	100	49	8	49
16	2	2	48	71	39	100	34	16	
30	2	2	32	39	29	100	23	30	23
50	2	2	20	12	21	100	14	50	
100	1	1	13	3	14	98	9	100	
200	1.2	1.1	9.5	2.5	9.8	97.0	6.9	200	6.9
%AC in aggr.	0.00	0.00	0.00	0.00	5.86	0.00	0.88		

Combined Aggregate: Bulk SpG: 2.608 Sand Equivalency:

TEST RESULTS

Percent bitumen	5.5	6.0	6.5	7.0	4.5	5.0
Max Sp. Gr. T209	2.424	2.405	2.386	2.367	2.462	2.443
Bulk Sp. Gr. T166	2.358	2.371	2.363	2.356	2.306	2.348
% Voids CPL 5105	2.7	1.4	1.0	0.5	6.3	3.9
Stability CPL 5105	38	27	16	12	33	37
Modulus CPL 5110	723	534	352	268	818	710
Strength coefficient	0.44	0.44	0.35	0.25	0.44	0.44
VMA (effective)	15.4	15.3	16.0	16.6	16.5	15.4
VMA (bulk)	14.6	14.5	15.3	16.0	15.6	14.5
% of bulk VMA filled	81	90	93	97	59	73
Dust / AC ratio	1.20	1.09	1.00	0.93	1.48	1.32
Cohesiometer	262.5	257.9	235.2	215.4	162.6	208.4

IMMERSION-COMPRESSION CPL 5104		LOTTMAN	CPL 5109
% bitumen		4.9	% bitumen
PSI Wet		55	Wet D.T.St
PSI Dry		55	Dry D.T.St
% Absorption		7.18	% Voids
% Swell		62	% Saturation
% Ret. Strength		100	% T.S.Ret.
% Additive used		0.0	% Additive
Asphalt additive type			

Optimum asphalt content 4.9 Lab Max. SpG at Optimum 2.447
Stability at Optimum A.C. 36 % Voids at Optimum A.C. 4.25
Asphalt film thickness at Optimum A.C.: 7.7 microns

Robert LaForce 757-9724

Division of Transportation
State of Colorado
Form DOH 429 Flex 2.00

Date Received 06/22/94

Project No: C 0751-002
Location: SH 75, Bowles to C470
District # 6 Subaccount: 10154
Lab # 496x-499x
Field Sample # 64226

LABORATORY DESIGN for HOT BITUMINOUS PAVEMENT - CONSTRUCTION

Item 403 Grading C 1% Crumb Rubber, 20-50-2500, Sinclair AC-10
Pit name: KWC Contractor/Supplier: Kiewit

SIEVE ANALYSIS: T11 & T27, sampled by CP30

Test No.->	496x	497x	498x	499x	Cr.Ru	Hyd	As Used		Job Mix
% used-->	20.0	20.0	48.0	10.0	1.0	1.0			
1 1/2	100	100	100	100	100	100	100	1 1/2	
1	100	100	100	100	100	100	100	1	
3/4	99	100	100	100	100	100	100	3/4	100
5/8	40	100	100	100	100	100	88	5/8	
1/2	19	98	100	100	100	100	83	1/2	83
3/8	4	60	100	100	100	100	73	3/8	73
4	2	4	98	100	100	100	60	4	60
8	2	3	72	100	100	100	48	8	48
16	2	2	48	71	61	100	33	16	
30	2	2	32	39	1	100	21	30	21
50	2	2	20	12	1	100	13	50	
100	1	1	13	3	1	98	8	100	
200	1.2	1.1	9.5	2.5	0.0	97.0	6.2	200	6.2

%AC in aggr.
Combined Aggregate: Bulk SpG: 2.569 Sand Equivalency:

TEST RESULTS				
Percent bitumen	5.5	6.0	6.5	7.0
Max Sp. Gr. T209	2.397	2.379	2.361	2.342
Bulk Sp. Gr. T166	2.264	2.281	2.291	2.307
% Voids CPL 5105	5.6	4.1	3.0	1.5
Stability CPL 5105	29	24	22	12
Modulus CPL 5110	257	233	228	195
Strength coefficient	0.44	0.44	0.40	0.25
VMA (effective)	17.8	17.5	17.6	17.3
VMA (bulk)	16.7	16.6	16.6	16.5
% of bulk VMA filled	66	75	82	91
Dust / AC ratio	1.08	0.98	0.90	0.83
COHESIOMETER	99.67	108.62	134.49	153.41

IMMERSION-COMPRESSION CPL 5104		LOTTMAN	CPL 5109
% bitumen		6.1	% bitumen
PSI Wet		30	Wet D.T.St
PSI Dry		33	Dry D.T.St
% Absorption		8.25	% Voids
% Swell		59	% Saturation
% Ret. Strength		93	% T.S.Ret.
% Additive used		0.0	% Additive
Asphalt additive type			

Optimum asphalt content 6.1
Stability at Optimum A.C. 24
Asphalt film thickness at Optimum A.C.: 10.7 microns

Lab Max. SpG at Optimum 2.375
% Voids at Optimum A.C. 3.89

Date Reported 7/25/94

Robert LaForce 757-9724
Flexible Pavement Engineer

APPENDIX C

Project Specifications

REVISION OF SECTION 403
HOT BITUMINOUS PAVEMENT

Section 403 of the Standard Specifications is hereby revised for this project as follows:

Subsection 403.01 shall include the following:

This work includes construction of test sections with one or more courses of HBP, Hot Bituminous Pavement (Rubber Modified Asphalt Concrete), HBP (RUMAC), on a prepared base in accordance with these specifications, and in conformity with the lines, grades, thicknesses, and typical cross sections shown on the plans or established.

The test sections shall be as follows:
1. 1-500 Ton test section of HBP (Gr. C) (Asphalt)
2. 1-500 Ton test section of HBP (Gr. C) (Asphalt)(RUMAC) at 3 lbs./ton CRM
3. 1-500 Ton test section of HBP (Gr. C) (Asphalt)(RUMAC)(1% CRM) at 1% CRM by weight of total mix.

The balance of the bituminous pavement on the project shall be HBP (Gr. C) (Asphalt)(RUMAC) at 1 lb./ton CRM.

The test sections shall be placed at locations designated by the Engineer.

The HBP (RUMAC) shall be composed of a mixture of aggregate, crumb rubber modifier (CRM), filler if required, and bituminous material.

HBP (RUMAC) may be covered by patent numbers 4,086,291 and 4,548,962 or others. Any use of this technology should include a determination of the validity of the patent rights and risk of infringement.

Subsection 403.02 shall include the following:

The design mix for hot bituminous pavement shall conform to the following:

TABLE 403-1

PROPERTY	TEST METHOD	VALUE FOR GRADING	
		C(C50)	PATCHING
Air Voids, percent	CPL 5105	3-5	3-5
Stability, minimum	CPL 5105	33	33
Lab Compaction (End Point Stress, psi)	CPL 5105	50	50
Aggregate retained on the No. 4 sieve with at least 2 mechanically induced fractured faces, % minimum	CP 45	70	70
Accelerated Moisture Susceptibility Tensile Strength Ratio (Lottman), minimum	CPL 5109	80	80
Minimum dry split tensile strength, psi	CPL 5109	30	30
Grade of Asphalt Cement		AC-10	AC-10
Voids in the mineral aggregate (VMA), % minimum	CP 48	See Table 403-2	
Voids filled with asphalt (VFA), %	AI MS-2	65-80	65-80

AI MS-2 = Asphalt Institute Manual Series 2

REVISION OF SECTION 403
HOT BITUMINOUS PAVEMENT

Note: The current version of CPL 5105 is available from the Region Materials Engineer.

Note: Design criteria for Grading C and Grading CX mixes should be approached with caution to avoid mixes that produce a maximum density plot. As a minimum, contractors are advised to develop mixes 2-3% above or below the maximum density line.

Note: Based on limited lab testing it is anticipated that to use crumb rubber at the one percent or higher rate, a number of changes will be required in the mix.

Approximately 3 percent of the fine aggregate will need to be eliminated to make room for each 1% crumb rubber.

Crumb rubber acts like an absorptive aggregate, and it is anticipated that the asphalt content for a mix containing 1% crumb rubber will increase approximately 0.5% to 1.0%.

TABLE 403-2

Minimum Voids in the Mineral Aggregate (VMA)			
Nominal Maximum Size* Inches (mm)	Design Air Voids**		
	3.0%	4.0%	5.0%
1 1/2 (37.5)	10.0	11.0	12.0
1 (25.0)	11.0	12.0	13.0
3/4 (19.0)	12.0	13.0	14.0
1/2 (12.5)	13.0	14.0	15.0
3/8 (9.5)	14.0	15.0	16.0

* The Nominal Maximum Size is defined as one sieve larger than the first sieve to retain more than 10%.

** Interpolate specified VMA values for design air voids between those listed.

REVISION OF SECTION 403
HOT BITUMINOUS PAVEMENT

The Contractor shall prepare a quality control plan outlining the steps taken to minimize segregation of HBP. This plan shall be submitted to the Engineer and approved prior to beginning the paving operations. When the Engineer determines that segregation is unacceptable, the paving shall stop and the cause of segregation corrected before paving operations will be allowed to resume.

The hot bituminous pavement and HBP(RUMAC) shall not contain more than 15 percent reclaimed asphalt pavement. The HBP(RUMAC)(1% CRM) shall not contain recycled asphalt pavement.

Hot bituminous pavement for patching shall conform to the gradation requirements for Hot Bituminous Pavement (Grading C).

A minimum of one percent hydrated lime by weight of the combined aggregate shall be added to the aggregate for all hot bituminous pavement, HBP(RUMAC), and HBP(RUMAC)(1% CRM).

HBP(RUMAC) shall conform to the requirements for the specified grading and shall include 1 lb./ton, 3 lbs./ton and 1% CRM by weight of total mix, CRM in the mixture.

CRM shall meet the requirements of subsection 712.15. The selection of the CRM properties, including process method and gradation, shall be as recommended by the manufacturer/supplier. Gradation shall be either CRM-II or CRM-III as shown in subsection 712.15, Table 712-9.

The Contractor's proposed job mix formula (JMF) for HBP (RUMAC) shall be submitted in accordance with subsection 401.02 at least 30 days prior to beginning production. The Contractor shall submit with the JMF: the source, composition and proportion of CRM.

The following stability requirements apply to the HBP (Gr. C)(Asphalt)(RUMAC)(1% CRM) mix only:

(1) Stability tests will be performed for information only and the mixes will be designed at the normal void level.

(2) Mix design criteria for the appropriate grading shall apply to this item however, stability requirements will be determined prior to addition of the CRM.

(3) Stability of field produced material will be tested for information only.

REVISION OF SECTION 403
HOT BITUMINOUS PAVEMENT

The Contractor shall prepare a work plan detailing the method and sequence for adding CRM into the mixing process at a uniform rate of 1 lb./ton, 3 lbs./ton and 1% by weight of total mix. This plan shall be submitted to the Engineer and approved prior to beginning the paving operations. This plan shall provide for the addition of CRM so that it is not combined with the virgin aggregate prior to drying. Direct contact of the CRM with the burner flame shall not be allowed.

Subsection 403.03 shall include the following:

Areas to be patched shall be excavated and squared to a neat line, leaving the sides of the excavation vertical. Prior to placement of the patch the exposed sides of the existing pavement shall be thoroughly coated with Emulsified Asphalt (slow-setting). Hot bituminous pavement shall then be placed and compacted in succeeding layers not to exceed three inches in depth. Construction of the HBP(RUMAC) test sections shall conform to the following additional requirements:

(1) The hot mix asphalt mixing plant shall have automatic controls that coordinate the proportioning, timing and discharge of the mixture. The plant shall be capable of uniformly feeding and measuring the amount of the CRM placed into the mixing chamber.

(2) Drum mixing plants shall not add the CRM to the aggregates cold feed system The CRM must be added beyond the aggregate drying and heating section of the mixing chamber.

(3) When using a batch plant, the batch size and CRM bag size shall be adjusted to use whole bags of CRM. Adding partial bags of CRM into the mixing chamber will not be permitted.

(4) HBP (RUMAC) shall not be conveyed on rubber belts.

(5) Unless permitted by the Engineer pneumatic-tire rollers shall not be used to compact HBP (RUMAC).

(6) For the HBP (RUMAC)(1% CRM) rolling shall continue until the temperature of the mat is 140 degrees F.

Subsection 403.05 shall include the following:

Pay Item	Pay Unit
Hot Bituminous Pavement (Grading C)(Asphalt)(RUMAC)	Ton
Hot Bituminous Pavement (Grading C)(Asphalt)(RUMAC)(1% CRM)	Ton

REVISION OF SECTION 403
HOT BITUMINOUS PAVEMENT

Aggregate, asphalt cement, asphalt recycling agent, additives, hydrated lime, CRM, and all other work necessary to complete each hot bituminous pavement item will not be paid for separately but shall be included in the unit price bid.

Excavation, preparation, and tack coat of areas to be patched will not be measured and paid for separately, but shall be included in the work.

Mixtures containing either 1 lb./ton or 3 lbs./ton CRM will be paid for under the pay item Hot Bituminous Pavement (Grading_) (Asphalt) (RUMAC).

General Note: A compaction test section shall be established for each type of mix.