FINAL REPORT

INVESTIGATION OF ASPHALT CONTENT DESIGN FOR OPEN-GRADED BITUMINOUS MIXES

by

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(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways and the University of Virginia)

Charlottesville, Virginia

March 1974
VHRC 73-R39

SUMMARY

Several design procedures associated with determining the proper asphalt content for open-graded bituminous mixes were investigated. Also considered was the proper amount of tack coat that should be placed on the old surface prior to paving operations.

The design procedures obtained from other highway agencies were evaluated in the laboratory for their prospective usefulness to the Virginia Department of Highways.

Based on the laboratory tests and evaluation of field test sections the following conclusions were obtained.

1. The maximum mixing temperature should be determined in order to avoid separation of asphalt and aggregate, which may cause flushed spots in the finished surface.

2. The EOA determination for asphalt content may be useful until experience is gained.

3. Fabrication and visual observation of Marshall type specimens may be useful: (a) in identifying mixes that over-densify under heavy traffic and (b) in indicating the proper asphalt content.

4. The "optimum fine aggregate determination" does not appear particularly useful in Virginia.

It is recommended that the amount of tack be determined by the condition of the existing pavement surface.

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INTRODUCTION

Bituminous hot plant mixes with an open gradation are becoming increasingly popular due to their anti-hydroplaning and anti-spray characteristics. These mixes are known by a number of names such as open-graded plant mix seal, porous friction course, and popcorn mix.

Open-graded plant mix seals not only provide lateral surface drainage of water but also channels between the aggregate particles for internal lateral and vertical drainage. Under heavy rainfall the water will drain vertically through the mix and laterally out to the roadway shoulder; thereby preventing the buildup of thick water films between the pavement surface and the automobile tire. The Marshall design procedure is primarily applicable to dense graded mixes; therefore, it can not be used to design open-graded mixes.

Since these mixes contain more voids than do dense-graded mixes, the aggregates must be coated with thicker asphalt films to prevent premature asphalt hardening and deterioration. A number of states and government agencies use a special design procedure to determine the proper asphalt content for open-graded mixes. The Asphalt Institute(1) and FHWA(2) have published summaries of design procedures used by various agencies. The procedures for asphalt content design include one or more of the following:

1. Optimum asphalt content is estimated from a modified Centrifuge Kerosene Equivalent (CKE) test,

2. densification of "Marshall type" specimens is estimated at several asphalt contents,

3. drainage of asphalt cement from aggregate particles is estimated for several asphalt contents at the specified mix temperature, and

4. limitation on voids contained in lab specimens.

Virginia placed thirteen sections of open-graded mix during 1972 and 1973. Heavy reliance was placed on the experience of North Carolina, which uses no standard design procedure. The asphalt content has been designed strictly by visual observation of mixes prepared in the lab. Because of some problems with the performance of the mixes, apparently connected with the mix asphalt content and the amount of tack coat, the Bituminous Research Advisory Committee recommended that the Bituminous Section investigate the possible causes. This investigation examined several of the design procedures listed above and also part of a design procedure recently developed by the FHWA(3) to determine if a more scientific design procedure is feasible.

PURPOSE AND SCOPE

The purpose of this investigation was to evaluate several existing design methods for establishing the asphalt content of open-graded bituminous plant mixes with the intent of selecting a design procedure to be used in Virginia. Also the amounts of asphalt tack placed on old pavement surfaces were examined.

Six mixes that were placed in 1973 were used to evaluate the design procedure in the laboratory.

LABORATORY PROCEDURE

Materials

The mixes used for laboratory testing are described in Table 1. Virginia's open-graded mixes are designated MS-11 and will be so designated throughout the remainder of this report. Although the AC-20 asphalt cements used in the field mixes could not be obtained, an AC-20 which should have possessed similar viscosity characteristics was used.

Table 1

Description and Location of MS-11 Mixes

Mix	I	II	III	IV	V	VI
Gradation — % Passing						
Sieve						
1/2	100	100	100	100	100	100
3/8	88	84	86	92	90	92
4	16	27	25	28	19	26
8	4	10	7	7	4	2
200	1	2	1	2	1	1
% Asphalt	7.0 design (4.3 - 7.5)	7.0	7.0	6.5	7.2	6.7
Aggregate Type and Quarry	basalt, Saunders Warrenton, Va.	C. gravel, Vulcan Mtls. Erwin, Tenn.	granite, Tidewater Stone Richmond, Va.	marble, Rockydale Lynchburg, Va.	C. gravel, Grottoes Sand & Gravel, Grottoes, Va.	limestone, S. M. Perry Winchester, Va.
Traffic Vol. and No. Lanes	14,000/4	14,000/4	26,000/3	10,000/4	9,000/4	4,200/4
Mix Location	SBL Rt. 29-211 Near New Baltimore	NBL & SBL Rt. 23 - From Va.-Tenn. state line to Holston River Bridge	SBL Rt. I-195 (Richmond-Petersburg Turnpike) at Broad Street Interchange	EBL Rt. 460- From Beaver Creek Bridge to 1.2 mi. E. Beaver Creek Bridge	NBL and SBL Rt. I-81 - from Greenville interchange to 1.0 mi. North	EBL Rt. 50 - From Rt. 600 to end of dual lane at Gore

Laboratory Tests

Modified CKE

The modified CKE test was used to estimate the optimum asphalt content (EOA). This test allows for the surface roughness and absorption characteristics of the aggregate in the computation of the EOA. Two tests were performed for each mix.

The EOA was determined by the following procedure.

1. 105 gram sample of aggregate passing the 3/8 inch sieve and retained on the No. 4 sieve was prepared.

2. Sample was dried in the oven to constant weight and allowed to cool.

3. 100.0 grams were placed in a metal funnel with a piece of No. 10 sieve soldered to the bottom of the opening.

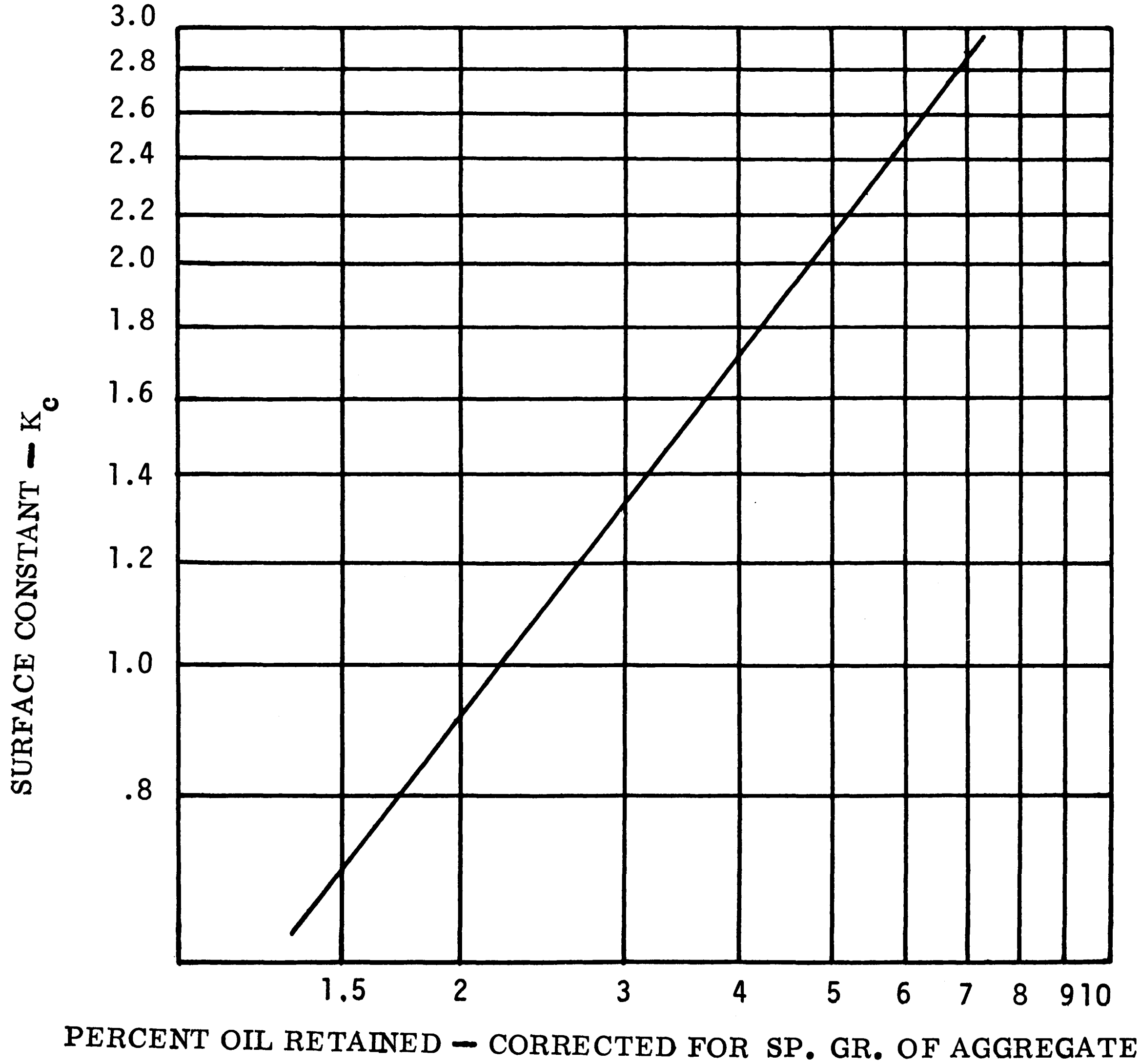
4. Funnel and sample were immersed in SAE No. 10 lubricating oil for 5 minutes, removed and allowed to drain for 2 minutes.

5. Funnel and sample were then placed in a 140^{o}F oven for 15 minutes, removed from the oven, cooled and the sample weighed to nearest 0.1 gram.

6. Percent oil retained was used with Figure 1 to determine aggregate surface capacity, K_c.

7. EOA based on weight of aggregate was calculated by:

   Percent asphalt = $2.0\ K_c + 4.0$.



Material Used: Aggregate - Passing 3/8", Ret. No. 4 Sieve
Oil - SAE 10

Oil Retained Corrected (%) = Oil Retained (%) x $\frac{\text{"apparent" sp. gr. of Coarse Aggregate}}{2.65}$

Figure 1. Chart for determining surface capacity (K_c) of coarse aggregate (From reference 3).

Fraction Total Densification (FTD) Determination

The FTD was determined using the Colorado Modified Super Compaction Method[2]. This method is designed to ensure that the mix will maintain sufficient voids under specified traffic conditions with maximum asphalt content.

Three 4" diameter x $2\frac{1}{2}$" high samples were compacted, one at the field asphalt content, one 0.5% below, and one 0.5% above. The compaction procedure was as follows:

1. The asphalt cement and aggregate were combined, mixed with a portable mixer and molded at 250° F on a California kneading compactor. Each specimen received 90 blows at 450 psi and a double plunger compressive load of 1,000 psi for 1 minute.

2. The specimens were cooled, removed from the mold, and the bulk specific gravity determined by weighing the specimen and measuring the outside dimensions.

3. The specimens were cooled to approximately 0° C in a cooling chamber and sawed vertically for visual observation.

Colorado uses visual observation to determine the fraction of the specimen that has total densification (no air voids).[2] Photographs of samples made by the Colorado Division of Highways show that total densification progresses from the top to the bottom of the specimen as the asphalt content is increased. For example a mix at 5.5% asphalt content was totally densified in the top half of the specimen, therefore it had an FTD of one-half, or 50%. The same mix at 6.5% asphalt content was densified in the top two-thirds of the specimen, therefore it had an FTD of two-thirds, or 67%.

The Colorado design criteria specify maximum FTD's of 2/3 and 1/2 respectively for highways with less than 30,000 vpd and greater than 30,000 vpd; therefore 6.5% asphalt would be used for a highway with less than 30,000 vpd, and 5.5% asphalt would be used for a highway with more than 30,000 vpd.

Although the Colorado compaction procedure was followed the pattern of total densification obtained in the present study did not seem to follow the pattern obtained in Colorado. The densification appeared to progress throughout the specimen as asphalt content was increased rather than from the top of the specimen. Therefore, it was quite difficult to make an accurate visual determination of the FTD.

Optimum Fine Aggregate Content

Smith, Rice and Spelman developed a method for predicting the optimum amount of fine aggregate for an open-graded mix.[3] This test was included as part of this investigation since the amount of fine aggregate does influence the optimum amount of asphalt in a mix. The procedure consists of obtaining the void capacity of the coarse aggregate fraction of the mix (material retained on No. 8 sieve) and using the Voids Mineral Aggregate (VMA) data to calculate the amount of fine aggregate that can be tolerated in the voids of the coarse aggregate. The procedure by Smith, Rice and Spelman was followed except as noted below.

A portable electrical vibrating rammer equipped with a special tamper foot was used to compact the coarse aggregate in a 6" diameter CBR mold (Figure 2). The rammer had a vibrating frequency of approximately 3,200 cycles per minute whereas the specified frequency was 3,600 cycles per minute. The difference was not believed to be significant.

Figure 2. Compaction of coarse aggregate for "Optimum Fine Aggregate Content" determination.

In summary, the procedure consists of placing a 5-lb. sample of coarse aggregate (+ No. 8 sieve material) into the mold, vibrating for 15 seconds and measuring the thickness of the sample. The vibrated unit weight and VMA were computed. The fine aggregate content is expressed by

Fine Aggregate (Passing No. 8 sieve) = VMA + Asphalt Absorption

- Design Asphalt Content

- Design Void Content

and is computed by

$$Y = \left[\left[\% \text{ VMA} - V \right] - \left[(\% \text{ AC})\ (X)/U_a \right] \right] \div \left[\left[(\% \text{ VMA} - V)/100 \right] + \left[X/U_f \right] \right]$$

Where:

Y	=	Percent passing No. 8 sieve
% VMA	=	Percent voids mineral aggregate of coarse aggregate = $100 - (100)\ (X)/U_c$
U_c	=	Theoretical bulk dry solid unit weight of coarse aggregate (+ No. 8)
V	=	Design percent air voids
% AC	=	Percent asphalt by total weight of aggregate
X	=	Vibrated unit weight of coarse aggregate (+ No. 8)
U_a	=	Unit weight of asphalt cement
U_f	=	Theoretical bulk dry solid unit weight of fine aggregate (passing No. 8 sieve)

The percent asphalt used in computations was the EOA obtained from the modified CKE test and the design air voids was 15%.

Maximum Mixing Temperature

If the mixing and hauling temperatures are excessively high in an open-graded mix the asphalt will separate from the aggregate and drain to the bed of the trucks. This drainage can result in flushed spots in the mix which may be confused with a rich or fat mix. Therefore, the maximum mixing temperature was determined for each of the six mixes by the following procedure.[3] Approximately 1,000 grams of each aggregate were prepared using the gradations from Table 1. The aggregate was then mixed with an AC-20 asphalt cement at the asphalt contents shown in Table 1 at 225° F, which for this particular asphalt produces the recommended viscosity of 800 centistokes. The mixture was transferred to a 9-inch pyrex plate with a minimum of manipulation and returned to the oven at the mixing temperature. The plate was observed after 15 and 60 minutes and the amount of asphalt drainage noted (Figure 3). "A slight puddle at points of contact between aggregate and glass plate is suitable and desirable."[3] The test was repeated at two additional temperatures selected by considering the results of the first test. If the asphalt puddled excessively at 225°F the other mixing temperatures were lower and if the asphalt did not puddle excessively, the other test temperatures were increased until excessive puddling occurred.

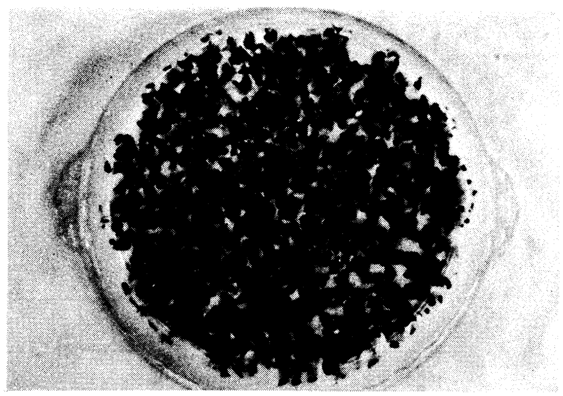


Figure 3. Bottom view of pyrex plate in "Maximum Mixing Temperature" determination.

DISCUSSION

Modified CKE Estimation of Asphalt Content

The modified CKE test yields an EOA that is based on the absorptive and surface characteristics of the coarse aggregate. The EOA calculated by the FHWA suggested formula (EOA = $2.0\ K_c + 4.0$) was 6.5 - 6.6% for five of the six mixes and the asphalt content of the mix in the field installation was 6.5 - 7.2% (Table 2). The EOA was reasonably close to the asphalt content used in the field, generally about 0.5% less. The EOA calculated by the Colorado formula (EOA = $1.5\ K_c + 4.0$) was approximately 0.7% less than that calculated by the FHWA procedure.

Since the EOA is generally less than that used in most of the six mixes in the field, some reevaluation of the asphalt content of future MS-11 mixes may be in order.

Table 2

Summary of Results

Mix Identification	Asphalt Content Used in Field, %	EOA	Fine Aggregate in Field Mix, % (-#8 Sieve)	Optimum Fine Aggregate, % (-#8 Sieve)	Asphalt Content, %	Fraction Total Densif., %	Voids, %	Lab Max. Mix. Temp., °F 15 min.	Lab Max. Mix. Temp., °F 60 min.	Max. Mix. Temp., °F
I Basalt	7.0 design (4.3 - 7.5)	6.6	4	22	6.5 7.0 7.5	20 20 40	20 18 19	250	215	265
II C. Gravel	7.0	6.6	10	20	6.5 7.0 7.5	10 20 50	19 16 16	250	250	250
III Granite	7.0	6.6	7	22	6.5 7.0 7.5	10 30 50	18 16 15	230	230	220
IV Marble	6.5	6.6	7	22	6.0 6.5 7.0	50 50 50	11 11 10	250	230	240
V C. Gravel	7.2	6.5	4	23	6.7 7.2 7.7	10 20 40	18 18 18	250	230	240
VI Limestone	6.7	5.6	2	21	6.2 6.7 7.2	10 20 45	20 20 19	230	200	215

Fraction Total Densification

It was extremely difficult to assess the fraction total densification of the specimens in terms of absolute numbers. The voids were usually evenly distributed throughout the specimen; therefore total densification was seldom achieved. The percent total densification was based on the voids present as compared to voids in an ideal mix. For example, 50% total densification would indicate that 50% of the voids (as compared to an ideal mix) were eliminated.

Figure 4 illustrates the decrease of voids as the asphalt content is increased to 7.5% in Mix No. II. One obvious observation was that mix No. IV (Table 2) tended to over-densify at all reasonable asphalt contents (Figure 5). According to the Colorado mix design criteria, three of the mixes (II, III, IV) densified beyond an acceptable level at 0.5% asphalt content above that used in the field. A maximum of 50% FTD is specified for high traffic roads (over 30,000 vpd).

When the total voids in the mix are compared to FTD information (refer to Table 2) it appears that in order to maintain 50% FTD the voids should be greater than 15%. Although this study was not designed to permit the derivation of a correlation between FTD and void data, it appears that a correlation could be developed. The results for total voids would be quantitative and not qualitative such as those for FTD.

Optimum Fine Aggregate Content

This procedure was designed to determine the void capacity of the coarse aggregate in a compacted mix and thus the space available to accommodate asphalt cement and fine aggregate. The laboratory procedure determined that approximately 22% should pass the No. 8 sieve for the six mixes (Table 2). The mixes placed in the field actually had must less fine aggregate, 2-10%.

Since the specimens containing 15% air voids and compacted by the Colorado method appeared too dense, it is believed that the MS-11 mixes should be designed for more air voids. The 15% design void content was used to compute the fine aggregate content; however, if the design void content were increased the calculated fine aggregate content would agree better with that used in the field MS-11 mixes.

Maximum Mixing Temperature

The maximum mixing temperature was determined for two periods, 15 minutes and 60 minutes. The 15-minute temperature would correspond to a short haul and/or little or no waiting at the paver, and the 60-minute temperature would correspond to a long haul and/or waiting at the paver. The selection of the 15 or 60 minute temperature depends on the location of the job relative to the plant and the waiting time at the paver.

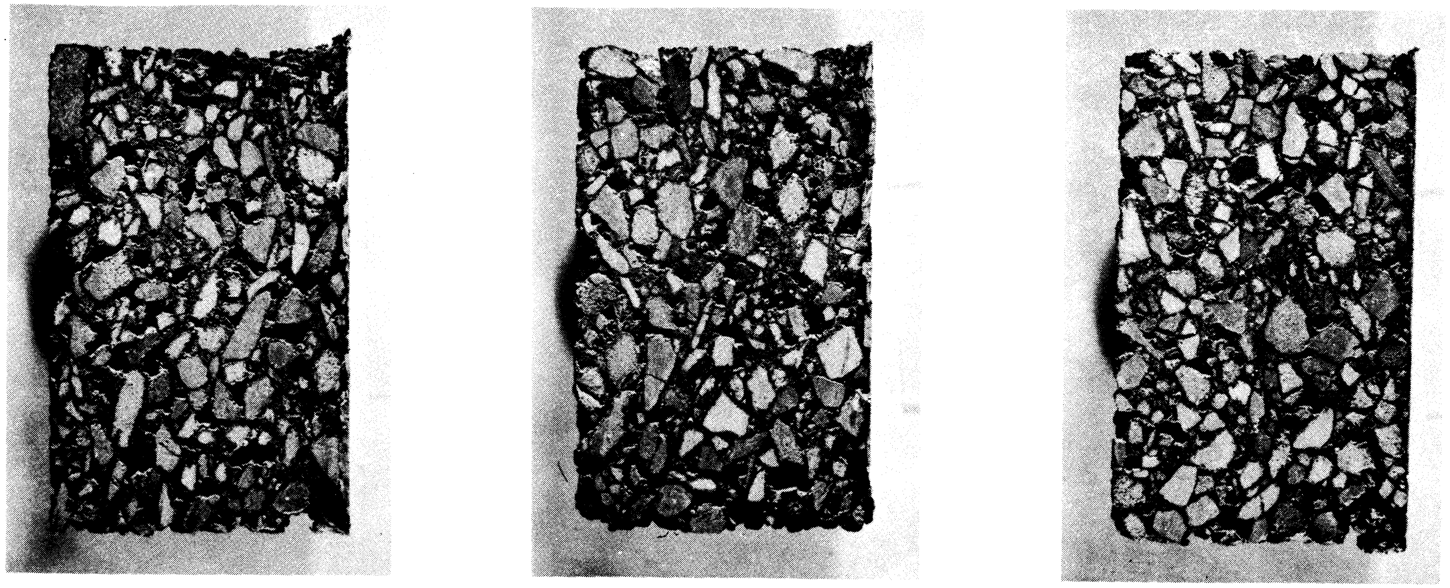


Figure 4. Sawed FTD specimens for mix No. II, showing decrease in voids as the asphalt is increased from 6.5% (left photo), to 7.0% (middle) to 7.5% (right).

Figure 5. Sawed FTD specimens for mix No. IV showing over-densification at all asphalt contents (6.0% left, 6.5% middle, 7.0% right).

As described previously the maximum mixing temperature is the highest temperature at which excessive loss of the asphalt cement will not occur. The loss of asphalt at a certain temperature depends on the viscosity of the asphalt and the absorptive and surface characteristics of the aggregate.

The maximum mixing temperature for the 15-minute time was 230° to 250° F for the six mixes. The maximum mixing temperature for the 60-minute time was 200° - 250°F. These results indicate that consideration should be given to mix temperature on jobs requiring long waiting times and that the loss of asphalt cement is dependent on aggregate type in addition to the asphalt viscosity.

In four of the six mixes the mixing temperature at the plant was higher than the laboratory determined mixing temperature for the 60-minute period. One of these mixes, mix No. I, presented problems in the field that were attributed to the high temperature. It was possible that the remaining three mixes did not have long waiting periods and/or the asphalt viscosity of the AC-20 used in the field was high enough to prevent excessive runoff. Mix No. II exhibited isolated flushed spots in the field that could not be attributed to the plant mixing temperature according to the maximum mixing temperature recorded in the field. However, the actual viscosity of the field asphalt could have caused the maximum mixing temperature to be somewhat lower than that determined from the AC-20 asphalt used in the laboratory and resulted in excessive asphalt drainage.

Tack Coat

Since the amount of tack and asphalt content of the MS-11 mix are interrelated, the tack coat is also discussed in this report. There can be cases where flushed asphalt problems may be a direct result of excessive tack coat and not excessive asphalt cement in the mix. The following discussion regarding the proper amount of tack for a MS-11 mix is based on opinions derived from discussions with other engineers and from personal observations.

The amount of tack placed on the surface before the MS-11 mix is placed should be dependent on the condition of the underlying surface. If the surface is cracked, rough, or badly deteriorated it will require more tack than a smooth, uncracked surface. The amount of tack specified by the Virginia Department of Highways has been 0.1 gsy of residual asphalt. It is the author's opinion that the specification for tack should be more flexible than it has been in the past. For instance, approximately 0.1 gsy was placed on the surface prior to placing mix No. II. This surface was a fine sand mix with no cracks; therefore the tack could not penetrate the surface. The excessive tack remaining on the surface possibly was a factor in some of the flushing that has occurred on this project. The amount of tack should be decided upon considering the condition of the existing surface on each job.

USEFULNESS OF TESTS

The following procedures are summarized in order of decreasing usefulness to the particular needs of the Virginia Department of Highways.

1. The most useful test appears to be the determination of the maximum mixing temperature. The tests indicated that the mixing temperature was too high on one project (No. I), which had temperature regulation difficulties. The test also indicated that the mixing temperature on mix No. VI should have been maintained at about 200^{o} - 230^{o} F. Through intuitive judgment by the engineer, the maximum mixing temperature was maintained at 215^{o} F; therefore, trouble was averted. Testing of the mix before construction will demonstrate to the inspection personnel the criticality of controlling the mixing temperature.

2. The EOA determination may be useful as an indication of the proper asphalt content. The EOA results were consistently lower than the asphalt contents used in the field, which may indicate that less asphalt should be used. The EOA determination is especially helpful on aggregates having unusual absorption and/or surface roughness, such as slag or smooth limestone.

3. A compaction and observation procedure similar to that used in the FTD determination may be useful to identify types of aggregate that tend to over-densify under compaction and traffic. This procedure may be especially helpful in the design of mixes for highways with high traffic volumes. It may also be useful as a visual indication of the excessive asphalt contents that cause the voids to become totally or intolerably filled. Although the data resulting from this determination are not quantitative they can be interpreted qualitatively for asphalt content. In order to be used in field laboratories the compaction procedure would have to be adapted to the Marshall hammer.

4. Results from the "optimum fine aggregate content" determinations indicate that the mixes should have contained approximately 12% - 20% more - No. 8 sieve material. It is the author's opinion that the mixes would not have tolerated this much fine aggregate without severe flushing problems.

   If the "optimum fine aggregate content" is calculated, the design air voids criterion of 15% should be examined carefully. A larger value may be more realistic.

RECOMMENDATIONS

It is recommended that in the design of open-graded mixes the Department:

1. Use the modified CKE test to determine the estimated optimum asphalt content. Although the EOA probably will not change appreciably from year to year it will be useful until experience has been gained for those aggregates normally used.

2. Use a procedure similar to the FTD determination to help indicate: (a) mixtures that may tend to densify under heavy traffic and (b) the proper asphalt content.

3. Determine the maximum mixing temperature for each mix in the laboratory by the procedure described in this report.

4. Specify the amount of tack after examining the condition of the pavement surface on which the MS-11 mix will be placed. A smooth, nonabsorptive surface with no cracks would require approximately 0.05 gsy and a badly cracked, very absorptive surface would require the maximum 0.1 gsy.

REFERENCES

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3. Smith, R. W., J. M. Rice, and S. R. Spelman, "Design of Open-Graded Asphalt Friction Courses," Report No. FHWA-RD-74-2, January 1974 Interim Report, Federal Highway Administration (January 1974).