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Factors Affecting the Measurement of Effective Specific Gravity for Reclaimed Asphalt Pavement

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Abstract: Proper use of high amounts of reclaimed asphalt pavement (RAP) in recycled asphalt mixtures requires a better understanding of RAP properties before mix design to ensure confidence that RAP properties are not changed by the mix design or asphalt production process. This paper presents the results of an investigation into the measurement of effective specific gravity of RAP and if RAP has any propensity to absorb additional asphalt during mix design or production. Factors of heating time, heating temperature, warm mix additives and amount of virgin asphalt added to RAP were investigated. The factors included two warm mix additives, three mixing temperatures, three asphalt contents and three RAP sources for a total of 34 test conditions and 68 tests. Results indicate that RAP does not absorb noticeable amounts of virgin asphalt or existing RAP asphalt during mix design or under approximate production conditions. A proposed method to improve measurement simplicity for the effective specific gravity of RAP by first coating RAP samples with 2% virgin binder is also discussed.

Key words*: Asphalt absorption; Effective specific gravity; Reclaimed asphalt pavement.*

Introduction

Reclaimed asphalt pavement (RAP) is asphalt concrete that has been removed from an existing pavement after some un-quantified amount of environmental exposure and traffic. It is most commonly obtained by the cold milling of pavements as part of maintenance and rehabilitation activities. RAP may then be recycled into a new asphalt mixture with additional virgin aggregate and binder. Conservation of natural resources and reduced cost make recycled mixtures a viable alternative to all virgin asphalt mixtures [1-2]. In recent years, the advent of technologies allowing reduced production temperatures has generated interest in warm mix asphalt (WMA). The laboratory and field performance of WMA have been evaluated elsewhere [3-4]. The use of WMA for high RAP content mixtures (more than 25%) is an appealing concept to reduce cost and conserve natural resources.

A key issue with RAP is that the original properties of the asphalt mixture that became RAP are seldom known and instead must be measured in the material's current state before RAP can be recycled [5]. An important question is whether there exists the possibility for key RAP parameters to change during mix design or mixture production. For example, if RAP effective specific gravity (G_{se}) changes during mix design, the amount of effective asphalt or voids filled with asphalt in the final mixture can change, leading to performance problems in the field [6]. Calculation of RAP asphalt absorption requires a measurement of RAP G_{se}, which can present testing difficulties in the laboratory.

The objective of this paper is to evaluate factors that may affect the potential for the amount of asphalt absorbed by RAP aggregate to change during the mix design or production of hot or warm recycled mixtures with or without warm mix additives. In addition, an improved method for measurement of RAP G_{se} is suggested. The work presented in this paper is a precursor to the development of a method to predict quantities of absorbed, inert and effective bituminous components in RAP presented in [5].

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Experimental Program

Two experiments were performed to investigate the potential for additional absorption of asphalt by RAP aggregate and are described in following subsections. All testing was of 100% RAP with or without additional virgin binder, and no virgin aggregate was added. Maximum theoretical specific gravity (G_{mm}) was determined for all samples according to *AASHTO T 209-09*. Other variables used throughout this paper are as follows: G_{se} = effective specific gravity of aggregate determined by Eq. 1; P_{AC} = total asphalt content on mixture basis, including both virgin and RAP asphalt ($P_{be(V)} + P_{b(R)}$); $P_{be(V)}$ = virgin asphalt content on mixture basis (does not include RAP asphalt); and $P_{b(R)}$ = RAP asphalt content on mixture basis (does not include virgin asphalt). Additional discussion of the non-standard terms P_{AC}, $P_{be(V)}$, and $P_{b(R)}$ is given in Doyle et al. [5]. Eq. (1) was used to calculate G_{se} from G_{mm} test results. An asphalt binder specific gravity (G_b) of 1.03 was assumed for all calculations.

$$G_{se} = \frac{100 - P_{AC}}{\frac{100}{G_{mm}} - \frac{P_{AC}}{G_b}} \tag{1}$$

Materials Tested

Three RAP sources were tested. Properties are given in Table 1, including extracted aggregate gradation and specific gravities, as well as recovered asphalt viscosity and continuous performance grade (PG) temperatures. *R-1* and *R-2* RAP sources were obtained

Table 1. Properties of RAP Materials Tested After Asphalt Extraction.

RAP ID (Sieve Size)	R-1(% Passing)	R-2(% Passing)	R-3 (% Passing)
25.0 mm	100	100	100
19.0 mm	100	100	100
12.5 mm	96.5	99.8	92.2
9.5 mm	90.0	98.2	82.1
4.75 mm	60.1	73.1	55.5
2.36 mm	41.9	52.8	43.7
1.18 mm	34.1	40.3	38.5
0.60 mm	29.2	33.4	33.2
0.30 mm	19.5	22.9	20.6
0.15 mm	11.8	13.0	11.4
0.075 mm	8.4	9.3	7.3
G_{sb} [a]	2.483	2.526	2.504
G_{sa} [b]	2.600	2.597	2.577
Abs [c] (%)	1.8	1.1	1.1
P_{AC} (%)	5.5	5.6	5.0
Viscosity (Pa•s) [d]	52.9	9.1	26.5
Continuous PG	117.8+1.71 [e]	105.8-3.47	112.6+4.36 [e]

a) Bulk specific gravity of aggregate by *AASHTO T 84* and *T 85*.
b) Aggregate apparent specific gravity by *AASHTO T 84* and *T 85*.
c) Aggregate water absorption by *AASHTO T 84* and *T 85*.
d) Tested by *AASHTO T 316*, test temperature was 135℃.
e) *R-1* and *R-2* sources yielded positive low temperature PG grades.

from the surface milling of single pavements. *R-3* was obtained from a stockpile containing materials from several pavements. Much of the coarse aggregate had been stripped of its asphalt coating. To reduce experimental variability, all RAP material was sieved before use and then batched to meet a desired gradation.

Sasobit® and Evotherm™ 3G were the two warm mix additives investigated. Sasobit® is a wax additive used to promote compaction at warm mix temperatures. It was added at 1.0% of the total binder weight based on previous research [7]. Evotherm™ 3G is a chemical additive designed to promote mixing and compaction at warm mix temperatures. It was added at 0.5% of the total binder weight based on the manufacturer's recommendations. Warm mix additives were added to the heated RAP and virgin binder during the mixing process.

RAP Absorbed Asphalt Experiment 1

Table 3. Asphalt Contents for 100% RAP at Varying Conditions.

RAP Source	Total Asphalt Content (P_{AC}) Range	(%)	$P_{be(V)}$ (%)	$P_{b(R)}$ (%)
R-1	High	8.1	2.8	5.3
	Med	7.1	1.7	5.4
	Low	6.0	0.6	5.4
R-2	High	8.2	2.7	5.5
	Med	7.2	1.7	5.5
	Low	6.2	0.6	5.6
R-3	High	7.4	2.5	4.9
	Med	6.4	1.5	4.9
	Low	5.5	0.5	5.0

In the first RAP absorption experiment, RAP was heated in an oven for 2 hours at the mixing temperature, mixed with virgin asphalt, and then short-term aged for 1.5 hours at the same temperature. After short-term aging, the specimens were cooled and G_{mm} was determined. Three factors were investigated for the *R-1* RAP source: 1) additional virgin asphalt content (three levels: high, medium, and low); 2) RAP heating and compaction temperature (two levels: 116℃ and 138℃); and 3) warm mix additive (three levels: none, Sasobit® and Evotherm™ 3G). Based on experimental results with the *R-1* source, only the factor of additional virgin asphalt content was examined for the *R-2* and *R-3* sources. The factors and levels tested are given in Table 2, and asphalt content details are given in Table 3. Two G_{mm} replicates were prepared for each treatment of 48 total specimens.

RAP Absorbed Asphalt Experiment 2

The second RAP absorption experiment was performed on the *R-1* and *R-3* RAP sources. It consisted of testing eight G_{mm} replicates from two samples of RAP. The first sample of RAP was split. One half was used to determine G_{mm} (2 replicates), and the other half was heated for 2 hours at 171℃ then cooled and used to determine G_{mm}. The second sample of RAP was heated for 2 hours at 171℃ then mixed with 2% additional virgin binder (no warm mix). The second sample was split. One half was immediately cooled, and the other half was placed in an oven at the hot mix compaction temperature (146℃) for 4 hours before it was removed and cooled. G_{mm} was determined for each half of the second sample. A 4 hour short-term age was chosen as being conducive to producing a maximum potential for asphalt absorption. Hot mix temperatures were chosen in favor of warm mix temperatures, as they are more favorable to asphalt absorption.

A final component investigated the long-term potential for

Table 2. Experimental Design of 100% RAP at Varying Conditions.

RAP Source	Heating & Mixing Temp (℃)	Warm Mix Additive and Total Asphalt Content [Table 3] None High			Evotherm™ 3G 0.5% High			Sasobit® 1.0% High		
		None High	Med	Low	Evotherm™ 3G 0.5% High	Med	Low	Sasobit® 1.0% High	Med	Low
R-1	116	X	X	X	X	X	X	X	X	X
	138	X	X	X	X	X	X	X	X	X
R-2	138	X	X	X	NT	NT	NT	NT	NT	NT
R-3	138	X	X	X	NT	NT	NT	NT	NT	NT

Note: Experimental treatments with an X were tested; treatments with NT were not tested.

Table 4. Pooled Variance *t*-test Test for G_{se} of *R-1* RAP.

Comparison	n	Mean	Variance	t-stat	t-crit	Sig?
None	12	2.581	1.02×10^{-4}	1.56	±2.30	No
	12	2.575	4.36×10^{-5}			
None	12	2.581	1.02×10^{-4}	1.48	±2.30	No
Evotherm™ 3G	12	2.574	1.39×10^{-4}			

Note: Significance testing performed at the 95% confidence level.

Table 5. ANOVA Tests for G_{se} of *R-1*, *R-2*, and *R-3* RAP.

RAP	Source	df	SS (10^{-6})	MS (10^{-6})	F	P_{value}	Sig?
R-1	Temp	1	260.9	260.9	3.04	0.091	No
	P_{AC}	2	540.9	270.5	3.15	0.057	No
	Temp*P_{AC}	2	59.0	29.5	0.34	0.712	No
	Error	30	2573.5	85.8			
	Total	35	3434.4				
R-2	P_{AC}	2	41.8	20.9	0.80	0.525	No
	Error	3	77.9	26.0			
	Total	5	119.7				
R-3	P_{AC}	2	140.9	70.5	3.92	0.145	No
	Error	3	53.9	18.0			
	Total	5	194.8				

Note: Significance testing performed at the 95% confidence level.

asphalt absorption in *R-1* RAP. The RAP was heated for 15 minutes at 177℃ to crudely approximate the relatively short period of heating at a high temperature that RAP experiences in an asphalt plant during production. The RAP was then mixed with 2% additional virgin binder before short-term aging at 146℃ for 1 hour and 24 hours. One hour generally represents the shortest period of heating RAP may experience during production (i.e. mixing followed by transport and immediate placement), while 24 hours generally represents the longest period of heating RAP may experience (i.e. overnight storage in insulated asphalt silos before transport and placement). Two G_{mm} replicates were made and tested for each condition.

Results and Data Analysis

RAP Absorbed Asphalt Experiment 1

The first step in analysis is to evaluate the effects of warm mix additives on *R-1* RAP. A pooled variance *t*-test was used to compare replicates containing Sasobit® and Evotherm™ 3G to the replicates without warm mix additives (Table 4). Results indicate that there was no significant difference in the mean values for either comparison. With no statistical differences, all data with and without warm mix additives at a given temperature and asphalt content were grouped together for the next analysis.

The G_{se} data for *R-1* RAP was analyzed as a two-factor, completely randomized experimental design using an ANOVA test. Results are provided in Table 5. The interaction of temperature and total asphalt content was not significant. The main effects of temperature and total asphalt content were found to not be statistically significant, and therefore no additional statistical analysis was conducted. Overall, results indicate that the warm mix additives and temperatures tested did not induce any additional asphalt absorption for the *R-1* RAP source.

Temperature and warm mix additives were not considered for the two remaining RAP sources. G_{se} data for the *R*-2 and *R*-3 sources were analyzed independently as single factor, completely randomized experimental designs. Table 5 provides results of the ANOVA analyses. Based on the results, RAP total asphalt content was not found to be a significant parameter for G_{se} results for the *R-2* and *R-3* RAP sources. Overall, the amount of virgin asphalt added did not affect the determination of aggregate G_{se} for the *R-1*, *R-2*, or *R-3* RAP sources.

RAP Absorbed Asphalt Experiment 2

The as-received (unheated) data provided a baseline measurement of the RAP aggregate absorbed asphalt. The data after 2 hours of heating provided a measurement of whether any additional RAP asphalt was absorbed by the RAP aggregate. The sample without short-term aging provided a baseline measurement of new asphalt absorption for the mixture. The 4 hour short-term aging period at standard hot mix temperature (146℃) was selected to be favorable to new asphalt absorption and represents the best possible opportunity for additional asphalt absorption by the RAP aggregate.

The difference in G_{se} results for the two tested conditions is 0.012 for *R-1* and 0.010 for *R-3*. Both differences are less than the allowable range of 0.014 for four determinations of G_{mm} by a single operator. The allowable range of 0.014 was determined from a precision statement of *AASHTO T 209* and an appropriate multiplier for four tests by a single operator from *ASTM C 670*. For *R-1* RAP, two G_{mm} samples were prepared; one was aged for 1 hour, and the other was aged for 24 hours. The range of test results for the four G_{mm} samples was 0.013, which is also within the allowable single operator range of 0.014. All the results indicate that a negligible amount of additional asphalt (aged or virgin), if any, is absorbed by the *R-1* or *R-3* RAP aggregates during laboratory heating and short-term aging.

Improved Method to Measure G_{mm} for RAP

The standard *AASHTO T 209* test for G_{mm} is a simple and reliable test method. However, for uncoated RAP there is a tendency for fine material to be lost during the test, as evidenced by the dark cloud that appears in the water bath while obtaining the submerged mass of the sample. Also, broken RAP aggregate surfaces produced during the milling process can affect test results. It is much easier to obtain accurate G_{mm} measurements for G_{se} calculation with RAP coated with an additional 2% virgin asphalt on a mixture mass basis than with only the RAP.

2% virgin asphalt was selected for practicality in the laboratory. Table 6 provides evidence to suggest that results from the proposed method agree with those from *AASHTO T 209*. Fig. 1 illustrates the differences between as-received RAP and RAP coated with virgin asphalt. *R-3* RAP was selected as the example in Fig. 1, as it had the most uncoated aggregates of all the sources tested. Some aggregate had stripped during service, but test data show that the asphalt remained in the aggregate pores leading to consistent G_{se} measurements. RAP that has been contaminated with base material

Table 6. Results of Absorbed Asphalt Experiment 2.

Material Tested	Condition	P_{AC} (%)	G_{mm} [a]	G_{se}
R-1 + 0% $P_{be(V)}$	As-received	5.5	2.382	2.579
R-1 + 0% $P_{be(V)}$	2 hr. heat at 171℃	5.5	2.373	2.567
R-1 + 2% $P_{be(V)}$	2 hr. heat at 171℃, no aging	7.4	2.315	2.571
R-1 + 2% $P_{be(V)}$	2 hr. heat at 171℃, 4 hr. aging at 146℃	7.4	2.319	2.577
		R-1 G_{se} Summary: Average 2.574		Range 0.012
R-3 + 0% $P_{be(V)}$	As-received	5.0	2.415	2.599
R-3 + 0% $P_{be(V)}$	2 hr. heat at 171℃	5.0	2.422	2.608
R-3 + 2% $P_{be(V)}$	2 hr. heat at 171℃, no aging	6.9	2.351	2.598
R-3 + 2% $P_{be(V)}$	2 hr. heat at 171℃, 4 hr. aging at 146℃	6.9	2.358	2.608
		R-3 G_{se} Summary: Average 2.603		Range 0.010

a) Average of two measurements.

Fig. 1. Loose *R-3* RAP Samples with and without Virgin Binder.

that has never been coated with asphalt would cause difficulty, whereas stripped aggregate does not appear to cause difficulty.

Summary and Conclusions

The data in this paper provide evidence that G_{se} can be reliably and efficiently determined by measuring G_{mm} on RAP coated with additional virgin binder. The evidence is supported by data showing that RAP does not absorb any noticeable amounts of virgin asphalt. Factors of heating time, heating temperature, warm mix additives and amount of virgin asphalt added to RAP were all investigated and found to not produce any statistically significant changes in RAP G_{se}. Since G_{se} is directly related to absorbed asphalt content for a given aggregate, this result indicates that the quantity of RAP absorbed asphalt was not changed by any of the factors examined for the three test RAP sources. The difficulty in testing G_{mm} on RAP versus the ease of determining G_{mm} on RAP coated with virgin binder was also discussed.

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