SCHOOL OF
CIVIL ENGINEERING

INDIANA

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JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP/92/14 - 1

Final Report

POTENTIAL USE OF TIRE RUBBER
AND EBONITE IN ASPHALT

Abidin Kaya

PURDUE UNIVERSITY

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP/92/14 - 1

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AND EBONITE IN ASPHALT

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FINAL REBORT

Synthesis Study

POTENTIAL USE OF TIRE RUBBER AND EBONITE IN ASPHALT

by

Abidin Kaya

Joint Highway Research Project
Project No.: C-36-50M
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Prepared as Part of an Investigation
conducted by the
Joint Highway Research Project
Engineering Experiment Station
Purdue University

In Cooperation with the
Indiana Department Transportation
and the
U.S Department of Transportation
Federal Highway administration

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 not necessarily reflect the official views or policies of the Federal Highway Administration. This Report does not constitute a standard, specification, or regulation.

School of Civil Engineering
Purdue University
West Lafayette, Indiana 47907

July 1992

FINAL REPORT

Synthesis Study

POTENTIAL USE OF TIRE RUBBER AND EBONITE IN ASPHALT

To: Vincent Drnevich, Director
Joint Highway Research Project

July, 1992
Project No: C-36-50M
File No: 2-4-38

From: L.E. Wood
Professor of Civil Engineering
Purdue University
West Lafayette, Indiana

Subj: Synthesis Study on the "Potential Use of Tire Rubber and Ebonite in Asphalt"

Attached is the final report on the subject study. The study has been performed by Abidin Kaya, Graduate Research Assistant, under my direction.

This study will be useful in determining physical properties of rubber-asphalt mixes; problems which may be associated with rubber-asphalt mixes; and experiences of other states with rubber-asphalt mixes. The recommendations help INDOT define the technical, economic and environmental feasibility of rubber-asphalt mixes. The report also summarizes knowledge of ebonite as a possible asphalt additive.

The report is submitted for review, comment, and acceptance in fulfillment of the referenced study.

Respectfully Submitted

L.E. Wood

cc:

A.G. Alschaeffl
D. Andrews
P.L. Bourdeau
M.D. Bowman
M.J. Cassidy
L.M. Chang
S. Dimond
J.J. Dillon
W.L. Dolch
V.P. Drnevich

A.R. Fendric
J.D. Fricker
D.W. Halpin
K.R. Hoover
R.H. Lee
C.W. Lovell
R.H. Lowry
D.W. Lucas
B.G. McCullouch
B.K. Patridge

J.A. Ramirez
G.J. Rorbakken
C.F. Scholer
G.B. Shoener
K.C. Sinha
D.L. Tolbert
C.A. Venable
T.D. White
J.R. Wright
R.F. Wukasch

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16. Abstract <p>This report evaluates effectiveness of rubber-asphalt and ebonite-asphalt mixes based on a review of published literature, and unpublished reports. It discusses in detail various aspects of these mixes, including: different applications, physical properties, experiences of state highway agencies, and claimed advantages and problems associated with their use.</p> <p>Although rubber-asphalt mixes have superior physical properties, they have performed either only slightly better or equal to conventional asphalt mixes in the field. The salient problems associated with rubber asphalt mixes which restrict their use are: stickiness, high cost, and air pollution. The cost of rubber-asphalt mixes is much higher than conventional asphalts, and there is little evidence that rubber-asphalt mixes will have an increased service life sufficient to justify the high costs.</p> <p>Ebonite-asphaltic mixes have possible applications assuming that the ebonite can be economically cleaned of lead contamination.</p>			
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TABLE OF CONTENTS

Table of Contents	iii
List of Tables	v
List of Figures	vi
List of Abbreviations	vii
Abstract	viii
 1. INTRODUCTION	 1
1.1 Background	1
1.2 Objectives	4
1.3 Research Approach	4
 2. USE OF GROUND TIRE RUBBER IN ASPHALT MIXES	 5
2.1 Joint-Crack Sealant	5
2.2 Rubber-Asphalt Chip Seal	6
2.3 Rubber-Asphalt Stress Absorbing Membrane(SAM)	6
2.4 Rubber-Asphalt Stress Absorbing Membrane Interlayer (SAMI)	7
2.5 Rubber-Asphalt Concrete	8
2.5 Rubber Modified Asphalt Hot Mix (HMA)	9
 3. PHYSICAL PROPERTIES OF RUBBER ASPHALT MIXES	 10
3.1 Viscosity	10
3.2 Fatigue Resistance	16
3.3 Voids Concepts	20
3.4 Elastic Recovery	23
3.5 Rubber Types	23
 4. EXPERIENCES OF STATES WITH RUBBER ASPHALT MIXES	 27
4.1 Connecticut	27
4.1.1 Thick Overlays	27
4.1.2 Thin Overlays	28
4.1.3 Chip Seals	28
4.1.4 Surface Relieving Interlayers (SRI)	29
4.1.5 Rubber-Asphalt Joint Seals	29
4.2 Florida	29
4.3 Michigan	30
4.4 Minnesota	31
4.5 New York	31
4.5.1 Albany County Project	32

4.5.2 Delaware County Project	32
4.6 Pennsylvania	34
4.7 Washington	34
4.7.1 Rubber-Asphalt Open-Graded Friction Course	35
4.7.2 Rubber-Asphalt Binder Stress Absorbing Membrane Interlayer	35
4.7.3 PlusRide Asphalt and Concrete Pavement	36
5. EVALUATION OF THE CLAIMED ADVANTAGES OF RUBBER ASPHALT MIXES	37
5.1 Increased Skid Resistance	38
5.2 Deicing	38
5.3 Reduced Noise Level	39
5.4 Decreased Stopping Distance	40
5.5 Greater Durability	40
5.6 Reduced Reflective and Thermal Cracking	41
6. PROBLEMS ASSOCIATED WITH RUBBER ASPHALT MIXES	42
6.1 Environmental Problems	42
6.2 Stickiness	43
6.3 Cost	43
6.4 Availability	43
7. USE OF EBONITE IN ASPHALT PAVEMENT	46
8. DISCUSSION	49
9. CONCLUSIONS	53
10. RECOMMENDATIONS	55
11. REFERENCES CITED	56

LIST OF TABLES

Table 1.	Classification of Rubber-Asphalt Mixes	3
Table 2.	ASTM Requirements for Viscosity Graded Asphalt Cements (D 3381-83)	11
Table 3.	Consistency Temperature Characteristics of Asphalt Rubber Material	14
Table 4.	Bid Price Relationship for Modified Rubber Asphalt Mixes Compared to Conventional Asphalt Mix	33

LIST OF FIGURES

Figure 1.	Temperature Susceptibility of Viscosity Graded Asphalt Cements	12
Figure 2.	The Effect of Coarse Crumb Rubber on Viscosity and Devulcanized Rubber on Viscosity	15
Figure 3a.	Effect of Coarse Crumb Rubber on Viscosity with Increase of Time	17
Figure 3b.	Effect of Fine Crumb Rubber on Viscosity with Increase of Time	17
Figure 4.	Effect of Digestion Time on Viscosity of Asphalt-Rubber Mix	18
Figure 5a.	Laboratory Fatigue Curves at -6 °C	19
Figure 5b.	Laboratory Fatigue Curves at 10 °C	19
Figure 6a.	Mean Resilient Modulus for a 0.05-Second Load Time of Various for Different Rubber Content	21
Figure 6b.	Mean Resilient Modulus for a 0.10-Second Load Time of Various for Different Rubber Content	21
Figure 7.	Effect of Rubber Content Variations on Percent Voids in Mix	22
Figure 8.	Effect of Time and Temperature of Digestion on Elastic Recovery for Natural Rubber Tire Buffings	24
Figure 9.	Effect of Particle Size on Elastic Recovery for Tire Retarder's Buffings	26
Figure 10.	Grain Size Distribution of Ebonite Samples	48

LIST of ABBREVIATIONS

ADOT	Arizona Department of Transportation
ADOTPF	Alaska Department of Transportation and Public Facilities
ASTM	American Society for Testing and Materials
°C	Celsius Centigrade
Caltrans	California State Department of Transportation
ConnDOT	Connecticut Department of Transportation
CRA	Crumb Rubber Additive
CRM	Crumb Rubber Modifier
dB	Decibel
DOT	Department of Transportation
FDOT	Florida Department of Transportation
EPA	Environmental Protection Agency
°F	Degree Fahrenheit
Ft	Foot/Feet
HMA	Hot Mix Asphalt
INDOT	Indiana Department of Transportation
MDOT	Michigan Department of Transportation
MnDOT	Minnesota Department of Transportation
NYSDOT	New York State Department of Transportation
SAM	Stress Absorbing Membrane
SAMI	Stress Absorbing Membrane Interlayer
SDHPT	Texas State Department of Highways and Public Transportation
SRI	Stress Relieving Interlayers
US	United States
WSDOT	Washington State Department of Transportation

ABSTRACT

This report evaluates the effectiveness of rubber-asphalt and ebonite-asphalt mixes based on a review of published literature and unpublished reports. It discusses in detail various aspects of these mixes, including: different applications, physical properties, experiences of state highway agencies, and claimed advantages and problems associated with their use.

The addition of ground tire rubber in asphalt significantly changes the physical properties of the mix. In general, physical properties, i.e., viscosity, elastic recovery, fatigue life, of rubber-asphalt mixes are much better than those of conventional asphalt.

Although rubber-asphalt mixes have superior physical properties, they have performed either only slightly better or equal to conventional asphalt mixes in the field. The salient problems associated with rubber asphalt mixes which restrict their use are: stickiness, high cost, and air pollution. The cost of rubber-asphalt mixes is much higher than conventional asphalts, and there is little evidence that rubber-asphalt mixes will have an increased service life sufficient to justify the high costs.

Based on the experiences of most of the states, it is recommended that use of rubber-asphalt mixes not be encouraged until INDOT acquires first hand results from pilot projects.

Ebonite-asphaltic mixes have possible applications assuming that the ebonite can be economically cleaned of lead contamination.

SECTION 1

INTRODUCTION

1.1 Background

Disposal of waste tires is becoming an increasingly serious problem, with large stockpiles all over the country. Current estimates by the Environmental Protection Agency (EPA) indicate that over 242 million scrap tires are generated each year in the U.S.

It is estimated that approximately 5 million waste tires are generated annually in the state of Indiana, with 40 stockpiles containing million of tires in different counties (Lovell et al., 1992).

Tires are made with 30 different kinds of rubber and each portion of the tire has a different formulation or rubber, both natural and synthetic. The composition of tire rubbers them bulky, resilient, compaction resistant and non-biodegradable since rubber is combustible with a high energy output. Therefore, scrap tire piles pose two significant threats to the public: fire hazards, and health hazards.

The use of tire rubber as an additive in asphalt pavement mixes has been proposed to recycle the rubber and preserve natural sources. Pilot projects have been developed to evaluate the effectiveness of rubber-asphalt by 45 of the 50 states in the U.S. since 1960. In this regard, the Indiana Department of Transportation (INDOT) has constructed two test section to evaluate the effectiveness of rubber-asphalt mixes since 1990. One project, on SR-18 west of US-31 (in the east bound lanes) was constructed in 1991 of four different combinations of rubber modified

asphalt (1 to 3% rubber in asphalt by weight). An earlier project (1990) on I-465 near the Indianapolis airport used asphalt rubber and six other additives or modifiers. INDOT has also experimented with rubberized asphalt crack sealants. It is too soon to draw any conclusions based on current performance.

Although many states have been involved with rubber-asphalt mixes, only a few have been totally satisfied with rubber asphalt mixes.

In general, the addition of crumb rubber to asphalt can be divided into two categories: wet process and dry process. The wet process blends the crumb rubber with hot asphalt cement prior to incorporating the binder into the project. This binder can contain as much as 30% crumb rubber additive (CRA), (Ahmed, 1991). In dry process, the crumb rubber is mixed with the aggregate before mixture is charged with asphalt. When dry process is used, the crumb rubber acts as an aggregate substitute. This process is called rubber modified asphalt and generally contains an average of 3% (1 to 5%) rubber by weight in asphalt.

From the literature, it seems that the definition of rubber asphalt mixes is not clear. Different researchers use different definitions for different combination of rubber asphalt mix. For example, Asphalt-rubber has been defined by ASTM D-8 as:

"a blend of asphalt cement, reclaimed tire rubber and certain additives in which the rubber component is at least 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles."

The blend is typically formulated at elevated temperatures to promote chemical and physical interaction of the two constituents. Various petroleum distillates are sometimes added

to the blend to reduce viscosity and enhance workability (Estakhri et al., 1992).

In most of the cases, regardless of the amount of rubber in the asphalt, the mix is called rubber-asphalt, asphalt-rubber, rubberized asphalt or rubber modified asphalt. Although definition is not the primary aim of this work, it is appropriate to clarify them.

Regardless of the amount of rubber in the mix or binder, in the definition term rubber will be the adjective and modify asphalt as the noun. Herein, it is suggested that "rubber-asphalt mix" be the generic term regardless the amount of the rubber in mix or binder. "Asphalt rubber" denotes a binder which contains 15-30% rubber by weight. "Rubber modified asphalt" shall be used for combinations of aggregate and asphalt that contain up to 3% rubber. "Rubberized asphalt" shall be used for binder which contain rubber amounts between 3 and 15%. In this report, all rubber-asphalt mixes will be so defined. The classification is summarized in Table 1.

Table 1. Classification of Rubber-Asphalt Mixes

<u>Rubber Content</u>	<u>Classification</u>
0 to 5% (in the mix)	Rubber Modified Asphalt
5 to 15% (in the binder)	Rubberized Asphalt
15% and over (in the binder)	Asphalt Rubber

1.2 Objectives

Senate Bill 209 in 1991 directed the Indiana Department of Transportation to explicitly study the use of ground tire rubber and ebonite in asphalt. In this regard, to evaluate the effectiveness of rubber-asphalt and ebonite-asphalt mixes, research was initiated to synthesize all existing information on both mixes based on published and unpublished literature.

1.3 Research Approach

In order to accomplish the stated objectives the following items were included:

- Review all available published literature and unpublished reports on rubber-asphalt and ebonite-asphalt mixes.
- Communicate personally with other state transportation agencies to learn their experiences and recommendations.
- Synthesize of the information that most fits the study objectives.
- Report recommendations to the INDOT.

SECTION 2

USE OF GROUND TIRE RUBBER IN ASPHALT MIXES

Rubber-asphalt mixes have been used for the following applications:

- Rubber-asphalt joint/crack sealant
- Rubber-asphalt chip seal
- Rubber-asphalt stress absorbing membrane (SAM)
- Rubber-asphalt stress absorbing membrane interlayer (SAMI)
- Rubber-asphalt concrete
- Rubber-asphalt concrete or modified asphalt hot mix

2.1 Joint-Crack Sealant

Perhaps the most common use of rubber and asphalt is as a joint/crack sealant which contains 15-30% crumb rubber with the asphalt cement. However, the use of the tire rubber in crack sealants is not high in volume.

There are several factors that affect the performance of joint/crack sealants. The choice of a sealant should take into account the pavement, type of crack or joint, shape/size of the crack or joint, time before next scheduled major rehabilitation, traffic volume, degree of pavement distress, and maximum/minimum temperatures (Estakhri et al., 1992).

Although Roberts et al. (1989) reported that there is a trend away from using tire rubber in crack fillers, Texas State Department of Highways and Public Transportation (SDHPT)

accepts a slightly wider variety of products. This allows other suppliers to enter the market.

2.2 Rubber-Asphalt Chip Seal

The Arizona Department of Transportation (ADOT) has stated that although such rubber-asphalt mixes are initially more expensive than the conventional chip seal, in the long run this material turns out to be economical. This is due to reduced maintenance and an increased life time (Schnormeier, 1983). Supporting evidence comes from other southern states, viz, Texas, Florida (Estakhri et al., 1992, and Roberts et al., 1989).

2.3 Rubber-Asphalt Stress Absorbing Membrane (SAM)

A surface treatment using an asphalt-rubber spray application is called a "Stress Absorbing Membrane" (SAM). The purpose of a SAM is to seal the underlying cracks and prevent the entry of surface water into the pavement structure. Heitzman (1992) indicated that SAM's can not resist the amount of strain that is typical of major transverse thermal cracks in asphalt concrete pavements or contraction joints in portland cement concrete pavements. SAM's can resist and delay development of reflective cracks only when the cracks are inactive.

The amount of crumb rubber additive in binder is between 20-30% by weight of asphalt cement. In general, the thickness of application is between 3/8 and 5/8 in. or 0.5 to 0.65 gallons per square yard of binder is applied to the surface (Singh and Athay, 1983).

Some states (Arizona, Texas, California) had good experiences with SAM's, whereas others (Pennsylvania, Connecticut, Minnesota) reported that SAM's perform the same as conventional asphalt although the costs are twice as much as conventional asphalt (Schnormeier, 1986, Estakhri et al., 1992, Kirk, 1992, Mellot, 1989, Stephens, 1989).

2.4 Rubber-Asphalt Stress Absorbing Membrane Interlayer (SAMI)

A Stress Absorbing Membrane Interlayer (SAMI) is a layer of rubber-asphalt sandwiched between the existing pavement and an overlay. SAMI's were developed by the Arizona DOT in 1975 (Schnormeier, 1983). The difference between a SAMI and a SAM is that a SAMI has an overlay whereas a SAM does not. The purpose of a SAMI is to act as a barrier to crack propagation from cracks in the underlying layers. In general, SAMI is used when a pavement shows sign of significant fatigue cracks (Singh and Athay, 1983).

There are two-layer SAMI's and three-layer SAMI's. A two layer SAMI places the SAMI on the existing pavement and overlays the SAMI with 1 to 3 inches of hot mix asphalt (HMA). A three-layer SAMI begins with the placement of a leveling course of HMA. The SAMI is followed by an additional 1 to 3 inches of HMA. A three-layer SAMI is applied when there is deterioration of existing pavement cracks and joints (Heitzman, 1992).

It has been indicated that this type of interlayer is very effective in reducing stress concentrations above existing joints and cracks, and in retarding or eliminating reflection cracking due to thermal expansion or contraction of the underlying rigid pavement. Delaying reflective cracking is the primary benefit of a SAMI.

In general, a SAMI is used when a pavement shows sign of significant fatigue cracks (Singh and Athay, 1983). Several states have reported that SAMI's performed many times better than conventional asphalt and are cost effective (Schnormeier, 1992). Other states reported SAMI's perform only slightly better or the same as conventional asphalt and double the cost. Some states (Arizona, Florida) reported that SAMI's are cost effective because they require less to maintain than conventional asphalt chip seals. However, comparison is often not possible because most of the projects did not have conventional asphalt control sections.

2.5 Rubber-Asphalt Concrete

Finely ground rubber tire particles may be mixed into the hot asphalt cement to create a rubberized asphalt binder. This binder is then added to a normal gradation of paving aggregate. This type of modification is called rubber-asphalt concrete. The rubber particles are smaller than those used in rubber modified asphalt. Generally, the rubber content in the binder is 25 to 30% by weight. The California Department of Transportation (Caltrans) has been using rubber-asphalt concrete extensively for more than ten years (Kirk, 1992). It is reported that rubber-asphalt concrete is more durable and more abrasion resistant, than a conventional dense asphalt concrete hot mix. After evaluating several projects with different thicknesses, Caltrans reported that the cost of rubber-asphalt concrete is 40% to 100% over conventional asphalt concrete. Although rubber-asphalt concrete costs 40% to 100% more than conventional asphalt, Caltrans avers that rubber-asphalt concrete is cost effective because costs to maintenance are less.

2.6 Rubber Modified Asphalt Hot Mix (HMA)

Rubber modified asphalt hot mix was introduced by European engineers to increase skid resistance in the late 1960s (Esch, 1984, Eaton et al., 1991). Rubber modified asphalt hot mix was marketed by Swedish companies under the trade name of "Rubit". In the United States it was patented under the trade name of "PlusRide" in the 1970s.

The rubber contents range from 1 to 5% by weight of the mix, but in general 3% rubber is added to the hot mix to replace some of the aggregates. Larger rubber particles, 1/16 up to 3/8 in., are used as compared to the particles used in the asphalt rubber concrete. The larger rubber particles are thought to act as elastic aggregates that flex on the pavement surface under traffic and contribute to ice disbanding (Eaton et al, 1991).

SECTION 3

PHYSICAL PROPERTIES OF RUBBER ASPHALT MIXES

3.1 Viscosity

Viscosity at any given temperature and shear rate is essentially the ratio of shear stress to shear strain. At high temperatures (i.e., 275 °F) asphalt cements behave as simple Newtonian liquids, whereas at low temperatures asphalt cements behave like non-Newtonian liquids. This is due to the fact that at high temperatures the ratio of shear stress to shear strain is constant, however, this ratio is not constant at low temperatures (Roberts and et al., 1991).

Standard ASTM test procedures require measurement of the viscosity of asphalt cement at 140 °F (ASTM D2171) and 275 °F (ASTM D2170) by using a capillarity viscometer. The standard units of measurement for viscosity are the poise and centistoke; the lower the number of poises or centistokes, the less viscous is the material. Table 2 presents ASTM requirements for viscosity graded asphalt cement.

The temperature susceptibility of an asphalt is an indicator of potential construction and performance problems. Highly temperature-susceptible asphalts are associated with "tender" pavements during construction and with increased low temperature cracking and high temperature rutting after construction (Diringer and Smith, 1985). The Temperature susceptibility of viscous graded asphalt cements is presented in Figure 1.

Huff and Vallerga (1981) carried out research to test physical properties of rubber-asphalt mixes. The tests were performed on AR-4000 asphalt and AR-4000 blended with the extender oil and ground rubber. Table 3 presents the test results. It can be concluded that the influence

Table 2. ASTM Requirements for Viscosity Graded Asphalt Cements (D 3381-83) (After Roberts et al., 1991).

Note—Grading based on original asphalt.

Test	Viscosity Grade				
	AC-2.5	AC-5	AC-10	AC-20	AC-40
Viscosity, 140°F (60°C), P	250 ± 50	500 ± 100	1000 ± 200	2000 ± 400	4000 ± 800
Viscosity, 275°F (135°C), min. cSt	80	110	150	210	300
Penetration, 77°F (25°C), 100 g, 5 s, min	200	120	70	40	20
Flash point, Cleveland open cup, min. °F (°C)	325 (163)	350 (177)	425 (219)	450 (232)	450 (232)
Solubility in trichloroethylene, min. %	99.0	99.0	99.0	99.0	99.0
Tests on residue from thin-film oven test:					
Viscosity, 140°F (60°C), max. P	1250	2500	5000	10 000	20 000
Ductility, 77°F (25°C), 5 cm/min, min. cm	100 ^a	100	50	20	10

^a If ductility is less than 100, material will be accepted if ductility at 60°F (15.5°C) is 100 minimum at a pull rate of 5 cm/min.

TABLE 2 Requirements for Asphalt Cement Viscosity Graded at 140°F (60°C)

Note—Grading based on original asphalt.

Test	Viscosity Grade				
	AC-2.5	AC-5	AC-10	AC-20	AC-40
Viscosity, 140°F (60°C), P	250 ± 50	500 ± 100	1000 ± 200	2000 ± 400	4000 ± 800
Viscosity, 275°F (135°C), min. cSt	125	175	250	300	400
Penetration, 77°F (25°C), 100 g, 5 s, min	220	140	80	50	40
Flash point, Cleveland open cup, min. °F (°C)	325 (163)	350 (177)	425 (219)	450 (232)	450 (232)
Solubility in trichloroethylene, min. %	99.0	99.0	99.0	99.0	99.0
Tests on residue from thin-film oven test:					
Viscosity, 140°F (60°C), max. P	1250	2500	5000	10 000	20 000
Ductility, 77°F (25°C), 5 cm/min, min. cm	100 ^a	100	75	40	25

^a If ductility is less than 100, material will be accepted if ductility at 60°F (15.5°C) is 100 minimum at a pull rate of 5 cm/min.

TABLE 3 Requirements for Asphalt Cement Viscosity Graded at 140°F (60°C)

Note—Grading based on residue from rolling thin-film oven test.

Tests on Residue from Rolling Thin-Film Oven Test:^a

Test	Viscosity Grade				
	AR-1000	AR-2000	AR-4000	AR-8000	AR-16000
Viscosity, 140°F (60°C), P	1000 ± 250	2000 ± 500	4000 ± 1000	8000 ± 2000	16000 ± 4000
Viscosity, 275°F (135°C), min. cSt	140	200	275	400	550
Penetration, 77°F (25°C), 100 g, 5 s, min	65	40	25	20	20
% of original penetration, 77°F (25°C), min	...	40	45	50	52
Ductility, 77°F (25°C), 5 cm/min, min. cm	100 ^b	100 ^b	75	75	75
Tests on original asphalt:					
Flash point, Cleveland open cup, min. °F (°C)	400 (205)	425 (219)	440 (227)	450 (232)	450 (238)
Solubility in trichloroethylene, min. %	99.0	99.0	99.0	99.0	99.0

^a Thin-film oven test may be used but the rolling thin-film oven test shall be the referee method.

^b If ductility is less than 100, material will be accepted if ductility at 60°F (15.5°C) is 100 minimum at a pull rate of 5 cm/min.

Figure 1. Temperature Susceptibility of Viscosity Graded Asphalt Cements (After Roberts et al., 1981).

of the rubber on the asphalt is to decrease its temperature susceptibility. Rubber particles swell when heated in asphalt. The extent of this swelling, which affects the viscosity of a material, is a function of the blending temperature. The improvement in viscosity is substantial at the high temperatures. Reducing the temperature dependence of viscosity and increased adhesion are the most promising effects of rubber modified asphalt use (Stephens, 1989, and Schnormeier, 1986).

If heat is maintained for a prolonged time, during the mixing of rubber with asphalt cement, the rubber may break down, resulting in an undesirable decrease in viscosity. Excessive material viscosity causes asphalt to fail due to too-low blending temperature (Allen and Turgeon, 1990, and Maupin, 1992).

The effect of rubber on viscosity was determined by Roberts et al. (1989). Figure 2 presents the effects of rubber content on viscosity. As can be seen from Figure 2, viscosity increases with increasing rubber content, and the increase is exponential.

Pavlovich and Shuler (1979) measured the average absolute viscosity of rubber-asphalt (25% rubber and 75% asphalt) to be 146,000 poises with a range from 27,000 to 475,000 at 140 °F. Unaged asphalt averages only 6,130 poises. Thus the increase in absolute viscosity is two orders of magnitude. Piggott et al., (1977) also showed that the addition of 5% rubber by weight of the total binder would increase the asphalt viscosity at 200 °F by 10-15 percent.

Roberts et al (1989) reported that during the asphalt and rubber blending operation, viscosity can be controlled by diluting the blend with petroleum distillates or aromatic extender oil.

On the other hand, Maupin (1992) presented relationships between viscosity and time with three different rubber contents for coarse and fine crumb rubber. Figures 3a,b present the

Table 3. Consistency Temperature Characteristics of Asphalt Rubber Material (After Huff and Vallerga, 1981).

Property	Test Method	AR-4000 Asphalt	Asphalt-Rubber Material ^a
Penetration	ASTM D-4		
39.2° F		9	17
77.0° F		76	101
Softening point (ring and ball) (° F)	ASTM D-36	120	132
Dynamic viscosity at 140° F (poises)	ASTM D-2171	1800	7580
Kinematic viscosity (cSt)	Brookfield		
165° F		-	165 000
170° F		45 600	-
190° F		6 200	-
212° F		1 984	-
230° F		860	-
250° F		450	-
265° F		-	3 400
277° F		194	-
310° F		82	-
330° F		58	-
350° F		42	912
400° F		-	720

^aContains 78.4 percent AR-4000 asphalt, 1.6 percent extender oil, and 20 percent rubber blend.

Figure 2. The Effect of Coarse Crumb Rubber on Viscosity and Devulcanized Rubber on Viscosity (After Roberts et al., 1989).

Maupin (1992) results. As can be seen in the Figures, there is considerable variation in the test results, and there are no significant differences in viscosity for both rubber types.

Time and temperature are the factors that affect the viscosity of rubber-asphalt blends. Roberts et al. (1989) indicated that the viscosity of rubber-asphalt mixes is reduced as temperature and time are increased beyond the time required to produce the initial reaction between liquid asphalt and solid tire rubber. Figure 4 shows the effect of digestion time on viscosity of rubber-asphalt mix. Schnormeier (1986) presented field viscosity data for conventional asphalt and rubber-asphalt. Although the viscosity of rubber-asphalt is almost constant, the viscosity of conventional asphalt changes significantly with time.

3.2 Fatigue Resistance

Fatigue resistance is the ability of a material to resist repeated loads that, in this case, can induce tensile strains which lead to cracking. The asphaltic mix should not crack when subjected to repeated loads over a period of time. The Alaska Department of Transportation and Public Facilities (ADOTPF) performed several tests on rubber modified asphalt (rubber content ranged from 1 to 3%) at 10 °C (50 °F) and -6 °C (21 °F) to test for fatigue properties. ADOTPF concluded that, based on fatigue, the rubber modified asphalt mix is superior to conventional mixes. Figures 5a,b show the laboratory fatigue curves for 10 °C and -6 °C. Although rubber modified asphalt mixes give better fatigue life than conventional asphalt mixes, it should be noted that these differences are more pronounced at -6 °C than at 10 °C (Roberts et al., 1989).

Figure 3a. Effect of Coarse Crumb Rubber on Viscosity with Increase of Time (After Maupin, 1992).

Figure 3b. Effect of Fine Crumb Rubber on Viscosity with Increase of Time (After Maupin, 1992).

Figure 4. Effect of Digestion Time on Viscosity of Asphalt-Rubber Mix (After Roberts et al., 1989).

Figure 5a. Laboratory Fatigue Curves at -6 °C After Takallou et al., 1985).

Figure 5b. Laboratory Fatigue Curves at 10 °C (After Takallou et al., 1985).

Roberts et al. (1989), Piggott and Woodhams (1979), and Jimenez and Meier (1985) also concluded that rubber in asphalt significantly improves the fatigue life, and the addition of 5% rubber to HMA systems probably doubles the fatigue life. Roberts et al. (1991) also performed a series of tests to investigate the properties of rubber modified asphalt mixes. Figures 6a,b show the mean resilient modulus for 0.05 and 0.1 second loading times. As can be observed from the Figures, the mean modulus decreases with increasing rubber content. It is also important to note that with decrease in temperature the mean resilient modulus increases. These results are very similar to those Takallou et al. (1985) and Stuart and Mogawer (1991). It can also be concluded that the resilient modulus increases with decrease in temperature and, as the load time increases, the resilient modulus decreases. Roberts et al. (1989) recommended that laboratory test results should not translated directly to the field, although improvements would be expected.

3.3 Voids Concepts

Void in the mineral aggregate (VMA) is one of the most important properties of the asphalt mix. The amount of voids significantly affects the performance of a mixture because if the VMA is too small, the mix can have durability problems and if VMA is too large, the mix can have stability problems. The percent air in the total mix for compacted dense graded HMA is generally considered to fall between 3 and 5% (Roberts et al., 1991).

The ADOTPF performed several tests to find the critical rubber content to achieve the lowest percent air voids for rubber modified asphalt. Figure 7 presents the test results, where

Figure 6a. Mean Resilient Modulus for a 0.05-Second Load Time of Various for Different Rubber Content (After Roberts et al., 1991).

Figure 6b. Mean Resilient Modulus for a 0.10-Second Load Time of Various for Different Rubber Content (After Roberts et al., 1991).

Figure 7. Effect of Rubber Content Variations on Percent Voids in Mix (After Esch, 1984)

it can be seen that as rubber content increases, so does void ratio. As void ratio decreases, asphalt content increases. It was concluded that 2.5% is the most economical quantity of rubber in asphalt for rubber modified asphalt. Takallou et al, (1986) stated that the fatigue life of rubber modified asphalt increased with increasing percent air voids, although this is contrary to the conventional relationship between air voids and fatigue life.

3.4 Elastic Recovery

Oliver (1981) showed that for tire retread buffings, the elastic strain recovery increases linearly with increasing rubber content. Figure 8 shows the relationship between rubber concentration and elastic recovery. Elastic recovery increases with both temperature and digestion up to 220 °C. There is no further increase for 2-hour synthetic rubber digestion and a significant reduction in elastic recovery occurs for the 1-hour and 2-hour digestion above 240 °C.

3.5 Rubber Types

Rubber type is one of the factor that effects the properties of rubber-asphalt mixes. When asphalt cement and crumb rubber modifier (CRM) are blended together, there is an interaction between the materials. Reaction between asphalt cement and CRM is influenced by temperature at which blending/reaction occurs, the length of time the temperature remains elevated, and the

Figure 8. Effect of Time and Temperature of Digestion on Elastic Recovery for Natural Rubber Tire Buffings (After Oliver, 1981).

type and amount of mechanical energy (Heitzman, 1992). Other factors are also important, such as particle shape and size, rubber type and rubber gradation. Particle structure is the most important one (Takallou et al., 1985).

The rate of reaction between CRM and asphalt cement can be increased by increasing the surface area of the CRM. Oliver (1981) showed the change of elastic recovery with particle size. See Figure 9. Oliver (1981) concluded that improvement in elastic recovery is due to the difference in morphology of the particles, with smaller particles being more porous and the larger particles having more flat surfaces. This is most likely due to the fact that the rate of swell of the rubber for the smaller particle size is much greater than that of the large particles. Therefore, it would be desirable to use fine particle sizes rather than large particle sizes.

It has been shown that the minus No. 25 to plus No. 40 crumb rubber, when mixed with asphalt and held at a temperature of 190 °C for approximately 20 minutes, swells to approximately twice its original volume (Morris and McDonald, 1976). Besides swelling, rubber particles become much softer and more elastic. These phenomena are due to chemicals and physical reactions between the resins in the asphalt and rubber.

Takallou et al (1986) stated that the mixture with fine rubber has the highest modulus and lowest fatigue life, and the mixture with coarse rubber has the lowest modulus and highest fatigue life. For example, gap-graded aggregate mixtures with a blend of 80% coarse and 20% fine rubber have the lowest modulus and highest fatigue life at 10 °C and -6 °C.

It was found that large quantities of rubber (> 20% by weight of binder) are required to produce the desired effect i.e., to form a matrix. The resulting mass had a viscosity much too high for most conventional asphalt applications (Huff and Vallerga, 1981).

Figure 9. Effect of Particle Size on Elastic Recovery for Tire Retarder's Buffings After Oliver 1981).

SECTION 4

EXPERIENCES OF STATES WITH RUBBER-ASPHALT MIXES

4.1 Connecticut

An extensive rubber-asphalt mix experimental program was undertaken by the State of Connecticut and Civil Engineering Department of the University of Connecticut with the Federal Department of Transportation in 1977-78 (Stephens, 1989). Reclaimed tire rubber was incorporated into five different forms of pavement rehabilitation: thick overlays (4 cm), thin overlays (1.5 cm), chip seals, crack and joint sealing and stress relieving interlayers (same as SAMI). Experiences of ConnDOT with each case are as follow:

4.1.1 Thick Overlays

The thick overlay was tested with one and two percent rubber at three levels of surface conditions at three level of traffic. ConnDOT had different experiences with different rubber content, with different traffic levels. One percent rubber reduced the longitudinal cracking, whereas two percent rubber increased the longitudinal cracking. Neither one nor two percent rubber performed better than conventional asphalt.

4.1.2 Thin Overlays

Thin overlays were placed at four locations. One percent rubber reduced the amount of cracking by two-thirds, whereas further increases in the amount of rubber resulted in more cracking. This evaluation is based upon limited data.

4.1.3 Chip Seals

Chip seals were tested at four different sites. Two of them were sand sealed a few months after construction. ConnDOT reported that at the three and four year evaluations, all rubberized seals were in better condition than the control sections. However, after nine years, all sections have been covered, and in the new surfaces show less cracking when over the rubberized seals. ConnDOT also reported cracking in the two seals that were sand sealed when new was many times less than that in the regular sand-emulsion seals.

4.1.4 Surface Relieving Interlayers (SRI = SAMI)

ConnDOT reported that the use of a SRI did not improve performance. Average performance with and without SRI was nearly the same. The rubber-asphalt layer, as constructed, did not act as stress reliever.

4.1.5 Rubber-Asphalt Joint Seals

Summer/winter joint and crack filling was compared. After an evaluation of nine years, ConnDOT reported that there were no differences in the apparent amount of joint sealant remaining in the pavement. Significantly more material placed in the summer remained than that placed in the winter.

4.2 Florida

The Florida Department of Transportation (FDOT) has experimented with rubber asphalt mixes since the late 1970s. Three projects were developed (from 1989 through 1990 (Ruth, 1991)) to evaluate the use of rubber in asphalt. The first pilot project was constructed in Gainesville in March, 1989, using a dense-graded friction course containing 3, 5, and 10 percent rubber by weight of total binder. FDOT reports that stickiness was a problem in this project.

The second project was constructed using 5 to 17 percent rubber (by weight of total binder) in an open graded friction course on a state road near Starke in June 1989. FDOT concluded that 10% to 15% rubber is best for open-graded friction courses.

The third pilot project was constructed on Interstate 95 in September 1990 using 10% rubber by weight of asphalt cement. The purpose of this project was determine if rubberized asphalt could be blended and incorporated into an open-graded friction course mixture using a prototype production blending unit on a conventional construction project. The project was completed without encountering any major problems of construction.

After construction and evaluation of all three pilot projects, FDOT concluded that tire rubber is feasible for friction course construction.

FDOT reported that using rubber in an asphalt binder will increase the cost 10%.

4.3 Michigan

Sixteen test and control sections were developed to evaluate the effectiveness of rubber modified asphalt for reducing cracking and increasing the life of pavement overlays. This effort was undertaken by the Michigan Department of Transportation (MDOT) in 1978 and 1979 on M 46, in Saginaw County (DeFoe, 1985). In this project ground rubber crumb and reclaimed rubber was incorporated at two percentages levels, 0.5% and 1.5% by weight of mix. Only one of the sixteen sections showed lower cracking than the conventional sections, and two of the sixteen section showed many more reflection cracks than conventional asphalt. It was also reported that the 1.5% ground rubber sections were disintegrating and required frequent maintenance patching. MDOT concluded that no overall reduction in reflective cracking was achieved with any of the rubber mixtures. MDOT also reported that there were no significant differences in pavement friction values measured for several mixtures used in the projects; however, some reduction in rutting was obtained with 1.5% ground rubber mixes.

MDOT recommended that tire rubber not be added to bituminous paving mixtures. Prior to considering future projects involving rubber additions, benefit-cost evaluations should be performed on the candidate mixtures.

4.4 Minnesota

The Minnesota Department of Transportation, MnDOT, has experimented with various uses of asphalt-rubber and rubber modified asphalt (Allen and Turgeon, 1990). MnDOT has researched the use of asphalt rubber in seal-coats, interlayers, crack sealings, asphalt concrete systems, and rubber-asphalt concrete. SAM's and SAMI's have been tested in two different projects. The test projects are located on State Road 63 near Rochester, Xerxes Avenue in Minneapolis, and State Road 10 from Hawley to Detroit.

MnDOT considered one of two SAM projects as a success, whereas the other one was a failure. MnDOT concluded that when a SAM is properly prepared and placed it may be cost competitive.

None of the SAMI projects eliminated reflective cracking, however they did reduce the reflective cracking. MnDOT reported that the benefits do not appear to justify the cost increase.

4.5 New York

The New York State Department of Transportation (NYSDOT) was required to evaluate the use of rubber modified asphalt in the construction or improvement of state highways by the state legislation in 1987 (White, 1990, Shook, 1990). NYSDOT was also required to investigate and report on the economic, environmental, technical and other implications of the use of scrap motor vehicle tires in asphalt pavements. Pilot construction projects were placed with four different rubber contents at two different sites. Four rubber modified asphalt mixtures were

included (Plus Ride, 1, 2, 3 % (by weight of mix) rubber) in asphalt. Test sections were placed on Route 144 in the town of Bethlehem, Albany County, and on Route 17 in the town of Deposit, Delaware County.

4.5.1 Albany County Project

The pavement was 20 years old, with 40-ft. joint spacing, and was located in a rural area. The daily traffic was 5,000 vehicles with 16% trucks. The new pavement was overlaid on 8-inch Portland cement concrete pavement with a 1-inch asphalt overlay. The test pavement was a 0.75 to 1-inch leveling course and a 1.5 inch thick 6F top course.

4.5.2 Delaware County Project

The second test project was constructed on New York State Route 17 near the town of Deposit, Delaware County. The road was in poor condition therefore before applying rubber-asphalt mix, a 2.5-inch thick leveling course, a 1.5-inch binder course and a 1.5-inch top course were constructed. This was followed by the placement of either conventional, PlusRide, 1, 2, or 3% rubber modified mixes.

NYSDOT reported that although there is not enough experience with rubber-asphalt mixes, economical and environmental problems were present. The pilot projects showed increases in cost over the conventional asphalt, as shown in Table 4.

Table 4
 Bid Price Relationship for
 Rubber-Modified Asphalt Mixes
 Compared to Conventional Asphalt Mix (After White 1990)

Mix	Albany County Project	Delaware County
---	-----	-----
1% Rubber	+ 50%	+ 114%
2% Rubber	+ 50%	+ 114%
3% Rubber	+ 50%	+ 114%
PlusRide	+ 50%	+ 129%

NYSDOT estimated that the use of rubber-asphalt mix would increase costs by 60% over conventional asphalt. The factors which cause modified rubber asphalt to be more costly than conventional asphalt include: increase in the volume of asphalt cement binder, more costly aggregate (stone); filler gradation; more energy, time, labor, and equipment; and the cost of granulated rubber. The rubber mixes tended to be sticky, adhering to the equipment and making release from the delivery truck beds more difficult. The stickiness increased with increases in rubber content.

4.6 Pennsylvania

The Pennsylvania Department of Transportation (PennDOT) has been evaluating the use of asphalt-rubber since the early 1960's (Mellot, 1989). PennDOT built two projects to evaluate, under actual field conditions, the effectiveness of a rubber-asphalt membrane interlayer (with 33% granulated, reclaimed rubber by weight of binder), SAMI in retarding the development of reflective-type cracking in bituminous overlays. The experimental projects were located in Center Counties, SR 307 and 322 and Cambria and Indiana County, SR 314 and 22. Both projects involved base repair, a leveling course, SAMI, and 0.5 in. of wearing surface course material. After evaluating numerous projects, PennDOT reported that the SAM and SAMI performed as well as the control section without the asphalt-rubber membrane. PennDOT concluded that SAM's and SAMI's are appropriate only in asphaltic pavement courses, but that the use of SAM's and SAMI's should be discouraged because of the increased cost.

4.7 Washington

The Washington State Department of Transportation (WSDOT) has constructed several pilot projects to evaluate asphalt rubber and PlusRide with asphalt and concrete pavement. Experiences of WSDOT with each application are summarized below.

4.7.1 Rubber-Asphalt Open-Graded Friction Course

This project was undertaken on I-5 in Vancouver, Washington, in 1986. A 1200 ft section of conventional open-graded pavement and a 3000 foot section of polymer-asphalt open-graded pavement were included as control sections (Allison, 1990). The rubber-asphalt binder consisted of 20% recycled vulcanized rubber and 80% AR4000W asphalt cement. The polymer-asphalt binder consisted of AC-20 paving grade asphalt rubberized with 1.2 to 2% by weight of virgin synthetic styrene-butadiene rubber.

After three months inspection there are no differences among the pavements although rubber-asphalt cost more than 51% over conventional asphalt.

4.7.2 Rubber-Asphalt Binder Stress Absorbing Membrane Interlayer (SAMI)

A pilot project was constructed to evaluate SAMI's regarding to reflection of the cracks. WSDOT reported that rubber-asphalt SAMI's slightly decrease the transverse reflection cracks but cost twice as much as paving grade asphalt.

4.7.3 PlusRide Asphalt and Concrete Pavement

WSDOT has constructed several pilot projects to evaluate PlusRide (Allison 1990, Schultz, 1987). WSDOT expressed its experiences as follows:

"It appears the PlusRide product does not stand up to its' developers claims. There is no evidence of better frictional properties, noise reduction or increased service life on this experimental project."

SECTION 5

EVALUATION OF THE CLAIMED ADVANTAGES OF RUBBER ASPHALT MIXES

It has been claimed that asphalt rubber mix has several advantages. The reported benefits of rubber-asphalt can be summarized as follows (Ahmed, 1991, Takallou et al., 1986, Esch, 1984, Estakhri et al., 1992, Kirk, 1992):

- Reduced noise.
- Greater resistance to aging.
- Reduced reflective and thermal cracking.
- Increased resistance to studded tire wear.
- Higher viscosity than conventional asphalt.
- Greater durability.
- Recycling of used rubber tires.

The reported rubber modified asphalt advantages can be summarized as follow (Ahmed, 1992, Takallou et al., 1986, Kirk, 1992):

- Increased skid resistance
- Reduced noise
- Deicing
- Greater durability
- Decreased stopping distance.
- Recycling used tires.

5.1 Increased Skid Resistance

The addition of rubber in asphalt is said to increase the skid resistance of pavement. ConnDOT has performed several test to investigate skid resistance of rubber-asphalt (Stephens, 1989). After eight year evaluation, they reported their experiences as:

"For any one age, no significant differences are found between skid number for different mixes. However, there is 97.5 probability that the skid numbers in 1980 are greater than in 1977 or 1978."

5.2 Deicing

It has been claimed that rubber modified asphalt has deicing properties because of increased flexibility and the action of protruding rubber particles. Deicing properties of the pavement increase with an increase of rubber content. To test the deicing properties of rubber modified asphalt many projects were developed by several states; however, test results are in contradiction. After extensive research, Eaton et al. (1991) concluded that with increasing rubber content (i.e., an increase presence of larger particles on the pavement surface), there are increases in the incidence of cracking. Surface characteristics other than the presence of rubber particles does not appear to affect cracking. Takallou et al. (1985) reported that coarse rubber in asphalt is effective for ice removal and decreases stopping distance as much as 25%.

5.3 Reduced Noise Level

One of the primary advantages of rubber-asphalt mixes is said to be the reduction of noise. It has been claimed that rubber modified asphalt reduces the noise on the order of 90% (10 Db) due to the open graded design and the inclusion of crumb rubber (Arizona, Alaska). Sainton (1990) reported that noise reduction has been recorded up to 50% (3 Db) in France. Heerkens (1985) reports that open-graded rubberized asphalt reduces the noise level at least 3.5 Db compared to dense graded, whereas the reduction is only 0.5 Db when compared with conventional asphalt. On the other hand, other states (New York, Wisconsin, Minnesota, Pennsylvania) reported that they did not record significant noise reduction. Standberg et al (1990) tested modified rubber asphalt (Rubit) in Sweden, for noise reduction. They reported that rubber modified asphalt surfaces emit noise equivalent to that of the reference surfaces. Standberg et al., (1990) concluded that traffic noise reduction can not be used as an argument for using rubber modified asphalt.

It is also important to note that the reporting of noise reduction values for various agencies are in contradiction. It seems from the available data that each agency followed different procedures and compared the results with different conditions. Therefore, it is hard, if not impossible, to draw any conclusions about noise reduction.

5.4 Decreased Stopping Distance

The ice control mechanism results from the flexing of the protruding rubber particles, and the greater flexibility of the mix causes a breakdown of surface ice deposits under traffic action. Esch (1982) reported that PlusRide reduces the stopping distances 3 to 50% with an average of 25%. However, there are no significant data that support deicing of rubber modified asphalt.

5.5 Greater Durability

Arizona DOT believes that the durability of asphalt rubber is much greater than conventional asphalt. They presented the following numerical evidence.

Asphalt rubber as a binder in hot mix has lasted for more than 15 years. Rubber-asphalt as a seal coat has lasted over 21 years. Schnormeier (1992) concluded that asphalt rubber has 2 to 3 times the life of the standard asphalt. The Texas State Department of Highways (SDHPT) reported that it is unlikely that asphalt rubber would last 2 to 3 times longer than standard asphalt.

The durability of asphalt rubber mixes improves due to reduced age hardening and improved retention of aggregate. Age hardening decreases due to anti-oxidants in the rubber and increased film thickness. Retention of aggregate improves due to increased film thickness and greater resiliency (Ruth, 1991).

While most of the states reported that rubber asphalt-mixes performed as well as conventional asphalt or slightly better, there is no evidence that asphalt rubber mixes would last

longer than conventional asphalt.

5.6 Reduced Reflective and Thermal Cracking

It has been argued that reflective and thermal cracking can be reduced with stress absorbing layers such as SAM's and SAMI's. SAMI is especially effective in reducing stress concentrations above existing joints and cracks. SAMI reduces reflection cracking by cushioning or dissipating the stresses from the underlying pavement before they are transferred to the overlay (Ahmed, 1991).

SECTION 6

PROBLEMS ASSOCIATED WITH RUBBER-ASPHALT MIXES

The following problems are associated with the use of rubber-asphalt.

6.1 Environmental Problems

Potential environmental problems include smoking (fumes) which result from high temperature construction practices. Several states (California, Connecticut, Florida, New York, Pennsylvania) have reported that air pollution increases with adding rubber to hot mix asphalt (HMA). The magnitude of the air pollution increases with an increase of rubber content in the asphalt. Smith (1983) reported that "A great deal of smoke was produced by the hot rubberized asphalt", during the placement of rubber-asphalt mixes.

There is an increased tendency for smoke to be emitted as well as the creation of a burning rubber odor. White (1990) and De Laubenfels (1985) reported that a great deal of smoke was produced by hot rubberized asphalt during experimental projects.

The encouraged use of rubber in asphalt could create a problem in the future for widely accepted practice of recycling of asphalt paving mixes. Further research is vital in this arena.

6.2 Stickiness

Stickiness is one of the main problem associated with rubber- asphalt mixes. Rubber-asphalt mixes with high percentages of rubber content (higher than 3%) tend to adhere to the equipment and to truck beds. Extra care and water additives are required in rolling to prevent adherence to the rollers. Florida reported that stickiness of rubber-asphalt mixes increases with increasing rubber content. It is also reported that the process of cleaning equipment after using rubber-asphalt mix is extensive and time consuming.

MnDOT reported that rubber-asphalt mixes are more susceptible to adverse weather or the occurrence of equipment problems. NYSDOT (White, 1990) reported that stickiness also makes it difficult to properly reduce pavement voids, which may cause early failure. Iowa Department of Transportation (IDOT) has reported that during the placement of rubber-asphalt mixes shoving and cracking of the mix became a problem as it was being rolled (Anderson, 1991).

6.3 Cost

All other conditions being equal, use of ground tire rubber in asphalt costs approximately 60% more than conventional asphalt. If this is the case, it is estimated that using tire rubber in asphalt will cost \$11 for each tire. It is said that the cost will decrease by increasing usage of rubber-asphalt mixes. The factors that increase the cost include: increased asphalt cement binder content, increased energy costs, increased cleaning expenses, increased labor cost, equipment modification, extra work to design and testing of mix samples.

Increased Asphalt-Cement Binder Content: An increase in the volume of asphalt cement binder is required when using rubber in asphalt. Rubber-asphalt mixes need more costly aggregate (stone) and filler gradation. Roberts et al. (1989) indicated that at any given temperature, rubber asphalt binders have higher viscosity than conventional asphalt.

Increased Energy Costs: The mixing temperature is increased with addition of rubber into the asphalt. The mixing temperature of the conventional asphalt generally is about 300 °F whereas that for rubber-asphalt mixes is about 375 °F. The higher the temperature, the more energy consumed. Therefore, rubber-asphalt mixes will cost more than conventional asphalt due to increased energy requirements.

Increased Cleaning Expenses: Because of its stickiness, rubber-asphalt mixes adversely affect the beds of trucks and other equipment during placement. Thus, additional labor and cleaning materials are required.

Labor: NYSDOT (White, 1990) reported that during the pilot projects additional labor was required to feed the belt and to place the bagged rubber in the aggregate hopper at the time of mixing.

Equipment Modification: During construction of pilot projects, rubber bags were introduced to the binder by hand. If rubber will be used continuously, additional conveying equipment should be designed to decrease labor and obtain homogeneous mix.

Rubber-asphalt mixes require more mixing time and time to test the samples than conventional asphalt. Furthermore, it has been reported that working with rubber-asphalt mixes is much slower than conventional asphalt.

It is likely that an increase in the use of rubber-asphalt mixes will decrease the cost differential. However, other rubber tire disposal methods are being developed. NYSDOT and ConnDOT report that energy production facilities for scrap tire have been built in New York and Connecticut. Two of these plants plan not only to use the scrap tires in their states but neighboring states' scrap tires as well.

Because of the many factors influencing the life of any pavement surface, it is very difficult to assess the cost-effectiveness of rubber-asphalt mixes. However, at this time the use of tire rubber in asphalt is not economical since there is no strong evidence that rubber-asphalt lasts longer or performs better.

6.4 Availability

Approximately 5 million waste tires are generated annually in the state of Indiana with 40 stockpiles containing million of tires in different counties (Lovell et al. 1992). Therefore, the potential for use of tires in rubber-asphalt mixes is great enough that there would not be shortage of rubber. However, trained and experienced contractors and labor could be in short supply. This could cause inflated bid prices for rubber-asphalt mixes. Indiana has one facility for grinding tires located in South Bend.

SECTION 7

USE OF EBONITE IN ASPHALT PAVEMENT

A variety of waste materials has been used in asphalt pavements in the past by Indiana Department of Transportation (INDOT) to conserve natural resources, obtain better performance, and offset the rising cost of quality natural aggregates. In this respect Senate Bill 209 (1991), directed INDOT to investigate the potential uses of ebonite in asphalt pavements.

Ebonite is present in discarded battery cases which are made of rubber, plastics, and asphalt with various of types of filters and fiber (Manke 1965). Apparently there are two types of ebonite: hard and soft. Hard ebonite contains about 32% sulfur (S), whereas soft ebonite contains only 3% S. Ebonite is hard at ordinary temperatures but softens at about 140 °F and becomes flexible at 212 °F. In general, ebonite is hard, nonelastic, is resistant to abrasion and has high impact resistance (Martell, 1958).

Amounts of heavy metals present in fragments of battery cases are of major concern. Apparently, the amount of the lead within ebonite particles is above the Environmental Protection Agency (EPA) and Indiana Department of Environmental Management (IDEM) requirements. However, Cole (1992) states that a recently developed cleaning process would enable ebonite to be classified as nonhazardous for disposal purposes. According to the EPA definition, if a waste material contains more than 210 ppm lead the waste is considered a hazardous waste material.

Although Collivignarelli et al., (1986) reported that the purity of ebonite depends upon the size of the particles (the smaller the size, the higher the purity), they did not give any specific relationship. The purity is also function of the cleaning process.

There is almost no available literature on ebonite. No state has had experience with ebonite in asphalt pavements according to Ahmed (1991). Therefore it is difficult, if not impossible, to draw any conclusions about usage of ebonite in asphalt pavements.

ACE Battery Company of Indianapolis sent two different ebonite samples with two different grain size (coarse and fine grained samples) to investigators at Purdue University. The grain size distributions of the samples are given in Figure 10. Both fine and coarse samples are poorly graded according to the Unified Soil Classification System (USCS).

Texas Transportation Institute (TTI) evaluated physical properties of ebonite in 1965 (Manke et al., 1965). According to Manke et al., (1965) ebonite has both desirable and undesirable properties for use in asphalt pavements. The desirable properties of ebonite as aggregate are strength, low specific gravity, angularity, and resistance to abrasion. Undesirable properties of ebonite (battery cases) are flammability, smooth-sided particles and contamination due to presence of heavy metals.

Manke et al (1965) concluded that, ebonite can be used as aggregate in asphalt pavement. The optimum amount of the ebonite should be determined by experiment. However, a 10 to 20% replacement of portions of the aggregate with ebonite might be possible.

Environmentally speaking, the use of ebonite is questionable due to the presence of heavy metals. Therefore, it would not be realistic to use ebonite unless the contamination due to heavy metal should be reduced to safe level.

Ace Battery Company of Indianapolis and U.S. Bureau of Mines (Cole, 1992) have argued that the amount of lead in ebonite would meet EPA specifications. If this can be documented, a major objection against the use of ebonite in asphalt pavements would be overcome. This would need to be accomplished under IDEM and EPA specifications.

Grain Size Distribution for Ebonite Samples from ACE Battery

Figure 10. Grain Size Distribution of Ebonite Samples.

SECTION 8

DISCUSSION

The use of ground tire rubber with asphalt and its advantages and disadvantages have been presented. Some of the case histories support the use of ground tire rubber with asphalt, whereas some studies discourage the use of ground tire rubber in asphalt.

Some physical properties of rubber-asphalt mixes that have been presented are superior in terms of both design and performance of the pavement. It should be stressed that most superior properties of rubber-asphalt mixes reported are based on laboratory studies. None of these properties have been properly verified in the field, which is a necessary step.

The California Department of Transportation (Caltrans) has been doing extensive research on rubber-asphalt mixes products for 13 years. Based upon extensive field test results, Kirk (1992) states their experiences with rubber-asphalt mix products as follow:

"At this point in time, we are doing just that, guessing; but, these guesses are being made on selected experimental projects".

Therefore, it is too soon to draw any solid conclusions based on any laboratory and field test results.

It is also important to note that reported test results are in contradiction both for advantages and disadvantages. For example, ADOTPF claimed that rubber modified asphalt reduces the noise level up to 90% whereas the amount of the noise reduction is only up to 50% in France. Nonetheless, in Sweden, home of asphalt rubber, it is argued that rubber modified

asphalt does not reduce the noise level (Standberg et al., 1990). It is well known that gradation type is one of the factors that controls noise level. For example, everything being equal, the noise level of an open graded pavement will be less than that of a dense graded pavement. Therefore, comparison of noise reduction must be with same type of gradation.

It has been argued by ADOT that SAM's are extremely effective whereas PennDOT and NYSDOT recommended discouraging the use of SAM's due to their poor experiences. The Minnesota Department of Transportation reported that SAM's perform the same as or slightly better than conventional asphalt.

There are differences not only in laboratory and field test results but also the reasons why ground tire rubber would be used in asphalt. Namely, to enhance the properties of the resulting mixture or merely to dispose of the discarded tires. The Wisconsin DOT has expressed the opinion that the use of rubber tires in asphalt has been a political decision rather than a technical one (Jaskaniec, 1990).

Although several factors contribute to the effectiveness of rubber-asphalt mixes, weather conditions and adequate preparation and construction procedures are the two most important factors.

It appears that every state used rubber in asphalt with different procedures. Most of the states experimented with rubber modified asphalt whereas, Arizona and Texas experimented with asphalt rubber. Therefore, it would be expected that properties of these two products would be different.

It is the opinion of the author that some of the differences come from procedures followed during the tests. Therefore, it would not be realistic to draw any conclusion based on any of the state results. To reach an ultimate conclusion, long term test results should be

evaluated, considering every aspect of rubber- asphalt mixes.

Under dry weather conditions badly cracked pavement can remain structurally sound for a long time whereas this is impossible in wet region conditions due to migration of rain through the pavement. Arizona and Texas have dry weather conditions; therefore, climatic conditions can have significant effect on pavement structures. On the other hand, it is difficult to explain the good experiences of Alaska with rubber modified asphalt. Poor experiences of almost all midwest states with rubber-asphalt mixes are not explained by climatic conditions. There must be other factors that affect the performance of rubber-asphalt mixes.

Most of the states had experiences with rubber-asphalt mixes when rubber-asphalt mixes were still in an experimental stage. Reported negative performance of many pilot projects may be related to improper construction and design practices rather than the material itself.

It has been reported that rubber-asphalt mixes have the poorest appearance in the first year but improve with age, whereas conventional asphalt mixes have their best appearance in the first year and deteriorates in its quality with time. As most of the states which had poor experiences with rubber-asphalt mixes prepared their reports soon after demonstration projects, therefore, it is too early to draw any conclusion about the effectiveness of rubber-asphalt mixes.

The question arises as to why tire rubber should be used in asphalt. Should it be to get better performance or to dispose of excess scrap tires ? If the answer is to get better performance, then there is no convincing evidence that fully supports the use of ground tire rubber in asphalt. Rubber-asphalt mixes are in an experimental stage; therefore, rubber-asphalt mixes should not be increased in use until a longer service life is proved. If the answer is to dispose of the scrap tires, then tire rubber should be used with large percentages in asphalt. For example, FDOT estimated that if 3% of tire rubber is used in asphalt, only 10% of tires

scrapped would be used, which would not decrease the disposal problems significantly.

Perhaps use as a fuel source and raw material in production of other polymeric materials would be a much more effective way to dispose of scrap tires. Plants are using scrap tires as a fuel source in California, Connecticut, New York and other states. Kandal (1990) stated that Rubber Research Elastomers, Inc., of Minneapolis has developed a patented process for treating granulated tire rubber to produce a raw material for use in the production of other rubber products.

In addition to the high cost and other uncertainties, rubber- asphalt mixes can create some environmental problems. These problems should be resolved prior to the widespread use of ground tire rubber in asphalt.

SECTION 9

CONCLUSIONS

The followings can be concluded from the discussion on rubber asphalt mix products.

1. The asphalt rubber and rubber modified asphalt mixes are two different products and have significantly different engineering properties.
2. Adding tire rubber into asphalt mixes significantly increases the viscosity of the binder as well as resulting mix. Viscosity increases with an increase of rubber content. The viscosity of the binder/mix also depends upon particle size of the rubber: the smaller the size, the higher the viscosity.
3. Fatigue life of the rubber-asphalt mixes is considerably higher than that of the conventional asphalt mixes. If the performance of the pavement is based on the fatigue behavior, rubber-asphalt mixes are superior. Fatigue life of rubber-asphalt mixes increases with increasing void ratio, contrary to the conventional relationship between void ratio and fatigue life.
4. Type size and shape of the granulated rubber affect the properties of rubber asphalt mixes. It is desirable to use fine particle sizes rather than coarse sizes.

5. Most of the reported experiences by states are in contradiction due to following different procedures, differing placement procedures and different climatic conditions. A number of states reported the occurrences of cold temperature cracking, shorter compaction periods, constructibility problems and increasing mixing and laydown temperatures.

6. Some environmental problems such as plant emissions (odor and pollution) are also associated with rubber-asphalt mixes and could restrict the use of tire rubber in asphalt.

7. In general, rubber asphalt mixes perform better or equal to conventional asphalt. However, rubber-asphalt mixes are more expensive than conventional asphalt and benefits to offset the increased cost have yet to be proven conclusively.

8. Ebonite has both desirable and undesirable properties for asphalt pavement. Some amount of ebonite could possibly be used as an asphalt pavement material if it is free of heavy metals. Further research must be conducted in order to determine the optimum amounts of ebonite that could be utilized in asphalt pavements.

SECTION 10

RECOMMENDATIONS

1. The longer performance life of rubber-asphalt mixes has not been conclusively proven. Therefore, at this stage, rubber asphalt mixes should be used sparingly in pavements until the Indiana Department of Transportation (INDOT) obtains experimental results that document the benefits from the use of tire rubbers in asphalt paving mixtures.

2. The amount of tire stockpiles can not be significantly reduced by incorporating this rubber in asphalt pavements. Other usages of tires must be considered, such as energy source, lightweight highway embankments, and retaining wall backfills.

3. Cleaned ebonite can potentially be used in asphalt paving mixtures. However, ebonite should not be used before conducting an extensive laboratory study followed by a well documented IDOH test section.

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SECTION 11

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