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RELATING ASPHALT ABSORPTION TO PROPERTIES OF ASPHALT CEMENT AND AGGREGATES

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May 1992

**Presented at the Annual Meeting of the Transportation Research Board
in Washington, DC, January 12-16, 1992**



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ABSTRACT

Mineral aggregates used in hot mix asphalt (HMA) mixtures have some porosity and as such tend to absorb some amount of asphalt cement. Several indirect and direct methods for estimating or determining asphalt absorption have been researched in the past. However, there is a need to study the asphalt absorption phenomenon as related to the physical properties of the mineral aggregate and asphalt cement binder.

Eight mineral aggregates of different absorptive characteristics, geologic origin and mineral compositions were selected from the SHRP Materials Reference Library (MRL). Four asphalt cements ranging from AC-5 to AC-30 grades were also obtained from SHRP MRL. A total of 96 HMA mixtures were prepared and tested for asphalt absorption. Physical properties of aggregates (including pore characteristics) and asphalt cements were determined.

Generally, the asphalt absorption decreased with increase in viscosity (at the mixing temperature) of the asphalt cement. A high percentage of maltene (oil) fraction in asphalt cement is likely to increase the total asphalt absorption possibly due to selective absorption. There appears to be a threshold pore diameter of 0.05 micron in the aggregate below which no appreciable asphalt absorption takes place. The most important pore size range affecting the asphalt absorption appears to be 0.05-0.1 microns.

RELATING ASPHALT ABSORPTION TO PROPERTIES OF ASPHALT CEMENT AND AGGREGATES

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INTRODUCTION

Mineral aggregates used in hot mix asphalt (HMA) mixtures have some porosity and as such tend to absorb some amount of asphalt cement. Although some absorption may lead to improved strength in a compacted mixture through particle interlocking, the portion of the asphalt that is absorbed is no longer available as binder (1). The situation is further aggravated because of the time-dependent nature of the absorption phenomenon. Moreover, the asphalt available in thin films serving as a binder may have different physical, chemical and theological properties if selective absorption takes place (2). The absorption of asphalt in mineral aggregates may cause the following which may lead to premature failure of the asphalt paving mixtures (1):

1. Incorrect computation of percent air voids, voids in mineral aggregate or voids filled with asphalt. Since one or more of these are generally used as criteria for asphalt mixture design, incorrect calculations may lead to mixtures lacking durability or stability.
2. Not having enough effective binder may lead to ravelling, cracking, or stripping.
3. Possible premature age hardening and low temperature cracking as a result of changes in asphalt properties due to selective absorption.
4. Construction problems such as segregation and tender mixes.

In view of the above consequences, the absorption of asphalt by mineral aggregates needs to be studied. Often times aggregates having relatively high asphalt absorption may have to be utilized either because of high quality aggregates getting depleted at an ever increasing rate or because geographic proximity often predicates the use of such aggregates.

Most highway agencies utilize the Rice method (maximum theoretical specific gravity of voidless paving mixtures) in calculating the amount of asphalt absorbed. Other methods such as bulk impregnated specific gravity are also used. Also, some aggregates have been observed to continue to absorb asphalt with time during construction and the early life of an asphalt pavement.

Hot mix asphalt (HMA) mixtures which appear very rich during production can get leaner and leaner with time inducing premature ravelling and/or cracking (3). There is a need to study the asphalt absorption phenomenon as related to the properties of the mineral aggregate and asphalt cement binder.

REVIEW OF LITERATURE

Many investigators in the past have attempted to evaluate asphalt absorption of aggregates through correlations with absorption using other liquids of which kerosene has been the most commonly used. Hveem (4) devised the centrifuge kerosene equivalent test (CKE) in 1942. The CKE is defined as the quantity of kerosene absorbed by 100-g of aggregate under specified conditions of soaking and centrifuging. It has been shown to be a function of the surface area and absorptive capacity of the aggregate and has been used as a part of the design of bituminous mixtures by Hveem method. Lohn (5) also used a similar approach and correlated asphalt absorption of an aggregate with kerosene absorption. He studied the effects of factors such as saturation time, centrifuge force and centrifuge time as well and finally adopted 10 minutes of saturation and 8 minutes of centrifuging at a force of 400 times gravity. Donaldson et al (6) further proposed some modifications to the Hveem CKE method by increasing the soaking time to 30 minutes and by testing a non-absorptive aggregate of the same gradation for the purpose of

comparison. Since kerosene has wetting properties similar to that of asphalt, it has been believed to give a better representation as an absorption agent as compared to water (6, 7). A modified CKE procedure was developed by Cechetini (8), which can determine the surface areas and evaluate absorptive behavior of crushed aggregate mixes. Together with this information and the data characterizing the asphalt to be used, the amount of asphalt needed by an aggregate can be determined from a nomograph. Some other investigators (9, 10) have tried to use oils to evaluate the absorptive capacity of coarse aggregates. However, because of the differences in wetting properties and viscosities of these liquids and asphalts, only approximate estimations could be made of the asphalt absorption of the aggregates.

In 1936, a procedure was described by Reigel (11) for determination of relative absorption of water and liquid bituminous material by the coarse aggregate using a water displacement method. It was recommended that absorption of liquid bituminous material be estimated at 75 percent of the water absorption.

In 1942, Goshorn and Williams (12) developed the immersion method. The aggregate is in contact with an unlimited supply of asphalt at relatively low viscosity for an extended period of time in this method. Therefore, the absorption is much higher than would be expected in actual HMA mixtures (13). Rice (14, 15) proposed a vacuum procedure to determine the maximum specific gravity of the voidless HMA mixture. In this method, the absorption of asphalt by aggregates is calculated from the maximum specific gravity of the mixture, the asphalt content, and the bulk specific gravity of the aggregate used in the HMA mixture. This method is now standardized as ASTM D2041.

A different approach was used by Larsen (16) who conducted a high pressure test instead of vacuum saturation to determine the effective specific gravity of the aggregate. Asphalt absorption was calculated as percent of the volume of aggregate and ranged from 26 to 88 percent of the water absorption.

The U.S. Army Corps of Engineers (17, 18) developed and has used the bulk impregnated specific gravity in the design and control of bituminous mixtures. It is a function of the ratio of asphalt to water absorption, which varies widely but follows a definite pattern with different types of aggregates. The asphalt absorption can be found knowing the bulk impregnated specific gravity of the mixture, the bulk specific gravity of the aggregate and the specific gravity of the asphalt used in the HMA mixture.

Absorption of asphalt by aggregates has also been determined by calorimetric analysis with photometer (13). The basic principle is that the amount of light absorbed by a given solution is proportional to the intensity of the incident light and to the concentration of the absorbing species in the path of the light beam. However, only solutions of light concentration can be used and the mechanism of absorption of asphalt in solution is likely to be different from that in an HMA mixture.

Cross-sectional measurements have also been employed to evaluate asphalt absorption (13). Compacted specimen of the HMA mixture is cut in halves by a diamond saw to expose the inner surface of the aggregates. The sample is then placed in an opaque projector and from its image projected on a screen, tracings are made of the external contours of the rock particles and lines of deepest asphalt penetration. The total area of a particle and area penetrated by the asphalt are measured by a planimeter, and the percentage of asphalt absorption is calculated. Limitations of this method are selective absorption of asphalt and different sizes of aggregate in a mixture.

More recently the Methylene Blue test has been used in Europe to indirectly measure the absorption/adsorption, surface area, cationic exchange capacity, soundness, and overall clay characteristics of aggregates. This test, first developed in France (19), uses Methylene Blue to

quantify the absorption/adsorption of an aggregate. The method has serious limitations: (a) a powdered aggregate is used, and (b) no asphalt cement is used.

Franco and Lee (20) have recently evaluated the viability of using an air meter for determining the maximum specific gravity of HMA mixtures. The air meter normally has been used for determining the percent of air entrained in Portland cement concrete.

Thus many methods of estimating or determining the amount of asphalt cement absorbed by the mineral aggregate have been researched in the past. However, very few studies (21, 22) have been conducted to determine the effect of the properties of mineral aggregate and asphalt cement binder on asphalt absorption.

OBJECTIVES

This research project was undertaken as a part of SHRP A-O03B to study asphalt absorption as related to the physical properties of mineral aggregate and asphalt cement binder.

MATERIALS USED

All the materials used in this study were obtained from the Strategic Highway Research Program (SHRP)'s Materials Reference Library (MRL).

Aggregates

SHRP MRL has eleven different aggregates, eight of which were used in this study. The aggregates used were:

- RB - Watsonville Granite
- RC - McAdam Limestone
- RD - Frederick Limestone
- R F - Glacial Gravel
- RG - Commercial Sandstone
- RJ - Wyoming Gravel
- RK - Blue Mountain Basalt
- RL - Texas Gulf Coast Gravel

These aggregates were selected to include all SHRP core aggregates, to encompass the complete range of water absorption, and to include aggregates of different geologic origins and mineralogical composition. Only one size aggregate, i.e., passing 1/2-in. sieve and retained on 3/8-in. sieve was used. The bulk specific gravity and water absorption of the aggregates, as determined by ASTM C127, along with their code names are reported in Table 1. The core aggregates are also identified.

Table 1. Properties of Aggregates Used

Aggregate	Source	Bulk Specific Gravity**	Water Absorption** (% Wt. Agg.)
RB	Watsonville Granite	2.692	1.68
RC*	McAdam Limestone	2.485	2.88
RD*	Frederick Limestone	2.713	0.38
RF	Glacial Gravel	2.700	1.39
RG	Commercial Sandstone	2.660	0.49
RJ*	Wyoming Gravel	2.653	0.56
RK	Blue Mountain Basalt	2.828	1.73
RL*	Texas Gulf Coast Gravel	2.590	0.72

* Core aggregate

** Determined by ASTM C127

Asphalt Cements

The asphalt cements used in this study were:

AAB-2	- Wyoming Sour	(AC-5)
AAK-2	- Boscan	(AC-10)
AAM-1	- West Texas	(AC-20)
AAK-1	- Boscan	(AC-30)

Various properties of these four asphalt cements, as obtained from SHRP MRL, and their code names are given in Table 2. These asphalt cements were selected to encompass all viscosity graded asphalt cements commonly used for paving. All four were SHRP core asphalt cements.

TESTING PLAN AND PROCEDURES

This study was divided into two phases. For phase 1, a design consisting of 8 aggregates x 4 asphalt cements (8x4) was employed with 3 replicates for each treatment combination giving a total of 96 tests. The replicates were considered as blocks and the design was a completely randomized blocked design.

Phase 2 involved the determination of various properties of the eight aggregates and four asphalt cements mentioned above. The various properties determined were:

Asphalt cements:	Viscosity, maltene viscosity.
Aggregates:	Pore volume, pore diameter, pore size distribution, particle shape and texture, and water absorption.

Separation of asphalt cements into maltene and asphaltene fractions was done using ASTM D4124. Viscosity of the maltene fraction of asphalts was then determined using ASTM D2171. Pore volumes, pore diameters, and pore size distributions were determined through mercury porosimetry. Index of particle shape and texture was determined using ASTM D3398 and water absorption was determined using ASTM C127. In addition to the standard procedure, a variation was done in the determination of water absorption by subjecting the aggregates to a residual pressure of 30 mm of Hg under water for 10 minutes before soaking for 24 hours. During mercury porosimetry, mercury was injected in the pores of aggregate at increasing pressures and

Table 2. Properties of Asphalt Cements Used

Property	Asphalt Cement			
	MB-2	AAK-2	AAM-1	AAK-1
Grade	AC-5	AC-10	AC-20	AC-30
<u>Original Asphalt Cement</u>				
Specific Gravity	1.014	1.027	0.993	1.035
Viscosity at				
140°F Poise	403	996	1992	3256
275°F, cSt	193	320	569	562
Penetration, 0.1 mm (77°F, 100 g, 5 sec)	166	154	64	70
Ductility, cm (39.2°F, 1 cm/min)	81.0	150+	4.6	27.8
Softening Point (R&B), °F	115	108	125	121
Component Analysis				
Asphaltenes (n-heptane)	16.7	20.5	3.9	21.1
Polar Aromatics	35.7	39.4	50.3	41.8
Naphthene Aromatics	36.5	30.6	41.9	30.0
Saturates	10.8	7.5	1.9	5.1
Element Analysis				
Nitrogen, %	0.50	0.70	0.50	0.80
Sulfur, %	5.40	6.90	2.40	6.60
Vanadium, ppm	163	1165	60	1427
Nickel, ppm	36	117	29	128
<u>Thin Film Oven Test</u>				
Mass Change, %	-0.0149	-1.2305	+0.0516	-0.5483
Viscosity of TFOT Residue at				
140°F, poise	1073	3098	3947	9708
275°F, cSt	263	533	744	930
Viscosity Ratio (140°F)	2.66	3.11	1.98	2.98

the change in volume were measured. The pore radius, r , related to any pressure, p , based on cylindrical pores, was computed using the Washburn (23) equation:

$$r = \frac{2\sigma \cos\theta}{p}$$

where, σ = Surface tension of mercury
 θ = Contact angle between aggregate and mercury

This data was then used to determine the cumulative porosity of the aggregate up to each pore diameter and its pore size distribution. It should be realized that pores are not necessarily cylindrical in shape. Nevertheless, this assumption has to be made for simplicity.

No statistical experiment design was used for this phase.

DISCUSSION OF RESULTS

During phase 1 of the study, Rice method with 4 hours of aging in the oven at 290°F was used to determine asphalt absorption values for all the combinations of the eight SHRP MRL aggregates and four SHRP MRL asphalt cements used in this study. Four hours aging was established by the authors in a previous SHRP study (24) to ensure that all potential asphalt absorption takes place before testing. Various asphalt cement and aggregate properties were also determined during phase 2 of the study for developing correlations with asphalt absorption values.

The data obtained from the study is reported in Tables 3 and 4. Table 3 shows the asphalt absorption values as percent by weight of aggregate for the aggregate and asphalt combinations used during this study. Table 4 gives a summary of the properties of aggregates used in this study. The properties reported include the bulk specific gravity and absorption data, results from mercury porosimetry and the particle shape and texture index data as obtained using ASTM D3398. The 24-hr soaked values were determined using ASTM C127. In addition, the aggregates were subjected to a residual pressure of 30 mm Hg under water for 10 minutes before running ASTM C127. These values are referred to as vacuum + 24-hr soaking in Table 4. The bulk specific gravity of the aggregates used was also determined using mercury porosimetry at atmospheric pressure. Water absorption values shown under mercury porosimetry were back-calculated using the cumulative porosity of aggregates and their bulk specific gravity as determined by mercury porosimetry. An analysis of variance (ANOVA) was conducted for the phase 1 data presented in Table 3 and is reported as Table 5. It can be seen that both asphalt cements (A) and aggregates (B) significantly affect asphalt absorption at $\alpha = 0.05$. The interaction AXB (asphalt cements x aggregates) is also found to be significant at $\alpha = 0.05$.

The variation of asphalt absorption values with the viscosity at 290°F (of the original asphalt cements) is shown in Figures 1 and 2. The asphalt absorption, in general, decreases with increase in viscosity of the asphalt cement used. However, the absorption for AAM-1 (AC-20) is somewhat higher than that for AAK-1 (AC-30) although viscosity (at 290°F) of AAM-1 is more than that of AAK-1.

Table 3. Absorption Values from Phase 1 Experiments (Percent by Weight of Aggregates)

Asphalt Cement	MB-2 Wyoming Sour (AC-5)	AAK-2 Boscan (AC-10)	MM-1 West Texas (AC-20)	MK-1 Boscan (AC-30)
Aggregate				
RB - Watsonville Granite	0.92	0.81	0.95	0.70
Water Abs. = 1.68%	0.89	0.71	0.84	0.67
Bulk S.G. = 2.692	0.69	0.66	0.81	0.75
Avg. =	0.83	0.73	0.87	0.71
RC - McAdam Limestone	1.16	0.68	0.95	0.63
Water Abs. = 2.88%	1.07	0.85	0.87	0.67
Bulk S.G. = 2.485	1.06	0.76	1.00	0.70
Avg. =	1.10	0.76	0.94	0.67
RO - Frederick Limestone	0.17	0.21	0.24	0.15
Water Abs. = 0.38%	0.19	0.21	0.20	0.12
Bulk S.G. = 2.713	0.15	0.11	0.15	0.18
Avg. =	0.17	0.18	0.20	0.15
RF - Glacial Gravel	0.37	0.70	0.37	0.43
Water Abs. = 1.39%	0.52	0.54	0.38	0.40
Bulk S.G. = 2.700	0.43	0.49	0.38	0.42
Avg. =	0.44	0.58	0.38	0.42
RG - Commercial Limestone	0.20	0.09	0.19	0.12
Water Abs. = 0.49%	0.13	0.09	0.12	0.11
Bulk S.G. = 2.660	0.13	0.06	0.08	0.09
Avg. =	0.15	0.08	0.13	0.11
RJ - Wyoming Gravel	0.18	0.14	0.18	0.03
Water Abs. = 0.56%	0.11	0.22	0.10	0.14
Bulk S.G. = 2.653	0.27	0.15	0.17	0.35
Avg. =	0.19	0.17	0.15	0.17
RK - Blue Mountain Basalt	0.04	0.09	0.07	0.04
Water Abs. = 1.73%	0.07	0.11	0.05	0.02
Bulk S.G. = 2.828	0.09	0.06	0.05	0.01
Avg. =	0.07	0.09	0.06	0.02
RL - TX G. Coast Gravel	0.23	0.10	0.13	0.21
Water Abs. = 0.72%	0.16	0.31	0.25	0.15
Bulk S.G. = 2.590	0.20	0.33	0.23	0.20
Avg. =	0.20	0.25	0.20	0.19

Table 4. Aggregate Properties from Phase 2 Experiments

Aggregate source		Bulk Specific Gravity			Water Absorption (% Wt. Agg.)			Median Pore Dia. (Micron)		Index of Particle Shape & Texture
		Vacuum+		Mercury Porosimetry	Vacuum+		Based on Volume	Based on Surface Area		
		24-hr Soaking	24-hr Soaking		24-hr Soaking	24-hr Soaking				
RB	Watsonville Granite	2.692	2.709	2.759	1.68	1.58	0.76	0.054	0.006	14.6
RC	McAdam Limestone	2.485	2.494	2.467	2.88	2.95	3.40	0.178	0.015	13.2
RD	Frederick Limestone	2.713	2.722	2.8W	0.38	0.28	0.29	0.013	0.006	15.2
RF	Glacial Gravel	2.700	2.707	2.638	1.39	1.46	1.87	0.119	0.007	12.9
RG	Commercial Limestone	2.660	2.659	2.662	0.49	0.49	0.31	0.010	0.006	17.8
RJ	Wyoming Gravel	2.653	2.650	2.640	0.56	0.61	0.71	0.026	0.005	12.7
RK	Blue Mountain Basalt	2.828	2.821	2.831	1.73	1.80	0.18	0.006	0.005	14.1
RL	Texas Gulf Coast Gravel	2.590	2.589	2.589	0.72	0.80	0.45	0.008	0.005	11.9

Table 5. ANOVA for Absorption Data from Phase II Experiments

Source	df	SS	MS	Fo	'Crit.
Total	95	57.784			
Aggregates (A)	7	52.751	7.5358	265.4	2.2*
Asphalt Cements (B)	3	0.757	0.2522	8.9	2.8*
AxB	21	2.506	0.1193	4.2	1.8*
Blocks (Replicates)	2	0.011			
Error	62	1.760	0.0284	--	--

* Significant at $\alpha=0.05$

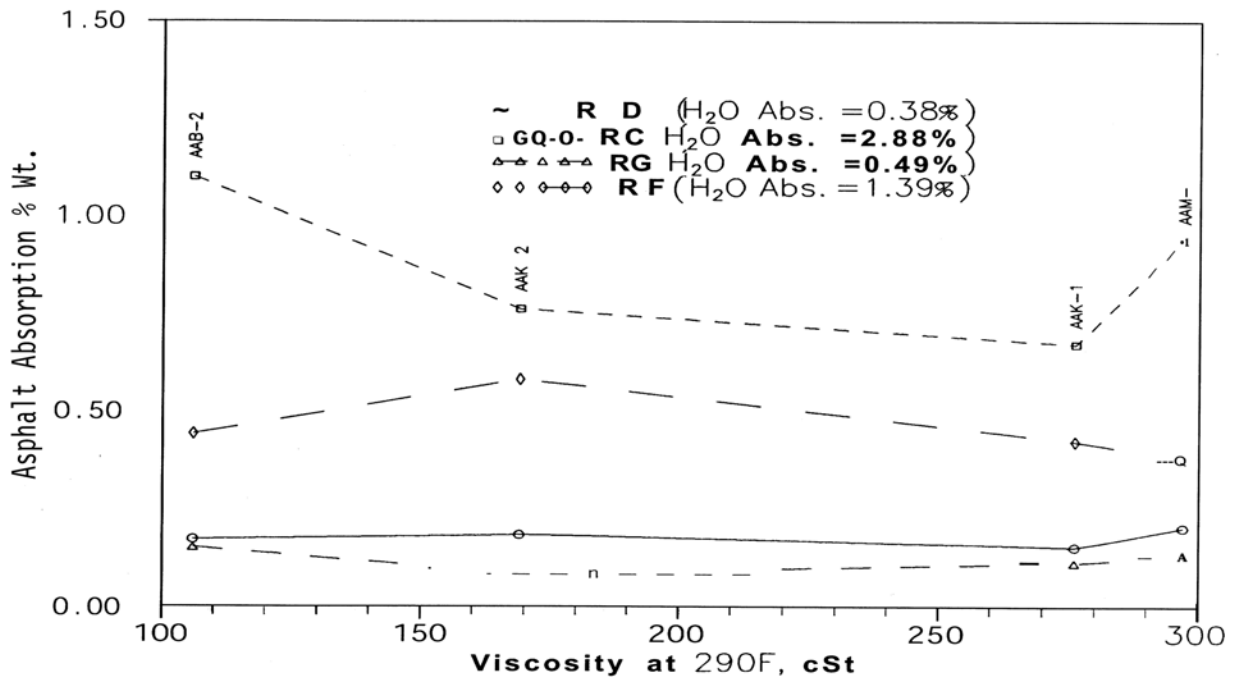


Figure 1. Asphalt Absorption vs. Viscosity of Asphalt Cement

It was suspected that the viscosity of the maltene (oil) fraction of AAM-1 might be lower than that of AAK-1 giving rise to selective absorption. Both of these asphalt cements were thus separated into asphaltene and maltene fractions using ASTM D 4124. The maltene fractions thus obtained were tested for viscosity at 140°F. Three samples were tested for each asphalt cement and the results obtained are given below:

Asphalt Cement	AAK-1	AAM-1
Grade	AC-30	AC-20
Absolute Viscosity of maltene fraction at 140°F, Poise	91 58 110	1,218 2,034 1,584
Average	86	1,584

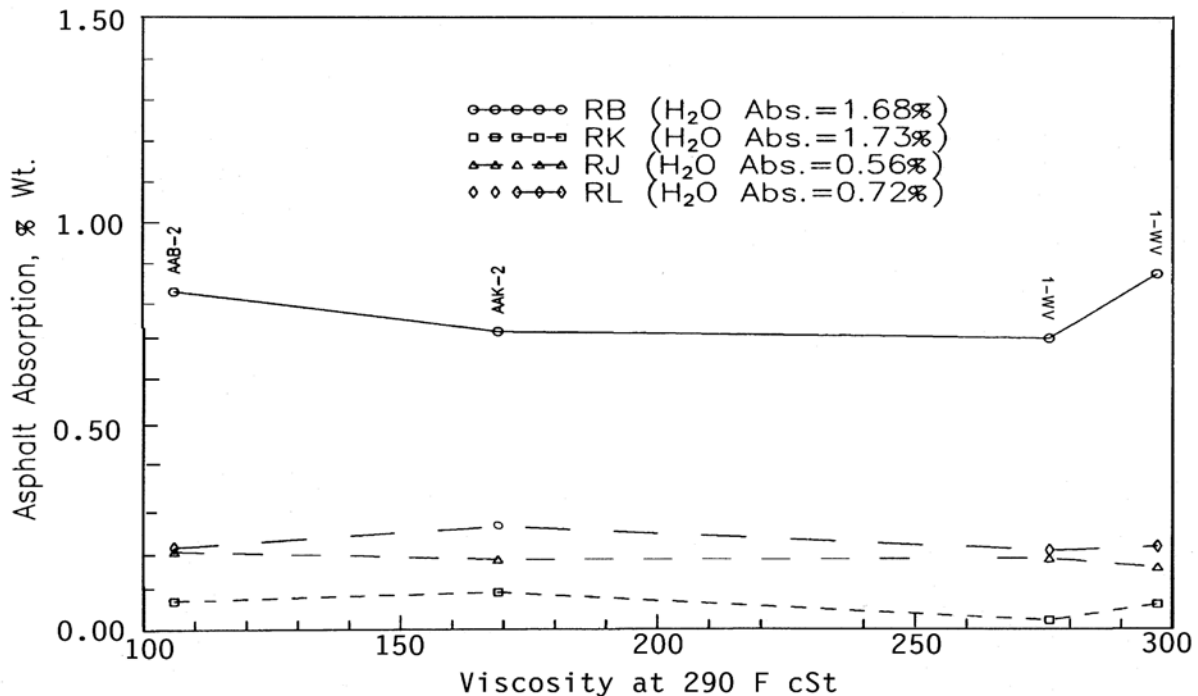


Figure 2. Asphalt Absorption vs. Viscosity of Asphalt Cement

It can be seen from the data above that the viscosity of maltene fraction of AAM-1 is also higher as compared to that of AAK-1 and hence does not explain why AAM-1 would be absorbed more than AAK-1. However, an interesting thing to note is that the maltene fraction of AAM-1 (96.1 percent) is much higher as compared to that of AAK-1 (78.9 percent) as can be calculated from data reported in Table 2. This means that the maltene content of an asphalt cement may affect the amount of asphalt cement absorbed by the aggregate.

The asphalt absorption is also plotted against water absorption as shown in Figure 3. There is a definite general relationship between the water and asphalt absorption values. There are some exceptions to this general trend, however. Aggregates RB and RK both have almost the same water absorption, however, RK absorbs considerably less asphalt cement as compared to RB. This can be explained by looking at the pore size distribution curves Figures 4 and 5 for the two aggregates where aggregate RB is seen to have a considerable amount of pores of large diameter while RK has much smaller pores.

The particle shape and texture data as reported in Table 4 was also correlated with asphalt absorption values, however, no relationships were noticed. Further investigation into correlations between material properties and asphalt absorption was conducted using mercury porosimetry data obtained for all the eight aggregates used in the study. This data is reported in summary form in Table 4. The asphalt absorption data was also transformed to percent by volume of aggregates. The mercury porosimetry data was further analyzed to obtain:

1. Forward cumulative porosities (from start of intrusion) up to the pore sizes of 100, 50, 25, 10, 5, 2, 1, 0.5, 0.2, 0.1, 0.05, 0.01, and 0.0035 microns.
2. Backward cumulative porosities (increasing pore size) up to the pore sizes of 0.01, 0.05, 0.1, 0.2, 0.5, 1, 2, 5, 10, 25, 50 and 100 microns. Backward cumulative were obtained to give an insight into a threshold pore size above which the value of R^2 suddenly jumps from a lower value to a substantially higher value.

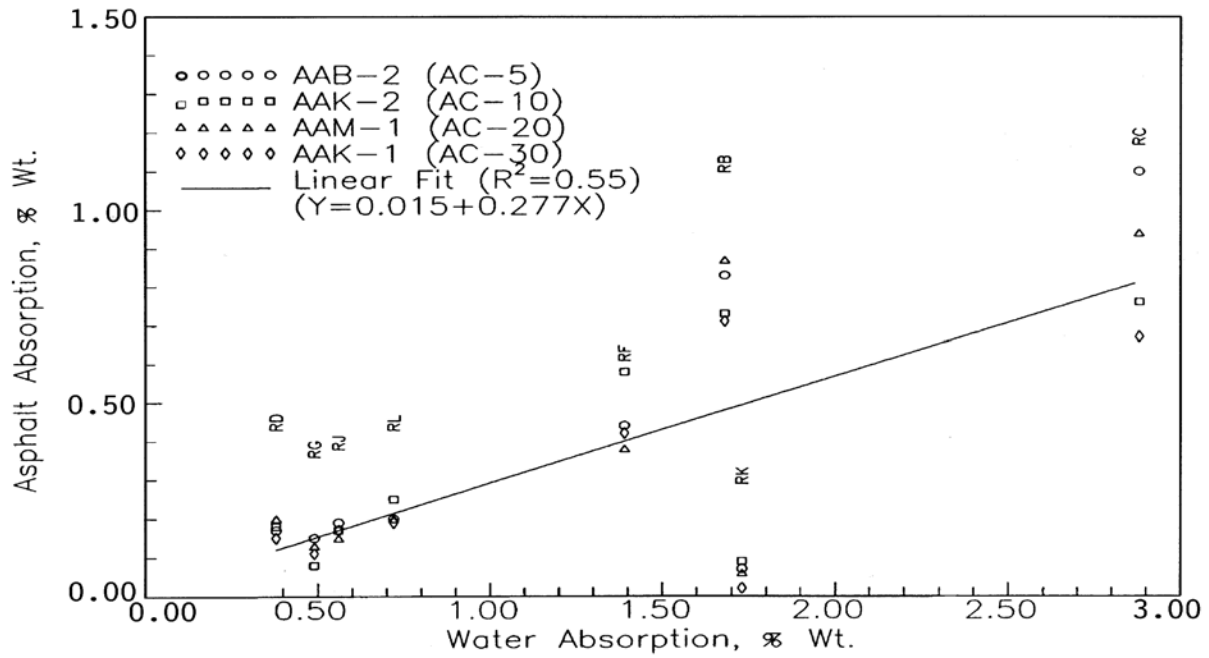


Figure 3. Asphalt Absorption vs. Water Absorption

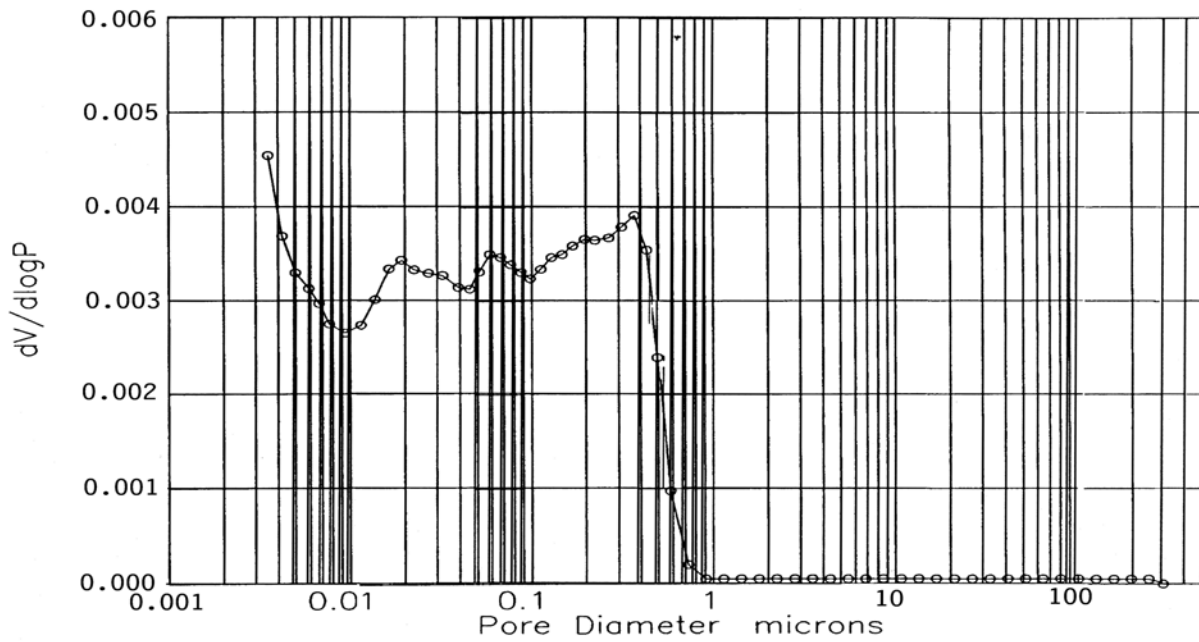


Figure 4. Pore Size Distribution for RB Using Hg Porosimetry

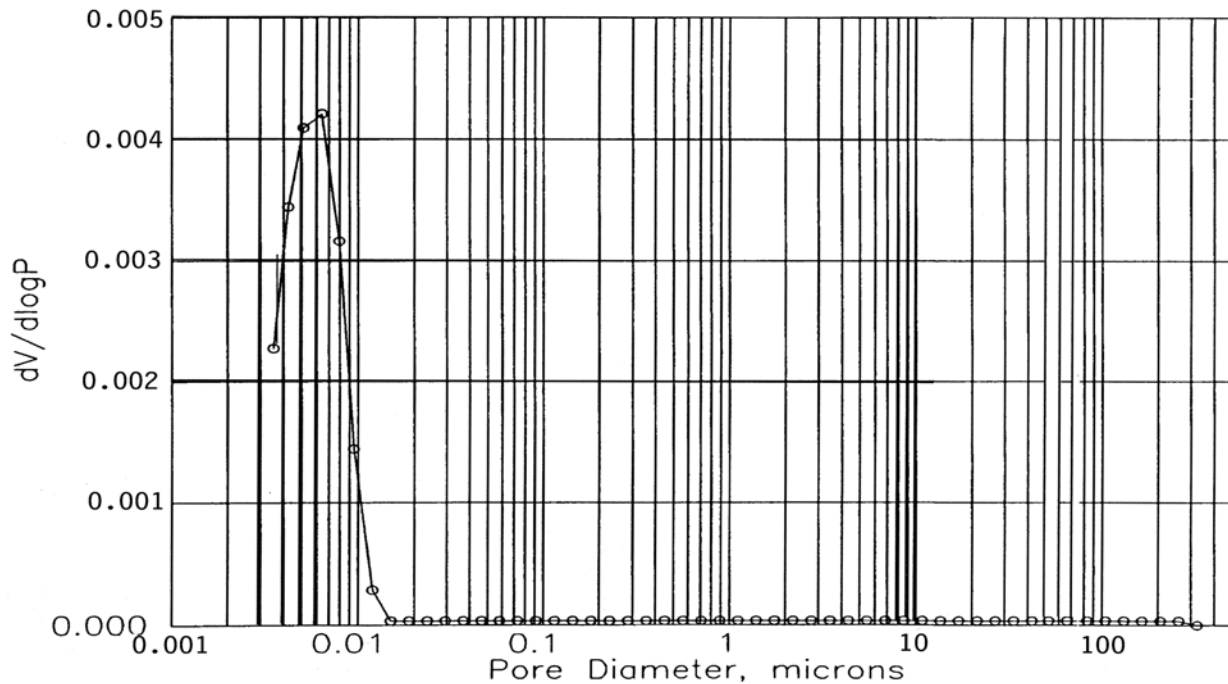


Figure 5. Pore Size Distribution for RK Using Hg Porosimetry

3. Porosities between the pore size ranges of 100-50, 50-25, 25-10, 10-5, 5-2, 2-1, 1-0.5, 0.5-0.2, 0.2-0.1, 0.1 -0.05, 0.05-0.01, and 0.01-0.0035 microns. This would give information as to which pore size range is more important in determining the amount of asphalt cement absorbed into aggregate pores.

The above data is shown in Table 6. Correlations were run between the above data and asphalt absorption values for all the four asphalt cements used in the study to get a best fit model. It was found that a power relationship would fit the data the best. Results of these correlations based on the power relationship are reported in Table 7. The following observations are made:

1. For forward cumulative, the maximum values of coefficient of determination (R^2) were obtained for cumulative porosities up to the pore sizes of 0.01 micron for all asphalt cements except M-2 for which it was obtained up to the pore size of 0.05 micron. The values of R^2 ranged from 0.74 to 0.83.
2. For backward cumulative, the maximum values of R^2 were obtained for cumulative porosities up to the pore size of 0.5 micron for all asphalt cements except AAK-1 for which it was obtained up to the pore size of 0.05 micron. The values of R^2 ranged from 0.70 to 0.79. However, the jump in the value of R^2 for all asphalt cements occurred at a pore diameter of 0.05 micron indicating that this might be the threshold pore diameter in determining whether asphalt cement will be absorbed into the pores of the aggregate or not.
3. For porosities in individual pore size ranges, the values of R^2 for the above asphalt cements peaked for porosities between 0.1-0.05 microns in general. For asphalt cement M-2, however, the maximum value of R^2 was obtained for the pore size range of 0.2-0.1 microns. The range of R^2 values was from 0.76 to 0.88. The inferences drawn from the individual pore size ranges are in line with those obtained from the backward cumulative porosities. That is, there seems to be a threshold pore diameter of 0.05 micron below which no appreciable asphalt absorption takes place.

The aggregate particle shape and texture index data alone, as expected, does not have any correlation with the asphalt absorption data.

Table 6. Cumulative Porosity and Porosity Between Individual Pore S1 ZE Ranges (Percent by Volume of Aggregate)**a. Forward Cumulatives (start of intrusion up to size indicated)**

Aggregate	Pore Diameter (microns)												
	100	50	25	10	5	2	1	0.5	0.2	0.1	0.05	0.01	0.0035
RB	0.0070	0.0111	0.0152	0.0203	0.0244	0.0300	0.0342	0.1104	0.5168	0.8014	1.0827	1.6890	2.1050
RC	0.0379	0.0583	0.0786	0.1059	0.1265	0.1537	0.3690	1.3336	3.9051	5.7957	6.9680	8.0500	8.3860
RD	0.0010	0.0010	0.0020	0.0020	0.0030	0.0037	0.0040	0.0040	0.0050	0.0345	0.1218	0.5057	0.8510
RF	0.0301	0.0463	0.0630	0.0846	0.1012	0.1570	0.2957	0.5642	1.7511	2.6560	3.4259	4.3728	4.9310
RG	0.0040	0.0060	0.0081	0.0111	0.0132	0.0162	0.0183	0.0210	0.0240	0.0264	0.0362	0.4257	0.8300
RJ	0.1068	0.1301	0.1482	0.1961	0.2324	0.2878	0.3370	0.4048	0.5241	0.6273	0.7647	1.3031	1.8760
RK	0.0052	0.0083	0.0113	0.0154	0.0174	0.0215	0.0245	0.0276	0.0316	0.0346	0.0377	0.0825	0.5140
RL	0.0633	0.0964	0.1297	0.1737	0.2060	0.2500	0.2833	0.3166	0.3674	0.4056	0.4448	0.5514	1.1710

b. Backward Cumulatives (0.0035 micron up to size indicated)

Aggregate	Pore Diameter (microns)											
	0.01	0.05	0.1	0.2	0.5	1	2	5	10	25	50	100
RB	0.4160	1.0223	1.3036	1.5882	1.9946	2.0708	2.0750	2.0806	2.0847	2.0898	2.0939	2.0980
RC	0.3360	1.4180	2.5903	4.4809	7.0524	8.0170	8.2323	8.2595	8.2801	8.3074	8.3277	8.3481
RD	0.3453	0.7292	0.8165	0.8460	0.8470	0.8470	0.8473	0.8480	0.8490	0.8490	0.8500	0.8500
RF	0.5582	1.5051	2.2750	3.1799	4.3668	4.6353	4.7740	4.8298	4.8464	4.8680	4.8847	4.9009
RG	0.4043	0.7938	0.8036	0.8060	0.8090	0.8117	0.8138	0.8168	0.8189	0.8219	0.8240	0.8260
RJ	0.5729	1.1113	1.2487	1.3519	1.4712	1.5390	1.5882	1.6436	1.6799	1.7278	1.7459	1.7692
RK	0.4315	0.4763	0.4794	0.4824	0.4864	0.4895	0.4925	0.4966	0.4986	0.5027	0.5057	0.5088
RL	0.6196	0.7262	0.7654	0.8036	0.8544	0.8877	0.9210	0.9650	0.9973	1.0413	1.0746	1.1077

Table 6. Cumulative Porosity and Porosity Between Individual Pore S1 ZE Ranges (Percent by Volume of Aggregate) (Cont.)

c. Pore Volume between Individual Sizes

Aggregate	Pore Diameter (microns)											
	100-50	50-25	25-10	10-5	5-2	2-1	1-0.5	0.5-0.2	0.2-0.1	0.1-0.05	0.05-0.01	0.01-0.0035
RB	0.0041	0.0041	0.0051	0.0041	0.0056	0.0042	0.0762	0.4064	0.2846	0.2813	0.6063	0.4160
RC	0.0204	0.0203	0.0273	0.0206	0.0272	0.2153	0.9646	2.5715	1.8906	1.1723	1.0820	0.3360
RD	0.0000	0.0010	0.0000	0.0010	0.0007	0.0003	0.0000	0.0010	0.0295	0.0873	0.3839	0.3453
RF	0.0162	0.0167	0.0216	0.0166	0.0558	0.1387	0.2685	1.1869	0.9049	0.7699	0.9469	0.5582
RG	0.0020	0.0021	0.0030	0.0021	0.0030	0.0021	0.0027	0.0030	0.0024	0.0098	0.3895	0.4043
RJ	0.0233	0.0181	0.0479	0.0363	0.0554	0.0492	0.0678	0.1193	0.1032	0.1374	0.5384	0.5729
RK	0.0031	0.0030	0.0041	0.0020	0.0041	0.0030	0.0031	0.0040	0.0030	0.0031	0.0448	0.4315
RL	0.0331	0.0333	0.0440	0.0323	0.0440	0.0333	0.0333	0.0508	0.0382	0.0392	0.1066	0.6196

Table 7. Correlation of Asphalt Absorption with Mercury Porosimetry Data

a. Forward Cumulative													
Pore Dia (microns)	100	50	25	10	5	2	1	0.5	0.2	0.1	0.05	0.01	0.0035
1. Asphalt Cement MB-2	(AC-5)												
Intercept	1.388	1.322	1.357	1.251	1.256	1.208	1.235	1.279	1.115	1.061	0.909	0.709	0.443
Slope	0.161	0.163	0.185	0.175	0.187	0.189	0.217	0.278	0.294	0.366	0.407	0.576	0.851
R Sq.	0.078	0.086	0.094	0.092	0.098	0.102	0.165	0.354	0.537	0.681	0.743	0.813	0.762
2. Asphalt Cement MK-2	(AC-10)												
Intercept	1.459	1.368	1.427	1.287	1.293	1.249	1.236	1.221	1.055	1.008	0.918	0.668	0.431
Slope	0.186	0.186	0.215	0.200	0.214	0.220	0.239	0.284	0.295	0.372	0.411	0.519	0.794
R Sq.	0.113	0.122	0.138	0.132	0.141	0.151	0.217	0.400	0.590	0.764	0.828	0.716	0.723
3. Asphalt Cement AAM-1	(AC-20)												
Intercept	1.105	1.069	1.110	1.034	1.047	1.016	1.056	1.133	1.020	0.987	0.911	0.672	0.429
Slope	0.120	0.122	0.144	0.134	0.146	0.148	0.178	0.247	0.271	0.350	0.396	0.560	0.811
R Sq.	0.042	0.047	0.055	0.052	0.058	0.061	0.107	0.270	0.443	0.601	0.680	0.742	0.670
4. Asphalt Cement AAK-1	(AC-30)												
Intercept	1.300	1.156	1.209	1.068	1.091	1.041	1.016	1.009	0.859	0.825	0.750	0.520	0.304
Slope	0.218	0.208	0.240	0.221	0.242	0.245	0.262	0.313	0.327	0.421	0.478	0.698	0.966
R Sq.	0.100	0.098	0.111	0.103	0.115	0.121	0.168	0.314	0.466	0.629	0.719	0.834	0.688
b. Backward Cumulatives													
Pore Dia (microns)	0.01	0.05	0.1	0.2	0.5	1	2	5	10	25	50	100	
1. Asphalt Cement MB-2	(AC-5)												
Intercept	0.345	0.830	0.601	0.525	0.484	0.475	0.470	0.464	0.460	0.456	0.452	0.449	
Slope	-0.876	1.964	1.396	1.076	0.893	0.857	0.848	0.848	0.849	0.850	0.852	0.852	
R Sq.	0.049	0.671	0.754	0.774	0.789	0.786	0.781	0.777	0.776	0.773	0.772	0.770	
2. Asphalt Cement MK-2	(AC-10)												
Intercept	0.568	0.769	0.575	0.508	0.470	0.462	0.457	0.452	0.448	0.443	0.440	0.437	
Slope	-0.181	1.745	1.269	0.985	0.823	0.789	0.783	0.785	0.787	0.790	0.792	0.794	
R Sq.	0.002	0.577	0.678	0.706	0.729	0.727	0.725	0.725	0.726	0.726	0.727	0.727	
3. Asphalt Cement AAM-1	(AC-20)												
Intercept	0.297	0.780	0.574	0.504	0.466	0.458	0.454	0.448	0.445	0.441	0.438	0.435	
Slope	-0.996	1.861	1.333	1.028	0.854	0.819	0.809	0.809	0.810	0.811	0.812	0.813	
R Sq.	0.061	0.583	0.665	0.684	0.698	0.695	0.689	0.685	0.683	0.680	0.679	0.678	
4. Asphalt Cement AAK-1	(AC-30)												
Intercept	0.397	0.634	0.428	0.369	0.338	0.331	0.327	0.323	0.319	0.315	0.313	0.310	
Slope	-0.309	2.453	1.643	1.225	1.001	0.957	0.949	0.952	0.955	0.959	0.961	0.963	
R Sq.	0.004	0.733	0.731	0.703	0.693	0.687	0.685	0.686	0.687	0.688	0.688	0.689	

Table 7. Correlation of Asphalt Absorption with Mercury Porosimetry Data (Cont.)

c. Pore Volume Between Individual Sizes												
Pore Dia (microns)	100-50	50-25	25-10	10-5	5-2	2-1	1-0.5	0.5-0.2	0.2-0.1	0.1-0-05	0.05-0.01	0.01-0.0035
1. Asphalt Cement MB-2	(AC-5)											
Intercept	1.543	2.635	1.304	2.300	1.620	1.714	1.628	1.479	1.717	1.840	1.391	0.345
Slope	0.152	0.268	0.128	0.242	0.187	0.203	0.220	0.261	0.334	0.401	0.665	-0.876
R Sq.	0.100	0.138	0.080	0.138	0.109	0.256	0.493	0.687	0.784	0.795	0.622	0.049
2. Asphalt Cement MK-2	(AC-10)											
Intercept	0.796	3.214	1.297	2.501	1.834	1.691	1.501	1.393	1.642	1.681	1.132	0.568
Slope	0.047	0.319	0.138	0.271	0.227	0.213	0.214	0.260	0.339	0.387	0.523	-0.181
R Sq.	0.011	0.213	0.102	0.187	0.175	0.307	0.507	0.742	0.879	0.808	0.418	0.002
3. Asphalt Cement MM-1	(AC-20)											
Intercept	1.213	2.067	1.036	1.817	1.278	1.415	1.425	1.346	1.6W	1.738	1.295	0.297
Slope	0.116	0.230	0.092	0.205	0.146	0.172	0.199	0.247	0.330	0.399	0.647	-0.996
R Sq.	0.056	0.098	0.040	0.096	0.064	0.177	0.391	0.593	0.739	0.763	0.570	0.061
4. Asphalt Cement MK-1	(AC-30)											
Intercept	1.238	2.770	1.036	2.659	1.550	1.392	1.265	11.17	1.468	1.679	1.228	0.397
Slope	0.170	0.341	0.145	0.335	0.246	0.227	0.236	0.291	0.393	0.492	0.847	-0.309
R Sq.	0.087	0.156	0.072	0.185	0.133	0.224	0.397	0.596	0.758	0.841	0.706	0.004

CONCLUSIONS

The main conclusion drawn from this study is that no single model can be developed using asphalt absorption data obtained on a limited number of asphalt cements and aggregates. The case of every asphalt cement has to be treated differently. However, some general trends are apparent.

1. Generally, the asphalt absorption decreases with increase in viscosity (at the mixing temperature) of the asphalt cement used. However, there is some indication that a high percentage of maltene (oil) fraction in an asphalt cement can increase its total absorption possibly due to the phenomenon of selective absorption.
2. A definite general relationship between the water and asphalt absorption values was observed. Aggregates which absorb more water are likely to absorb more asphalt cement. However, an exception was noted in case of an aggregate which has much smaller pores, and, therefore, absorbed significantly less asphalt cement compared to water.
3. Cumulative aggregate porosity up to 0.01 micron pore diameter has a good correlation with asphalt absorption. The R^2 values for different asphalt cements using a power fit range from 0.74 to 0.83.
4. There appears to be a threshold pore diameter of 0.05 micron in the aggregate below which no appreciable asphalt absorption takes place.
5. The most important pore size range in the aggregate affecting the asphalt absorption appears to be 0.05-0.1 microns.

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