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COMPARISON OF COLORADO COMPONENT HOT MIX ASPHALT MATERIALS WITH SOME EUROPEAN SPECIFICATIONS

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The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Colorado Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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16. Abstract

The purpose of this report is to identify differences in Colorado's aggregates and asphalt cements as measured and compared to some of the European tests and specifications.

Performance-related tests for asphalt cements developed by SHRP will be the ultimate method to identify performance and should be well received in Europe. Based upon the standard empirical tests on asphalt cements from four refineries commonly used in Colorado, the asphalt cements are comparable to those used in France.

The 17 most frequently used aggregate sources in Colorado were tested for this study. The angularity of fine aggregates is measured with the NAA test procedure. The quality of the P200 is measured with respect to angularity, durability, and stiffening. Angularity of P200 is measured with the stiffening power, durability with the methylene blue and sand equivalent tests, and stiffening with the power of absorbtion, stiffening power (ring and ball softening point) and Rigden voids index test. The results from these tests are interrelated. Gradations commonly used by the French and Germans are compared to the CDOT master range.

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I. INTRODUCTION

In September 1990, a group of individuals representing 1AASHTO, FHWA, NAPA, SHRP, AI, and TRB participated in a two-week tour of six European countries. Information about this tour has been published in "Report on the 1990 European Asphalt Study Tour" (1). Several areas for potential improvement of asphalt pavements were identified, including the use of performance-related testing equipment that is used in several European countries. The Colorado Department of Transportation (CDOT) and the FHWA Turner-Fairbank Highway Research Center (TFHRC) were selected to demonstrate this equipment.

Since the Europeans have such a vastly different method for approving hot mix asphalt (HMA) and the components: aggregates and asphalt cements, it was desired to compare the quality of Colorado's standard materials to some of the test requirements of the Europeans. The purpose of this report is to identify differences in Colorado's aggregates and asphalt cements, as measured and compared to some of the European procedures and specifications.

II. ASPHALT CEMENT PROPERTIES

The tests typically specified for asphalt cements in France are very similar to tests currently used in Colorado and many other states. They include: penetration (AASHTO T 49) at 25°C (77°F), ring and ball softening point (AASHTO T 53), and thin film aging (AASHTO T 179).

The tests being developed by SHRP to identify the properties of asphalt cement will be far superior to the standard empirical binder tests currently used in Colorado and Europe. The Europeans, who taught the author of their specifications, agreed wholeheartedly. Nevertheless, testing was performed using standard tests that currently are used in Colorado and Europe for comparative purposes.

The French specify asphalt cements with the penetration grading system; Colorado uses the viscosity grading system. So, some estimates correlating the two grading systems had to be made. There are four refineries and two grades, AC-10 and AC-20, of asphalt cement that are commonly used in Colorado which were tested for this comparison.

Results of testing asphalt cements as compared to French specifications are shown in Tables 1 and 2. The results indicate that asphalt cements commonly used in Colorado are comparable to those used in France. The penetration retention values for AC-10 were mostly unacceptable and for AC-20 were unacceptable from one refinery. This indicates that the cracking susceptibility of HMA pavements that use sources common to Colorado may be slightly greater than those used in France.

Table 1. Results of Asphalt Cement Testing for AC-10.

	Refinery				French Spec.
	A	B	C	D	
Pen. Retention (%)	(48)	(57)	(55)	61	> 60 %
Softening Point (°C)	54	56	54	53	> 52°C
Change in Softening Point (°C)	4	8	6	3	< 8°C

() - Failing Test Result

Table 2. Results of Asphalt Cement Testing for AC-20.

	Refinery				French Spec.
	A	B	C	D	
Pen. Retention (%)	(59)	61	60	68	> 60 %
Softening Point (°C)	57	57	57	57	> 52 °C
Change in Softening Point (°C)	5	4	4	6	> 8 °C

() - Failing Test Result

III. COMPONENT AGGREGATE PROPERTIES

It should be noted that the ultimate method for determining the suitability of different combinations of aggregates and asphalt cements is to conduct performance-related testing on the HMA. However, when an HMA fails performance-related tests, properties of the component aggregates could reveal areas for improving the HMA. The purpose of performing tests on aggregates is to glean an insight into the potential relationship with performance-related tests.

Colorado Materials. Numerous aggregate sources are used in Colorado. The 17 most frequently used aggregate sources, as determined from paving projects constructed in 1991, were tested for this study. Six of the sources were aggregate quarries and 11 were aggregate pits. Both crushed and natural fine aggregates from eight of the pits were analyzed.

Summary of Tests. The tests which are described in the following sections, were performed to measure the angularity, moisture susceptibility, and stiffening characteristics of the aggregates. Although the properties measured are interrelated, the tests are categorized by the most influential factor they characterize.

All of the tests on aggregates in this study are used by the French and/or Germans and are comparable to tests currently used or previously studied in the United States. In some instances, tests from the United States are used because of equipment and procedure availability. Specifications for the tests were taken from the appropriate specifying agency.

There have been numerous studies (2,3, and many more) that relate the physico-chemical properties of the material that passes the No. 200 (75 micron) sieve size (P200) to expected performance. The properties include geometric characteristics, surface properties, heat of absorption, adhesion, etc. Although the physico-chemical tests are more accurate, the tests examined in this study are used as specifications by some countries and could be tested easily for information or specification purposes by any state highway agency.

Summary of Results. Results are shown in Table 3. The aggregate sources tested are labeled as follows: quarried (Q), crushed aggregates from pits (PC), and natural aggregates from pits (PN). The test results are based entirely upon the use of material from each individual aggregate source. When an HMA is produced with two or more different sources, the tests should be performed with the combination of materials proposed for the HMA.

Some tests involve only P200 material, and it is difficult to obtain representative samples of the P200. Dry sieving does not secure all of the P200, especially since the detrimental P200 is more likely to remain on the aggregate. Drying the P200 after wet sieving could cause the P200 to agglomerate. The tests on the P200 performed in this study are still considered useful indicators.

TABLE 3. PROPERTIES OF COMMONLY USED COLORADO AGGREGATES

		SAND EQIV.	STIFFENING POWER	METHYLENE BLUE	RIGDEN VOIDS	FLOW COEFFICIENT	
MAXIMUM			20°C	10 mg/g	40% VOIDS		
MINIMUM		50	10°C			44	
QUARRIES							
						VOIDS	TIME
Q1		72	17	9.9	(42.2)	49.6	7.3
Q2		(35)	(31)	(20.9)	(44.9)	49.7	7.5
Q3		(49)	19.5	6.5	(45.4)	50.4	7.1
Q4		66	(25)	8.7	(45.5)	48.0	7.0
Q5		(43)	(21.5)	(10.5)	(47.4)	49.7	7.3
Q6		59	17	10.0	(42.8)	47.5	7.3
PITS CRUSHED							
PC1		74	18.0	9.0	(42.8)	48.2	7.2
PC2		(46)	(22.0)	8.8	(45.6)	45.9	6.5
PC3		56	15.5	8.1	(42.8)	47.8	7.3
PC4		70	(29.5)	5.9	39.7	48.0	7.5
PC5		74	16.0	6.9	(40.5)	(43.8)	6.3
PC6		(38)	(24.0)	(13.5)	(45.1)	44.9	6.4
PC7		69	(21.0)	7.5	(44.4)	48.9	7.2
PC8		68	15.0	5.6	(40.4)	47.9	7.3
PC9		66	20.0	(19.6)	(45.1)	44.2	6.2
PC11			16.0	7.6	(41.8)	49.3	7.6
PC13		(40)	(24.0)	(20+)	(47.1)	(43.2)	6.0
PITS NATURAL							
PN1		(41)	(21.0)	(20+)	(45.5)	45.0	6.1
PN2		(40)	(24.0)	7.2	(46.0)	44.4	6.5
PN3		(31)	(23.5)	(40.5)	(45.4)	(41.7)	6.0
PN4		(26)	(30.0)	(20+)	(50.1)	(43.2)	6.1
PN5		(41)	(48.0)	(20+)	(50.9)	(42.7)	5.8
PN6		(38)	(33.0)	(20+)	(49.3)	(41.9)	6.0
PN7		66	(21.0)	(12.5)	(46.6)	46.7	6.2
PN8		65	15.0	(11.8)	(42.7)	(41.2)	5.9

() = Failing Test Result

A. **Angularity**

Angularity of particles is critical for achieving a mixture that resists permanent deformation. The French test fine aggregates and P200 material to determine angularity. Although the French also measure the angularity of the coarse aggregates, the test was not performed for this study.

Fine Aggregate Tests. The French control fine and coarse aggregate angularity during crushing. The Germans often require edelsplitt, which is double crushing. There are differences between the European and American methods of controlling quality, and it is not considered possible in Colorado to specify and enforce control on contractors' crushing operations. CDOT exercises no control over a contractors' crushing operation. However, the angularity of the fine aggregates is very important and can be controlled in an end-result method.

1) The Test. The National Aggregate Association (NAA) has developed a test to subjectively quantify the angularity of fine aggregates passing the No. 8 sieve (2.36 mm). The apparatus is shown in Photo 1, Appendix B. The French determine the angularity of fine aggregates by using a device and procedure comparable to that recommended by the NAA. The flow coefficient or uncompacted voids, measured by using the NAA test Method A (Appendix A), are reported in this study. NAA test Method A is preferred over Method B because the influence of gradation on the uncompacted voids is not a variable.

2) The Specification. The specification value is obtained based upon studies performed by Kandhal (4) and Mogawer and Stuart (5). Kandhal (4) performed tests on crushed and natural fine aggregates throughout Pennsylvania. Kandhal (4) determined a value of 44.5 differentiated between the angularity of the two materials.

Mogawer and Stuart (5) performed testing on fine aggregates from Maryland, New Jersey, Virginia, and Wisconsin. The NAA Method is a very quick and simple test that correlates excellently with a very accurate but time-consuming test, ASTM D 3398. Mogawer and Stuart (5) determined an uncompacted void level of 43.4 separated good and poor natural fine aggregates. It should be noted that the aggregate sizes used in the determination of the bulk specific gravity of the aggregates can influence the results. A value of 44 was used for this study.

3) The Results. The flow coefficients indicate that fine aggregates from quarries have excellent angularity; all far exceeded the specified value. Although most of the crushed fine aggregates from pits were excellent, some were marginal or failed. It is well known that some pits (PC-5, PC-6, and PC-9) are "blends" of crushed and natural fine aggregates. Apparently, the blending can lower the angularity value.

Some aggregate pits are located close to the parent rock, so it was expected that the natural fine aggregates would have a high angularity. Three natural materials (PN-1, PN-2, and PN-7) met the angularity specification. Most natural fine aggregates were rounded.

Stiffening Power. Minimum and maximum values are specified for the stiffening power. The minimum value specified by the French relates to angularity, and the maximum value relates to the detrimental effects leading to fatigue, thermal cracking, and moisture susceptibility. The stiffening test's characterization of properties other than those relating to angularity will be discussed in subsequent sections.

1) The Test. The stiffening power test used by the French is the increase in the ring and ball softening point that occurs between a neat asphalt cement and a 60:40 blend by weight of P200 with the same asphalt cement. The ring and ball softening point device is shown in Photo 2, Appendix B.

By using a very high P200 to asphalt ratio, 1.5 by weight, the angular P200 particles can interlock and create stiffening. The resultant stiffening of the asphalt cement can be a measure of the P200 angularity. Since the stiffening can also indicate deleterious material, durability tests must also be performed.

2) The Specification. Stiffening at a constant P200 to asphalt ratio could be related to high P200 angularity or high susceptibility to moisture damage. A minimum value of $10^{o}C$ ($18^{o}F$) is specified to ensure angularity of the P200. A maximum value of $20^{o}C$ ($36^{o}F$) is specified to prevent using P200 which may accelerate distresses related to stiffening or moisture susceptibility. The upper specification limit of this test is related to other tests that were performed for this study, and is described in subsequent sections.

3) <u>The Results</u>. The P200 from quarried fine aggregates were all greater than the 10°C (18°F) minimum, indicating acceptable angularity. Three of the quarried P200s (Q-2, Q-4, and Q-5) exceeded the 20°C (36°F) maximum, and two were considered moisture susceptible (Q-2 and possibly Q-5) since they also failed the sand equivalent and methylene blue tests. Q-4 exceeded the maximum value but is not considered extremely moisture susceptible, just extremely angular.

P200 of crushed fine aggregates from pits exhibited the same trend. All materials met the minimum stiffening power requirements, indicating acceptable angularity. Of the four that exceeded the maximum requirements (PC-2, PC-4, PC-6, and PC-7), one (PC-6) failed both moisture susceptibility tests. The other three that exceeded the maximum value are not considered extremely moisture susceptible.

Of the P200 from natural fine aggregates from pits, all but one source (PN-8) exceeded the maximum stiffening. PN-8 was a wet pit, and the material was obtained through dredging; deleterious P200 was probably washed off the aggregates. Of the pits that exceeded the maximum specification, all but one (PN-2) of the sources were believed to be moisture susceptible because they failed the methylene blue test. The pit that did not fail the methylene blue test (PN-2) had to be dewatered to recover the aggregates.

B. MOISTURE SUSCEPTIBILITY

The type of P200 significantly influences the potential of an HMA pavement to be moisture susceptible (3,6). To identify sources that may have deleterious P200 material and be susceptible to moisture damage, the French specify sand equivalent and methylene blue tests. Some types of P200 can increase the stiffening power because the P200 is deleterious, not angular. It is important to perform both angularity and durability tests.

Sand Equivalent. The procedure used for the sand equivalent test in this study was AASHTO T 176, and the device is shown in Photo 3, Appendix B. The purpose of the test is to quantify the cleanliness of the fine aggregates passing the No.4 sieve (4.75 mm) by ensuring the absence of deleterious material.

The results specified by the French vary with traffic loading. Cleanliness values greater than or equal to 60, 50, and 40 are required for high, medium and low traffic, respectively.

Methylene Blue. The methylene blue test and specification reported in this study were based upon the International Slurry Surfacing Association, Technical Bulletin No. 145. A copy of the test procedure is in Appendix A, and the titration device is shown in Photo 4, Appendix B. The purpose of the test is to identify the amount of harmful clays of the smectite group in the P200 and to provide an indication of the surface activity of the aggregate. Active P200 is less moisture susceptible than P200 with low surface activity.

Results from the methylene blue test can be interpreted as a general rule-of-thumb as shown in Table 4.

Table 4. Relationship of Methylene Blue Values and Anticipated Pavement Performance.

Methylene Blue (mg/g)	Expected Performance
5-6	Excellent
10-12	Marginally acceptable
16-18	Problems or possible failure
20+	Failure

Summary of Moisture Susceptibility Results. The methylene blue and sand equivalent values were generally in agreement. Of the 24 aggregates tested, 12 passed the methylene blue test and 13 passed the sand equivalent test. Nine aggregates passed both tests and eight failed both tests; seven aggregates passed one test but not both. PC-9 had the only major discrepancy between the sand equivalent (very good) and methylene blue (very poor) values. The methylene blue test is used to determine the acceptability of a P200 and has no relationship to the quantity of P200 used. It is possible that an unacceptable P200 could be used in a very small percentage of the total HMA mix and still result in an HMA that performs acceptably.

Most of the quarried sources exhibited good to marginal potential for resistance to stripping. One of the sources (Q-2) appeared to have a major potential for stripping when used in excessive amounts. The 37.5 mm

(1-1/2 in.) rock from Q-2 was crushed to create P200 material. The P200 from the pure rock crushed in the laboratory had 8.5 mg/g (acceptable), while the P200 from the blasting had a methylene blue value of 21 mg/g (unacceptable). Apparently silt or shale seams can exist and contribute to unacceptable durability results when the aggregate is not screened after blasting.

The two crushed aggregate pits (PC-6 and PC-9) that exhibited durability concerns based on the methylene blue value had low angularity values. The crushed aggregates from these pits are commonly "blended" with natural fine aggregates. The "blending" process lowers the angularity and increases the moisture susceptibility of the aggregate. The P200 from PC-5 had acceptable methylene blue values even though it was a "blended" product.

Results from the methylene blue test indicate that all of the P200 from natural fine aggregates that were not washed exhibited durability concerns. One source (PN-2) was from a dewatered pit and had an acceptable methylene blue value. A wet pit (PN-8) had a marginally unacceptable test result.

C. <u>Stiffening</u>

It is well known that the performance of asphalt cement depends on the entire HMA mixture. The reaction of the asphalt cement and aggregate, in particular the P200, could be examined to provide additional insight into the expected performance of the HMA. When an excellent asphalt cement is combined with a poor aggregate, stiffening effects can be detrimental. Short term problems can create difficulty in achieving compaction (7,8,9,10), and long-term problems could result in a brittle HMA that could potentially be more susceptible to fatigue (7) and thermal (11) cracking.

Power of Absorption. The French and Germans both use the power of absorption test. This and other similar mastic tests are discussed by Kandhal (6) and Anderson (12).

1) The Test. The purpose of the test is to identify the amount of P200 required to excessively stiffen a constant quantity of asphalt cement. P200 is added to the asphalt cement until an end point is reached, which is defined as the crumbling point. A comparison of the asphalt cement in the neat and crumbling point states is shown in Photo 5, Appendix B. In the crumbling point state, the asphalt cement is gray, dull, and not sticky. The balling point is sometimes used by others with a different specification value.

It may be difficult to make comparisons when using this mastic test, so Anderson (13) does not recommend using the test as a specification. Although the test is considered repeatable for one operator, the end point is somewhat subjective and may not be repeatable for several different operators. Additionally, the types of P200 that cause excessive stiffening reach the end point in an asymptotic manner, so the end point is difficult to relate to stiffening.

2) The Specification. The French require a minimum of 40g of P200 to absorb 15g of asphalt cement. If more than 40g of P200 can be added to the asphalt cement, then the P200 has a low demand for asphalt cement and is considered good. The more P200 that can be absorbed, the better the results and the "stronger" the power of absorption. If less than 40g of P200 completely absorbs the asphalt cement, then the P200 has a high demand for asphalt cement and is considered detrimental. The less P200 that completely absorbs a given amount of asphalt cement, the "weaker" the power of absorption.

Additionally, the power of absorption is believed to be related to moisture susceptibility. A P200 with a weak power of absorption will demand a high quantity of asphalt cement and will not allow for sufficient coating and protection of the aggregates against moisture damage.

3) The Results. Because of the inaccuracies of this test and the potential for other tests to measure the same property, the power of absorption was performed only for samples from the quarried aggregate sources (Table 5). Results indicate that the P200 from most quarries is acceptable. Q-2 appeared problematic, but it was also problematic in the moisture susceptibility tests: methylene blue and sand equivalent. The P200 from Q-6 also had a high demand for asphalt cement and could potentially be problematic.

Table 5. Power of Absorption Results for the P200 from Quarries.

Quarry	Power of Absorption
Q-1	40 grams
Q-2	(35)
Q-3	40
Q-4	44
Q-5	45
Q-6	(36)
Q-7	43

() - failing test result is less than 40

4) Relationship to Other Tests. Other tests have a strong potential to measure the stiffening property and demand a P200 has for asphalt cement in a related but more objective manner than the power of absorption. The Rigden voids index test can be used to measure the amount of "free asphalt" a P200 allows.

An example of "free asphalt" is shown in Table 6. A P200 that allows a high quantity of "free asphalt" is desirable. Essentially, when a large quantity of P200 is required to absorb the 15g of asphalt cement (strong power of absorption), the P200 provides more "free asphalt" for a given amount of P200 in an HMA. When a low amount of P200 completely absorbs 15g of asphalt cement (weak power of absorption), there is less "free asphalt" for a given amount of P200 in an HMA.

Table 6. Example of Power of Absorption and Free Asphalt.

Mix	Quantity P200 to Absorb 15g AC	Example: P200 in an HMA	Free Asphalt
Fail	30g	6%	Less free asphalt
Pass	50g	6%	More free asphalt

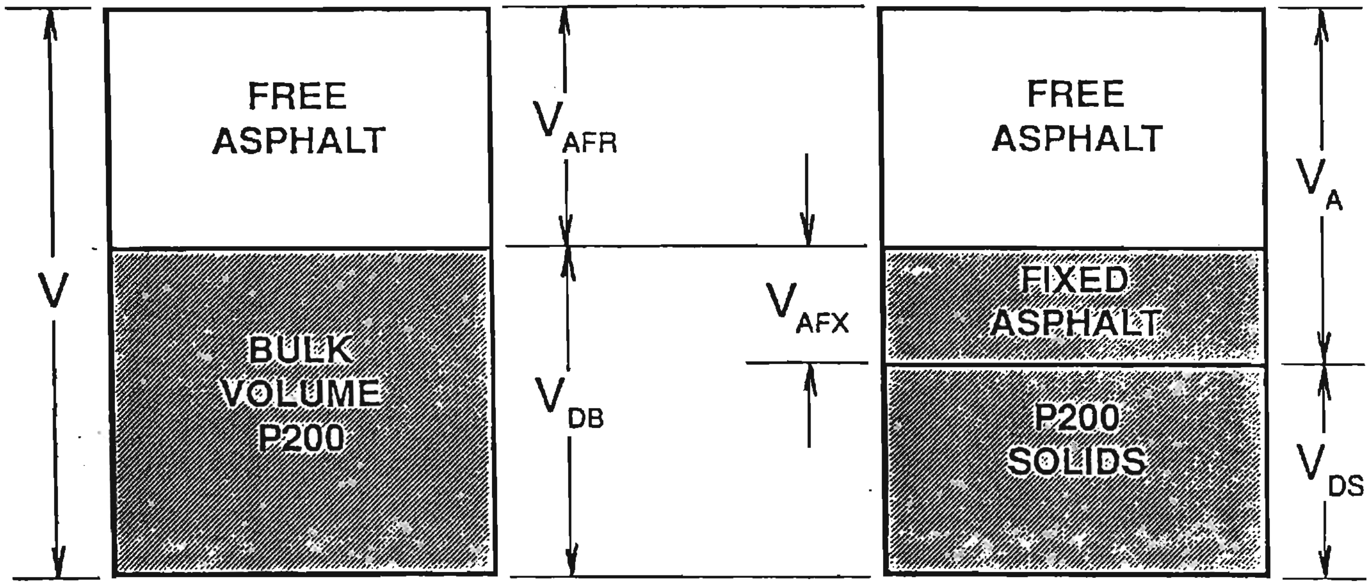
Rigden Voids Index Test. The Rigden voids index test was developed by Rigden (14) and further explained by Heukelom (10). It was later modified by Anderson (8). The original test developed by Rigden (14) is used by the French and Germans; the test method as modified by Anderson (8) was used in this study.

1) The Test. The Rigden voids index test is performed by compacting a sample of P200 and calculating the bulk density and air voids. The apparatus used to compact the sample and measure the compacted volume is shown in Photo 6 of Appendix B.

While the volume of asphalt cement required to fill the air voids of the compacted P200 is equated to fixed asphalt cement, the remaining asphalt cement in the HMA is considered free. The purpose of the test is to identify P200s for use in HMA which will not have high quantities of fixed asphalt cement.

2) The Specification. The French require a P200 that has a maximum of 40% air voids (fixed asphalt cement) in the

FIG. 1 Definition of Parameters Used to Describe Voids in a P200 and Asphalt Cement Mastic



V_A = Volume of Asphalt

V_{AFR} = Volume of Free Asphalt

V_{DS} = Volume of P200 Solids

V_{AFX} = Volume of Fixed Asphalt

V_{DB} = Bulk Volume of Compacted P200 bulk volume of the P200 based on the Rigden voids index test and shown below:

$$V_{DB} = V_{AFX} + V_{DS} \qquad \text{[Eqn. 1]}$$

where the variables are defined in Fig. 1. The bulk density is measured by the Rigden voids index test, and the voidless density is determined by the specific gravity of the P200. The air voids, or fixed asphalt cement, must be less than 40% of the bulk density of the P200.

Air voids greater than 40% (lower bulk densities) indicate that the P200 demands higher amounts of asphalt cement; this results in less free asphalt cement for a stiffer HMA. Air voids lower than 40% (higher bulk densities) indicate that the P200 demands lower amounts of asphalt cement; this results in more free asphalt cement for a less stiff HMA. Higher free asphalt cement is preferred. The relationship of free asphalt, fixed asphalt, bulk density of P200, and solid density of P200 is shown in Fig. 1.

3) <u>The Results.</u> Unfortunately, all but one of the materials in Colorado tested for this study (every single aggregate source: quarried, crushed from a pit, and natural from a pit) fail the French requirement. Although Colorado's materials do not meet the French specifications for the Rigden voids index, it is believed they can still be used to create quality HMA pavements. Studies in the United States have limited the P200 to asphalt ratio by using the Rigden voids index test results as related to the actual amount of stiffening.

Actual Amount of Stiffening. The actual amount of stiffening created by the quantity of P200 used in the HMA is a test performed and specified by the Germans. Additionally, several investigators in the United States have studied the concept. The actual stiffening is related to the Rigden voids index test, and a maximum P200 to asphalt ratio can then be specified.

1) The Test. The actual amount of stiffening is the increase in the ring and ball softening point that occurs between a neat asphalt cement and a blend of P200 with the same asphalt cement. The actual amount of stiffening can also be measured with the absolute viscosity.

Advantages of the viscometer have been pointed out by Anderson (13): availability to state highway agencies, a rational test method, etc. Advantages of the ring and ball softening point have been pointed out by Kandhal (6): less settlement problems, repeatability, simplicity, etc. Based upon the experience of the CDOT, the stiffening was measured with the ring and ball softening point for this study.

Either test can be used since the results of the two tests correlate very well. Kandhal (6) noted that the stiffening of the asphalt cement began to increase dramatically after an increase of 11°C (20°F) was obtained using the ring and ball softening point. An increase of 11°C (20°F) using the ring and ball softening point correlated with a stiffening ratio of 11.5 using the absolute viscosity.

2) <u>The Specification.</u> The Germans require a maximum P200 to asphalt ratio that produces an increase of 20°C (36°F) in the ring and ball softening point above the neat asphalt cement.

Kandhal's (6) test results indicate that the stiffening of 11°C (20°F) with the ring and ball softening point was the maximum allowable. The maximum of 11°C correlated with less than 40% free asphalt cement (greater than 60% bulk volume of P200) as determined with the Rigden voids index test on the P200 from an HMA with a known optimum asphalt content. The method to calculate the free asphalt cement and maximum allowable P200 to asphalt ratio in an HMA is explained by Equations 2-5.

3) <u>The Relationship of Stiffening with P200 to Asphalt Ratio.</u> The amount of free asphalt cement depends on the Rigden voids index test to calculate V_{AFX} and the specific gravity of the solids to calculate V_{DS}. The relationships are shown with Equations 2 through 5:

$$100 = V_A + V_{DS} \quad \text{[Eqn. 2]}$$

$$V_A = V_{AFR} + V_{AFX} \quad \text{[Eqn. 3]}$$

$$V_{AFR} = 100 - V_{AFX} - V_{DS} \quad \text{[Eqn. 4]}$$

where the variables are defined in Fig. 1. V_A is the volume of asphalt cement in the entire HMA.

The free asphalt cement in each specific HMA mixture can then be calculated using Equation 5 as derived by Anderson (8):

$$V_{AFR} = \frac{1 + D/A_V \left(1 - \frac{G_{DS}\ \gamma_W}{\gamma_{DB}}\right)}{1 + D/A_V} \times 100\% \qquad \text{[Eqn. 5]}$$

where:
V_{AFR} = Percent volume of free asphalt cement,
D/A_V = P200 (Dust)/asphalt ratio by volume,
G_{DS} = Specific gravity of P200 (dust) solids,
γ_W = Density of water, and
γ_{DB} = Bulk density of compacted P200 from the Rigden voids test.

Kandhal's recommendation (6) for test methodology was: 1) perform the Rigden voids index test, 2) calculate the free asphalt cement in a specific HMA, 3) if the free asphalt cement was greater than 50%, the HMA was acceptable, 4) if the free asphalt cement was less than 50%, perform the actual stiffening test, and 5) if the actual stiffening was less than 11°C (20°F), the HMA was acceptable.

Anderson (12) also developed acceptable P200 to asphalt ratios based on more than 50% free asphalt cement as shown in Fig. 2. Later, Anderson (13) established maximum P200 to asphalt ratios based on a minimum of 45% free asphalt cement.

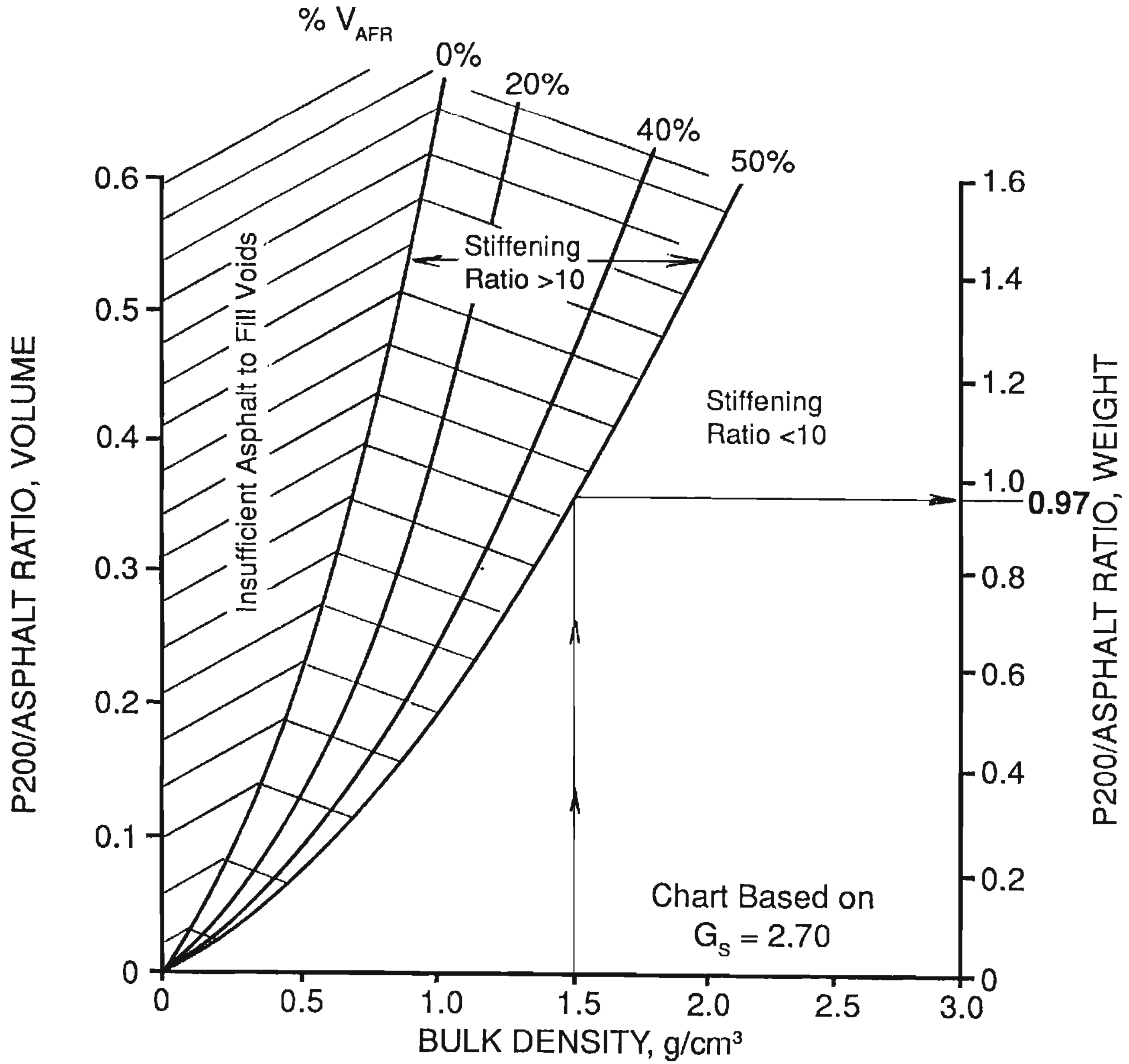


FIG. 2. Design Curves for Controlling Stiffening on Basis of P200 Bulk Density.

Chart not to scale

The upper limit of stiffening from the ring and ball softening point of 11°C (20°F) was thought to be conservative (13). Although the precise amount of free asphalt cement to limit stiffening remains unclear, there is a need for a maximum P200 to asphalt ratio.

P200 to Asphalt Ratio. The maximum P200 to asphalt ratio of each aggregate source should be limited as related to the actual stiffening that a P200 creates with the asphalt cement. The Rigden voids index test is related to stiffening and is a simple and quick method for determining the maximum P200 to asphalt ratios for different types of P200. It should be noted that the Rigden voids index may not be related to detrimental effects experienced in cold temperatures (11).

1) The Specification. The recommended P200 to asphalt ratio, by weight, recommended by the FHWA (15) is 1.2. It should be recognized that some types of P200 are less harmful to the HMA and asphalt cements than other types of P200. P200 to asphalt ratios, by weight, have been recommended as high as 1.5 by Anderson (8), 1.3 by Anderson (16), and 1.6 by Huschek (11). It appears that the maximum P200 to asphalt ratio should be variable, depending on the actual P200 used in a particular HMA.

2) The Results. For the purpose of this study, the optimum asphalt content of specific HMAs was not known. Therefore, a minimum of 30%, 40% and 50% free asphalt cement was used in Equation 5 with the Rigden voids index

TABLE 7. MAXIMUM P200 TO ASPHALT RATIOS

	DELTA 11°C (R&B)		30% FREE ASPHALT		40% FREE ASPHALT		50% FREE ASPHAL	
	P200/A_w	P200/A_v	P200/A_w	P200/A_v	P200/A_w	P200/A_v	P200/A_w	P200/A_v
QUARRIES								
Q1	1.22	.44	1.89	.68	1.48	.53	1.13	.41
Q2	1.06	.39	1.72	.63	1.35	.49	1.04	.38
Q3	1.14	.41	1.75	.62	1.37	.49	1.06	.38
Q4	1.03	.38	1.65	.61	1.30	.49	1.01	.37
Q5	.95	.36	1.56	.59	1.22	.46	.95	.36
Q6	1.19	.44	1.81	.67	1.41	.52	1.08	.40
PITS CRUSHED								
PC1	1.10	.41	1.78	.67	1.40	.52	1.07	.40
PC2	1.11	.41	1.62	.61	1.30	.49	1.00	.37
PC3	1.17	.44	1.76	.67	1.38	.52	1.06	.40
PC4	1.15	.44	1.93	.73	1.45	.55	1.11	.42
PC5	1.18	.46	1.85	.72	1.43	.56	1.09	.42
PC6	1.06	.40	1.66	.62	1.31	.49	1.01	.38
PC7	1.12	.42	1.69	.64	1.33	.50	1.02	.39
PC8	1.27	.48	1.91	.72	1.48	.56	1.13	.42
PC9	1.11	.42	1.65	.63	1.30	.49	1.00	.38
PC11	1.25	.47	1.83	.69	1.43	.54	1.10	.41
PC13	1.02	.38	1.57	.59	1.25	.47	.96	.36
PITS NATURAL								
PN1	1.05	.39	1.65	.61	1.31	.49	1.01	.37
PN2	1.07	.40	1.62	.60	1.28	.48	.99	.37
PN3	1.12	.42	1.65	.62	1.30	.49	1.00	.38
PN4	.93	.35	1.43	.54	1.14	.43	.89	.33
PN5	.87	.32	1.41	.53	1.12	.42	.87	.32
PN6	.92	.35	1.47	.55	1.17	.44	.91	.34
PN7	1.07	.40	1.61	.60	1.27	.47	.98	.36
PN8	1.24	.46	1.79	.67	1.40	.52	1.07	.40

A_w - ratio by weight A_v - ratio by volume test results, and the maximum P200 to asphalt ratios were calculated (Table 7). The maximum P200 to asphalt ratio that actually increased the ring and ball softening point of the asphalt cement 11°C (20°F) is also shown in Table 7.

Results indicate that a wide variation for maximum P200 to asphalt ratios exist for the most commonly used materials in Colorado. Results are summarized in Table 8. The actual increase in the ring and ball softening point of 11°C (20°F) corresponds with approximately 47% free asphalt. An increase in the ring and ball softening point of 15°C (27°F) corresponds to 40% free asphalt. The German specification of 20°C (36°F) would allow a minimum of approximately 35% free asphalt cement.

Table 8. Acceptable Ranges of P200 to Asphalt Ratios.

Criteria	Ranges of Acceptable P200 to Asphalt Ratios (by Weight)
11°C (R&B)	0.87 to 1.27
50% Free Asphalt	0.87 to 1.13
40% Free Asphalt	1.12 to 1.48
30% Free Asphalt	1.41 to 1.91

Based on experience with the materials in Colorado, good performance is expected with 50% free asphalt; poor performance is expected with 30% free asphalt. A criteria of 40% free asphalt based on the Rigden voids index test or an increase of 15°C (27°F) in the ring and ball softening point appears reasonable. When an HMA fails the performance-related fatigue or thermal cracking tests, the Rigden voids index test results can provide an indication if the P200 to asphalt cement ratio needs to be adjusted.

The maximum P200 to asphalt ratios do not relate directly to the durability results obtained from the methylene blue and sand equivalent tests. Some P200 sources are unacceptable from a moisture susceptibility perspective but are still allowed in relatively high quantities from a stiffening perspective. Both stiffening and moisture susceptibility testing should be performed.

D. **P200 Size**

The P200 plays a dual role in the HMA as reported by Puzinauskas (17); it is both part of the aggregate that provides contact points and part of the asphalt cement that binds larger aggregates together. Many asphalt paving technologists have claimed that the role of the P200 is directly related to its size.

1) The Test. Since P200 size is scrutinized closely, the particle sizes were measured for this study. The gradation of the P200 can be measured with the hydrometer analysis (ASTM D 422). For this study, Elf Asphalt, Inc. in Terre Haute, Indiana used a Leeds & Northrup Particle Size Analyzer to measure the gradation of the material passing the No. 325 sieve (45 microns).

The particle size analyzer determines the size distribution of the particles in a wet slurry mixture. It utilizes the phenomenon of low-angle, forward-scattered light from a laser beam projected through a stream of particles. The amount and direction of light scattered by the particles is measured by an optical detector array. A microcomputer then analyzes the scatter and calculates the size distribution of the particles in the mixture. The size distribution results are reported by volume.

2) <u>The Specification.</u> There are no guidelines or specifications for P200 size. The size of the P200 is not a standard test used by the French or Germans. Only poor and limited correlations exist with the P200 size and the effects of angularity, moisture susceptibility, and stiffening (6,8,12,13,16). Anderson (16) determined the fineness of the P200 alone is not sufficient for defining how the P200 will behave in an HMA.

3) <u>The Results.</u> The size distributions of the P200 by volume are reported in Table 9. The fineness modulus (FM) is commonly used to characterize the fineness of concrete sand, and it was calculated for each of the P200 sources in this study.

It is calculated by dividing by 100 the sum of the percentage of material retained on a standard series of sieves. In this study the fineness modulus was calculated by dividing by 100 the sum of the percent of

TABLE 9. PARTICLE SIZE DISTRIBUTION OF P200 MATERIALS

		PERCENT PASSING (MICRONS)							FINENESS MODULUS
		75	45	30	20	10	5	3	(F.M.)
QUARRIES									
Q1		100	76	63	47	26	13	7	3.68
Q2		100	77	65	51	29	14	7	3.57
Q3		100	72	54	38	19	8	4	4.05
Q4		100	75	61	46	26	12	6	3.74
Q5		100	60	41	27	13	6	3	4.50
Q6		100	79	61	44	23	11	6	3.76
PITS CRUSHED									
PC1		100	72	56	42	23	11	6	3.90
PC2		100	62	48	33	17	8	5	4.27
PC3		100	67	53	39	23	11	6	4.01
PC4		100	52	38	27	15	7	4	4.57
PC5		100	67	53	37	22	10	5	4.06
PC6		100	60	40	25	12	5	3	4.55
PC7		100	64	51	37	21	10	5	4.12
PC8		100	64	49	34	18	8	5	4.22
PC9		100	69	53	39	21	10	5	4.03
PC11		100	75	60	45	25	12	7	3.76
PC13		100	70	55	40	21	10	5	3.99
PITS NATURAL									
PN1		100	61	48	36	20	10	5	4.20
PN2		100	59	43	30	15	6	3	4.44
PN3		100	70	60	51	36	19	9	3.55
PN4		100	69	57	43	23	12	6	3.90
PN5		100	85	79	72	56	31	15	2.62
PN6		100	71	58	44	25	13	7	3.82
PN7		100	61	45	31	16	8	4	4.35
PN8		100	64	48	34	18	8	4	4.24

P200 coarser than 75, 45, 30, 20, 10, 5, and 3 microns. The finer the material, the smaller is the fineness modulus.

The fineness modulus was correlated with properties of the P200 that relate to angularity, moisture susceptibility and stiffening. The relationships as defined by the coefficients of determination, r^2, are shown in Table 10.

Table 10. Correlation of P200 Size with Angularity, Durability, and Stiffening Properties.

Fineness Modulus vs.	Coefficient of Determination r^2
Stiffening Power	0.27
Methylene Blue	0.19
Maximum P200/A_V	0.10
Maximum P200/A_W	0.07
Rigden Voids Index	0.07
Sand Equivalent	0.03

The properties of the P200 determined from tests performed in this study are assumed to have a relationship with performance. There is a very poor relationship between P200 size and the tests performed in this study. The size of the P200 alone is not sufficient to provide an indication of the effect the P200 will have on the HMA.

IV. AGGREGATE GRADATIONS

A master range concept for HMA gradations, used by France and Germany, is comparable to that used in Colorado. The type of HMA placed determines the aggregate gradations used on French roadways. The master ranges are shown in Figs. 3-5. The classical mix is the standard paving mixture. The maintenance mix is used for maintenance purposes, and the drainage asphalt is a wearing course similar to an open graded friction course. The master ranges of German HMA are shown in Figs. 6-9. Most of the master ranges are similar to those used in Colorado. The top sizes of aggregates commonly used in Colorado are 37.5 mm (1-1/2 in.), 19.0 mm (3/4 in.) and 12.5 mm (1/2 in.). The top sizes of aggregates used in France and Germany are much smaller: 16 mm (5/8 in.), 11 mm (7/16 in.) or 8 mm (5/16 in.). The smaller top-size aggregates provide easier construction while providing excellent performance.

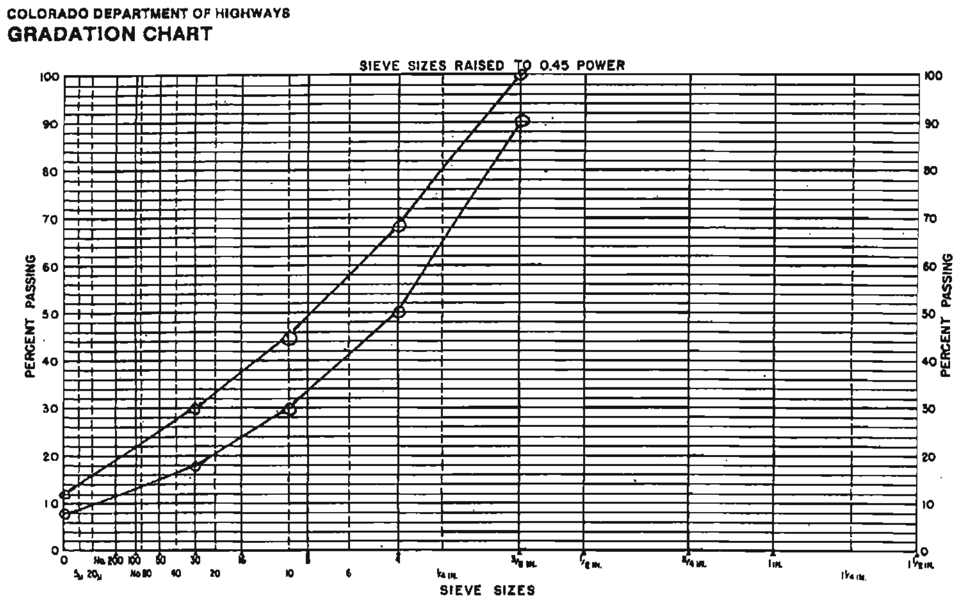


Fig 3. French Classical HMA

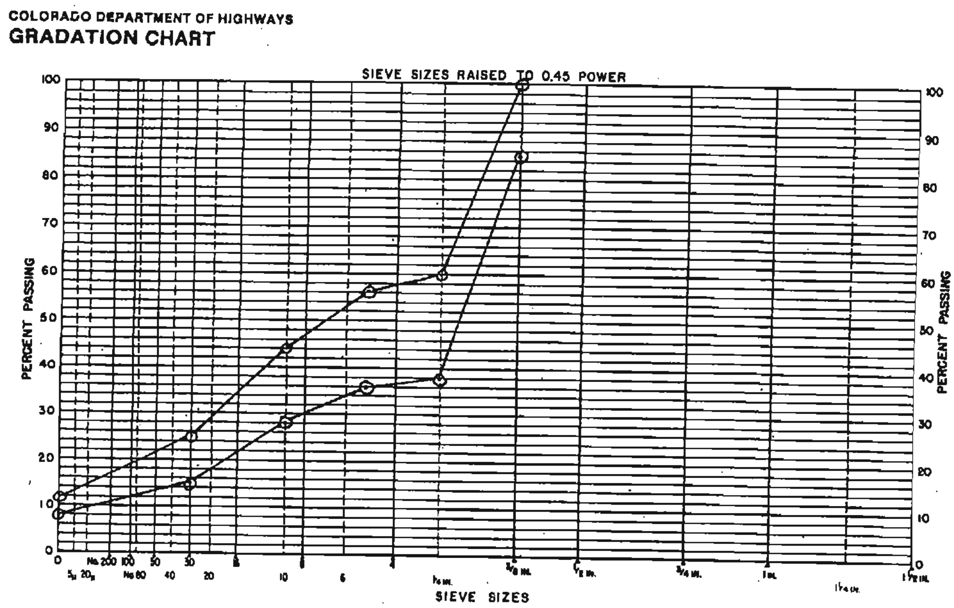


Fig. 4. French Maintenance HMA.

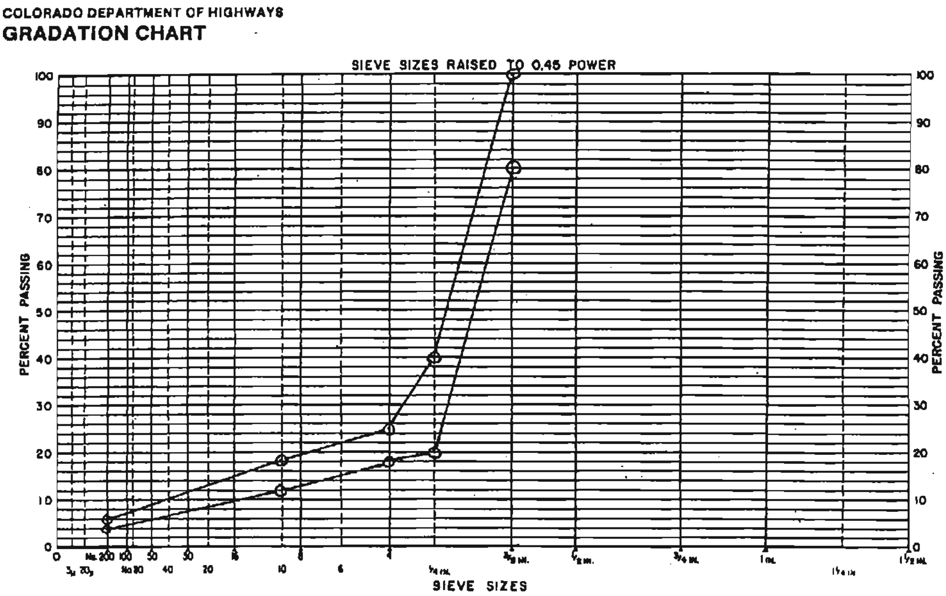


Fig. 5. French Drainage Layer

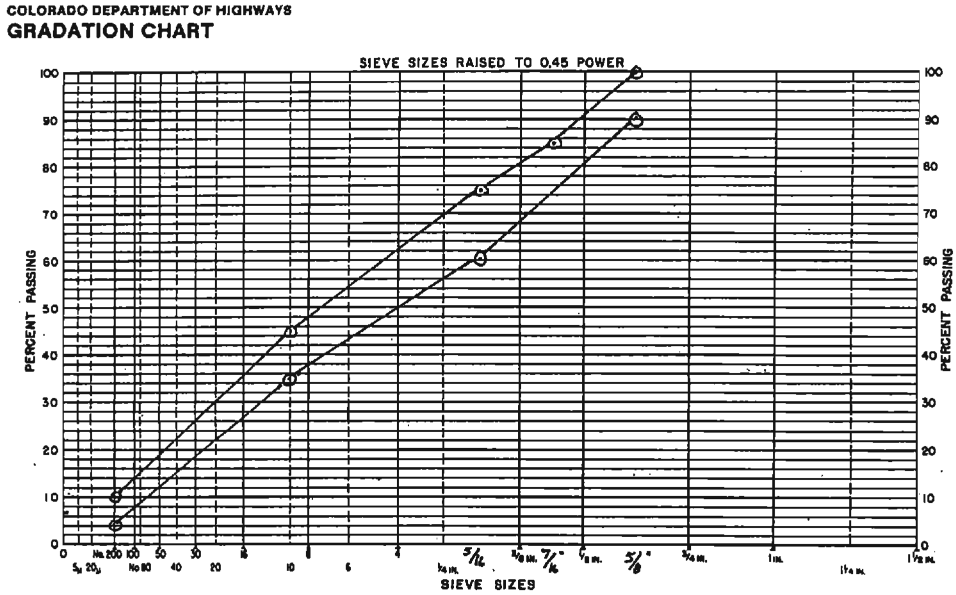


Fig. 6. German Asphalt Concrete (Wearing Course).

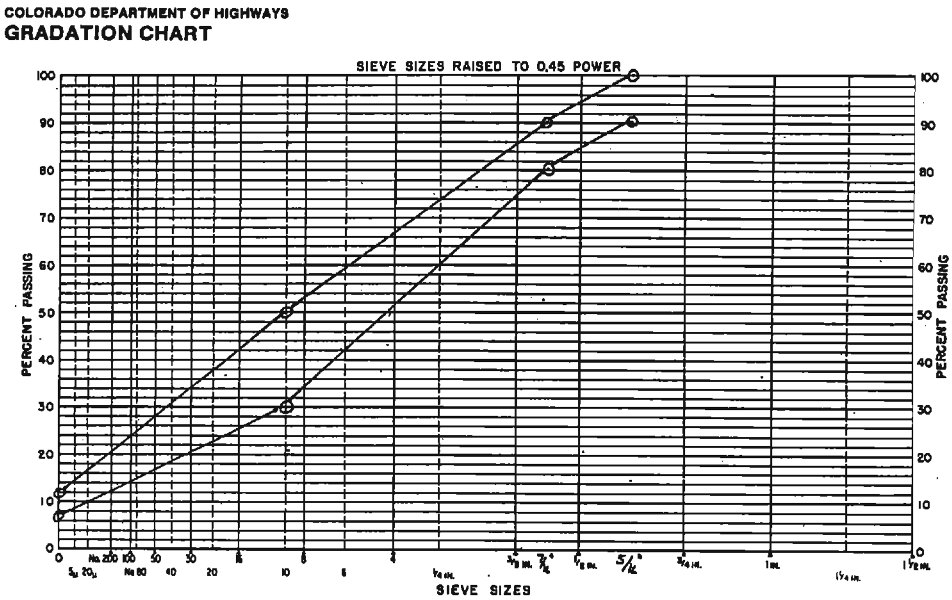


Fig. 7. German All-Purpose HMA.

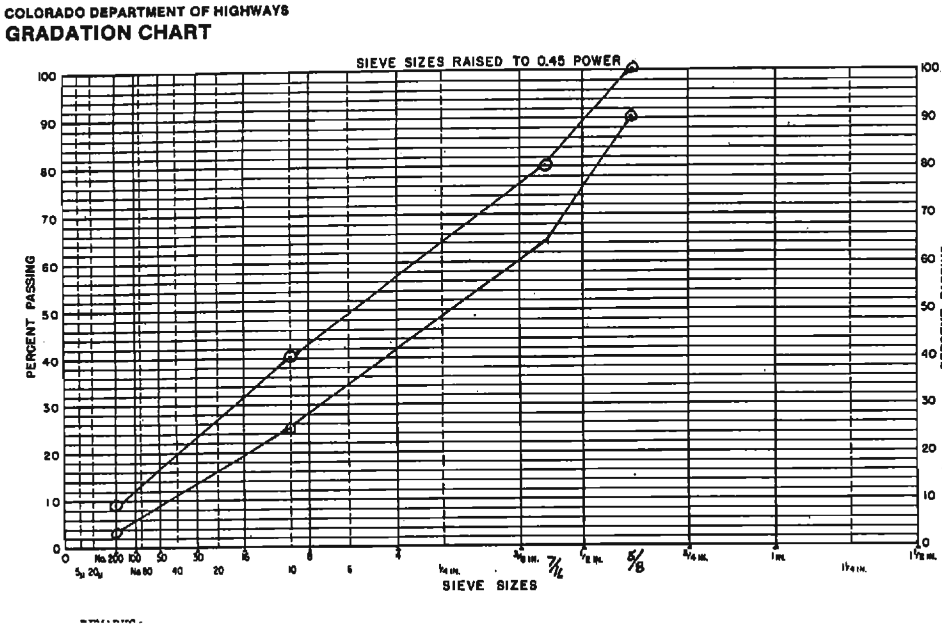


Fig. 8. German Asphalt Binder Course.

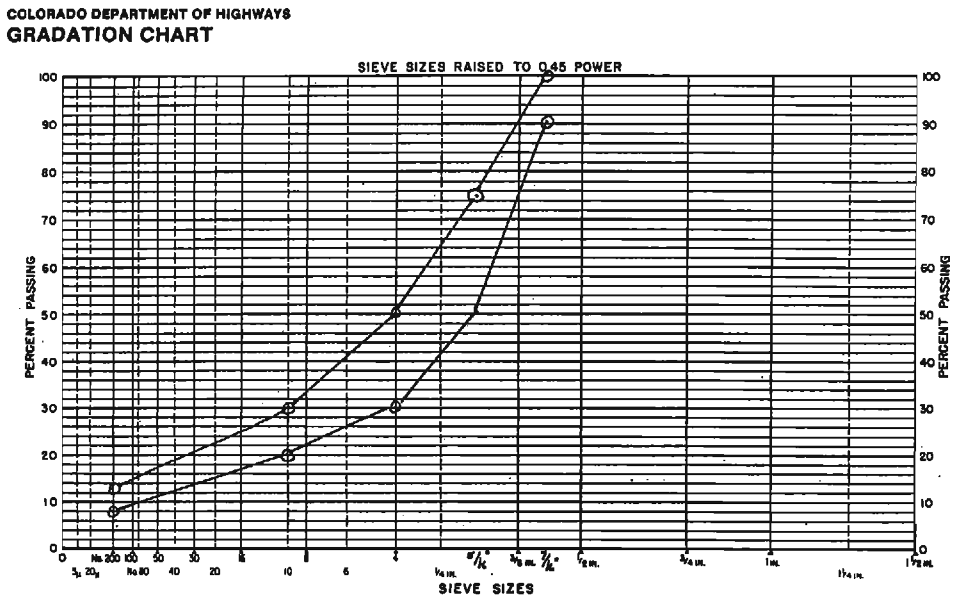


Fig. 9. German Split Mastix Asphalt

V. CONCLUSIONS

The performance of an HMA pavement is related to the entire interaction of aggregates and asphalt cement. When an HMA fails performance-related tests, testing the component aggregates and asphalt cement can indicate areas for potential improvement.

Following are conclusions based on testing of four most commonly used asphalt cement sources and 17 most commonly used aggregate sources in Colorado:

1) Performance-related tests for asphalt cements developed by SHRP should be well received in Europe and will be the ultimate method for identifying performance. Using standard empirical tests for asphalt cements specified in Europe, Colorado's asphalt cements are comparable to those used in France but appear slightly more susceptible to cracking.

2) The angularity of fine aggregates from quarries is excellent. Most crushed fine aggregates have excellent angularity. However, when crushed and natural fine aggregates from pits are blended, the angularity values are marginally acceptable or unacceptable. Although some natural fine aggregates are very close to the parent source and have marginally acceptable angularity, most natural fine aggregates are rounded.

3) All P200 meet the minimum stiffening power that measures the angularity of the P200. When the maximum

stiffening power is exceeded, there generally are moisture susceptibility concerns. Because the stiffening power appears to be related to both angularity and moisture susceptibility properties, both tests need to be performed.

4) In most cases the methylene blue and sand equivalent tests appear to provide comparable results in characterizing a P200 to be moisture susceptible. For tests that fail performance-related moisture susceptibility testing, these indicators can provide valuable information for potential improvement of the HMA.

5) When crushed and natural fine aggregates from pits are "blended," angularity and durability values can be marginal. When an HMA fails to meet performance-related testing requirements for rutting or stripping, lower quantities of natural fine aggregates may be necessary. Pre-screening aggregates and processing only larger aggregates may be necessary.

6) A P200 can cause adverse stiffening of an HMA which, in turn, affects fatigue and thermal cracking. The quantity of P200 needs to be examined when performance related testing indicates any problems.

Maximum allowable P200 to asphalt ratios are quite variable for the most commonly used aggregates in Colorado. Maximum P200 to asphalt ratios, by weight, can range from 1.12 to 1.48 for 40% free asphalt as determined from the Rigden voids index test. 40% free asphalt is approximately equal to an increase in 15^{o}C (27^{o}F) of the ring and ball stiffening point.

Based upon methylene blue and sand equivalent testing, the Rigden voids index test may not suitably limit the amount of P200 that affects the moisture susceptibility of the HMA.

7) Tests on the P200 for angularity, moisture susceptibility, and stiffening are interrelated. Testing must be performed on each property for a complete understanding of the effect of P200 on HMA.

8) There is a very poor relationship between P200 size and the tests performed in this study. The size of the P200 alone is not sufficient to provide an indication of the effect the P200 will have on the HMA.

9) Gradations of the frequently used HMA in France and Germany are comparable to the current master range used in Colorado. There is a noticeable difference in the top size of the aggregate; the French and Germans use smaller top sizes.

VI. **REFERENCES**

1. Report on the 1990 European Asphalt Study Tour (June 1991), American Association of State Highway and Transportation Officials, Washington, D.C., 115+ pages.

2. Craus, J., I. Ishai, and A. Sides (1978), "Some Physico-Chemical Aspects of the Effect and the Role of the Filler in Bituminous Paving Mixtures, " Proceedings of the Association of Asphalt Paving Technologists, Vol. 47, pp. 558-588.

3. Craus, J., I. Ishai, and A. Sides (1981), "Durability of Bituminous Mixtures as Related to Filler Type and Properties," Proceedings of the Association of Asphalt Paving Technologists, Vol. 50, pp. 291-318.

4. Kandhal, P.S., J.B. Motter, and M.A. Khatar (1991), "Evaluation of Particle Shape and Texture: Manufactured Versus Natural Sands," Transportation Research Record 1301, AASHTO TRB, National Research Council, Washington, D.C., pp. 48-56.

5. Mogawer, W.S., and K.D. Stuart (1992), "Evaluation of Test Methods Used to Quantify Sand Shape and Texture," Preprint Transportation Research Record, AASHTO TRB, National Research Council, Washington, D.C., 32 pages.

6. Kandhal, P.S. (1981), "Evaluation of Baghouse Fines in Bituminous Paving Mixtures," Proceedings of the Association of Asphalt Paving Technologists, Vol. 50, pp. 150-210.

7. Anderson, D.A. (1987), "Guidelines for Using Dust in Hot-Mix Asphalt Concrete Mixtures," Proceedings of the Association of Asphalt Paving Technologists, Vol. 56, pp. 492-516.

8. Anderson, D.A. (1987), "Guidelines on the Use of Baghouse Fines," National Asphalt Pavement Association, IS 101, 31 pages.

9. Eick, J.H. and J.F. Shook (1978), "The Effect of Baghouse Fines on Asphalt Mixtures," Asphalt Institute Research Report No. 78-3, Lexington, Kentucky.

10. Heukelom, W. (1965), "The Role of Filler in Bituminous Mixes," Proceedings of the Association of Asphalt Paving Technologists, Vol. 34, pp. 396-429.

11. Huschek, S. and Ch. Angst (1980), "Mechanical Properties of Filler-Bitumen Mixes at High and Low Service Temperatures," Proceedings of the Association of Asphalt Paving Technologists, Vol. 49, pp. 440-475.

12. Anderson, D.A. and J.P. Tarris (1982), "Adding Dust Collector Fines to Asphalt Paving Mixtures," National Cooperative Highway Research Program Report 252, AASHTO TRB, National Research Council, Washington, D.C., 90 pages.

13. Anderson, D.A. and S.M. Chrismer (1984), "Evaluation of Tests for Characterizing the Stiffening Potential of Baghouse Dust in Asphalt Mixes," Transportation Research Record 968, Asphalt Mixtures and Performance, AASHTO TRB, National Research Council, Washington, D.C., pp. 31-37.

14. Rigden, P.J. (1947), "The Use of Fillers in Bituminous Road Surfacings," Journal of the Society of Chemical Industry, Vol. 66, pp. 299.

15. Heinz, R.E. (1988), "Asphalt Concrete Mix Design and Field Control," Federal Highway Administration, FHWA Technical Advisory T 5040.27, 27 pages.

16. Anderson, D.A., and J.P. Tarris (1982), "Effect of Baghouse Fines on Mixture Design Properties," National Asphalt Pavement Association, QIP 102, 24 pages.

17. Puzinauskas, V.P. (Revised 1983), "Filler in Asphalt Mixtures," Asphalt Institute Research Report No. 69-2, Lexington, Kentucky, 29 pages.

Appendix A

Methylene Blue Test Procedure

National Aggregate Association Test Procedure

INTERNATIONAL SLURRY SURFACING ASSOCIATION

TECHNICAL BULLETIN

1101 CONNECTICUT AVE., N.W., WASHINGTON D.C. 20036

No. 145
Proposed
February
1989

Test Method for Determination of Methylene Blue Adsorption Value (MBV) of Mineral Aggregate Fillers and Fines

1. SCOPE

This test method is used to quantify the amount of harmful clays of the smectite group, organic matter and iron hydroxides present in an aggregate, thus giving an overall indication of the surface activity of a given aggregate.

2. APPARATUS AND REAGENTS

(a) 50 ml or suitable burette mounted on a titration stand.
(b) 250 ml or suitable glass beaker.
(c) Magnetic mixer with stir bar or variable speed mixer capable of 700 RPM.
(d) 2000 gram capacity scale or balance sensitive to within 0.01 gram.
(e) Glass rod 8 mm diameter x 250 mm.
(f) Laboratory timer or stop watch.
(g) 8" standard US Sieves #200 (75 mm) and #325 (44 mm) (or others as designated) and pan.
(h) 1000 ml volumetric flask.
(i) Methylene Blue - reagent grade.
(j) Distilled or deionized water.
(k) Whatman No. 40 filter paper.

3. PROCEDURE

A representative sample of the fine aggregate to be tested is dried to constant weight and screened through either the #200 Sieve or the #325 Sieve. The portion of the aggregate passing the desired sieve is retained for testing while the balance is discarded. One gram weighed to the nearest .05 gram, of the 0/#200 or 0/#325 aggregate is combined with 30 grams of distilled water in a suitable beaker and stirred until thoroughly wet and dispersed. A magnetic stirrer has been found to be satisfactory.

One gram of Methylene Blue is dissolved in distilled water, made up to 1000 ml so that 1 ml of solution contains 1 mg of methylene blue. This MB solution is titrated stepwise in .5 ml aliquotes from the burette into the continually stirred fine aggregate suspension. After each addition of MB, stirring is continued for 1 minute. After this time, a small drop of the aggregate suspension is removed and placed on the filter paper with the glass rod. Successive additions of MB are repeated until the end point is reached.

Initially, a well defined circle of Methylene Blue-stained dust is formed and is surrounded with an outer ring or corona of clear water. The end point is reached when a permanent light blue coloration or "halo" is observed in this ring of clear water. When the initial end point is reached, stirring is continued for five minutes and the test repeated to ascertain the permanent endpoint. Small additions of Methylene Blue are continued until the 5 minute permanent end point is reached.

4. REPORT

The Methylene Blue Value of a specific fine aggregate fraction is reported as milligrams of Methylene Blue per gram of specific fine aggregate fraction; e.g.,

MBV = 5.5 mg/g, 0/#200, or
MBV = 4.0 mg/g, 0/#325, or
MBV = 2.3 mg/g, 0/#8, etc.

NOTES

1. The literature at our disposal reports many variations of the method. MB solution concentrations are reported as 1 mg/ml, 4.5 mg/ml, 10 mg/ml and 1 mol to .08 mol solutions. Sample sizes reported are 1 gram, 20 grams, 30 grams, 200 grams and 1000 grams. Specimen gradations are 0/#325, 0/#200, 0/#10, 0/#8, 0/#4 and clean 3/8" one-size chips. For simplification and standardization, we suggest reporting the MBV as mg of MB/g of specific aggregate fraction.
2. The preparation of the aggregate for testing also varies. When whole aggregate gradations as received are used, it is possible to detect and quantify adherent fines. Some procedures use laboratory crushers to reduce large size clean aggregates to specific fines fractions for testing.
3. Though no standard MBV is proposed in this Technical Bulletin, Standards have been set in Northern Ireland for Chip Seal (Surface Dressing) aggregate fines produced by crushing as follows:

"The aggregate should be rejected if the Blue Value exceeds the values given below ...:

	%MB by weight	(mg/g)
Basalt Rock	1.0	(10.0)
Gritstone	.7	(7.0)

REFERENCES

1. Afnor Tentative Standard P18-592, July, 1980. "Aggregates-Methylene Blue Test" Afnor Tour Europe, Cedex 7, 92080 Paris La Defense (copyrighted).
2. Alan Woodside, personal communication to Benedict, University of Ulster, at Jordanstown, Northem Ireland, 5/85.
3. Michael Breunan, personal communication to Coyne 1/89, School Engineering, University College, Galway, Ireland.
4. M. Doyle "Methylene Blue Test on Fine Aggregates" Sahuaro Pet. In-house test method, Phoenix, Arizona.
5. T. Szymoniak and T. S. Vinson "Determining Clay Minerals in Basalt Aggregates," TRB 1989, Session 123 (#880019).

From J. Chemical Tech. & Biotechnology, 1985.
Digest 35A (a compendium):

6. E. T. Stewart & L. M. McCullough, "The Use of the Methylene Blue Test to Indicate the Soundness of Road Aggregates." (Belfast).
7. J. F. Hills & G. S. Pettifer, "The Clay Mineral Content of Various Rock Types Compared with the Methylene Blue Value" (Wimpey Labs, Middlesex).
8. J. Bemstead "Application of the Methylene Blue Test to Cement Raw Materials" (Blue Circle Ind., Greenhithe, Kent).
9. J. R. Hosking & D. C. Pike, "The Methylene Blue Dye Adsorption Test in Relation to Aggregate Drying Shrinkage" (Trrl, Crowthorne, Berkshire).
10. R. K. Taylor "Cation Exchange of Clays and Mudrocks by Methylene Blue," Univ. /Durham/UK.

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March 10, 1989

Proposed Method of Test for Particle Shape and Texture of Fine Aggregate Using Uncompacted Void Content

1. Scope

1.1 This method covers the determination of the loose uncompacted void content of a fine aggregate for use as a measure of its angularity and texture.

1.2 Procedures are included for the measurement of void content using either a graded sand or through the use of several individual size fractions for void content determinations.

1.2.1 Graded Sample (Method A) -- Consists of 190 grams of a standard sand grading which can be obtained from the individual sieve fractions in a typical fine aggregate sieve analysis.

1.2.2 Individual Size Samples (Method B) -- Consists of 190 grams each of three fine aggregate size fractions: (1) No. 8 to No. 16; (2) No. 16 to No. 30; and (3) No. 30 to No. 50. For Method B each size is tested separately.

2. Summary

2.1 A 100 cm^3 cylinder is filled with fine aggregate of prescribed gradation by allowing the sample to flow through a funnel from a fixed height into the calibrated cylinder. The cylinder is struck off and weighed. Uncompacted void content is calculated as the difference between the cylinder volume and the absolute volume of the measured weight of fine aggregate collected in the cylindrical container. It is calculated using the bulk dry specific gravity of the sand. Two runs are made on each sample and the results are averaged.

2.1.1 For the graded sample (Method A) the void content so determined is used directly.

2.1.2 For the individual size fractions (Method B), the mean void content percent is calculated using the void content results from tests of each of the three individual size fractions: No. 8 to 16, No. 16 to 30, and No. 30 to 50.

3. Significance and Use

3.1 This procedure provides a numerical result in terms of percent void content determined under standardized conditions which correlates with the particle shape and texture properties of a fine aggregate. An increase in void content by this procedure indicates greater angularity and rougher texture. Lower void content results are associated with more rounded smooth sands.

3.2 The void content determined on the standard graded sample is not directly comparable with the average void content of the three individual size fractions from the same sample tested separately. Single size particles have higher void contents than graded samples. Therefore, use either one method or the other as a measure of shape and texture; and identify which method is applicable with respect to reported data.

3.2.1 The graded sample (Method A) is most useful for a quick test which indicates the particle shape properties of a graded fine aggregate.

3.2.2 Obtaining and testing individual size fractions (Method B) is more time consuming than the graded sample.

3.2.3 Generally, the bulk dry specific gravity of the sand, graded as received, is used for calculating the void content. Occasionally, if the mineralogy of the size fractions varies markedly it may be necessary to determine the specific gravity of the size fraction used.

3.3 Void content information from either of the two procedures will be useful as an indicator of properties such as: the mixing water demand of portland cement concrete; in asphaltic concrete the effect of the fine aggregate on stability and voids in the mineral aggregate; or the stability of the fine aggregate phase of a base course aggregate.

4. Applicable Documents

4.1 ASTM Standards

4.1.1 Method C 128 for fine aggregate specific gravity

4.1.2 Method C 136 for sieve analysis of aggregate

4.1.3 Method C 117 for Minus No. 200 in aggregate.

5. Apparatus

5.1 Funnel -- The lateral surface of the right frustum of a cone sloped 60 ± 4° from the horizontal with an opening of 0.375 ± 0.025 in. (9.5 ± 0.6 mm) in diameter. The funnel shall be smooth on the inside and at least 1.5 in. (38 mm) high [(a)]. It shall have a volume of at least 200 cm^3 or shall be provided with a supplemental container to provide the required volume.

5.2 Funnel stand -- A support capable of holding the funnel firmly in position with its axis collinear with the axis of the measure and the funnel opening 4.5 ± 0.1 in. (114 ± 3 mm) above the top of the cylinder. A suitable arrangement is shown in Figure 1.

5.3 Measure -- A right cylinder of approximately 100 cm^3 capacity having an inside diameter of 1.52 ± 0.05 in. (38.6 ± 1.3 mm) and an inside height of approximately 3.37 in. (85.6 mm) made of drawn copper water tube meeting ASTM Specification B 88 Type M [(b)] or equally rigid material. The bottom of the measure shall be at least 0.25 in. (6.3 mm) thick, shall be firmly sealed to the tubing, and shall be provided with means for aligning the axis of the cylinder with that of the funnel.

5.4 Pan -- A shallow metal or plastic pan of sufficient size to contain the funnel stand. The purpose of the pan is to catch and retain sand grains that overflow the measure during filling or strike off.

5.5 A metal spatula about 4 in. (100 mm) long with sharp straight edges. The end shall be cut at a right angle to the edges. The straight edge of the spatula is used to strike off the fine aggregate.

5.6 Scale or balance capable of weighing the measure and its content to ± 0.1 g.

(a) Pycnometer top C 9455 sold by Hogentogler and Co., Inc., 9515 Gerwig, Columbia, Maryland 21045, 301-381-2390. Appears to be satisfactory, except that the size of the opening may have to be enlarged slightly, and any burrs or lips that are apparent should be removed by light filing or sanding.

(b) Type M copper drain, waste and vent pipe should have outside and inside diameters of approximately 1.63 (41.4 mm) and 1.52 (38.6 mm) inches, respectively.

6. Calibration of Measure

6.1 Weigh the dry, empty measure with a flat, glass plate slightly larger than its diameter and with the top edge of the container lightly coated with grease. Fill the measure with water at a temperature of 65 to 75 F (18 to 24 C). Place the glass plate on the measure, being sure that no air bubbles remain. Dry the outer surfaces of the measure and determine the combined weight of measure, glass plate, grease and water.

6.2 Calculate the volume of the measure as follows:

$$V = \frac{W}{0.998} \quad \text{where}$$

V = volume of cylinder in cm^3

W = net weight of water in grams

7. Sampling

7.1 The sample(s) used for this test shall be obtained from a completed sieve analysis of aggregate by Method C 136 after washing as required in ASTM C 117. Maintain the necessary size fractions obtained from one or more sieve analyses in a dry condition in separate containers for each size.

8. Preparation of Test Samples

8.1 Method A - Graded Sample -- weigh out and combine the following quantities of dry sand from each of the sizes:

Individual Size Fraction	Weight, g
No. 8 to No. 16	44
No. 16 to No. 30	57
No. 30 to No. 50	72
No. 50 to No. 100	17
	190

The tolerance on each of these weights is ± 0.2 g. Mix the test sample until it appears homogenous.

8.2 Method B - Individual Size Samples -- Prepare a separate 190 g sample of dry fine aggregate for each of the following size fractions:

Individual Size Fraction	Weight, g
No. 8 to No. 16	190
No. 16 to No. 30	190
No. 30 to No. 50	190

The tolerance on each of these weights is ± 1 g. Do Not mix these samples together. Each size is tested separately.

9. Procedure

9.1 If the sand has become moist, dry the sand to the constant weight in accordance with Method C 136 and cool to room temperature.

9.2 Mix the test sample until it appears homogeneous. Using a finger to block the opening, pour the test sample into the funnel. Center the funnel over the measure, remove the finger, and allow the sample to fall freely into the measure.

9.3 After the funnel empties, remove excess sand from the measure by a single pass of the spatula with the blade vertical using the straight part of its edge in light contact with the top of the measure. Until this operation is complete, exercise care to avoid vibration or disturbance that could cause compaction of the fine aggregate in the measure. Brush adhering grains from the outside of the measure and weigh the measure and contents to the nearest 0.1 g. Retain all sand grains.

Note 1 -- After strike-off the measure may be tapped lightly to compact the sample to make it easier to transfer the measure to scale or balance without spilling any of the sample.

9.4 Collect the sample from the retaining pan and measure, and repeat the procedure again.

9.5 For each run record the weight of the container and sand. Also record the weight of the empty measure.

10. Calculation

10.1 Calculate the uncompacted voids for each determination as follows:

$$U = \frac{V - \frac{W}{G}}{V} \times 100$$

where V = volume of measure in cm^3

W = net weight of fine aggregate in measure (Gross weight minus the weight of the empty measure)

G = bulk dry specific gravity of fine aggregate measured in accordance with Method C 128, Test for Specific Gravity and Absorption of Fine Aggregate.

U = uncompacted voids, percent.

Note 2 -- For most aggregate sources the fine aggregate specific gravity does not vary much from sample to sample or from size to size in the minus No. 8 fraction. Therefore, unless there is reason to believe that the specific gravity of individual sizes is appreciably different, it is intended that the value used in this calculation may be from a routine specific gravity test of an as-received grading of the fine aggregate. If significant variation between different samples is expected then specific gravity should be determined on material from the same field sample from which the uncompacted void content sample was derived. Normally the as-received gradation can be tested for specific gravity, particularly if the No. 8 to No. 100 size fraction represents more than 50 percent of the as-received grading. However, it may be necessary to test the graded No. 8 to No. 100 sizes for specific gravity for use with the graded void sample (Method A) or the individual size fractions for use with the individual size method (Method B). A difference in specific gravity of 0.05 will change the calculated void about one percent.

10.2 For the Graded Sample (Method A) calculate the average uncompacted voids for the two determinations and report the result as U_G.

10.3 For the Individual Size Fractions (Method B) calculate:

10.3.1 First, the average uncompacted voids for the two determinations made on each of the three size-fraction samples:

U_1 = Uncompacted Voids, No. 8 - 16, percent

U_2 = Uncompacted Voids, No. 16 - 30, percent

U_3 = Uncompacted Voids, No. 30 - 50, percent

10.3.2 Second, the mean uncompacted voids (U_m) including the results for all three sizes:

$$U_m = \frac{U_1 + U_2 + U_3}{3}$$

11. Report

11.1 For the <u>Graded Sample</u> (Method A) report:

11.1.1 The Uncompacted voids (U_G) in percent to the nearest one-tenth of a percent.

11.1.2 The Specific gravity value used in the calculation and whether it was determined on: (a) another sample from the same source, (b) as-received gradation from this sample, or (c) regraded sand from this sample.

11.2 For the <u>Individual Size Fractions</u> (Method B) report the following percent voids to the nearest one-tenth of a percent:

11.2.1 Uncompacted Voids for size fractions No. 8 - 16 (U_1), No. 16 - No. 30 (U_2), and No. 30 - No. 50 (U_3).

11.2.2 Mean Uncompacted Voids (U_m).

11.2.3 Specific gravity value(s) used in the calculations, and whether the specific gravity value(s) were determined on: (a) another sample from the same source (b) as-received gradation from this sample, or (c) individual size fractions from this sample.

12. Precision

12.1 <u>Within Laboratory</u> — Analysis of within laboratory data from sixteen laboratories which made void content tests on independent samples of three similar sources of rounded sands, graded in accordance with the graded standard sand in C 778, resulted in a within laboratory standard deviation (1S) of 0.13 percent voids for repeat determinations on the same sample.

Differences greater than 0.37 percent voids between duplicate tests on the same sample by the same operator should occur by chance less than 5 percent of the time (D2S limit).

12.2 Multi-Laboratory -- Analyses of data from sixteen laboratories which made void content tests on independent samples of three similar sources of rounded sands, graded in accordance with the graded standard sand in C 778, resulted in a multi-laboratory standard deviation (1S) of 0.33 percent voids. Since this value includes random variance due to the difference in samples, the standard deviation for multi-laboratory tests on the same sample should be lower. Differences greater than 0.93 percent voids between tests in two different labs should occur by chance less than 5 percent of the time (D2S limit) for these rounded sands.

12.3 Additional precision data is needed for tests of sands having different levels of angularity and texture tested in accordance with both procedures included in this Method.

C:\WP\LAB\PARTSHPE.TEX

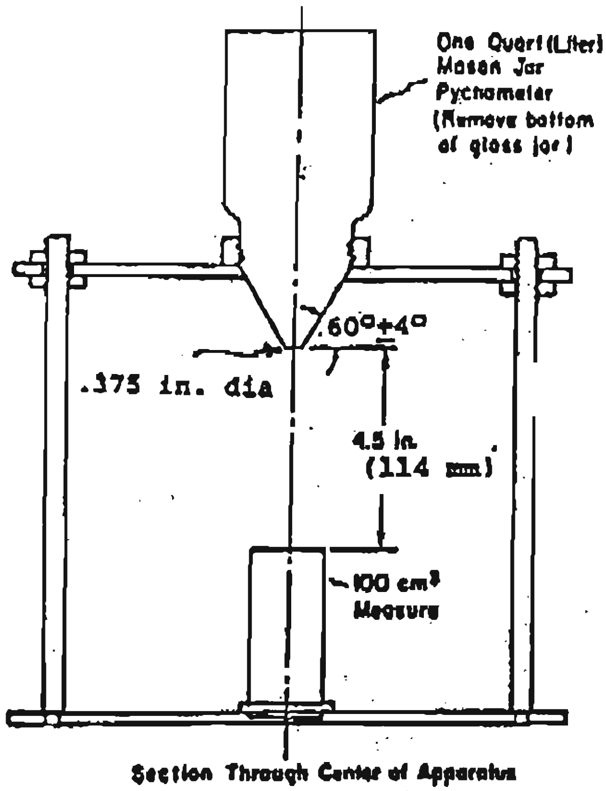
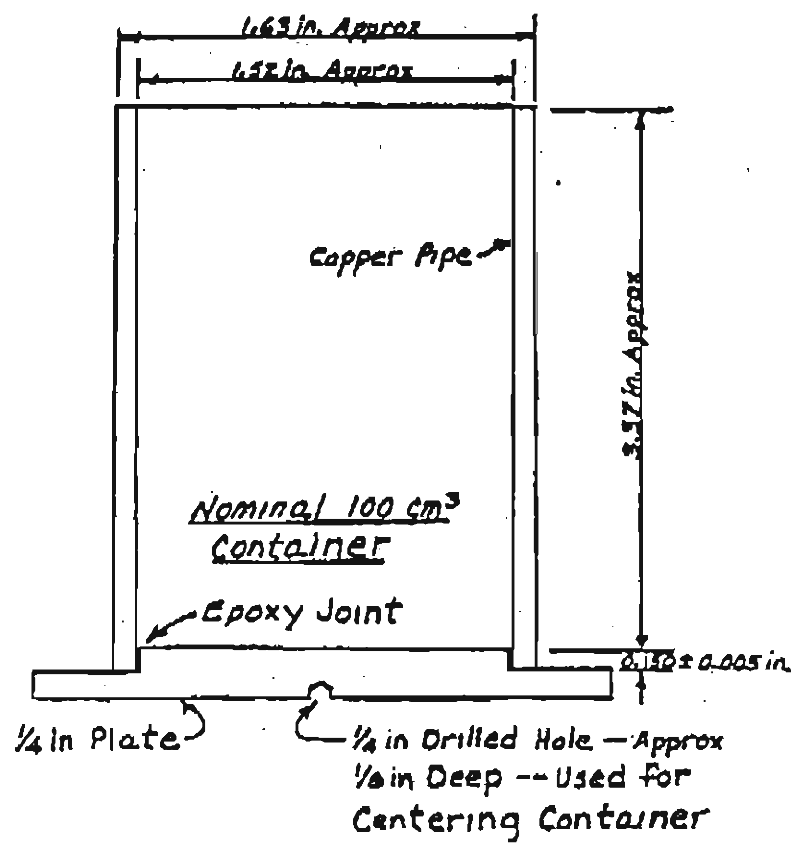

One Quart (Liter) Mason Jar Pycnometer (Remove bottom of glass jar)
60° ± 4°
.375 in. dia
4.5 in. (114 mm)
100 cm³ Measure
Section Through Center of Apparatus

Figure 1


1.63 in. Approx
1.52 in. Approx
Copper Pipe
3.37 in. Approx
Nominal 100 cm³ Container
Epoxy Joint
0.150 ± 0.005 in.
1/4 in Plate
1/4 in Drilled Hole — Approx 1/8 in Deep -- Used for Centering Container

Appendix B

Photos of Testing Equipment

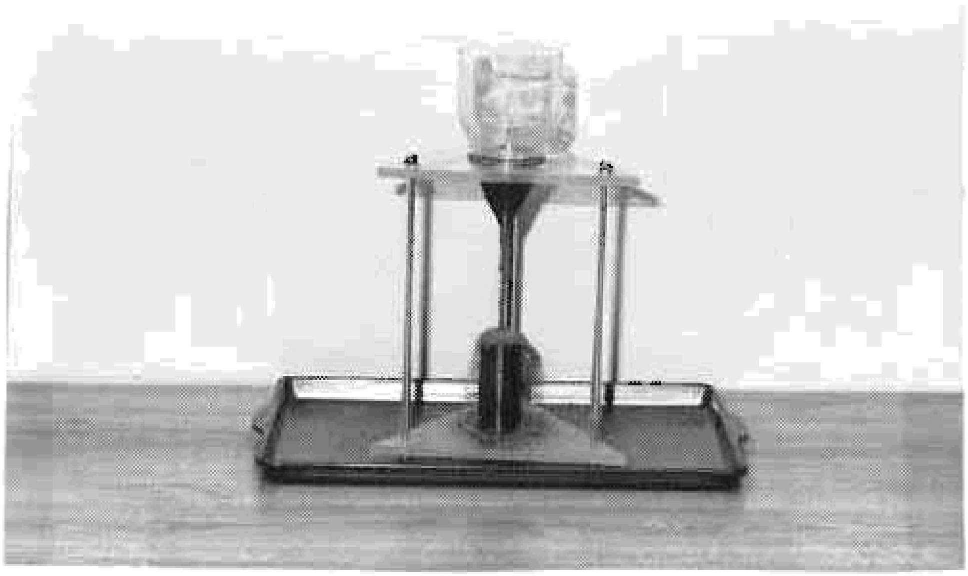


Photo 1. NAA Particle Shape and Texture Test Procedure

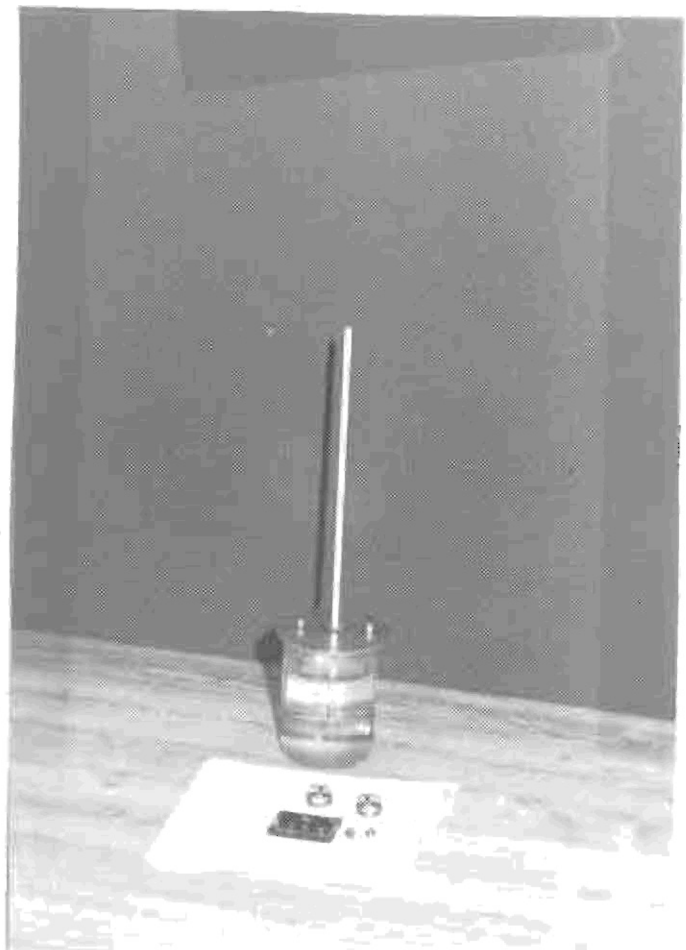


Photo 2. Ring and Ball Equipment Used to Measure Stiffening Effect of P200

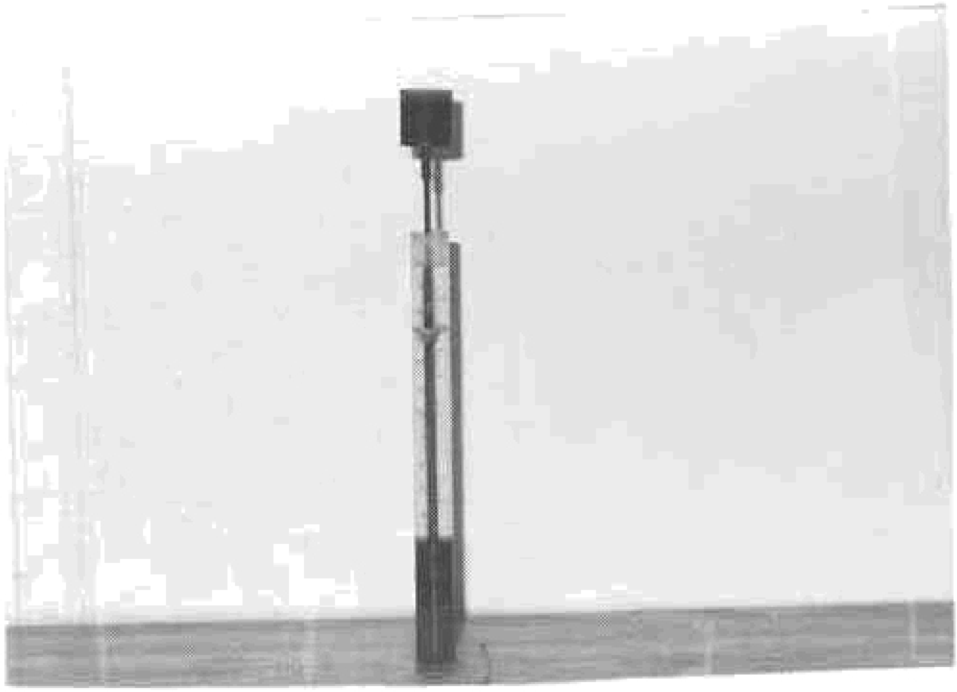


Photo 3. Sand Equivalent Test

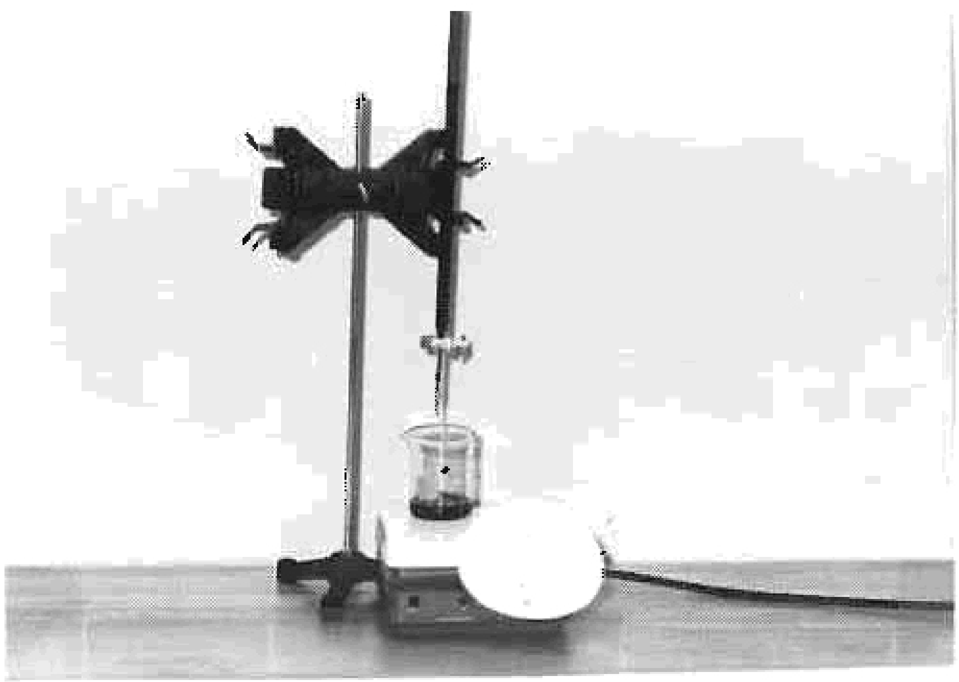


Photo 4. Methylene Blue Test

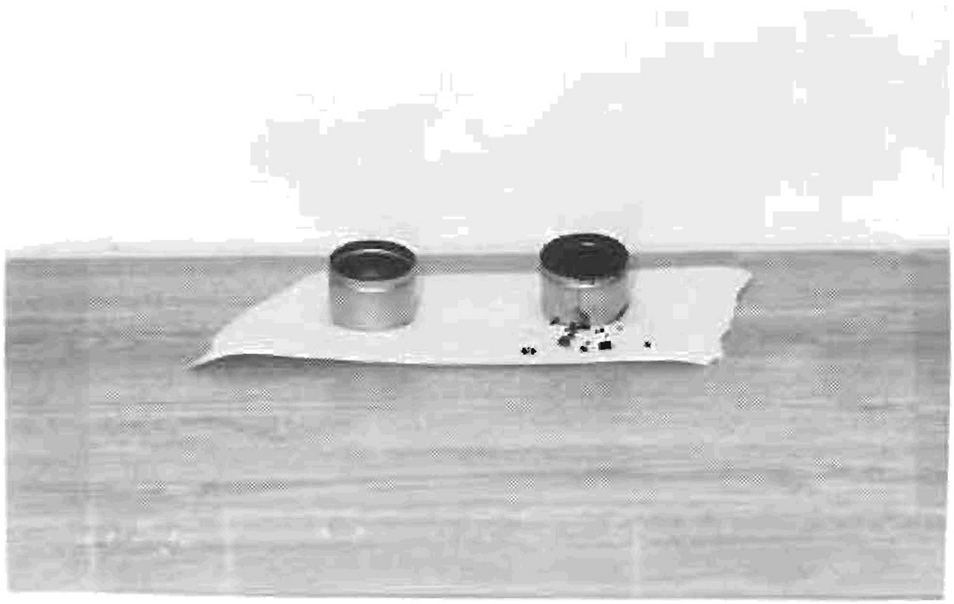


Photo 5. Comparison of Neat Asphalt Cement and the Asphalt Cement at the Crumbling Point

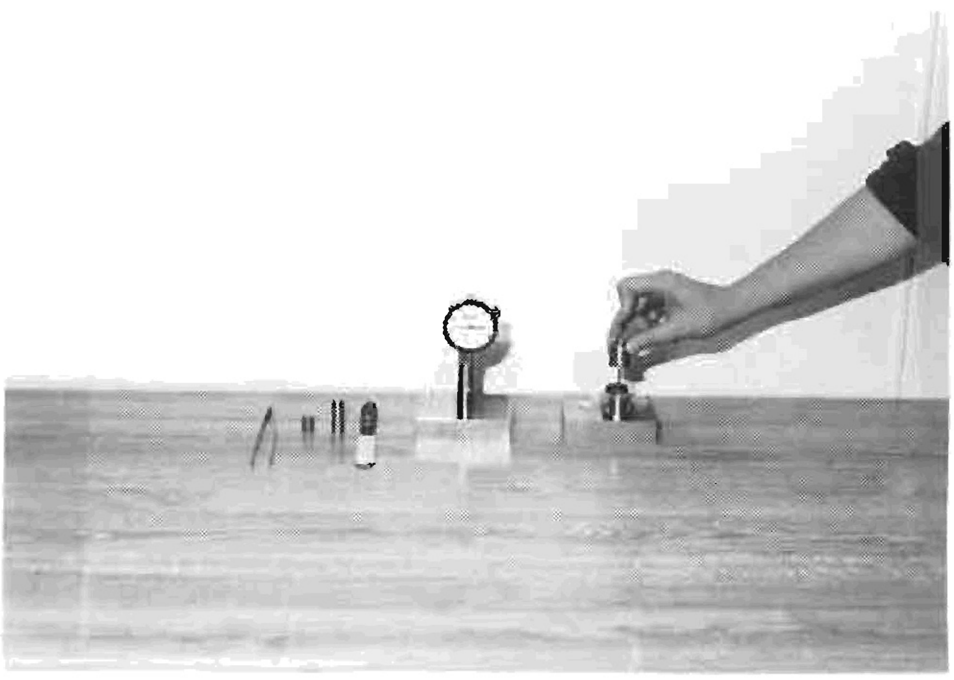


Photo 6. Rigden Voids Index Test Equipment