Laboratory Study on Draindown of Asphalt Cement in Stone Matrix Asphalt

E. R. BROWN AND RAJIB BASU MALLICK

Draindown of asphalt cement is one problem encountered so far with stone matrix asphalt. A simple test to quantitatively measure draindown was developed in this study. A round robin study was conducted to measure the variability of the test method and a detailed experiment was carried out to find the effects of the percentage passing the 4.75 mm (No. 4) sieve, stabilizer, filler, and asphalt content on draindown. Results of the round robin study showed that the proposed test method is a good test to distinguish between mixes with and without draindown potential. Draindown of asphalt cement was found to be affected significantly by type of filler, the percentage passing the 4.75 mm (No. 4) sieve, the asphalt content, and the type and amount of stabilizer.

Stone matrix asphalt (SMA) has proven to be a rut-resistant and cost-effective surface material in Europe for the past 20 years. Because of its success in Europe, a number of SMA projects have been constructed in the United States since 1991 to evaluate its performance. These projects have been monitored since their placement and will continue to be monitored for several years. One problem observed so far with SMA has been draindown of the asphalt cement and the resultant fat spots. Stabilizers are needed to control draindown in SMA. There are several draindown tests (*1,2*) that have been used for SMA, but most are subjective. Also, some of the currently used methods, such as the Schellenberg test, do not appear to perform well with polymer stabilizers. A method, applicable to a wide range of stabilizers, is needed to quantitatively measure draindown and to relate this measured draindown to that observed in the field (*3*).

OBJECTIVE

The objective of this study was to develop a draindown test and to evaluate the effects of various factors on draindown of asphalt cement in SMA mixes.

SCOPE

Results from two research studies—development and round robin study of a draindown test and a detailed draindown study—are presented. A test to quantify draindown of asphalt cement in SMA mixes was developed. To evaluate the test method, a round robin study was conducted with eight participating agencies. Twenty preblended aggregate samples, cellulose fibers, AC–20 asphalt cement, and wire baskets for draindown tests (described in the "Test Plan" section) were sent to each of the eight participating laboratories. Each agency was requested to prepare mixtures at 7.0 percent asphalt content with and without fiber. Draindown tests were conducted on the mixes and the results reported.

A detailed study was conducted to evaluate the draindown potential of SMA mixes with different kinds and amounts of fibers and fillers. Two types of fibers—a cellulose fiber (a typical cellulose made in Europe) and a mineral fiber—and one type of polymer were used in various SMA mixtures and evaluated in the draindown test. In addition to these mixtures, a control mix was prepared without any fiber or polymer for comparison purposes. Two types of aggregates, gravel and limestone, with two types of fillers, baghouse fines and marble dust, were used. The percentage passing the 4.75 mm (No. 4) sieve was varied for each type of aggregate. The amount of draindown for each test was measured and the results analyzed to evaluate the effects of the various parameters on draindown.

TEST PLAN

In the round robin study for draindown, a traprock being used on an SMA project in Maryland was used as the aggregate. The specific gravity, absorption, and gradation for the aggregate are shown in Table 1. The binder used was an AC–20 asphalt cement from Chevron, Inc., U.S.A., Mobile, Alabama (Table 2).

Agricultural lime and a cellulose (a typical cellulose made in the United States) were used as filler and fiber material, respectively. Preblended aggregate materials, fiber, and asphalt cement were sent to the different participating agencies. Each laboratory was requested to conduct the draindown test on the SMA mix at 7.0 percent asphalt cement with and without the 0.3 percent fibers and to report the results.

The part of the study intended to evaluate the effects of various factors on draindown in SMA was carried out with gravel and limestone aggregates. The gradations of the aggregates for the mixtures evaluated are shown in Table 3. Two kinds of fiber (a typical cellulose made in Europe and a mineral fiber) and one polymer were investigated at two different percentages. Baghouse fines and a marble filler were evaluated in this investigation. The experimental plan is shown in Table 4.

After the aggregates were batched to produce the required gradation, the fibers were added and the resulting mix was kept in an oven at 157°C (315°F) for 4 hr. The asphalt cement and aggregates were then mixed at 154°C (310°F) for 2 min and transferred carefully into the wire mesh basket. These temperatures were chosen to glean information about the draindown potential of mixes in the laboratory. For actual mix evaluation, it is suggested that the test be conducted at anticipated plant production temperature.

National Center for Asphalt Technology, 211 Ramsay Hall, Auburn University, Ala. 36849–5354.

TABLE 1 Properties and Gradation of Traprock Aggregate Used in Round Robin Study

Property	Coarse Aggregate	Fine Aggregate
Apparent Specific Gravity	3.05	3.03
Bulk Specific Gravity	3.00	2.98
Absorption, Percent	0.6	0.6

Sieve Size	Percent Passing
19.0mm (3/4 inch)	100.0
12.5 mm (1/2 inch)	84.9
9.50 mm (3/8 inch)	64.2
4.75 mm (No. 4)	26.8
2.36 mm (No. 8)	14.3
1.18 mm (No. 16)	12.0
0.60 mm (No. 30)	11.7
0.30 mm (No. 50)	11.2
150 μm (No. 100)	10.3
75 μm (No. 200)	8.5

TABLE 2 Properties of Asphalt Cement Used in Round Robin Study

Test	Test Results
Viscosity @ 60°C (140°F), poise	2083
Viscosity @ 135°C (275°F), cst	423
COC Flash Point, °C (°F)	315.5 (600)
Penetration @ 25°C (77°F), 0.1mm	83
Thin Film Oven Test i) Weight Loss, % ii) Viscosity @ 60°C (140°F), poise iii) Ductility @ 25°C (77°F), cm iv) Viscosity ratio	 0.01 6258 150+ 3
Specific Gravity @ 25°C (77°F)	1.021
Kg/liter (lbs/gallon) @ 25°C (77°F)	1.019 (8.502)

TABLE 3 Gradation of Aggregates Used in Draindown Study

Sieve Size	Percent Passing		
	Mix A	Mix B	Mix C
19.0 mm (3/4 inch)	100.0	100.0	100.0
12.5 mm (1/2 inch)	100.0	100.0	100.0
9.50 mm (3/8 inch)	75.0	65.0	60.0
4.75 mm (No. 4)	50.0	30.0	20.0
2.36 mm (No. 8)	39.9	24.9	17.5
1.18 mm (No. 16)	34.3	22.1	16.1
0.60 mm (No. 30)	30.0	20.0	15.0
0.30 mm (No. 50)	21.5	17.0	14.8
150 μm (No. 100)	15.1	13.9	13.3
75 μm (No. 200)	10.0	10.0	10.0

TABLE 4 Experimental Plan for Draindown Study

FIBER/POLYMER	AGGREGATE																							
	Gravel												Limestone											
	GRADATION												GRADATION											
	20 % Fine				30 % Fine				50 % Fine				20 % Fine				30 % Fine				50 % Fine			
	FILLER												FILLER											
	Bgf		Mar		Bgf		Mar		Bgf		Mar		Bgf		Mar		Bgf		Mar		Bgf		Mar	
	Asphalt Content, %												Asphalt Content, %											
	6	7	6	7	6	7	6	7	6	7	6	7	6	7	6	7	6	7	6	7	6	7	6	7
AC	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C.1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C.3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M.1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M.3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
P3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
P8	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

NOTE: Bgf - Baghouse fines
Mar - Marble
AC - Asphalt cement without any Additive (Control)
C.1 - 0.1% (of mix) Cellulose Fiber
C.3 - 0.3% (of mix) Cellulose Fiber
M.1 - 0.1% (of mix) Mineral Fiber
M.3 - 0.3% (of mix) Mineral Fiber
P3 - 3.0% (of binder) polymer
P8 - 8.0% (of binder) polymer

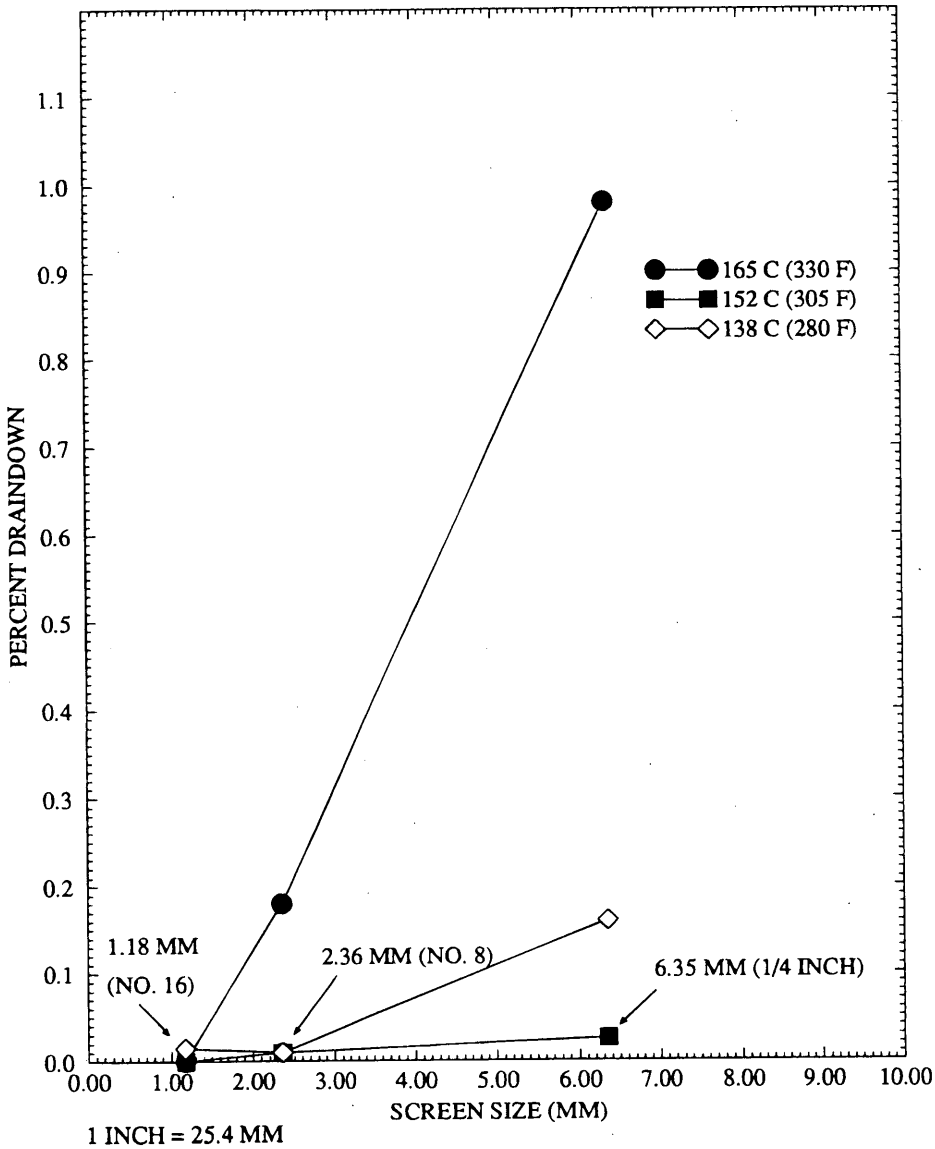

FIGURE 1 **Percentage of draindown of asphalt cement for different screen sizes.**

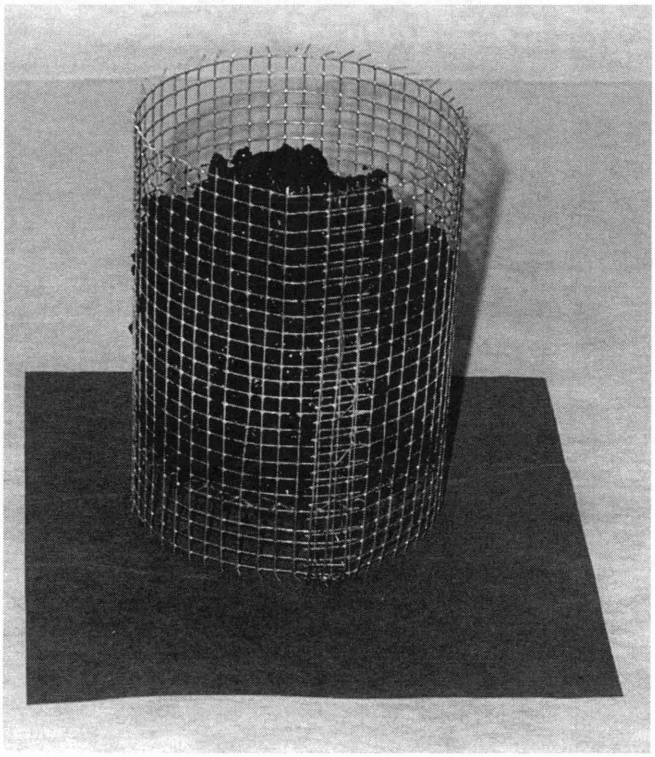

FIGURE 2 Typical wire mesh basket used for draindown studies.

The openings in the wire basket were chosen to be 6.35 mm (¼ in.) by 6.35 mm (¼ in.). This opening size was selected after a study was conducted to evaluate the effect of screen opening and temperature on draindown of asphalt cement. The results are shown graphically in Figure 1. It was shown that much more flow was obtained with the 6.35 mm (¼ in.) screen openings, and the flow was found to be more sensitive to differences in temperature. Most likely, the larger openings are more sensitive to mix design also. Another important factor in deciding the opening size was to select an opening as big as possible to better simulate actual conditions for draindown. The potential problem of draindown of larger fine aggregates along with the asphalt cement was not encountered with the 6.35 mm (¼ in.) openings; however, the smaller fine aggregate, such as dust, did draindown just as it does in the field. Occasionally fine aggregate particles fall through the screen when transferring the mixture into the wire baskets. These particles should be removed before the test. A typical wire mesh basket is shown in Figure 2.

The basket with the mix was placed into a preheated oven and maintained at 149°C (300°F) for 2 hr. Preweighed papers were placed underneath the container to collect the asphalt cement drippings. The drippings were collected and weighed at 30-min intervals for the 2-hr period. The cumulative weights were calculated and expressed as a percentage of the initial weight of the mix, and the numbers were reported as draindown corresponding to the time of observation. The different steps in the draindown test are presented in Figure 3.

Benefits of Draindown Test

The draindown test appears to be a simple, fast procedure that can be used to evaluate the draindown potential of various mixtures. This test can be used effectively for research, mix design, and quality control. After this test has been verified to be correlated to actual draindown in the field, it can be used in the laboratory to evaluate a number of materials and mixtures to provide guidance for specifying materials. It can be used during the mix design to evaluate the potential for draindown in the designated mix and to evaluate the effect of material variations on draindown. This test can be used for quality control during construction to indicate when the SMA mix is approaching the threshold at which draindown occurs. The test may indicate all impending problems before they actually show up in the SMA mixture on the roadway.

TEST RESULTS AND ANALYSIS

ROUND ROBIN STUDY

The percentage of draindown values evaluated in the round robin study and the corresponding statistics for mixes with and without cellulose fibers are given in Table 5. The percentage of draindown in mixes without cellulose are observed to be about 70 times more than that in mixes with 0.3 percent cellulose. Even though the variability of the draindown is relatively high, there is still a clear difference between the test results with and without cellulose.

Effect of Mixture Variation on Draindown

A summary of results of the draindown tests with different aggregates, gradations, fillers, fibers, and polymer is shown in Table 6. A typical plot of cumulative draindown versus time is shown in Figure 4. Note that for most mixtures, most of the draindown occurs within the first hour, which should allow the test to be standardized at 1 hr. Also notice that the amount of draindown for the samples shown in Figure 4 is increased by a factor of approximately 5 when increasing the asphalt content from 6 to 7 percent. This indicates that there may be a threshold point above which significant draindown occurs but below which little or no draindown occurs. It is believed that an asphalt content above this threshold point will result in a draindown that is significantly higher than the draindown observed at a lower asphalt content. Plots of average cumulative draindown against time for different variables in SMA mixtures are shown in Figures 5 through 9. For example in Figure 5 all of the data from mixtures with baghouse fines were averaged and plotted versus time. This was also done with all the data having marble filler.

Figure 5 shows that the SMA mixtures using the baghouse fines had much less draindown than the mixtures using the marble dust. The likely reason for this difference is the particle size and shape for the two fillers.

Figure 6 shows the effect of asphalt content on draindown for various SMA mixtures. An asphalt content of 6 percent is approximately optimum for most of the SMA mixtures shown, and 7 percent asphalt content is on the high side. The data show that a 1 percent increase in asphalt content resulted in a significant increase in average draindown (1.6 percent to 3.4 percent). The higher amount

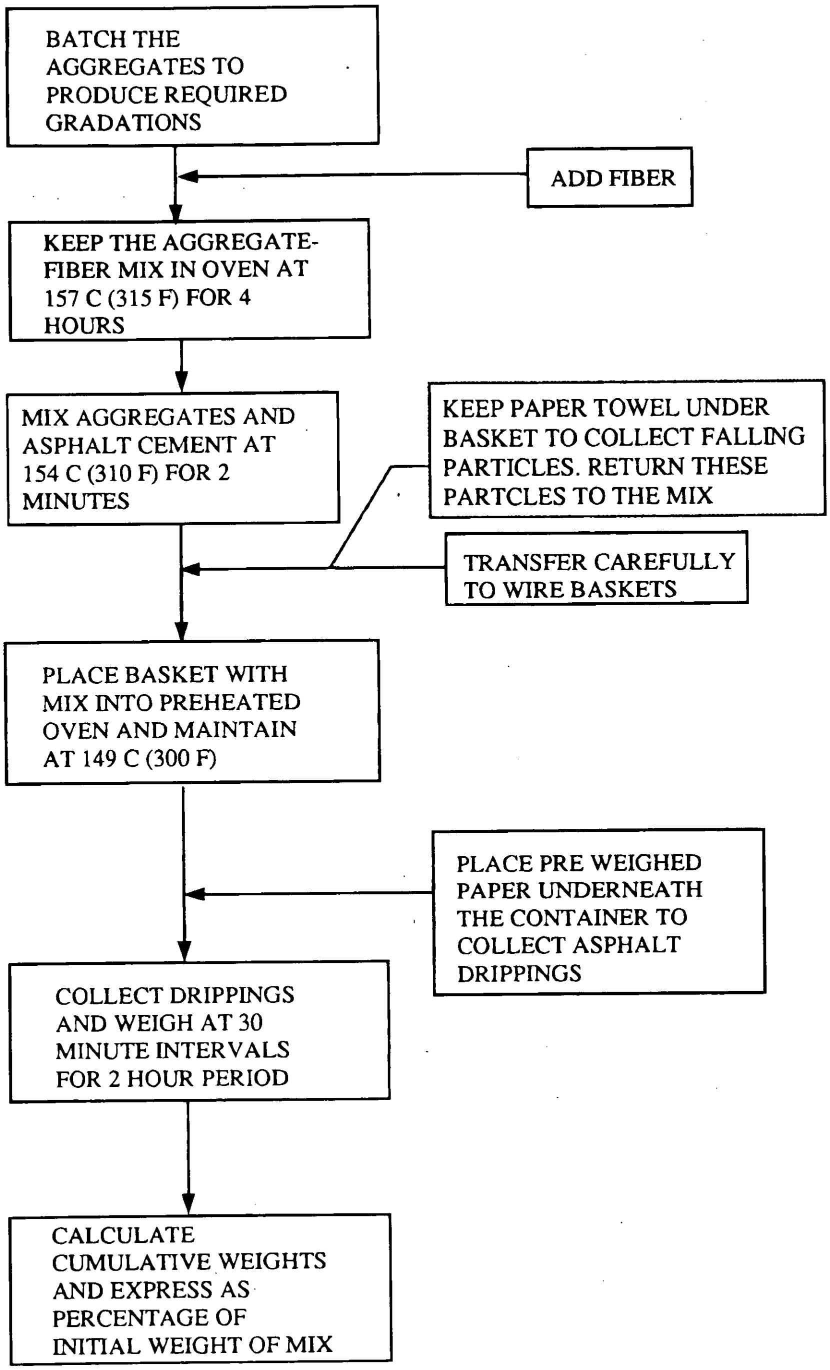

FIGURE 3 Test procedure for draindown of SMA mixtures.

TABLE 5 Summary of Draindown Results From Round Robin Study

AGENCY	PERCENT DRAINDOWN (7.0 PERCENT AC)	
	WITHOUT CELLULOSE	WITH 0.3 PERCENT CELLULOSE
Asphalt Institute	6.70	0.03
FHWA, TA	6.25	0.04
FHWA, R&D	5.01	0.00
Georgia DOT	1.32	0.05
Kentucky DOH	2.41	0.01
Maryland DOT	5.20	0.02
Michigan DOT	5.30	0.23
Missouri HTD	9.60	0.05
NCAT	9.70	0.27
Average	5.70	0.08
Standard Deviation	2.82	0.10

of draindown at 7.0 percent asphalt content is a result of draindown of filler material and asphalt cement. In the mix design process, steps should be taken to produce a mixture with an asphalt content having a high threshold for draindown and to produce a mixture that is not sensitive to draindown when minor mixture variations occur.

The type and amount of stabilizer material significantly affects the draindown of SMA (Figure 7). For the additives evaluated in this study, it appears that 0.3 percent mineral fiber and 0.3 percent cellulose fiber produced the least amount of draindown (0.4 percent). The mixtures with no additive and 3.0 percent (binder weight) polymer produced the most draindown. The mixtures containing 8.0 percent polymer (binder weight), 0.1 percent cellulose fiber, and 0.1 percent mineral fiber produced intermediate draindown. The data indicate that stabilizer type and amount significantly affect draindown results. For this study, all draindown tests were conducted at 149°C (300°F). This test needs to be conducted at the mix temperature anticipated in the field to better evaluate the true draindown potential of the various mixtures. It may be noted that the optimum binder content is different for mixes with different kinds of stabilizers. The results of this study are valid only for comparison purposes (among different types of stabilizers) at similar asphalt contents. The mixes prepared with different stabilizers will have draindown that is a function of the optimum asphalt contents.

Figure 8 shows that the amount of material passing the 4.75 mm (No. 4) sieve affects draindown. The mixtures with 20 percent passing the 4.75 mm (No. 4) sieve had significantly more draindown (4.7 percent) than the mixes with 50 percent passing the 4.75 mm (No. 4) sieve (0.44 percent). Mixes with 30 percent passing the 4.75 mm (No. 4) sieve had an intermediate amount of draindown (2.3 percent). The finer mixes have more surface area and lower optimum asphalt content and therefore should have less draindown. Probably the biggest reason for differences in draindown is the size of the internal voids. With the coarser mixes, the internal voids of the uncompacted mix are larger, resulting in more draindown. The mix with 50 percent passing the 4.75 mm (No. 4) sieve under normal circumstances would not experience draindown (this is a dense-graded mixture), and the data appear to confirm this fact.

Figure 9 shows the effect of aggregate type on draindown. The amount of draindown for the two aggregates investigated was approximately equal, and this would be expected to be true for other aggregates. Hence it appears based on this limited study that the aggregate type may have little effect on draindown.

As is evident from the results of the draindown tests, significant differences seem to exist between results obtained from mixes with different material combinations. An Analysis of Variance was conducted on the test results to evaluate the effects of different factors on draindown values. A summary of the results are shown in Table 7. At a significance level of 0.05, it is seen that all the different factors—filler type, percentage of fines, asphalt content, and fiber type—have significant effects on draindown, as shown in Figures 5 through 9. This is true for both types of aggregates used. Table 8 shows the groupings of the different variables obtained from Duncan's multiple range test. For both types of aggregates, the mixes with marble filler experienced higher draindown values than those mixes with baghouse fine filler. For both types of aggregates, draindown decreased with an increase in the percentage passing the 4.75 mm (No. 4) sieve. This is expected because the high surface area and tighter packing of the fine aggregates help reduce the flow of asphalt cement in the mixes. With respect to the effects of fiber, in both cases the mixes with 0.3 percent cellulose and 0.3 percent mineral fiber show the lowest amount of draindown.

Under the test conditions for this study, the data show that SMA mixtures tend to have more draindown when the asphalt content is higher, the filler is coarser (marble versus baghouse fines), the percentage passing the 4.75 mm (No. 4) sieve is lower, and a polymer is used instead of a fiber (at similar asphalt content). The amount of draindown is obviously affected by temperature and amount of material passing the 75 μm (No. 200) sieve, but these items were not

TABLE 6 Summary of Results From Draindown Study

GRAVEL MIXES

FIBER / POLYMER	TIME MINUTES	Percent Passing 4.75 mm (No. 4) Sieve											
		20				30				50			
		Filler											
		Baghouse Fines		Marble		Baghouse Fines		Marble		Baghouse Fines		Marble	
		Asphalt Content, %											
		6	7	6	7	6	7	6	7	6	7	6	7
AC	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.62	5.01	4.15	7.88	0.10	0.98	2.45	5.81	0.04	0.21	0.12	0.60
	60	0.93	6.30	7.67	10.4	0.19	1.50	3.93	7.49	0.05	0.29	0.19	1.08
	90	1.15	6.74	8.64	11.0	0.26	1.79	4.71	8.20	0.05	0.36	0.20	1.38
	120	1.28	6.93	9.16	11.2	0.26	1.93	5.03	8.48	0.05	0.40	0.23	1.63
C.1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.36	2.57	0.87	5.98	0.01	0.31	0.14	0.67	0.09	0.08	0.03	0.48
	60	0.68	3.86	1.90	8.00	0.04	0.53	0.24	0.85	0.12	0.14	0.05	0.75
	90	0.79	4.52	2.55	8.42	0.05	0.61	0.27	0.90	0.13	0.19	0.05	0.84
	120	0.89	4.85	2.73	8.53	0.06	0.66	0.28	0.91	0.15	0.23	0.05	0.86
C.3	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.07	1.29	0.03	0.14	0.00	0.00	0.03	0.01	0.07	0.10	0.04	0.05
	60	0.18	2.19	0.04	0.17	0.00	0.01	0.04	0.02	0.08	0.12	0.05	0.10
	90	0.25	2.91	0.05	0.19	0.00	0.01	0.04	0.03	0.09	0.13	0.05	0.12
	120	0.30	3.28	0.07	0.21	0.00	0.01	0.04	0.03	0.09	0.14	0.05	0.13
M.1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.11	2.96	4.19	8.55	0.05	0.63	1.59	4.99	0.08	0.16	0.05	0.55
	60	0.19	4.57	6.79	10.0	0.14	0.89	2.42	6.68	0.08	0.27	0.12	1.12
	90	0.22	5.18	7.33	10.5	0.17	0.98	2.76	6.96	0.08	0.35	0.17	1.56
	120	0.25	5.43	7.63	10.5	0.18	1.09	3.00	7.12	0.08	0.36	0.21	1.73
M.3	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.02	0.27	1.65	3.36	0.00	0.15	0.35	0.87	0.04	0.12	0.08	0.15
	60	0.04	0.36	2.76	5.35	0.00	0.31	0.57	1.21	0.05	0.16	0.09	0.26
	90	0.05	0.47	3.38	5.77	0.00	0.47	0.64	1.38	0.05	0.18	0.11	0.34
	120	0.06	0.53	3.58	5.91	0.00	0.57	0.70	1.54	0.05	0.18	0.11	0.41
P3	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.49	2.57	3.30	8.31	0.11	1.30	3.90	4.96	0.14	0.29	0.15	0.43
	60	0.74	4.35	7.13	10.2	0.23	2.22	5.25	6.41	0.21	0.46	0.20	0.69
	90	0.90	4.91	8.20	10.8	0.32	2.71	5.69	6.90	0.23	0.57	0.24	0.89
	120	0.99	5.12	8.72	11.1	0.36	2.98	5.87	7.14	0.24	0.63	0.28	1.01
P8	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.09	1.30	2.28	7.06	0.10	0.46	1.71	5.18	0.16	0.10	0.11	1.21
	60	0.16	2.47	4.70	10.1	0.20	0.92	3.50	7.56	0.20	0.15	0.26	1.71
	90	0.25	3.45	6.13	11.1	0.27	1.16	4.50	8.43	0.20	0.17	0.36	2.09
	120	0.34	4.11	6.93	11.5	0.30	1.35	4.88	8.72	0.20	0.17	0.44	2.21

NOTE: AC - Asphalt Cement without any Additive (Control)
C.1 - 0.1 % (of mix) Cellulose Fiber
C.3 - 0.3 % (of mix) Cellulose Fiber
M.1 - 0.1 % (of mix) Mineral Fiber
M.3 - 0.3 % (of mix) Mineral Fiber
P3 - 3.0 % (of binder) Polymer
P8 - 8.0 % (of binder) Polymer

TABLE 6 *(continued)*

LIMESTONE MIXES

FIBER / POLYMER	TIME MINUTES	Percent Passing 4.75 mm (No. 4) Sieve											
		20				30				50			
		Filler											
		Baghouse Fines		Marble		Baghouse Fines		Marble		Baghouse Fines		Marble	
		Asphalt Content, %											
		6	7	6	7	6	7	6	7	6	7	6	7
AC	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.12	1.42	6.07	9.86	0.11	0.61	1.70	5.53	0.06	0.03	0.04	0.20
	60	0.23	2.67	7.63	10.9	0.28	0.84	2.50	7.62	0.07	0.05	0.05	0.26
	90	0.28	3.39	8.16	11.4	0.44	1.01	2.92	8.42	0.07	0.06	0.05	0.30
	120	0.34	3.56	8.36	11.6	0.57	1.15	3.19	8.64	0.07	0.06	0.05	0.37
C.1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.00	0.55	4.29	8.66	0.02	0.08	1.90	5.04	0.06	0.04	0.14	0.19
	60	0.02	1.40	6.19	10 1	0.04	0.14	2.83	6.78	0.07	0.06	0.17	0.29
	90	0.05	2.53	6.92	10.5	0.04	0.16	3.35	7.31	0.07	0.06	0.19	0.36
	120	0.09	3.78	7.28	10.8	0.04	0.17	3.69	7.50	0.07	0.07	0.19	0.38
C.3	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.03	0.13	0.67	2.48	0.02	0.03	0.92	2.99	0.04	0.14	0.09	0.08
	60	0.03	0.25	1.03	4.00	0.03	0.06	1.31	4.20	0.05	0.24	0.11	0.09
	90	0.03	0.33	1.36	4.52	0.05	0.07	1.50	4.92	0.05	0.37	0.12	0.09
	120	0.04	0.44	1.70	4.77	0.05	0.09	1.66	5.30	0.05	0.42	0.12	0.09
M.1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.09	1.18	2.73	7.29	0.05	0.41	0.83	4.72	0.03	0.12	0.05	0.12
	60	0.23	3.29	3.62	8.36	0.07	0.68	1.32	6.56	0.04	0.17	0.07	0.22
	90	0.40	5.90	4.00	8.62	0.08	0.92	1.63	7.21	0.05	0.19	0.07	0.25
	120	0.62	8.87	4.20	8.71	0.10	1.14	1.78	7.42	0.05	0.20	0.07	0.30
M.3	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.09	0.14	0.16	6.97	0.03	0.07	0.25	1.12	0.04	0.06	0.02	0.03
	60	0.13	0.26	0.20	8.41	0.05	0.12	0.41	1.39	0.05	0.09	0.03	0.04
	90	0.15	0.34	0.23	8.94	0.05	0.14	0.50	1.49	0.05	0.12	0.03	0.06
	120	0.17	0.41	0.24	9.10	0.05	0.15	0.53	1.55	0.05	0.14	0.04	0.06
P3	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.35	1.96	4.81	9.85	0.13	0.33	1.37	4.13	0.08	0.27	0.09	0.96
	60	0.74	4.42	7.23	11.4	0.18	0.52	2.38	6.01	0.12	0.59	0.14	1.39
	90	1.04	5.99	7.77	11.8	0.22	0.63	3.03	7.02	0.17	0.82	0.16	1.54
	120	1.29	6.70	8.08	11.9	0.24	0.68	3.23	7.34	0.19	0.93	0.17	1.59
P8	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.05	0.81	3.39	8.15	0.05	0.22	0.35	2.75	0.12	0.28	0.12	0.43
	60	0.12	1.75	6.27	10.6	0.08	0.38	0.74	5.00	0.15	0.33	0.16	0.71
	90	0.20	2.38	7.65	11.4	0.09	0.45	1.06	6.11	0.17	0.38	0.20	0.96
	120	0.23	2.92	8.24	11.7	0.09	0.50	1.19	6.68	0.18	0.43	0.22	1.14

NOTE: AC - Asphalt Cement without any Additive (Control)

C.1 - 0.1 % (of mix) Cellulose Fiber
C.3 - 0.3 % (of mix) Cellulose Fiber
M.1 - 0.1 % (of mix) Mineral Fiber
M.3 - 0.3 % (of mix) Mineral Fiber
P3 - 3.0 % (of binder) Polymer
P8 - 8.0 % (of binder) Polymer

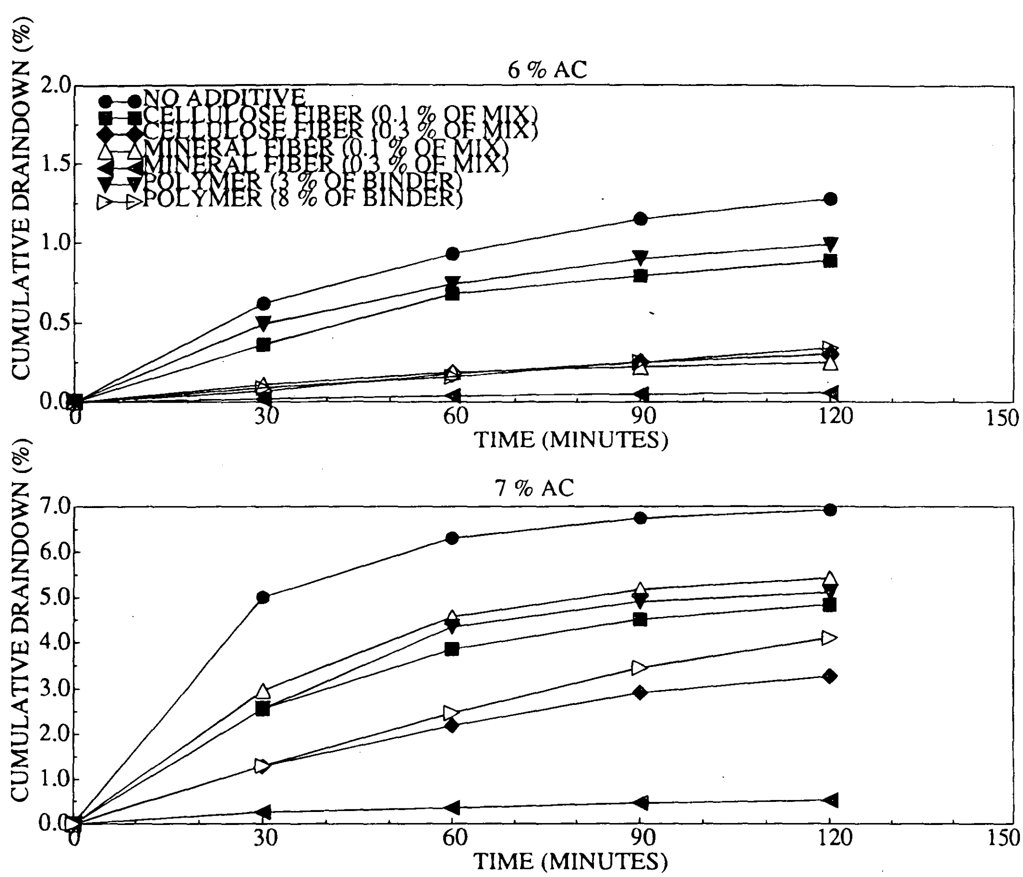

FIGURE 4 Typical draindown versus time plot for SMA using gravel aggregates, baghouse fines, and 20 percent passing the 4.75 mm (No. 4) sieve.

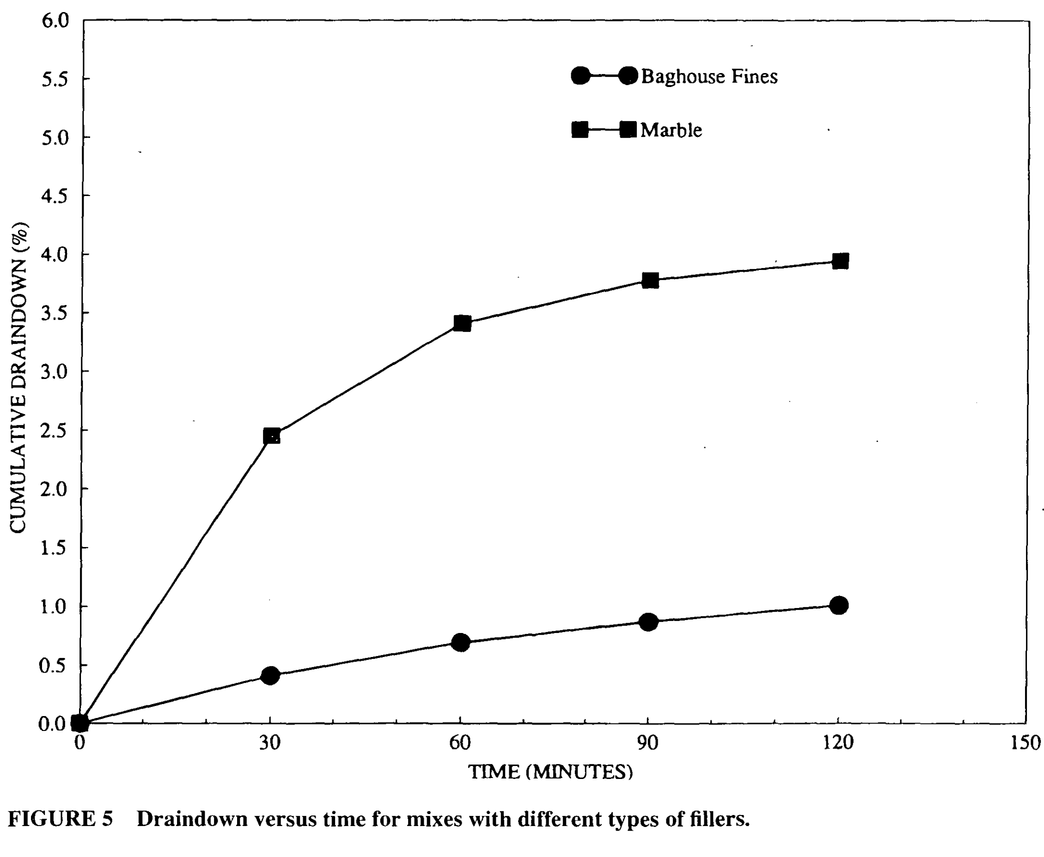

FIGURE 5 Draindown versus time for mixes with different types of fillers.

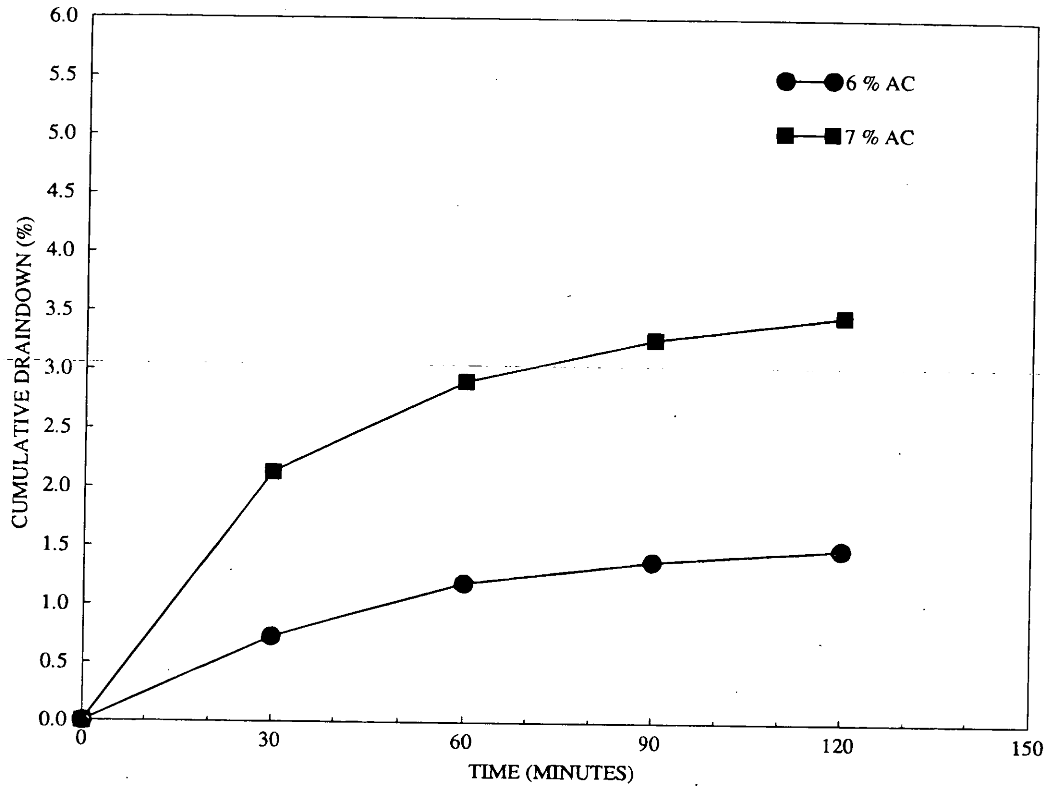

FIGURE 6 Draindown versus time for mixes with different types of contents.

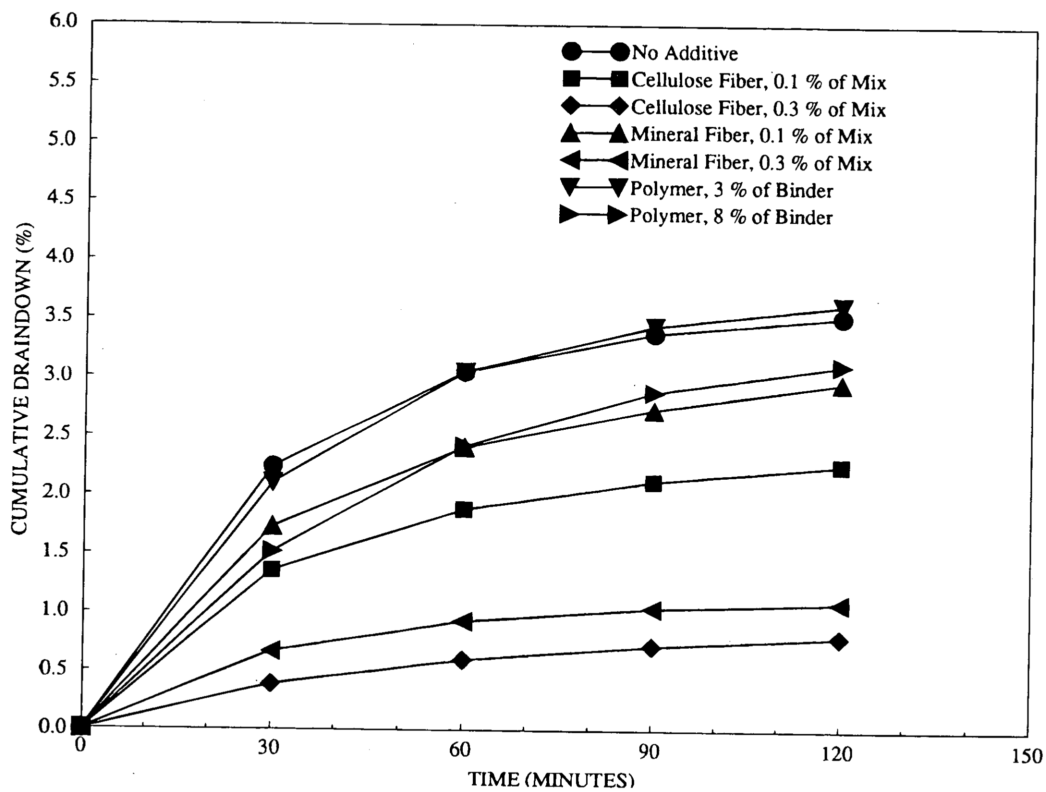

FIGURE 7 Draindown versus time for mixes with different types of additives.

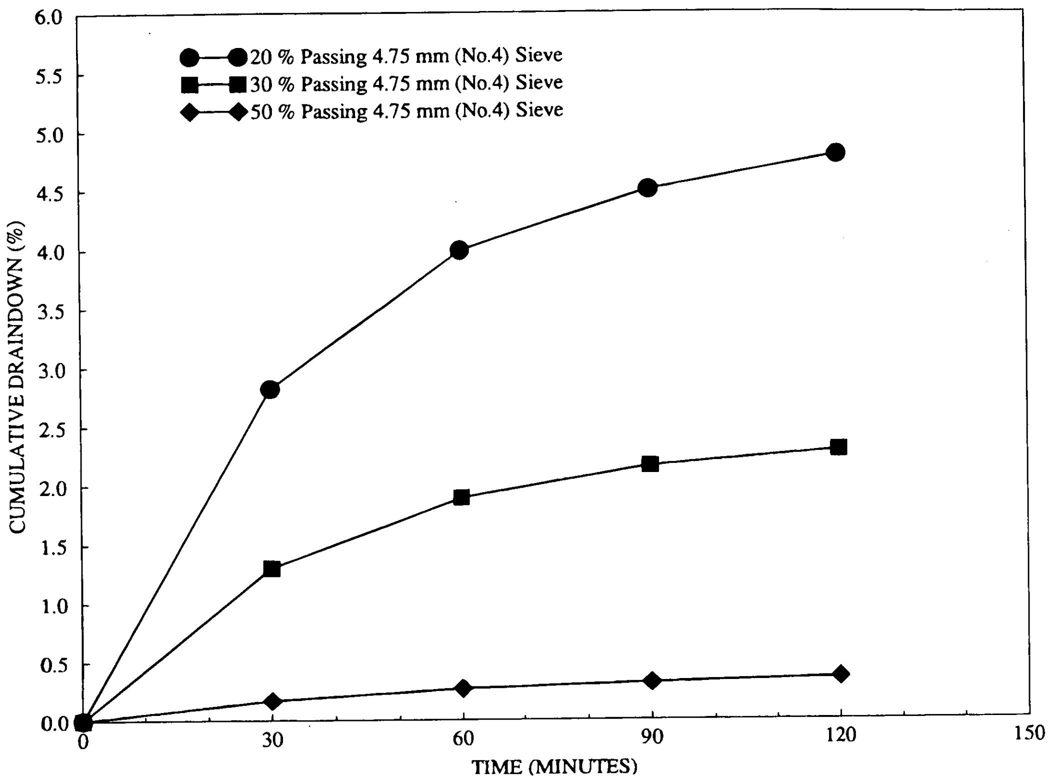

FIGURE 8 Draindown versus time for mixes with different percentages of material passing the 4.75 mm (No. 4) sieve.

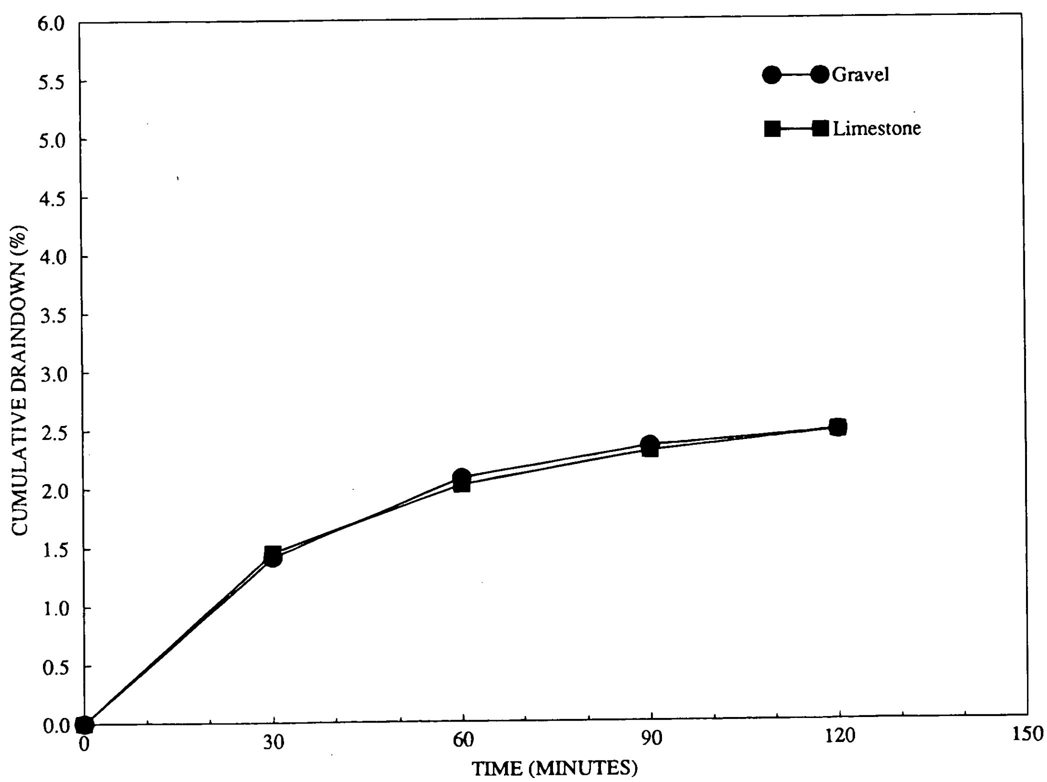

FIGURE 9 Draindown versus time for mixes with different types of aggregates.

TABLE 7 Summary of Analysis of Variance Results of Draindown Tests

SUMMARY OF ANALYSIS OF VARIANCE RESULTS OF DRAINDOWN TESTS (RESULTS AT 120 MINUTES USED)

Source	DF	Type 1 SS	Mean Square	F Value	Pr>F
GRAVEL MIXES					
Filler Type	1	461.70	461.70	128.37	0.0001
% pass 4.75 mm (No. 4) Sieve	2	774.32	387.16	107.65	0.0001
Stabilizer Type and Amount	6	421.91	70.32	19.55	0.0001
% AC	1	204.84	204.84	56.95	0.0001
LIMESTONE MIXES					
Filler Type	1	639.31	639.31	153.94	0.0001
% pass 4.75 mm (No. 4) Sieve	2	887.25	443.63	106.82	0.0001
Stabilizer Type and Amount	6	199.02	33.17	7.99	0.0001
% AC	1	295.36	295.36	71.12	0.0001

NOTE: SS Sum of Squares
DF Degrees of Freedom
Pr Probability

evaluated in this study. There was no difference in draindown for the two aggregates used.

Based on the results of this study, the draindown test appears to be a good way to quantify the draindown in the laboratory, which should be related to the draindown that would be observed in the field. Additional work is needed to finalize this draindown procedure, but it does appear to have the potential of being a very good test for mix design and control of SMA mixture. A correlation needs to be developed between laboratory draindown and draindown experienced in the field. To do this, some method must be developed to quantify the amount of draindown in the field. The draindown test in the laboratory also needs to be conducted at the expected field mixture temperature. It is also suggested that this test be conducted at temperatures above that anticipated for mix production to evaluate the sensitivity to temperature changes which may occur due to normal production variation or due to modifications in mixing temperature.

CONCLUSIONS

From the results of this study, the following conclusions can be made:

- Draindown of asphalt cement in SMA mixes is significantly affected by the type of filler, the percentage passing the 4.75 mm (No. 4) sieve, the asphalt content, the type of stabilizer, and the amount of stabilizer. In general, the mixes with 0.3 percent cellulose fiber and 0.3 percent mineral fiber exhibited the lowest amount of draindown. Obviously mix temperature is a major factor, but it was not evaluated in this study. The study showed that the aggregate type had no significant effect on draindown.
- The proposed draindown test is a fast, inexpensive test that appears to quantitatively evaluate the draindown potential of an SMA mixture.
- The results from the round robin study showed that the proposed draindown test is a good test to distinguish between mixes with and without draindown potential.
- The draindown test should become part of SMA specifications to minimize any draindown potential.

RECOMMENDATIONS

It is recommended that further research be conducted to observe and evaluate the following:

- Effect of temperature on draindown,
- Effect of amount and size of material passing the 75 μm (No. 200) sieve on draindown, and
- Comparison of laboratory draindown results with draindown observed in the field.

TABLE 8 Grouping of Variables on the Basis of Draindown Values

VARIABLE	TYPE OR VALUE OF VARIABLE	MEAN VALUE OF DRAINDOWN (%)	GROUP
GRAVEL MIXES			
AC Content	7 %	3.37	A
	6 %	1.57	B
Filler	Marble	3.82	A
	Baghouse fines	1.12	B
% pass 4.75 mm (No. 4) Sieve	20	4.72	A
	30	2.27	B
	50	0.44	C
Stabilizer	Control (Plain)	3.88	A
	Polymer, 3 %	3.70	A
	Polymer, 8 %	3.43	A
	Mineral Fiber,0.1%	3.13	A
	Cellulose Fiber, 0.1 %	1.68	B
	Mineral Fiber, 0.3 %	1.13	C B
	Cellulose Fiber, 0.3 %	0.36	C
LIMESTONE MIXES			
AC Content	7 %	3.56	A
	6 %	1.39	B
Filler	Marble	4.07	A
	Baghouse fines	0.89	B
% pass 4.75 mm (No. 4) Sieve	20	4.86	A
	30	2.31	B
	50	0.27	C
Stabilizer	Polymer, 3 %	3.53	A
	Control (Plain)	3.16	A
	Cellulose Fiber, 0.1 %	2.84	A
	Mineral Fiber, 0.1 %	2.78	A
	Polymer, 8 %	2.78	A
	Cellulose Fiber, 0.3 %	1.22	B
	Mineral Fiber, 0.3 %	1.13	B

NOTE: Means with the same letter are not significantly different
Level of significance, alpha = 0.05

REFERENCES

1. Stuart, K. D. *Stone Mastic Asphalt (SMA) Mixture Design.* Report FHWA-RD-92-006. FHWA, U.S. Department of Transportation, 1992.
2. Walsh, I. D. Stone Mastic Asphalt Wearing Course. *Kent County Council Specification,* Clause 995 AK. Nov. 1993.
3. Brown, E. R., and R. Basu Mallick. Stone Matrix Asphalt—Properties Related to Mixture Design. Draft Report, *NCAT Publication.* Auburn University, Ala., Feb. 1994.

Publication of this paper sponsored by Committee on Flexible Pavement Construction and Rehabilitation.