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Evaluation of Tests for Characterizing the Stiffening Potential of Baghouse Dust in Asphalt Mixes

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ABSTRACT

Since the enactment of the 1970 Clean Air Act many asphalt plants have been forced to install baghouse dust collectors. Often this dust is added to asphalt concrete mixtures. The dust can stiffen mixes, thereby making them hard to compact, or it can act as an extender, thus causing bleeding and tenderness. There are no accepted specification tests for controlling the stiffening or the extending effects of baghouse dust. A variety of simple test procedures were evaluated for possible use for specification or quality control purposes to control stiffening. The customary physical properties of the dust, such as pH, shape, and gradation, do not predict stiffening. Two types of test procedures--fractional voids and consistency--were correlated with stiffening as measured by the increase in viscosity or softening point caused by the addition of dust to asphalt cement. Fractional voids in dust-asphalt mixtures were calculated from the bulk volume of dust compacted with impact and vibratory compaction and by consolidation in fluid media. Consistency tests included the kerosene, balling and crumbling, and bitumin number tests. The best correlation with stiffening ratio was obtained from the fractional voids as determined from the dry impact compaction. This test procedure is acceptable for process control and acceptance procedures; the other test procedures are not acceptable. The best means of determining the stiffening effect is to determine the stiffening directly with capillary viscometry. However, before either the fractional void test or the direct measure of stiffening is included as a specification criteria for stiffening, they must be determined through correlation with field performance.

Since the enactment of the 1970 Clean Air Act the operators of many asphalt concrete plants have found it necessary to install secondary dust-collection systems. These systems collect the fine dust that would otherwise be released from the exhaust gas to the atmosphere. Filter fabric dust collectors are the most commonly used secondary collection systems. They are usually referred to as baghouses, and the collected dust is called baghouse dust. Baghouse dust may be extremely fine (1 μm to 30 μm) or it may contain a wide range of particle sizes (1 μm to 300 μm), according to the configuration of the plant (1). Finer dust is produced when a cyclone or other type of primary collector is used in series with a baghouse. The cyclone collector effectively removes dust larger than 30 μm, thereby stripping the coarser fraction from the dust collected in the baghouse. Therefore, baghouse dust from different plants can vary widely in gradation.

Baghouse dust often presents a disposal problem, and in many plants it is common to add baghouse dust to the asphalt concrete. Some paving technologists are reluctant to do this because they believe that the dust can adversely affect the quality of the asphalt concrete. For example, baghouse dust can act as an asphalt extender, thus reducing the design asphalt content. If the addition of baghouse dust is not accounted for in the mix design, bleeding and tenderness can result (2,3).

Other problems that have been attributed to the improper use of baghouse dust include poor compaction and raveling resulting from excessive stiffening of the asphalt concrete (4-6). Concern about the stiffening effect of baghouse dust has led many highway agencies to restrict its use (7). Other agencies have adopted or are considering test procedures that are intended to control the use of baghouse dust (8). These test procedures are designed primarily to control mixture stiffening caused by baghouse dust.

The purpose of this paper is to report on a laboratory evaluation of several test procedures that measure the stiffening of asphalt cement that results from the addition of a fine mineral dust. The

stiffening effect produced by baghouse dust is not reflected in the usual Marshall mixture design parameters. A specification limit on the dust/asphalt ratio or dust content in a mixture is insufficient because of the widely varying stiffening effects caused by different dusts. Therefore, if control of stiffening is desired, an additional specification requirement or test procedure is warranted. The objective of this study was to evaluate test procedures that could be used at the plant as quality control and quality assurance or for source acceptance purposes.

In the past variability in the fineness or gradation of baghouse dust has also been cited as a problem. However, recent research has indicated that the gradation of baghouse dust is extremely uniform on a day-to-day and within-day basis (1). Improper plant operations or poorly designed dust handling systems may cause a problem of uniformity in the feed rate of baghouse dust to the pugmill. This problem is not addressed in this paper.

METHODOLOGY

First, a variety of different tests were used to characterize the physical properties of the dust. Second, the stiffening produced by the addition of baghouse dust to two different asphalt cements was determined directly by softening point and viscosity measurements on the dust-asphalt mixtures. Third, a number of different tests proposed as indirect measures of stiffening were conducted, and the results were compared with the actual stiffening measures in the viscosity tests.

Materials

As part of a larger study (NCHRP Project 10-19, Adding Dust Collector Fines to Asphalt Paving Mixtures), baghouse dust samples were collected from 26 asphalt concrete plants (1). The samples, collected in 12 states, represent the range of generic aggregate types in common use in the United States. Samples from 15 plants were selected for detailed study. A description of the samples is given in Table 1. Tests conducted on these samples included gradation, fineness modulus, pH, hygroscopic moisture, and Atterberg limits (1). The gradation data, including fineness modulus, are given in Table 2.

The properties of the two different asphalt cements used in the study are given in Table 3. The test results of the two asphalts were nearly identical, and therefore only the results for asphalt WB are presented in this paper.

Direct Measurement of Stiffening

Each of the dusts was added to the asphalt cement in two dust/asphalt ratios (0.20 and 0.40 by volume).

TABLE 1 Description of Dusts Used in Study

Plant No.	Aggregate Type	pH	Hygroscopic Moisture	Liquid Limit	Plastic Limit	Plasticity Index[a]
1	Dolomite	11.6	4.1	-	-	NP
2	Dolomite	11.2	0.6	-	-	NP
5	Traprock	9.8	1.9	39	37	2
6	Siliceous gravel	5.6	0.4	-	-	NP
7	Traprock	11.2	1.9	34	31	3
9	Limestone	12.1	0.6	-	-	NP
10	Limestone	10.9	0.4	-	-	NP
13	Gravel	12.1	1.5	34	32	2
14	Gravel	10.5	1.2	30	27	3
15	Limestone	12.2	1.2	32	29	3
20	Granite	8.3	0.7	35	35	NP
24	Granite	9.2	0.9	35	34	1
26	Granite	7.2	1.9	39	37	2
30	Traprock	6.4	0.8	32	31	1
33	Siliceous gravel	7.7	1.5	33	29	4

[a]NP = nonplastic.

TABLE 2 Grain-Size Distribution for Dusts Used in Study

Plant No.	Grain-Size Distribution (% passing) No. 30 (600 μm)	No. 50 (300 μm)	No. 200 (75 μm)	50 μm	20 μm	10 μm	5 μm	1 μm	Fineness Modulus[a]	Cu[b]
1	99	96	60	54	18	7	2	1	2.43	27
2	99	89	64	61	43	27	14	3	2.21	4
5	100	100	100	99	95	73	41	7	1.21	2
6	99	94	43	40	23	12	4	0	2.55	10
7	100	100	100	99	91	63	35	7	1.40	3
9	100	94	47	44	27	17	9	3	2.42	5
10	95	88	35	34	22	15	9	3	2.65	4
13	100	100	96	94	80	61	40	12	1.33	2
14	100	99	83	81	72	61	47	12	1.47	2
15	100	100	98	97	92	73	44	8	1.14	2
20	100	100	93	92	75	52	27	4	1.59	3
24	100	100	99	97	83	52	29	7	1.44	3
26	100	100	100	100	95	78	49	12	1.10	2
30	100	99	94	92	71	45	23	5	1.59	4
33	100	99	73	69	47	35	25	7	1.90	3

[a]Based on percent retaining on 600, 300, 50, 10, 1 μm.
[b]Based on ratio of percent passing 50 μm divided by percent passing 5 μm.

TABLE 3 Physical Properties of Asphalt Cements

Property	Asphalt A	Asphalt WB
Viscosity (poises, 140°F)	2042	2208
Viscosity (cSt, 275°F)	404	438
Penetration, 77°F	73	100
Aging Index, 140 viscosity	2.26	3.00
Rostler-Sternburg composition (%)		
A	22.5	28.1
N	21.0	26.9
A_1	14.8	18.8
A_2	33.9	21.2
P	7.7	5.0
$(N + A_1)/(A_2 + P)$	0.86	1.74

The resulting dust-asphalt mixture was then tested for softening point (ASTM D 36) and viscosity (ASTM D 2171) at 60°C. The increase in softening point (Δ°F) greater than that of the neat asphalt cement was considered as one measure of stiffening. In addition, the stiffening ratio (SR) was calculated by dividing the viscosity of the dust-asphalt matrix by the viscosity of the neat asphalt cement. The results of these tests are given in Table 4. There

TABLE 4 Stiffening Ratios for Dust-Asphalt Mixtures

	Dust-Asphalt Ratio							
	Asphalt A		Asphalt WB					
Plant No.	0.2	0.4	0.2	0.4	Aggregate Type	D_{80} (μm)	D_{50} (μm)	D_{20} (μm)
1	1.6	3.5	1.7	3.4	Dolomite	100	35	17
2	1.7	3.3	1.8	3.6	Dolomite	200	30	7
5	2.6	21.4	2.8	19.3	Traprock	10	7	3
6	1.8	3.8	2.4	4.2	Siliceous gravel	200	80	15
7	2.6	17.2	2.9	18.2	Traprock	15	7	3
9	1.7	2.8	1.6	3.1	Limestone	200	80	16
10	1.8	3.8	1.8	3.4	Limestone	260	100	12
13	2.4	12.0	2.6	11.7	Gravel	19	6	2
14	2.6	12.0	2.8	12.1	Gravel	50	6	2
15	2.3	8.7	2.4	8.4	Limestone	12	6	2
20	2.4	10.6	2.5	10.9	Granite	18	10	4
24	2.6	16.3	2.7	16.8	Granite	20	10	4
26	3.2	100.4	3.6	71.8	Granite	12	5	2
30	2.0	4.6	2.0	4.1	Traprock	27	10	5
33	2.1	5.2	2.2	5.5	Siliceous gravel	42	10	2

was a high degree of correlation between stiffening ratio and the increase in softening point temperature (Figure 1). This result agrees with the observations of other researchers (8); however, the relationship between the logarithm of stiffening and the softening point is nonlinear. Because of the strong correlation between stiffening ratio and softening point, only the stiffening ratio was considered further. Stiffening ratio was chosen because it is based on rational test measurements (viscosity versus softening point) and because the test procedure (ASTM D 2171) is readily performed in most asphalt testing laboratories. No difficulties were encountered in measuring the viscosity of the dust-asphalt mixtures.

Indirect Measurement of Stiffening

The test procedures used as indirect measures of stiffening can be divided into two categories: (a) measurements of the fractional voids in a compacted or consolidated bed of dust, and (b) measurements of the amount of liquid (asphalt cement, kerosene, or water) required to bring the dust-liquid mixture to a specified consistency.

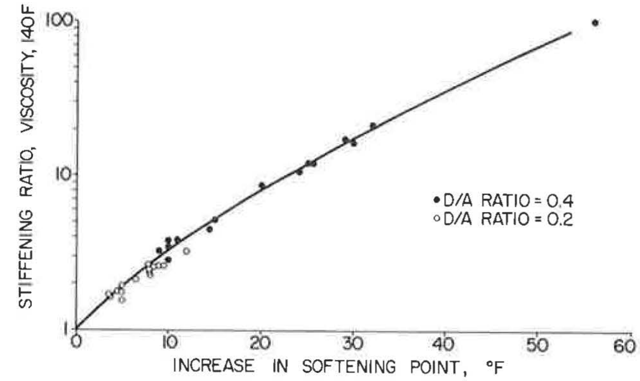

FIGURE 1 Change in softening point (°F) versus stiffening ratio, viscosity, 140°F.

Fractional Voids

Rigden (9) has proposed that the volume fraction of voids in a dry compacted bed of dust can be used as a measure or predictor of the stiffening potential of a mineral dust. In the fractional voids concept, the dust-asphalt mixture is composed of three volume fractions, as shown in Figure 2: the solid volume of the dust particles (V_{DS}) and the free (V_{AFR}) and fixed (V_{AFX}) volume of the asphalt cement. The fixed asphalt volume is defined as the volume of asphalt required to fill the volume between the solid dust particles, assuming that the dust is compacted or consolidated to some reference density. The free asphalt provides fluidity to the mixture and can be related to the viscosity of the mixture.

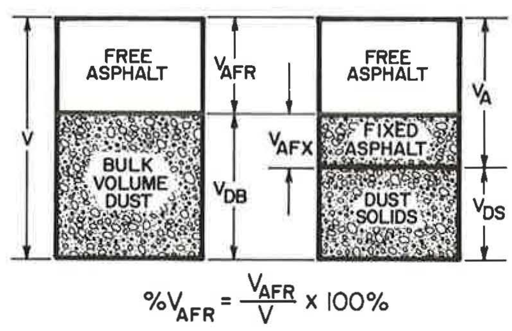

FIGURE 2 Schematic of fractional voids in dust-asphalt system.

At a given dust/asphalt ratio, the dust with the smaller bulk volume (V_{DB}) will yield more free asphalt volume. This will allow more asphalt to lubricate the mixture and will result in a lower viscosity.

Three methods were used to produce a compacted bed of dust so that the bulk volume of the dust could be measured. First, vibratory compaction of the dry dust was obtained by placing approximately 50 to 70 g of dust in a 100-mL graduated cylinder, which was fastened to a 16-gage steel base plate (Figure 3) (10). The base plate was vibrated until the level of the dust in the graduated cylinder reached equilibrium. The bulk volume of the dust was read from the graduations on the cylinder. Vibratory compaction, as described, produced highly repeatable results, much more so than manual tapping of the cylinder, as proposed by other researchers (8).

The bulk volume of the dust was also obtained by allowing 5 g of dust to settle in both polar (methyl-

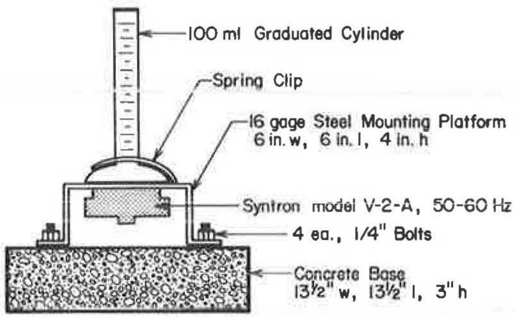

FIGURE 3 Schematic of dry vibration compaction procedure.

ethylketone) and nonpolar (toluene) liquids. In this paper bulk volume obtained in this manner is referred to as settled volume. A special 10-mL graduated test tube (Fisher No. 14-950A) was used and the settled volume was read directly from the graduations on the cylinder (10). It is important that the samples be de-aired before the settling process is initiated.

The third procedure was the dry impact compaction procedure described by Rigden (9). In this test a small drop hammer is used to compact the dust into a mold. The bulk volume was calculated on the basis of the area of the mold and the height of the compacted bed of dust. A 9.5-mm-diameter steel mold and a 100-g weight dropped 25 times through a 30-mm height of fall was used to compact the test samples. The most repeatable results are obtained when the height of the compacted bed approximates its diameter. Rigden also tested the compacted sample in a simple air permeability device to obtain the surface area and the average particle diameter of the dust (9).

Consistency Tests

Bitumen Number

This test, reported by van der Baan and Van Dijk (11) for mineral filler, does not involve bitumen; rather, water is added to the dust until it attains a specified consistency, as measured by a penetrometer. A standard penetrometer device (ASTM D 5) can be used for this test, although a modified penetrometer needle is required. The modified needle has a flat base that is 7.98 mm in diameter (10). The dust-water mixture is placed in a cylinder 30 mm in diameter by 30 mm deep. The volume of water required to bring the dust to a consistency corresponding to a penetration of 5 to 7 mm is reported as the bitumen number.

Kerosene Adsorption

In this test (12) 20 g of dust is placed, without any compaction, into a watch glass. Kerosene is then slowly dropped from a burette onto the surface of the dust. Capillary action causes the kerosene to saturate the dust. When the outer edge of the dust in the watch glass is saturated with kerosene, the flow is stopped and the volume of kerosene is recorded. The volume of adsorbed kerosene is a measure of the voids in the dust when the dust is in a loose condition.

Asphalt Mixing Test

In this test dust is added incrementally to 15 g of asphalt at 163°C. As the dust is added and mixed into the asphalt, two distinct changes in the consistency of the dust-asphalt mixture can be observed. These changes, in order of occurrence, are the balling point and crumbling point (8). The amount of dust that has been added (in grams) when balling or crumbling occurs is recorded.

DISCUSSION OF RESULTS

Physical Data

A considerable amount of physical test data, such as gradation, fineness modulus, pH, minerological content, and shape factors as determined from SEM photomicrographs, was obtained for each dust. None of these data explained the different levels of stiffening that were found for the different dusts. The test data (Table 2 and 4) indicate that the amount of stiffening is not directly related to the fineness or fineness modulus of the dust. Although in most cases a greater amount of stiffening was produced by the single-sized finer dusts, it is important to note that a dust can be extremely fine and still not produce a large stiffening effect. For example, the grain-size distribution of the dust from plant 15 was virtually the same as that for plant 26; however, the stiffness ratios were 8.65 and 100.4, respectively, for a dust/asphalt ratio of 0.4. Therefore, fineness alone, or measures of fineness, are not appropriate specification tests for baghouse dust.

Fractional Voids

The percentage of free asphalt in the dust-asphalt mixture ($\%V_{AFR}$), defined schematically in Figure 2, was calculated as follows:

$$\%V_{AFR} = \left\{(W_A G_{DS}\gamma_{DB} + W_{DS}G_A\gamma_{DB} - W_{DS}G_A G_{DS}) \div [\gamma_{DB}(W_A G_{DS} + W_{DS}G_A)]\right\} 100 \quad (1)$$

where

- G_A = specific gravity of asphalt,
- G_{DS} = specific gravity of dust solids,
- W_A = weight of asphalt in dust-asphalt mixture (g),
- W_{DS} = weight of dust solids in dust-asphalt mixture (g), and
- γ_{DB} = bulk density of the compacted dust (g/cm^3).

The bulk density of the dust (γ_{DB}) was obtained from the dry impact compaction, dry vibration, and settled volume tests. The bulk density is simply the weight of the dry dust divided by its bulk volume (V_{DB}). These values were used to calculate $\%V_{AFR}$ according to Equation 1. Regression equations for stiffening ratio versus $\%V_{AFR}$ were then obtained for each bulk volume test procedure. R^2 values for $\%V_{AFR}$ versus stiffening ratio for dry impact, nonpolar solution, dry vibratory, and polar solution were 0.94, 0.89, 0.88, and 0.80, respectively. Plots of stiffening ratio versus $\%V_{AFR}$ for dry impact and dry vibratory densification are shown in Figures 4 and 5. The relationship shown in Figure 4 is considerably better than that shown in a previous paper (13), where several methods of impact compaction were used to generate the data.

Another advantage of the original Rigden (9) procedure is that the compacted sample can also be used to monitor the fineness of the dust. By using air permeability theory (9), it is possible to calculate

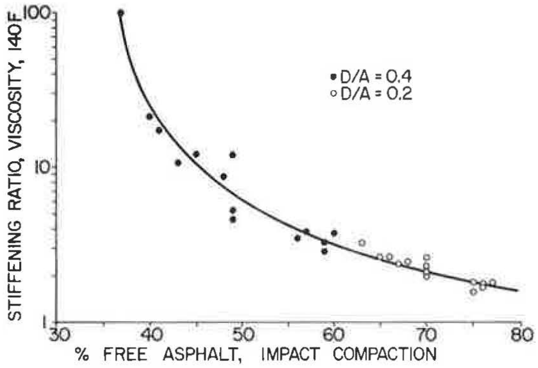

FIGURE 4 Percent free asphalt volume–drop hammer compaction versus stiffening ratio, viscosity, 140°F.

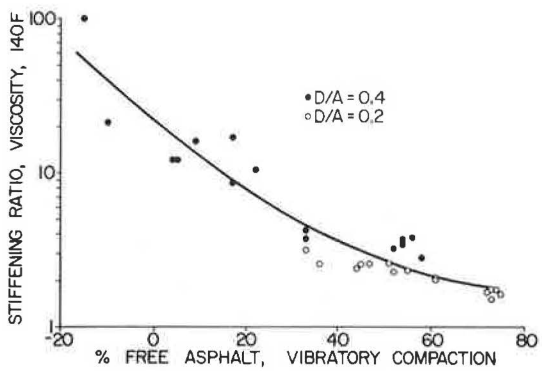

FIGURE 5 Percent free asphalt volume–vibratory compaction versus stiffening ratio, viscosity, 140°F.

the average hydraulic radius of the compacted dust and, in turn, calculate the average particle size of the dust. The results of these calculations are shown in Figure 6, where D_{10} [size corresponding to 10 percent passing (μm)] is plotted versus the average size as calculated from the hydraulic radius.

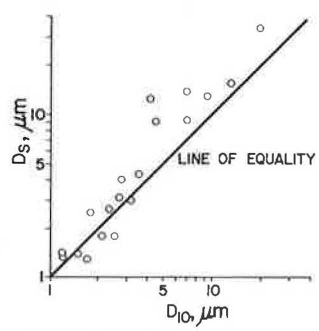

FIGURE 6 Average percent passing 10 μm versus average grain size from air permeability measurements.

Kandhal (8) has proposed that stiffening ratios greater than 10 can lead to unacceptable field performance. In Figure 4, which is based on dry impact compaction, it can be seen that the percentage of free asphalt must be greater than 45 percent if the stiffening ratio is to be less than 10. The curve plotted in Figure 4 was used to construct the isobars of $\%V_{AFR}$ that are shown in Figure 7, plotted

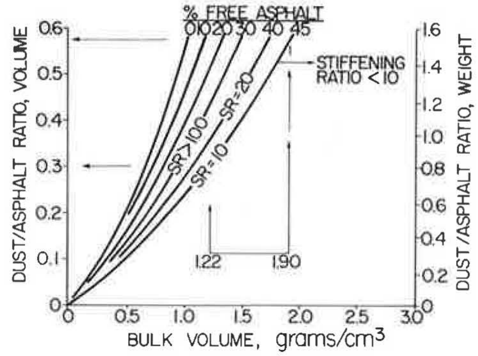

FIGURE 7 Proposed design chart for selecting dust/asphalt ratio and impact compaction.

on a graph of bulk volume versus dust/asphalt ratio. As long as the bulk volume and dust/asphalt ratio falls to the right of the V_{AFR} = 45 percent curve, the stiffening ratio will be less than 10 and thus result in an acceptable mixture. Dust/asphalt ratios that fall to the left of this curve would be acceptable only if the measured stiffening ratio is less than 10. In the example shown in Figure 7, a dust with a bulk volume of 1.90 would be acceptable as long as the dust/asphalt ratio is less than 0.60, but a dust with a bulk volume of 1.22 would require that the dust/asphalt ratio be less than 0.30.

Consistency Tests

The results of the consistency tests were correlated with the stiffening ratio to determine whether these tests, which can be performed with relative ease, can be used in lieu of a viscosity or softening point test.

A plot of stiffness ratio versus bitumen number is shown in Figure 8. Although a general relation-

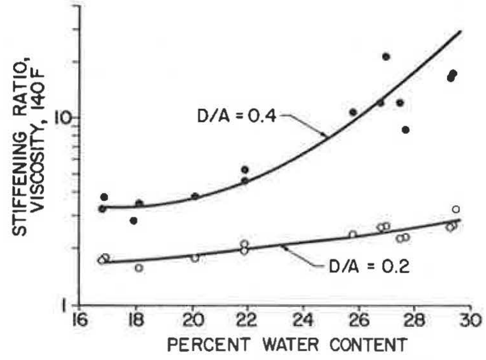

FIGURE 8 Bitumen number versus stiffening ratio, viscosity, 140°F.

ship is indicated, the correlation coefficient is relatively low (R^2 = 0.83). Stiffening ratio increases asymptotically at the larger stiffening ratios, and therefore this test method cannot be recommended for specification purposes.

The results of the asphalt mixing test are presented in Figure 9, where the balling and crumbling points are plotted versus stiffening ratio. The balling and crumbling points are highly related, as shown in Figure 10, and there is little to be gained by determining both points. Because the balling

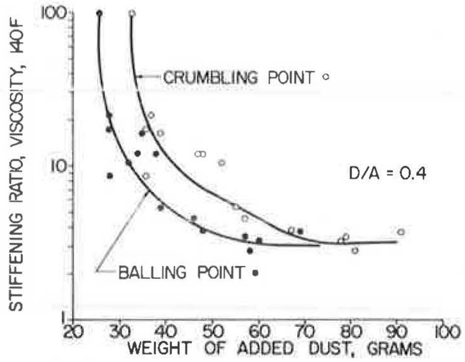

FIGURE 9 Stiffening ratio versus crumbling and balling points for dust-asphalt mixtures.

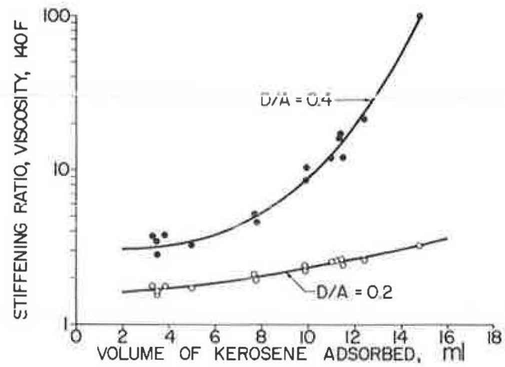

FIGURE 11 Volume of kerosene adsorbed versus stiffening ratio, viscosity, 140°F.

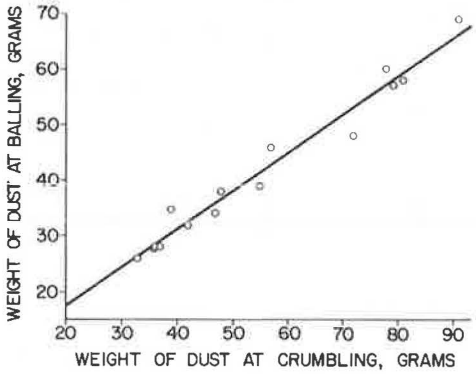

FIGURE 10 Crumbling point versus balling point.

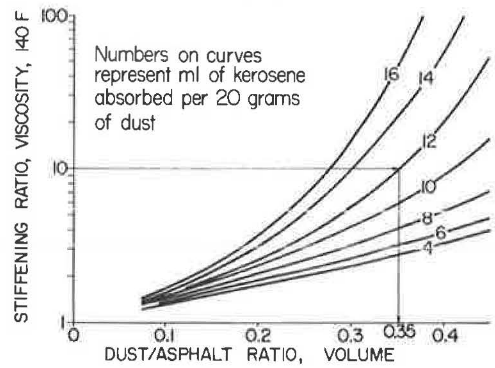

FIGURE 12 Proposed design chart for selecting dust/asphalt ratio based on kerosene adsorption.

point is easier to reproduce, this point is considered sufficient.

However, the test cannot be recommended for two reasons. First, the results cannot be conveniently related to stiffening ratio. Therefore, the test procedure is useful only in accepting or rejecting a dust and not in determining the maximum allowable dust/asphalt ratio. Second, neither the balling point nor the crumbling point is a good predictor of stiffening because the stiffening ratio increases asymptotically for the dusts that produce stiffer mixtures.

The stiffness ratio versus the volume of adsorbed kerosene is shown in Figure 11 for dust/asphalt ratios of 0.20 and 0.40. Excellent correlation between stiffness ratio and adsorbed kerosene volume was observed ($R^2 = 0.98$ for both dust/asphalt ratios). Because the relationships shown in Figure 11 are unique for each dust/asphalt ratio, the regression equations for each dust/asphalt ratio were used to construct the curves shown in Figure 12.

Such curves can be used for design purposes if the dust/asphalt ratio for a particular asphalt concrete mixture is known. The example in Figure 12 shows that, given a design dust/asphalt ratio of 0.35 and an adsorbed kerosene volume of 10 mL, the expected stiffening ratio is 12.0. The kerosene adsorption test is simple to perform and could also be used at a plant as a process control or quality assurance test to monitor changes in dust properties. Unfortunately, the repeatability of this test procedure between different operators has been found to be poor because of difficulties in determining the end point (saturation point).

SUMMARY AND CONCLUSIONS

The use of capillary viscosity (ASTM D 2171, 60°C), is the most direct method of measuring the stiffening effect of the fine mineral dust added to asphalt cement. Physical properties of the dust, such as particle shape, gradation, and pH, do not explain the difference in stiffening encountered in different dusts. Therefore, specification criteria based on gradation or physical properties, such as those described earlier, are not warranted as controls of stiffening.

Stiffening can be predicted from the fractional voids concept; however, the accuracy of the prediction depends on the method used to determine the bulk volume of the dust. The dry impact method of densifying the dust produced the best correlation and the highest level of densification. The test procedures that produced the closest packing of the dust appear to give the best correlation with stiffening. As the compactive energy increases, the tendency for fines to segregate according to size, or to form flocculated structures, is diminished. This segregation effect was noticeable in the liquid sedimentation tests and, to a lesser extent, in the vibrated density tests.

The asphalt mixing test (balling and crumbling points) and the bitumen number test procedure do not warrant further consideration as test procedures to control stiffening. Neither test is easily related to a dust/asphalt ratio, which makes it difficult to control that ratio in a mixture.

The fractional voids ($\%V_{AFR}$) and the kerosene adsorption test gave excellent correlations with

stiffening. Both tests could be used as source acceptance tests, for process control in the plant, and as a means to specify an upper limit on the dust/asphalt ratio in a mixture.

Further development of the kerosene adsorption test is required to refine the specific details of the test procedure before it can be accepted as a specification test. Accuracy and precision data must be developed for both the kerosene and the dry impact fractional voids procedure. Of even greater importance is the need to relate the stiffness of the dust-asphalt mixture to the rheology of the asphalt concrete mixture. This is required in order to set upper limits for allowable stiffening. Although an upper limit of 10 has been suggested for the stiffening ratio (8), this may be conservative (13); further research is needed to verify a tolerable limit for stiffening ratio.

The following conclusions are based on the research described in this paper.

1. Use of the volume percent free asphalt ($\%V_{AFR}$) as a predictor of stiffening is reliable, provided that a standard, repeatable method is used to obtain the measurement of bulk volume.

2. If a predicted stiffening ratio based on Rigden's fractional void concept is desired, the dry impact compaction procedure is the preferred method for obtaining bulk volume. The percent free asphalt volume from the dry impact compaction test provided the best correlation with stiffening ratio.

3. Data from the kerosene adsorption test provided the highest correlation with stiffening ratio. The test is not repeatable between operators and therefore there must be further development of this test before it can be recommended.

4. The bitumen number and the balling and crumbling point tests are not acceptable as specification tests to control stiffening.

5. Regardless of which test method is used to determine the stiffening characteristics of a dust, a chart such as the one shown in Figure 7 can be used for design purposes to select an allowable dust/asphalt ratio.

6. Dust gradation plays a limited role in determining asphalt stiffening and it should not be used by itself as a performance-related specification for dust.

7. The maximum dust/asphalt ratio for an asphalt concrete mixture varies from one dust to another. The maximum allowable ratio should be based on the stiffening of each individual dust and not set as an arbitrary value for all mixtures.

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