EFFECT OF MOISTURE ON TYPICAL VIRGINIA SURFACE TREATMENT MATERIALS

by

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Special Summer Undergraduate Trainee

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SUMMARY

Several aspects of the stripping and whip off characteristics of typical Virginia surface treatment materials were investigated. Sixty different binder-aggregate combinations were tested with the AASHO Designation T182-57 stripping test, a plate immersion stripping test, and a centrifuge whip off test, the last two of which were recently devised by the Virginia Highway Research Council.

By statistically evaluating the results, it was concluded that:

1. The grade and source of asphalt and the type of aggregate cause significant differences in the stripping characteristics,
2. the whip off decreases with increased curing time,
3. there is no significant difference in performance between the crushed and uncrushed gravel,
4. the AASHO test has limited value in determining degrees of stripping, whereas the plate immersion test offers a valid method of numerically determining stripping differences between binder-aggregate combinations,
5. the AP-00 performs better than the emulsions,
6. the cationic emulsions perform better with carbonates than with silicates,
7. the limestone performs the best and uncrushed gravel the poorest with all asphalts, and
8. there is a slight interaction between asphalts and aggregates.

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INTRODUCTION

The problem of securing and maintaining adhesion between asphalts and aggregate in the presence of water has been recognized by asphalt technologists almost from the beginning of asphalt road construction.(1) However stripping — the displacement of binder from the stone after initial set due to moisture — was not widely recognized until around 1940.(2) Since that time there have been innumerable papers written on this problem. There are two basic schools of thought on the problem; one blames the stripping on the aggregate, the other blames it on the asphalt.(3) The difference of opinion arises from the fact that the large number of variables involved make adhesion and stripping almost impossible to thoroughly understand and explain. Besides those inherent in the aggregate and asphalt, the variables include water content, method of adding water, history of soaking water, oil content, viscosity of oil, curing, mixing and rolling, temperature variation, etc.(3,4,5,6)

SIGNIFICANCE

In the summer of 1966 a surface treatment test section was placed on Route 11 in Wythe County using AP-2 as the binder and a No. 7 local limestone. At the end of the day's operation, the stone was firmly bound with heavy traffic not throwing stones at 60 mph. During the night it rained very hard and the next morning the asphalt was completely stripped from the aggregate. Since similar conditions had not produced the same results in previous test sections, a laboratory investigation was undertaken. It consisted mainly of performing stripping tests on several mixes of different aggregates and different blends. The results of these tests indicated that the adhesion characteristics of the asphalts used in Virginia vary. In other words, it is believed in this case that stripping resulted from properties of the asphalt rather than those of the aggregate.

PURPOSE AND SCOPE

The primary purpose of this investigation was to determine if different grades and sources of asphalts used in Virginia have a significant effect on the stripping characteristics of bituminous mixtures.

The secondary purposes of the study were to (1) compare the stripping characteristics of a crushed and uncrushed gravel from the same source, (2) determine the adhesivity in some of the surface treatment materials used in Virginia at various stages of curing, and (3) find a reliable method of test for determining the stripping characteristics of asphalts and aggregates.

The scope of the project was limited in time to the author's summer vacation from school. The investigation was divided into two distinct parts, with the first part consisting of performing stripping tests on several binder-aggregate combinations. The stripping tests used were the AASHO Designation T182-57, which is included in the Virginia Specifications, and the plate test used by the Research Council. The stripping test was modified as explained later under Procedure. Ten asphalts were tested: five AP-00's, four cationic emulsions, and one anionic emulsion. The aggregate used consisted of one limestone, one diabase, one granite, one greenstone and one crushed and uncrushed gravel from the same source. The use of three test samples for the plate test and two test samples for the AASHO test with each combination of aggregate and binder resulted in a total of 300 tests.

The second part of the investigation consisted of centrifuging for a certain time and certain speed a bituminous treatment placed on a metal plate. This test is an indication of the "whip off" of stone on a fresh surface treatment. Eight plates were made for each combination of aggregate and binder. Two plates were centrifuged at time intervals of two, six, twenty-four, and forty-eight hours after the mix was placed. By using the same binder-aggregate combinations used in the first part, this procedure resulted in 480 tests.

MATERIALS

As previously stated, the materials consisted of ten asphalts and six aggregates. The cationic emulsion and AP-00 were chosen as the main types of asphalt investigated because it was felt these were used more frequently in Virginia for surface treatments than were other types. Samples were obtained from five of the state's eight highway construction districts; the other three have no local suppliers. The asphalts were differentiated and numbered by brand name, that is, Shell, Texaco, etc., rather than by source. However, the ten asphalts tested did include two emulsions of the same brand but obtained from two different suppliers. The six aggregates used were chosen as being representative of the types used in Virginia. Samples of No. 78 stone were obtained and scalped on the 3/8" sieve. The plus 3/8" material was used in the tests.

EQUIPMENT

The centrifuging system consists of a centrifuge head fashioned so that two six inch by six inch metal plates can be fastened on it at an angle of 15° from the horizontal. As the head rotates on a standard centrifuge, stone particles are thrown off when adhesion fails. Figures 1, 2 and 3 show the centrifuge, the centrifuge head, and sample plates before and after centrifuging.

The immersion system consisted merely of a large tub or barrel filled with water in which plates were hung vertically from the sides. Figures 4 and 5 show the barrel and the sample plates before and after immersion.

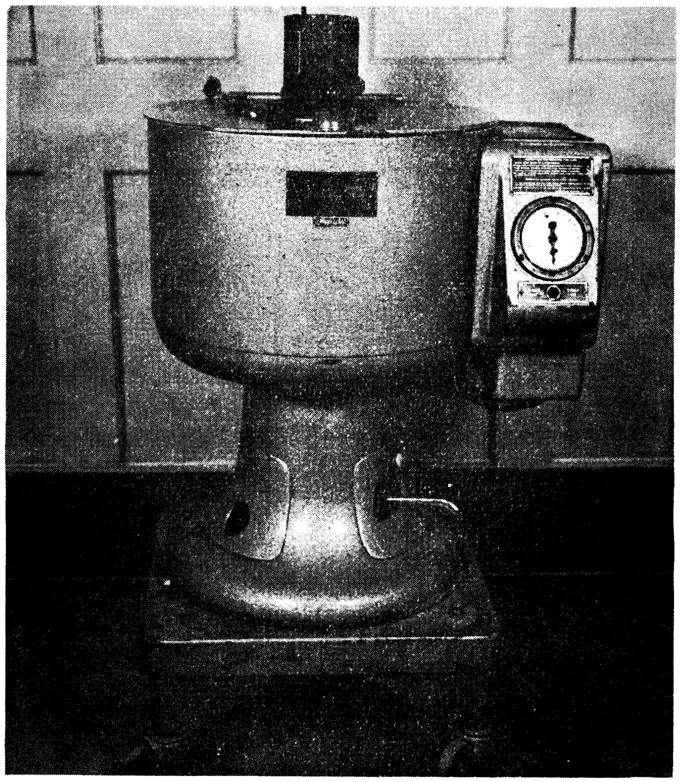

Figure 1. Centrifuge.

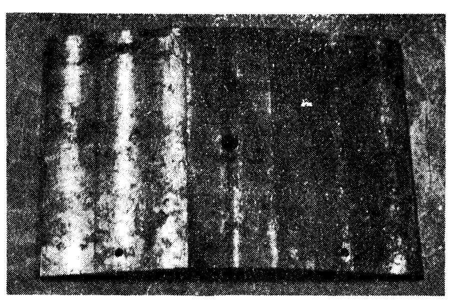

Figure 2. Centrifuge head.

Figure 3. Centrifuge sample plates before (above) and after centrifuging.

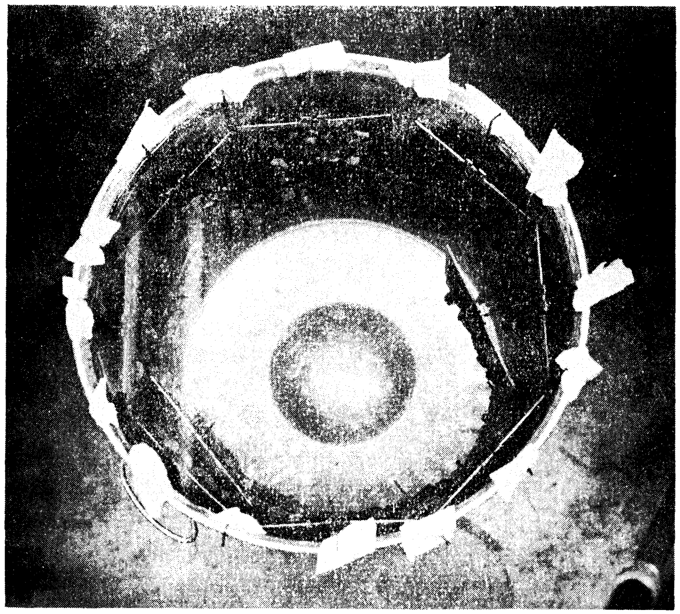

Figure 4. Sample plates before 24 hour immersion.

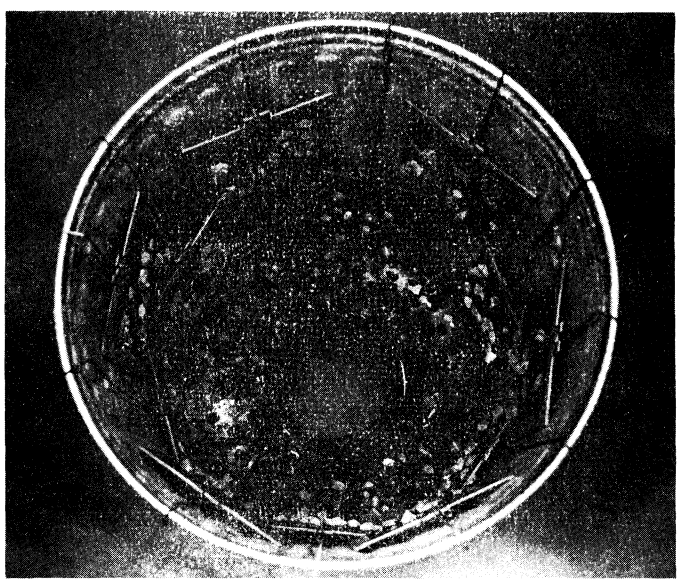

Figure 5. Sample plates after 24 hour immersion.

PROCEDURE

Preparation of Plates

The procedure for making the sample plates was the same for the immersion and centrifuging tests. In general, the plate was preheated to 100° to 120° F to simulate road conditions and then weighed on a set of balance scales. With the plate on the scales, thirteen grams of AP-00* at 275°F or twenty grams of emulsion at 175°F were added to the plate. Based on emulsions containing approximately 65% asphalt by weight, the amount added was approximately the same for both AP-00 and the emulsions (.65 x 20 = 13). The asphalt was then spread on the plate so as to uniformly coat a small square. Then exactly forty stones of a certain aggregate were placed individually on the plate within the asphalt coated square. The forty stones were randomly picked from a sample of the aggregate which had passed the 3/4" sieve and had been retained on the 3/8" sieve. In the case of AP-00, which has a higher viscosity at application temperature than do the emulsions, the stones were then rolled twice with a small, solid steel cylinder weighing approximately 10.5 lb. The plate was then laid aside for the required curing time.

Centrifuging

As previously stated, eight plates were made for each binder-aggregate combination, and two were centrifuged after each curing period, viz., 2 hours, 6 hours, 24 hours and 48 hours. The two plates at each time were centrifuged for two minutes at seven hundred rpm. The stones remaining were then counted and recorded as a percent whip off by dividing the number of stones that had been displaced by forty.

Immersion Tests

Three plates were made for each binder-aggregate combination. The plates were allowed to cure for twenty-four hours and then immersed vertically in water for twenty-four hours. They were then evaluated as in the centrifuging test, except the results were recorded as a percent stripped.

The "Stripping Test for Bitumen-Aggregate Mixtures", AASHO Designation: T 182-57, was also used in the investigation. It consisted basically of mixing an aggregate and binder and immersing the mixture for sixteen to eighteen hours. The stripping was evaluated by visually estimating the percentage of the total aggregate area remaining coated as being above or below 95%. A brief description of the results for each test was recorded in addition to the above or below 95% evaluation. The following modifications were employed:

1. The aggregate used passed the 3/8" sieve and was retained on the 3/8" sieve.

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*For asphalt #1, 21 grams were added to the plate.

2. The material was mixed in small porcelain dishes.

3. The aggregate was not washed.

4. The coated aggregate was immersed in quart jars.

5. The emulsions were heated to 175°F, the application temperature recommended in the Virginia specifications.

It was felt that only numbers 3 and 5 above would have any significant effect on the results. These two changes were considered justifiable in order to more closely simulate actual mixing conditions.

Because of the period of time that elapsed between obtaining and testing the asphalt, the heavier particles of the emulsions had settled to the bottom. To overcome this, the samples were agitated vigorously before use.

RESULTS

Immersion Test Results

1. There is no question that the five AP-00 asphalts tested performed better than did the five emulsions. This fact is well illustrated in Tables I and II as well as in Figures 6 and 7. The average stripping for emulsions was 85.3% while only 30.4% for AP-00; a difference of 54.9%. One reason for the large difference could be that the tests were performed after 24 hours of curing and, as will be shown later, the emulsions probably were not fully cured after this amount of time. Nevertheless, it seems safe to say the AP-00 asphalts would have performed better after any amount of curing.

2. An analysis of variance was performed on both the AP-00 asphalts and emulsions and the results are shown in Tables III and IV. In both cases, both factors of asphalt and aggregate are significant at the 95% confidence level. However, as indicated by the components of variance and standard deviations, the variability is greater for asphalts, particularly the emulsions. Asphalt accounts for roughly 40% of the variation in both cases, while aggregate accounts for only 23% with AP-00 and 7% with emulsions. The effect of interaction is not significant for AP-00's but is slightly significant for emulsions. Thus, for emulsions the measurement of stripping depends to a varying extent on a particular combination of aggregate and asphalts as well as the various asphalts and aggregates. This effect is illustrated in Figures 6 and 7. In Figure 6 there is no interaction effect and the curves have about the same shape. However in Figure 7, where the interaction is slightly significant, the shapes of the curves change, especially for asphalts 9 and 10.

TABLE I

TABLE OF MEANS, AP-00

		Limestone	Diabase	Granite	Greenstone	Crushed Gravel	Uncrushed Gravel	Average
Asphalt	(1)	20.00000	26.66667	46.66667	17.50000	33.33333	39.16667	30.55556
	(2)	35.00000	40.00000	50.83333	36.66667	48.33333	48.33333	43.19444
	(3)	20.83333	29.16667	40.00000	20.83333	35.83333	31.66667	29.72222
	(4)	6.66667	12.50000	27.50000	17.50000	12.50000	20.00000	16.11111
	(5)	27.50000	35.00000	43.33333	23.33333	27.50000	38.33333	32.50000
Average		22.00000	28.66667	41.66667	23.16667	31.50000	35.50000	30.41667

TABLE II

TABLE OF MEANS, EMULSIONS

		Limestone	Diabase	Granite	Greenstone	Crushed Gravel	Uncrushed Gravel	Average
Asphalt	(6)	90.83333	88.33333	76.66667	94.16667	96.66667	100.00000	91.11111
	(7)	83.33333	82.50000	90.83333	93.33333	86.66667	92.50000	88.19444
	(8)	84.16667	92.50000	98.33333	99.16667	95.00000	97.50000	94.44444
	(9)	43.33333	76.66667	71.66667	45.83333	63.33333	79.16667	63.33333
	(10)	65.0000	96.66667	99.16667	96.66667	88.33333	91.66667	89.58333
Average		73.33333	87.33333	87.33333	85.83333	86.00000	92.16667	85.33333

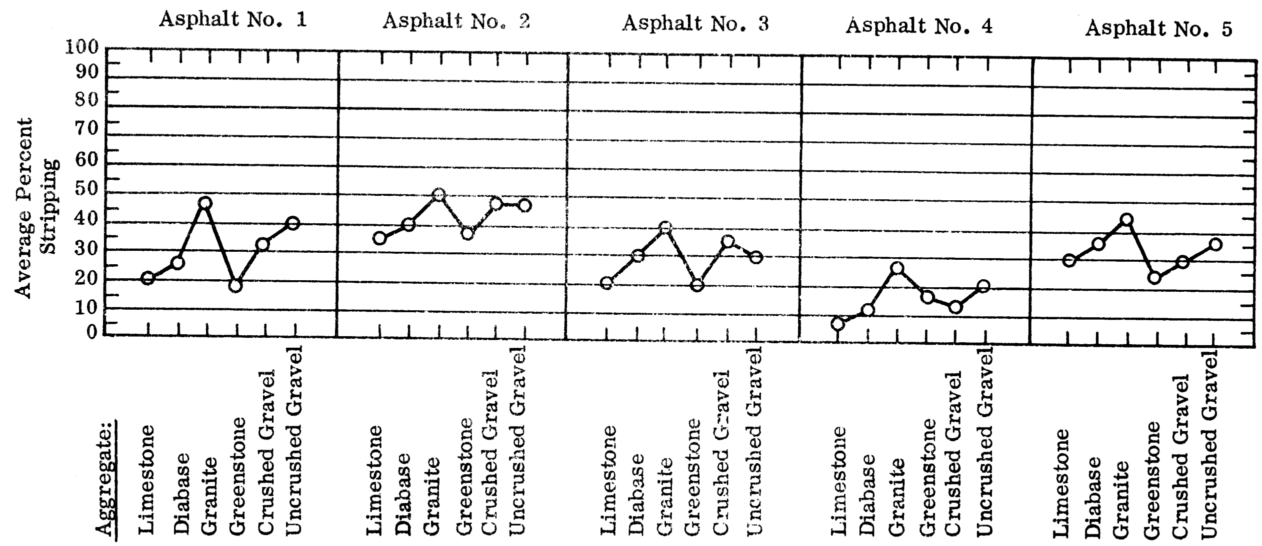

Figure 6. Stripping results — **AP-00.**

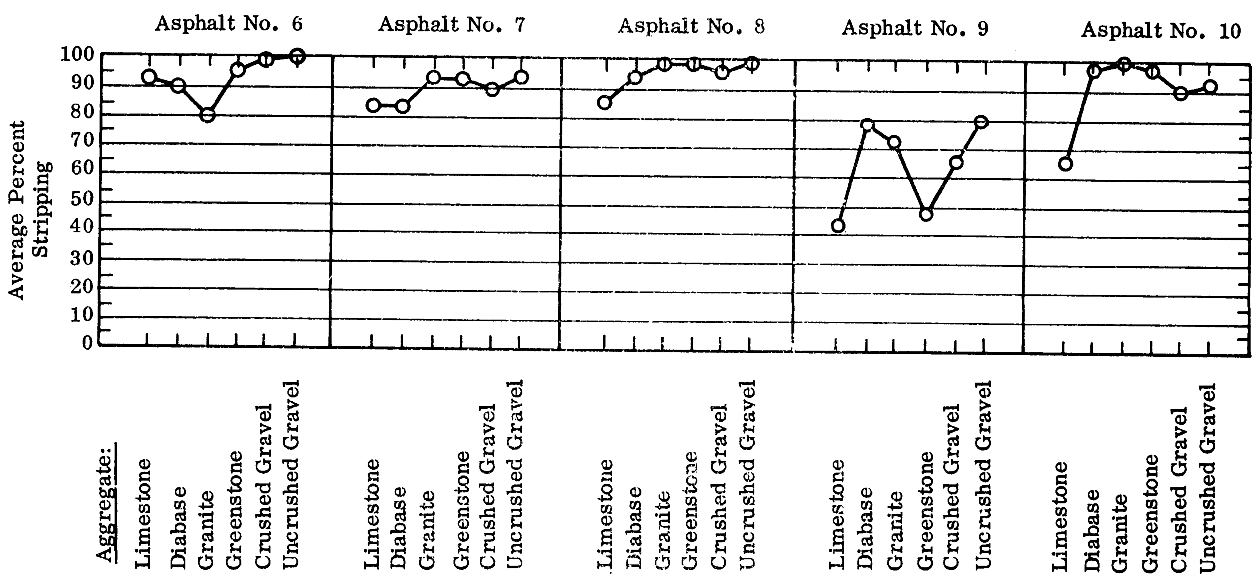

Figure 7. Stripping results — **Emulsions.**

TABLE III

ANALYSIS OF VARIANCE RESULTS, AP-00

	Source of Variation				
	(1) Asphalt	(2) Stone	(1) x (2) Interaction	Error	Total
Sum of Squares	6709.72	4200.62	984.44	5020.83	16,915.62
Degree of Freedom	4	5	20	60	89
Mean Squares	1677.43	840.12	49.22	83.68	
F Ratio	20.07	10.04	0.59		
Significant at 95% Confidence Level	Yes	Yes	No		
Component of Variance	40%	23%			
	90.45	52.73	Nil	83.68	226.86
Standard Deviation	9.51	7.26		9.15	15.05
95% Confidence Interval	8.59	9.81			

TABLE IV

ANALYSIS OF VARIANCE RESULTS, EMULSIONS

	Source of Variation				
	(1) Asphalt	(2) Stone	(1) x (2) Interaction	Error	Total
Sum of Squares	11,279.58	2990.83	4836.25	7208.33	26,315.00
Degrees of Freedom	4	5	20	60	89
Mean Squares	2,819.90	598.17	241.81	120.14	
F Ratio	23.5	5.0	2.01		
Significant at 95% Confidence Level	Yes	Yes	Yes*		
Component of Variance	44%	7%			
	143.23	23.75	40.56	120.14	327.68
Standard Deviation	11.97	4.88	6.37	10.96	18.02
95% Confidence Interval	10.29	11.75			

*Not significant at 95% confidence level.

3. With regard to which particular asphalt or aggregate performed best, the significance of difference in the mean of the various asphalts and aggregates was determined and, using the confidence intervals shown in Tables III and IV, is presented in Tables V — VIII. Of the AP-00 asphalts No. 4 performed significantly better than any of the other four, while No. 2 performed significantly worse than any of the other four. There was no significant difference in the performances of asphalts 1, 3 and 5. For the emulsions, No. 9 performed significantly better than the rest, with there being no significant difference in the performance of the other four.

   Limestone and greenstone, and to a lesser degree, diabase, performed best with AP-00, and granite performed the worst. With emulsions, limestone performed the best with no significant difference in the performance of the other aggregates. The interaction effect of emulsions and aggregates is well illustrated in Figure 7, which shows that the limestone performs relatively much better with asphalts 9 and 10, and diabase with asphalt No. 9.

TABLE V

SIGNIFICANT DIFFERENCE IN MEANS OF ASPHALTS, AP-00

		Asphalt No. 2		Asphalt No. 5		Asphalt No. 1		Asphalt No. 3	
Asphalt	Means	43.19	Sig.	32.50	Sig.	30.56	Sig.	29.72	Sig.
No. 4	16.11	27.08	Yes	16.39	Yes	14.45	Yes	13.61	Yes
No. 3	29.72	13.37	Yes	2.78	No	0.84	No		
No. 1	30.56	12.63	Yes	1.94	No				
No. 5	32.50	10.69	Yes						

TABLE VI

SIGNIFICANT DIFFERENCE IN MEANS OF ASPHALTS, EMULSIONS

		Asphalt No. 8		Asphalt No. 6		Asphalt No. 10		Asphalt No. 7	
Asphalt	Means	94.44	Sig.	91.11	Sig.	89.58	Sig.	88.19	Sig.
No. 9	63.33	31.11	Yes	27.78	Yes	26.25	Yes	24.86	Yes
No. 7	88.19	6.25	No	2.92	No	1.39	No		
No. 10	89.58	4.86	No	1.53	No				
No. 6	91.11	3.33	No						

TABLE VII

SIGNIFICANT DIFFERENCE IN MEANS OF AGGREGATES, AP-00

		Granite		Uncrushed Gravel		Crushed Gravel		Diabase		Greenstone	
Aggregate	Means	41.67	Sig.	35.50	Sig.	31.50	Sig.	28.67	Sig.	23.17	Sig.
Limestone	22.00	19.67	Yes	13.50	Yes	9.50	Yes	6.67	No	1.17	No
Greenstone	23.17	18.50	Yes	12.33	Yes	8.33	No	5.50	No		
Diabase	28.67	13.00	Yes	6.83	No	2.83	No				
Crushed Gravel	31.50	10.17	Yes	4.00	No						
Uncrushed Gravel	35.50	6.17	No								

TABLE VIII

SIGNIFICANT DIFFERENCE IN MEANS OF AGGREGATES, EMULSIONS

		Uncrushed Gravel		Granite		Diabase		Crushed Gravel		Greenstone	
Aggregate	Means	92.17	Sig.	87.33	Sig.	87.33	Sig.	86.00	Sig.	85.33	Sig.
Limestone	73.33	18.84	Yes	14.00	Yes	14.00	Yes	12.67	Yes	12.50	Yes
Greenstone	85.83	6.34	No	1.50	No	1.50	No	0.17	No		
Crushed Gravel	86.00	6.17	No	1.33	No	1.33	No				
Diabase	87.33	4.84	No	0.00	No						
Granite	87.33	4.84	No								

Modified AASHO Test Results

As seen in Table IX, all aggregates and asphalts, except emulsion No. 6, performed satisfactorily with respect to the above or below 95% coating evaluation. However, by visual inspection, trends were established as to which asphalts and aggregates performed the best and which the worst. It appeared that AP-00 No. 1 and emulsion No. 8 had the least stripping, while AP-00 No. 4 and emulsion No. 6 had the most. These results are certainly not very consistent with the immersion test results, where AP-00 No. 4 performed significantly better than the other AP-00 asphalts and emulsion No. 9 performed significantly better than the other emulsions.

With regard to aggregates, diabase seemed to perform the best and granite the worst with AP-00, which is fairly consistent with the immersion test results. It was not possible to establish trends of aggregate performance with emulsions.

The inconsistent results of the immersion and AASHO tests seem to indicate that one of the test methods is not very reliable.

TABLE IX

AASHO TEST RESULTS

Above or Below 95% of Total Area Remaining Coated

Asphalt No.	1	2	3	4	5	6	7	8	9	10
Aggregate										
Limestone	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above
Diabase	Above	Above	Above	Above	Above	Above	Above	Above	Above	Above
Granite	Above	Above	Above	Below	Above	Below	Above	Above	Above	Above
Greenstone	Above	Above	Above	Above	Above	Below	Above	Above	Above	Above
Crushed Gravel	Above	Above	Above	Above	Above	Below	Above	Above	Above	Above
Uncrushed Gravel	Above	Above	Above	Above	Above	Below	Above	Above	Above	Above

Centrifuge Test Results

1. As with the immersion tests, the five AP-00 asphalts performed better than did the emulsions. The comparison is illustrated in Tables X and XI and Figures 8, 9, and 10. The AP-00 asphalts have less whip off in all cases, but the difference becomes smaller as the curing time increases.

2. It was indicated during the discussion of the immersion test results that perhaps the curing times used resulted in the AP-00 asphalts performing better. While the curing time does have an obvious effect, it appears (again as illustrated in Tables X and XI as well as Figures 8, 9 and 10) that AP-00 probably would perform better after any amount of curing.

3. As with the immersion test results, an analysis of variance was performed on the whip off measurements for both types of asphalt. The results are shown in Tables XII and XIII. As expected, time was the most important variable, particularly for emulsions (note the component of variance percentages in both tables). For both AP-00 and emulsions the asphalt was significant at the 95% confidence level, and aggregate type was significant with both AP-00 and the emulsions. As with the immersion test, asphalt was more important than aggregate type considering both AP-00 and emulsions. However, the relative importance was considerably less (in fact, aggregate had slightly more effect with AP-00). For both AP-00 and emulsions the interaction effect of time and asphalt type was significant; and to a lesser degree so was the interaction effect of asphalt and aggregate. These interactions are illustrated in Figures 8 and 9. The interaction of time and asphalts is well illustrated in Figure 9 in the comparison of asphalts 7 and 8 at different curing times. Number 8 is superior at the shorter curing times, but not the longer curing times. The comparison of No. 6 with any of the other asphalts also illustrates the interaction. This type of interaction effect may certainly be an important consideration when a faster curing asphalt is desired. It is important to remember that while the interaction effects discussed are statistically significant they are relatively unimportant in comparison to the effects of curing time and asphalt.

4. With regard to how particular times, asphalts, and aggregates performed, the significance in the differences in the means of these various factors was determined using the confidence intervals determined in Tables XII and XIII. This information is presented in Tables XVI — XXI. Here it can be seen that the longer curing times obviously would have significantly better results. About the only thing of importance to note was that the results of AP-00 after 48 hours of curing were not significantly better than after 24 hours of curing. It is important to remember the effect of curing time on immersion test results.

   For the AP-00 asphalts, No. 4 performed significantly better than any of the other four, just as in the immersion test, Number 3 performed significantly worse than any of the others, and Nos. 1, 2 and 5 were about the same. In the immersion test, No. 2 performed the worst, and Nos. 3 and 5 were equal. Perhaps this inconsistency can be explained by saying that water has a more pronounced effect on asphalt No. 2 and a lesser effect on No. 3.

Asphalts 8 and 10 (particularly 8) performed the best of the emulsions and No. 6 and No. 9 (particularly No. 6) the worst. In the immersion tests, there was no significant difference in the performance except that No. 9 performed significantly better than the rest. Again, the explanation may be the relative effects of water on these asphalts.

With regard to aggregate, limestone performed the best with both types of asphalt, and uncrushed gravel the worst; the degree of significance was less with the emulsions. As for uncrushed vs. crushed gravel, there was no significant difference in performance. Again, these results are consistent with the immersion test results.

5. Considering asphalt, the results of the centrifuge test were fairly close to the AASHO test results with the exception of asphalt No. 4, for which opposite results were obtained. It would appear, however, that the AASHO test may not be critical enough with a sample above or below 95% evaluation to determine how asphalts and aggregates will perform under various conditions.

6. It may be worthwhile to indicate that asphalt No. 6, which performed worst of the emulsions, is the anionic type.

TABLE X

TABLE OF MEANS, AP-00

	1	2	3	4	5	Average
2 hr.	21.45833	32.08333	45.20833	25.20833	31.04167	31.00000
6 hr.	30.41667	27.29167	31.04167	14.58333	23.54167	25.37500
24 hr.	23.95833	13.95833	21.66667	7.91667	18.12500	17.12500
48 hr.	10.20833	13.95833	21.66667	7.08333	13.95833	13.37500
Ave.	21.51042	21.82292	29.89583	13.69792	21.66667	21.71875

TABLE XI

TABLE OF MEANS, EMULSIONS

	6	7	8	9	10	Average
2 hr.	99.37500	97.50000	87.08333	98.75000	97.91667	96.12500
6 hr.	93.75000	92.70833	57.29167	86.87500	73.95833	80.91667
24 hr.	75.00000	20.20833	21.04167	44.58333	36.87500	39.54167
48 hr.	65.83333	5.20833	10.41667	18.54167	4.58333	20.91667
Ave.	83.48958	53.90625	43.95833	62.18750	53.33333	59.37500

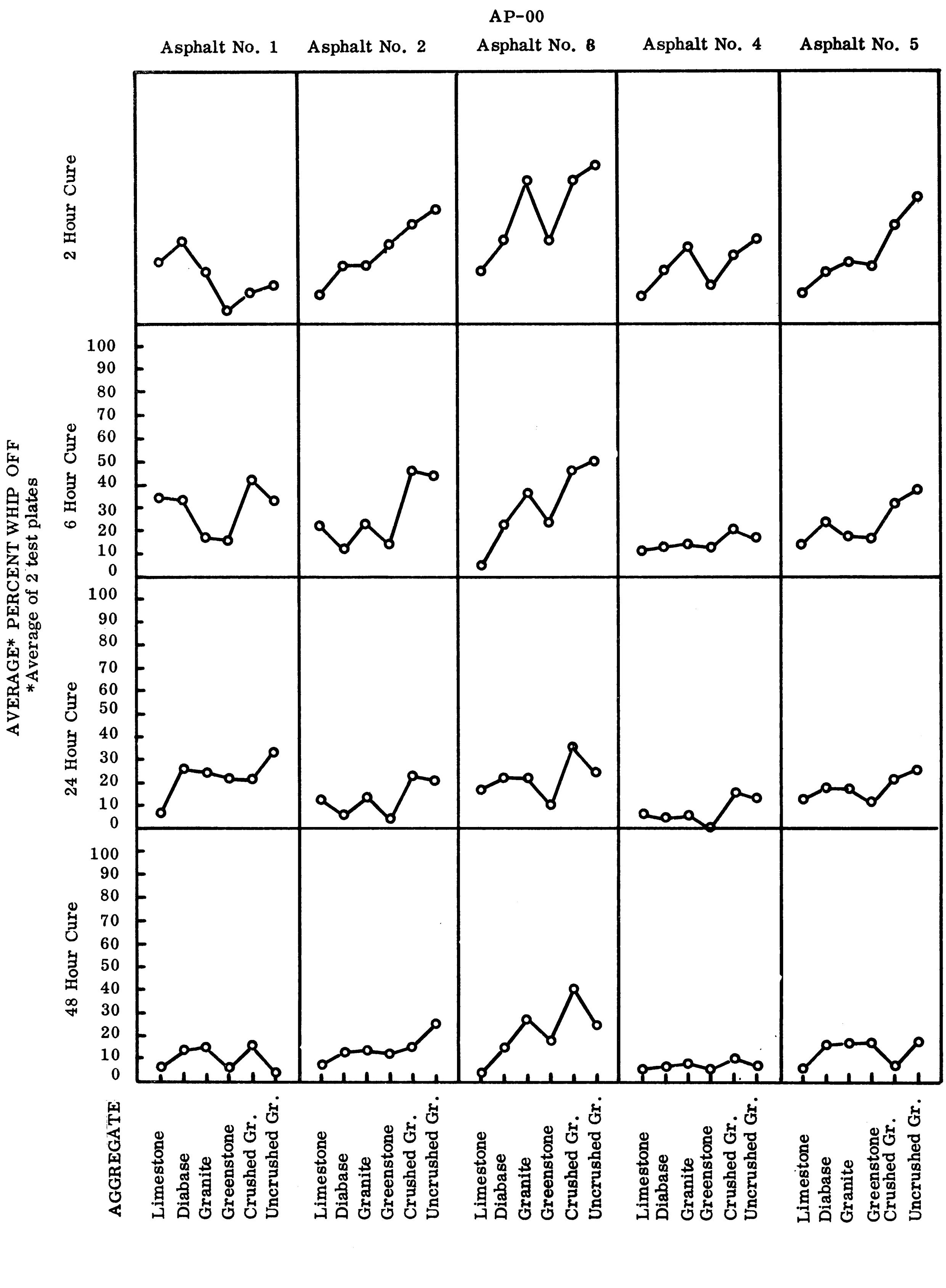

Figure 8. Centrifuging results.

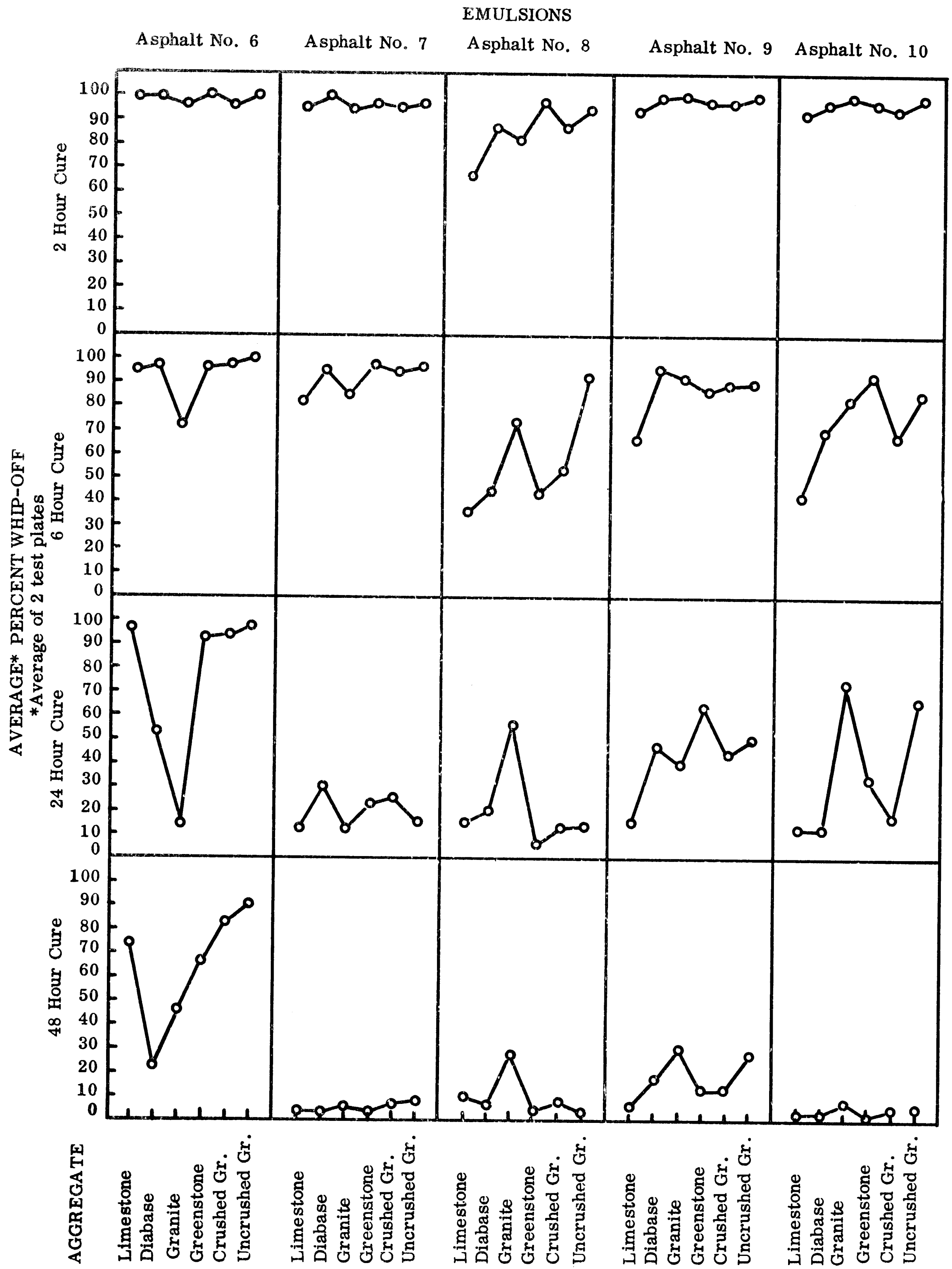

Figure 9. Centrifuging results.

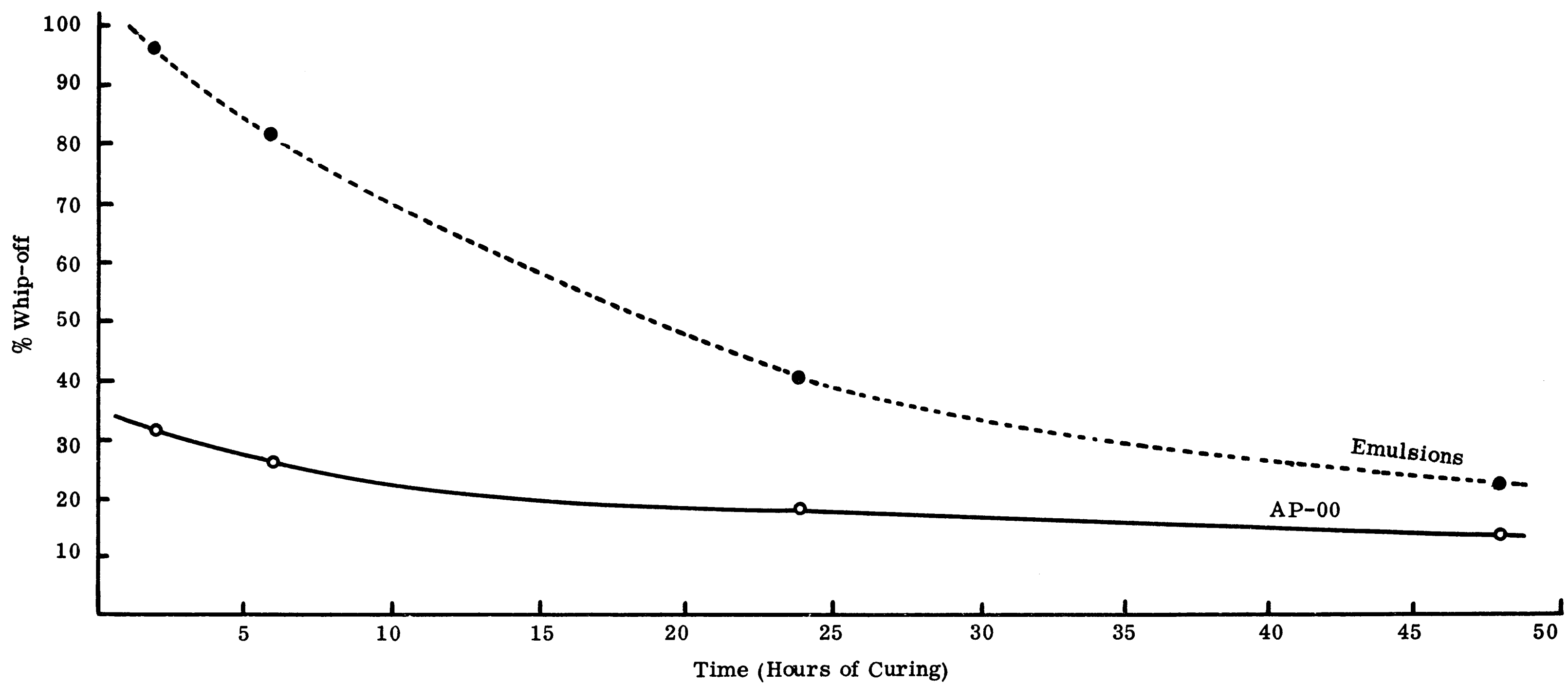

Figure 10. Centrifuging.

Average whip off vs. time of curing.

TABLE XII

ANALYSIS OF VARIANCE RESULTS, AP-00

	Source of Variation							
	(1) Time	(2) Asphalt	(3) Aggregate	(1) x (2) Interaction	(1) x (3) Interaction	(2) x (3) Interaction	Error	Total
Sum of Squares	11,413.83	6,300.26	9,281.17	3,189.95	2,076.64	4,315.05	10,045.37	46,622.27
Degrees of Freedom	3	4	5	12	15	20	120	239
Mean Square	3,804.61	1,575.07	1,856.23	265.83	138.44	215.75	83.71	
F Ratio	45.45	18.82	22.17	3.18	1.65	2.58		
Significant at 95% Confidence Level	Yes	Yes	Yes	Yes	No	Yes		
Component of Variance	58.1 = 24%	24.5 = 10%	39.6 = 16%	15.2 = 16%	5.5 = 2%	16.5 = 7%	83.71	243.14
Standard Deviation	7.6	4.9	6.3	3.9	2.3	4.1	9.1	
95% Confidence Interval	4.32	5.15	5.90					

TABLE XIII

ANALYSIS OF VARIANCE RESULTS, EMULSIONS

	Source of Variation							
	(1) Time	(2) Asphalt	(3) Aggregate	(1) x (2) Interaction	(1) x (3) Interaction	(2) x (3) Interaction	Error	Total
Sum of Squares	221,220.62	42,888.28	6,055.00	25,546.30	3,256.88	17,600.47	26,751.20	343,318.75
Degrees of Freedom	3	4	5	12	15	20	120	239
Mean Square	73,740.21	10,722.07	1,211.00	2,128.86	217.12	880.02	222.92	
F Ratio	330.79	48.10	5.43	9.55	.97	3.45		
Significant at 95% Confidence Level	Yes	Yes	Yes	Yes	No	Yes		
Component of Variance	1193.6 = 65%	165.3 = 9%	8.4 = NIL	158.8 = 9%	NIL	82.1 = 4.5%	222.92 = 12%	
Standard Deviation	34.5	12.9	2.9	12.6		9.1	14.9	
95% Confidence Interval	7.08	8.43	9.67					

TABLE XIV

TABLE OF MEANS, AP-00

	Aggregate						
	1	2	3	4	5	6	Average
	20.00000	28.12500	20.93750	13.75000	24.06250	22.18750	21.51042
	13.75000	14.68750	19.06250	16.56250	31.87500	35.00000	21.52292
Asphalt	12.50000	24.06250	37.18750	22.50000	43.75000	39.37500	29.89583
	8.43750	11.56250	15.31250	8.75000	19.06250	19.06250	13.69792
	11.25000	20.00000	20.31250	18.12500	25.31250	35.00000	21.66667
Average	13.18750	19.68750	22.56250	15.93750	28.81250	30.12500	21.71875

TABLE XV

TABLE OF MEANS, EMULSIONS

	Aggregate						
	1	2	3	4	5	6	Average
	92.50000	68.12500	57.81250	89.37500	93.43750	99.68750	83.48958
	48.43750	57.18750	50.31250	55.93750	56.56250	55.00000	53.90625
Asphalt	32.81250	40.31250	60.62500	38.12500	40.93750	50.93750	43.95833
	45.93750	65.62500	66.56250	66.25000	61.56250	67.18750	62.18750
	37.50000	45.93750	66.56250	57.81250	47.18750	65.00000	53.33333
Average	51.43750	55.43750	60.37500	61.50000	59.93750	67.56250	59.37500

TABLE XVI

SIGNIFICANT DIFFERENCE IN CURING TIMES, AP-00

		2 Hours		6 Hours		24 Hours	
Time	Means	31.00	Sig.	25.38	Sig.	17.12	Sig.
48 Hours	13.37	17.63	Yes	12.01	Yes	3.75	No
24 Hours	17.12	13.88	Yes	8.26	Yes		
6 Hours	25.38	5.62	Yes				

TABLE XVII

SIGNIFICANT DIFFERENCE IN CURING TIMES, EMULSIONS

		2 Hours		6 Hours		24 Hours	
Time	Means	96.12	Sig.	80.92	Sig.	39.54	Sig.
48 Hours	20.92	75.20	Yes	60.00	Yes	18.62	Yes
24 Hours	39.54	56.58	Yes	41.38	Yes		
6 Hours	80.92	15.20	Yes				

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TABLE XVIII

SIGNIFICANT DIFFERENCE IN MEANS OF ASPHALTS, AP-00

		Asphalt No. 3		Asphalt No. 2		Asphalt No. 5		Asphalt No. 1	
Asphalt	Means	29.90	Sig.	21.82	Sig.	21.67	Sig.	21.51	Sig.
No. 4	13.70	16.20	Yes	8.12	Yes	7.97	Yes	7.81	Yes
No. 1	21.51	8.39	Yes	.31	No	.16	No		
No. 5	21.67	8.23	Yes	.15	No				
No. 2	21.82	8.08	Yes						

TABLE XVIX

SIGNIFICANT DIFFERENCE IN MEANS OF ASPHALTS, EMULSIONS

		Asphalt No. 6		Asphalt No. 9		Asphalt No. 7		Asphalt No. 10	
Asphalt	Means	83.49	Sig.	62.19	Sig.	53.91	Sig.	53.33	Sig.
No. 8	43.96	39.53	Yes	18.23	Yes	9.95	Yes	9.37	Yes
No. 10	53.33	30.16	Yes	8.86	Yes	.58	No		
No. 7	53.91	29.58	Yes	8.28	No				
No. 9	62.19	21.30	Yes						

TABLE XX

SIGNIFICANCE IN DIFFERENCE OF MEANS OF AGGREGATES, AP-00

		Uncrushed Gravel Aggregate No. 6		Crushed Gravel Aggregate No. 5		Granite Aggregate No. 3		Diabase Aggregate No. 2		Greenstone Aggregate No. 4	
Aggregate No.	Mean	30.12	Sig.	28.81	Sig.	22.56	Sig.	19.69	Sig.	15.94	Sig.
Limestone — 1	13.19	16.93	Yes	15.62	Yes	9.37	Yes	6.50	Yes	2.75	No
Greenstone — 4	15.94	14.18	Yes	12.87	Yes	7.62	Yes	3.75	No		
Diabase — 2	19.69	10.43	Yes	9.12	Yes	2.87	No				
Granite — 3	22.56	7.56	Yes	6.25	Yes						
Crushed Gravel — 5	28.81	1.31	No								

TABLE XXI

SIGNIFICANCE IN DIFFERENCE OF MEANS OF AGGREGATES, EMULSIONS

		Uncrushed Gravel Aggregate No. 6		Greenstone Aggregate No. 4		Granite Aggregate No. 3		Crushed Gravel Aggregate No. 5		Diabase Aggregate No. 2	
Aggregate No.	Mean	67.56	Sig.	61.50	Sig.	60.38	Sig.	59.94	Sig.	55.44	Sig.
Limestone — 1	51.44	16.12	Yes	10.06	Yes	8.94	No	8.50	No	4.00	No
Diabase — 2	55.44	12.12	Yes	6.06	No	4.94	No	4.50	No		
Crushed Gravel — 5	59.94	7.60	No	1.56	No	.44	No				
Granite — 3	60.38	7.18	No	1.12	No						
Greenstone — 4	61.50	6.06	No								

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CONCLUSIONS

Based on the results of the centrifuge and immersion tests, it is concluded that:

1. Asphalt type has a more significant effect on the stripping characteristics of a bituminous surface treatment than does the aggregate type. In fact, different sources of the same type of asphalt have a greater effect than does the type of aggregate, particularly with emulsions.

2. With regard to stripping as measured by the immersion test, and retention as measured by the centrifuge whip off test, AP-00 performed much better than emulsions. In both tests asphalts of the same type performed significantly different, but the differences were not always consistent for the two tests (i.e., the best performer for the centrifuge test was not always the best in the immersion test), which perhaps indicates that water has varying effects on asphalts of the same type.

3. In both tests, limestone performed better (and in most cases significantly better) with both the AP-00 and the cationic emulsions than did the other five aggregates; it was followed by greenstone and diabase. The granite, crushed and uncrushed gravel performed the poorest. The result of limestone performing best with the cationic emulsions and the two gravels performing the worst is contrary to the popular belief that cationic emulsions perform better with silicates (gravels). It might be noted, however, that with the lone anionic emulsion (No. 6) diabase and granite performed the best, with limestone being no better than the gravels.

4. In neither of the two tests was there any significant difference in the performance of crushed or uncrushed gravel. Crushed gravel did perform slightly better in all cases, but as just stated the difference was never statistically significant.

5. Stone retention as measured by the centrifuge whip off test increases as curing time increases. As indicated in (1) above retention is always better with AP-00 than with emulsions; however, the difference decreases with longer curing times, which means of course, that a much longer curing period is required for emulsions. The correlation between retention and curing time varies significantly, depending on the particular asphalt involved; but aggregate has very little effect.

6. There were some inconsistencies between the results of the centrifuge tests and immersion test (i.e., the best performance was not shown by the same asphalts or aggregates in both tests), which perhaps indicates, as expected, that water has unequal effects on the retention capacities of different asphalts.

7. The AASHO stripping test, while being of some limited value in determining whether a binder-aggregate combination is satisfactory or unsatisfactory, is not a critical enough test to determine the stripping characteristics of asphalts and aggregates and their combinations. It is felt that the centrifuge test and plate immersion test devised by the Research Council offer methods of numerically determining the retention and stripping characteristics of different asphalts and aggregate, as well as particular combinations of the two materials.

RECOMMENDATIONS

1. Based on the results of this study it is recommended that highway engineers give consideration to using AP-00 for surface treatments where high, early retention is desired.

2. Based on the results of this study and a report by Dr. W. Cullen Sherwood(7), it is recommended that for surface treatments incorporating carbonate aggregates, highway engineers give consideration to using emulsions other than the anionic types.

3. Since both asphalt and aggregate play an important role in successful surface treatments and since both differ, not only among types and grades, but also sources, the Highway Department should adopt a test that evaluates the actual material in the combination that is to be used on the road. As pointed out in the paper, an interaction exists among aggregates and asphalts; therefore, the AASHO Test Designation T 182-65 might be misleading.

   The Department has several alternatives for testing asphalt-aggregate adhesion:

   A. Continue to use AASHO T 182-65, but rather than use reference aggregate or asphalt use the materials that are going to be placed on the road.

      The disadvantage of this is twofold:

      1. The first paragraph of the test method states:

         1. It should not be used as a measure of field performance because such correlation has not been established.

         2. If the materials do pass in combination it does not mean that the best combination locally available is being used.

B. Adopt the plate test used in this investigation.

While it is believed by the author that this test is more realistic than the AASHO test, i.e., it is more nearly related to what happens in the field, it has the same disadvantage as the AASHO test has.

C. A third approach is one that has appeal to the author; i.e., the Department could employ either the AASHO Test T 182-65 or the plate test on all of the local materials available throughout the state, and use the findings of these tests, tempered with engineering judgment, to make a decision as to what materials are to be used in combination (the word materials as used here means specific quarry with regard to aggregate and the specific type, grade and source of asphalt).

A standard level of performance could be established with whatever test is used.

It should be understood that regardless of what approach is taken, the Department and the contractor should have a firm understanding that once a specific material is approved it shall not be changed without mutual consent (again the term material has a precise definition).

COMMENTS

1. It is the author's opinion that there is still much to be learned about the effect of asphalt on the stripping characteristics of surface treatments.

2. Emulsions should be tested soon after they are obtained. As mentioned in the report, there is a tendency for the heavier particles to settle, and this may ruin the emulsion.

3. When using the AASHO stripping test with emulsions, there is a tendency for the water to become so cloudy as to impede evaluation of the mixture in the water.

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