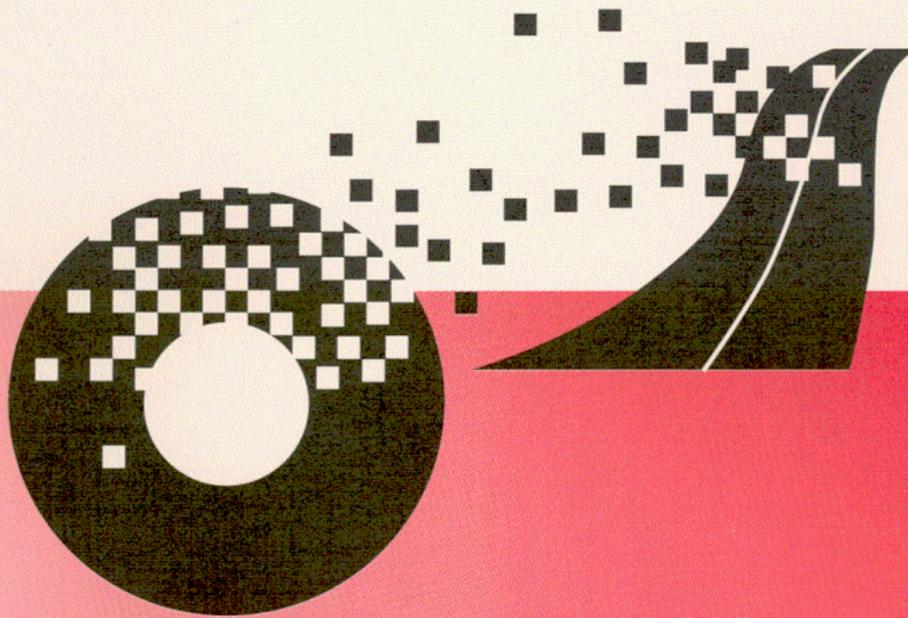


# An Evaluation of Dense Graded Asphalt-Rubber Concrete in Minnesota



Physical Research





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**AN EVALUATION OF  
DENSE GRADED ASPHALT-RUBBER CONCRETE  
IN MINNESOTA**

Final Report  
November 1991

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## **EXECUTIVE SUMMARY**

The Minnesota Department of Transportation is continually investigating ways to improve the cold temperature performance of its asphalt concrete pavements. One reported method is to modify the asphalt binder with ground reclaimed automobile and truck tire rubber. In 1984, a project on TH 7 (State Project #4703-17) was selected for the field trial of an asphalt-rubber cement dense graded concrete utilizing a product produced by Arizona Refining of Phoenix Arizona.

Construction of the asphalt-rubber cement dense graded asphalt concrete required some special effort and specialized equipment to maintain adequate mixing and placing temperatures. Evaluations included crack counting, resilient modulus, in-place air voids rutting, roughness, recovered penetration and cost considerations.

Interesting results regarding the resilient modulus of the asphalt rubber samples were found. However, the formulation used provided little or no perceived benefits to the roadway at much higher costs. The high costs were due in part to the nature of the project. However, this appears to be a cumbersome and expensive procedure with the primary benefit being waste tire utilization.

## **ACKNOWLEDGEMENT**

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The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or policies of the State of Minnesota at the time of publication. This report does not constitute a standard, specification, or regulation.

The author and the State of Minnesota do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this report.



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## I. INTRODUCTION.

The Minnesota Department of Transportation is continually investigating ways to improve the cold temperature performance of its asphalt concrete pavements. One reported method is to modify the asphalt binder with ground reclaimed automobile and truck tire rubber. The resulting asphalt-rubber binder is said to deter thermal cracking and resist stripping due to greater film thickness on the aggregate and greater impermeability to water. The process would offer an environmentally safe way to dispose of a significant quantity of waste tires. The purpose of this study has been to evaluate the performance of an asphalt-rubber ( A-R ) binder used in a dense graded asphalt concrete.

## II. BACKGROUND

A project on TH 7 (State Project #4703-17) was selected for the field trial. This project was already under contract for completion during the 1984 construction season. A supplemental agreement to provide for the test sections was negotiated with the prime contractor W. Hodgman and Sons, Inc. with Arizona Refining of Phoenix, Arizona providing the A-R cement.

The original structure, placed in 1958, consisted of a 2" plant-mixed bituminous surface on a cement treated aggregate base with an aggregate subbase ( approximate total base and subbase thickness, 12 inches ). This pavement received a 3" plant-mixed bituminous overlay in 1966. The roadway is located in a rural-agricultural area and receives 2450 ADT with 540 HCADT (based upon the 1986 Mn/DOT Traffic Flow Map). See Figure 1.

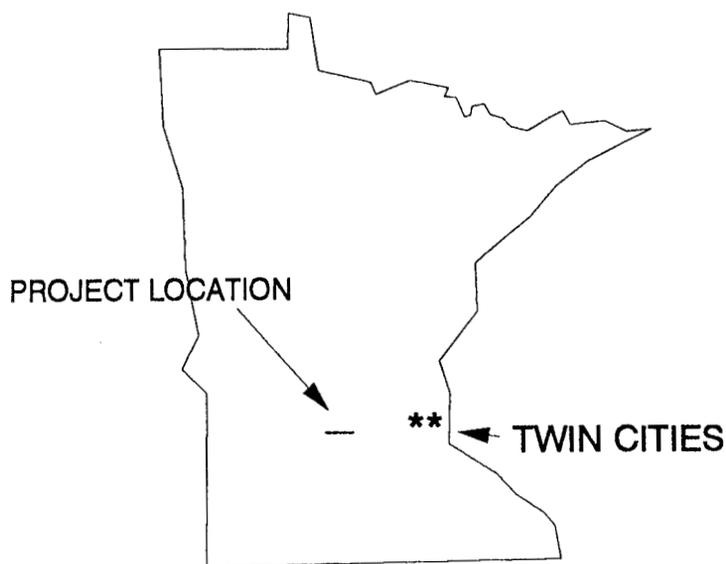


Figure 1. Project Location

Two cross-sections were constructed on this project. The first is a simple overlay of the existing structure employing a 1-1/2" lift of specification 2341M ( modified ) wear course. The second cross-section included removal of the inplace bituminous pavement (approximately 5-1/2 inches), placement of 7-1/2 inches of specification 2332 (50% hot recycled) plant-mixed base, followed by 1-1/2 inches of spec 2331 levelling mixture. Then a 1-1/2 inch 2331 binder mix was placed, with a 1" lift of 2341M wear course completing the reconstruction. The test sections employed A-R cement in the 2331 binder and 2341M wear courses in a variety of combinations. The layout of the test sections and the type of mix used is shown in Figure 2.

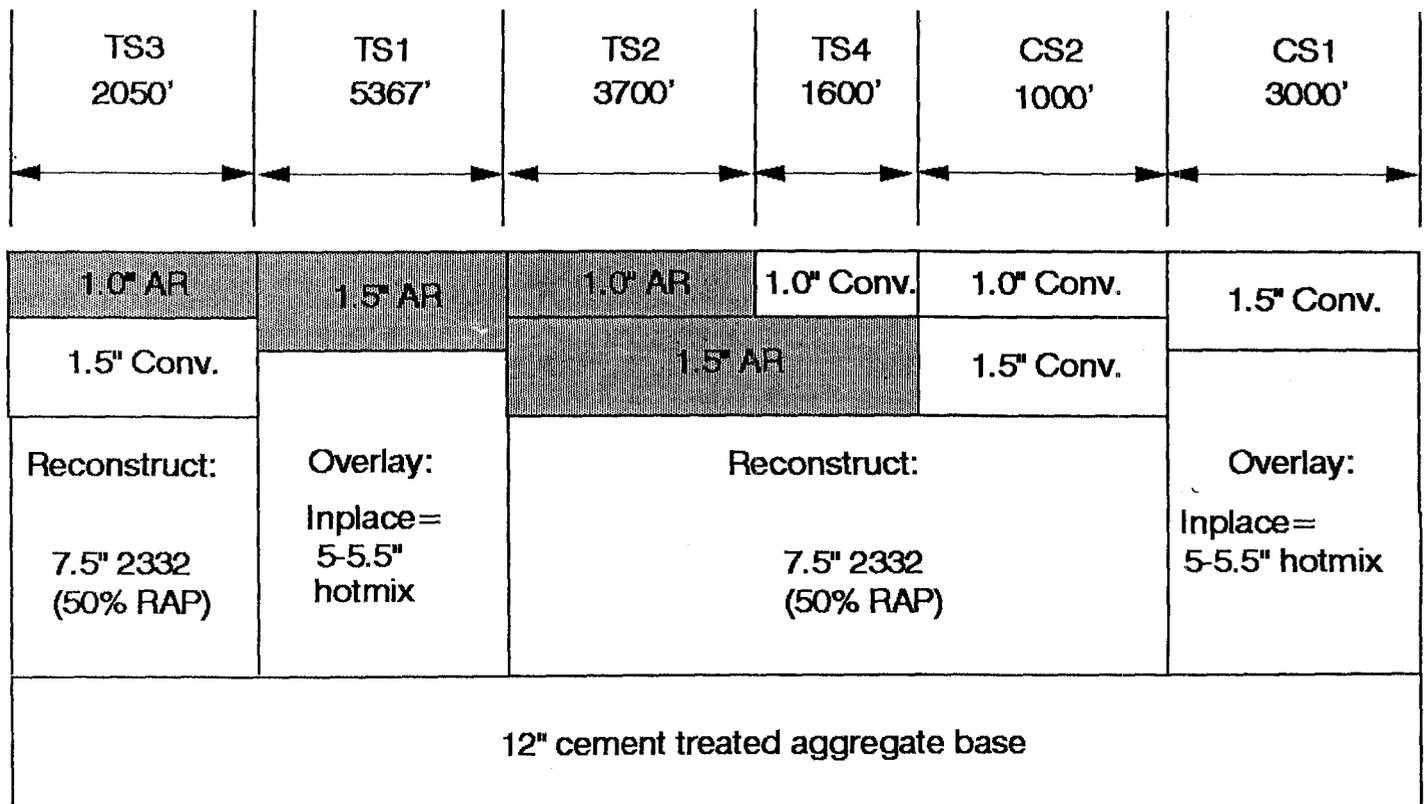


Figure 2. Project Layout.

### III. TRIAL MIX

The Marshall method was employed to arrive at a mix design for the aggregates from the project and the A-R material. The trial mix recommendations were as follows:

Binder	Spec. 2341 Mod. Wear		Spec. 2331 Mod.		
	Aggregate Gradation	Formula	Working Range	Formula	Working Range
% Passing 3/4" Sieve	100	100-100	100	100-100	100-100
" " 5/8" "	100	100-100	97	89-100	89-100
" " 3/8" "	94	86-100	89	81- 97	81- 97
" " # 4 "	70	62- 78	78	70- 86	70- 86
" " #10 "	54	46- 62	64	56- 72	56- 72
" " #40 "	26	19- 33	29	22- 36	22- 36
" " #200 "	4	1- 7	5	2- 8	2- 8
Percent A-R Bitumen		7.6%			6.9%
Marshall Stability (75 blows)		1454			1592
Marshall Flow		6.0			7.5
TM Marshall Density lbs/cu.ft.		138.6 lbs/cu.ft.			135.0
Percent of Voids (Rice)		4.0		7.0 @ 6.7% A-R	

2341M Wear: 20 % River Warren, 80% Barka Pit  
2331M Barka Pit

**Table 1. Trial Mix Data**

These recommendations were followed during construction of the westbound lane; the percent A-R bitumen was increased by 0.3% when the eastbound lane was constructed.

### IV. CONSTRUCTION

The A-R blending unit was provided by Arizona Refining Co. The rubber granules were delivered in 50 lb bags. The rubber was produced by Spartan (WT24) and Baker (WT20, WT16). The "WT" refers to the maximum sieve size for the granules. The specification required that 100% of the rubber pass the No. 8 sieve, which all met.

The bags were broken open and hand fed in the receiving hopper of the blending unit. The A-R batches contained 2,541 gallons of 120/150 Pen asphalt cement and ninety-eight 50 lb bags of rubber. With this mix, the amount of rubber in the A-R binder was 20.2% ; the specification required 20 %  $\pm$  3% rubber.

Since the project was not ready for the A-R research sections until

late in the paving season, the A-R blending was not commenced until a determination that the weather would be favorable for paving was made each morning. This limited production since 90-120 minutes were required to blend the materials, complete the asphalt-rubber reaction, and to reheat the A-R blend to 375 to 400 F before introduction into the plant. (The A-R specification prohibited the introduction of the A-R bitumen into the plant at a temperature below 350 F.) Two Bearcat distributors, also provided by Arizona Refining Co., were used to transport the A-R bitumen from the blending area to the working storage tank adjacent to the plant. This tank was insulated and equipped with heating coils. However, the capacity of the heater was not sufficient to maintain the A-R bitumen at the required temperature for an extended period. The storage tank therefore required discharging the A-R bitumen back into the distributors for return to the blender's tanks when delays stopped production.

The A-R mixture was placed with a Blaw-Knox PF 180 paver. Since pneumatic tired rollers cannot be used on A-R mixes, a steel wheeled vibratory roller was used for compaction. The first roller pass was performed in the vibratory mode with all remaining passes done in the static mode. "Ordinary Compaction" was specified for the A-R mixes. Ordinary Compaction requires compaction until there is no further evidence of consolidation and all roller marks are eliminated.

The A-R mixes were placed in late October. Periodic mix temperature checks indicated the mix temperatures were in the 350 to 370 F range at the plant. Temperatures behind the paver were in the 280 to 300 F range but cooled to 150F during compaction operations. Air temperatures were in the mid-50 to low-60 range during construction of the tests sites.

## **V. EVALUATION**

### **A. Cracking.**

Cracks were mapped in two 300' samples areas of Test Section 1 and Control Section 2 prior to overlay. These four sample areas as well as one 300' section for every other test section were monitored for cracking.

Results from the crack monitoring are displayed on Table 2. on the following page. The majority of the extensive cracking in the sampled sections in Test Section 1 and Control Section 1 appear to have at returned within five years after construction, with the exception of Control Section 1B. Test Sections 2 and 4 had no cracking after two years, but had begun to catch up to the amount of transverse cracking in Control Section 2 at the five year mark.

Test sections with AR wear, TS2 and TS3, have yet to display any longitudinal cracking as opposed to the reconstruct sections with

conventional wear, Test Section T4 and Control Section 2. The longitudinal cracking found in these sections is primarily at the centerline joint. The shortness of the AR wear sections and resulting shorter turn around time coupled with the higher AR mix temperatures probably provided for a warmer and thus better centerline joint. Considering the time of year, the centerline joint may have been quite cold for the conventional sections.

**LINEAL FEET OF CRACKING IN 300' OF ROADWAY**

	1984*		1985		1986		1989		1991	
	Tran	Long	Tran	Long	Tran	Long	Tran	Long	Tran	Long
TS 1 A	664	230	260	20	478	185	646	350	**	**
B	382	50	288	20	320	60	350	75	**	**
CS 1 A	598	645	164	0	338	70	450	150	**	**
B	360	785	0	0	0	0	192	220	**	**
TS 2	-	-	0	0	0	0	102	0	112	0
TS 3	-	-	0	0	24	0	192	0	204	0
TS 4	-	-	0	0	0	0	152	130	248	130
CS 2	-	-	0	0	76	0	200	300	283	300

\*= Prior to Overlay

\*\*= Much of cracking obliterated by chip seal.

Tran= Transverse; Long= Longitudinal

**Table 2. Crack Count Data.**

Factors such as the cement treated aggregate base; the bituminous base or in-place pavement; and the climate appear to have had a greater influence on the amount of cracking than the use of AR in the wear and binder courses.

**B. Resilient Modulus, Inplace Air Voids.**

Five years after construction, five cores were taken transversely across The eastbound lane of each test section. Resilient modulus (Mr), ASTM D4123, of each of the test and control section layers was determined using an MTS testing apparatus. Damage done due to the coring and sawing of samples precluded Mr testing on several samples.

In general, the Mr values exhibited by the A-R binder samples are lower, ie less stiff, than the conventional binder samples. This is most evident in the 1.5" overlay wear course and the 1.5" binder courses in the reconstruct sections. The samples from the 1" thick

### RESILIENT MODULUS vs. LOCATION

Wear Course, 1.5" Overlay Sections

T.H. 7 Cosmos to Cedar Mills

Resilient Modulus, ksi.

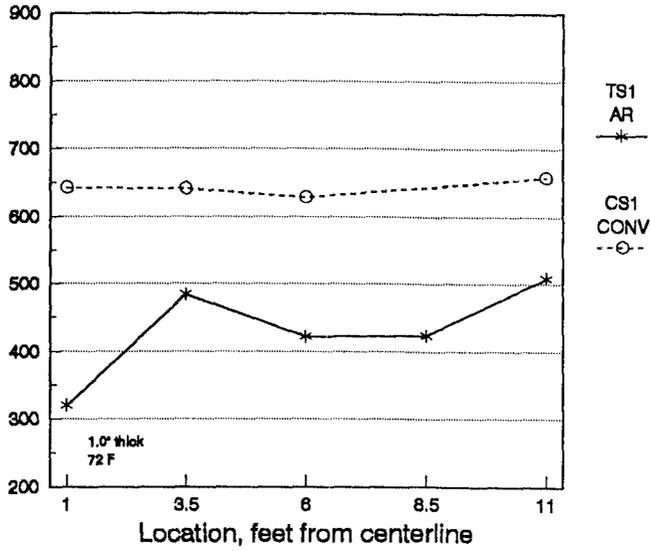


Figure 3. Resilient Modulus vs. Location  
Wear Course, 1.5" Overlay Sections

### INPLACE AIR VOIDS vs. LOCATION

Wear Course, 1.5" Overlay Sections

T.H. 7 Cosmos to Cedar Mills

Inplace Rice Voids (%)

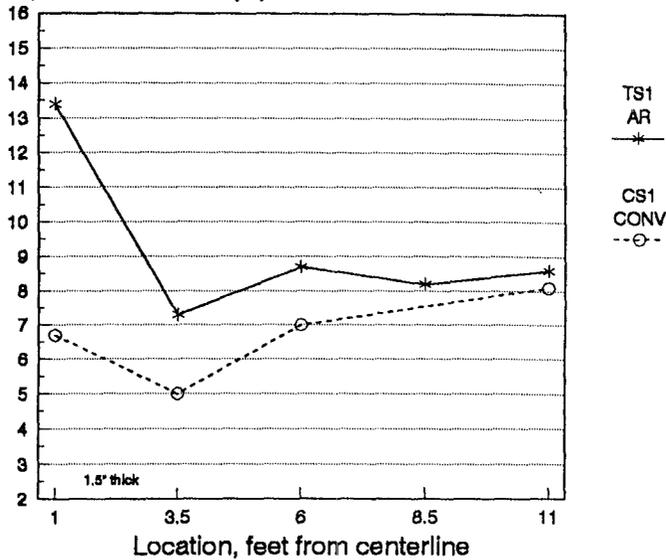


Figure 4. Air Voids vs. Location  
Wear Course, 1.5" Overlay Section

## RESILIENT MODULUS vs. LOCATION

Wear Course, Reconstruct Sections  
T.H. 7 Cosmos to Cedar Mills

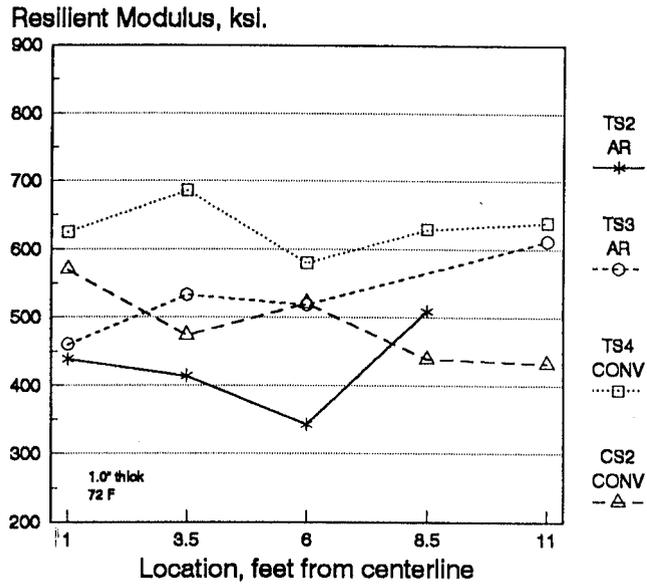


Figure 5. Resilient Modulus vs. Location  
Wear Course, Reconstruct Sections

## INPLACE AIR VOIDS vs. LOCATION

Wear Course, Reconstruct Sections  
T.H. 7 Cosmos to Cedar Mills

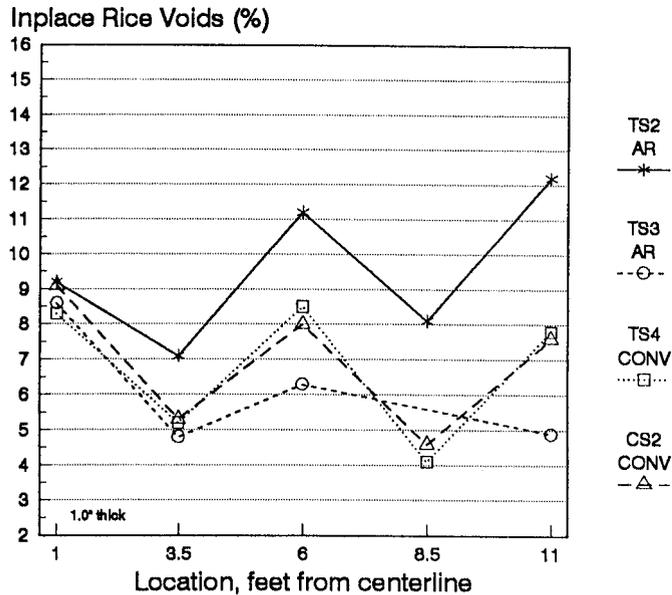


Figure 6. Air Voids vs. Location  
Wear Course, 1.5" Reconstruct Section

## RESILIENT MODULUS vs. LOCATION

Binder Course, Reconstruct Sections  
T.H. 7 Cosmos to Cedar Mills

Resilient Modulus, ksi.

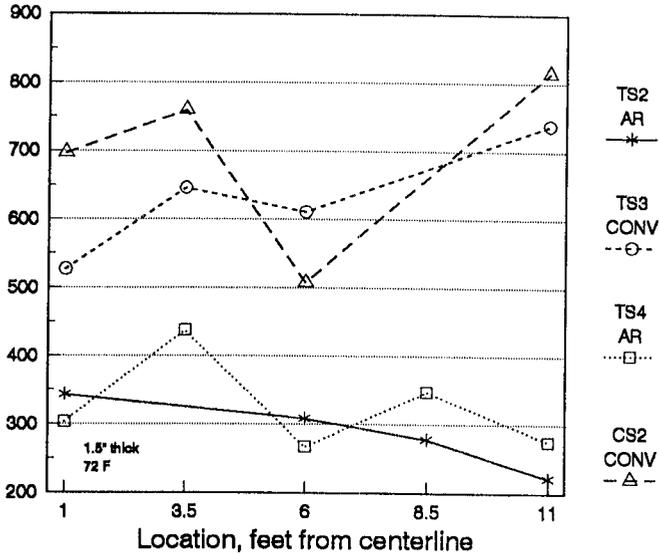


Figure 7. Resilient Modulus vs. Location  
Binder Course, Reconstruct Sections

## INPLACE AIR VOIDS vs. LOCATION

Binder Course, Reconstruct Sections  
T.H. 7 Cosmos to Cedar Mills

Inplace Rice Voids (%)

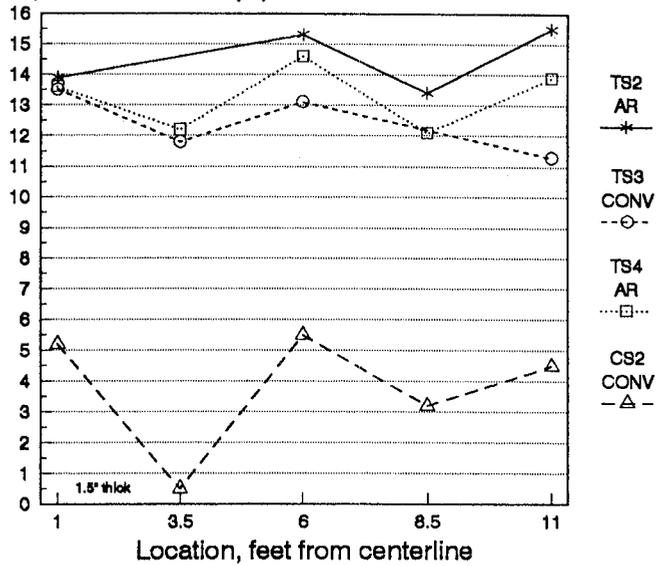
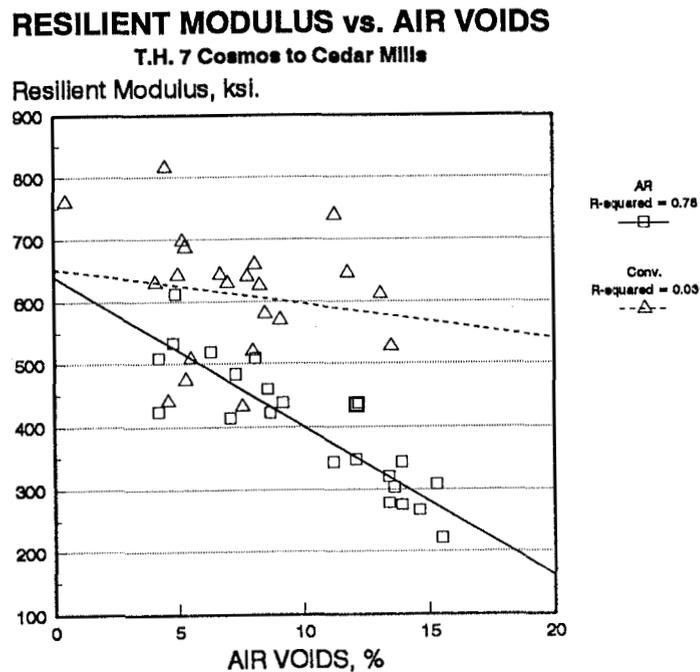


Figure 8. Air Voids vs. Location  
Binder Course, Reconstruct Section

wear course in the reconstruct sections follow this trend but the separation is less evident.

For the most part, the in-place air voids in the A-R samples were higher than the conventional mixes. This is probably due in part to the relatively higher temperatures desired for A-R construction not being maintained during late fall paving. It is worth noting that even with these high air void content no stripping was observed in either the AR or conventional materials. Also, the Marshal design procedure indicated more air voids for this mixture.

A plot of Mr vs. air voids reveals a fairly strong correlation between the two (R-squared= 0.78) for the A-R samples. See figure 9. No such relationship is seen for the conventional asphalt samples (R-squared= 0.03). It may be that oxidation has embrittled the plain asphalt cement to a point where the amount of air voids present no longer effects the Mr test. While the A-R samples react as one would expect for samples containing 5 to 15% voids; higher air void contents equate to lower Mr values with all other factors being equal.



**Figure 9. Resilient Modulus vs. Air Voids**

**C. Rutting and Roughness Measurements.**

Densification in the wheel paths is apparent in figures 4,6, and 8. Measurements of rutting and international roughness index (IRI) were taken in August of 1991 using a South Dakota Profilograph.

One hundred foot intervals throughout each test and control section were evaluated. The average rut depth and IRI for each one hundred foot interval is then reported. The results are shown in Table 3 below.

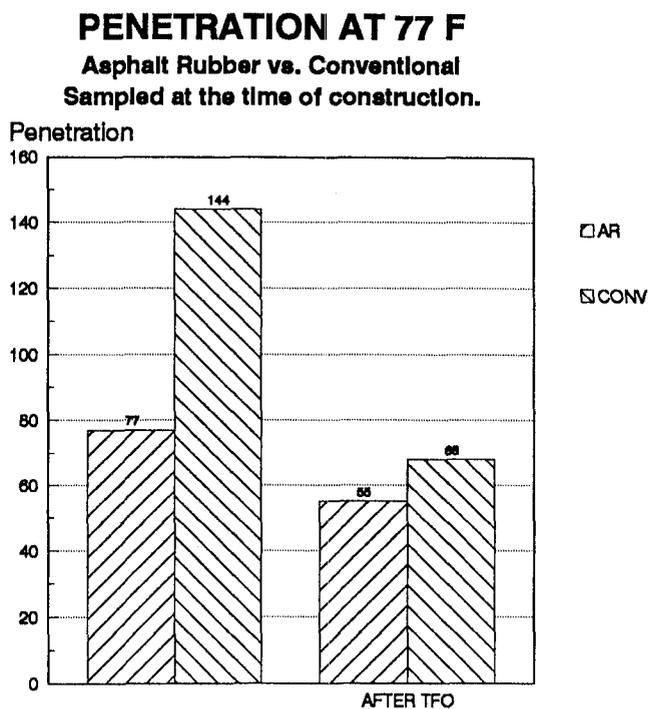
	Range of Rut Depth (inches)	Range of IRI (m/km)
Test Section 1	0.00 - 0.11	1.35 - 3.97
Control Section 1	0.00 - 0.15	1.16 - 3.83
Test Section 2	0.00 - 0.04	1.10 - 3.13
Test Section 3	0.00 - 0.15	1.42 - 2.61
Test Section 4	0.00 - 0.01	1.42 - 3.09
Control Section 2	0.00 - 0.02	1.47 - 2.49

**Table 3. Rut and Ride Data.**

None of the test or control sections exhibits significant amounts of rutting at this time. The international roughness index does not show any discernable difference between the test and control sections.

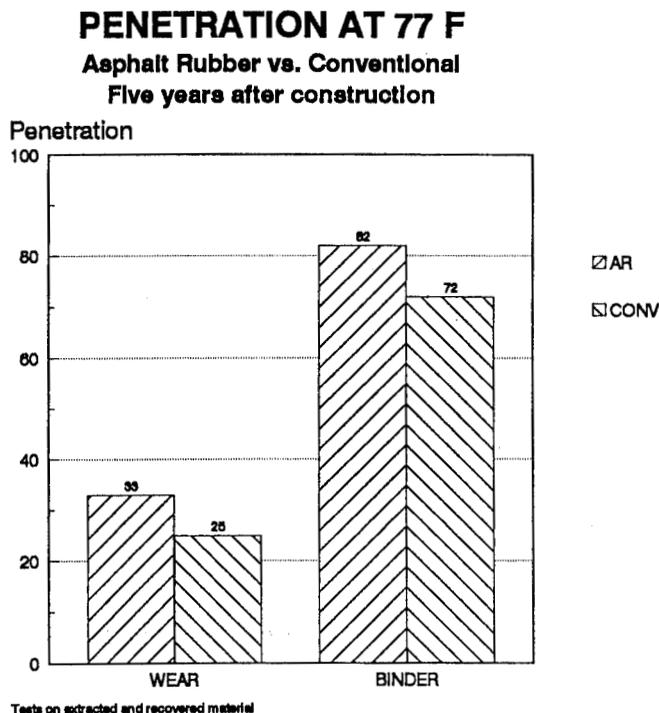
**C. Asphalt-Rubber vs. Asphalt Cement Binder.**

Samples of both the A-R and conventional asphalt were taken at the time of construction. Penetration test at 77 degrees F revealed the following:



**Figure 10. Penetration at time of construction.**

Test on samples after extraction and Abson recovery five years after construction gave the following results:



**Figure 11. Penetration five years after construction.**

On a percentage basis the AR material was less susceptible to thin film oven aging (TFO). The drop in penetration of the conventional material after TFO is not uncommon.

The five-year-old samples yielded slightly higher, ie softer, penetration values for the A-R samples than the conventional asphalt. Also, the binder layer materials were significantly softer than the exposed wear course materials in both cases. Considering the oxidation one would expect to occur, this is not surprising.

Solvents used for the extraction and Abson recovery of the samples may dissolved portion of the rubber in the A-R material. Therefore, it is difficult to speculate on the accuracy of these results.

#### D. Cost.

Since the conventional 2331 mixes contained recycled asphalt pavement, only a cost comparison of the 2341 wear course will be made. Average costs per ton were:

A-R mixes	\$56.58 / ton
Conventional mix	\$23.27 / ton

There are several possible reasons for this large disparity:

1. The prices were negotiated under a supplemental agreement to an existing contract. Prices are therefore higher than would be expected if the asphalt-rubber items had been included in the original contract let for bid.
2. The system includes use of patent equipment and procedures available only from two companies at the time, both of which were located in Arizona. Presently only one of these two outlets is in business.
3. Reclaimed rubber was not available within Minnesota.
4. Only a small portion of the project contained the experimental material.
5. Unfamiliarity of local contractors with the material.

One benefit is the reuse of discarded tires. Assuming 20 lbs of reclaimed rubber per tire, this project cost \$4.29 per tire consumed. With present "tipping" fees at \$1.00 per tire, this concept could not be funded at these prices with the present disposal fee structure.

#### VI. CONCLUSIONS.

1. Construction of an asphalt-rubber dense graded asphalt concrete requires some special effort and specialized equipment to maintain adequate mixing and placing temperatures.
2. Factors such as the cement treated aggregate base; the bituminous base or in-place pavement; and the climate appear to have had a greater influence on the amount of cracking than the use of AR instead of plain asphalt in the wear and binder courses.
3. In general, the A-R pavement samples exhibited lower resilient moduli than samples containing conventional asphalt. The A-R samples tended to display higher air void contents than samples from conventional sections. One might expect inordinate amounts of oxidation at such high air void levels. However, even at

these high air void contents the AR samples do not display embrittlement in terms of their resilient modulus values.

4. As measured by the air void and density content of core samples, densification in the wheel tracks is present in both A-R and conventional sections. However, significant amounts of rutting ( > 0.15" ) are not present in any of the sections.
5. International roughness index revealed no discernable difference between the AR and conventional sections.
6. Penetration values for the extracted and recovered AR were slightly higher than for the conventional asphalt. These results are suspect due to the solvents used and their potential reactions with the rubber in the AR.
7. The formulation of asphalt-rubber used provided little or no perceived benefits to the roadway at much higher costs. The high costs were due in part to the nature of the project. However, this appears to be a cumbersome and expensive procedure with the primary benefit being waste tire utilization. The inconclusive benefits to the roadway of the A-R material do not justify the 140+% increase in cost.

## VII. RECOMMENDATIONS

The sections should continue to be monitored. Especially with respect to probable hot recycling of the material.

Further construction of sections of this type is not recommended. However, the product has purportedly been reformulated using a softer/higher penetration asphalt cement as its base material. If future sections are constructed, outside variables such as the cement treated base and the recycled asphalt base should be minimized to facilitate a more direct comparison. Also, better density controls should be in place during construction.



## **APPENDIX**

Note: If a value has been left blank the sample was damaged and the test could not be run.



**TEST SECTION 1. AR WEAR COURSE**

	Core Distance From Centerline				
	1'	3.5'	6'	8.5'	11'
DENSITY	128.7	137.8	135.8	136.4	135.8
AIR VOIDS	13.4	7.3	8.7	4.2	4.2
M <sub>R</sub>	320	484	422	424	509

Density is bulk density in lbs/ft<sup>3</sup>.  
 Air Voids is in place air voids in percent.  
 M<sub>R</sub> at 72°F in ksi.

**CONTROL SECTION 1. CONVENTIONAL WEAR COURSE**

	Core Distance From Centerline				
	1'	3.5'	6'	8.5'	11'
DENSITY	140.2	142.8	139.2		138.1
AIR VOIDS	6.7	5.0	7.0		4.2
M <sub>R</sub>	643	642	629		659

Density is bulk density in lbs/ft<sup>3</sup>  
 Air Voids in percent  
 M<sub>R</sub> at 72°F in ksi.

**TEST SECTION 2. AR WEAR COURSE**

	Core Distance From Centerline				
	1'	3.5'	6'	8.5'	11'
DENSITY	135.0	138.1	132.0	136.6	130.5
AIR VOIDS	9.2	7.1	11.2	8.1	12.2
M <sub>R</sub>	438	414	343	509	

Density is bulk density in lbs/ft<sup>3</sup>  
 Air Voids in percent  
 M<sub>R</sub> at 72°F in ksi.

**TEST SECTION 2. AR BINDER COURSE**

	Core Distance From Centerline				
	1'	3.5'	6'	8.5'	11'
DENSITY	129.1		127.0	129.8	126.7
AIR VOIDS	13.9		15.3	13.4	15.5
M <sub>R</sub>	343		308	278	222

Density is bulk density in lbs/ft<sup>3</sup>  
 Air Voids in percent  
 M<sub>R</sub> at 72°F in ksi.

**TEST SECTION 3. AR WEAR COURSE**

	Core Distance From Centerline				
	1'	3.5'	6'	8.5'	11'
DENSITY	135.8	141.5	139.3		141.4
AIR VOIDS	8.6	4.8	6.3		4.9
M <sub>R</sub>	460	533	519		612

Density is bulk density in lbs/ft<sup>3</sup>  
 Air Voids in percent  
 M<sub>R</sub> at 72°F in ksi.

**TEST SECTION 3. CONVENTIONAL BINDER COURSE**

	Core Distance From Centerline				
	1'	3.5'	6'	8.5'	11'
DENSITY	132.6	135.2	133.3		136.1
AIR VOIDS	13.5	11.8	13.1		11.3
M <sub>R</sub>	527	645	611		738

Density is bulk density in lbs/ft<sup>3</sup>  
 Air Voids in percent  
 M<sub>R</sub> at 72°F in ksi.

**TEST SECTION 4. CONVENTIONAL WEAR COURSE**

	Core Distance From Centerline				
	1'	3.5'	6'	8.5'	11'
DENSITY	137.8	142.4	137.6	142.0	138.6
AIR VOIDS	8.3	5.2	8.5	4.1	7.8
M <sub>R</sub>	625	686	580	628	638

Density is bulk density in lbs/ft<sup>3</sup>  
 Air Voids in percent  
 M<sub>R</sub> at 72°F in ksi.

**TEST SECTION 4. AR BINDER COURSE**

	Core Distance From Centerline				
	1'	3.5'	6'	8.5'	11'
DENSITY	129.6	131.6	128.0	131.8	129.1
AIR VOIDS	13.6	12.2	14.6	12.1	13.9
M <sub>R</sub>	304	438	267	347	275

Density is bulk density in lbs/ft<sup>3</sup>  
 Air Voids in percent  
 M<sub>R</sub> at 72°F in ksi.

**CONTROL SECTION 2. CONVENTIONAL BINDER COURSE**

	Core Distance From Centerline				
	1'	3.5'	6'	8.5'	11'
DENSITY	136.6	142.2	138.2	143.3	138.8
AIR VOIDS	9.1	5.3	8.0	4.6	7.6
M <sub>R</sub>	570	474	521	440	432

Density is bulk density in lbs/ft<sup>3</sup>  
 Air Voids in percent  
 M<sub>R</sub> at 72°F in ksi.

**CONTROL SECTION 2. CONVENTIONAL BINDER COURSE**

	Core Distance From Centerline				
	1'	3.5'	6'	8.5'	11'
DENSITY	145.5	152.6	144.9	148.5	146.5
AIR VOIDS	5.2	0.5	5.5	3.2	4.5
M <sub>R</sub>	697	760	508		815

Density is bulk density in lbs/ft<sup>3</sup>  
 Air Voids in percent  
 M<sub>R</sub> at 72°F in ksi.







