Evaluation of Recycled Rubber in Asphalt Cement Concrete

Field Testing

Final Report
For
HR-330, 330A, 330B, 330C, 330D

October 2002

Iowa Department
Of Transportation

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8. ABSTRACT

Roughly 242 million used tires are generated annually in the United States. Many of these tires end up being landfilled or stockpiled. The stockpiles are unsightly, unsanitary, and also collect water which creates the perfect breeding ground for mosquitoes, some of which carry disease.

In an effort to reduce the number of used tire stockpiles the federal government mandated the use of recycled rubber in federally funded, state implemented department of transportation (DOT) projects. This mandate required the use of recycled rubber in 5% of the asphalt cement concrete (ACC) tonnage used in federally funded projects in 1994, increasing that amount by 5% each year until 20% was reached, and remaining at 20% thereafter. The mandate was removed as part of the appropriations process in 1994, after the projects in this research had been completed.

This report covers five separate projects that were constructed by the Iowa Department Of Transportation (DOT) in 1991 and 1992. These projects had all had some form of rubber incorporated into their construction and were evaluated for 5 years.

The conclusion of the study is that the pavements with tire rubber added performed essentially the same as conventional ACC pavement. An exception was the use of rubber chips in a surface lift. This performed better at crack control and worse with friction values than conventional ACC. The cost of the pavement with rubber additive was significantly higher. As a result, the benefits do not outweigh the costs of using this recycled rubber process in pavements in Iowa.

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Asphalt Rubber Cement, Rubber Chips, Recycled Tires, ACC, ARC	73

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Introduction

Roughly 242 million used tires are generated annually in the United States (Shelquist, 1993). Many of these tires end up being landfilled or stockpiled. These stockpiles are unsightly, unsanitary, and can cover several acres of land. The tires also collect water, which creates the perfect breeding ground for mosquitoes.

In an effort to reduce the number of used tire stockpiles the federal government mandated the use of recycled rubber in federally funded, state implemented department of transportation (DOT) projects through the Intermodal Surface Transportation Efficiency Act (ISTEA) Section 1038 in 1991. This mandate required the use of recycled rubber in 5% of the asphalt cement concrete (ACC) tonnage used in federally funded projects in 1994, increasing that amount by 5% each year until 20% was reached, and remaining at 20% thereafter (Ichniowski, 1993). The mandate was removed as part of the appropriations process in 1994, after the projects in this research had been completed.

As a result of the mandate, several state DOTs started testing the use of recycled rubber in ACC. At the time two processes for the incorporation of recycled rubber in ACC were in use, the wet process and the dry process. These will be described later.

In 1991, the Iowa DOT began testing the use of rubber modified ACC in several projects located through out the state. The initial projects were located in Muscatine, Dubuque, Plymouth, and Black Hawk counties.

A Note on Terminology

There are several terms used in this report that can have different meanings for different people. In an attempt to minimize confusion, some of those terms are defined below for the purposes of this report (i.e. these definitions are not intended to set any sort of standard).

ACC – asphalt cement concrete (in the new parlance this is referred to as hot mixed asphalt or HMA).

ARC – asphalt rubber cement. By itself this is intended to mean just the asphalt binder, mixed or reacted with rubber products.

ARC mix – this is the combination of ARC with aggregate to form a paving mixture.

binder – this is the conventional asphalt binder (i.e. the black sticky stuff that hasn't been mixed with aggregate yet).

Objective

The objectives of this research are to determine if the different types of rubber modified ACC perform as well or better than conventional ACC and if the cost of incorporating rubber from recycled tires into the mixes justifies its use in asphalt paving.

Process Descriptions

There were two main processes in use at the time of this research for the addition of recycled rubber into ACC - these are described below:

(1) With the wet process, ground rubber is introduced into a mixing chamber, also known as a reactor, full of asphalt binder heated to a temperature of 290 to 400 ºF. The mixture of binder and rubber is allowed to react for 15 to 20 minutes and then stored in a heated mixing tank or metered directly into the asphalt plant in place of the normal binder. The end product of this reaction is called asphalt rubber cement (ARC).

(2) The second process, called the dry process, incorporates the ground rubber directly into the mix at the asphalt plant. Depending on the type of plant used, the rubber is either augered into the outer barrel of a double barrel drum mix plant or is dumped or blown into the pug mill of a batch plant (Brock). Some advantages of using the dry method are the ease of handling the material and the fact that far less equipment is needed to incorporate the rubber with the asphalt. There is concern however that the rubber will not react completely during the relatively short time spent in the drum.

Additionally, in this research there was one test section placed using rubber chips in the mix. The chips used in this section were nominally 1/4 inch tire-rubber chips. These chips were fed into the plant in the same way as the dry process.

Project Locations

The five projects covered by this report were located in Muscatine, Dubuque, Plymouth, and two projects in Black Hawk counties. Locations are described below and maps are shown with each project description.

Table 1
Project Locations

Project	County	Location
HR-330	Muscatine	US 61 from Muscatine to Blue Grass
HR-330A	Plymouth	IA 140 from Kingsley to IA 3
HR-330B	Black Hawk	IA 21 from the Waterloo city limits to the Tama county line
HR-330C	Dubuque	US 151 from Cascade to US 61
HR-330D	Black Hawk	IA 947 (University Ave./Main Street) from First Street in Cedar Falls to Green Hills Road in Waterloo

Project Details

There were five projects involved with this research. Each of four of those projects is described in detail below, including information on mix designs and construction. One which will not be described is HR-330B in Black Hawk county. This project had several problems with materials and construction that were unrelated to the performance of ARC. The problems were sufficient to warrant the removal of the project from consideration in this report.

HR-330 Muscatine County

This project was located on US 61 between Muscatine and Blue Grass. A map is shown below along with a list of the test sections:

Figure 1
Muscatine County Project Location

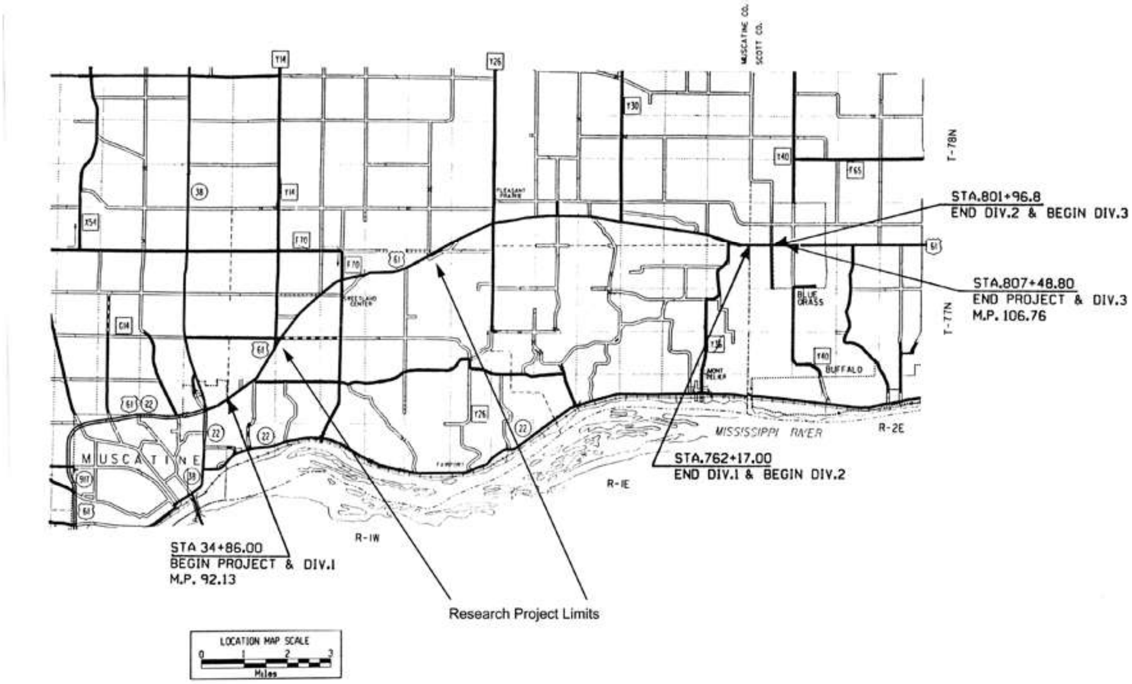


Table 2
Muscatine County Project Stationing

Test Section	Station to Station	Lane	Type of Mix Used
1	129+00 to 150+00	EB	Control
2	150+00 to 154+00	EB&WB	Rubber Chip Surface Only
3	154+00 to 180+00	EB	ARC Surface Only
4	180+00 to 212+50	EB	Control
5	212+50 to 239+00	EB	ARC Intermediate & Surface
6	239+00 to 262+65	EB	Control
7	262+65 to 290+00	EB	ARC Surface Only
8	290+00 to 317+00	EB	Control

The existing pavement consisted of 10 inch by 24 foot jointed PCC, constructed in 1957. Traffic volume (from 1988) was 7490 vehicles per day (vpd) with 17 percent trucks. Paving for this project consisted of four inches of ACC placed in two lifts.

The main contractor for the project was Manatt's Inc. of Brooklyn, Iowa; there was also a subcontractor, Determann Construction. Manatt's provided all of the conventional asphalt mix from their plant at the project site. Determann Construction provided the ARC mix and the rubber chip mix from an asphalt plant at the Wendling Quarry in Moscow. Manatt's placed both the conventional and rubber chip mixes for this project and Determann Construction placed the ARC mix.

Materials

In this project two materials were evaluated, ordinary ARC and rubber chips in the surface course. The ground tire rubber and the rubber chips were provided by Rouse Rubber Products of Vicksburg, Mississippi. Both were delivered in 50 pound paper bags.

Rouse had originally intended to use a GF-80 rubber or a GF-40 rubber for the ARC. However, preliminary testing of these products indicated that they could not meet the specified gradation limits. Rouse then submitted a GF-35 rubber which did meet the gradation limits and was used in the project. The gradation limits are listed in the Special Provisions in Appendix A; the actual gradation of the rubber used in this project is provided in Appendix B.

There were two asphalt binders used in this project. AC-10 was used for the conventional mixes and the rubber chip mix. AC-5 was used for the ARC. Both were supplied by Amoco Oil Company of Davenport.

Mix Design

Samples of all of the materials were tested in the laboratory. Several mix design changes were made during construction – the mix designs and changes are provided in Appendix C.

The first mix design change occurred during an ARC section. At station 225+75, the intermediate lift was being placed and it appeared dry and exhibited cracking and shoving. The asphalt binder content (AC-5) was increased from 6.6 to 6.8 percent in response. Unfortunately, shortly afterward the gradation was reported out of compliance. The binder content was lowered back to 6.6 percent and an aggregate interchange was made (increasing ½ inch chips and lowering manufactured sand – both by 5 percent). These changes were made to the mix for the intermediate lift - the surface course mix design did not change.

There was a change made during the placement of the rubber chip section as well (rubber chip mix was only placed as a surface course). Both ½ inch and ¾ inch limestone percentages were decreased and the sand fraction was increased. This change was made because of excessive voids (low densities) in the lab compacted field mix.

ARC and Rubber Chip Plant Operation

ARC was produced with a Rouse reactor prior to being added to the batch plant. This reactor was supervised by a technical director employed by Rouse. The finely ground GF-35 rubber was manually fed into a hopper on the reactor. From there it was gravity fed into the reaction chambers where it was agitated with asphalt binder for 15 to 20 minutes. It was then pumped from the reactor into the batch plant. The temperature of the ARC before it was discharged into the batch plant was between 300 and 350 ºF.

The piping system leading from the reactor to the batch plant was undersized. This caused a slowdown in production, dropping it from an average of 250 tons per hour to 150 tons per hour. Some of the decrease in production was attributed to the increase in viscosity of the ARC as it cooled during the transfer.

Rubber chips were added directly to the mix at the batch plant by means of a hopper. Fifty pound bags of rubber chips were manually dumped into the hopper and combined with the mix. The plant was operated for an extra 15 seconds before dumping the mix into the truck.

Paving

The ARC mix intermediate and surface courses were placed with a Blaw-Knox PF-500 paver. Both mixes behaved similar to a conventional mix.

As noted before, portions of the intermediate lift were very dry and subject to cracking and shoving during rolling. The mix design changes yielded some improvement. Determann also tried using a smaller roller but that was of no help. The following morning, after traffic had been on the mat, it appeared to have improved. Some of the cracks had closed up and the mat had become more stable.

The appearance of the ARC mix surface course was much different than the intermediate course. It appeared more uniform with more voids. Placement went well but it needed extra time before the rolling operation could begin. This was due to the ARC mix being placed at a higher temperature than conventional mixes. The gates of the paver were adjusted to alleviate some shoving at the edges of the mat.

The rubber chip surface mix was placed using a Cedar Rapids CR531 paver. This mix looked much coarser and richer than a conventional mix. The contractor had problems with shoving of the mix and with the mix sticking to the roller drum. Two possible causes for this were the high binder content (7.6 percent) or the high temperature of the chip mix at placement (330 ºF). The mix design change described earlier was made between paving the east and westbound lanes in this section.

Construction Testing

Samples were obtained at the time of construction by University of Northern Iowa representatives for laboratory testing as part of the first phase of this research. Results from ductility tests, ageing tests, tensile creep tests and fatigue tests are available from that report (Varzavand et al, 1996). The Iowa DOT also obtained samples for creep and resilient modulus testing. Those tests will be discussed later.

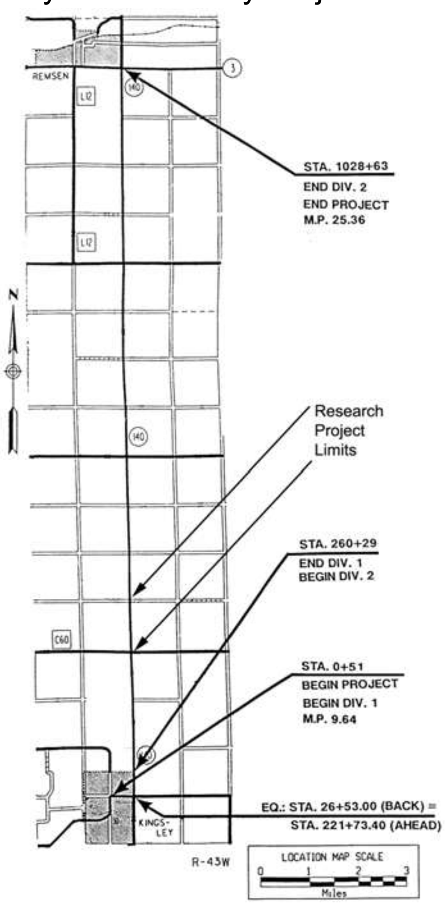
HR-330A Plymouth County

This project was located on IA 140 north of Kingsley. A map is shown below along with a list of the test sections:

Table 3
Plymouth County Stationing

Test Section	Station to Station	Lane	Type of Mix Used
1	375+00 to 428+00	NB&SB	ARC Intermediate & Surface
2	428+00 to 481+00	NB	ARC Surface Only
3	555+00 to 582+00	NB&SB	Control

Figure 2
Plymouth County Project Location



The existing road consisted of a 2 ½ inch ACC lift over 6 inches of asphalt treated base, paved sometime in the late 1960s. A seal coat had been placed in 1983. The pavement was 22 feet wide and had major cracking and distress evident. Traffic volume was 700vpd with 14 percent trucks. Paving for this project consisted of three inches of ACC placed in two lifts. The plans called for type A ACC in the surface lift and type B in the intermediate lift.

The contractor for the project was Brower Construction Company of Sioux City, Iowa. ARC mixes were hauled from their stationary plant in Sioux City, while conventional mixes were produced at a portable plant adjacent to the job site.

Materials

The ground tire rubber was provided by Rouse Rubber Products of Vicksburg, Mississippi. GF-60 crumb rubber was used on this project. Both the coarse aggregates and natural sand were purchased from L.G. Everist, Hawarden, Iowa. The AC-5 binder was supplied by Jebro Inc. of Sioux City, Iowa.

Mix Design

Samples of all of the materials were tested in the laboratory. The mix designs used on this project are provided in Appendix C.

The intended asphalt binder content in the ARC mix was 6.6 percent. The laboratory originally recommended an binder content of 7.5 percent in the ARC surface mix, but after reviewing the mix design, this content was lowered to 6.8 and again to 6.6 percent. During construction, the binder content was raised to 7.1 percent because of high air voids in the lab compacted mix. The change brought the air voids down from 5.3 to 3.9 percent.

ARC Plant Operation

The ARC plant setup was different from the other projects because the pipe from the asphalt tanker carrying AC-5 was connected directly to the reactor. The technician from Rouse was concerned that this would cause problems with the viscosity, but it did not seem to make a difference. The contractor also insulated the line from the reactor for this project. After mixing in the reactor, the ARC was piped to the Brower batch plant which produced ARC mix at 170 tons/hour. This is a normal production rate for the plant.

Paving

Paving began on October 17, 1991. The contractor was using a PF-180 H Blaw-Knox paver. As with the Muscatine project, there was some difficulty with shoving and cracking of the mat. The weather was cooler than it had been on the Muscatine project, temperatures were around 40 ºF. As a result, the roller had to stay fairly close to the paver. In general, the paving of the ARC mix was no more difficult than a conventional mix on this project.

HR-330C Dubuque County

This project was located on US 151 from Cascade to US 61. A map is shown below along with a list of the test sections:

Figure 3
Dubuque County Project Location

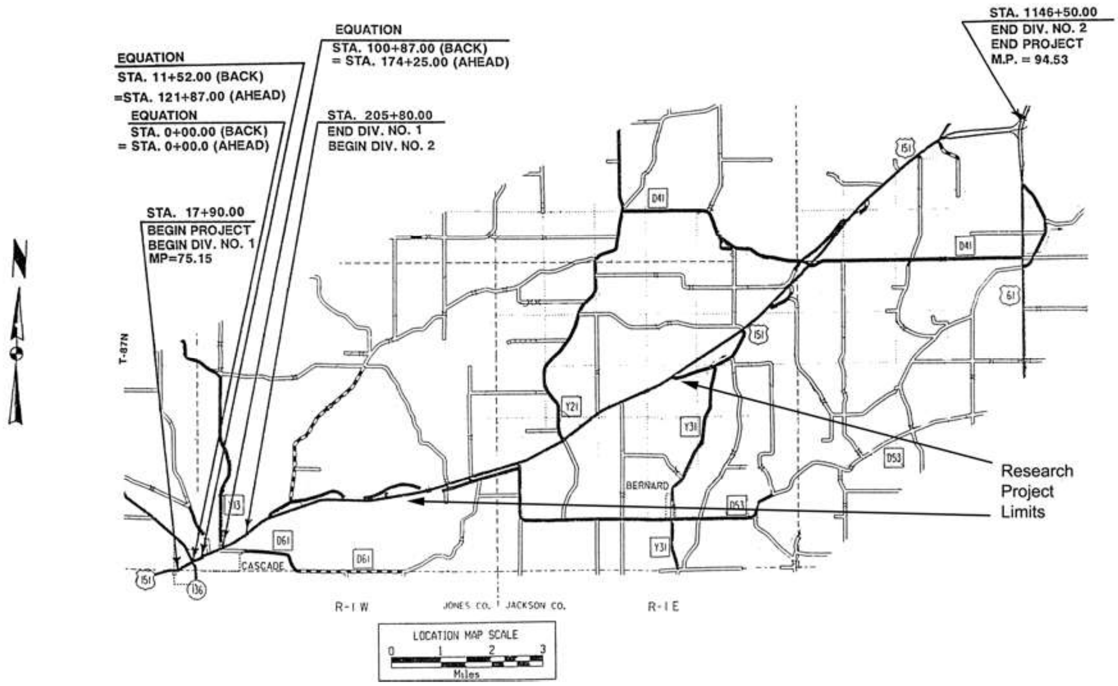


Table 4
Dubuque County Project Stationing

Test Section	Station to Station	Lane	Type of Mix Used
1	415+00 to 433+00	SB	ARC Surface Only
2	415+00 to 433+00	NB	ARC Intermediate & Surface
3	625+00 to 652+00	NB&SB	ARC Intermediate & Surface
4	365+00 to 391+50	NB&SB	Control
	665+00 to 691+50	NB&SB	Control

The existing road consisted of 9 inch by 24 foot jointed PCC, constructed in 1972. It exhibited faulting at the transverse joints but otherwise very little distress. The surface was diamond ground prior to construction and this corrected some of the faulting. Traffic volume was 3525 vpd with 15 percent trucks. Paving for this project consisted of three inches of ACC placed in two lifts. Both intermediate and surface lifts were designated as type A ACC in the plans.

The contractor for the project was Mathy Construction Company of Onalaska, Wisconsin. ARC and ACC mixes were hauled from River City Asphalt in Dubuque, Iowa.

Materials

The ground tire rubber was provided by Rouse Rubber Products of Vicksburg, Mississippi. GF-60 crumb rubber was used on this project. Coarse aggregates were supplied by River City Stone, Brown quarry in Dubuque. Sand was supplied by Aggregate Materials, Nine Mile Pit near Cascade, Iowa. The AC-5 binder was supplied by Koch Materials Company of Dubuque, Iowa.

Mix Design

Samples of all of the materials were tested in the laboratory. The mix designs used on this project are provided in Appendix C. In this project, the same ARC mix was used for both the intermediate and surface lifts. The intended binder content in the ARC mix was 5.9 percent. Aggregates in the mix consisted of 75 percent ¾ inch crushed limestone and 25 percent natural sand.

ARC Plant Operation

ARC mix was produced at the River City plant located in the Brown Quarry in Dubuque using a Simplicity® plant. The conventional ACC was produced from a Bituma plant set up at Baid-Cascade East.

During production, the binder content of 5.9 percent was made up of 5.1 percent asphalt binder and 0.8 percent rubber. This means the rubber content of the binder was approximately 13.6 percent when the specification called for 15 percent. On September 19, Rouse recalibrated their reactor to increase the amount of rubber to 15 percent of the binder.

The Simplicity® plant operated at normal speed when producing the ARC mix. It averaged 150 tons/hour with no slowdown from the ARC.

Paving

Paving with the ARC mix began in September, 1991 (the conventional mixes were placed in April 1992). The contractor was using a Barber-Greene SB-170 paver. This pavement had been diamond ground, which could be a factor in preventing shoving and cracking.

However, segregation was a problem on this job. The contractor first tried changing from the Barber-Greene paver to a Blaw-Knox PF-180 modified with a mixing device in the front of the hopper tunnel. This did improve the consistency, but segregation still occurred at times. The contractor switched from dump trucks to flowboy trucks and it seemed to alleviate the problem.

Ambient temperature was cool, averaging around 50ºF, and the mat cooled rapidly. For that reason, the contractor was concerned he might experience difficulty achieving density. Because of this concern, he requested permission to use a rubber tire roller. The specifications prohibit this for asphalt rubber mixtures but they were given permission to try. As expected, the rubber tires picked up fines and the use was discontinued.

In general, the paving of the ARC mix and conventional mix were similar. The ARC was placed in September, 1991 and the conventional mix was placed in April, 1992. Both experienced problems with segregation. In both cases the problem was significantly diminished when the contractor switched from dump trucks to flowboy trucks.

HR-330D Black Hawk County

This project was located on IA 947 (University Avenue) in Cedar Falls and Waterloo. A map is shown below along with a list of the test sections:

Figure 4
Black Hawk Project Location

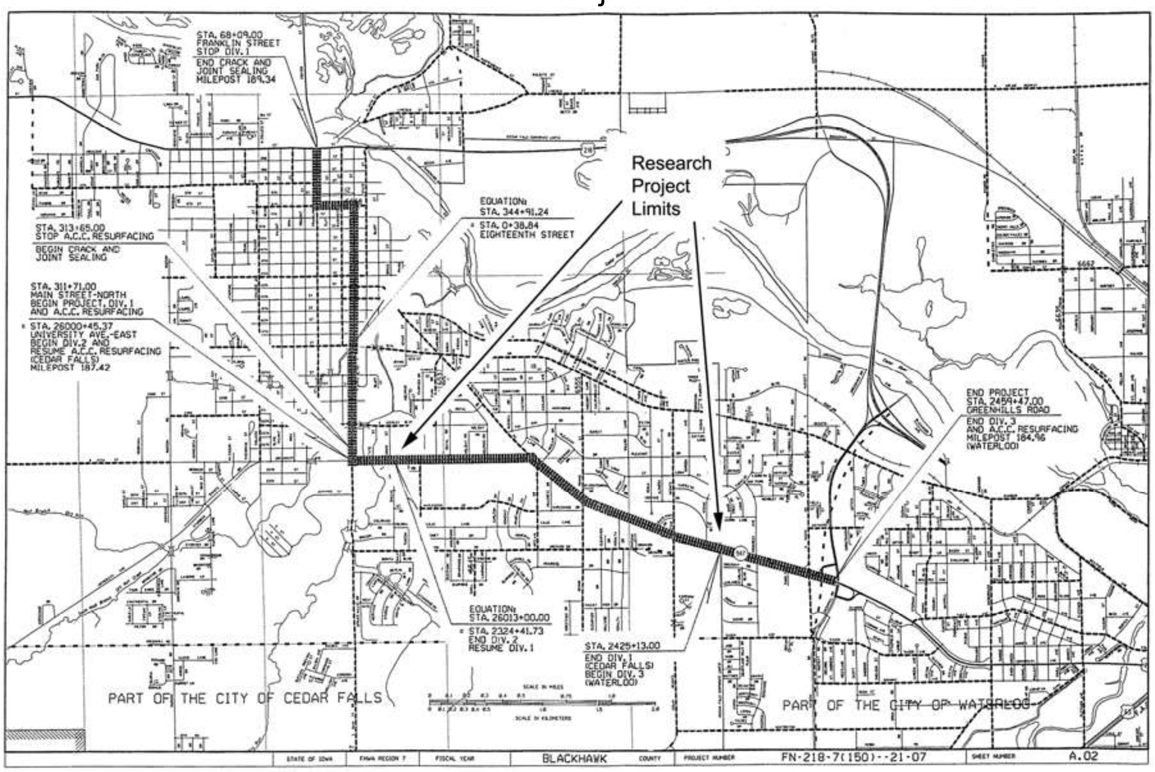


Table 5
Black Hawk Project Stationing

Test Section	Station to Station	Lane	Type of Mix Used
1	2360+00 to 2370+00	EB	Control
2	2370+00 to 2395+00	EB	ARC Surface Only
3	2395+00 to 2420+00	EB	ARC Intermediate & Surface
4	2420+00 to 2429+00	EB	Control

The existing road consisted of PCC with various thicknesses. It was a six-lane highway. Traffic volume was 19,000 vpd with 3 percent trucks. Paving for this project consisted of three inches of ACC placed in two lifts. Both intermediate and surface lifts were designated as type A ACC in the plans.

The contractor for the project was Aspro Inc. of Waterloo, Iowa. Both ARC and ACC mixes were produced at Aspro's stationary plant in Waterloo.

Materials

The ground tire rubber was provided by Rouse Rubber Products of Vicksburg, Mississippi. GF-60 crumb rubber was used on this project. Coarse aggregates were supplied by BMI Waterloo South and fine aggregates from Aspro pits in Waterloo. The AC-5 binder was supplied by Koch Materials Company of Dubuque, Iowa.

Mix Design

Samples of all of the materials were tested in the laboratory. The mix designs used on this project are provided in Appendix C. The intended binder contents in the ARC mix were 5.1 percent for the intermediate lift and 5.2 percent for the surface lift.

ARC Plant Operation

Both the ARC and conventional mixes were produced at Apro's Barber-Greene batch plant in Waterloo, Iowa.

Because of cold weather, (temperatures as low as 46 ºF), they had to use torches to melt the binder in the supply lines from the reactor to the plant. The lines had to be insulated to keep the temperature at approximately 350 ºF.

ARC production was slowed down because of these challenges to about 40 tons/hour. Their normal output of ACC is 240 tons/hour and of ARC mix is 200 tons/hour.

Paving

The placement of ARC and conventional ACC in October 1991 went very well. The ARC appeared very stable under the rollers. No shoving or cracking was evident. Once again this pavement had been milled which could be a factor in preventing shoving and cracking.

The mat temperature was approximately 300 ºF. The rollers had to remain close to the paver. There were no signs of segregation in the mixes.

Data Analysis

The first objective of this research was to determine if the ARC and ARC mixes performed at least as well as conventional asphalt binder and ACC. If the ARC mixes performed as well as or better than the controls, then the cost issues will be of greater importance. If the ARC mixes did not perform as well as the controls, then cost issues will be moot.

Keeping in mind the objective, the task of determining differences in performance was accomplished (except in cases where the answer was obvious by inspection) using one-way analysis of variance (ANOVA). ANOVA is a general technique that provides statistics for comparing a group of means. The results of the test tell us if any of the means are statistically different (although the results do not tell us which means are different).

This test is robust for moderate departures from normality and from a constant variance assumption (Pollard,1977). Which is another way of saying we are not risking very much by assuming that the sample data are from normal populations and have constant variance – those assumptions were made here. Statistical test results are provided in Appendix D.

Viscosity

Viscosity requirements for the ARC were listed in the Special Provisions for each project. The samples were tested according to ASTM D2669 Brookfield at 347 ºF for one hour. A summary of the results is shown in Table 6 below. The Special Provision indicated that the viscosity value should be between 1000 and 4000 centipoise. All of the samples tested for these projects met the specification.

Table 6
Viscosity Data

Project	Percent Rubber	Measured Viscosity (cps)
Muscatine Co.	15	1100
Plymouth Co.	15	1900
Dubuque Co.	15	1550
Black Hawk Co.	15	2350

Creep and Resilient Modulus

These tests were performed on ACC and ARC mixes (i.e. containing both binder and aggregate). Three sets of samples were selected from each project: one from a laboratory mix, one from a plant mix (before placement), and one from a core out of the pavement. The lab and plant mixes were pre-compacted with the Marshall apparatus to either 50 or 75 blows. Because resilient modulus is considered a non-destructive test, samples were reused afterward for the creep test. Detailed descriptions of these tests and the analysis procedures are provided in HR-311 (Marks, 1993) and MLR-88-16 (Marks, et al, 1990).

The resilient modulus is intended to describe some of the crack resistant characteristics of an asphalt mixture. This test was performed using a Retsina Mark VI Resilient Modulus Non-Destructive Testing Device. The general procedure used is described in ASTM D-4123. A cylindrical specimen is subjected to short pulsed loads ranging up to 1000 pounds force vertically along the axis and the horizontal deformation is measured. This horizontal deformation is related to the resilient modulus by the following formula (Marks, et al, 1990):

$$M = \frac{P(\nu + 0.2734)}{t(d)}$$

Where: M= resilient modulus
P = vertical load
ν = Poisson's ratio
t = specimen thickness
d = horizontal deformation

Table 7 shows resilient modulus values for mixes used in surface lifts only (larger numbers, expressed in units of 10^6 pounds per square inch, are better). Shaded cells indicate statistically significant comparisons (however, note that the underlying data has a large amount of variation with early utilization of this test).

Table 7
Resilient Modulus (10^6 psi)

HR-330	50 Blows		75 Blows		Rubber Chips	
	Conv	ARC	Conv	ARC	50 Blows	75 Blows
Lab	0.35	0.16	0.42	0.27	0.08[1]	0.10[1]
Plant	0.66	1.02	0.76	1.13	0.58	0.68

	Conv	ARC	Chips
Core	0.28	0.30	0.14

HR-330A	50 Blows		75 Blows	
	Conv	ARC	Conv	ARC
Lab	0.33	0.09	0.44	0.16
Plant	0.40	0.40	0.51	0.41

	Conv	ARC
Core	0.10	0.12

HR-330C		50 Blows	75 Blows
	Conv	ARC	ARC
Lab	0.36[2]	0.31	0.45
Plant	0.63[2]	0.88	1.04

	Conv	ARC
Core	0.13[3]	0.16[3]

HR-330D	50 Blows		75 Blows	
	Conv	ARC	Conv	ARC
Lab	0.41	0.16	0.66	0.27
Plant	0.76	0.68	1.02	0.80

	Conv	ARC
Core	n/a	0.15

Notes: (1) All of the laboratory values are less than their respective plant values. This is likely due to the fact that the plant samples have aged more than a laboratory sample. The laboratory values for the chip mix are considerably lower than plant values. Most likely this is because the laboratory mix method did not adequately duplicate the mix method with chips at the plant.
(2) The data record shows only one test each of lab and plant mixes and does not indicate how many Marshall blows were used.
(3) The values for cores from conventional and ARC mixes are based on two samples and one sample respectively rather than three samples as for other mixes.

One should note that in the referenced reports, the resilient modulus data had a large amount of variability and both resilient modulus and creep tests exhibited low correlations between lab/plant values and cores. The variation in results of this test can be large enough that a “statistically significant” difference between two samples may not represent a practical difference, and “lack of a statistical difference” may not mean that the two samples are the same in a practical sense.

With this noted, in the table above there are about 16 useable comparisons between conventional and ARC mixes. Of these there are nine that have statistically significant differences. Finally, all but two of those favor the conventional mix over the ARC mix.

In contrast to the resilient modulus values, the creep values are intended to provide information about the ability of a mixture to resist rutting. Creep testing was performed using a device fabricated by Iowa DOT Materials personnel.

In this test, the samples are first cut with a diamond saw to a thickness of 2½ inches. The faces are then polished to remove surface irregularities and coated with a mixture of graphite and silicone gel lubricant to reduce friction. After a seating load, the height of each sample is measured. Finally, the sample is subjected to creep loads. Creep loads are a series of stepped loads over the course of five hours reaching a final value of 200 psi. While under load, the height of the sample is measured regularly. Once the sample has either reached 200 psi or failed (failure is defined as a total height decrease of 0.05 inch), the change in height is recorded and used to determine a creep resistance factor (CRF).

The CRF was developed by the Iowa DOT to provide a single quantitative value for creep test results. It is calculated with the following formula:

$$\mathrm{CRF} = \frac{t}{300}\left[100 - c\left(1000\right)\right]$$

where: CRF = the creep resistance factor
t = time in minutes at failure or 300 if failure did not occur
c = change in height in inches or 0.05 inch if failure occurred

Table 8 shows CRF values for mixes used in surface lifts only (larger numbers, which are unitless, are better). Shaded cells indicate statistically significant comparisons. Notes are the same as those in Table 7.

Table 8
Creep Resistance Factor

HR-330	50 Blows		75 Blows		Rubber Chips	
	Conv	ARC	Conv	ARC	50 Blows	75 Blows
Lab	69.0	36.7	75.2	44.1	10.2	9.7
Plant	71.3	66.2	67.8	67.3	30.8	34.4

	Conv	ARC	Chips
Core	26.1	22.8	16.9

HR-330A	50 Blows		75 Blows	
	Conv	ARC	Conv	ARC
Lab	54.7	38.2	65.3	23.7
Plant	47.8	44.3	55.9	68

	Conv	ARC
Core	10.2	0.6

HR-330C		50 Blows	75 Blows
	Conv	ARC	ARC
Lab	67.2[2]	31.2	44.0
Plant	71.5[2]	55.7	68.8

	Conv	ARC
Core	31.8[3]	10.7[3]

HR-330D	50 Blows		75 Blows	
	Conv	ARC	Conv	ARC
Lab	63.7	21.6	73.2	30.0
Plant	50.1	66.5	70.3	72.7

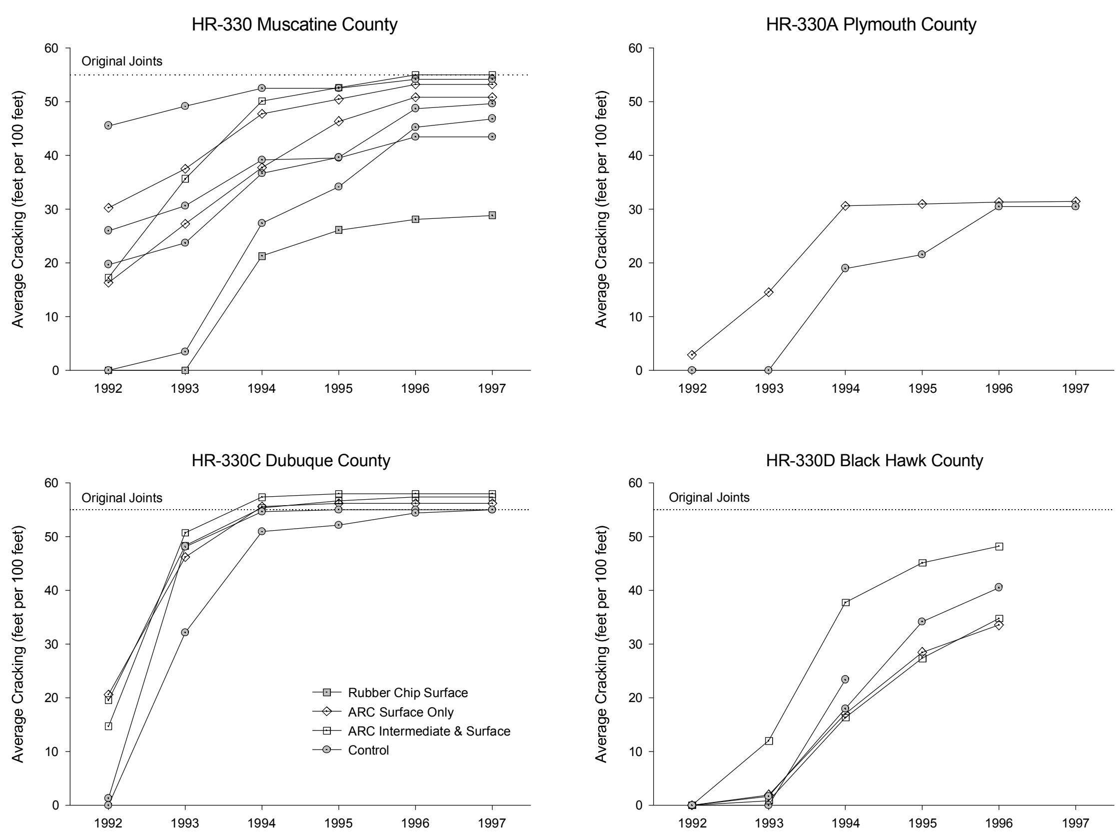
	Conv	ARC
Core	n/a	17.0

Again, in the table above there are about 16 useable comparisons between conventional and ARC mixes. Of these there are nine that have statistically significant differences, and all but one of those favor the conventional mix over the ARC mix.

Cracking

Crack surveys were performed on all of the projects prior to construction and annually for five years thereafter. Graphs of the cracking results for each of the projects are provided in Figure 5 below. All but one of the projects involved an ACC overlay over jointed PCC pavements. As a result, the vast majority of cracks were expected to be reflective cracks over joints. That is to say, these particular projects would not provide a good measure of the ability of ARC mixes to resist thermal cracking compared to conventional ACC. However, the main emphasis of ARC mixes is in their purported ability to delay reflective cracking. As a result, one could reasonably expect to see a difference in crack retarding effect between the various mixes. That is, it should be possible to determine whether any of the ARC mixes delayed the reflective cracks a year or two compared to the conventional mix control sections when the mixture was placed over jointed PCC pavement.

Figure 5
Crack Survey Results



Data Normalization – For evaluation of the amount of cracking in an ACC overlay, it is important to take into account the amount of cracking that was in the underlying pavement. This is because of the reflective cracking that occurs through asphalt overlays. If there is more cracking underneath an overlay, then it is reasonable to expect more cracking in the overlay. Each of these graphs has been normalized for cracking that had already occurred in the original pavement – the normalization was performed as follows:

For projects HR-330, HR-330C and HR-330D with underlying jointed PCC pavements, the vast majority of cracks appearing in the overlay were the result of reflective cracking over transverse joints in the PCC. With a joint spacing of 20 feet, there are generally 5 joints per 100 feet; and each joint accounts for 11 feet of cracking per lane. This means that, for the most part, the amount of cracking in the underlying pavement was constant at 55 feet per lane per 100 feet.

In the cases where the crack survey showed four or six joints (because of variability in joint placement) or in HR-330D where there was significantly more cracking than just joints, the data were multiplied by the appropriate ratio to normalize them to five joints or 55 feet of cracking per 100. HR-330A consisted of an overlay over seal coated base material with a lot of cracking and distress visible. For this project, the cracking was normalized to an arbitrary value of 55 feet per 100 feet based on just the transverse cracks in the underlying pavement.

Discussion

Examination of Figure 5 reveals that out of all of the projects and test sections, the only one that exhibited a significant crack retarding effect was the rubber chip surface mix in the Muscatine project. A control section in this project performed in a similar manner for the first few years. But the rubber chip section retained better performance even out to five years.

The statistical analysis of these data indicated a difference in means within the Muscatine project and the Black Hawk project (the Muscatine analysis was performed exclusive of the data from the rubber chip surface treatment). From inspection of the graphs, it does not appear that the treated sections are performing significantly better than the control sections (again this is not taking into consideration the rubber chip treated surface section).

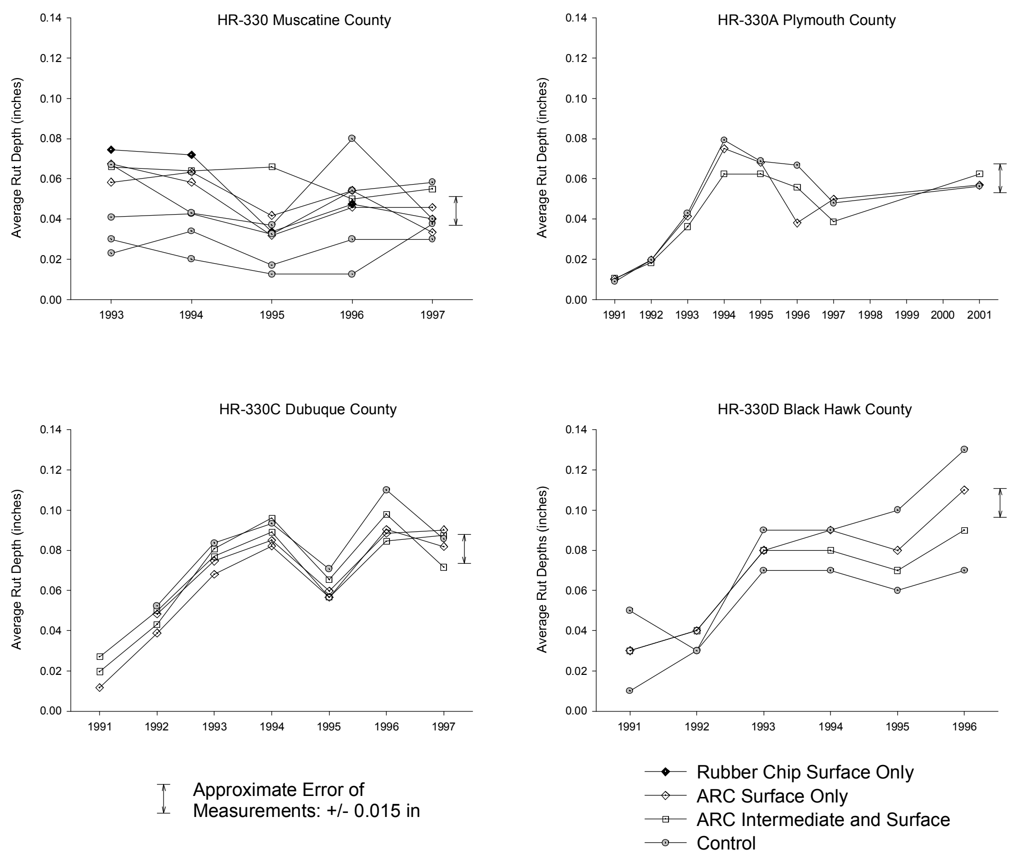
A couple of notes about the Dubuque county project (HR-330C) are warranted here. The treatment and control sections for this project were completed six months apart with the treatment section being paved in the fall of 1991 and the control sections paved in the spring of 1992. Thus when the first crack survey was performed in spring of 1992, the control section was brand new and, understandably, did not exhibit any cracking. If one was to slide the control data plot to the left by one-half year, the cracking plots would line up almost perfectly.

The inherent assumption in a research project of this type is that all of the test groups are identical except for the variable being tested, in this case the addition of rubber. Making that assumption here (i.e. assuming the same aggregate, asphalt binder, paving conditions, personnel, etc.) when the treatment and control sections were six months apart, is risky at best.

Rutting

Rutting takes two different forms. It can be a result of pavement compaction within wheel paths – which is an inherent characteristic of a particular ACC mix. The second type of rutting occurs with a subgrade failure. For the projects considered in this report, all of the rutting that may have occurred is assumed to have been of the first type. Figure 6 provides graphs of the rutting measurements during the first five years after paving for these projects.

Figure 6
Rut Survey Results



The only project that showed a statistical difference in rut depths after five years was Black Hawk county, HR-330D. Here once again the control sections bracket the treated sections after five years.

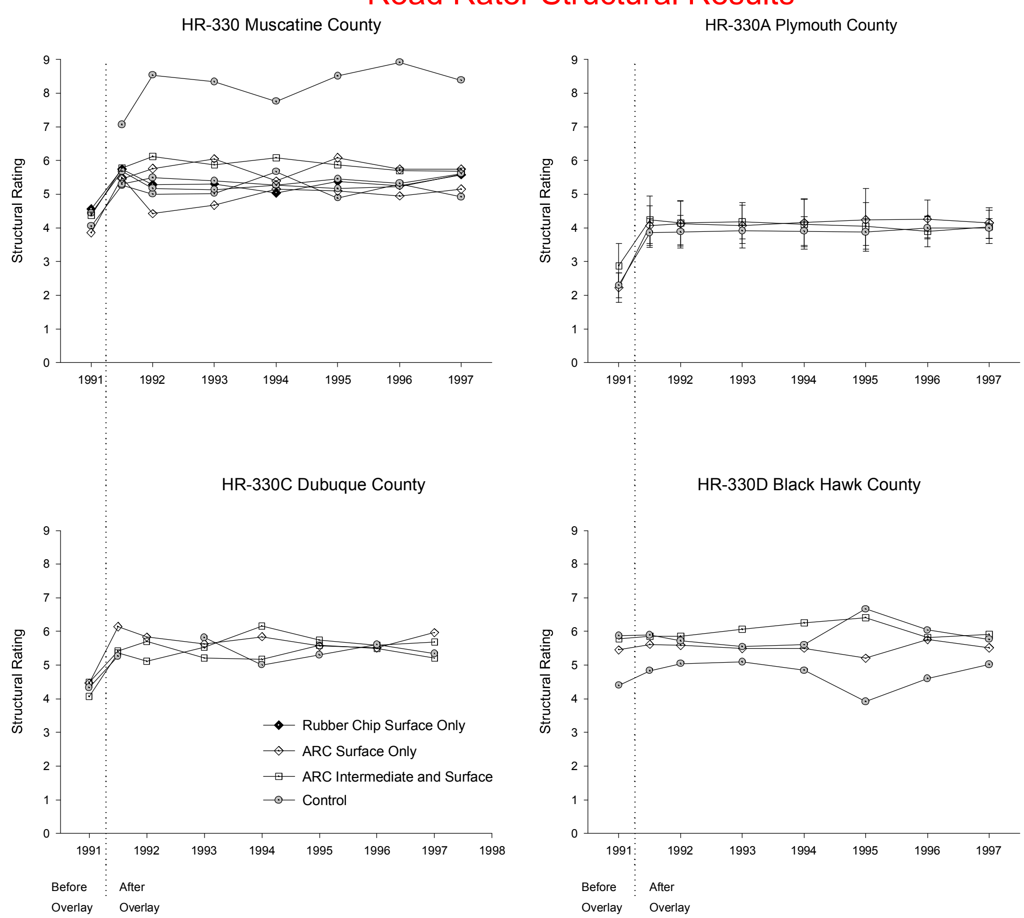
The reader may be concerned (justifiably) with the shapes of these graphs. In the graph for Plymouth county, and perhaps Black Hawk county, rutting appears to increase for three years, and then decrease, which doesn't sound reasonable. The likely explanation for this is that rut depth measurements for these projects were performed using a four-foot straightedge. As time goes by, a rut can widen enough that the depth as measured with this device actually decreases. The disturbing drop in all of the values of the Dubuque county graph in 1995 is probably due to incorrect calibration of the straight edge.

Structural Evaluation

Structural evaluation was performed using the Road Rater test equipment. Road Rater is a non-destructive, frequency based test of pavement structure. The Road Rater structural ratings simulate AASHTO structural numbers under springtime conditions assuming coefficients specific to different types of pavements. For example the coefficient of sound PCC is estimated to be a structural number of 0.5 per inch of thickness and that for new ACC is 0.44 structural numbers per inch of thickness.

Graphs of the structural data are shown below. In most of them the structural values increased immediately after placement of the overlay as would be expected. However, there was no significant difference noted between the structural ratings of the test sections and control sections. Note the control section in the Muscatine project that has significantly higher ratings than any of the other sections. This section was located on a super-elevated curve where it was much thicker than the other sections. The data (Road Rater, Rutting, Cracking, etc.) from this section were not used in the evaluation of the project.

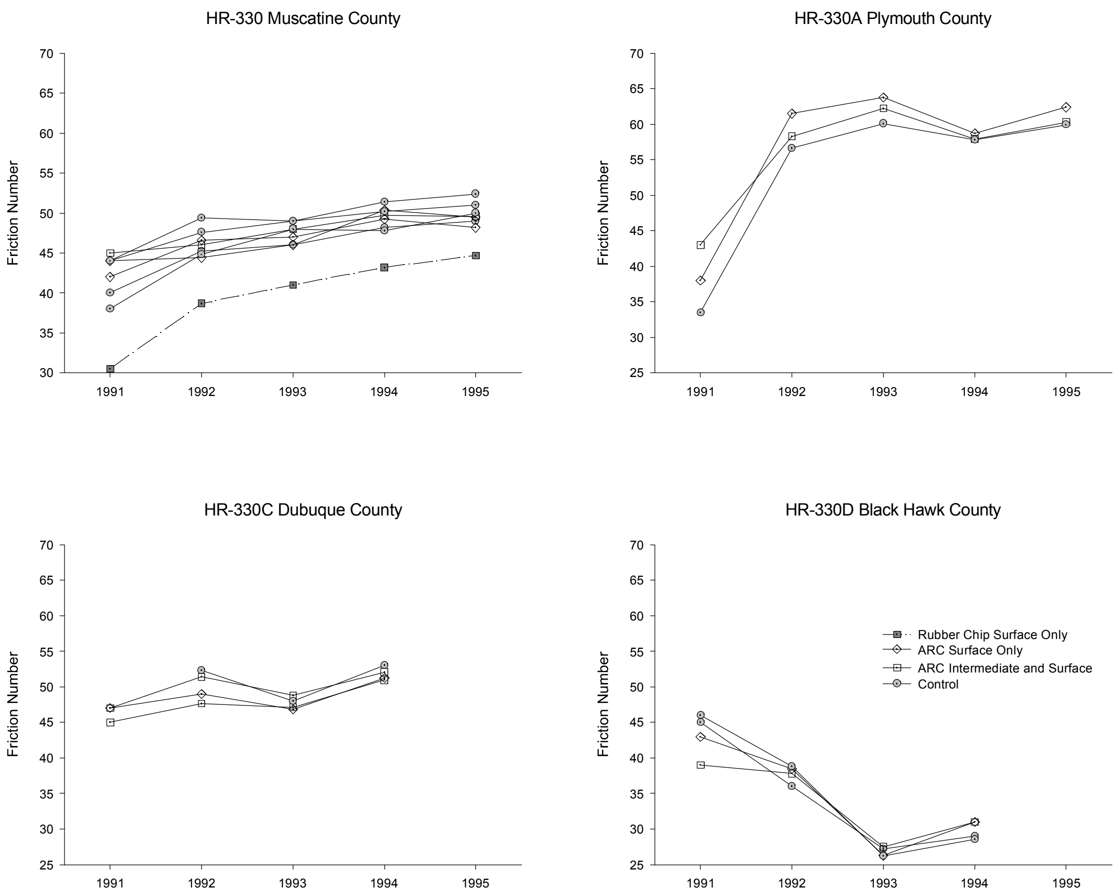
Figure 7
Road Rater Structural Results



Friction

This test is used to determine the frictional characteristics of the surface of the pavement under wet and dry conditions. The testing was performed at 40 mph using a standard tread (ASTM E-501) test tire.

Figure 8
Friction Testing Results



In the graphs above it's apparent that there is very little difference between the ARC mix and the conventional control. This is reasonable – the friction is strongly a function of the aggregate in the surface lift rather than the binder. That's why asphalt roads in Iowa often have quartzite in the surface lift. One would not necessarily expect a difference in friction to result from a change in the asphalt binder material.

The only exception is the rubber chip surface section which has significantly lower friction values. The reason for these low values is unclear. However, the rubber chips were considerably larger than the crumb rubber in the ARC mix. And the chips were added directly to the asphalt drum plant just prior to paving. So it is reasonable to suggest that larger pieces were exposed on the surface of the lift which affected the friction values. Maintenance workers commented that this section of the highway was really easy to keep clean in winter because the snow and ice didn't stick to the surface.

Also of interest are the low values for all sections in the Black Hawk project (HR-330D). Again, this was most likely a function of aggregate in the surface. Because of the urban location of this project, the frictional requirements were lower.

Cost Comparison

The second objective of this study was to determine the cost of using ARC verses conventional ACC. In all cases the ARC was more expensive, and in some - considerably more. This increase in cost can be attributed to the limited number of suppliers of crumb or powered rubber and the hauling distance from their plants, the limited number of reactors available, high cost of the proprietary technology, and possibly a contractor "fear-factor". A comparison of (in-place) costs between ARC mix and ACC is presented in Table 9 below.

Table 9
Cost Comparisons

County	Highway	Lift	Conventional Cost ($/ton)	ARC Cost ($/ton)
Muscatine	US 61	Binder	26.69	70.25
Muscatine	US 61	Surface	30.10	64.49
Dubuque	US 151	Binder	18.69	27.19
Dubuque	US 151	Surface	21.16	27.19
Plymouth	IA 140	Binder	20.97	31.36
Plymouth	IA 140	Surface	22.19	32.63
Black Hawk	IA 947	Surface	26.63	61.48
Black Hawk	IA 21	Binder	17.78	46.03
Black Hawk	IA 21	Surface	18.18	48.99

Conclusions

There were few differences in performance between the ARC mixes and the conventional ACC mixes used in these projects. Several of the differences that were statistically significant, indicated better performance from the conventional ACC. The rubber chip surface course appeared to perform better at retarding reflective crack formation and was helpful in winter maintenance, but also exhibited lower friction values than the conventional mix. The placement of ARC mixes was very similar to conventional ACC as well. Costs were higher and in many cases considerably higher for the ARC mixes.

Because of the similarity in performance between the ARC mixes and conventional, the primary benefit of using these mixes would be in the disposal of old tires. Unless the disposal costs of tires becomes significantly higher with the extra money being used to subsidize the use of the rubber in pavements, the use will not be cost effective.

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Appendix A
Special Provisions

HR-330

REVISED

SPECIAL PROVISIONS
for
REACTED RUBBER BINDER -
ASPHALT CEMENT CONCRETE

F-61-4(49)—20-70, Muscatine-Scott Counties

October 2, 1990

THE STANDARD SPECIFICATIONS, SERIES OF 1984, ARE AMENDED BY THE FOLLOWING MODIFICATIONS. THIS IS AN ADDENDUM TO THE SPECIAL PROVISIONS, WHICH SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS AND SP-952(New).

952A.01 DESCRIPTION.

The reacted rubber binder-asphalt cement concrete mix composition will include the incorporation of reacted asphalt cement (reacted rubber) in the mixture, using the aggregates selected by the Contractor. The volumes of ingredients in the mixture shall be in accordance with the recommendation of the supplier of the asphalt cement (reacted rubber).

The Contractor shall have a representative of the supplier be available on the project site during the erection of the asphalt plant, during the initial production of the materials. The Contractor shall have a representative of the supplier on call for technical assistance during production operations.

952A.02 GENERAL REQUIREMENTS.

Reacted rubber binder-asphalt cement concrete mix shall conform to the requirements of the standard specifications for the standard mixes as called for in the plans, these Special Provisions, and the Standard Specifications which are modified as follows.

A. Mineral Aggregate for Reacted Rubber Binder - Asphalt Cement Concrete Mix.

Mineral aggregates shall meet Type "A" quality as per the plans and specifications except the gradation shall meet the following:

Sieve size	Percent passing
1"	100
3/4"	98-100
1/2"	76-92
3/8"	60-83
#4	40-62
#8	26-45
#30	11-24
#200	3-7

B. Asphalt Cement (Reacted Rubber)

The asphalt cement (reacted rubber) shall be a uniform mixture of compatible paving grade asphalt cement, ground reclaimed vulcanized rubber, and if required by the mixture design, a liquid anti-strip agent. The asphalt cement (reacted rubber) shall meet the following physical parameters when reacted at 350 ±10 degrees Fahrenheit for 60 minutes.

Test	Requirements
Viscosity Haake, 350^{O}F	1500 - 4000 CP
Cone Penetration 77^{O}F ASTM D1191	Per job mix
Softening Point 135-200^{O}F ASTM D36	Per job mix
Resilience 77^{O}F ASTM D3407	15% min.

952A.03 GROUND RECLAIMED VULCANIZED RUBBER.

The rubber used shall be produced from the recycling of automobile and truck tires. Final grinding of the rubber shall be accomplished with ambient temperature processes only. The use of ground rubber from multiple sources is acceptable provided the over-all blend of rubber meets the gradation requirements. The gradation of the rubber when tested in accordance with ASTM C136 using approximately 50 grams shall be in accordance with the following table.

Sieve Size	Percent passing
#10	100
#30	90-100
#50	10-90

Gradation of the rubber may be adjusted due to compatibility and reaction characteristics with the asphalt cement as required in the job mix formula.

Specific gravity of the rubber shall be 1.15 ± 0.05 and it shall be free from fabric, wire, or other contaminating materials. However, up to four percent calcium carbonate may be included to prevent the particles of rubber from sticking together.

The rubber shall be dry so as to be free flowing and not produce foaming when blended with hot asphalt cement. Not more than 1% of the particles shall exceed six times their minimum dimension.

952A.04 PACKAGING.

The ground rubber shall be supplied in moisture resistant disposable bags which weigh 50 ± 2 lbs. The bags shall be palletized into units each containing 50 bags to provide net pallet weights of 2500 ± 100 lbs. Glue shall be placed between layers of bags to increase the unit stability during shipment. Palletized units shall be double wrapped with ultra-violet resistant stretch wrap.

952A.05 CERTIFICATION.

The manufacturer shall ship with the rubber, certificates of compliance which certify that all requirements of these specifications are complied with for each production lot number of shipment.

952A.06 ASPHALT CEMENT (REACTED RUBBER) BLEND DESIGN

The asphalt cement (reacted rubber) shall be grade AC-5. The mixture design shall be performed by the asphalt-rubber supplier. The proportion of ground rubber shall be between 10 and 25 percent by weight of the asphalt cement.

The Contractor shall supply to the Engineer a mix formulation at least 10 days before pavement construction is scheduled to begin. The mix formula shall consist of the following information.

A. Aggregate
   Source
   Gradation
   Blend Percentages
   Mixture Gradation

B. Asphalt Cement (Reacted Rubber)
   Source and grade of asphalt cement.
   Source and grade of ground rubber.
   Ground rubber percentage for the asphalt cement (reacted rubber).
   Temperature when added to the aggregate.

C. Asphalt Cement (Reacted Rubber) Content

D. Mix Temperature

E. Placement Temperature

F. Density Requirement - The mixture design will be based on 75 blow marshall.

952A.07 ASPHALT CEMENT (REACTED RUBBER) MIXING AND PRODUCTION EQUIPMENT

All equipment utilized in production and proportioning of the asphalt cement (reacted rubber) shall be described as follows:

A. An asphalt heating tank with a hot oil heat transfer system or retort heating system capable of heating asphalt cement to the necessary temperature for blending with the ground rubber. If required, this unit shall be capable of heating a minimum of 3,000 gallons of asphalt cement to 375° F.

B. An asphalt cement (reacted rubber) mechanical blender with a two stage continuous mixing process capable of producing a homogeneous mixture of asphalt cement and ground rubber, at the mix design specified ratios, as recommended by the supplier of the ground rubber. This unit shall be equipped with a ground rubber feed system capable of supplying the asphalt cement feed system as not to interrupt the continuity of the blending process. A separate asphalt cement feed pump and finished product pump are required. This unit shall have both an asphalt cement totalizing meter in gallons and a flow rate meter in gallons pef minute.

C. An asphalt cement (reacted rubber) storage tank equipped with a heating system to maintain the proper temperature for pumping and adding of the binder to the aggregate and an internal mixing unit within the ground vessel capable of maintaining a proper mixture of asphalt cement and ground rubber.

D. An asphalt cement (reacted rubber) supply system equipped with a pump and metering device capable of adding the asphalt cement (reacted rubber) by volume to the aggregate at the percentage required by the job-mix formula.

An interlock of the asphalt-rubber binder and aggregate feed systems will not be required. The Contractor shall be required to accurately proportion the reacted asphalt cememt to the mixture.

952A.08 ASPHALT CEMENT (REACTED RUBBER) MIXING AND REACTING PROCEDURE.

A. Asphalt Cement Temperature

The temperature of the asphalt cement shall be between 290° and 400 degrees F. at the addition of the ground rubber, or as directed by the supplier.

B. Blending and Reacting

The asphalt and ground rubber shall be combined and mixed together in a blender unit, pumped into the agitated storage tank, and then reacted for a minimum of 45 minutes or as directed by the supplier from the time the ground rubber is added to the asphalt cement. Temperature of the asphalt cement (reacted rubber) mixture shall be maintained between 290° and 375 degrees F. during the reaction period, or at a temperature specified by the supplier.

C. Transfer

After the material has been reacted, the asphalt cement (reacted rubber) shall be metered into the mixing chamber of the reacted rubber binder-asphalt cement concrete production plant at the percentage required by the job-mix formula.

D. Delays

When a delay occurs in binder use after its full reaction, the asphalt cement (reacted rubber) shall be reheated slowly just prior to use to a temperature between 290° and 375 degrees F., and shall also be thoroughly mixed before pumping and metering into the hot mix plant for mixing with the aggregate. The viscosity of the asphalt cement (reacted rubber) shall be checked by the asphalt-rubber supplier. If the viscosity is out of the range specified in Section 952.02B of this special provision the asphalt cement (reacted rubber) shall be adjusted by the addition of additional asphalt cement or ground rubber to produce a material with the appropriate viscosity.

952A.09 COMPACTION REQUIREMENT. The Reacted Rubber Binder-Asphalt cement concrete shall be compacted to 95% of laboratory density.

952A.10 COMPACTION EQUIPMENT.

A minimum of two rollers meeting Article 2001.05B shall be furnished. Pneumatic tired rollers will not be allowed.

952A.11 METHOD OF MEASUREMENT AND BASIS OF PAYMENT.

The Reacted Rubber Binder - Asphalt Cement Concrete Mix will be measured as per the standard specification, and be paid for in tons. Asphalt cement (reacted rubber) for use in the Reacted Rubber Binder - Asphalt Cement Concrete Mix will be measured as per the standard specifications and be paid for in tons.

SP-954A
Revision of SP-954

REVISED

SPECIAL PROVISIONS
for
ASPHALT CEMENT CONCRETE SURFACE COURSE
(RUBBER CHIPS ADDED)

F-61-4(49)—20-70, Muscatine-Scott Counties

October 2, 1990

THE STANDARD SPECIFICATIONS, SERIES OF 1984, ARE AMENDED BY THE FOLLOWING MODIFICATIONS. THIS IS AN ADDENDUM TO THE SPECIAL PROVISIONS, WHICH SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS AND SP-954(New).

954A.01 DESCRIPTION.

The Asphalt Cement Concrete Surface Course (Rubber Chips Added) mixtures will include the incorporation of approximately 5% #4 sieve size tire-rubber chips into the asphalt cement concrete mixture.

954A.02 REQUIREMENTS.

The Asphalt Cement Concrete Surface Course (Rubber Chips Added) shall conform to the standard mix design criteria, which are modified as follows.

A. Mineral Aggregate.

Mineral aggregates shall meet the Type "A" surface course quality as specified in the plans and Iowa DOT Standard Specifications, except the gradation shall meet the following.

Sieve size	Percent passing
1"	100
3/4"	98-100
1/2"	76-92
3/8"	60-83
#4	40-62
#8	26-45
#30	11-24
#200	3-7

B. Asphalt Cement.

Asphalt cement shall meet requirements of Section 4137 of the Standard Specifications, grade AC-10. The amount of asphalt cement required shall be within a range of 5.5% to 8.0%, based on total weight of mixture and as determined by the job mix formula.

C. Rubber Chips.

Rubber chips shall be produced from the recycling of automobile and truck tires at ambient temperature. The rubber chips shall be cubical or thread-shaped, and individual rubber particles, irrespective of diameter, shall not contain more than 2% of the total to be more than 3/8" in length. The maximum allowable moisture content of the rubber chips is 2.0 percent.

The rubber chips shall conform to the following gradation requirements.

Sieve Size	Percent Passing by Weight
3/8"	100
#4	95-100
#8	8-50
#16	0-7

The rubber chip supplier shall furnish a written certification of compliance with these requirements.

954A.03 MIXING AND PRODUCTION EQUIPMENT.

The rubber chips shall be proportioned into the plant by a method which will uniformly feed the mixer within ± 10% percent of the required amount.

A. Batch Plants.

Whole bags of rubber chips may be fed into the mixer providing the total batch weight has been adjusted so no partial bags need to be used.

The rubber chips shall not be added into the dryer with the cold feed. They rubber chips shall be added into the aggregate after it leaves the dryer or into the mixer itself.

B. Drum-Mix Plants.

There shall be a means of accurately calibrating the continuous feed system.

Satisfactory means shall be provided to have a positive interlocking control between the flow of granulated rubber, asphalt cement, and aggregates.

Drum-mixing plants shall be equipped with a heat shield or other means to prevent the open flame from coming in contact with the granulated rubber.

954A.04 MIXING.

The Contractor shall prepare a work plan describing the planned procedures for mixing and placing the Asphalt Cement Concrete Surface Course (Rubber Chips Added).

The rubber chips shall be mixed with the aggregate and asphalt cement for at least 15 seconds before discharge from the mixer.

The temperature of the finish mixture shall meet the requirements in Article 2 303.05E, or as otherwise directed by the rubber chip supplier.

954A.05 CONSTRUCTION.

The asphalt cement concrete surface course (rubber chips added) shall be placed as specified in the standard specifications for other Type "A" asphalt cement concrete course surface mixtures, except pneumatic tire rollers will not be allowed due to possible pickup of the mixture on the tires.

954A.06 COMPACTION

Asphalt rollers and compaction procedures for the special surface course shall conform with the Standard Specification requirements and supplemented with the following.

A. Breakdown compaction should begin immediately behind the paving machine. However, some delay may be required to prevent roller pickup.

B. Breakdown compaction shall be accomplished using a minimum 10 ton vibratory or static steel roller.

   A minimum 8 ton steel roller in a non-vibratory mode shall be used for finish rolling.

C. A minimum of 10 coverages shall be made in a vibratory made. Fewer coverages can be made if it can be shown that maximum density can still be achieved. Rolling must be completed before the temperature of the mat drops below 180 $^{\circ}$ F., unless otherwise directed by the Engineer.

954A.07 METHODS OF MEASUREMENT.

The Asphalt Cement Concrete Surface Course (Rubber Chips Added) properly placed will be measured in tons as provided in Article 2303.27A.

Asphalt cement will be measured as provided in Article 2303.27B.

954A.07 BASIS OF PAYMENT.

For the number of tons of Asphalt Cement Concrete Surface Course (Rubber Chips Added) placed, the Contractor will be paid the contract price per ton. This payment shall be full compensation for furnishing and placing the asphalt mixture, including the rubber chips.

For amount of asphalt cement used in the work, the Contractor will be paid the contract price per ton.

Iowa Department of Transportation

SPECIAL PROVISIONS
for
ASPHALT RUBBER CEMENT (ARC) CONCRETE

FN-140-2(6)—21-75, Plymouth County

July 16, 1991

THE STANDARD SPECIFICATIONS, SERIES OF 1984, ARE AMENDED BY THE FOLLOWING MODIFICATIONS. THESE ARE SPECIAL PROVISIONS, WHICH SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

1022.01 DESCRIPTION.

The asphalt rubber cement (ARC) concrete mix composition will include the incorporation of ARC in the mixture, using the aggregates selected by the Contractor.

The Contractor shall have a representative of the rubber supplier available on the project site during the initial production of the ARC materials. The Contractor shall have a representative of the rubber supplier on call for technical assistance during production operations.

1022.02 GENERAL REQUIREMENTS.

The ARC concrete mixes shall conform to the requirements of the standard specifications for the standard asphalt cement concrete mixes as specified in the plans. The Standard Specifications are modified as follows:

A. Mineral Aggregate for the ARC Concrete Mixes.

Mineral aggregates shall meet Type "A" quality as specified in the plans and the standard specifications except the gradations for the concrete mixtures shall meet the following:

Sieve size	Percent passing 1/2" ARC Concrete Mixture	Percent passing 3/4" ARC Concrete Mixture
1"		100
3/4"	100	98-100
1/2"	94-100	76-92
3/8"	74-94	60-83
#4	47-69	40-62
#8	29-51	26-45
#30	12-27	11-24
#200	3-7	3-7

B. Asphalt Rubber Cement (ARC)

The ARC shall be a uniform mixture of compatible paving grade asphalt cement, ground reclaimed vulcanized rubber, and if required by the mixture design, a liquid anti-strip agent. The ARC shall meet the following physical parameters when reacted at 350 ±10 degrees Fahrenheit for 60 minutes.

Test	Requirements
Viscosity Brookfield, 350^{O}F	1500 - 4000 CP
Resilience 77^{O}F ASTM D3407	10% min.

C. Asphalt Extender Oil

An asphalt extender oil may be added, if necessary, to meet the requirements of Section 1022.02B of these special provisions. Extender oil shall be a resinous, high flash point, aromatic hydrocarbon meeting the following test requirements.

Viscosity, SSU, at 100 degrees F (ASTM D88)	2500 min.
Flash Point, COC, degrees F (ASTM D92)	390 min.
Molecular Analysis (ASTM D 2007):	
Asphaltenes, Wt. %	0.1 min.
Aromatics, Wt. %	55.0 min.

1022.03 GROUND RECLAIMED VULCANIZED RUBBER.

The rubber used shall be produced from the recycling of automobile and truck tires. Final grinding of the rubber shall be accomplished with processes performed at the ambient temperature. The use of ground rubber from multiple sources is acceptable provided the over-all blend of rubber meets the gradation requirements. The gradation of the rubber when tested in accordance with ASTM C136 using approximately 50 grams shall be in accordance with the following table.

Sieve Size	Percent passing
#10	100
#30	25-100
#50	10-100

Gradation of the rubber may be adjusted due to compatibility and reaction characteristics with the asphalt cement as required in the job mix formula.

Specific gravity of the rubber shall be 1.15 ± 0.05 and it shall be free from fabric, wire, or other contaminating materials. However, up to four percent calcium carbonate may be included to prevent the particles of rubber from sticking together.

The rubber shall be dry so as to be free flowing and not produce foaming when blended with hot asphalt cement. Not more than 1% of the particles shall exceed six times their minimum dimension.

1022.04 PACKAGING.

The ground rubber shall be supplied in moisture resistant disposable bags which weigh 50 ± 2 lbs. The bags shall be palletized into units each containing 50 bags to provide net pallet weights of 2500 ± 100 lbs. Glue shall be placed between layers of bags to increase the unit stability during shipment. Palletized units shall be double wrapped with ultra-violet resistant stretch wrap.

1022.05 CERTIFICATION.

The manufacturer shall ship with the rubber, certificates of compliance which certify that all requirements of these specifications are complied with for each production lot number of shipment.

1022.06 ASPHALT RUBBER CEMENT (ARC) MIXTURE DESIGN

The asphalt cement to be reacted with rubber shall be grade AC-5. The proportion of ground rubber shall be between 10 and 25 percent by weight of the asphalt cement.

The Contractor shall supply to the Engineer, for approval, a mix formulation at least 10 days before pavement construction is scheduled to begin. Mix design criteria for the ARC concrete mixes shall be the same for the non-rubber asphalt cement concrete (ACC) mixtures used on this project.

1022.07 ASPHALT RUBBER CEMENT (ARC) MIXING AND PRODUCTION EQUIPMENT

Unless otherwise authorized by the Engineer, all equipment utilized in production and proportioning of the ARC shall be described as follows:

A. An asphalt heating tank with a hot oil heat transfer system or retort heating system capable of heating asphalt cement to the necessary temperature for blending with the ground rubber.

B. An ARC mechanical blender with a two stage continuous mixing process capable of producing a homogeneous mixture of asphalt cement and ground rubber, at the mix design specified ratios, as recommended by the supplier of the ground rubber. This unit shall be equipped with a ground rubber feed system capable of supplying the asphalt cement feed system as not to interrupt the continuity of the blending process. A separate asphalt cement feed pump and finished product pump are required. This unit shall have both an asphalt cement totalizing meter in gallons and a flow rate meter in gallons per minute.

C. An ARC storage tank equipped with a heating system to maintain the proper temperature for pumping and adding of the binder to the aggregate and an internal mixing unit within the ground vessel capable of maintaining a proper mixture of asphalt cement and ground rubber.

D. An ARC supply system equipped with a pump and metering device capable of adding the ARC by volume to the aggregate at the percentage required by the job-mix formula.

   An interlock of the ARC and aggregate feed systems will not be required. The Contractor shall accurately proportion the ARC into the mixture.

1022.08 ASPHALT RUBBER CEMENT MIXING AND REACTING PROCEDURE.

A. **Asphalt Cement Temperature.**

   The temperature of the asphalt cement shall be between 290^{o} and 400 degrees F. at the addition of the ground rubber, as directed by the supplier.

B. **Blending and Reacting.**

The asphalt and ground rubber shall be combined and mixed together in a blender unit, pumped into the agitated storage tank, and then reacted for a minimum of 45 minutes from the time the ground rubber is added to the asphalt cement, or as directed by the supplier. Temperature of the ARC mixture shall be maintained between 290^{O} and 375 degrees F. during the reaction period, or at a temperature specified by the supplier.

C. **Transfer.**

After the material has been reacted, the ARC shall be metered into the mixing chamber of the ARC concrete production plant at the percentage required by the job-mix formula.

D. **Delays.**

When a delay occurs in ARC use after its full reaction, the ARC shall be reheated slowly just prior to use to a temperature between 290^{O} and 375 degrees F., and shall also be thoroughly mixed before pumping and metering into the hot mix plant for mixing with the aggregate. The viscosity of the ARC shall be checked by the supplier to assure specification compliance.

1022.09 COMPACTION REQUIREMENT.

The ARC concrete shall be compacted to 95% of laboratory density.

1022.10 COMPACTION EQUIPMENT.

A minimum of two rollers meeting Article 2001.05B shall be furnished. Pneumatic tired rollers will not be allowed.

1022.11 METHOD OF MEASUREMENT AND BASIS OF PAYMENT OF ASPHALT RUBBER CEMENT (ARC) CONCRETE.

The ARC Concrete Mix will be measured as per the standard specification, and be paid for in tons. ARC for use in the ARC Concrete Mix will be measured as per the standard specifications and be paid for in tons.

SP-1017
(New)

Iowa Department of Transportation

SPECIAL PROVISIONS
for
ASPHALT RUBBER CEMENT (ARC) CONCRETE

F-151-5(34)--20-31, Dubuque County

June 4, 1991

THE STANDARD SPECIFICATIONS, SERIES OF 1984, ARE AMENDED BY THE FOLLOWING MODIFICATIONS. THESE ARE SPECIAL PROVISIONS, WHICH SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

1017.01 DESCRIPTION.

The asphalt rubber cement (ARC) concrete mix composition will include the incorporation of ARC in the mixture, using the aggregates selected by the Contractor.

The Contractor shall have a representative of the rubber supplier available on the project site during the initial production of the ARC materials. The Contractor shall have a representative of the rubber supplier on call for technical assistance during production operations.

1017.02 GENERAL REQUIREMENTS.

The ARC concrete mixes shall conform to the requirements of the standard specifications for the standard asphalt cement concrete mixes as specified in the plans. The Standard Specifications are modified as follows:

A. **Mineral Aggregate for the ARC Concrete Mixes.**

Mineral aggregates shall meet Type "A" quality as specified in the plans and specifications except the gradation shall meet the following:

Sieve size	Percent passing
1"	100
3/4"	98-100
1/2"	76-92
3/8"	60-83
#4	40-62
#8	26-45
#30	11-24
#200	3-7

B. Asphalt Rubber Cement (ARC)

The ARC shall be a uniform mixture of compatible paving grade asphalt cement, ground reclaimed vulcanized rubber, and if required by the mixture design, a liquid anti-strip agent. The ARC shall meet the following physical parameters when reacted at 350 ±10 degrees Fahrenheit for 60 minutes.

Test	Requirements
Viscosity Brookfield, 350°F	1500 - 4000 CP
Resilience 77°F ASTM D3407	10% min.

C. Asphalt Extender Oil

An asphalt extender oil may be added, if necessary, to meet the requirements of Section 1017.02B of these special provisions. Extender oil shall be a resinous, high flash point, aromatic hydrocarbon meeting the following test requirements.

Viscosity, SSU, at 100 degrees F (ASTM D88)	2500 min.
Flash Point, COC, degrees F (ASTM D92)	390 min.
Molecular Analysis (ASTM D 2007):	
Asphaltenes, Wt. %	0.1 min.
Aromatics, Wt. %	55.0 min.

1017.03 GROUND RECLAIMED VULCANIZED RUBBER.

The rubber used shall be produced from the recycling of automobile and truck tires. Final grinding of the rubber shall be accomplished with processes performed at the ambient temperature. The use of ground rubber from multiple sources is acceptable provided the over-all blend of rubber meets the gradation requirements. The gradation of the rubber when tested in accordance with ASTM C136 using approximately 50 grams shall be in accordance with the following table.

Sieve Size	Percent passing
#10	100
#30	25-100
#50	10-100

Gradation of the rubber may be adjusted due to compatibility and reaction characteristics with the asphalt cement as required in the job mix formula.

Specific gravity of the rubber shall be 1.15 ± 0.05 and it shall be free from fabric, wire, or other contaminating materials. However, up to four percent calcium carbonate may be included to prevent the particles of rubber from sticking together.

The rubber shall be dry so as to be free flowing and not produce foaming when blended with hot asphalt cement. Not more than 1% of the particles shall exceed six times their minimum dimension.

1017.04 PACKAGING.

The ground rubber shall be supplied in moisture resistant disposable bags which weigh 50 ± 2 lbs. The bags shall be palletized into units each containing 50 bags to provide net pallet weights of 2500 ± 100 lbs. Glue shall be placed between layers of bags to increase the unit stability during shipment. Palletized units shall be double wrapped with ultra-violet resistant stretch wrap.

1017.05 CERTIFICATION.

The manufacturer shall ship with the rubber, certificates of compliance which certify that all requirements of these specifications are complied with for each production lot number of shipment.

1017.06 ASPHALT RUBBER CEMENT (ARC) MIXTURE DESIGN

The asphalt cement to be reacted with rubber shall be grade AC-5. The proportion of ground rubber shall be between 15 and 25 percent by weight of the asphalt cement.

The Contractor shall supply to the Engineer, for approval, a mix formulation at least 10 days before pavement construction is scheduled to begin. Mix design criteria for the ARC concrete mixes shall be the same for the non-rubber asphalt cement concrete (ACC) mixtures used on this project.

1017.07 ASPHALT RUBBER CEMENT (ARC) MIXING AND PRODUCTION EQUIPMENT

Unless otherwise authorized by the Engineer, all equipment utilized in production and proportioning of the ARC shall be described as follows:

A. An asphalt heating tank with a hot oil heat transfer system or retort heating system capable of heating asphalt cement to the necessary temperature for blending with the ground rubber. If required, this unit shall be capable of heating a minimum of 3,000 gallons of asphalt cement to 375^{O} F.

B. An ARC mechanical blender with a two stage continuous mixing process capable of producing a homogeneous mixture of asphalt cement and ground rubber, at the mix design specified ratios, as recommended by the supplier of the ground rubber. This unit shall be equipped with a ground rubber feed system capable of supplying the asphalt cement feed system as not to interrupt the continuity of the blending process. A separate asphalt cement feed pump and finished product pump are required. This unit shall have both an asphalt cement totalizing meter in gallons and a flow rate meter in gallons per minute.

C. An ARC storage tank equipped with a heating system to maintain the proper temperature for pumping and adding of the binder to the aggregate and an internal mixing unit within the ground vessel capable of maintaining a proper mixture of asphalt cement and ground rubber.

D. An ARC supply system equipped with a pump and metering device capable of adding the ARC by volume to the aggregate at the percentage required by the job-mix formula.

   An interlock of the ARC and aggregate feed systems will not be required. The Contractor shall accurately proportion the ARC into the mixture.

952A.08 ASPHALT RUBBER CEMENT MIXING AND REACTING PROCEDURE.

A. **Asphalt Cement Temperature.**

   The temperature of the asphalt cement shall be between 290^{O} and 400 degrees F. at the addition of the ground rubber, as directed by the supplier.

B. Blending and Reacting.

The asphalt and ground rubber shall be combined and mixed together in a blender unit, pumped into the agitated storage tank, and then reacted for a minimum of 45 minutes from the time the ground rubber is added to the asphalt cement, or as directed by the supplier. Temperature of the ARC mixture shall be maintained between 290^{o} and 375 degrees F. during the reaction period, or at a temperature specified by the supplier.

C. Transfer.

After the material has been reacted, the ARC shall be metered into the mixing chamber of the ARC concrete production plant at the percentage required by the job-mix formula.

D. Delays.

When a delay occurs in ARC use after its full reaction, the ARC shall be reheated slowly just prior to use to a temperature between 290^{o} and 375 degrees F., and shall also be thoroughly mixed before pumping and metering into the hot mix plant for mixing with the aggregate. The viscosity of the ARC shall be checked by the supplier to assure specification compliance.

1017.09 COMPACTION REQUIREMENT.

The Asphalt Rubber Cement (ARC) concrete shall be compacted to 95% of laboratory density.

1017.10 COMPACTION EQUIPMENT.

A minimum of two rollers meeting Article 2001.05B shall be furnished. Pneumatic tired rollers will not be allowed.

1017.11 METHOD OF MEASUREMENT AND BASIS OF PAYMENT OF ASPHALT RUBBER CEMENT (ARC) CONCRETE.

The Asphalt Rubber Cement Concrete Mix will be measured as per the standard specification, and be paid for in tons. Asphalt Rubber Cement for use in the ARC Concrete Mix will be measured as per the standard specifications and be paid for in tons.

Iowa Department of Transportation

SPECIAL PROVISIONS
for
ASPHALT RUBBER CEMENT (ARC) CONCRETE

FN-218-7(150)--21-07, Black Hawk County

April 30, 1991

THE STANDARD SPECIFICATIONS, SERIES OF 1984, ARE AMENDED BY THE FOLLOWING MODIFICATIONS. THESE ARE SPECIAL PROVISIONS, WHICH SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

1008.01 DESCRIPTION.

The asphalt rubber cement (ARC) concrete mix composition will include the incorporation of ARC in the mixture, using the aggregates selected by the Contractor.

The Contractor shall have a representative of the rubber supplier available on the project site during the initial production of the ARC materials. The Contractor shall have a representative of the rubber supplier on call for technical assistance during production operations.

1008.02 GENERAL REQUIREMENTS.

The ARC concrete mixes shall conform to the requirements of the standard specifications for the standard asphalt cement concrete mixes as specified in the plans. The Standard Specifications are modified as follows:

A. Mineral Aggregate for the ARC Concrete Mixes.

Mineral aggregates shall meet Type "A" quality as specified in the plans and specifications except the gradation shall meet the following:

Sieve size	Percent passing
1"	100
3/4"	98-100
1/2"	76-92
3/8"	60-83
#4	40-62
#8	26-45
#30	11-24
#200	3-7

1008.05 CERTIFICATION.

The manufacturer shall ship with the rubber, certificates of compliance which certify that all requirements of these specifications are complied with for each production lot number of shipment.

1008.06 ASPHALT RUBBER CEMENT (ARC) MIXTURE DESIGN

The asphalt cement to be reacted with rubber shall be grade AC-5. The proportion of ground rubber shall be between 15 and 25 percent by weight of the asphalt cement.

The Contractor shall supply to the Engineer, for approval, a mix formulation at least 10 days before pavement construction is scheduled to begin. Mix design criteria for the ARC concrete mixes shall be the same for the non-rubber asphalt cement concrete (ACC) mixtures used on this project.

1008.07 ASPHALT RUBBER CEMENT (ARC) MIXING AND PRODUCTION EQUIPMENT

Unless otherwise authorized by the Engineer, all equipment utilized in production and proportioning of the ARC shall be described as follows:

A. An asphalt heating tank with a hot oil heat transfer system or retort heating system capable of heating asphalt cement to the necessary temperature for blending with the ground rubber. If required, this unit shall be capable of heating a minimum of 3,000 gallons of asphalt cement to 375^{O} F.

B. An ARC mechanical blender with a two stage continuous mixing process capable of producing a homogeneous mixture of asphalt cement and ground rubber, at the mix design specified ratios, as recommended by the supplier of the ground rubber. This unit shall be equipped with a ground rubber feed system capable of supplying the asphalt cement feed system as not to interrupt the continuity of the blending process. A separate asphalt cement feed pump and finished product pump are required. This unit shall have both an asphalt cement totalizing meter in gallons and a flow rate meter in gallons per minute.

C. An ARC storage tank equipped with a heating system to maintain the proper temperature for pumping and adding of the binder to the aggregate and an internal mixing unit within the ground vessel capable of maintaining a proper mixture of asphalt cement and ground rubber.

D. An ARC supply system equipped with a pump and metering device capable of adding the ARC by volume to the aggregate at the percentage required by the job-mix formula.

   An interlock of the ARC and aggregate feed systems will not be required. The Contractor shall accurately proportion the ARC into the mixture.

952A.08 ASPHALT RUBBER CEMENT MIXING AND REACTING PROCEDURE.

A. **Asphalt Cement Temperature.**

   The temperature of the asphalt cement shall be between 290^{O} and 400 degrees F. at the addition of the ground rubber, as directed by the supplier.

IOWA DEPARTMENT OF TRANSPORTATION

TO OFFICE: Contracts DATE: May 21, 1991

ATTENTION: Harvey Olson REF. NO.: 436/HR-330D

FROM: Vernon J. Marks

OFFICE: Materials - Research

SUBJECT: Request for Addendum on Black Hawk FN-218-7(150)--21-07

By this memo we are requesting modifications of Special Provision SP-1008. Section 1008.02 A. should be modified as follows:

A. Mineral Aggregate for the ARC Concrete Mixes

Mineral aggregates shall meet Type "A" quality as specified in the plans and specifications. The gradation for the size 3/4 inch mixture shall meet the following:

Sieve Size	Percent Passing
1"	100
3/4"	98-100
1/2"	76-92
3/8"	60-83
#4	40-62
#8	26-45
#30	11-24
#200	3-7

The gradation for the size 1/2 inch mixture shall be as specified in the plans and specifications.

The second sentence of Section 1008.06 should be modified to read "The proportion of ground rubber shall be between 10 and 25 percent by weight of the asphalt cement."

VJM:kmd
cc: B. Brown
R. Monroe
T. Cackler

IOWA DEPARTMENT OF TRANSPORTATION

TO OFFICE: Contracts | DATE: May 20, 1991

ATTENTION: Harvey Olson | REF. NO.: 436/HR-330D

FROM: Vernon J. Marks

OFFICE: Materials - Research

SUBJECT: Request for Addendum on Black Hawk FN-218-7(150)--21-07

By this memo we are requesting an addendum to modify the second sentence of Section 1008.06 of Special Provision SP-1008 to read "The proportion of ground rubber shall be between 10 and 25 percent by weight of the asphalt cement."

VJM:kmd
cc: B. Brown
R. Monroe
T. Cackler

Appendix B
Rubber Gradations

Sieve Analysis of Rubber Chip Mixture

Sieve Size	Spec. Limit	Dist. Materials Gradation 1	Dist. Materials Gradation 2	Plant Samples 1	Plant Samples 2
1"	100	100	100	100	100
3/4"	98-100	100	100	100	100
1/2"	79-93	85	85	86	86
3/8"	57-71	66	65	61	68
4	38-52	44	48	43	48
8	28-38	33	37	32	37
16	---	26	29	25	30
30	15-23	20	21	19	21
50	---	12	12	11	13
100	---	8.2	8.5	8.4	8.4
200	4.1-8.1	6.1	6.4	6.3	6.5

Sieve Analysis of Fine Ground Reacted Rubber

Sieve Size	Ames Lab Gradation
10	100
30	98
50	54

Sieve Analysis of Recycled Rubber Chips

Sieve Size	Ames Lab Gradation
3/8"	100
4	100
8	37
16	5.7

IOWA DEPARTMENT OF TRANSPORTATION
OFFICE OF MATERIALS
TEST REPORT - BITUMINOUS AGGREGATES
LAB LOCATION - AMES

LAB NO....:AAT1-1518

MATERIAL........:GF-50 RUBBER
COUNTY..........:PLYMOUTH CONTRACTOR:BROWER
UNIT OF MATERIAL:ROUSE RUBBER FOR PLYMOUTH CO. FN-140
SAMPLED BY......: SENDER NO.:
DATE SAMPLED: DATE RECEIVED: 10/31/91 DATE REPORTED: 11/07/91

- -

SIEVE ANALYSIS %

#30	100.0
#50	96.0

COPIES TO:
CENTRAL LAB GEOLOGY V. MARKS
W. OPPEDAL

DISPOSITION:

SIGNED: ORRIS J. LANE, JR.
TESTING ENGINEER

ooooo

AATI-1520
00

IOWA DEPARTMENT OF TRANSPORTATION
OFFICE OF MATERIALS
TEST REPORT - BITUMINOUS AGGREGATES
LAB LOCATION - AMES

LAB NO....:AATI-1520

MATERIAL.........:ASPHALT RUBBER
INTENDED USE.....:ASPHALT BINDER
PRODUCER.........:RIVER CITY
PROJECT NO......:FN-151-5(34)--21-07
COUNTY...........:DUBUQUE CONTRACTOR:MATHY CONST.
SOURCE...........:BROWNS QRY
UNIT OF MATERIAL:POWDER RUBBER GF-60
SAMPLED BY......:ANDERSON SENDER NO.:CP1-24
DATE SAMPLED: 09/17/91 DATE RECEIVED: 10/31/91 DATE REPORTED: 10/31/91

% PSG.

#10	100
#30	99
#50	50

COPIES TO:
CENTRAL LAB V. MARKS R. MONROE
GEOLOGY

DISPOSITION:

SIGNED: ORRIS J. LANE, JR.
TESTING ENGINEER

ooooo

AATI-1519
00

IOWA DEPARTMENT OF TRANSPORTATION
OFFICE OF MATERIALS
TEST REPORT - BITUMINOUS AGGREGATES
LAB LOCATION - AMES

LAB NO....:AATI-1519

MATERIAL........:GF-60 ROUSE RUBBER
INTENDED USE....:REACTED RUBBER SURFACE
PRODUCER........:ASPRO
PROJECT NO......:FN-218-7(150)--21-07
COUNTY..........:BLACK HAWK CONTRACTOR:ASPRO
SOURCE..........:ASPRO PIT
UNIT OF MATERIAL:GF-60 RUBBER GRANULES
SAMPLED BY......:B. STEFFES SENDER NO.:CP1-31
DATE SAMPLED: 10/01/91 DATE RECEIVED: 10/30/91 DATE REPORTED: 10/31/91

- -

GRADATION

% PSG.	
#10	100
#30	98
#50	37

COPIES TO:
CENTRAL LAB GEOLOGY V. MARKS

DISPOSITION:

SIGNED: ORRIS J. LANE, JR.
TESTING ENGINEER

ooooo

Appendix C
Mix Designs

ABD1-0125
BD

DEPARTMENT OF TRANSPORTATION
OFFICE OF MATERIALS
TEST REPORT - ASPHALT MIX DESIGN
LAB LOCATION - AMES

LAB NO....:ABD1-0125

MATERIAL........:TYPE A
INTENDED USE....:BINDER-RUBBERIZED
PROJECT NO......:F-61-4(49)--20-70
COUNTY..........:MUSCATINE CONTRACTOR:MANATTS
SPEC NO.........:0952.00 SIZE......:3/4
SAMPLED BY......: SENDER NO.:
DATE SAMPLED: DATE RECEIVED: DATE REPORTED: 06/18/91
PROJ. LOCATION: FROM E.C.L. MUSCATINE TO WCL BLUE GRASS

AGG SOURCES: CR. LST, CHIPS & MAN. SAND- WENDLING, MOSCOW QRY, MUSCATINE CO; SAND- WENDLING, ATALISSA PIT, MUSCATINE CO.

JOB MIX FORMULA-COMB. GRADATION

1 1/2"	1"	3/4"	1/2"	3/8"	NO.4	NO.8	NO.16	NO.30	NO.50	NO.100	NO.200
		100.0	92.0	83.0	60.0	45.0	34.0	24.0	11.0	6.7	4.6
TOLERANCE /100 :		98	7	7	7	5		4			2

MATERIAL MIX	A70002	A70002	A70002	A70504	
% AGGR. PROP.	45.00	20.00	10.00	25.00	0.00

ASPHALT SOURCE AND	AMOCO			
APPROXIMATE VISCOSITY POISES	0472			
% ASPHALT IN MIX	4.00	5.00	6.00	0.00
NUMBER OF MARSHALL BLOWS	75	75	75	0
MARSHALL STABILITY - LBS.	1650	1537	1717	0
FLOW - 0.01 IN.	10	10	10	0
SP GR BY DISPLACEMENT (LAB DENS)	2.289	2.322	2.377	0.000
BULK SP. GR. COMB. DRY AGG.	2.769	2.769	2.769	0.000
SP. GR. ASPH. @ 77 F.	1.024	1.024	1.024	0.000
CALC. SOLID SP. GR.	2.631	2.589	2.548	0.000
% VOIDS - CALC.	0.00	0.00	6.71	0.00
RICE SP.GR.	2.544	2.502	2.451	0.000
% VOIDS - RICE	0.00	7.19	3.02	0.00
% WATER ABSORPTION - AGGREGATE	1.22	1.22	1.22	0.00
% VOIDS IN MINERAL AGGREGATE	20.64	20.34	19.31	0.00
% V.M.A. FILLED WITH ASPHALT	36.98	49.29	65.24	0.00
CALC. ASPH. FILM THICK. MICRONS	6.46	8.36	10.26	0.00
FILLER/BITUMEN RATIO	0.00	0.81	0.00	0.00
TEMP=	215			
WT=	7300			
SLOPE=	3.71			
INTER=	-4.27			

A CONTENT OF 5.7% ASPHALT IS RECOMMENDED TO START THE JOB.

COPIES TO:

CENTRAL LAB W. OPPEDAL MANATTS
D. HEINS J. ADAM R. MONROE
DIST. 5 MT. PLEASANT RES.

DISPOSITION:

SIGNED: ORRIS J. LANE, JR.
TESTING ENGINEER

ooooo

ABD1-0106
BD

I 'A DEPARTMENT OF TRANSPORTATION
OFFICE OF MATERIALS
TEST REPORT - ASPHALT MIX DESIGN
LAB LOCATION - AMES

LAB NO....:ABD1-0106

MATERIAL........:TYPE A (RUBBER)
INTENDED USE....:SURFACE
PROJECT NO......:F-61-4(49)--20-70
COUNTY..........:MUSCATINE CONTRACTOR:MANATTS
SPEC NO.........:0952.00 SIZE......:3/4
SAMPLED BY......: SENDER NO.:
DATE SAMPLED: DATE RECEIVED: DATE REPORTED: 06/06/91
PROJ. LOCATION: FROM ECL MUSCATINE TO WCL BLUE GRASS

- -

AGG SOURCES: GRANITE- ORTONVILLE STONE, ORTONVILLE, MN;
CR. LST & CHIPS- WENDLING, MOSCOW QRY, MUSCATINE CO;
SAND- WENDLING, ATALISSA, MUSCATINE CO.
% TOTAL BINDER: 4.68 5.83 6.98

JOB MIX FORMULA-COMB. GRADATION

1 1/2"	1"	3/4"	1/2"	3/8"	NO.4	NO.8	NO.16	NO.30	NO.50	NO.100	NO.200
		100.0	88.0	69.0	48.0	36.0	28.0	20.0	9.8	6.4	4.3

TOLERANCE /100 :

1 1/2"	1"	3/4"	1/2"	3/8"	NO.4	NO.8	NO.16	NO.30	NO.50	NO.100	NO.200
		98	7	7	7	5		4			2

MATERIAL MIX	AMN026	A70002	A70002	A70504	
% AGGR. PROP.	27.00	38.00	10.00	25.00	0.00

ASPHALT SOURCE AND	AMOCO			
APPROXIMATE VISCOSITY POISES	0472			
% ASPHALT IN MIX	4.00	5.00	6.00	0.00
NUMBER OF MARSHALL BLOWS	75	75	75	0
MARSHALL STABILITY - LBS.	1483	1830	1597	0
FLOW - 0.01 IN.	9	9	10	0
SP GR BY DISPLACEMENT (LAB DENS)	2.324	2.371	2.378	0.000
BULK SP. GR. COMB. DRY AGG.	2.736	2.736	2.736	0.000
SP. GR. ASPH. @ 77 F.	1.024	1.024	1.024	0.000
CALC. SOLID SP. GR.	2.595	2.554	2.514	0.000
% VOIDS - CALC.	0.00	7.16	5.42	0.00
RICE SP.GR.	2.520	2.467	2.413	0.000
% VOIDS - RICE	7.78	3.89	1.45	0.00
% WATER ABSORPTION - AGGREGATE	0.09	0.97	0.97	0.00
% VOIDS IN MINERAL AGGREGATE	18.46	17.67	18.30	0.00
% V.M.A. FILLED WITH ASPHALT	43.46	59.47	70.36	0.00
CALC. ASPH. FILM THICK. MICRONS	7.45	9.57	11.69	0.00
FILLER/BITUMEN RATIO	0.00	0.88	0.00	0.00
TEMP=	200			
WT=	7400			

SLOPE 3.50 ICPT.(-377)

COPIES TO:

CENTRAL LAB	MANATTS	W. OPPEDAL
D. HEINS	V. MARKS	J. ADAM
R. MONROE	DIST. 5	MT. PLEASANT RES.

DISPOSITION: A CONTENT OF 4.9% ASPHALT (5.72% TOTAL BINDER) IS RECOMMENDED TO START THE JOB. TOLERANCE ON #200 ALSO CONTROLLED BY FINES/BITUMEN RATIO.

SIGNED: ORRIS J. LANE, JR.
TESTING ENGINEER

ABD1-0226
BD

IOWA DEPARTMENT OF TRANSPORTATION   CORRECTED
OFFICE OF MATERIALS
TEST REPORT - ASPHALT MIX DESIGN
LAB LOCATION - AMES

LAB NO....:ABD1-0226

MATERIAL........:TYPE B CL 1 ARC
INTENDED USE....:BINDER
PROJECT NO......:FN-140-2(6)--21-75
COUNTY..........:PLYMOUTH   CONTRACTOR:BROWER
SPEC NO.........:5018.00   SIZE......:3/4
SUPP SPEC NO....:1022.00
SAMPLED BY......:   SENDER NO.:
DATE SAMPLED: DATE RECEIVED: DATE REPORTED: 10/16/91
PROJ. LOCATION: FROM WITHIN KINGSLEY TO IOWA 3

- -

AGG SOURCES: CR. GRAVEL, GRAVEL & SAND- EVERIST,
HAWARDEN NORTH, SIOUX COUNTY
BINDER CONTAINS 15% REACTED RUBBER

JOB MIX FORMULA-COMB. GRADATION

	1 1/2"	1"	3/4"	1/2"	3/8"	NO.4	NO.8	NO.16	NO.30	NO.50	NO.100	NO.200
		100.0	99.0	88.0	71.0	53.0	41.0	31.0	18.0	9.1	5.3	4.1
TOLERANCE /100 :			98	7	7	7	6		5			3

MATERIAL MIX	A84510	A84510	A84510		
% AGGR. PROP.	45.00	30.00	25.00	0.00	0.00

ASPHALT SOURCE AND	JEBRO			
APPROXIMATE VISCOSITY POISES	0461			
% ASPHALT IN MIX	6.00	7.00	8.00	0.00
NUMBER OF MARSHALL BLOWS	50	50	50	0
MARSHALL STABILITY - LBS.	1330	1228	1137	0
FLOW - 0.01 IN.	7	7	11	0
SP GR BY DISPLACEMENT (LAB DENS)	2.361	2.362	2.349	0.000
BULK SP. GR. COMB. DRY AGG.	2.711	2.711	2.711	0.000
SP. GR. ASPH. @ 77 F.	1.033	1.033	1.033	0.000
CALC. SOLID SP. GR.	2.485	2.448	2.413	0.000
% VOIDS - CALC.	4.98	3.52	2.64	0.00
RICE SP.GR.	2.468	2.431	2.402	0.000
% VOIDS - RICE	4.34	2.84	2.21	0.00
% WATER ABSORPTION - AGGREGATE	0.52	0.52	0.52	0.00
% VOIDS IN MINERAL AGGREGATE	18.14	18.97	20.28	0.00
% V.M.A. FILLED WITH ASPHALT	72.54	81.45	87.00	0.00
CALC. ASPH. FILM THICK. MICRONS	12.64	14.85	17.05	0.00
FILLER/BITUMEN RATIO	0.00	0.60	0.00	0.00

NUC. CAL: NONE
COPIES TO:

CENTRAL LAB	W. OPPEDAL	BROWER
D. HEINS	J. ADAM	R. MONROE
DIST. 3	SIOUX CITY RES.	

DISPOSITION: A CONTENT OF 6.8% BINDER IS RECOMMENDED
TO START THE JOB.

SIGNED: ORRIS J. LANE, JR.
TESTING ENGINEER

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IOWA DEPARTMENT OF TRANSPORTATION
OFFICE OF MATERIALS
TEST REPORT - ASPHALT MIX DESIGN
LAB LOCATION - AMES

LAB NO....:ABD1-0227

MATERIAL........:TYPE A ARC
INTENDED USE....:SURFACE
PROJECT NO......:FN-140-2(6)--21-75
COUNTY..........:PLYMOUTH — CONTRACTOR:BROWER
SPEC NO.........:5018.00 — SIZE......:1/2
SUPP SPEC NO....:1022.00
SAMPLED BY......: — SENDER NO.:
DATE SAMPLED: — DATE RECEIVED: — DATE REPORTED: 10/11/91
PROJ. LOCATION: FROM WITHIN KINGSLEY TO IOWA 3

- -

AGG. SOURCES: 1/2" & 1/8" CR. GRAVEL & SAND - EVERIST, HAWARDEN NORTH, SIOUX CO.; QTZ. SAND - EVERIST, DEL RAPIDS, S.D.
BINDER CONTAINS 15% REACTED RUBBER

JOB MIX FORMULA-COMB. GRADATION

	1 1/2"	1"	3/4"	1/2"	3/8"	NO.4	NO.8	NO.16	NO.30	NO.50	NO.100	NO.200
			100.0	99.0	82.0	62.0	48.0	34.0	21.0	11.0	5.8	4.2
TOLERANCE /100 :				92	7	7	5		4			2

MATERIAL MIX	A84510	A84510	A84510	ASD002	
% AGGR. PROP.	55.00	10.00	25.00	10.00	0.00

ASPHALT SOURCE AND	JEBRO			
APPROXIMATE VISCOSITY POISES	0461			
% ASPHALT IN MIX	6.00	7.00	8.00	0.00
NUMBER OF MARSHALL BLOWS	50	50	50	0
MARSHALL STABILITY - LBS.	1515	1673	1546	0
FLOW - 0.01 IN.	6	8	10	0
SP GR BY DISPLACEMENT (LAB DENS)	2.313	2.335	2.332	0.000
BULK SP. GR. COMB. DRY AGG.	2.716	2.716	2.716	0.000
SP. GR. ASPH. @ 77 F.	1.033	1.033	1.033	0.000
CALC. SOLID SP. GR.	2.486	2.450	2.414	0.000
% VOIDS - CALC.	6.98	4.69	3.40	0.00
RICE SP.GR.	2.450	2.423	2.392	0.000
% VOIDS - RICE	5.59	3.63	2.51	0.00
% WATER ABSORPTION - AGGREGATE	0.44	0.44	0.44	0.00
% VOIDS IN MINERAL AGGREGATE	19.95	20.05	21.01	0.00
% V.M.A. FILLED WITH ASPHALT	65.03	76.63	83.79	0.00
CALC. ASPH. FILM THICK. MICRONS	11.60	13.61	15.61	0.00
FILLER/BITUMEN RATIO	0.00	0.56	0.00	0.00

A CONTENT OF 7.5% BINDER IS RECOMMENDED TO START THE JOB.
NUC. CAL.: NONE
COPIES TO:

CENTRAL LAB	R. MONROE	J. ADAM
D. HEINS	BROWER	W. OPPEDAL
DIST. 3	SIOUX CITY RES.	

DISPOSITION:

SIGNED: ORRIS J. LANE, JR.
TESTING ENGINEER

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ABD1-0210 MIX DESIGN
PI

IOWA DEPARTMENT OF TRANSPORTATION
OFFICE OF MATERIALS
TEST REPORT - ASPHALT MIX DESIGN
LAB LOCATION - AMES

LAB NO....:ABD1-0210

MATERIAL.........:TYPE A ARC
INTENDED USE....:BINDER/SURFACE
PROJECT NO.......:FN-151-5(34)--21-31
COUNTY...........:DUBUQUE CONTRACTOR:MATHY
SPEC NO..........:1017.00 SIZE......:3/4
SAMPLED BY......: SENDER NO.:
DATE SAMPLED: DATE RECEIVED: DATE REPORTED: 09/18/91
PROJ. LOCATION: FROM CASCADE TO U.S. 61

- -

AGG. SOURCES: 3/4" & 1/2" CR. LST. & MAN. SAND - RIVER CITY STONE, BROWN QRY., DUBUQUE CO.; SAND - AGGREGATE MATLS., NINE MILE, DUBUQUE CO.
BINDER IS 15% REACTED RUBBER

JOB MIX FORMULA-COMB. GRADATION

1 1/2"	1"	3/4"	1/2"	3/8"	NO.4	NO.8	NO.16	NO.30	NO.50	NO.100	NO.200
	100.0	92.0	79.0	62.0	44.0	33.0	23.0	12.0	6.9	4.3	

TOLERANCE /100 :

	98	7	7	7	5		4			2	

MATERIAL MIX	A31010	A31010	A31010	A31502	
% AGGR. PROP.	40.00	15.00	20.00	25.00	0.00

ASPHALT SOURCE AND	KOCH			
APPROXIMATE VISCOSITY POISES	0496			
% ASPHALT IN MIX	6.00	7.00	8.00	0.00
NUMBER OF MARSHALL BLOWS	50	50	50	0
MARSHALL STABILITY - LBS.	987	930	972	0
FLOW - 0.01 IN.	10	9	8	0
SP GR BY DISPLACEMENT (LAB DENS)	2.296	2.341	2.351	0.000
BULK SP. GR. COMB. DRY AGG.	2.783	2.783	2.783	0.000
SP. GR. ASPH. @ 77 F.	1.024	1.024	1.024	0.000
CALC. SOLID SP. GR.	2.564	2.524	2.485	0.000
% VOIDS - CALC.	0.00	7.25	5.38	0.00
RICE SP.GR.	2.494	2.468	2.426	0.000
% VOIDS - RICE	7.94	5.15	3.09	0.00
% WATER ABSORPTION - AGGREGATE	1.39	1.39	1.39	0.00
% VOIDS IN MINERAL AGGREGATE	22.45	21.77	22.28	0.00
% V.M.A. FILLED WITH ASPHALT	53.40	66.72	75.85	0.00
CALC. ASPH. FILM THICK. MICRONS	10.22	12.14	14.07	0.00
FILLER/BITUMEN RATIO	0.00	0.57	0.00	0.00
TEMP=	220			
WT=	7300			
SLOPE=	3.98			

A CONTENT OF 7.5% BINDER IS RECOMMENDED TO START THE JOB.
THIS IS 896 AC TO 158 RUBBER.
COPIES TO:

CENTRAL LAB	R. MONROE	J. ADAM
D. HEINS	RIVER CITY ASPHALT	W. OPPEDAL
DIST. 6	MANCHESTER RES.	

DISPOSITION:

SIGNED: ORRIS J. LANE, JR.
TESTING ENGINEER

IOWA DEPARTMENT OF TRANSPORTATION
OFFICE OF MATERIALS
TEST REPORT - ASPHALT MIX DESIGN
LAB LOCATION - AMES

LAB NO....:ABD1-0193

MATERIAL........:TYPE A
INTENDED USE....:BINDER/SURFACE
PROJECT NO......:FN-151-5(34)--21-31
COUNTY..........:DUBUQUE
CONTRACTOR:MATHY
SUPP SPEC NO....:1017.00
SIZE.......:3/4
SAMPLED BY......:
SENDER NO.:
DATE SAMPLED:
DATE RECEIVED:
DATE REPORTED: 08/22/9
PROJ. LOCATION: FROM CASCADE TO U.S. 61

AGG SOURCES: CR. LST & CHIPS- BARD CONC., CASCADE EAST, DUBUQUE CO; SAND- TSCHIGGFRIE, MCCABE PIT, DUBUQUE CO.

JOB MIX FORMULA-COMB. GRADATION

1 1/2"	1"	3/4"	1/2"	3/8"	NO.4	NO.8	NO.16	NO.30	NO.50	NO.100	NO.200
		100.0	89.0	74.0	51.0	36.0	28.0	21.0	11.0	7.0	4.7
TOLERANCE /100 :											
		98	7	7	7	5		4			2

MATERIAL MIX	A31006	A31006	A31510		
AGGR. PROP.	37.50	37.50	25.00	0.00	0.00

ASPHALT SOURCE AND	KOCH			
APPROXIMATE VISCOSITY POISES	0945			
% ASPHALT IN MIX	5.00	6.00	0.00	0.00
NUMBER OF MARSHALL BLOWS	50	50	0	0
MARSHALL STABILITY - LBS.	2702	2653	0	0
FLOW - 0.01 IN.	7	10	0	0
SP. GR BY DISPLACEMENT (LAB DENS)	2.369	2.399	0.000	0.000
BULK SP. GR. COMB. DRY AGG.	2.763	2.763	0.000	0.000
SP. GR. ASPH. @ 77 F.	1.026	1.026	0.000	0.000
CALC. SOLID SP. GR.	2.597	2.555	0.000	0.000
% VOIDS - CALC.	8.77	6.12	0.00	0.00
RICE SP.GR.	2.506	2.461	0.000	0.00
% VOIDS - RICE	5.47	2.52	0.00	0.00
% WATER ABSORPTION - AGGREGATE	1.61	1.61	0.00	0.00
% VOIDS IN MINERAL AGGREGATE	18.55	18.38	0.00	0.00
% V.M.A. FILLED WITH ASPHALT	52.73	66.69	0.00	0.00
CALC. ASPH. FILM THICK. MICRONS	8.36	10.35	0.00	0.00
FILLER/BITUMEN RATIO	0.00	0.87	0.00	0.00
TEMP=	220			
WT=	7400			
SLOPE=	4.14			
INTER=	-4.62			

A CONTENT OF 5.4% ASPHALT IS RECOMMENDED TO START THE JOB.
TOLERANCE ON #200 ALSO CONTROLLED BY FINES/BITUMEN RATIO.
COPIES TO:

CENTRAL LAB	W. OPPEDAL	MATHY
C. HEINS	J. ADAM	R. MONROE
DIST. 6	MANCHESTER RES.	Mark
		Dennis

DISPOSITION:

SIGNED: ORRIS J. LANE, JR.
TESTING ENGINEER

ABD1-0195
BD

IOWA DEPARTMENT OF TRANSPORTATION
OFFICE OF MATERIALS
TEST REPORT - ASPHALT MIX DESIGN
LAB LOCATION - AMES

LAB NO....:ABD1-0195

MATERIAL........:TYPE A ARC
INTENDED USE....:BINDER
PROJECT NO......:FN-218-7(150)--21-07
COUNTY..........:BLACK HAWK — CONTRACTOR:ASPRO
SPEC NO.........:5015.00 — SIZE......:3/4
SAMPLED BY......: — SENDER NO.:
DATE SAMPLED: — DATE RECEIVED: — DATE REPORTED: 08/28/91
PROJ. LOCATION: UNIVERSITY AVE. IN CEDAR FALLS & WATERLOO

- -

AGG SOURCES: CR LST, 3/4 & 1/2" CHIPS- BASIC MATERIALS, WATERLOO SOUTH, BLACK HAWK CO.; SAND- MANATTS, ASPRO PIT, BLACK HAWK CO.
BINDER IS 15% REACTED RUBBER

JOB MIX FORMULA-COMB. GRADATION

	1 1/2"	1"	3/4"	1/2"	3/8"	NO.4	NO.8	NO.16	NO.30	NO.50	NO.100	NO.200
		100.0	99.0	82.0	64.0	42.0	30.0	23.0	15.0	7.0	4.6	4.0
TOLERANCE /100 :			98	7	7	7	5		4			2

MATERIAL MIX	A07004	A07004	A07004	A07506	
% AGGR. PROP.	45.00	24.00	10.00	21.00	0.00

ASPHALT SOURCE AND	KOCH			
APPROXIMATE VISCOSITY POISES	0496			
% ASPHALT IN MIX	5.00	6.00	7.00	0.00
NUMBER OF MARSHALL BLOWS	75	75	75	0
MARSHALL STABILITY - LBS.	1970	1957	1567	0
FLOW - 0.01 IN.	7	7	9	0
SP GR BY DISPLACEMENT (LAB DENS)	2.363	2.375	2.362	0.000
BULK SP. GR. COMB. DRY AGG.	2.712	2.712	2.712	0.000
SP. GR. ASPH. @ 77 F.	1.024	1.024	1.024	0.000
CALC. SOLID SP. GR.	2.534	2.495	2.458	0.000
% VOIDS - CALC.	6.75	4.82	3.90	0.00
RICE SP.GR.	2.468	2.430	2.409	0.000
% VOIDS - RICE	4.22	2.26	1.95	0.00
% WATER ABSORPTION - AGGREGATE	0.97	0.97	0.97	0.00
% VOIDS IN MINERAL AGGREGATE	17.23	17.68	19.00	0.00
% V.M.A. FILLED WITH ASPHALT	60.81	72.73	79.50	0.00
CALC. ASPH. FILM THICK. MICRONS	11.49	14.03	16.58	0.00
FILLER/BITUMEN RATIO	0.00	0.78	0.00	0.00
TEMP=	210			
WT=	7300			
SLOPE=	4.67			
INTER=	-5.53			

A CONTENT OF 5.1% BINDER IS RECOMMENDED TO START THE JOB.

COPIES TO:

CENTRAL LAB	W. OPPEDAL	ASPRO
D. HEINS	J. ADAM	R. MONROE
DIST. 2	WATERLOO RES.	

DISPOSITION:

SIGNED: ORRIS J. LANE, JR.
TESTING ENGINEER

ooooo

ABD1-0196 MIX DESIGN
BD

IOWA DEPARTMENT OF TRANSPORTATION
OFFICE OF MATERIALS
TEST REPORT - ASPHALT MIX DESIGN
LAB LOCATION - AMES

LAB NO....:ABD1-0196

MATERIAL........:TYPE A ARC
INTENDED USE....:SURFACE
PROJECT NO......:FN-218-7(150)--21-07
COUNTY..........:BLACK HAWK CONTRACTOR:ASPRO
SPEC NO.........:5015.00 SIZE......:1/2
SAMPLED BY......: SENDER NO.:
DATE SAMPLED: DATE RECEIVED: DATE REPORTED: 08/28/91
PROJ. LOCATION: UNIVERSITY AVE. IN CEDAR FALLS & WATERLOO

- -

AGG. SOURCES: CR. LST. & CHIPS - BASIC MATERIALS, WATERLOO SOUTH, BLACK HAWK CO. SAND - MANATTS, ASPRO PIT, BLACK HAWK CO.
BINDER IS 15% REACTED RUBBER

JOB MIX FORMULA-COMB. GRADATION

	1 1/2"	1"	3/4"	1/2"	3/8"	NO.4	NO.8	NO.16	NO.30	NO.50	NO.100	NO.200
			100.0	98.0	82.0	52.0	36.0	27.0	18.0	7.9	4.7	4.2
TOLERANCE /100 :				92	7	7	5		4			2

MATERIAL MIX	A07004	A07004	A07506		
% AGGR. PROP.	39.00	36.00	25.00	0.00	0.00

ASPHALT SOURCE AND	KOCH			
APPROXIMATE VISCOSITY POISES	0496			
% ASPHALT IN MIX	5.00	6.00	7.00	0.00
NUMBER OF MARSHALL BLOWS	75	75	75	0
MARSHALL STABILITY - LBS.	2263	2028	1653	0
FLOW - 0.01 IN.	6	7	8	0
SP GR BY DISPLACEMENT (LAB DENS)	2.358	2.365	2.353	0.000
BULK SP. GR. COMB. DRY AGG.	2.715	2.715	2.715	0.000
SP. GR. ASPH. @ 77 F.	1.024	1.024	1.024	0.000
CALC. SOLID SP. GR.	2.534	2.495	2.457	0.000
% VOIDS - CALC.	6.93	5.20	4.24	0.00
RICE SP.GR.	2.469	2.428	2.398	0.000
% VOIDS - RICE	4.50	2.59	1.88	0.00
% WATER ABSORPTION - AGGREGATE	0.87	0.87	0.87	0.00
% VOIDS IN MINERAL AGGREGATE	17.49	18.12	19.40	0.00
% V.M.A. FILLED WITH ASPHALT	60.38	71.27	78.12	0.00
CALC. ASPH. FILM THICK. MICRONS	10.60	12.92	15.94	0.00
FILLER/BITUMEN RATIO	0.00	0.81	0.00	0.00
TEMP=	220			
WT=	7200			
SLOPE=	4.95			
INTER=	-6.05			

A CONTENT OF 5.2% BINDER IS RECOMMENDED TO START THE JOB.
COPIES TO:

CENTRAL LAB	R. MONROE	J. ADAM
D. HEINS	ASPRO	W. OPPEDAL
DIST. 2	WATERLOO RES.	

DISPOSITION:

SIGNED: ORRIS J. LANE, JR.
TESTING ENGINEER

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Appendix D
Statistical Summaries

This appendix provides a statistical overview of the data used in the report. Each group of data is shown in an ANOVA test result format. Sums, averages and variances are provided in the Summary portion of each table. Below that is the ANOVA portion. If the "F" value is greater than the "F crit" value (both highlighted), then there is a statistically significant difference in between one or more of the means at a 95 percent significance level.

Cracking Statistical Summary

HR-330

SUMMARY

Groups	Count	Sum	Average	Variance
Section 1	14	608.25	43.44643	159.5594
Section 3	18	957	53.16667	17.79412
Section 4	28	1414	50.5	78.11111
Section 5	12	660	55	0
Section 6	18	892.83	49.60167	73.73723
Section 7	21	1067	50.80952	66.2619

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1083.707	5	216.7414	3.221417	0.009559	2.300887
Within Groups	7064.543	105	67.28136			
Total	8148.25	110				

HR-330A

SUMMARY

Groups	Count	Sum	Average	Variance
Section 1	53	1662.81	31.37377	637.3763
Section 2	25	759.35	30.374	196.0946

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	16.97949	1	16.97949	0.034094	0.853999	3.966761
Within Groups	37849.84	76	498.0242			
Total	37866.82	77				

HR-330C

SUMMARY

Groups	Count	Sum	Average	Variance
Section 1	19	1067	56.15789	12.02924
Section 2	19	1100	57.89474	38.21053
Section 3	27	1547.036	57.29762	16.3435
Section 4a	26	1430	55	0
Section 4b	26	1429.5	54.98077	31.24962

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	163.1928	4	40.79821	2.165092	0.077489	2.452715
Within Groups	2110.487	112	18.84364			
Total	2273.68	116				

HR-330D

SUMMARY

Groups	Count	Sum	Average	Variance
Section 2	25	837.4495	33.49798	78.58623
Section 3a	11	382.4325	34.76659	72.00235
Section 3b	11	529.6423	48.1493	36.95179
Section 4	8	324.0512	40.5064	191.195

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1800.151	3	600.0503	7.09382	0.00045	2.78623
Within Groups	4313.976	51	84.58776			
Total	6114.127	54				

Creep Statistical Summary

HR-330

Lab 50 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
Conventional	3	207	69	4.75
ARC	2	73.4	36.7	50

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1251.948	1	1251.948	63.12342857	0.004159	10.12796
Within Groups	59.5	3	19.83333333			
Total	1311.448	4				

Lab 75 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
ARC	3	132.3	44.1	13.23
Conventional	3	225.5	75.16666667	5.583333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1447.706667	1	1447.706667	153.9022	0.000243	7.70865
Within Groups	37.62666667	4	9.406666667			
Total	1485.333333	5				

Plant 50 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
Conventional	3	214	71.33333333	4.333333333
ARC	3	198.5	66.16666667	5.583333333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	40.04166667	1	40.04166667	8.075630252	0.046784	7.70865
Within Groups	19.83333333	4	4.958333333			
Total	59.875	5				

Plant 75 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
ARC	3	202	67.33333333	1.083333
Conventional	3	203.5	67.83333333	38.08333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.375	1	0.375	0.019149	0.896627	7.70865
Within Groups	78.33333333	4	19.58333333			
Total	78.70833333	5				

Creep Statistical Summary

HR-330A

Lab 50 Marshall Blows

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Conventional	3	164	54.66666667	216.3233333
ARC	3	38.2	12.73333333	3.203333333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2637.606667	1	2637.606667	24.02994321	0.008032	7.70865
Within Groups	439.0533333	4	109.7633333			
Total	3076.66	5				

Lab 75 Marshall Blows

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
ARC	3	71	23.66666667	5.323333
Conventional	3	196	65.33333333	0.083333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2604.166667	1	2604.166667	963.3169	6.42E-06	7.70865
Within Groups	10.81333333	4	2.703333333			
Total	2614.98	5				

Plant 50 Marshall Blows

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Conventional	3	143.3	47.76666667	0.853333333
ARC	3	132.9	44.3	44.53

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	18.02666667	1	18.02666667	0.794417921	0.423137	7.70865
Within Groups	90.76666667	4	22.69166667			
Total	108.7933333	5				

Plant 75 Marshall Blows

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
ARC	3	204	68	6.25
Conventional	3	197.8	65.93333333	45.76333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6.406666667	1	6.406666667	0.246347	0.645696	7.70865
Within Groups	104.0266667	4	26.00666667			
Total	110.4333333	5				

Creep Statistical Summary

HR-330D

Lab 50 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
Conventional	3	191	63.66666667	261.5833333
ARC	3	64.9	21.63333333	0.163333333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2650.201667	1	2650.201667	20.25012735	0.010822	7.70865
Within Groups	523.4933333	4	130.8733333			
Total	3173.695	5				

Lab 75 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
ARC	3	90	30	18.84
Conventional	3	219.5	73.16666667	11.58333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2795.041667	1	2795.041667	183.7433	0.000171	7.70865
Within Groups	60.84666667	4	15.21166667			
Total	2855.888333	5				

Plant 50 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
Conventional	3	150.2	50.06666667	138.0633333
ARC	3	199.5	66.5	9.75

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	405.0816667	1	405.0816667	5.480989536	0.079278	7.70865
Within Groups	295.6266667	4	73.90666667			
Total	700.7083333	5				

Plant 75 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
ARC	3	218	72.66666667	1.083333
Conventional	3	211	70.33333333	0.333333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	8.166666667	1	8.166666667	11.52941	0.027391	7.70865
Within Groups	2.833333333	4	0.708333333			
Total	11	5				

Resilient Modulus Statistical Summary

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Lab 50 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
Conventional	3	1056666.7	352222.2222	581481481.5
ARC	3	473333.33	157777.7778	248148148.1

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	56712962963	1	56712962963	136.71875	0.000306	7.70865
Within Groups	1659259259	4	414814814.8			
Total	58372222222	5				

Lab 75 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
ARC	3	796666.67	265555.5556	3.84E+09
Conventional	3	1273333.3	424444.4444	3.69E+09

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	37868518519	1	37868518519	10.05853	0.033809	7.70865
Within Groups	15059259259	4	3764814815			
Total	52927777778	5				

Plant 50 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
Conventional	3	1983333.3	661111.1111	9848148148
ARC	3	3053333.3	1017777.778	7003703704

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.90817E+11	1	1.90817E+11	22.64637363	0.008913	7.70865
Within Groups	33703703704	4	8425925926			
Total	2.2452E+11	5				

Plant 75 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
ARC	3	3403333.3	1134444.444	1.05E+10
Conventional	3	2290000	763333.3333	1.87E+10

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.06585E+11	1	2.06585E+11	14.13175	0.019788	7.70865
Within Groups	58474074074	4	14618518519			
Total	2.65059E+11	5				

Resilient Modulus Statistical Summary

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Lab 50 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
Conventional	3	1000000	333333.3333	33333333.33
ARC	3	277666.67	92555.55556	326037037

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	86960907407	1	86960907407	483.9625889	2.53E-05	7.70865
Within Groups	718740740.7	4	179685185.2			
Total	87679648148	5				

Lab 75 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
ARC	3	487000	162333.3333	2.01E+08
Conventional	3	1306666.7	435555.5556	3.8E+09

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.11976E+11	1	1.11976E+11	55.92513	0.001709	7.70865
Within Groups	8008962963	4	2002240741			
Total	1.19985E+11	5				

Plant 50 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
Conventional	3	1213333.3	404444.4444	1381481481
ARC	3	1196666.7	398888.8889	25559259259

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	46296296.3	1	46296296.3	0.003436899	0.956063	7.70865
Within Groups	53881481481	4	13470370370			
Total	53927777778	5				

Plant 75 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
ARC	3	1223333.3	407777.7778	4.15E+08
Conventional	3	1516666.7	505555.5556	1.18E+10

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	14340740741	1	14340740741	2.349515	0.200093	7.70865
Within Groups	24414814815	4	6103703704			
Total	38755555556	5				

Resilient Modulus Statistical Summary

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Lab 50 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
Conventional	3	1220000	406666.6667	1411111111
ARC	3	476666.67	158888.8889	621148148.1

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	92090740741	1	92090740741	90.62892967	0.00068	7.70865
Within Groups	4064518519	4	1016129630			
Total	96155259259	5				

Lab 75 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
ARC	3	794333.33	264777.7778	5.24E+08
Conventional	3	1970000	656666.6667	2.54E+09

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.30365E+11	1	2.30365E+11	150.1712	0.000255	7.70865
Within Groups	6136074074	4	1534018519			
Total	2.36501E+11	5				

Plant 50 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
Conventional	3	2286666.7	762222.2222	337037037
ARC	3	2050000	683333.3333	6577777778

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	9335185185	1	9335185185	2.700053562	0.17569	7.70865
Within Groups	13829629630	4	3457407407			
Total	23164814815	5				

Plant 75 Marshall Blows

SUMMARY

Groups	Count	Sum	Average	Variance
ARC	3	2406666.7	802222.2222	4.59E+08
Conventional	3	3070000	1023333.333	1.25E+10

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	73335185185	1	73335185185	11.33725	0.02812	7.70865
Within Groups	25874074074	4	6468518519			
Total	99209259259	5				

Structure Statistical Summary

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SUMMARY

Groups	Count	Sum	Average	Variance
Section 1	9	39.53	4.392222	0.112394
Section 2	9	45.48	5.053333	0.224
Section 3	8	36.57	4.57125	0.19327
Section 4	9	44.81	4.978889	0.382511
Section 5	6	30.71	5.118333	0.422137
Section 6	8	38.57	4.82125	0.438327
Section 7	9	47.07	5.23	0.780275

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4.731745	6	0.788624	2.171076	0.061047	2.282604
Within Groups	18.5253	51	0.363241			
Total	23.25705	57				

HR-330A

SUMMARY

Groups	Count	Sum	Average	Variance
Section 1	22	81.67	3.712273	0.248399
Section 2	11	42.11	3.828182	0.210236
Section 3	12	44.01	3.6675	0.086075

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.159745	2	0.079873	0.405857	0.668991	3.219938
Within Groups	8.265575	42	0.196799			
Total	8.42532	44				

HR-330C

SUMMARY

Groups	Count	Sum	Average	Variance
Section 1	6	30.34	5.056667	0.842707
Section 2	6	28.74	4.79	0.4792
Section 3	12	51.6	4.3	0.488018
Section 4	22	97.63	4.437727	0.546456

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.891874	3	0.963958	1.726247	0.176206	2.827051
Within Groups	23.45332	42	0.558412			
Total	26.34519	45				

HR-330D

SUMMARY

Groups	Count	Sum	Average	Variance
Section 1	10	38.21	3.821	0.38381
Section 2	10	43.21	4.321	0.298366
Section 3	10	47.18	4.718	0.16504
Section 4	10	45.73	4.573	0.525157

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4.655628	3	1.551876	4.523192	0.008608	2.866265
Within Groups	12.35135	36	0.343093			
Total	17.00698	39				

Rutting Statistical Summary

HR-330

SUMMARY

Groups	Count	Sum	Average	Variance
Section 1	8	0.3	0.0375	0.001964
Section 2	20	0.8	0.04	0.002263
Section 3	12	0.55	0.045833	0.001572
Section 4	12	0.7	0.058333	0.001288
Section 5	10	0.55	0.055	0.003583
Section 6	10	0.4	0.04	0.001
Section 7	12	0.4	0.033333	0.001515
Section 8	9	0.3	0.033333	0.00125

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.006832	7	0.000976	0.531368	0.808495	2.119297
Within Groups	0.156125	85	0.001837			
Total	0.162957	92				

HR-330A

SUMMARY

Groups	Count	Sum	Average	Variance
Section 1	40	2.5	0.0625	0.001635
Section 2	22	1.25	0.056818	0.001975
Section 3	24	1.35	0.05625	0.001372

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.000768	2	0.000384	0.233111	0.792582	3.106507
Within Groups	0.13679	83	0.001648			
Total	0.137558	85				

HR-330C

SUMMARY

Groups	Count	Sum	Average	Variance
Section 1	44	3.6	0.081818	0.001057
Section 2	44	3.15	0.071591	0.001907
Section 3	122	10.67	0.087459	0.007723
Section 4A	56	4.8	0.085714	0.001156
Section 4B	56	5.05	0.090179	0.000584

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.010594	4	0.002648	0.725244	0.57523	2.400128
Within Groups	1.157625	317	0.003652			
Total	1.168219	321				

HR-330D

SUMMARY

Groups	Count	Sum	Average	Variance
Section 1	20	1.4	0.07	0.001947
Section 2	20	2.15	0.1075	0.003757
Section 3	20	1.75	0.0875	0.001283
Section 4	20	2.5	0.125	0.003289

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.03425	3	0.011417	4.443875	0.006239	2.724946
Within Groups	0.19525	76	0.002569			
Total	0.2295	79				