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Prithvi S. Kandhal
John B. Motter

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National Center for Asphalt Technology
NCAT
AUBURN UNIVERSITY
277 Technology Parkway • Auburn, AL 36830

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Prithvi S. Kandhal
Assistant Director
National Center for Asphalt Technology
Auburn University, Alabama

John B. Motter
Supervisor
Bituminous Testing Laboratory
Pennsylvania Department of Transportation
Pennsylvania

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ABSTRACT

One of the most common causes of seal coat failures is the presence of dust on the cover aggregate which prevents good adhesion between the applied bituminous binder and the aggregate. Precoating the aggregate with a very thin film of bituminous binder usually solves the dust problem and provides good adhesion.

This research was undertaken (a) to evaluate the adhesion of aggregates precoated to varying degree so that the optimum precoating requirement can be established, and (b) to develop an end-result type test in lieu of the subjective visual test for accepting precoated aggregates.

Five AASHTO No. 8 aggregates of different mineralogical compositions and absorptive characteristics were used. These aggregates were precoated with MC-30 cutback asphalt to varying degree (from salt & pepper effect to 90+ percent coating). Pennsylvania Aggregate Retention Test developed in this study was used to evaluate the effect of precoating on aggregate retention loss.

Immediate adhesion of the cover aggregate with the bituminous binder was best obtained at 90+ percent precoating. The agreement (reproducibility) between different evaluators who made subjective visual evaluation of the percent precoating was also by far the best at 90+ percent level. Of the three end-result type tests attempted, dry gradation test of the precoated aggregate was determined to be most appropriate with an acceptance criteria of 0.5 percent maximum minus 200 (dust).

It has been recommended to use AC-20 asphalt cement as a precoating material in lieu of MC-30 cutback asphalt, because it can be mixed at higher temperatures in a hot mix asphalt (HMA) plant, does not need any curing, and will cause better aggregate retention.

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INTRODUCTION

Pennsylvania Department of Transportation (PennDOT) is responsible for the maintenance of 43,000 miles of roadway. PennDOT's projected maintenance program for 1987 included placing seal coat applications over 5,000 miles of roadway requiring over 14 million gallons of emulsified asphalt. One of the most common causes of seal coat failures is the presence of dust on the cover aggregate which prevents good adhesion between the aggregate and the applied bituminous binder. Precoating the aggregate with a very thin film of bituminous binder usually solves the dust problem and provides good adhesion. PennDOT recommends the use of precoated aggregates in seal coats and surface treatments on the roads carrying more than 1500 average daily traffic (ADT).

The current PennDOT specifications require that "at least 90 percent of the total visible area of the aggregates shall be coated with a bituminous film—any thin, brownish, translucent areas will be considered full coated." Questions have been raised about the minimum degree of precoating required and its subjective determination. Some people believe that a lesser degree of coating (even a salt and pepper effect) will be as effective as 90 percent coating. A need was felt to develop an end-result type test in lieu of the subjective visual test for accepting the precoated aggregates for Department work.

The objectives of this research are (i) to evaluate the adhesion of aggregates precoated to varying degree so that the optimum precoating requirement can be established, and (ii) to develop an end-result type test in lieu of the subjective visual test for accepting precoated aggregates.

REVIEW OF LITERATURE AND CURRENT PRACTICES

PennDOT uses a rational design method (*1*, *2*) to establish the application rates of bituminous binder and cover aggregate. This was done in 1975 to have a uniform practice throughout the state and to minimize failures resulting from improper application rates. However, the specification allowed up to 2 percent of minus 200 material (hereinafter called 'dust') in the cover aggregate. This was considered excessive for applications on high volume roads and, therefore, specifications for precoated aggregates were developed in 1980 based on the experience in other States and overseas (particularly in Australia, New Zealand and United Kingdom).

Review of Literature

Before commencing this research, a review of literature on precoated aggregates was conducted. Highway Research Board's Special Report No. 96 (*3*) on "State-of-the-Art: Surface Treatments" summarized the existing literature in 1968 on this subject. It was mentioned that "one cannot overemphasize the importance of the physical condition (dusty) of the cover aggregate, the success or failure of a particular surface treatment might well depend solely upon the condition of the cover material." Benson and Gallaway (*4*)'s research indicated that for the presence of one percent dust there was a loss in aggregate retention of 12 percent by weight per unit area. One method of dealing with the dust problem is washing and drying the aggregate by mechanical means before application which solves the problem almost entirely. The other methods include coating the aggregate with either a bituminous material or a kerosene film before application. Precoating with a bituminous material almost guarantees good adhesion. Longer life experienced with precoated aggregates justifies the increased cost.

Harris (*5*) recommended the use of precoated aggregates in 1955 mentioning that "on heavily traveled roads, the trend is definitely towards the use of precoated aggregates, and probably as much as one hundred thousand tons will be used in Texas during 1955." Parr (*6*) reported about a surface treatment project over 33 miles long in Michigan, which gave 17 years of service without maintenance. The aggregate was precoated with an SC-1 oil (approximately one percent). While the cost of precoating is something to be considered, still the long life of the surface treatment had more than paid for the extra cost of precoating.

The Asphalt Institute (*7*) recommends that precoating the aggregate with a very thin film of asphalt usually solves the dust problem and provides good adhesion of the asphalt to the aggregate. The aggregate is run through a hot mix asphalt (HMA) plant dryer, cooled to under 200°F, then mixed in the pugmill with about one percent MC-70 to coat each particle thoroughly. The small amount of asphalt does not change the aggregate from a free flowing material which can still be applied with aggregate spreaders. The precoating adds to the cost of the aggregate but the additional cost is often justified by the better results obtained.

The Transport and Road Research Laboratory (TRRL) of the United Kingdom also suggests the use of precoated chippings to overcome the problem of dust (*8*). Coated chippings adhere immediately to the binder compared to dry uncoated chippings especially when the binder viscosity is relatively high. The most common technique is to heat the chippings to between 220°F and 300°F and to coat them with more normal grades of tar or bitumen. The high temperature used hardens the coating and makes the chippings easy to handle. A binder content of about 0.75 to 1 percent by weight of the chippings is suitable.

McLeod (*9*) has stated that rapid development of good adhesion between cover aggregate and bituminous binder is highly desirable. To achieve this, the National Roads Board of New Zealand requires all cover aggregates on state roads must be washed to remove dust and then precoated. Precoating is done by a special cationic emulsion or cutback asphalt at the rate of one gallon per cubic yard of chips. In Australia, to promote adhesion, stone chips are often similarly precoated with diesel fuel oil at the rate of 1-2 gallons per cubic yard of cover stone or with one percent of MC-30 or MC-70.

Precoated sandstone cover aggregate was used successfully on Interstate 81 in Pennsylvania in Federal Highway Administration Demonstration Project 55 (*10*). The seal coat job was completed in August 1980 using MC-30 Cutback as a precoating material, and CRS-2 (Pennsylvania Designation E-3) Emulsified Asphalt as the application binder.

Epps, Gallaway and Hughes (*11*) have prepared a field manual on design and construction of seal coats. They have stated that "precoated aggregates are more expensive than untreated aggregates but have been utilized to reduce the effect of a dusty aggregate, to reduce automobile glass damage due to flying stone and to promote bond with asphalt."

Current Practices

A questionnaire was sent to all 50 states of the United States and various highway agencies in Australia, New Zealand and United Kingdom. Australia and New Zealand are considered to be leading countries in obtaining most successful seal coat jobs in the world.

The questionnaire and the summary of the responses of 44 responding states from the United States on general seal coat practices such as, most commonly used aggregate gradation and applied bituminous materials, tests and specifications for minus 200 material (dust) in the cover aggregate are given in Reference *12*. Table 1 summarizes the response of highway agencies from the United States and abroad which use precoated aggregates in seal coats.

Only six states (Illinois, Oregon, Pennsylvania, Texas, Utah and Virginia) use precoated aggregates. Cutbacks, emulsions, and asphalt cements of different grades are used for precoating as shown in Table 1. Hot mix asphalt (HMA) plants are normally used for precoating in Pennsylvania. Lower mix temperatures are used when MC-30 is the precoating material. Three states specify minimum percentage of coating ranging from 85 to 100 percent. Five states evaluate th precoating by visual examination. Four states believe in specifying minimum percentage of coating.

Most of the seven agencies from abroad use petroleum distillates (such as, diesel) for precoating the cover aggregates (Table 1). Asphalt cements (bitumen) of different penetrations and cutback asphalts are also used for precoating. Six of the seven agencies either recommend specifications on minimum percentage of coating or specify minimum percentage of binder. Ministry of Works & Development, Auckland, New Zealand, has a test criteria for accepting the extent of precoating (Table 1). It should be noted that most of these agencies use single size cover aggregates whereas graded aggregates are quite commonly used in the United States. Also, these agencies use straight run asphalt cements (bitumen) and cutback asphalts in addition to emulsified asphalts as application bituminous materials.

Table 1a. Responses to the Questionnaire on Precoated Aggregates (United States)

Responding State	Bituminous Material Used for Precoating		% Precoating of Aggregate Surface		Minimum % Coating Necessary
	Grade(s) Used	% Total Bitumen	Specified?	How Determined?	
Illinois	Emulsion SS-1	1.0-2.0	100%	Visual	Yes
Oregon	Asphalts AR-2000 AR-4000	0.5-1.0	No	Visual	No
Pennsylvania	Cutbacks MC-30 MC-70 Asphalt AC-20	0.5-1.2 0.6-1.2	90%+	Visual	Yes
Texas	Emulsions MS-1 SS-1 Asphalts AC-10 AC-20	1.0	No	Visual	No
Utah	Asphalts AC-5 AC-10	---	No	---	Yes
Virginia	Emulsion CMS-2 Asphalt AC-20	1.0-1.5	85%+	Visual	Yes

Table 1b. Responses to the Questionnaire on Precoated Aggregates (Abroad)

Responding Agency & Country	Bituminous Material Used for Precoating		% Precoating of Aggregate Surface		Minimum % Coating Necessary
	Grade(s) Used	% Total Bitumen	Specified?	How Determined?	
Ministry of Work & Development Auckland, New Zealand	180/200 Pen. Bitumen + 60% Kerosene	Not Specified	75%+	Visual*	Yes
Main Roads Dept. Automotive Welshpool, Western Australia	Automotive Distillate	0.5+	No	Visual	Yes
Road Construction Authority Victoria, Australia	Cutback Asphalt Distillate	0.5-1.0 0.4-1.0	No**	Visual	No
Main Roads Dept. Queensland, Australia	20-25% Bitumen + Diesel Flux	0.7	75%+	Visual	Yes
Dept. of Main Roads Tasmania, Australia	Diesel Fuel + 1-2% adhesion agent (amine)	---	100%	Visual	Yes
Dept. of Main Roads N.S.W. Sydney, Australia	Proprietary Products	---	100%	Visual	---
Transport & Road Research Laboratory (TRRL) Berkshire, U.K.	70 or 100 Pen. Bitumen	0.5-1.0	No	Visual	No

* 100 chips are evaluated visually. No more than 2 chips shall have no precoating, no more than 5 chips shall have less than 50% coating, and the remainder shall have more than 75% coating.
** Engineering judgement used to assess uniformity and adequacy of precoating.

MATERIALS

Aggregates

Five AASHTO No. 8 (PennDOT's lB) cover aggregates of different mineralogical compositions and absorptive characteristics were used in this study. Table 2 gives the sources and properties of these aggregates. Table 3 gives the specified and as received gradations. llvo gradations (graded and single-size) as shown in Table 3 were used in the study for all five aggregates. These gradations were held consistent to eliminate gradation as a variable. The gradation of AASHTO No. 8 aggregate was based on the average of 425 samples of aggregates in Pennsylvania.

Table 2. Sources and Properties of Aggregates Used

	Aggregate Number				
	1	**2**	**3**	**4**	**5**
Producer	New Enterprise Stone & Lime Co. Ashcom	Obtained from Dist. 5-0	Wyoming Sand & Stone Co. Eaton Twp.	Columbia Asphalt Corp. Bloomsburg	State Aggregates Clifford
Type	Limestone	Limestone	Gravel	Siltstone	Sandstone
Bulk Sp. Gr.	2.795	2.758	2.559	2.678	2.639
% Water Absorption	0.31	0.97	1.95	1.69	1.66
Flakiness Index	27.2	54.2	15.9	28.0	16.0
Median Size, Inch	0.26	0.26	0.26	0.26	0.26
Average Least Dimension, in.	0.185	0.15	0.20	0.185	0.20
Particle Index (ASTM D3398)	15.9	---	12.3	14.7	13.9

Table 3. Gradation of Aggregates

Sieve	**Specification**	**Aggregate Gradation as Received**					**Gradation Used in Study**	
		1	**2**	**3**	**4**	**5**	**Graded***	**Single-Size**
% Pass.								
1/2"	100	100	100	100	100	100	100	100
3/8"	85-100	94	84	91	93	97	90	100
No. 4	10-30	27	15	26	30	27	18	0
No. 8	0-10	4.2	6.0	3.0	2.8	5.1	2.5	0
No. 200	0-2.4	0.2	1.4	0.6	0.4	1.0	Variable	Variable

* Based on the average of 425 samples of aggregates in Pennsylvania.

Precoating Bituminous Material

PennDOT specifications permit the use of MC-30 & MC-70 cutback asphalts and AC-20 asphalt cement as a precoating bituminous material. MC-30 Cutback asphalt (AASHTO M82) which is most commonly used in Pennsylvania, was used. The test properties of MC-30 such as, kinematic viscosity at 140°F, distillate volumes at various temperatures, percent asphalt and asphalt residue viscosity at 140°F, are given in Table 4.

Table 4. Test Properties of MC-30 Cutback (Precoating Material)

Test	Test Value
Kinematic Viscosity at 140°F, centistokes	116
Specific Gravity at 60°F	0.9545
Distillation:	
Distillate, percent by volume of total distillate to 680°F	
0-437°F	2.8
0-500°F	46.5
0-600°F	87.3
0-680°F	100.0
Asphalt, Percent by Volume	64.5
Asphalt, Percent by Weight	68.5
Viscosity of Asphalt Residue, 140°F, 30 cm Hg, poises	762

Application Bituminous Materials

PennDOT specifications permit the use of AASHTO RS-2 (PA. E-2) and CRS-2 (PA. E-3) emulsified asphalts and AC-2.5 asphalt cement as the application bituminous material in seal coats. However, CRS-2 (PA. E-3) emulsified asphalt being most commonly used in Pennsylvania, was used in this study. The test properties of this cationic emulsion such as, Saybolt Furol viscosity at 122°F, percent asphalt, and residue penetration are given in Table 5.

Table 5. Test Properties of CRS-2 Emulsified Asphalt

Test	Test Value
Particle Charge	Positive
Saybolt Furol Viscosity at 122°F, sec.	207
Asphalt, Percent by Weight	66.2
Test of residue from distillation: Penetration at 77°F, 100g, 5 sec.	132

TEST PROCEDURES

Tests on Aggregates

Bulk specific gravity and percent water absorption were determined in accordance with AASHTO T85.

Flakiness index measures the tendency of an aggregate particle toward particle flatness, and it represents the percentage by weight of flat particles having a least dimension smaller than 60 percent of the mean size (*13*).

Median size and average least dimension (ALD) of the aggregates were also determined according to the procedures given in the Asphalt Institute's Manual Series No. MS-19. These parameters and flakiness index are generally used for designing seal coats and surface treatments.

The particle index which is a quantitative measure of aggregate particle shape and texture characteristics was also measured in accordance with ASTM D3398.

Incorporation of Varying Dust Contents

Prior to the precoating phase of this study, it was believed necessary to study the effect of varying dust contents in the uncoated aggregate on aggregate retention. The aggregates were thoroughly washed with water to eliminate the minus 200 (dust) material completely. Then, varying amounts of dust (1, 2, 3, 4 and 5 percent by weight of the dry aggregate) were added to the aggregate. Water was added to the clean aggregate - dust mixture and thoroughly mixed to disperse the dust uniformly in the wet mixture. The mixture was then dried to constant weight. This procedure was used to simulate, as much as possible, the naturally occurring dust coatings on mineral aggregates.

Precoating Procedures

Aggregates containing 3.0 percent dust (establishment of this threshold value is discussed later) were precoated with MC-30 cutback asphalt to obtain the following five conditions:

1. No coating;
2. Salt & pepper effect;
3. Less than 50 percent coating;
4. More than 50 percent (but less than 90 percent) coating; and
5. More than 90 percent coating.

Any thin, brownish, translucent areas were considered to be coated. The percentage of coating was based on the total visible area of the precoated aggregate material. Individual particles were not considered.

A mechanical mixer was used to mix the aggregate and MC-30 cutback asphalt. Both materials were mixed at ambient temperature. Mixing time was approximately six minutes. Different percentages of MC-30 were used to obtain the required precoating conditions from salt and pepper effect to 90+ percent coating. This required varying the percentage of MC-30 (by weight of the aggregate) from 0.4 to 1.1. All samples were cured in a flat pan for two days and were considered to be free flowing.

Figure 1 shows an aggregate with five different precoating conditions. Figures 2 through 6 show the close-ups of these five conditions.

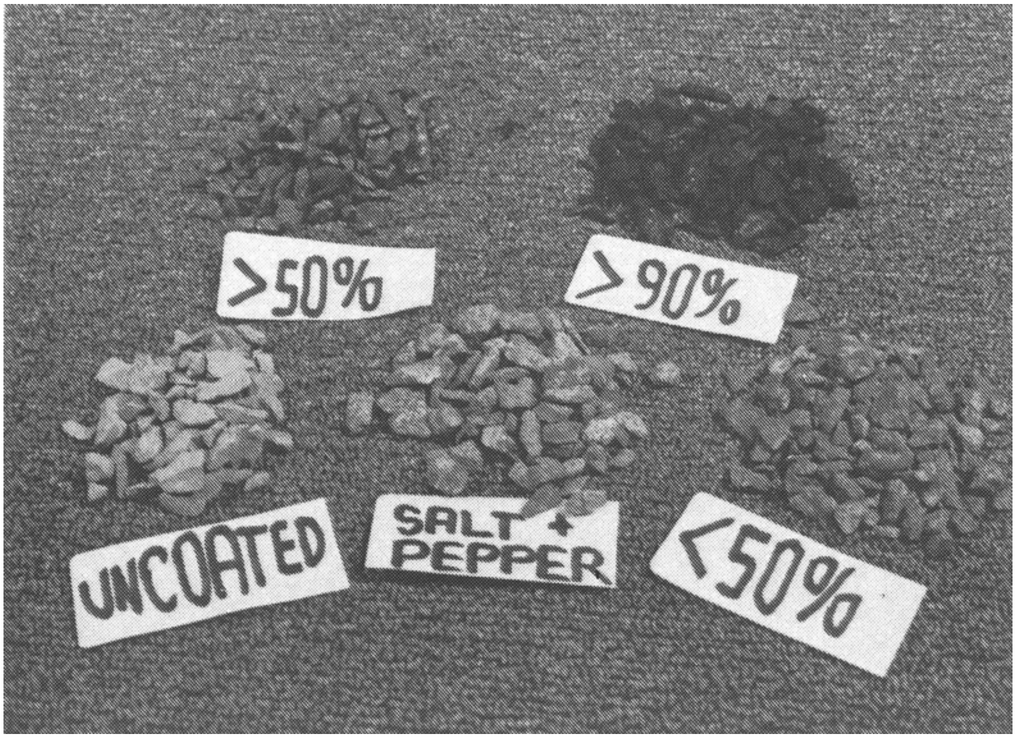

Figure 1. Typical Five Precoating Conditions

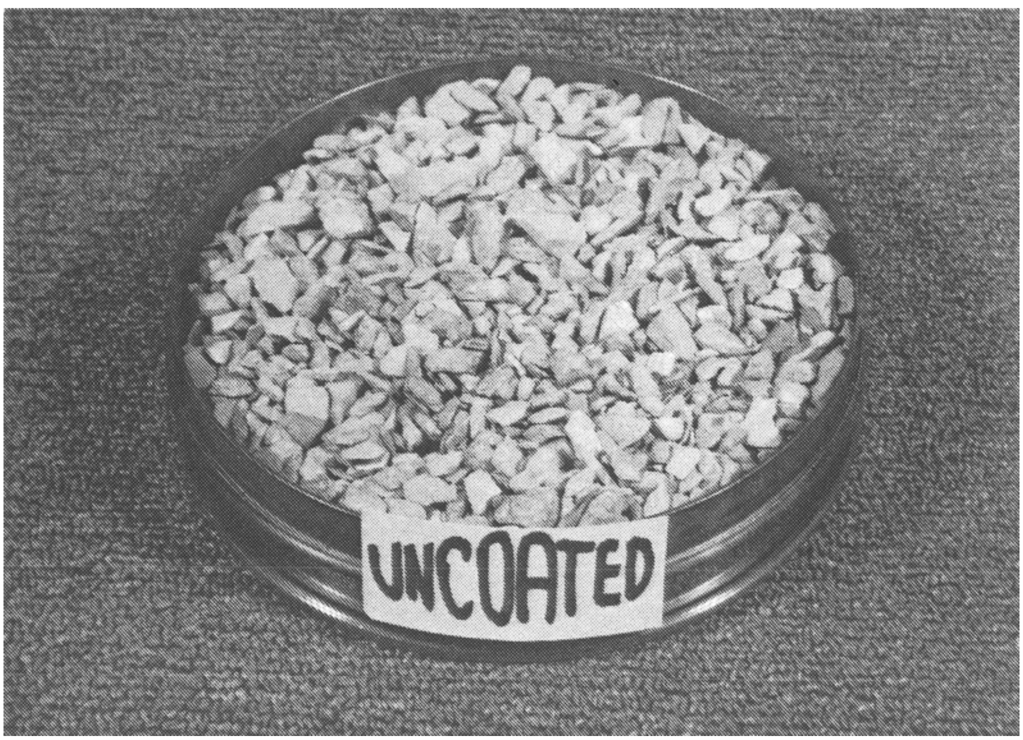

Figure 2. Uncoated Aggregate

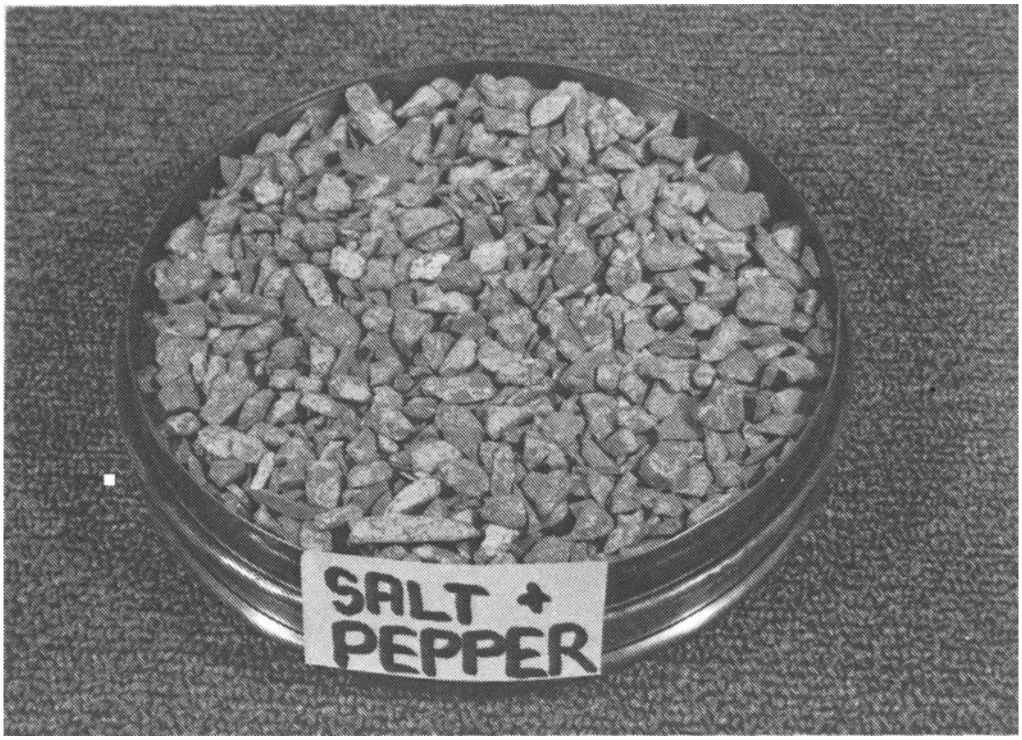

Figure 3. Salt and Pepper Effect

Figure 4. Precoating less than 50 Percent

Figure 5. Precoating more than 50 Percent

Figure 6. Precoating More Than 90 Percent

Pennsylvania Aggregate Retention Test

This test method was developed by trial and error during this study. It is a very simple method. The testing equipment needed is available in most highway materials testing laboratories. The equipment primarily consists of 8" sieves, 8" pans, a sieve shaker (sifter), rubber pads, a compression machine and a balance.

The procedure is described below:

1. Application of Bituminous Material: The emulsified asphalt (CRS-2) was poured on the back side of an 8" separator pan to obtain an application rate of 0.25 gallon per sq. yd. The emulsion was applied at 140 ± 5°F, and its weight was 36.8 grams to give the desired application rate in an 8" diameter pan. Figure 7 shows a pan with applied emulsion. The emulsion is exhibiting some curling because the pan was tilted for taking the picture.

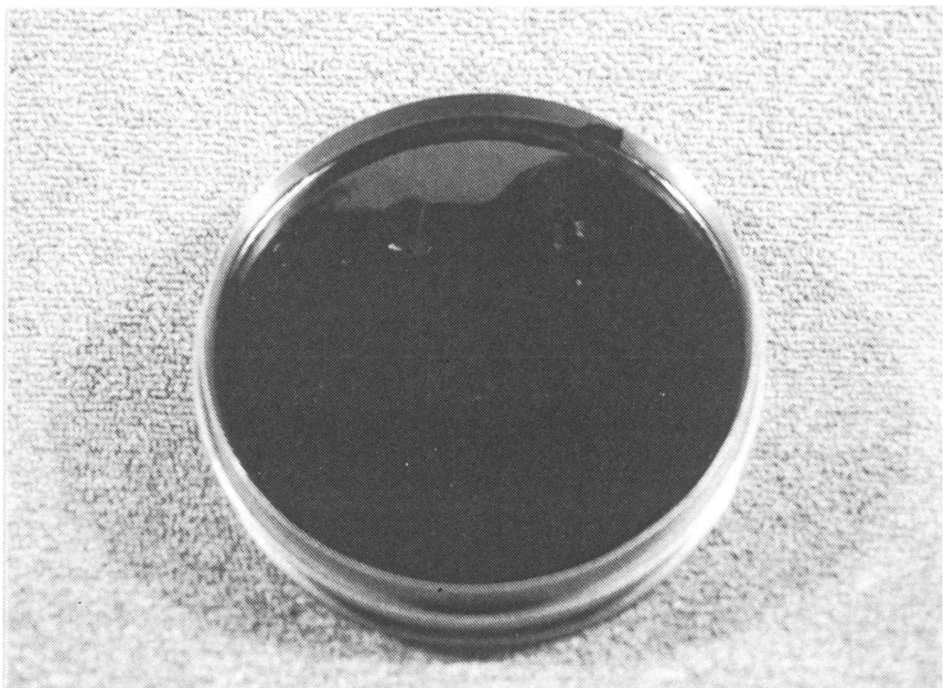

Figure 7. Pan with applied Emulsified Asphalt

2. Application of Cover Aggregate: It was established by trials that 300 grams of aggregate is sufficient to obtain a single particle layer in the 8" diameter pan. This corresponds to 17.4 lbs. per sq. yd. In the field the aggregate is applied by a chip spreader. It is difficult to simulate the field application in the laboratory. However, an attempt was made to mechanize the process to minimize the variation in applications.

   A Mary Ann laboratory sieve shaker (or sifter) as shown in Figure 8 was used. It is manufactured by Rainhart Co., Austin, Texas. It can take an unclamped stack of 8" diameter x 2" deep standard laboratory sieves and pans. These are laid on a pair of 45° inclined rubber-covered power-driven rollers which revolve the stack. The pan bottom rests on a free-wheeling turntable. The aggregate is tumbled, mixed and passed as it is carried up on the revolving inclined screen wire. To encourage clearing the openings, the sieve frames are tapped laterally (from below) by hardwood faced aluminum hammers. These cam-cocked and spring thrown hammers are pivoted on nylon sleeve bearing.

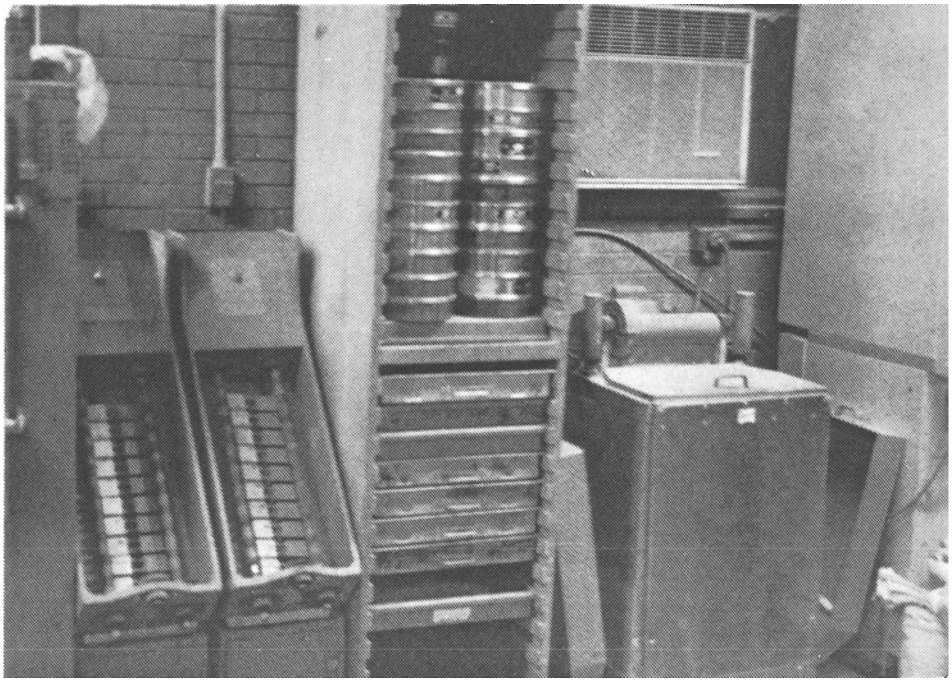

Figure 8. Mary Ann Laboratory Sieve Shaker

For this study, the sieve shaker was inclined at an angle of 60° rather than 45°. Attempts to make it more closer to vertical were not successful because the unclamped sieve stack would fall out.

The pan containing applied emulsion was placed at the bottom of five inverted 1/2" sieves. A retainer or collar (sieve with no screen) was placed on the top. Figure 9 shows the close-up of pan, 1/2" sieve and the retainer. Figure 10 shows the complete assembly and feeding of aggregate from the top. The screen mesh in each 1/2" sieve was rotated 45° from the adjacent top or bottom sieve so that two consecutive sieve meshes did not have the same orientation.

After the sieve assembly is placed on the shaker and it is turned on, 300 grams of aggregate is poured into the retainer at the top. After one minute, the pan containing emulsion and applied aggregate is removed and tapped to spread the aggregate evenly on the emulsion film. Figure 11 shows the aggregate spread in the pan.

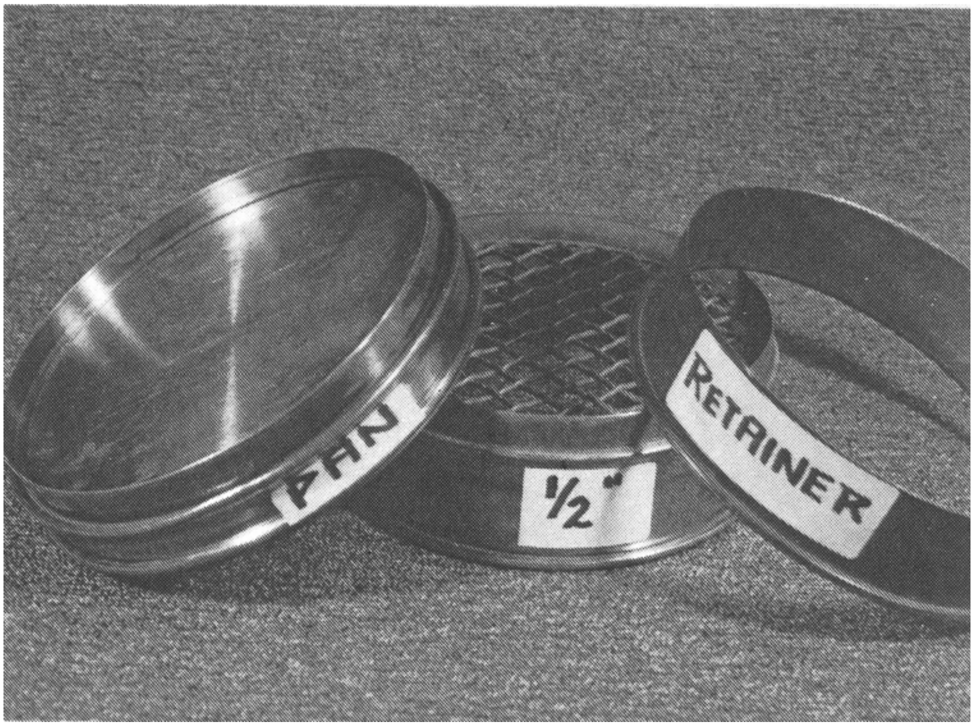

Figure 9. Retainer, 1/2" Sieve and Pan (Close up)

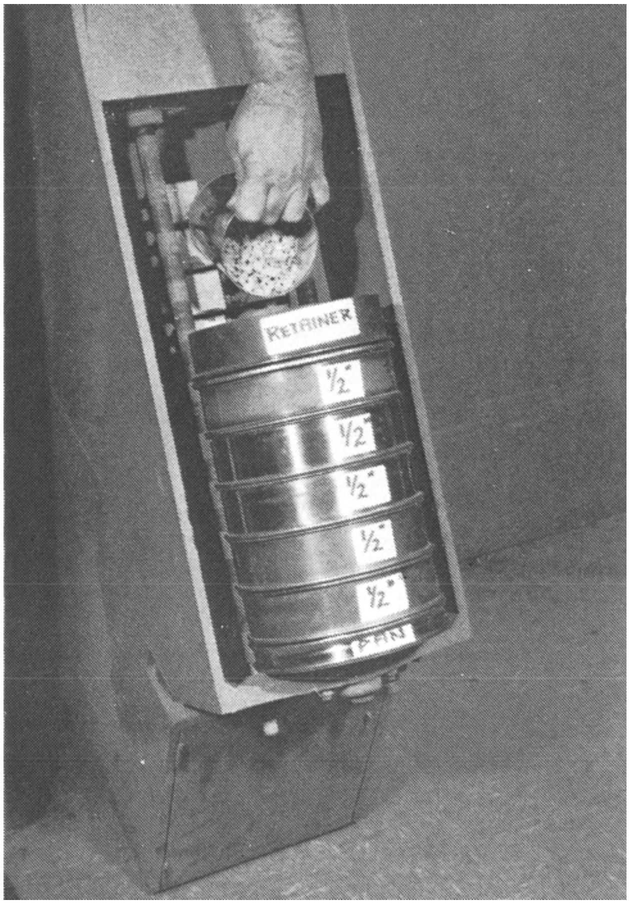

Figure 10. Complete Assembly for Applying Aggregate

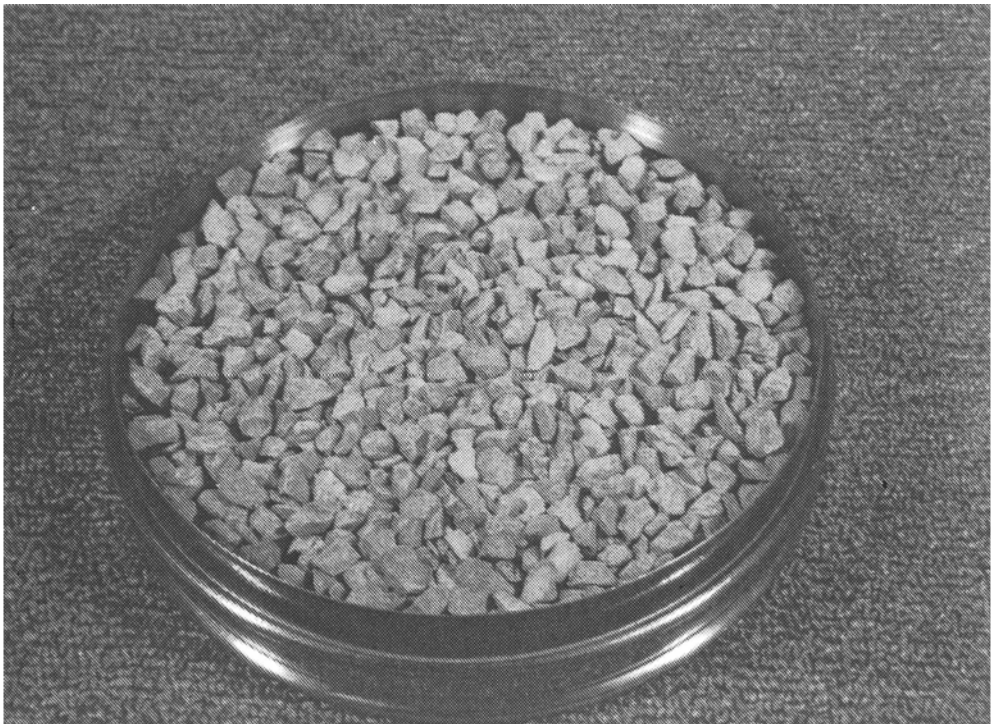

Figure 11. Aggregate Spread in the Pan

3. Compaction and Curing: Within 15 minutes, this pan is covered with a 7-1/2" diameter x 3/4" thick Neoprene bearing pad (of 50 durometer hardness) and placed under a compression machine to apply a load of 2000 lbs. for 5 seconds. This is equivalent to a pressure of 40-50 psi which is normally used in pneumatic tired rollers for seal coats. Figures 12, 13 and 14 show the above sequence of procedures.

   After compaction, the bearing pad is removed and the pan containing emulsion and aggregate is cured at ambient temperature for 24 ± 1 hours. The weight of pan + emulsion + aggregate is obtained after curing.

4. Initial Retention Loss: After the 24 hours' curing, the pan containing seal coat is inverted to allow the aggregate particles (which did not develop initial adhesion to the binder) to fall. These aggregate particles are weighed to determine the initial loss in grams. The percentage of initial loss is determined as follows:

$$\textit{Percent Initial Loss} = \frac{B}{A} \times 100$$

   where,
   A = Wt. of total aggregate (300 grns), and
   B = Initial loss in grams

5. Knock-Off Loss: After the initial loss is determined, the pan containing emulsion and aggregate is placed upside down at the top of the five 1/2" sieves (these are used for filling only) and a pan is placed at the bottom of the assembly to collect the knock-off loss as shown in Figure 15. This complete assembly is placed in the Mary Ann Sieve Shaker as described earlier and subjected to the shaking and tapping action for 5 minutes. The knock-off loss of the aggregate which is collected in the bottom pan is weighed (C). The percentage of knock-off loss is determined as follows:

Figure 12. Pan Containing Seal Coat with Neoprene Bearing Pad

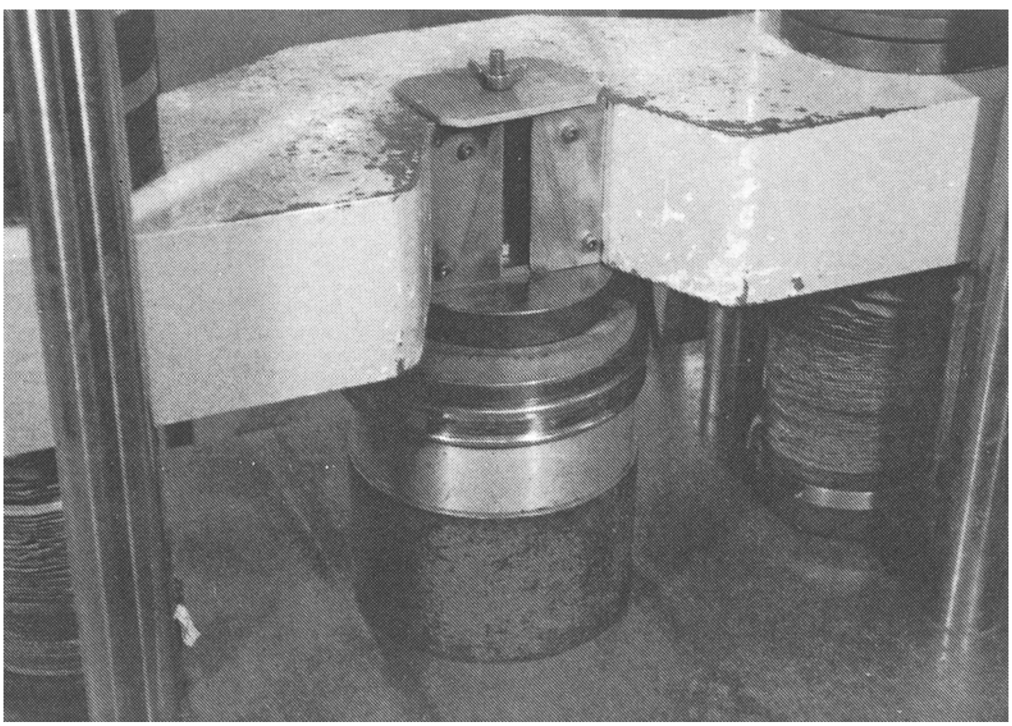

Figure 13. Sample Under Compression (Close up)

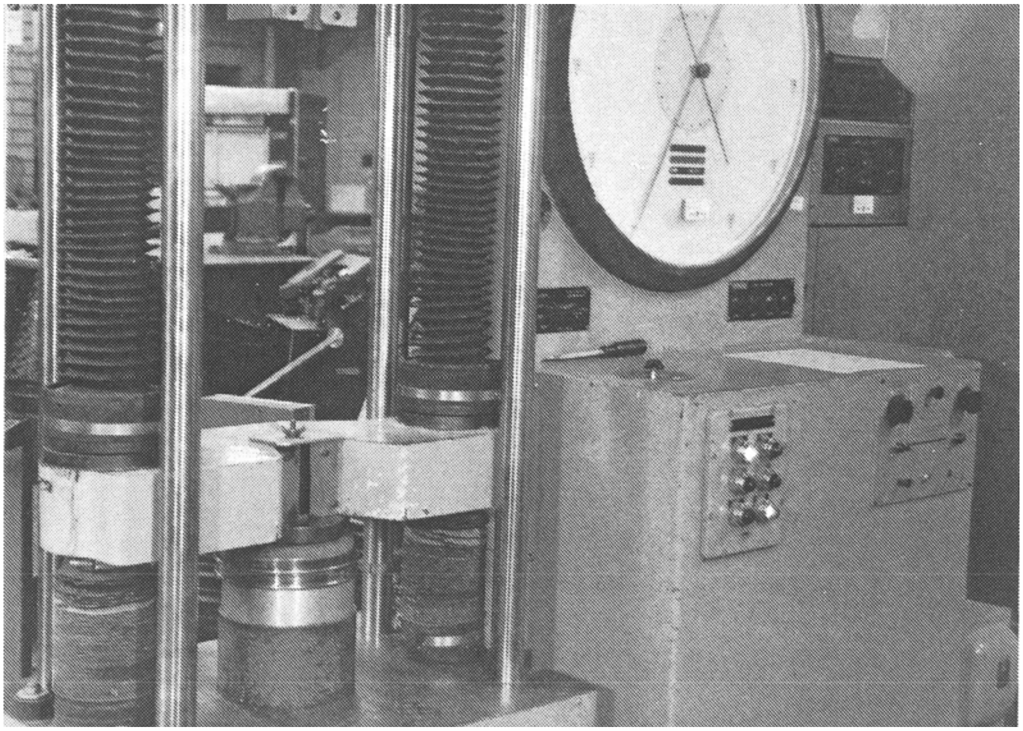

Figure 14. Compression Machine

$$Percent\ Knock\text{-}off\ Loss = \frac{C}{A-B} \times 100$$

where,
A = Wt. of total aggregate (300 gms)
B = Initial loss in grams, and
C = Knock-off loss in grams

It is realized that this knock-off test does not simulate the action of traffic in dislodging the aggregate from the seal coat. Nonetheless, it was used to give comparative results for uncoated aggregates containing varying dust contents, and the precoated aggregates with different conditions of precoating.

6. Total Loss: The total loss (initial loss + knock-off loss) was calculated as follows:

$$Percent\ Total\ Loss = \frac{D}{A} \times 100$$

where,
A = Wt. of total aggregate (300 gms)
D = Total loss in grams (B + C)

It should be noted that three aggregate retention tests were run for each sample type and the results averaged.

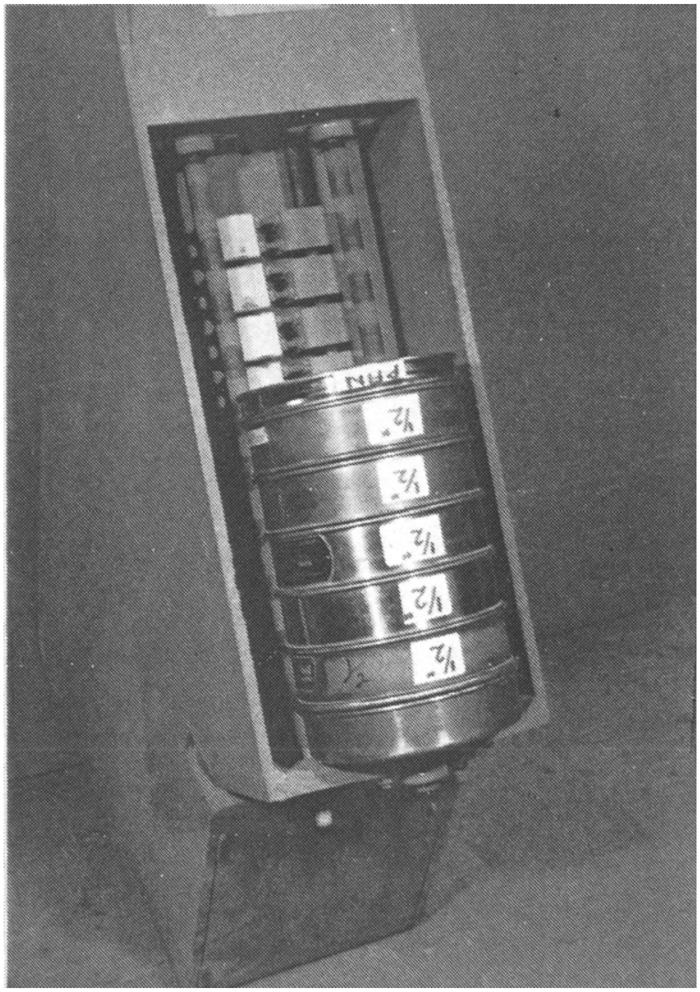

Figure 15. Knock-off Test Assembly

TEST RESULTS AND DISCUSSION

Aggregate Test Results

As mentioned earlier, the five aggregates (AASHTO No. 8 size) had different mineralogical compositions and absorptive characteristics. Tables 2 and 3 give the properties of the aggregates used. Limestone, gravel, siltstone and sandstone aggregates ranged in water absorption from 0.31 to 1.95 percent.

The flakiness index ranged from 15.9 percent (Aggregate 3 - gravel) to 54.2 percent (Aggregate 2 - limestone). The National Association of Australian State Road Authorities specifies 35 as the maximum permissible flakiness index for surface treatment.

The median size of 0.26" was same for all aggregates because the same gradation was used. The average least dimension (ALD) determined from median size and flakiness index ranged from 0.15 to 0.20".

The particle index ranged from 12.3 (Aggregate 3 - gravel) to 15.9 (Aggregate 1 - limestone).

Effect of Dust Contents on Aggregate Retention

Prior to precoating all aggregates, it was believed necessary to establish the dust content to be used consistently throughout the study. Therefore, varying amounts of dust (1, 2, 3, 4 and 5 percent) were added to the aggregates as described earlier.

The single size (3/8" - No. 4) gradation rather than the total (1/2" - No. 8) gradation was used to obtain better and more consistent results. Pennsylvania Aggregate Retention Test described earlier was used.

Figure 16 gives the plots of percent dust content versus percent knock-off loss for all aggregates. The following trends have been observed in this figure:

1. The rate of increase in knock-off loss with increasing dust contents (slope of the percent dust content versus percent knock-off loss line) becomes significantly greater after about 3 percent dust content in most cases. Therefore, this was considered a threshold value for all practical purposes and was used prior to precoating in the next phase of this study.
2. Most states specify a maximum of 2 percent (or 2.4 percent rounded off to 2) dust for unwashed aggregates. This seems to be reasonable for low volume roads particularly if the cost of washing or precoating the aggregate is very high.
3. No correlation was observed between the percent knock-off loss and percent water absorption or particle index of the aggregate. However, a good relationship was observed when the flakiness indices of the aggregates and the corresponding aggregate retention losses were ranked (*12*). It shows the trend that the aggregate retention loss increases with increasing values of flakiness index. It is quite possible that the flaky (flat) particles did not get pressed down well into the bituminous binder when compressed with the Neoprene bearing pad (pneumatic tired roller in the field) because of the surrounding protruding cubical particles. Therefore, when the percentage of flat particles in the sample (or flakiness index) increases the corresponding retention loss also increases.

Effect of Degree of Precoating on Aggregate Retention

All aggregates containing 3.0 percent dust contents were precoated to obtain five different conditions as described earlier in precoating procedures. Ten evaluators made subjective visual determinations of the percentage of coating on all aggregates for three conditions: less than 50 percent, more than 50 percent (but less than 90 percent), and more than 90 percent. The data is given in Table 6. It should be noted from the average data that it was difficult to achieve the condition of less than 50 percent precoating in actual practice because then the precoated aggregate tended to border on salt and pepper effect. The average observed coating obtained for this condition actually ranged from 45 to 54 percent. This can reasonably be considered about 50 percent although the tables will indicate it to be less than 50 percent.

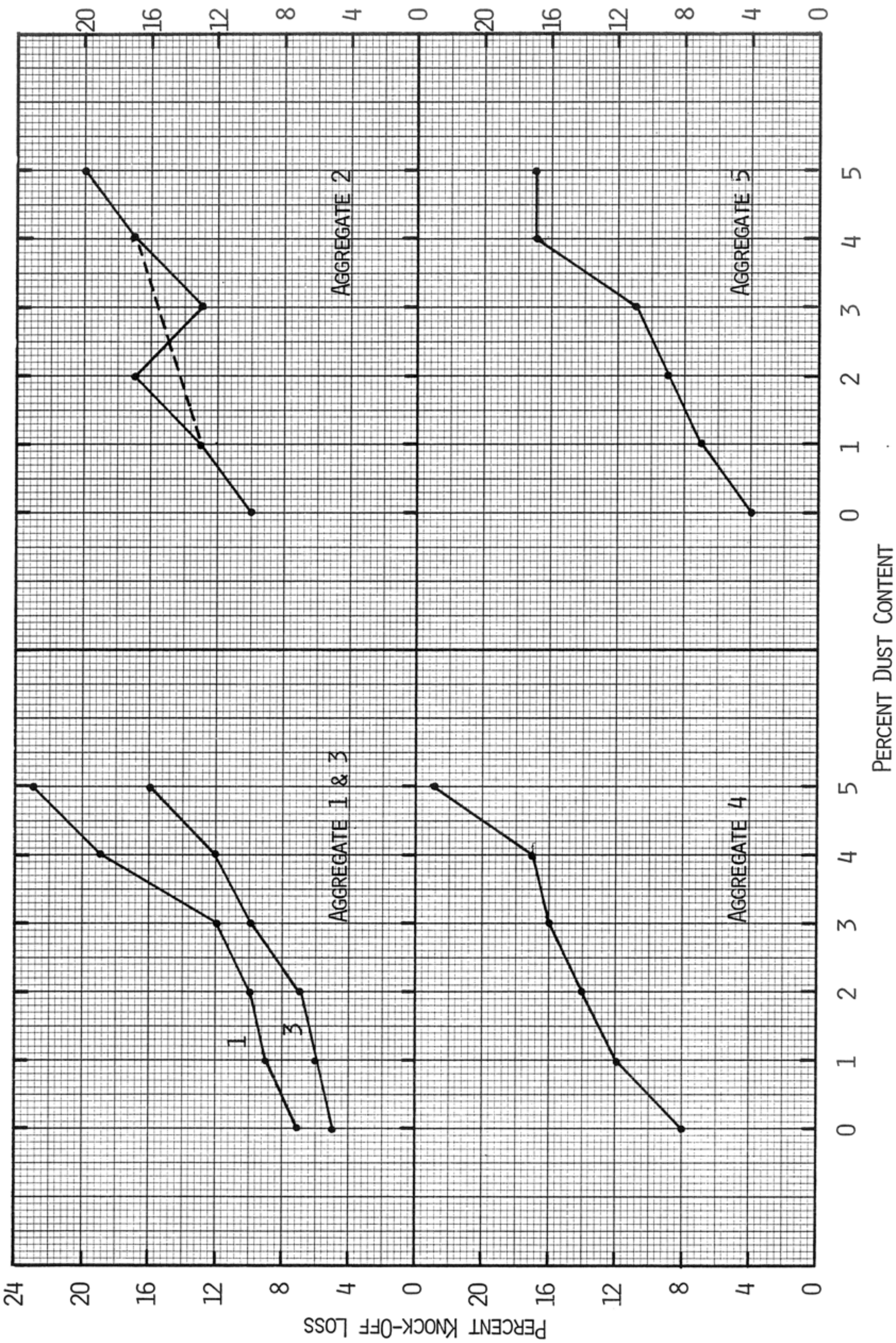

Figure 16. Percent Dust Content vs. Knock-off Loss (All Aggregates/One Size)

Table 6. Subjective Evaluation of Percent coating (10 Evaluators)

Evalu-ator	Percent Coating by Observation														
	Aggregate 1			Aggregate 2			Aggregate 3			Aggregate 4			Aggregate 5		
	<50	>50	90+	<50	>50	90+	<50	>50	90+	<50	>50	90+	<50	>50	90+
1	60	80	95	50	90	98	50	80	98	50	80	98	60	90	98
2	50	75	99	35	75	99	40	65	99	35	65	99	80	90	99
3	40	70	98	40	80	95	30	50	98	30	50	92	40	80	97
4	50	75	95	60	80	98	50	70	98	50	75	98	60	75	98
5	60	75	98	55	85	98	65	85	99	55	75	97	50	75	97
6	55	70	98	60	80	99	50	80	99	45	80	99	55	85	99
7	50	80	100	60	90	100	55	75	97	45	70	94	50	85	98
8	40	60	97	40	70	98	40	55	99	40	65	97	40	70	98
9	50	70	96	30	60	98	50	60	97	40	65	96	40	65	95
10	65	75	100	65	70	96	75	85	98	60	70	92	60	75	93
0	52	73	98	50	78	98	50	70	98	45	70	96	54	79	97
Std. Dev.	8.2	5.9	1.8	12.4	9.5	1.4	12.8	12.6	0.8	9.1	9.0	2.7	12.5	8.4	1.9

Note: It was difficult to obtain less than 50 percent coating because then it approached salt & pepper effect.

Table 6 gives the mean and standard deviations of percent coating on 15 precoated aggregate samples observed by 10 evaluators. It is quite evident from the data that the standard deviation decreases as the percentage of coating increases. In other words, the agreement between different evaluators becomes increasingly better when the percentage of coating is increased from 50 to 90+, the best agreement being for 90+ percent coating. It should be noted that the current PennDOT specifications require 90+ percent precoating and few, if any, problems have been experienced in judging this specified minimum percentage of precoating. It has been recognized by the American Society for Testing and Materials (ASTM) based on cooperative tests that only at 95 percent level can a reasonable degree of the reproducibility be obtained when rating the same sample by visual estimation. ASTM specifies 95 percent level in ASTM D 1664-80 "Coating and Stripping of Bitumen-Aggregate Mixtures" as a go-no-go test because the precision is not satisfactory for applications at lower levels (*14*).

All five aggregate precoated to different degrees were subjected to the Pennsylvania Aggregate Retention Test. Table 7 gives the aggregate retention loss data in percentages. Figure 17 gives the plots of percent precoated surface versus percent initial retention loss. The following observations are made:

1. Considering the percent initial loss, the 90+ percent precoating is by far the best. This means that immediate adhesion of the cover aggregate with the bituminous binder is best obtained with 90+ percent precoating. The primary function of precoating is to obtain immediate adhesion as discussed earlier in the review of literature.
2. Increasing the percentage of precoating decreased the initial aggregate retention loss. Salt and pepper condition is better than uncoated aggregate and so forth.
3. Initial aggregate retention loss was reduced by as much as 80 percent when the uncoated aggregate (containing 3 percent dust) was precoated with 90+ percent coating.

Table 7. Effect of Precoating on Aggregate Retention Loss (Percent)

	Coating	Aggregate Number				
		1	2	3	4	5
% Initial Loss						
$= \frac{B}{A} \times 100$	No Coating	21	34	18	21	18
	S. & P.	18	30	14	17	12
	Less than 50%	15	24	10	11	11
	More than 50%	13	15	10	10	9
	90%+	4	10	4	3	4
% Knock-off Loss						
$= \frac{C}{A-B} \times 100$	No Coating	12	13	10	16	11
	S. & P.	10	19	10	15	7
	Less than 50%	10	17	7	10	5
	More than 50%	11	19	6	8	4
	90%+	15	27	9	13	8
% Total Loss						
$= \frac{D}{A} \times 100$	No Coating	31	43	26	34	27
	S. & P.	26	44	22	29	19
	Less than 50%	23	37	17	21	16
	More than 50%	22	31	15	17	13
	90%+	18	31	13	16	12

Notes:
1. A = Wt. of total aggregate (300 grams), B = Initial loss in grams, C = Knock-off loss in grams, and D = 'Total loss in grams (B + C).
2. S. & P. = Salt & Pepper effect.
3. All aggregates (uncoated and precoated) contained 3.0% dust.
4. Above results are based on an average of 3 tests. Therefore, the initial loss and the knock-off may not add up exactly to the total loss.

It should be noted that 90+ percent coating gave poor results in the knock-off test. More than 50 percent coating gave the best results for Aggregates 3,4 and 5. The precoating on Aggregate 2 did not help at all. It is suspected that the MC-30 Cutback asphalt used as the precoating material in this study did not cure completely in two days. Although the initial adhesion was immediate and good, it appears that the cutback asphalt film around the aggregate was too soft (thus weakening the bond between the aggregate and emulsion residue) for the severe knock-off test. Therefore, it is recommended to use AC-20 asphalt cement as the precoating material because it can be mixed with the aggregate at high temperatures in a HMA plant and does not require any curing. If MC-30 or MC-70 cutback asphalt must be used it is recommended to ensure that the surface coating has cured completely.

It is also known that the rate of setting (breaking) of applied emulsified asphalts is slower with precoated aggregates compared to uncoated aggregates. The latter absorb water readily from the emulsified asphalt and thus accelerate the breaking process. This has been documented by the Transport and Road Research Laboratory in Road Note No. 39 (*15*) thus "The use of lightly-coated chippings when bitumen emulsions are used may lead to delay in the break of emulsion."

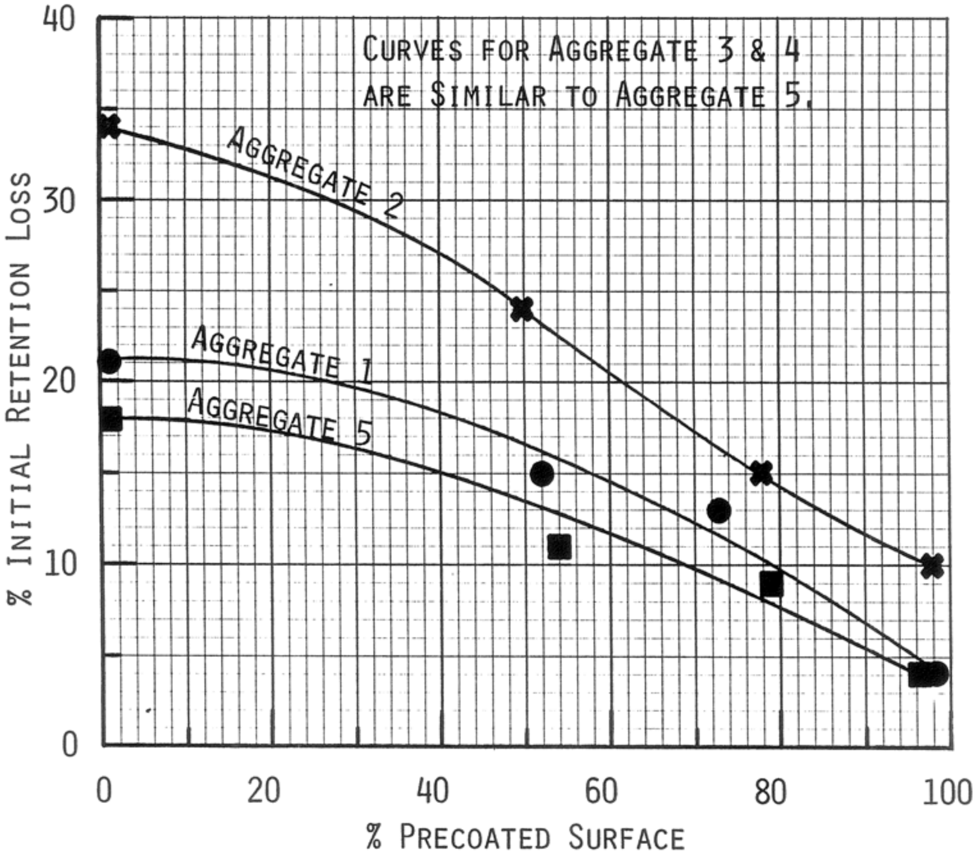

Figure 17. Percent Coating vs. Initial Retention Loss

Most experience in the past with the precoated aggregate in the United States and abroad has been with asphalt cements and cutback asphalts as application bituminous materials. Texas does not recommend the use of precoated aggregate with emulsions because the latter breaks and cures slowly (16). Undoubtedly, traffic control will be required for longer periods of time when precoated rather than uncoated aggregates are used with emulsified asphalts. Nonetheless, the importance of obtaining immediate and good adhesion which results from the use of precoated aggregates cannot be ignored.

If the total aggregate retention loss (initial loss + knock-off loss) is considered (Table 7), the benefits of precoating are apparent, and the 90+ percent precoating is still the best.

3/8" - No. 4 Versus 1/2" - No. 8

So far, the reported data and discussion pertained to the single size (3/8" - No. 4) aggregate gradation. Since AASHTO No. 8 aggregate (1/2" - No. 8) is used by PennDOT for seal coats and surface treatments, it was necessary to verify whether similar results are obtained when the total gradation is used. This was attempted on Aggregate 4 and 5.

These two total aggregates (1/2" - No. 8) were also precoated to different degree and evaluated by nine observers. The observed percent coating data is given in Reference 12. Similar to the single size aggregates, the standard deviation of the observed percent coating decreased as the coating increased. Again, the best reproducibility was obtained at 90+ percent precoating levels.

Dust contents varying from 0 to 5 percent were also attempted on the total gradation of

Aggregates 4 and 5. The comparative test data (single size versus total gradation) is given in Reference 12. The effect of percent dust content on percent knock-off loss is plotted graphically in Figure 18. The following observations are made:

1. Aggregate retention loss (initial as well as knock-off) increased with increasing dust contents.
2. The rate of increase in knock-off loss with increasing dust contents becomes significantly greater after about 3 percent dust content in both cases.
3. As expected, the aggregate retention loss at all dust content levels was greater for the total aggregate compared to the single size. The former contains additional smaller particles which tend to fill the voids between large particles and thus may not get effectively embedded into the applied binder.

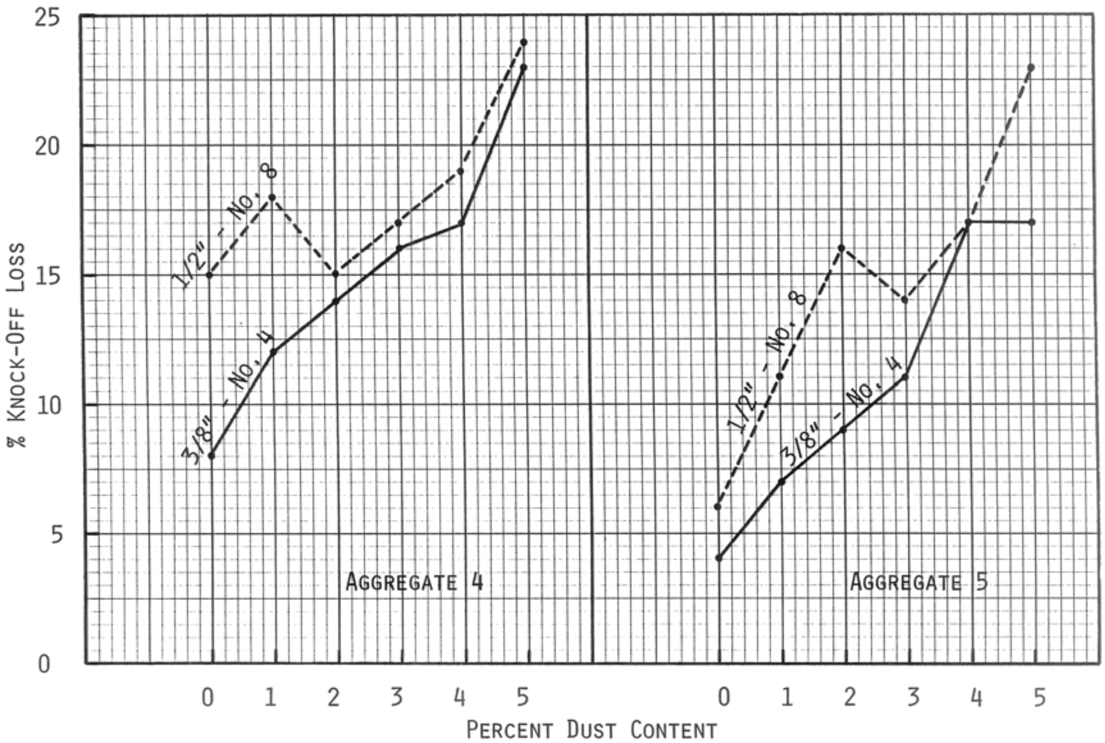

Figure 18. Percent Dust Content vs. Knock-off Loss (Two Aggregate Sizes)

The above observations are similar to uncoated single size aggregates reported earlier. Figure 19 gives the plots of percent precoated surface versus percent initial retention loss for Aggregate 4 (the plot for Aggregate 5 is very similar). The following observations are made based on the test data obtained on precoated total gradations of Aggregates 4 and 5:

1. Considering the percent initial loss, the 90+ percent precoating is by far the best. This means that immediate adhesion of the cover aggregate with the bituminous binder is best obtained with 90+ percent precoating of the total aggregate similar to the single size aggregate.
2. Unlike single size aggregates, the total aggregates had higher initial retention loss when precoated less than 50 percent compared to uncoated aggregates. Only when the percent coating exceeded 90 percent, a drastic reduction in the retention loss was realized. By increasing the precoating of Aggregate 4 from 76 to 97 percent, the initial retention loss was reduced by about 50 percent. This observation is very important because the results of this study are to be applied to the total aggregate (AASHTO No. 8) used by PennDOT and not the single size aggregate. It appears that increased precoating is required to

effectively bind the dust to the graded aggregate particles. This will be more evident when the end result test data are discussed later.

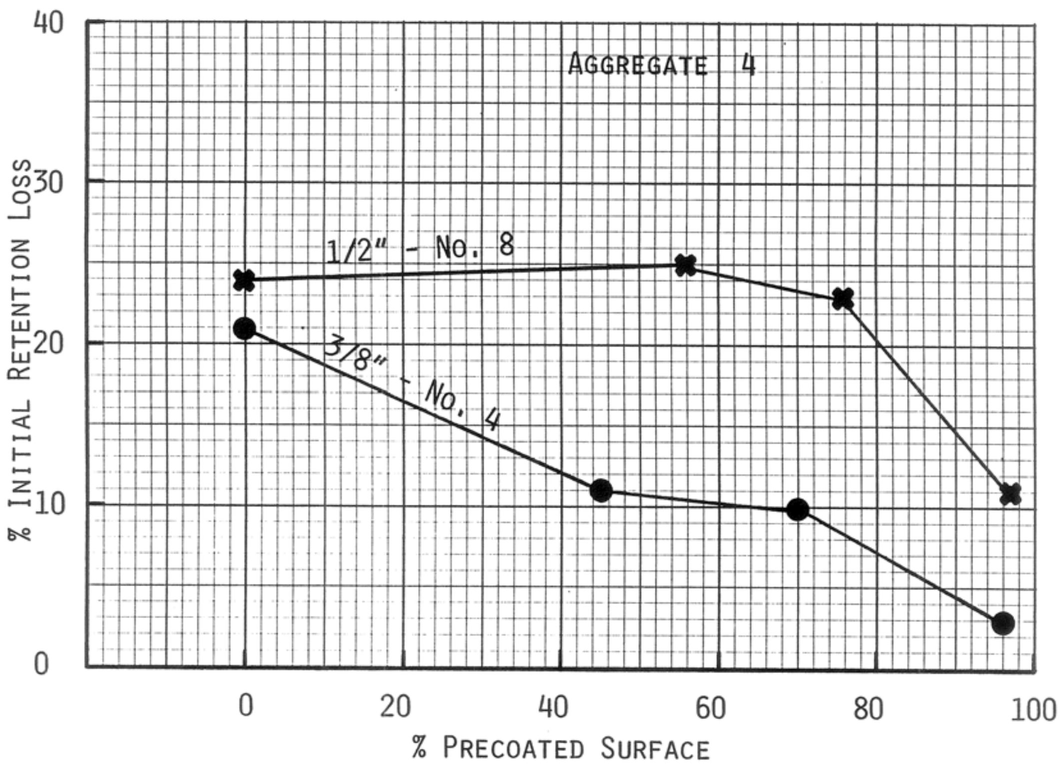

Figure 19. Percent Precoating vs. Initial Retention Loss (Two Aggregate Sizes)

End Result Tests

It has been demonstrated in the previous discussions that the subjective visual evaluation test is suitable and reasonably reproducible for 90+ percent precoated aggregates. However, the following end result type tests were attempted on the precoated total aggregate (1/2" - No. 8) to eliminate the subjective evaluation for final acceptance:

1. Dry Gradation Test: Since the precoated aggregates are free flowin , the samples were subjected to dry gradation test using 1/2", 3/8", No. 4, 8, 16, 30, 50, 100 and 200 sieves (sieving time was 10 minutes). This was attempted to quantify the presence of unbound fine material (passing No. 8) and dust (passing No. 200) in the sample. Table 8 contains the dry gradation data for all five aggregates precoated to different degree.

Table 8. Dry Gradation, Wash and Decantation Test Data (Precoated Total Aggregate)

Test	Aggregate 1				Aggregate 2				Aggregate 3			
	S&P	<50	>50	90+	S&P	<50	>50	90+	S&P	<50	>50	90+
I. Dry Gradation												
% Pass. 1/2"	100	100	100	100	100	100	100	100	100	100	100	100
3/8"	91	92	92	92	93	92	93	92	92	92	90	93
No. 4	21	22	23	19	22	21	21	17	21	21	20	19
No. 8	2.1	2.1	2.1	0.2	2.8	2.3	1.9	0.6	3.1	3.0	2.3	1.0
No. 16	1.8	1.7	1.7	0.03	2.2	1.8	1.4	0.07	2.0	2.0	1.2	0.20
No. 30	1.7	1.7	1.6	0	2.2	1.7	1.3	0.05	1.9	2.0	1.2	0.09
No. 50	1.7	1.6	1.6	0	2.1	1.7	1.2	0	1.9	1.9	1.2	0.08
No. 100	1.6	1.5	1.5	0	2.0	1.6	1.1	0	1.8	1.9	1.1	0.07
No. 200	1.4	1.4	1.3	0	1.8	1.4	0.9	0	1.7	1.8	0.9	0.06
II. Wash Test												
% Pass No. 200	1.4	1.4	1.2	0.2	1.9	1.5	1.2	0.2	1.4	1.1	0.7	0.2
III. Decantation Test												
% Loss	2.1	2.3	2.4	0.2	2.7	2.2	2.1	0.2	2.5	1.4	1.5	0.2

Test	Aggregate 4				Aggregate 5			
	S&P	<50	>50	90+	S&P	<50	>50	90+
I. Dry Gradation								
% Pass. 1/2"	100	100	100	100	100	100	100	100
3/8"	91	93	91	92	95	93	96	96
No. 4	22	20	18	15	21	21	21	22
No. 8	2.1	1.7	1.1	0.26	2.0	2.1	1.2	0.7
No. 16	1.7	1.4	0.8	0.04	1.4	1.5	0.5	0.1
No. 30	1.7	1.3	0.8	0.02	1.4	1.4	0.5	0.1
No. 50	1.7	1.2	0.7	0.01	1.3	1.3	0.4	0.04
No. 100	1.6	1.1	0.6	0	1.2	1.3	0.4	0.01
No. 200	1.5	1.0	0.4	0	1.0	1.0	0.3	0.01
II. Wash Test								
% Pass No. 200	1.4	1.4	0.9	0.2	0.8	0.9	0.4	0.3
III. Decantation Test								
% Loss	2.1	2.1	1.4	0.2	1.5	1.5	0.5	0.1

It is quite evident from the data (particularly Aggregates 1, 2 and 3) that a substantial amount of fine material (passing No. 8) and dust (passing No. 200) remains unbound (or loose) until the precoating level of 90+ percent is reached. This unbound dust is quite likely to fall off in the chip spreader during field operations, and interfere with the initial adhesion of the precoated aggregate to the bituminous binder. The previously discussed laboratory test data using the Pennsylvania Aggregate Retention Test supports this observation.

Figure 20 shows the plots of percent precoated surface versus percent unbound minus 200 for Agregates 4 and 5. It should be noted that the aggregates with about 50 percent precoating had more than 1.0 percent unbound minus 200. This is not considered acceptable especially after incurring the additional expenditure of precoating. PennDOT has been very successful in recent years in procuring washed aggregates (less then 1.0 percent minus 200) for seal coats at costs substantially lower than the precoated aggregates. A special provision used by the Districts permits the use of washed aggregates as an alternate to precoated aggregates.

It should also be noted that 90+ percent precoating reduces the unbound dust (minus 200) to less than 0.1 percent (Table 8) which insures the development of good initial adhesion.

If the dry gradation is used as an acceptance (or referee) test, it appears reasonable and practical to establish 0.5 percent maximum minus 200 as the acceptance criteria.

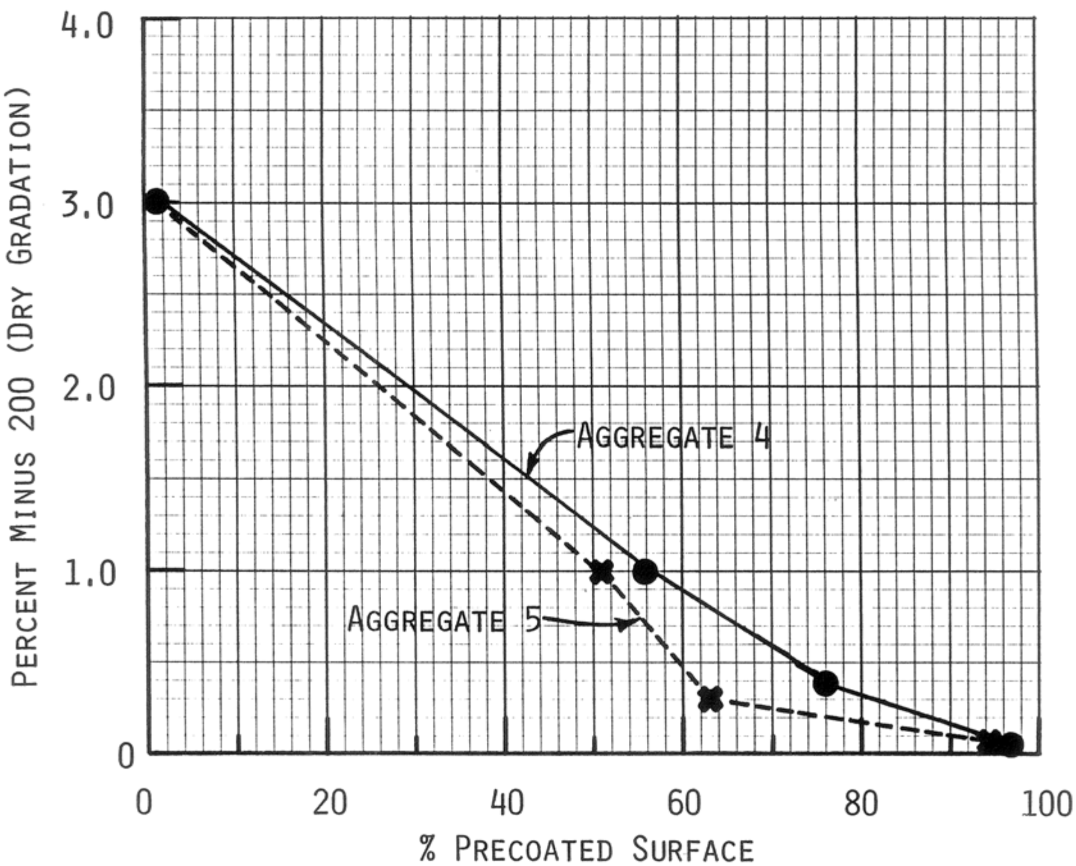

Figure 20. Percent Precoating vs. Minus 200 (Dry Gradation - Total Aggregate)

2. Wash Test: The precoated aggregate samples were subjected to wash test (with and without detergent) to determine the minus 200 by washing. Since the water containing detergent (Sodium Tripolyphosphate) started to strip the coating, the wash tests were performed under running tap water only. Two sieves (No. 16 and 200) were used. The test data is given in Table 8. The unbound dust contents obtained by wash test and dry gradation test are quite comparable. Again, 90+ percent precoating reduced the dust content by wash test to 0.3 percent.

   After running several wash tests, it was concluded that the reproducibility of this test may not be satisfactory because it involves physical manipulation (stirring) of the sample by the operator and also there is a likelihood of some partial stripping.

3. Recantation Test: The precoated aggregate sample was placed in an 8" stainless steel bowl and washed. When the water reached the top of the bowl, it was carefully poured off. This was repeated until the water was clear. The percent loss by recantation data is also given in Table 8.

   Except for 90+ percent precoated aggregate samples, the percent loss by recantation is higher than percent minus 200 obtained in the dry gradation and wash tests. Apparently, additional unbound fine material (larger than No. 200) was lost in the recantation procedure. Again, it was felt that the reproducibility of this simple test may not be as satisfactory as the dry gradation test because of the physical manipulation involved which can cause variable loss of fine material larger than No. 200 size. Nonetheless, this test procedure indicated the desirability of 90+ percent coating.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

One of the most common causes of seal coat failures is the presence of dust on the cover aggregate which prevents good adhesion between the applied bituminous binder and the aggregate. Precoating the aggregate with a very thin film of bituminous binder usually solves the dust problem and provides good adhesion. This research was undertaken (a) to evaluate the adhesion of aggregates precoated to varying degree so that the optimum precoating requirement can be established, and (b) to develop an end-result type test in lieu of the subjective visual test for accepting precoated aggregates.

Five AASHTO No. 8 aggregates of different mineralogical compositions and absorption characteristics were used. Two gradations: single-size (3/8" - No. 4) and total (1/2" - No. 8) were used. MC-70 cutback asphalt and CRS-2 (PA E-3) emulsified asphalt were used as the precoating and application bituminous materials, respectively.

Pennsylvania Aggregate Retention Test was developed for this study to evaluate the initial adhesion loss and knock-off loss. Uncoated aggregates with 0 to 5 percent dust contents were also evaluated. Precoating of aggregates was varied from salt & pepper effect to 90+ percent coating. Based on the preceding review of literature, test results and discussions the following conclusions are drawn:

1. The rate of increase in knock-off loss with increasing dust contents in uncoated aggregates was generally observed to be significantly greater over 3 percent dust content. Therefore, 3 percent is considered to be a threshold value for all practical purposes.
2. A good relationship was observed between the flakiness indices of the aggregates and the corresponding aggregate retention losses. The latter increase with increasing values of flakiness index.
3. Increasing the percentage of precoating decreased the initial aggregate retention loss. This loss was reduced by as much as 80 percent when the uncoated aggregate was precoated with 90+ percent coating.

4. Considering the percent initial retention loss, the 90+ percent precoating was observed by far the best. This means that immediate adhesion of the cover aggregate with the bituminous binder is best obtained with 90+ percent precoating.
5. Use of AC-20 asphalt cement (in lieu of MC-30 cutback asphalt) as a precoating material is recommended because it can be mixed with hot dry aggregate in a HMA plant, does not need any curing, and will cause better aggregate retention. If MC-30 or MC-70 cutback asphalt must be used it should be ensured that the coating has cured completely before the precoated aggregate is used.
6. Effects of dust content and extent of precoating on the aggregate retention loss were similar for the two gradations: 3/8" - No. 4 (single size) and 1/2" - No. 8 (total). However the corresponding retention losses were greater in the latter gradation as expected because it contained additional smaller particles.
7. Ten observers made 150 subjective visual examinations of the precoated aggregate samples. The agreement between different evaluators becomes increasingly better when the percentage of coating is increased from 50 to 90+, by far the best agreement (reproducibility) being for 90+ percent coating. The current PennDOT specifications require 90+ percent coating. Few, if any, problems have been experienced in judging this specified minimum coating except during the first two years when the precoated aggregate specifications were introduced in 1980.
8. Three simple end-result type tests: dry gradation test, wash test and recantation test were attempted on the precoated aggregates in this study. Dry gradation test was determined to be most appropriate with an acceptance criteria of 0.5 percent maximum minus 200 (dust).

The following recommendations are made:

1. Continue the current PennDOT specification (*17*) on the minimum coating of precoated aggregate (Section 471.2d) which reads as follows:
   > "Provide a precoating of 0.6 to 1.2 percent of residual bituminous binder (by weight of the mix) when using asphalt cement and 0.4 percent to 1.090 when using other bituminous material. Provide a selected rate sufficient to precoat particles with a thin film of bitumen. Coat at least 90 percent of the total visible area of aggregates with a bituminous film. Thin, brownish, translucent areas will be considered fully coated. A sample of uncoated aggregate will be used for coating determinations."
2. Use the dry gradation test as a referee or final acceptance test if the precoating by subjective visual evaluation is determined to be less than 90 percent. Add the following to the current specification quoted above:
   > "If the coating by visual examination is determined to be less than 90 percent by the Engineer, the precoated aggregate will be acceptable if on dry sieving for 10 minutes the material passing No. 200 sieve does not exceed 0.5 percent."
3. Caution the construction and maintenance personnel that the setting (breaking) of the emulsified asphalt will take longer time with precoated aggregate compared to uncoated aggregate and, therefore, traffic control is necessary for longer periods of time.

4. Add the following to Section 471.3(d) Protection of Surface:
   > "Emulsified asphalt, when used in conjunction with precoated aggregates, cure at a slower rate compared to uncoated aggregates. Allow sufficient time to ensure that complete curing has taken place prior to opening to vehicular traffic."

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