Mix Designs and Air Quality Emissions Tests of Crumb Rubber Modified Asphalt Concrete

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The mix design and air quality asphalt plant emissions testing of crumb rubber modified (CRM) bituminous concrete mixes are described. The wet process and the dry process were used to incorporate crumb rubber into standard bituminous concrete mixes, into an open graded friction course (OGFC) mix, into a recycled rubber reclaimed asphalt pavement (RAP) mix, and into a gap-graded propriety mix. The mix gradations are presented for six CRM bituminous concrete pavement-resurfacing and lane-widening projects. Asphalt plant emissions testing data are presented for the projects. Mix designs were developed successfully for three wet process CRM mixes using 10 percent, 15 percent and 18 percent crumb rubber by weight of an AC-20 or AC-10 asphalt cement. The emission tests indicated that total hydrocarbons, carbon monoxide, and particulate emissions for two of the mixes were within state of New Jersey emissions limits. The opacity and odor surveys indicated acceptable emissions. The third wet process project indicated some emissions values above the limit. The mix design was developed successfully for a project that used 20 percent rubber RAP in a fine aggregate surface course. The emissions tests indicate that total hydrocarbons and particulates were within emissions limits. One carbon monoxide reading was at the limit. Propriety gap-graded dry process CRM mixes design were constructed in the surface and base course of a resurfacing project. The propriety surface course mix raveled soon after construction and required replacement with the standard surface course. The air quality emissions tests indicated that the emissions data were higher than the standard mix and one total hydrocarbons reading was above the emissions limit. Three generic dry process mixes were constructed as a lane widening to develop CRM mix designs for surface course, base course, and base course with 10 percent crushed container glass. Air quality emissions values for the standard mix and CRM mix were above the emissions limits.

The objective of this study was to develop CRM bituminous concrete mixes, to compare those mixes to the standard mixes, and to compare the resulting air quality asphalt plant emissions during production of the mixes. With major emphasis on reducing the enormous numbers of scrap tires that were being landfilled and stockpiled, ground scrap tire rubber was incorporated into mixes for the potential benefit of both the long-term pavement properties and the environment. Furthermore, the Federal Intermodel Surface Transportation Efficiency Act (ISTEA) and the state recycling program has mandated the study and use of scrap tire rubber in highway applications.

BACKGROUND

The state of New Jersey discards annually approximately 10 million scrap tires. The nation discards annually some 285 million tires, of which 32 percent are retreaded, resold, or diverted to other uses such as tire-to-energy facilities. The remaining tires are stockpiled and landfilled, creating environmental concerns. The use of some scrap tires as ground tire rubber in bituminous concrete mixtures was proposed as a partial solution to mounting stockpiles of tires. This study of the ground tire rubber waste in bituminous concrete mixtures evaluates technical questions about the use of that material.

RESEARCH METHODOLOGY

With the intent of allowing market forces to determine the most efficient and beneficial method of incorporating ground tire in bituminous concrete, the New Jersey Department of Transportation (NJDOT) initiated a study of both the wet and dry processes for the addition of crumb rubber modifier into bituminous concrete mixes for several major projects. Since CRM technologies were available to reasonably assure the success of experimental pavements, the mixes were constructed in large projects where sufficient materials could be produced to compare asphalt plant air quality emissions, mix designs, asphalt plant production, and construction procedures. To compare future long-term pavement performance of the CRM mixes, standard pavement courses were constructed adjacent to CRM mixes.

The NJDOT standard laboratory materials test procedures were conducted to determine the appropriate mix designs with the rubber. Using job mix formula specifications and the Marshall method, gradation tests were made to determine quantities of aggregates and asphalt cement, as well as the optimum quantity of rubber. Marshall mix design plugs were tested in accordance with the current specifications to evaluate performance parameters such as mix stability, flow, density, and voids. In one project, resilient modulus testing was performed on Marshall specimens to compare the CRM mixes with the standard mixes.

The field sections were surveyed for cracking, rutting, skid resistance, and roughness, and the initial field data are reported.

Asphalt plant air quality emissions protocols were developed to test both the standard and CRM mixes for carbon monoxide, total hydrocarbons, particulate emissions, odors, and visual emissions. These data were compared to the New Jersey Department of Environmental Protection (NJDEP) standards. Also, the air emissions data of the production of standard bituminous concrete mixes were compared to the emissions data of the CRM mixes under similar test conditions. The air quality test procedures used were

- Carbon monoxide: US EPA Reference Method 10, "Determination of Carbon Monoxide Emissions from Stationary Sources";

Bureau of Research, Bureau of Materials, Recycled Materials Task Group, New Jersey Department of Transportation, 1035 Parkway Avenue, Trenton, N.J. 08625.

- Total hydrocarbon (THC) (as methane): NJ Air Test Method 3, Section 3.7, "Procedures for the Direct Measurement of Volatile Organic Substances Using a Flame Ionization Detector";
- Particulate emissions: NJ Air Test Method 1, "Sampling and Analytical Procedures for Determining Emissions of Particles from Manufacturing Processes and from Combustion of fuels"; and
- Opacity readings: NJ Air Test Method 2, "Procedures for the Visual Determination of the Opacity (%) and Shade or Appearance (Ringelmann Number) of Emissions from Sources."

CONSTRUCTION

Experimental Field Sections

From October 1991 to June 1994, experimental field sections of CRM bituminous concrete mixes were constructed as overlays and lane widening on six projects in urban and rural New Jersey. The projects were initiated to evaluate the use of crumb rubber in the NJDOT's standard surface course mix using the wet process, an open graded friction course (OGFC) mix using the wet process, gap-graded proprietary dry mix called Plus-Ride II using a dry process, a recycled CRM rubber-modified reclaimed asphalt pavement (RAP) surface course mix, and a generic dry process surface and base course mix. A summary of general information for the six demonstration projects is presented in Table 1. Summaries of the laboratory test properties and air quality emissions test results are presented in Table 2 and Table 3.

Wet Process CRM Mix (Rouse)

The first wet process CRM bituminous concrete surface course was constructed on a resurfacing project on Route I-95, Ewing Township, in October 1991. A standard bituminous concrete surface course was constructed on a contiguous section of Route I-295, Hopewell Township, as a control section for comparison with the CRM mix. The asphalt-rubber cement was blended at the plant by Rouse process.

The asphalt plant was a 2.7-tonnes McCarter (3-ton) batch type plant. The asphalt cement (AC-20) was blended with 10 percent of a No. 40 mesh recycled tire rubber in the on-site portable blending unit, heated to 177°C (350°F) and mixed with the aggregates and baghouse fines in the pugmill for 35 sec. The CRM mix was discharged from the plant between 143°C to 160°C (290°F to 320°F). As a reference, the standard mix was typically discharged at 138°C to 154°C (280°F to 310°F). The tire rubber was supplied in plastic bags. Dampness caused two pallets of these bags to solidify causing production delays.

The construction of the CRM surface course was preceded by milling 51 mm (2 in) of the existing bituminous concrete pavement to eliminate rutting. A bituminous stabilized base course replaced

TABLE 1 Summary of Crumb Rubber Modified Asphalt Concrete Experimental Field Projects

	Project #1	Project #2	Project #3	Project #4	Project #5	Project #6
Route	I-95&I-295	Ferry St.	I-195	US 130	I-95	I-287
Location	Ewing Twp.	City of Newark	Allentown	Logan Twp.	Ewing Twp.	
Bedminister						
	Hopewell Twp. Northbound		Westbound	Southbound	Hopewell Twp. Southbound	Northbound
Project	51 mm, overlay	38 mm, overlay	19 mm, overlay	51 mm, surface 51 mm, base overlay	51 mm, surface 76 mm, base overlay	51 mm surface 51 mm base lane widening
Mix Type	Surface Course Crumb Rubber Modified	Surface Course CRM-Recycled 20% RAP	Open Graded Friction Course (OGFC)	Plus-Ride II; Surface Course Base Course	Surface Course Base Course	Surface Course Base Course Base w/Glass
Mix Process	Wet	Recycled Dry	Wet	Propriety Dry	Wet	Generic Dry
AADT	43,700	N.A.	20,500	4,000	43,700	
54,700						
	6 lane, divided Suburban	2 lane, Urban	4 lane, divided Rural	4 lane, divided Rural	6 lane, divided Suburban	6 lane divided Rural
Date	October 1991	July 1992	August 1992	October 1993	June 1994	May 1994
Total Material						
Surface Course	2086 t	1088 t	435 t	3592 t	2441 t	1886 t
Base Course				4280 t	2897 t	2231 t
Base/glass						2022 t
Length	1159 m	244 m	549 m	2653 m	1067 m	2670 m
Air Quality Testing	yes	yes	yes	yes	yes	yes

TABLE 2 Summary of Laboratory Test Properties

Laboratory Tests	Project #1 Wet Process		Project #2 Recycled Rubber RAP		Project #3 Wet Process		Project #4 Propriety Gap Graded Dry Process			
	CRM Surface	Standard Surface	CRM-RAP Surface	Standard Surface	CRM OGFC Surface	Standard Surface	Standard Surface	Standard Base	CRM Surface	CRM Base
Marshall										
Stability, lbs.	2252	2383	2080	2590	n.a.	n.a.	1675	1550	1310	950
Flow 0.01" (0.02cm)	14	14	17	14	n.a.	n.a.	10	11.7	38.5	41.5
Air voids, %	2.7	2.7	3.6	3.3	18	n.a.	3.4	4.0	2.8	2.3

Laboratory Tests	Project #5 Wet Process				Project #6 Generic Dry Process					New Jersey Requirements Standard Mixes	
	CRM Surface	Standard Surface	CRM Base	Standard Base	CRM Surface	Standard Surface	Standard Base	CRM/ Glass Base	Standard Base	Mix 19mm Surface	Mix 39.7mm Base
Marshall											
Stability, lbs.	2650	2100	2409	2700	2670	2375	2510	2277	2280	1200 min.	1200 min.
Flow 0.01" (0.02cm)	12	12	13	12	12	16	12	17	14	6 - 16	6 - 18
Air voids, %	3.5	3.5	3.5	3.5	3.7	3.4	3.9	3.5	3.2	2 - 5	2 - 5

the milling. The CRM mix was placed as a surface course on the inside shoulder and mainline pavement with a standard paver. A breakdown roller, an intermediate roller, and a finish roller were used on the CRM surface course. The laydown temperatures of the mix were above 143°C (290°F). As a reference, the lay down temperature of most standard NJDOT mixes was about 138°C (280°F).

Construction Data

Using the Marshall method, the standard mix and the CRM mix were developed using NJDOT standard gradations. The composition samples for the mixes are shown in Table 4. The standard surface course and the CRM mixes have similar gradations with the exception of a

TABLE 3 Summary of Emissions Tests Results

		Project #1 Wet Process		Project #2 Recycled Rubber RAP				Project #3 Wet Process			Project #4 Propriety Dry Process					
	Emissions	Standard	CRM	Stand.Mix		CRM RAP		CRM-OGFC			CRM Mix			Virgin Mix		
Test Number	Standards	Mix	Mix	1	2	1	2	1	2	3	1	2	3	1	2	3
Concentration Data																
Total Hydrocarbons (as methane)																
ppmV-dry @ 7% O_2	250	n.a.	n.a.	32	34	26	32	129	150	147	245	289	244	134	125	133
Carbon Monoxide																
ppmV-dry @ 7% O_2	500	n.a.	n.a.	284	328	396	500.6	222	217	265	134	122	160	96	111	87
Particulates																
grains/scf	0.02	n.a.	n.a.	0.006	0.006	0.006	0.006	0.004	0.003	0.004	0.004	0.002	0.002	0.006	0.001	0.003
Opacity (%)	10	10.4	9.0	n.a	n.a.	n.a.	n.a.	0	0	0	0	0	0	0	0	0
Odor Survey	n.a.	0	0	n.a.	n.a.	n.a.	n.a.	0	0	0	2	2	3	2	2	3
Intensity: 0-none, 5-very strong																

		Project #5 Wet Process						Project #6 Generic Dry Process					
	Emissions	CRM Mix			Standard Mix			CRM Mix			Standard Mix		
Test Number	Standards	1	2	3	1	2	3	1	2	3	1	2	3
Concentration Data													
Total Hydrocarbons (as methane)													
ppmV-dry @ 7% O_2	250	417	362	307	78	70	66	1271	1301	1067	1042	324	517
Carbon Monoxide													
ppmV-dry @ 7% O_2	500	148	104	115	107	106	104	515	503	445	338	248	270
Particulates													
grains/scf	0.02	0.37	0.50	0.42	0.09	0.09	0.11	0.05	0.05	0.05	0.07	0.06	0.06
Opacity (%)	10	24	n.a	n.a.	19.2	n.a.	n.a.	3.4	4.3	4.7	4.4	4.2	4.9
Ordor Survey	n.a.	<1	<1	<1	<1	1.2	1.1	1.0	1.1	1.4	1.3	1.3	1.4
Intensity: 0-none, 5-very strong													

TABLE 4 Summary of Mix Gradations, Wet Process CRM Mix, Project No. 1, Route I-95

Sieve Size	Percent Passing-Job Mix Formula CRM Mix Surface Course	Standard Mix Surface Course	NJDOT Specification Mix size (19mm)3/4inch Surface Course
25.4 mm (1 inch)	100	100	100
19 mm (3/4 inch)	99	99	98-100
12.7mm (1/2 inch)	95	95	88-98
9.5 mm (3/8 inch)	87	87	65-88
No. 4	61	62	35-65
No. 8	45.5	45.5	25-50
No. 16	33	33	10-40
No. 30	23	23	12-30
No. 50	17	17	10-25
No. 200	5.9	6.1	3-10
A.C.	6.5	5.6	4.5-9.5

Sieve Size	Ground Tire Rubber Gradation (% passing)
40	100
60	98-100
80	90-100
100	70-90
200	35-60

higher percentage of asphalt cement for the CRM mix. Marshall stability, flow, and air voids are similar for both mixes.

The asphalt-rubber cement tests are shown in Table 5. The viscosity of the asphalt-rubber cement is five to six times greater than the virgin AC-20.

After paving, thin lift nuclear gauge density measurements were made to survey the as-built pavement density. The measured percent air voids of the CRM mix were 4.4 percent for the inside lane, 5.4 percent for the center lane, and 5.6 percent for the outside lane. The NJDOT specifications require percent air voids to fall between 2 and 8 percent. A vibratory roller was required to compact the CRM mix.

Similar density measurements were made on the standard bituminous concrete surface course mix. The measured percent air voids of the standard surface course were 7.7 percent for the inside lane and 4.5 percent for the center lane. The percent air voids of the standard surface course were higher than the CRM section; the reason for this was unclear.

ARAN Ride Quality Index values were made in June 1993. The CRM mix pavement had an average value of 4.10, and the standard bituminous surface had an average value of 4.15. Both values indicate a good pavement. Average rut depths on both sections were 4.7 mm ($\frac{3}{16}$ in.). Some fine cracking was noted in the inside lane of the CRM section shortly after construction. To date, cracking has not significantly increased.

The resilient modulus data of Marshall plugs are shown in Figure 1. The modulus data of the CRM mix are somewhat higher than the standard surface course mix.

Asphalt Plant Air Emissions Tests

The visible and fugitive emissions and odor survey were conducted at the plant during the CRM and standard mix production. Since the plant is located in Penns Park, Pennsylvania, the air quality emission protocol was developed with the Pennsylvania State criteria. The plant is set up to produce material based on those criteria. An environmental consultant conducted the source emissions test for visible emissions compliance and the odor survey at various locations of the plant facility.

A total of 36 odor survey tests were conducted during the 2 days of testing. The odor survey consisted of monitoring the odors emitting from the plant for intervals of 5 to 10 min at several property

TABLE 5 Asphalt Cement Test Results, Wet Process CRM Mix, Project No. 1, Route I-95

Test	Virgin AC-20 Sample #1	Virgin AC-20 Sample #2	CRM AC-20 Sample #1	CRM AC-20 Sample #2
Absolute Viscosity @ 140 F, Poises	1967	1982	10,032	10,388
Kinematic Viscosity @ 275 F, Centistrokes	412	420	2806	3007
Penetration @77 F 100g, 5 sec.	82	83	50	50
Specific Gravity	1.036	1.036	1.045	1.045

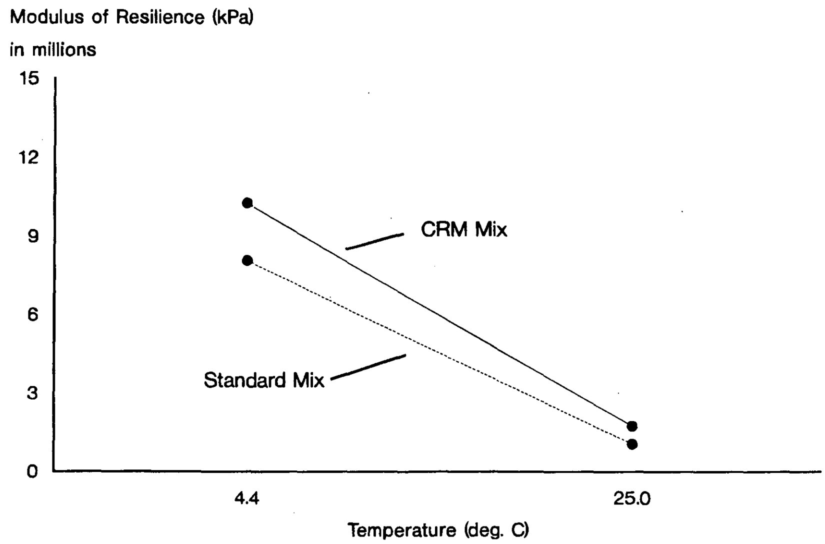

FIGURE 1 Modulus of Resilience Data, Project No. 1.

perimeter locations for each hour of production. The tests did not detect any odors emanating from the production of either mixes.

During the production of the CRM mix, six test runs of 30 min each were conducted both days with 6-min opacity readings every 15 sec at the outlet stack on the baghouse, with spot checks for fugitive emissions on the processing equipment downstream of the blender. During the production of the standard mix, 12 similar tests were conducted for 1 day's production.

The highest opacity reading of the CRM mix tests was 17.1 percent, which was taken during the start-up of the second day of the production. The high reading was attributed to the initial start-up problems of the plant and not the production of the CRM mix. The average opacity of the CRM mix tests was 10.4 percent and the standard mix was 9.0 percent. In Pennsylvania, the average opacity for the highest period should not exceed 20 percent. Although some CRM mix readings exceeded the New Jersey criteria, the test readings meet the Pennsylvania requirement where the plant was designed to operate. No statistical difference is noted between the opacity readings of the CRM and standard mix.

Recycled Rubber RAP (Dry Process)

In 1991, the City of Newark constructed a Plus-Ride dry process CRM pavement which raveled shortly after construction. The pavement was milled, and the rubber reclaimed asphalt pavement (RAP) was stockpiled for future use. The stockpile contained 226 tonnes (250 tons) of 3-percent rubber RAP.

The City of Newark proposed a Local Aid resurfacing project to use the stockpiled RAP. The proposed surface course mix used 20 percent rubber RAP in NJDOT's fine aggregate surface course mix. To complete the mix design, trial mixtures were prepared by varying the asphalt content for the virgin materials. This procedure permitted the asphalt cement (about 7 percent AC) in the rubber RAP to remain with the RAP in the mix. The mix composition is shown in Table 6. The surface course mix with 20 percent rubber RAP contained 6.4 percent asphalt cement and 0.46 percent crumb rubber (100 percent passing the No. 6-mm sieve size) from the RAP. In contrast, the surface course mix with RAP contained 5.55 percent asphalt cement. The Marshall tests for both mixes showed no sig-

TABLE 6 Summary of Mix Gradations Recycled Rubber RAP Project No. 2, City of Newark, Composition Analysis (Percent Passing)

Sieve Size	Surface Course Mix-RAP Composition Sample Fine Agg. Surface	Rubber RAP Mix Composition Sample Fine Agg. Surface	NJDOT Specification Mix size 9.5mm (3/8 inch) Fine Agg. Surface
12.7 mm	100	100	100
9.5 mm	99	98	80-100
No. 4	64	68	55-75
No.8	44.5	45.5	30-60
No. 16	32	32	20-45
No. 30	25	25	15-35
No. 50	17.0	17.0	10-30
No. 200	6.4	6.5	4-10
Asphalt Content	5.55	6.4	5-10
Rubber Content	--	0.46	--

nificant differences. However, the flow values of the rubber RAP samples were generally higher than the RAP mix samples.

The recycled rubber RAP mix was processed through a Bituma counter flow drum plant in Wharton, New Jersey, in July 1992. The mix was discharged from the plant and paved at normal temperatures. The mix was paved in a 38-mm resurfacing project on a city street in Newark. The nuclear density voids were 4.5 percent for the rubber RAP mix.

The air emissions tests were conducted at the asphalt plant stack outlet by an environmental consultant. The emissions tests included two 1-hour gaseous emissions tests for carbon monoxide, total hydrocarbons, and particulates during the asphalt plant production of the standard surface course material and the surface course with rubber RAP. The total hydrocarbons and particulates for both mixes were within emissions limits. Both carbon monoxide emissions test results for the rubber RAP mix were above the results for the standard mix without rubber. One carbon monoxide value of the rubber RAP mix test was at the emissions limit.

Wet Process CRM Mix Open Graded Friction Course

The wet process CRM mix open graded friction course was constructed on a resurfacing project on Route I-195, Allentown, in July 1992 to evaluate the use of CRM to stiffen the asphalt cement and reduce runoff during transportation. The Rouse process was used to blend 15 percent (No. 40 mesh size) crumb rubber by weight of the asphalt cement.

For most bituminous concrete mixes, the standard operating procedure for selecting the job mix formula is the Marshall method. However, the NJDOT determines the job mix formula for the open graded friction course by making trial batches having different asphalt cement contents and gradations consistent with the job mix specifications. The trial batches mixtures are spread evenly on heat resistant transparent pyrex dishes and placed in an oven for 1 hour. After the hour, the dishes are examined for a slight puddle at the points of contact between the aggregate and the glass dish and compared to photographs of desirable drainage conditions. The mixture meeting the "slight" puddle condition is selected for determination of the asphalt cement content. The job mix formula for the CRM open graded friction course is shown in Table 7.

A 2.7-tonnes (3-ton) Barber Green batch-type asphalt plant was used in the production of the mix. Similar to the above Route I-95, Ewing, project, the fine ground tire rubber was blended with the asphalt cement. The mix was discharged from the plant between 143°C and 160°C (290°F and 320°F). The laydown temperatures of the material were above 138°C (280°F) and ambient temperatures were above 16°C (60°F).

TABLE 7 Summary of Mix Gradations, Wet Process CRM, Open Graded Friction Course, Project No. 3, I-195 Job Mix Formula

Sieve Size	Percent Passing: NJDOT Specification OGFC	Percent Passing: CRM-OGFC Sample
12.7 mm	100	100
9.5 mm	80-100	94
No. 4	30-50	39
No. 8	5-15	10.5
No. 200	2-5	2.9
A. C./Rubber	5.7-7.0	6.6

Although some material cooled prematurely in the trucks causing clumping, no significant paving problems were noted on the project. Essentially, no asphalt cement runoff was noted in the trucks on the project.

Density measurements from cores indicated that the in-place air voids were above 15 percent as specified. The initial average skid measurements were good (SN = 52) for both lanes and the average Aran Ride Quality Index was good (ARQI = 4.23) for both lanes.

The air quality emissions testing was conducted according to the above methods and procedures at the asphalt plant. The concentration data were collected for three 1-hour tests. The data for total hydrocarbons, carbon monoxide, and particulates are below the standard. An odor survey was conducted upwind and downwind of the source at the property line; no odors were detected. The opacity (percent) of the plume from the baghouse exhaust was determined similar to the Route I-95 project. Observations were made at 60-sec intervals and were performed simultaneously with the emissions sampling. The opacity was 0.0 percent for all three runs.

Dry Process CRM Mix (Plus Ride)

The propriety gap-graded dry process CRM mix was constructed on a resurfacing project on Route 130, Logan Township in October/November 1993.

The gap-graded CRM mixes for the surface and base course contained 3 percent ground tire rubber by weight of the mix. The mix and rubber gradations are shown in Table 8. The Plus-Ride mixes are gap graded to allow space for the crumb rubber. For the Plus-Ride II Mix 12 and Mix 16, the gap grade was defined by restricting the amount of aggregate passing the No. 4 sieve and retained on the No. 8 sieve to be 8 percent. The gaping within this band of aggregate gradation is critical.

The crumb rubber was granulated reclaimed vulcanized rubber produced primarily from the processing of automobile and truck tires. The crumb rubber must be sufficiently dry so as to be free flowing and free of wire.

The mixes were produced in a 3.6-tonnes (4-ton) H & D batch type plant. For the CRM mix, the plant discharge temperatures were 151°C to 157°C (305°F to 315°F) and the laydown temperatures were 143°C to 151°C (290°F to 305°F).

Although paving was completed without significant material handling and compaction problems, the pavement began to ravel shortly after construction. Some of this serious deterioration is attributed to paving in the rain, but a significant portion of the deteriorated surface was not paved in the rain and cannot be explained without further testing. The deterioration appears to be isolated to the surface course, without affecting the base course material.

The air quality emissions testing parameters and methods were similar to the above tests. Three 1-hour tests were performed on the baghouse outlet during production of the standard surface course mix and the dry process CRM surface course mix. Previous emissions tests of this plant indicated typical carbon monoxide (CO) emissions under 150 ppm and total hydrocarbons (THC) under 200 ppm for virgin materials. On this project, the total hydrocarbons, carbon monoxide, and particulate emissions for the standard mix were below the emissions standard, and below the typical emissions for the plant. However, the THC for the CRM mix were above the

TABLE 8 Summary of Mix Gradations, Dry Process—Plus Ride II Mixes, Project No. 4, Route 130, Job Mix Formula

	Percent Passing	
Sieve Size	Plus Ride II - Mix 16 Base Course Sample	Plus Ride II - Mix 12 Surface Course Sample
19 mm	100	--
15.8 mm	---	100
9.5 mm	57	70
No. 4	34	34
No. 8	26	28
No. 30	19	19
No. 200	9.5	9.9
Asphalt Cement	7.7	7.7
Crumb Rubber	3.0	3.0

Sieve Size	Ground Tire Rubber Gradation (% passing)
6.3 mm	100
No. 4	76 - 100
No. 10	28 - 42
No. 20	16 - 24

Specific Gravity 1.15+/-0.05

typical emissions level of the plant, and higher than the THC for the standard mix. One value of THC exceeded the emissions standards. The CO and particulate emissions for the CRM mix were below the emissions standard.

Wet Process CRM Mix (McDonald)

For the third wet process project, a CRM bituminous concrete surface course and CRM bituminous stabilized base course were constructed on the southbound lanes of a resurfacing project on Route I-95, Ewing Township. The asphalt-rubber cement was blended at the plant by Asphalt Rubber Systems.

The asphalt plant was a 2.7-tonnes (3-ton) Barber Green batch type plant. The asphalt cement (AC-10) with an extender oil was blended with 18 percent Baker Rubber TR-24 and TBS-20 crumb rubber in the on-site portable blending unit, heated to 177°C (350°F) and mixed with the aggregates and baghouse fines in the mixer for 35 sec. The tire rubber was supplied in paper bags. The mix was discharged from the plant between 143°C and 160°C (290°F and 320°F).

The mix gradations are shown in Table 9. All mixes used the NJDOT standard specifications for gradations. The standard mixes contained 10 percent to 20 percent RAP. Laboratory test properties indicated that the Marshall stability, flow, and voids were similar for all mixes. The physical properties of the CRM asphalt cement are shown in Table 10.

The construction of the CRM surface course and base course was preceded by milling 50 mm (two in.) of the existing bituminous concrete pavement to eliminate rutting. A 75-mm (three-in.) bituminous stabilized base was placed on the milled surface. The 50-mm (two-in.) CRM surface course was placed on the base course. The CRM mix was placed as a surface course on the shoulders and mainline pavement with a standard paver. A breakdown roller, intermediate roller and a finish roller were used on the CRM surface course. The laydown temperatures were above 143°C (290°F). All in-place density measurements were within specifications. No problems were noted during paving.

The air quality emissions testing parameters and methods were similar to the above tests. Three 1-hour tests were performed on the baghouse outlet during production of the standard surface course mix and the wet process CRM surface course mix. For the CRM mix, the total hydrocarbons, opacity, and particulate emissions were above the limit. The total hydrocarbons were significantly higher than the standard mix. For the standard mix with RAP, the particulate emissions and opacity were also above the limit. Production problems were not apparent during the tests.

Generic Dry Process CRM Mix

The generic dry process was constructed on a lane reconstruction project on Route I-287, Bedminister, in November 1993 and June 1994.

The experimental design of the project consisted of (1) a test section of the generic dry process CRM bituminous concrete surface with 1 percent crumb rubber by weight of the mix on the standard bituminous stabilized base course, (2) a test section of the 1 percent CRM bituminous concrete surface on the CRM bituminous stabilized base course with 2 percent crumb rubber, (3) a test section of the 1 percent CRM surface course on the CRM/crushed container glass base course with 10 percent crushed container glass and 2 percent crumb rubber, and (4) a control section of the standard surface course and stabilized base course. The test sections were placed in the newly constructed northbound outside lane.

TABLE 9 Summary of Mix Gradations, Wet Process CRM Mix, Project No. 5, Route I-95

Sieve Size	Percent Passing-Job Mix Formula				NJDOT Specification
	Standard Surface Cr.	CRM Mix Surface Cr.	Standard Base Course	CRM Mix Base Course	Mix Size 37.9mm Base Course
50.8 mm	--	--	100	100	100
37.9 mm	--	--	100	100	90-100
25.4 mm	100	100	100	100	80-100
19 mm	99	99	--	--	--
12.7 mm	93	90	76	73	50-85
9.5 mm	--	80	--	--	--
No. 4	58	51	52	47	25-60
No. 8	45	34.5	41	35.0	20-50
No. 16	35	27	--	--	--
No. 30	26	21	--	--	--
No. 50	17	14	16	14.0	8-30
No. 200	5.8	4.4	5.5	5.4	4-12
A.C.	4.8	5.90	4.5	5.2	3.5-8

Ground Tire Rubber Gradation

Sieve Size	(% passing)
No.10	100
No.16	75-100
No.30	25-100
No.80	0-20
No.200	0-5

The CRM job mix formulas were performed by TAK Engineering using the Marshall method and are shown in Table 11. All mixes used the NJDOT standard specifications for mix gradations. The laboratory test properties were similar for all mixes. The standard mixes contained 10 percent to 20 percent RAP.

The mixes were processed through a 4.5-tonne (5-ton) McCarter batch type plant. The crumb rubber was introduced into the mixer from preweighed bags and mixed thoroughly for a minimum of 20 sec prior to introducing the asphalt cement. The wet mixing time was not less than 40 sec. The mix was discharged from the plant at between 143°C and 160°C (290°F and 320°F). The laydown temperatures were above 143°C (290°F). All in-place density measurements were within specifications. No problems were noted during paving.

The air quality emissions testing parameters and methods were similar to the above tests. Three 1-hour tests were performed on the baghouse outlet during production of the standard surface course mix and the generic dry process CRM base course mix. For the CRM mix, the total hydrocarbons, particulate, and one CO emissions values were higher than the standards. For the standard mix with RAP, the total hydrocarbons and particulate emissions were above the limit. The high emissions values for the CRM mix were attributed to intermittent production during a rainy period. The same emissions values for the standard mix were taken inadvertently during production of the plant's driveway mix which contained an unknown amount of RAP.

ANALYSIS AND DISCUSSION

This report describes the mix design and air quality asphalt plant emissions testing of crumb rubber modified bituminous concrete mixes. The wet process and the dry process were used to incorpo-

TABLE 10 Physical Properties of CRM Asphalt Cement, Wet Process CRM Mix, Project No. 5, Route I-95

Tests performed at 135 minutes reaction time	
Brookfield Viscosity @350°F, cp	3100
Viscosity, Haake@350°F, cp	1800
Penetration, needle@77°F (1/10mm, 100g, 5 sec.)	100
Penetration, needle@39.2°F (1/10mm,200g., 60 sec.)	61
Resilience@77°F % rebound	24
Ductility @39.2°F 1cm per min.	20.2
Softening Point °F	135.0
Cone Penetration @77°F 1/10mm	86

TABLE 11 Summary of Mix Gradations, Dry Process CRM Mix, Project No. 6, Route I-287

Sieve Size	Percent Passing-Job Mix Formula				
	Standard Surface Cr.	CRM Mix Surface Cr.	Standard Base Course	CRM Mix Base Course	CRM-Glass Base Course
50.8 mm	--	--	100	100	100
37.9 mm	--	--	100	100	100
25.4 mm	100	100	98	98	98
19 mm	100	100	--	--	--
12.7 mm	93	96	66	66	67
9.5 mm	77	77	--	--	--
No. 4	54	48	38	43	44
No. 8	42	32	30	30.0	30.0
No. 16	29	24	--	--	--
No. 30	20	18	--	--	--
No. 50	16	14	14	13.0	11.0
No. 200	6.6	6.0	5.8	7.6	5.9
A.C.	5.4	5.90	4.0	5.0	5.70
Rubber	--	1.0	--	2.0	2.0

Sieve Size	Ground Tire Rubber Gradation (% passing)	
	CRM Surface Course	CRM Base Course
No.4	--	100
No.8	100	63-77
No.16	63-77	45-55
No.30	45-55	27-33
No.50	22-28	8-12
No.80	8-12	--

rate crumb rubber into standard bituminous concrete mixes, an open graded friction course, a recycled rubber RAP, and a propriety gap-graded mix. The mix gradations are presented for six CRM bituminous concrete pavement resurfacing and lane widening projects. Asphalt plant emissions testing data are presented for the projects.

Using NJDOT standard mix gradations for bituminous concrete surface and base course, the mix designs were developed successfully for three wet process CRM mixes using 10 percent, 15 percent and 18 percent crumb rubber by weight of an AC-20 or AC-10 asphalt cement. The wet process used an on-site blending unit that heated the asphalt cement and crumb rubber to 176°C (350°F) before addition to the aggregate. In the asphalt plant, the CRM mixtures were heated about 6°C (10°F) higher than standard mixtures. Normal paving and compaction procedures were used for the projects. The paving temperatures were about 6°C higher than standard paving mixes. The wet process projects are performing initially similar to the standard paving mixes. The air quality emissions tests at the asphalt plants indicated mixed results with one project having test results above allowable standards.

Laboratory and modulus of resilience data indicate that the wet process mixes with AC-20 asphalt cement are somewhat stiffer than standard mixes. It is assumed that the stiffer CRM binder may resist rutting better than the virgin asphalt cement. However, the stiffer binder may be more susceptible to cracking.

For the open graded friction course mix, the CRM asphalt cement did not strip from the aggregate during transportation. As consistent with any open graded friction course, plant discharge and laydown temperatures are critical for handling and compaction. Previous experience has indicated that if the material cools, it has a tendency to clump and not provide desired compaction. Furthermore, if the plant mix temperatures are too high, the asphalt cement has a tendency to strip. From observations on this project, the CRM mix that was heated higher in the plant seemed to provide a better coating of the aggregate than standard OGFC mixes.

The mix design was developed successfully for a rubber reclaimed asphalt pavement (RAP) project which used 20 percent rubber RAP in a fine aggregate surface course. The rubber RAP was milled from a raveled gap-graded pavement. The construction data indicated that the density measurements are good. The air quality emissions tests indicated that the total hydrocarbons, and particulate emissions were within limits. However, one carbon monoxide reading was at the limit.

The propriety gap-graded dry process CRM mix design was constructed in the surface and base course of a resurfacing project. The 3 percent CRM mix required more asphalt cement, and the mix required the usual higher production temperatures. The CRM surface course mix raveled soon after construction and required replacement with the standard surface course. There were no problems with the CRM base course. The air quality emissions tests of the CRM mix indicated that the carbon monoxide readings were higher than the standard mix, and one reading was over the emissions limit.

Using NJDOT standard mix gradations, three generic dry process mixes were constructed as a lane widening. Containing 1 percent and 2 percent CRM, the mixes were developed for surface course, base course, and base course with 10 percent crushed container glass. Without blending equipment or additional processing, the generic dry process adds ground tire rubber directly into the mixer with the aggregate. Constructed in November 1993 and June 1994, the pavement surface course and base course look good. Some air quality emissions data for both mixes were above the limits. Intermittent production of the CRM mix may have contributed to high emissions values.

CONCLUSIONS

1. Using the NJDOT standard mix gradations and test properties, crumb rubber modified bituminous concrete mixes can be successfully developed with the NJDOT standard job mix formula methods, produced using the wet process and the generic dry process and constructed on overlays and new construction.

2. The wet process and generic dry process CRM mixes have similar Marshall stability, flow, and void test parameters compared with the NJDOT standard mixes. The wet process and generic dry process CRM mixes meet present test properties specifications and mix gradations.

3. From two projects, the initial field data such as rutting, cracking, smoothness, nuclear density, and skid resistance indicate that the CRM mixes produced by the wet process were similar to the standard mixes.

4. Using an NJDOT standard bituminous concrete mix gradation, rubber RAP from a gap-graded CRM mix can be successfully recycled in a bituminous concrete surface course. Additional rubber RAP projects should be conducted for wet and dry process RAP and constructed on the state highway system.

5. Although air quality plant emissions tests from two CRM mix projects indicated acceptable emissions levels, the emissions tests of the remaining four CRM mix projects indicated some unacceptable emissions levels. In addition, the emissions levels from the production of CRM mixes were generally higher than standard mixes.

6. The CRM asphalt cement in the OGFC permitted higher mix temperatures, provided better aggregate coating, and essentially eliminated asphalt cement runoff during transportation.

7. For the CRM bituminous concrete mixes, the plant discharge and the laydown temperatures were higher than standard bituminous concrete mixes.

8. The CRM bituminous concrete mixes required higher percentages of asphalt cement than the standard mixes.

Publication of this paper sponsored by Committee on Nonbituminous Components of Bituminous Paving Mixtures.