Chelsea Center for Recycling and Economic Development

University of Massachusetts

Technical Report # 26

Evaluation of Use of Manufactured Waste Asphalt Shingles in Hot Mix Asphalt

July 2000

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Chelsea Center for Recycling and Economic Development Technical Research Program

July 2000

This project was funded by EOEA through the Clean Environment Fund, which is comprised of unredeemed bottle deposits.

The Chelsea Center for Recycling and Economic Development, a part of the University of Massachusetts' Center for Environmentally Appropriate Materials, was created by the Commonwealth of Massachusetts in 1995 to create jobs, support recycling efforts, and help the economy and the environment by increasing the use of recyclables by manufacturers. The mission of the Chelsea Center is to develop an infrastructure for a sustainable materials economy in Massachusetts, where businesses will thrive that rely on locally discarded goods as their feedstock and that minimize pressure on the environment by reducing waste, pollution, dependence on virgin materials, and dependence on disposal facilities. Further information can be obtained by writing the Chelsea Center for Recycling and Economic Development, 180 Second Street, Chelsea, MA 02150.

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1. Abstract

About 20,000 tons of manufactured waste asphalt shingles are being deposited in landfill every year in the state of Massachusetts. This has caused a shortage of precious landfill space, and a significant increase in deposit fee. There is a need to evaluate the use of these waste shingles in hot mix asphalt (HMA), especially because the shingles contain a significant amount of asphalt binder, and studies in some states have shown that use of shingles can result in savings, and improve hot mix asphalt performance. A laboratory study was conducted by the Worcester Polytechnic Institute and University of Massachusetts at Dartmouth, with a research grant from the Chelsea Center for Recycling and Economic Development. The results show that volumetric and low temperature properties of hot mix asphalt with 3, 5 and 7 percent shingles are not significantly different from the properties of conventional hot mix asphalt used for surface courses. Standard deviation of test results for mixes with shingles are low, indicating consistency in the quality of the shingles. Mixes with 5 and 7 % shingles show significantly lower rutting potential compared to mix without any shingles. Hence, it seems that mixes with small amounts of shingles have the potential of savings as well as good performance. However, before any material can be used regularly, it must be evaluated under real-life production and construction conditions.

2. Background

Approximately one million tons of waste asphalt shingles are generated every year by roofing shingles manufacturers in the United States (**Newcomb et. al.**). This consists primarily of tab punch-outs, mis-colored and damaged shingles. Most of these waste shingles are deposited in landfills, creating a sizable disposal problem, and gradual loss of precious landfill space. Shingles are primarily composed of asphalt binder, hard rock granules and fillers, and fibers. Since shingles contain about 20 % asphalt binder by weight, its use in HMA can reduce the need for new asphalt binder significantly, and thus result in substantial savings. Waste shingles are being used in many states, such as North Carolina, Texas and Minnesota for recycling, as well as for improving the properties of HMA. However, the variation in property of asphalt in shingles has caused some concern about its use. Currently, the Massachusetts Highway Department (MHD) does not allow the use of shingles in HMA, because of its concern about consistency of asphalt in waste shingles (**Fung**). However, some studies have shown, that depending on the source of the shingles, minor amounts of shingles, such as 5 %, can improve the properties of HMA, as well as save about $2-$4per ton of mix (**Newcomb et al., Janisch and Turgeon**), even if some variation exists in the property of asphalt in the waste shingles. Hence, the primary problem seems to be in determining whether an acceptable amount of shingles with a range of properties can be recycled in HMA to reduce the need for new asphalt binder, and improve its performance.

Shingles constitute a major waste product in the US in general, and Massachusetts in particular. The shortage of landfill space is reflected in recent significant increase in landfill deposit fee, from $10-$20 per ton to $90-$100 per ton (**Peter**). If a successful use of waste shingles is found, not only can the shingles be directed to a useful and economic application, but the landfill space can also be saved. This project aims at evaluating the use of waste shingles for reducing the amount of new asphalt binder required in HMA and improving the performance of HMA. The information obtained from this study will enable manufacturers and end users to better understand and appreciate the effect of waste shingles on the properties of HMA. If the effects of locally generated waste shingles on HMA used in Massachusetts are found to be beneficial, the study will also provide researchers the scope to pursue further research to optimize the use of waste shingles, and utilize the full potential of recycling waste shingles. Because of the large amount of HMA used every year (8 million tons in Massachusetts, **Picard**), there is a possibility that the entire stock of manufactured waste asphalt shingles can be used up in HMA every year.

3. Literature Review

Grzybowski

The author indicates that waste roofing shingles can be used in HMA in the same way as recycled asphalt pavement (RAP) material, and that significant savings in amount of asphalt binder can be made. Experimental results are given which show that high temperature rutting resistance can be improved by the addition of shingles in HMA.

Janisch and Turgeon

In this report, the authors have concluded from field projects that the use of shingles in HMA can provide excellent performance and result in significant savings by reducing the amount of virgin asphalt binder required in HMA. They also concluded that shingle modified mixes are as resistant to moisture as are unmodified mixes, and that a slight increase in hardness of binder of the mix, resulting from the binder in the shingles did not have any adverse effect on low temperature properties of the HMA. Based on the results of laboratory and field study, the authors recommended the use of waste shingles in HMA in the state of Minnesota.

Newcomb, et al.

In this paper, the authors have shown that manufactured roofing shingle waste can be incorporated successfully into HMA, and that roofing shingle modified mixes show less temperature susceptibility than mixes without shingles. Significant savings in the use of asphalt binder can be made since shingles are made of 40-50% asphalt binder. The use of shingles also lowered the tensile strength of mixes at 18^{o}C, thus improving the resistance against low temperature cracking. The properties of HMA are affected mainly because of the presence of asphalt and fiber in the shingles. The authors recommended that tensile properties of shingle modified mixes must be determined for evaluation of use of waste shingles in HMA. The authors also showed that the effect on the properties of HMA is dependent on the amount of shingles used, and that the effect on tensile strength can get reversed at higher percentage of shingles.

Watson, et al.

In this paper, the authors have shown that pavements constructed with HMA which was modified with waste shingles, are performing well in the state of Georgia. The use of shingles at a rate of 5% of mix weight has resulted in significant savings in cost of new asphalt binder as well as savings in disposal cost. The authors have recommended the use of shingles for saving cost of asphalt binder and protecting the environment.

Wiseblood

A comprehensive study with HMA with shingles was conducted by Wiseblood in Massachusetts. This study included both laboratory mix design and paving of 13 miles of one and two foot berms on the Massachusetts Turnpike with HMA with 5% shingles. The major conclusions regarding HMA with shingles were: 1. Resistance to permanent deformation, as measured by Marshall stability, is increased significantly, 2. Fiberglass reinforcement in the shingles prevents cracking, and 3. The oxidized asphalt from the shingles is significantly less susceptible to temperature change and hence thermal cracking.

The main points from the literature review can be summarized as follows:

1. Waste shingles have been reused effectively in HMA.
2. Use of waste shingles can result in significant cost savings, by avoiding disposal and landfill space cost, and by reducing the amount of virgin asphalt binder required in HMA.
3. Laboratory tests have shown that the use of shingles can improve resistance of HMA against low temperature cracking and high temperature rutting.
4. Field performance of shingle modified HMA is reported to be good.
5. The effect of shingles on properties of HMA depends on the amount of shingles used.
6. When used in small amounts, there is no significant effect of hard binder on low temperature properties of HMA.

4. Scope of Work

This section outlines the scope of work completed in this project.

Description of Technology or Product Investigated

This study was conducted for the evaluation of use of manufactured waste asphalt shingles in hot mix asphalt. These shingles are produced as a result of manufacturing of roofing asphalt shingles, and are currently deposited in landfills. These shingles are regarded as wastes simply because they are punch outs or tabs from shingles, or are mis-colored or slightly damaged. Essentially, these shingles posses the same composition as the shingles that are used for roofing.

Material Addressed and its Source

The use of manufactured waste asphalt shingles for improving the performance of hot mix asphalt (HMA) was investigated. The waste shingles were obtained from GAF Industries, in Millis, MA. The asphalt binder and aggregates were obtained from Bardon Trimount, Inc. of Stoughton, MA. Bardon Trimount worked with GAF industries to process the shingles.

Selection of Materials

This study was conducted to evaluate the effect of using recycled shingles from Massachusetts, on hot mix asphalt used in Massachusetts. A blend of aggregates conforming to Superpave specifications was selected and a mix design was developed based on current Massachusetts Highway Department specification. The rate of addition of shingles was selected as 3%, 5% and 7% by weight of mix. A control mix, with 0% shingles, was also prepared.

Laboratory Testing

The recycled shingles were blended with aggregates prior to mixing with asphalt binder. After short term aging, the mixes were tested for theoretical maximum density (TMD). The samples were then compacted with 50 gyrations of a Superpave gyratory compactor. Next, the samples were tested for bulk specific gravity. From TMD and specific gravity of mixes and aggregates, the voids in total mix (VTM), voids in mineral aggregate (VMA) and voids filled with asphalt (VFA) were determined.

The VTM gives an indication of the voids in the compacted asphalt mix. Too high a VTM can result in durability problems, and too low a VTM can result in a stability problem. Similarly, VMA indicates the amount of voids inside the aggregate skeleton, part of which is filled with asphalt binder. If the VMA is too low, the mix becomes too sensitive to asphalt binder and the result may be an unstable asphalt mix. The mix may also be unstable with a high VMA.

Once the mixes met the volumetric criteria, they were tested for rutting (permanent deformation) potential, with an Asphalt Pavement Analyzer, and for indirect tensile strength and tensile strain at failure with a Material Testing System equipment. Figure 1 and Table 1 show the test plan and mix matrix, respectively. The APA is a state of the art loaded wheel tester, which applied "real world" moving wheel loads in a controlled temperature and moisture environment (Figure 2). The rutting resistance is determined from rut depths of samples subjected to wheel passes. The rutting tests were conducted at 60^{o}C (high temperature), whereas the tensile strength and strain tests were conducted at 4^{0}C. The tensile strength provides an indication of the stiffness of the mix. At low temperature, more is the stiffness, higher is the potential for thermal cracking.

Figure 1. Overall Test Plan

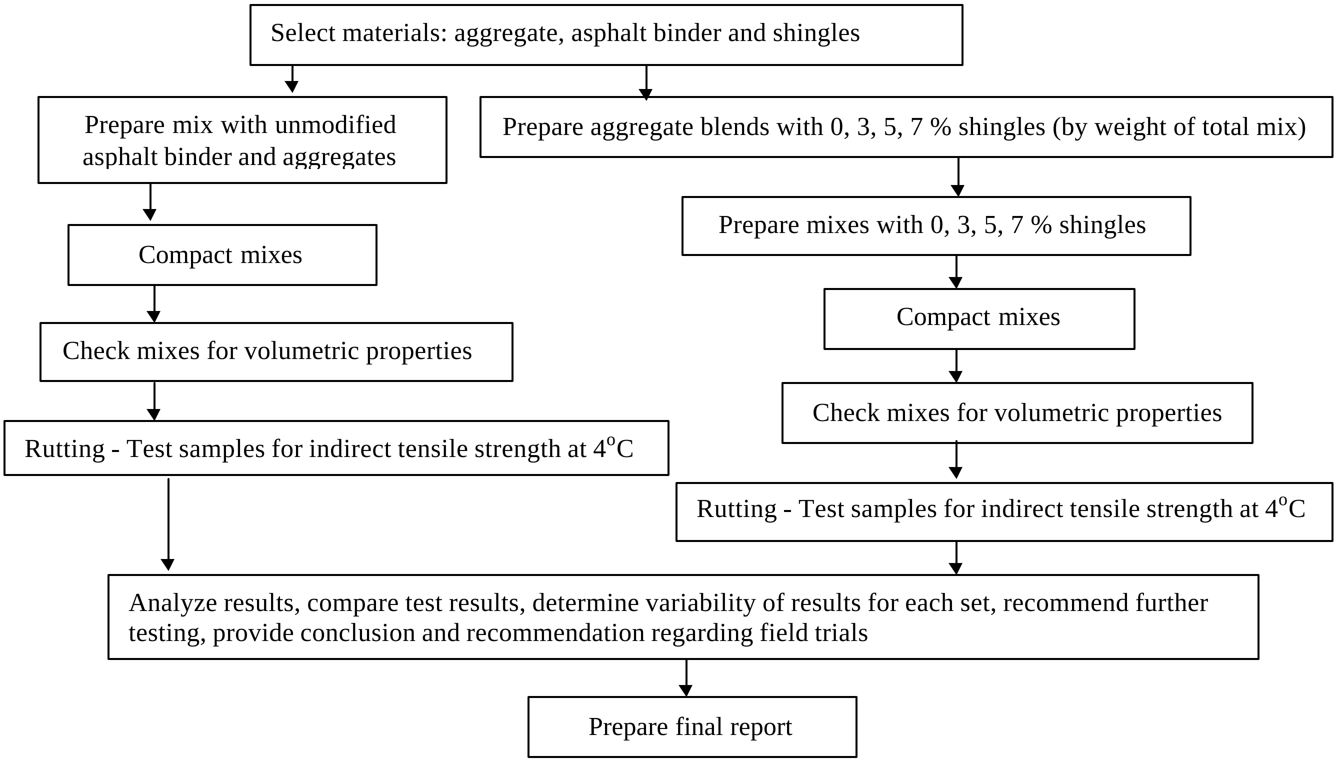


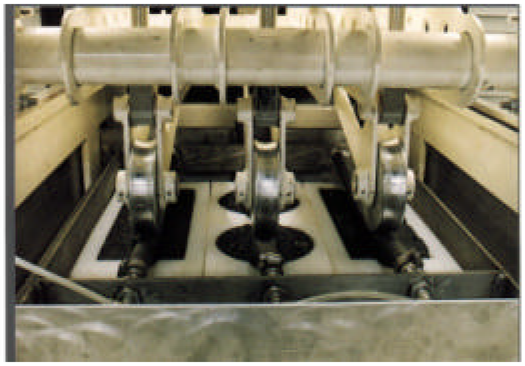
Table 1. Test Matrix for Materials

Mix	Mixes			
	Mixes with shingles at the rate of (by weight of mix)			Control mix
	3 %	5%	7%	
VTM, VMA, VFA, tensile strength at 4°C	X X X X	X X X X	X X X X	X X X X
Rutting		XXX	XXX	XXX

X denotes one sample

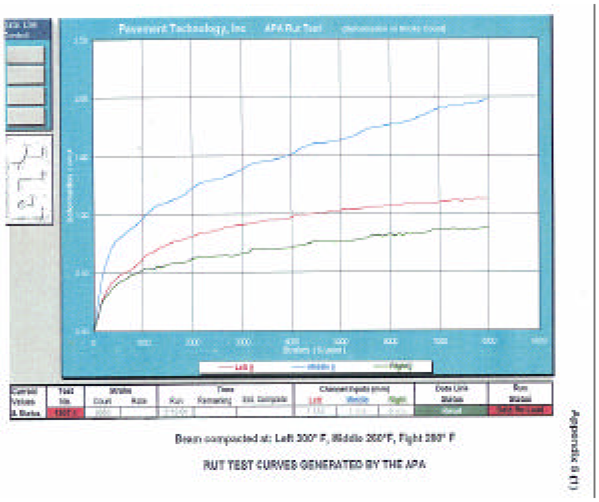
Figure 2. Use of Asphalt Pavement Analyzer

Asphalt Pavement Analyzer (APA)



Wheels inside the APA

Tested samples



Beam compacted at: Left 300° F, Middle 260°F, Right 280° F

RUT TEST CURVES GENERATED BY THE APA

Graphical Output from Data Acquisition System Showing Rutting for Different Samples

5. Results

Figure 3 shows the properties of aggregate, gradation, shingles, and asphalt binder used in this study. The aggregate is a Metagranodiorite from Bardon's Wrentham quarry, the binder is a PG 64-28, which is used in Massachusetts according to Superpave specifications.

Figure 3.
Properties of Mix Gradation, Aggregates, Shingles, and Asphalt Binder

Aggregate Gradation of Mix

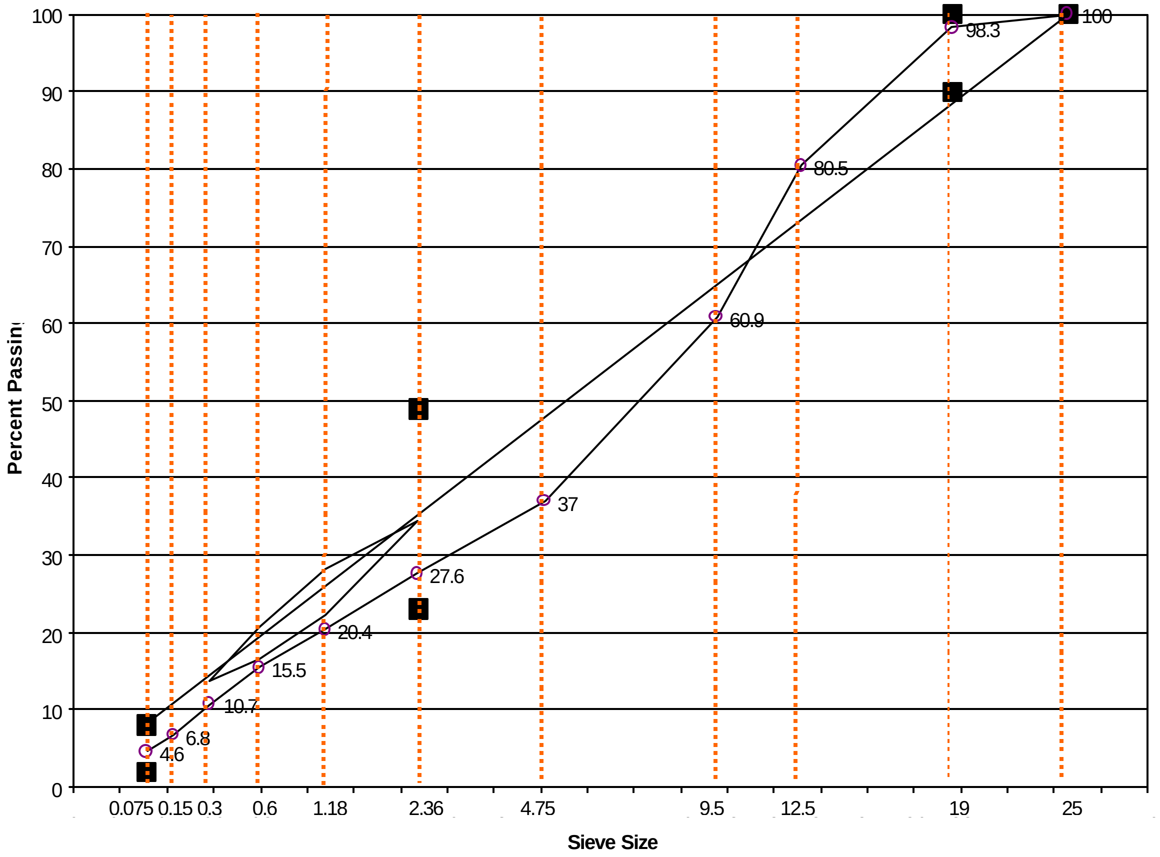
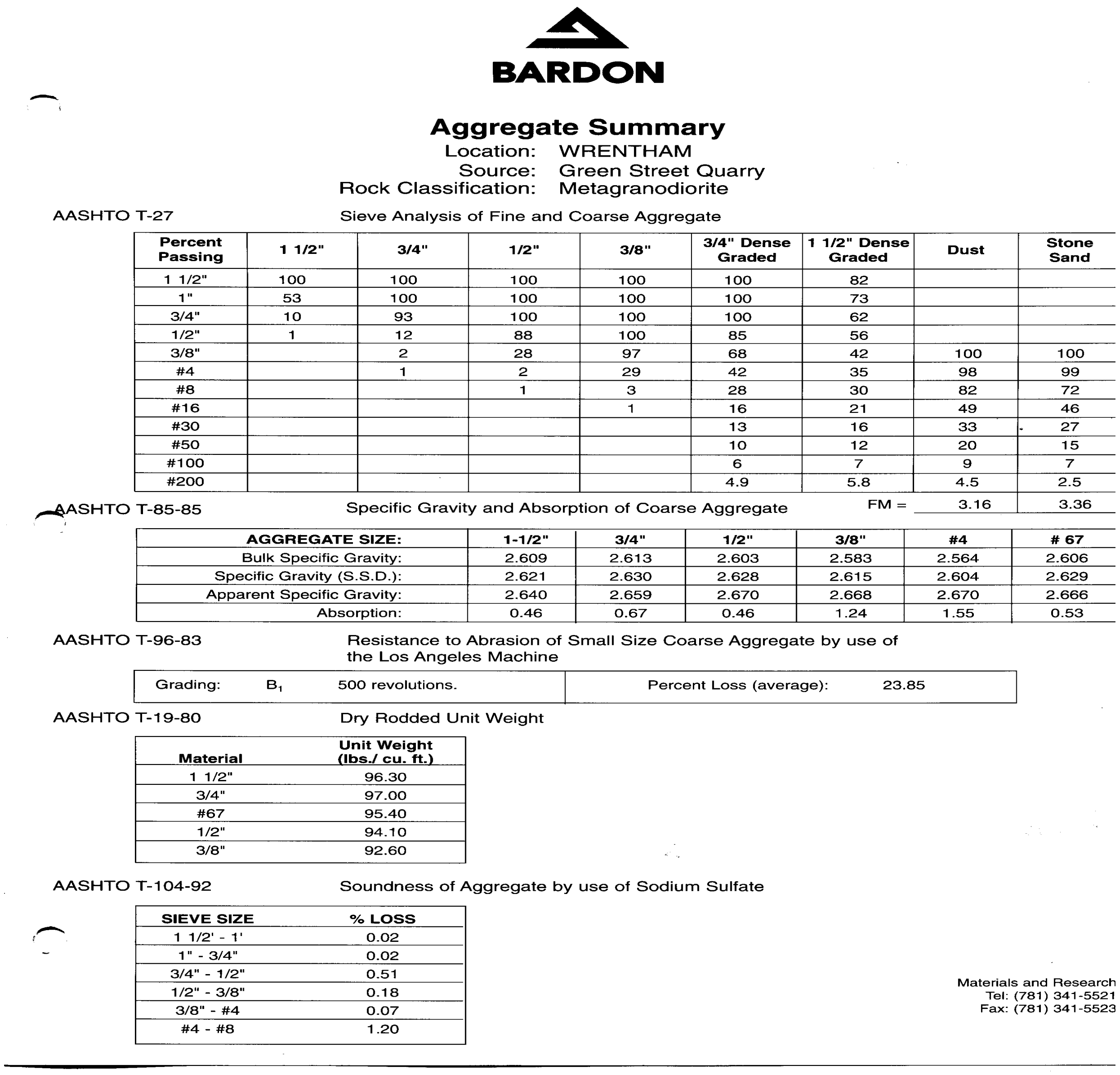


Figure 3
Properties of Mix Gradation, Aggregates, Shingles, and Asphalt Binder (cont.)



BARDON

Aggregate Summary

Location: WRENTHAM
Source: Green Street Quarry
Rock Classification: Metagranodiorite

AASHTO T-27 Sieve Analysis of Fine and Coarse Aggregate

Percent Passing	1 1/2"	3/4"	1/2"	3/8"	3/4" Dense Graded	1 1/2" Dense Graded	Dust	Stone Sand
1 1/2"	100	100	100	100	100	82		
1"	53	100	100	100	100	73		
3/4"	10	93	100	100	100	62		
1/2"	1	12	88	100	85	56		
3/8"		2	28	97	68	42	100	100
#4		1	2	29	42	35	98	99
#8			1	3	28	30	82	72
#16				1	16	21	49	46
#30					13	16	33	27
#50					10	12	20	15
#100					6	7	9	7
#200					4.9	5.8	4.5	2.5
						FM =	3.16	3.36

AASHTO T-85-85 Specific Gravity and Absorption of Coarse Aggregate

AGGREGATE SIZE:	1-1/2"	3/4"	1/2"	3/8"	#4	# 67
Bulk Specific Gravity:	2.609	2.613	2.603	2.583	2.564	2.606
Specific Gravity (S.S.D.):	2.621	2.630	2.628	2.615	2.604	2.629
Apparent Specific Gravity:	2.640	2.659	2.670	2.668	2.670	2.666
Absorption:	0.46	0.67	0.46	1.24	1.55	0.53

AASHTO T-96-83 Resistance to Abrasion of Small Size Coarse Aggregate by use of the Los Angeles Machine

Grading: B_1 500 revolutions.	Percent Loss (average): 23.85

AASHTO T-19-80 Dry Rodded Unit Weight

Material	Unit Weight (lbs./ cu. ft.)
1 1/2"	96.30
3/4"	97.00
#67	95.40
1/2"	94.10
3/8"	92.60

AASHTO T-104-92 Soundness of Aggregate by use of Sodium Sulfate

SIEVE SIZE	% LOSS
1 1/2' - 1'	0.02
1" - 3/4"	0.02
3/4" - 1/2"	0.51
1/2" - 3/8"	0.18
3/8" - #4	0.07
#4 - #8	1.20

Materials and Research
Tel: (781) 341-5521
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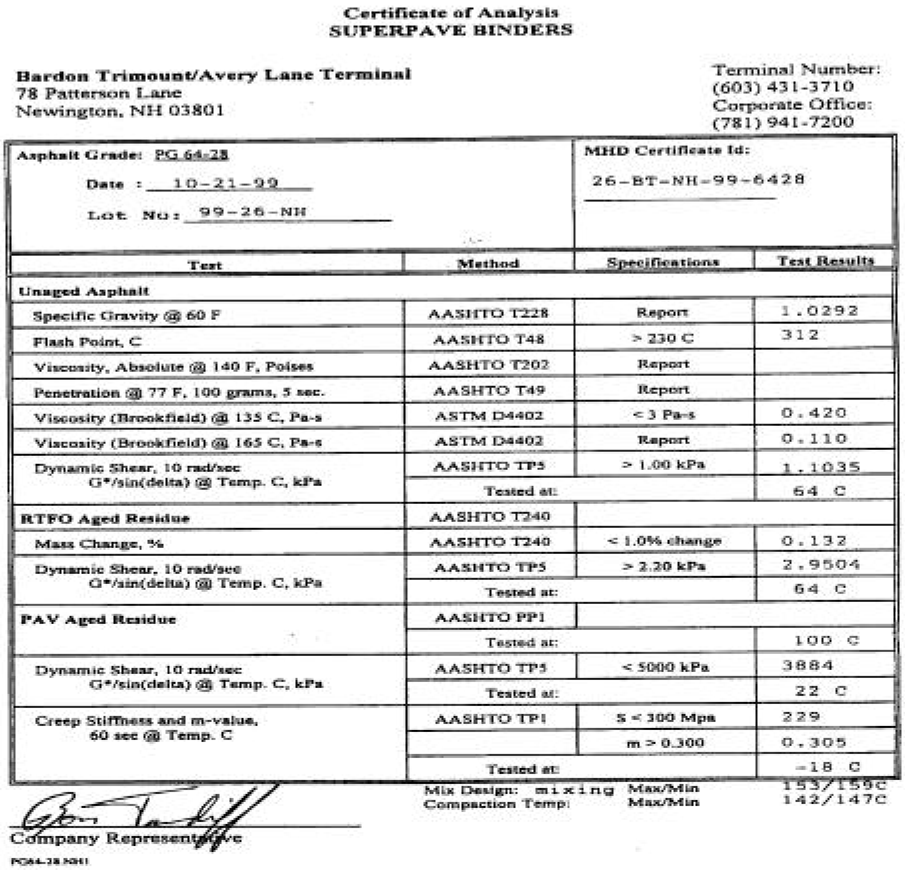
Figure 3
Properties of Mix Gradation, Aggregates, Shingles, and Asphalt Binder (cont.)

Asphalt Shingle Facts

Makeup	Asphalt	18-20%
	Limestone	39-40%
	Granules	30-33%
	Sand	5-7%
	Glass Mat	4-5%
Asphalt Fuel Value	158,500 btu/gal	
	20063 btu/pound	
	Crushed greenstone, Andesite or Rhyolite in a silicate clay coating	
	Greenstone – 40-50% silica, 15% aluminum oxide, 10% iron, calcium, magnesium and potassium oxides	
	Andesite is a black to gray rock with between 53 and 63% silica. Common minerals in andesite include plagioclase feldspar, pyroxene, and iron oxide, 15% aluminum oxide, 8% iron, calcium, magnesium and potassium oxides	
	Rhyolite is a light-colored rock with silica content greater than 68 weight percent. Sodium and potassium oxides both can reach about five weight percent. Common mineral types include quartz, feldspar and biotite. 15% aluminum oxide. 1%iron, calcium, and potassium oxides	
Limestone	Fine ground limestone; either dolomite or calcite	
Sand	Fine sand #60	
Mat	Nonwoven fiberglass mat	

Asphalt Binders



Certificate of Analysis
SUPERPAVE BINDERS

Bardon Trimount/Avery Lane Terminal
78 Patterson Lane
Newington, NH 03801

Terminal Number:
(603) 431-3710
Corporate Office:
(781) 941-7200

Asphalt Grade: PG 64-28 Date : 10-21-99 Lot No: 99-26-NH	**MHD Certificate Id:** 26-BT-NH-99-6428

Test	Method	Specifications	Test Results
Unaged Asphalt			
Specific Gravity @ 60 F	AASHTO T228	Report	1.0292
Flash Point, C	AASHTO T48	> 230 C	312
Viscosity, Absolute @ 140 F, Poises	AASHTO T202	Report	
Penetration @ 77 F, 100 grams, 5 sec.	AASHTO T49	Report	
Viscosity (Brookfield) @ 135 C, Pa-s	ASTM D4402	< 3 Pa-s	0.420
Viscosity (Brookfield) @ 165 C, Pa-s	ASTM D4402	Report	0.110
Dynamic Shear, 10 rad/sec G*/sin(delta) @ Temp. C, kPa	AASHTO TP5	> 1.00 kPa	1.1035
	Tested at:		64 C
RTFO Aged Residue	AASHTO T240		
Mass Change, %	AASHTO T240	< 1.0% change	0.132
Dynamic Shear, 10 rad/sec G*/sin(delta) @ Temp. C, kPa	AASHTO TP5	> 2.20 kPa	2.9504
	Tested at:		64 C
PAV Aged Residue	AASHTO PP1		
	Tested at:		100 C
Dynamic Shear, 10 rad/sec G*/sin(delta) @ Temp. C, kPa	AASHTO TP5	< 5000 kPa	3884
	Tested at:		22 C
Creep Stiffness and m-value, 60 sec @ Temp. C	AASHTO TP1	S < 300 Mpa	229
		m > 0.300	0.305
	Tested at:		-18 C

Mix Design: mixing	Max/Min	153/159C
Compaction Temp:	Max/Min	142/147C

Company Representative

PG64-28.NH1

Based on the information from Bardon Trimount, an asphalt percentage of 20% was assumed for the shingles. Accordingly, the percentage of virgin asphalt binder in the mixes was cut down to accommodate the asphalt binder from the shingles. Table 2 shows the actual percentage of virgin binder used for the different mixes. After mixing and aging, the asphalt content of each mix was determined with ignition oven testing. The asphalt content results are shown in Figure 3. The results indicate that the asphalt contents are very close to each other, and hence that the asphalt binder from the shingles did become a part of the mix. Hence, a lower amount of virgin asphalt binder can be used if shingles are used in the mix. The savings in virgin asphalt binder for different shingles content are shown in Figure 4.

Table 2. Amount of Asphalt Binder Added to The Different Mixes

Mix	**Binder Added**		**Shingles Added**
	%	**Gram**	**gram**
control	5.2	219.41	0
3 % shingles	4.6	192.87	129.68
5 % shingles	4.2	175.37	219.76
7 % shingles	3.8	158.00	312.97

Note: The given shingles contain about 20 % asphalt by weight

Figure 4. Asphalt Content of Different Mixes, as Determined from Ignition Test

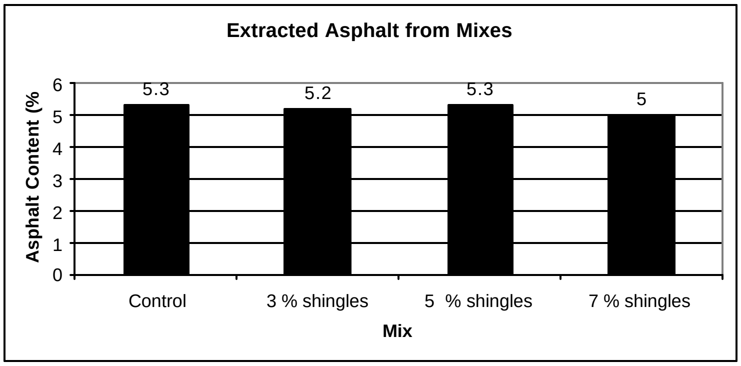
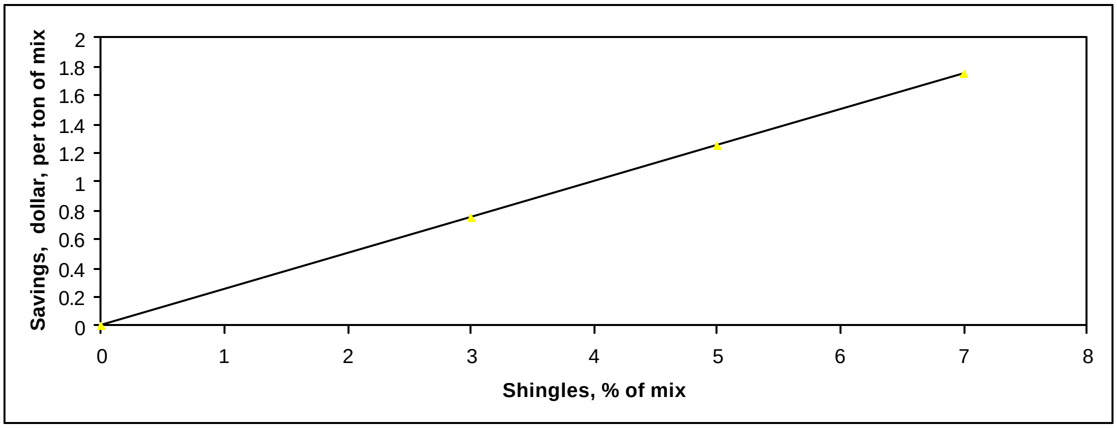


Figure 5. Savings in Using Shingles



Results of laboratory investigation with control and shingles modified mixes have shown that the addition of shingles at 3, 5 and 7% of aggregate weight does not cause any significant difference to volumetric properties, or high and low temperature properties. Figure 6 shows the test results for the HMA with and without shingles. The volumetric properties show that there is no significant difference between properties of HMA and HMA with shingles. The rut testing results show that addition of shingles actually helped reduce the rutting potential significantly. The low temperature results show that the properties of control and mix with shingles are not significantly different. Table 3 shows results of statistical analyses which shows that the volumetric and low temperature properties of the control and mixes with shingles are not significantly different, whereas the rut depths for the mixes with shingles are significantly lower than the rut depths of the control mixes.

Figure 6. Properties of Control Mix and Mixes with Shingles

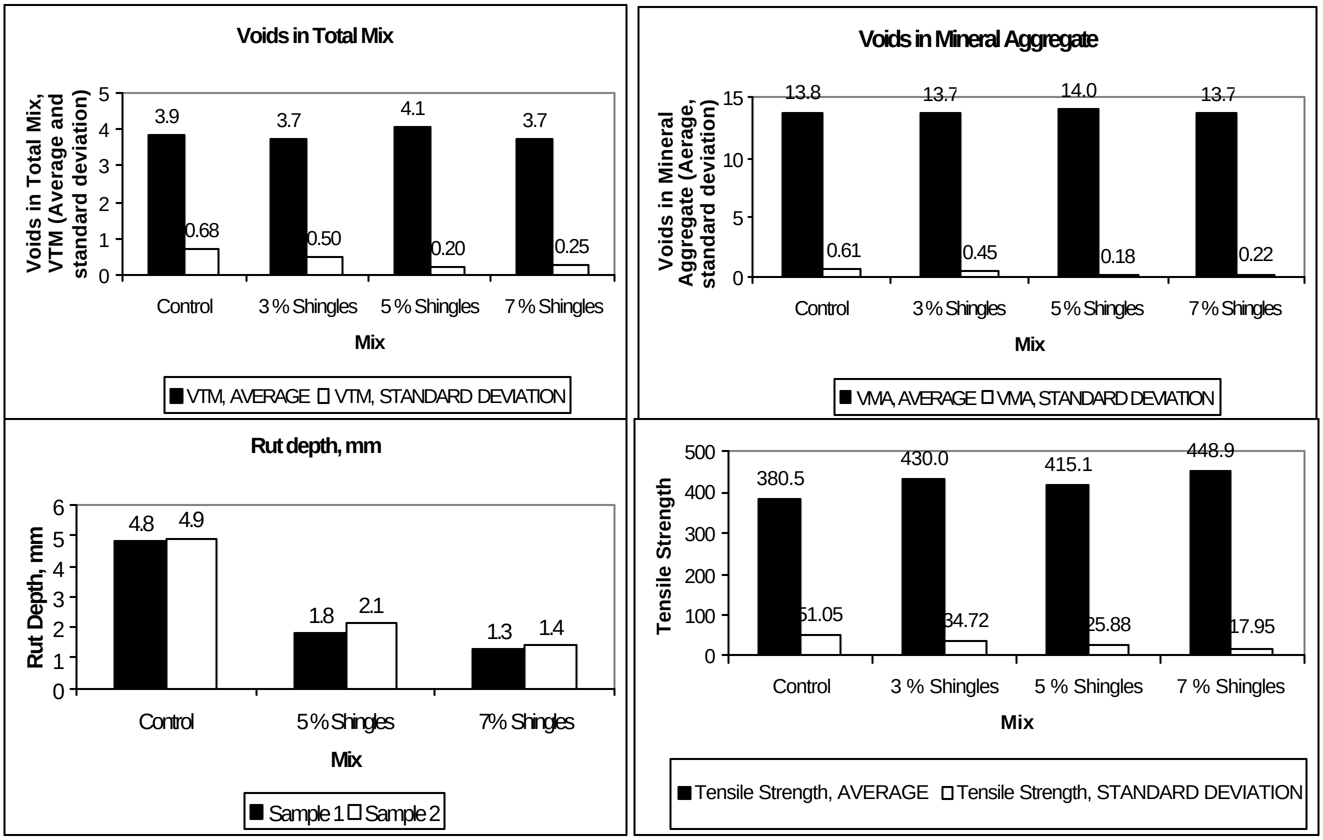


Table 3. Results of Statistical Analysis (level of significance, a = 0.05)

ANOVA Table for VTM

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Mix	3	.284	.095	.489	.6960	1.468	.120
Residual	12	2.321	.193				

Means Table for VTM
Effect: Mix

	Count	Mean	Std. Dev.	Std. Err.
Control	4	3.850	.645	.323
shingles_3_percent	4	3.747	.503	.252
shingles_5_percent	4	4.063	.203	.102
shingles_7_percent	4	3.727	.250	.125

CONCLUSION: Voids in Total Mix not significantly different since p-value>0.05

ANOVA Table for VMA

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Mix	3	.227	.076	.446	.7247	1.338	.114
Residual	12	2.035	.170				

Means Table for VMA
Effect: Mix

	Count	Mean	Std. Dev.	Std. Err.
Control	4	13.800	.627	.314
shingles_3_percent	4	13.708	.451	.225
shingles_5_percent	4	13.990	.182	.091
shingles_7_percent	4	13.690	.221	.111

CONCLUSION: Voids in Mineral Aggregate not significantly different since p-value>0.05

ANOVA Table for Rut Depth

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Mix	2	28.709	14.355	935.855	<.0001	1871.711	1.000
Residual	9	.138	.015				

Means Table for Rut Depth
Effect: Mix

	Count	Mean	Std. Dev.	Std. Err.
Control	4	4.915	.077	.038
shingles_5_percent	4	1.917	.185	.093
shingles_7_percent	4	1.410	.077	.038

CONCLUSION: Rut depths are significantly different since p-value<0.05

ANOVA Table for Tensile Strength

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Mix	3	10056.408	3352.136	2.792	.0859	8.375	.519
Residual	12	14409.126	1200.761				

Means Table for Tensile Strength
Effect: Mix

	Count	Mean	Std. Dev.	Std. Err.
Control	4	380.520	51.048	25.524
shingles_3_percent	4	430.055	34.720	17.360
shingles_5_percent	4	415.072	25.877	12.939
shingles_7_percent	4	448.938	17.946	8.973

CONCLUSION: Indirect Tensile Strength not significantly different since p-value>0.05

Figure 6 shows that the standard deviation of the test results for the voids in total mix (VTM) and voids in mineral aggregate (VMA) for the samples with shingles are significantly less than the standard deviation of the test results for the same properties for the samples without shingles. This shows that the either the shingles are quite consistent in their properties or that, at the low percentage used in this study (3, 5 and 7 %) any inconsistency in the properties of the shingles did not cause any significant effect on the properties of the mixes. A visual observation of the shingles indicated that the shingles were indeed very consistent in their properties.

6. Conclusions and Recommendations

The results from this study show that the use of manufactured waste shingles in HMA does not cause a significant difference in the quality of the HMA. Actually, the rutting resistance is improved by using manufactured waste shingles. Standard deviation of test results for mixes with shingles are low, indicating consistency in the quality of the shingles. Since the mixes with shingles were prepared with less asphalt binder than the control mixes, the results also show that the shingles contribute a significant amount of asphalt binder to the mix, and hence, using 5 % shingles, the amount of asphalt can be reduced significantly. This results in a saving of $1-$2 per ton of mix, in addition to the savings that is realized by not depositing the waste shingles in landfill. However, before any material can be used regularly in HMA, it must be evaluated under real-life production and construction conditions. Specific practical concerns with the use of shingles (for example, grinding and compaction), if any, would show up during production and construction monitoring, and post construction evaluation. Hence, it is necessary to conduct a field evaluation of use of shingles in HMA. Since 3 % shingles does not result in significant savings, it is recommended that test sections with 5 % shingles and control mix be constructed and evaluated for performance.

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