EVALUATION OF VARIOUS METHODS FOR DETERMINING THE AMOUNT OF ARGILLACEOUS MATERIAL IN COARSE AGGREGATE

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PREFACE

The purpose of this thesis is to present an evaluation of certain highway tests to determine their adaptability for measuring the quantity of clay-derived material in a sample of coarse aggregate.

In completing this part of the requirement for the degree of Master of Science in Civil Engineering, I wish to gratefully acknowledge my indebtedness:

To Dr. Moreland Herrin for his helpful advice and guidance throughout the graduate year.

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To my wife, Lenora, whose encouragement, understanding, consideration, and patience, has meant so very much to me in my educational endeavors.

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CHAPTER I

INTRODUCTION AND REVIEW OF THE LITERATURE

With the advent of the various asphaltic concrete design procedures, it is generally recognized that the stability problem, that used to harass the highway engineer, has been considerably lessened. The evolution of those design procedures based on the stability factor was undoubtedly the result of the shoving and rutting problem that arose as soon as asphalt roads began to be constructed. Today, by using any one of the design procedures along with its design criteria, it is possible for the highway engineer to design an asphalt-aggregate mixture that will have a predictable stability or strength when in service.

However, early highway engineers realized that other properties than the strength of the pavement should be considered in any design method. The two most important properties considered other than stability or strength were skid resistance and durability (12)[1].

<u>Skid</u> <u>Resistance.</u> Skid resistance is the property of the pavement that causes it to resist skidding or sliding along its surface. This property is directly

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[1]The number in parentheses indicates the reference in the Bibliography.

related to the coefficient of friction between the surface of the roadway and the tires. Skid resistance has been increased in the pavement by using aggregate in the mixture that is hard with a rough surface that will not easily polish smooth. Also, present design methods based on the stability factor tend to limit the amount of asphalt used in the mixture. This reduces the "bleeding" or "slicks" that were such a problem in early asphalt highways.

Durability Durability is the property of an asphaltic concrete pavement that causes it to resist disintegration, or deterioration from the action of weather or traffic.

Since the stability or strength problem has been essentially overcome, highway engineers are becoming more and more concerned with the durability property. The properties of an asphaltic concrete paving mixture may be derived from the properties of the asphalt and of the aggregate. Therefore, a study of the durability of the mixture itself must involve a study of the durability of the asphalt and of the aggregate separately (20.)

In a well designed asphalt-aggregate paving mixture each of the materials has a definite job to do in order that the mixture be satisfactory as a compacted roadway surface. The asphalt binder should coat the aggregate with a thin film, partially fill the void spaces between the aggregate, and cement the aggregate particles together.

This will seal the mixture from the seepage of water. The aggregate should transmit all of the applied load to the underlying base courses. It must also resist the abrasion of tires (12).

One can not make an all-inclusive statement as to the causes of failure of an asphaltic concrete roadway. It has been shown by a number of investigators that hardening or loss of penetration of the asphalt binder is conducive to nearly all of the types of failure. Hubbard and Gollomp (14) investigated the causes of cracks in the surface of highways. They concluded that most cracks were caused by one or more of the following reasons:

1.) Cracks existing in the base course had caused a zone of weakness and were transmitted to the surface.
2.) There was not enough asphalt in the mixture.
3.) The material was of a low voidage mixture that could not be well compacted.
4.) An asphalt with too low initial penetration had been used as the binder.
5.) The surface of the pavement had not been sealed quickly enough during construction which had allowed oxidation to occur.

It is recognized that these conditions and their resultant effect on the finished roadway surface are dependent upon the control exercised at the mixing plant and in the field.

It is of interest to note that the aggregate has been given only minor consideration in the literature when the durability of asphaltic concrete pavement is discussed, as may be noted in the preceding discussion of the causes of cracking. This may be justified when it is remembered that the primary function of the aggregate is in a load carrying capacity and is assumed, in most cases, to be protected by the asphalt film which surrounds it. There are, however, other properties of the aggregate than its ability to transmit load that must be considered when studying its contribution to the durability of an asphaltic concrete roadway.

Probably the most important property of the stone that should be considered is whether or not it has a natural affinity for the asphalt binder (i.e., the capability of the asphalt to adhere to the aggregate). Acidic aggregate, in general, have a tendency to let an asphalt strip from them more readily than do aggregate that are basic in nature. Therefore, most specifications require that the stone be basic in nature. A number of chemical additives have been placed on the market because of this characteristic of some aggregates. They all claim to alter the Ph of an acidic aggregate to basic, thereby increasing the adhesion between it and the asphalt binder. Some of these additives have been found to be beneficial when used on some acidic aggregate (11). Others have been found to lose their effectiveness in the presence of water.

Moisture has long been recognized as the chief cause of stripping and swelling (13). Some aggregates have a natural surface affinity for water. Such a "hydrophillic" aggregate will let water gradually replace the asphalt that is in contact with it. The water, in turn, causes swelling and deterioration of the aggregate which results in failure of the pavement.

Another property that must be considered when contemplating using a given aggregate for asphaltic concrete, is the adsorptive property. When asphalt is added to a hot aggregate, gasses are expanded within the aggregate. As it cools, the gasses create a vacuum within the pores of the aggregate that causes some of the asphalt in the mixture to be drawn into the aggregate. This adsorbed asphalt may be considered lost as far as its effectiveness in the mixture is concerned. Goshorn and Williams (10) have suggested that the amount of adsorbed asphalt may be predetermined by the use of a kerosene-equivalent test on the aggregate. The mix design asphalt content will then have to be adjusted to include that amount.

It has been estimated that as much as 25 per cent of the asphalt may adsorbed from a mixture that includes a particularly high adsorptive aggregate. Such a condition would result in a very ineffective roadway surface if the adsorptive property of the aggregate were disregarded. One researcher (23) noted three effects of the resultant leaner mixes that could occur:

1.) Leaner mixes tend to lessen the surface strength and toughness of the pavement.

2.) Leaner mixes cause the asphalt to weather faster and harden sooner.

3.) The resulting thinner films of leaner mixes are more susceptible to the action of water.

Also, it has become evident that the life of an asphaltic concrete pavement may be greatly decreased by the presence of argillaceious or clay-like material in the aggregate. Clay is a product of the weathering of igneous and sedimentary rocks. Shale is defined as consolidated clay that has been crystallized, dehydrated, and then cemented together. This process has been shown to be easily reversible by alternate wetting and drying. Argillaceous limestone is limestone that has an increasing amount of clay-like material. This line division, minerologically, between shale and argillaceous limestone is highly controversial.

Leith and Mead (7) made a very concise statement conconerning the weathering of rocks:

"Rocks that have been derived from clay, the product of the weathering of pre-existing rocks, are chemically stable and break down under weathering largely through physical processes. The susceptibility of each type to destruction by weathering is determined by the degree of metamorphism. The shales have been least metamorphosed, therefore, they weather most rapidly. Since shale is exceedingly fine-grained, the pore spaces are subcapillary in size. Water may be confined and the destructive effect of freezing and thawing is far greater than in a porous sandstone."

Theoretically, if good adhesion between an asphalt binder and a dry shale could be attained and preserved, it might be possible that a good pavement could be constructed. However, much of the effect of the aggregate on the durability of the compacted mixture depends on the location of the particle in the structure of the pavement. If "clay-derived" stone is exposed to the actions of weathering on the surface of the pavement, failure due to raveling or popping-out of the surface would occur within a very short time. It is the inability to control the individual placement of the aggregate in the laid-down mixture that has led highway engineers to regard even small amounts of clay-like aggregate in a mixture as being detrimental to the durability of the pavement.

Coarse aggregate produced from certain stone quarries have been found to contain large amounts of argillaceous limestone and shale. It is conceded that by a studied selection of the stone in a quarry, it is possible to eleminate much of the undesirable material from the crushed stone product. A study of the exposed weathered faces of rock within a stone quarry may give much data to the observer concerning shale and other clay-derived aggregate. An original piece of shale on such a weathered face may be represented by small chips or by a mass of caly. In other portions of the quarry that have been recently worked, the shale may appear to be quite hard and sound because it has not been exposed to many cycles of freezing and thawing, and wetting and drying.

It has long been evident in the highway engineering field that one thing lacking is a simple field test that would give a measure of the amount of argillaceous or clay-like material contained in a sample of coarse aggregate. It is the purpose of this paper to report the results and conclusions obtained from a number of suggested tests on a coarse aggregate that contains clay-like deleterious material. Also, an attempt was made to develop a simple means of determining the amount of shale and argillaceous limestone in a sample.

CHAPTER II

MATERIALS AND LABORATORY PROCEDURE

For the purpose of this investigation, it seemed logical to run a series of the standard coarse aggregate highway tests along with two recently suggested tests to see if some correlation between the properties of a sample and the percentage of clay-derived material involved could be determined. Therefore, the following tests were run:

1.) Specific Gravity and Adsorption Test

2.) Magnesium Sulfate Soundness Test

3.) Sand-Equivalent Test

4.) West Ball Mill Test

The Sand-Equivalent Test and the Wet Ball Mill Test have not, as yet, been accepted as standard tests by highway engineers.

Materials

The material used in this investigation was a crushed-run coarse aggregate that was obtainable in this area. A visual inspection of the aggregate, when it was wet with water, gave evidence that there were three basic types of stone present. The largest percentage of a representative sample of the aggregate was composed of a light grey limestone that has been determined through use in service as being suitable as an asphaltic concrete aggregate in this area.

The remainder of the sample could be nearly equally divided into a shaley limestone and an argillaceous limestone. The shaley limestone portion of the sample was composed of grey limestone with black shale encrustations on one or more of its faces, grey limestone with intermingled flecks of black shale throughout it, and black shale aggregate with little or no evidence of grey limestone present. The argillaceous limestone portion of the sample was easily recognizable by its characteristic color which ranged from a pale yellow to a deep yellow. This color may have been associated with the limonite content of the individual pieces.

Since the light grey limestone portion of a representative sample of this aggregate had been proven by field service to be an acceptable asphaltic concrete aggregate, it seemed logical to consider the remaining portion of the sample to be of a deleterious nature until proven otherwise. For this reason, the tests that were run on samples containing varying amounts of the shale and argillaceous material present were based on the per cent grey limestone in the sample.

Specific Gravity and Adsorption Test

The specific gravities and adsorptions of the three materials composing a sample of the aggregate used in this investigation were determined according to AASHO Designation: T85-45 (3).

An appropriately sized sample of the material to be tested was dried in an electric oven at a temperature of 100 to 110 C. It was then immersed in water at room temperature for 24 hours. After the immersion period, the sample of aggregate was made surface-dry by rolling it in an absorbant cloth. Then it was weighed and the weight recorded. Immediately thereafter, the sample was placed in a wire basket and its weight in water determined and recorded. The sample was then dried in the oven again at the same temperatures. Its dry weight was then determined and recorded. The bulk specific gravity and apparent specific gravity was determined from the data. The adsorption was taken as the water content after immersion based on the dry weight of the aggregate.

Magnesium Sulfate Soundness Test

The purpose of the Magnesium Sulfate Soundness Test is to obtain a measure of the resistance of an aggregate to disintegration due to freezing and thawing. Because the results of the test are not easily reproducable, the test in itself has long been a controversial one amoung highway engineers. However, this test was included in this investigation because it seemed desirable to establish, at least, the relative soundness of the three types of aggregate that composed a sample of the material.

The Magnesium Sulfate Soundness Test, as used in this investigation, was followed as recorded in AASHO Designation: T104-46 (4). An appropriately sized sample was soaked in a magnesium sulfate (Epsom Salt) solution that was maintained at room temperature. The solution was kept at a constant specific gravity of 1.295.

The sample that was to be tested was washed and dried, and separated into sizes by sieving to refusal. The proper weight of the sample for each size fraction was then weighed out and placed in separate containers for the test. The number of particles on fractions coarser than the 3/4-inch sieve was noted and recorded before the test began.

One complete cycle of the test consisted of two separate steps: 1) Storage of the sample in solution, and 2) drying the sample. The sample was immersed in the prepared solution of magnesium sulfate at room temperature for a period of from 16 to 18 hours. After the immersion period, the aggregate sample was removed from the solution, permitted to drain, and placed in a drying oven to dry to constant weight. The temperature of the oven was held at 100 to 110 C.

After the completion of the fifth cycle, the sample was allowed to cool to room temperature and then thoroughly washed. Care was taken not to lose any of the material that had flaked off during the test. When the sample was completely washed, it was placed in the oven again and allowed to dry at 100 to 100 C. to constant weight. The sample was then allowed to cool to room temperature and each sieve fraction was sieved over the same sieve on which it was retained before the test. The particles retained on the sieve were weighed and the weight recorded. Also, the number of peices were noted for the fractions of the sample coarser than the 3/4-inch sieve. The results of the test were taken as the weighed averages of the percentage passing each sieve fraction after the test.

Sand-Equivalent Test

The Sand-Equivalent Test used in this investigation was developed by F. N. Hveem (15) of the California Division of Highways. It was developed as a test to control the quality of aggregates for bituminous mixes and untreated base courses, and was designed as a simple, quick test that may be run in the field. The basis of the test is the fact that most road building materials are mixtures of desirable coarse particles and generally undesirable fine particles or clay. For this reason, the test was developed to be used on a fraction of a representative sample of the combined mixture that passes the U. S. No. 4 sieve.

However, the Sand-Equivalent Test was used in this investigation for two different purposes. First, it seemed desirable to establish a correlation between sand-equivalent values and the condition of a pavement in service. Samples of aggregate recovered by the Abson method (5) from specimen of an asphaltic concrete roadway that had shown varying degrees of raveling and popping-out of the surface were available. Sand-equivalent values were determined for these samples.

Secondly, since the material used for the main purpose of this investigation was a coarse aggregate, the Sand-Equivalent Test was not directly applicable because of the coarseness of the particles. Therefore, a sample of the aggregate passing a U. S. No. 4 sieve meeting the requirements of the Oklahoma Standard Specifications for Highway Construction Type "A" Asphaltic Concrete Aggregate Mix was prepared. Varying percentages of clay-like material were used in different tests to attempt to establish some correlation between the sand-equivalent values obtained and the per cent clay-like material in the sample (i.e., in this case argillaceous limestone and shaley limestone).

Since the Sand-Equivalent Test is essentially an emperical test, the method of using it as suggested by Hveem (15) was followed closely in this investigation.

Apparatus: 1) A transparent graduated measuring cylinder of 1-1/4-inch diameter, 17 inches in height, graduated from the bottom to 15-inches by tenths. 2) A 1/4-inch copper irrigator tube. 3) A 1-gallon bottle with siphon assembly, with a length of rubber tubing that could be attached to the irrigator tube. The bottle was placed about three feet above the working table to provide a working head. 4) A weighted foot, consisting of a metal rod 18-inches long attached at the lower end to a 1-inch diameter conical foot. A cap that would fit the top of the cylinder was centered loosely on the rod. A weight of 1-kilogram was attached to the top end of the rod. 5) A 3-ounce measuring can. 6) A funnel for transferring the sample from the can into the cylinder. 7) A working solution prepared by diluting 88-milliliter of a standard stock solution to 1-gallon with tap water. The standard Sand-Equivalent Stock Solution was available from the Central Valley Scientific Supply Company, 5266 Folsom Boulevard, Sacramento, California.

At the beginning of the test, the siphon was started by blowing through the siphon assembly into the top of the solution bottle. The working solution was siphoned into the graduated cylinder to a depth of 4-inches. A 3-ounce can full of the sample was then added to the cylinder. The bottom of the cylinder was tapped on the heel of the hand several times to dislodge any air bubbles that were present and to aid in wetting the sample. The cylinder was then allowed to stand for ten minutes.

At the end of the ten minute period, the cylinder was stoppered and shook vigorously from side to side, making about 90 cycles (a complete back and forth motion) in about 30 seconds. The cylinder was immediately set upright, unstoppered, and the irrigator tube inserted to the bottom of the cylinder. The fine grained material of the sample was washed upward in the cylinder as the irrigator tube was slowly withdrawn and removed from the cylinder when the liquid level reached exactly 15-inches. The cylinder and its contents were then allowed to stand undisturbed for exactly 20 minutes.

At the end of the 20 minute period, the level at the top of the suspension was read and recorded to the nearest 0.1 inch. The weighted foot was then gently lowered into the cylinder until it came to rest on the material at the bottom of the cyliner. The corresponding value at the bottom of the foot was read and recorded to the nearest 0.1 inch. The sand-equivalent value was calculated from the values determined from the test as the percentage ratio of the reading at the top of the suspension to the reading of at the bottom of the foot.

Wet Ball Mill Test

The Wet Ball Mill Test was devised by P. L. Melville in 1947 for the Virginia Department of Highways (25) as a method of measuring aggregate durability. He succeeded in correlating the results of the test on a number of aggregates with the field performance of those aggregates. The tests that showed a high sample wear were usually correlated with aggregate of poor field performance, while those of low sample wear were usually correlated with good field performance. Turner and Wilson (25) also used the Wet Ball Mill Test in their investigation of degradation of some Washington aggregates.

For the purpose of this investigation, however, the Wet Ball Mill Test was used to determine if it could be adapted to measure the per cent deleterious or clay-derived material in a sample of aggregate. The samples for the test contained 300 grams of material passing a 3/4-inch sieve but retained on a 1/2-inch sieve and 300 grams of material passing a 1/2-inch sieve but retained on a U. S. No. 4 sieve. The grinding charge consisted of 3,000 grams of rounded flint pebbles, which were hard enough to resist the actions of the mill.

The sample, the flint pebbles, and 600 grams of water were placed in a porcelain jug, which was then sealed with a porcelain lid. The jug was mounted horizontally in a mill frame and allowed to rotate at 60 revolutions per minute for 3-1/2 hours. Then the jug was removed from the mill and emptied into a large pan. The flint pebbles and larger pieces of rock were removed, and the remaining material placed in an electric oven to dry. After the sample was dry, it was sieved on a U. S. No. 10 sieve and the percentage of the total sample passing was determined. This percentage was taken as the test value.

CHAPTER III

SUMMARY OF SPECIFIC GRAVITY AND ADSORPTION TESTS

The results of the Specific Gravity and Adsorption Tests used in this investigation are shown in Table I. The tabulated values for the different materials are the arithmetic averages of a number of tests, all of which were acceptable according to the specifications of AASHO Designation: T85-45 (3).

Bulk Specific Gravity (Saturated Surface-Dry)

The bulk specific gravity of the samples tested were calculated as the ratio of the saturated surface-dry weight of the sample in air, to the difference of the weight of the saturated surface-dry sample in air and its weight in water. The largest difference in bulk specific gravity (0.05) was between the 100 per cent argillaceous limestone sample and the 100 per cent grey limestone sample. However, this per cent difference was considered to be too small to warrant further investigation of the bulk specific gravities of the samples as a basis for determining the amount of clay-like material in a sample of aggregate.

TABLE I

RESULTS OF SPECIFIC GRAVITY AND ADSORPTION TESTS
ON VARIOUS COARSE AGGREGATE SAMPLES

Material	Bulk Specific Gravity (S.S.D.)	Apparent Specific Gravity	Adsorption (%)
100% Grey Limestone	2.64	2.71	1.25
100% Argillaceous Limestone	2.59	2.70	2.84
100% Shaley Limestone	2.63	2.71	1.68
50% Argillaceous Limestone and 50% Grey Limestone	2.62	2.71	2.32
50% Shaley Limestone and 50% Grey Limestone	2.63	2.71	1.36

Apparent Specific Gravity

The apparent specific gravity of the samples tested was calculated as the ratio of the oven-dry weight in air to the difference of this weight and its saturated surface-dry weight in water. As may be noted in Table I, the difference in apparent specific gravities of the materials tested was too small to warrant further investigation for the purpose of this study.

Adsorption

The adsorptions of the samples (see Table I) were calculated as the arithmetic averages of the percentage ratio of the difference in weight of the saturated surface-dry sample and its oven-dry weight, to the weight of the oven-dry sample. It may be noted that there is considerable difference in the adsorption of the three materials composing a sample of the aggregate used in this investigation.

The difference in adsorption of the grey limestone sample and the argillaceous limestone sample was 1.59 per cent. Therefore, theoretically, a sample composed of equal percentages of the two materials should give an adsorption value of 2.05 per cent. However, (see Table I) an actual test value of 2.32 per cent was found for such a sample. The difference between the theoretical and the actual values may be attributed to the fact that the materials were identified and separated from the original aggregate sample on a color basis. Consequently, with the human error involved in such a method, there may have been little uniformity between the individual pieces of stone in either portion of the sample. This lack of uniformity would have definitely affected the test results.

The difference in adsorption of the shaley limestone sample and the grey limestone sample was 0.43 per cent. Similarly, a sample composed of 50 per cent shaley limestone and 50 per cent grey limestone should give a theoretical test value of 1.46 per cent. However, the actual test value as shown in Table I for such a sample was only 1.36 per cent. Again, this difference between the theoretical and actual values could be attributed to the manner in which the materials were identified and separated from the original aggregate sample.

Evaluation of Specific Gravity and Adsorption Tests

Because of the small difference in values for specific gravities of the three materials included in a sample of the coarse aggregate used in this investigation, it is evident that there is little possibility of devising a quantitative test for clay-derived material based on this property of the aggregate. However, from the foregoing discussion of the adsorption values in Table I, a suggestion for further investigation was evolved. Such investigation could involve the construction of a "calibration curve" for a given aggregate. The curve would necessarily be determined by a plot of the adsorption of graduated samples versus the per cent clay-derived material in the sample.

CHAPTER IV

SUMMARY OF MAGNESIUM SULFATE SOUNDNESS TESTS

The results of the Magnesium Sulfate Soundness Tests used in this investigation are tabulated in Table II, and were obtained as the sum of the weighted average percentage loss of material on each sieve size fraction of the sample tested. The tests were run according to the specifications of AASHO Designation: T104-46. (4).

As previously indicated, the Mangesium Sulfate Soundness Test is regarded by many highway engineers as being unacceptable as a highway materials test even though it is a standard test according to the American Association of State Highway Officials. Many highway materials researchers have illustrated the fact that the results of this test are completely unscientific. Different persons using the test on samples of the same aggregate may get entirely differing test results. However, the Magnesium Sulfate Soundness Test was included in this investigation because it was desirable to determine, at least, the relative resistance to freezing and thawing, as indicated by the test, of the three materials that composed a sample of the aggregate used in this investigation.

A sample of 100 per cent argillaceous limestone tested only 13.06 per cent (see Table II) while a sample of 100

TABLE II

RESULTS OF MAGNESIUM SULFATE SOUNDNESS TESTS ON VARIOUS COARSE AGGREGATE SAMPLES

Sample Tested			Weighted Average (Corrected Percentage Loss) (%)
Grey Limestone (%)	Argillaceous Limestone (%)	Shaley Limestone (%)	
100	0	0	15.67
0	100	0	13.06
0	0	100	38.11
50	50	0	16.97
50	0	50	24.26

per cent grey limestone gave a test value of 15.67 per cent. This is directly opposite to what was expected from the test, as the grey limestone has been proven by service to be the better of the two materials and would, therefore, be expected to register a lower test value than the argillaceous limestone. However, it would be safe to assume that the test values for the two materials would be rather close, which would indicate that their freezing and thawing characteristics are similar.

Again from Table II, a sample containing 100 per cent shaley limestone gave a test value of 38.11 per cent. This rather high test value, compared with the results of tests on the other two materials, suggests that the shaley limestone portion of the aggregate used in this investigation is more susceptible to freezing and thawing, which would indicate that it is of a more deleterious nature than the other materials.

Many highway engineers in this area consider the presence of yellow argillaceous limestone in a badly raveled or popped-out roadway surface of asphaltic concrete, to be the cause of its failure. Probably this is true because of the fact that argillaceous limestone has been recognized as a deleterious material, and because its yellow color is so easily discernable on the faces of a sawed sample from a failed roadway surface. However, the results of the Magnesium Sulfate Soundness Test in Table II show that the presence of shaley limestone in an asphalt-aggregate mixture would be much more detrimental than would the presence of argillaceous limestone. Along with the fact that the dark grey color of shaley limestone makes it not so easily discernable on the face of a sawed sample, it is possible that its undetected presence has already contributed greatly to pavement failure due to raveling and popping-out of the surface in this area.

Evaluation of Magnesium Sulfate Soundness Tests

It is possible that the Magnesium Sulfate Soundness Test could be used to detect clay-derived material in a coarse aggregate. However, the inherent variability in the results of the test on given samples must, necessarily, be less than the percentage loss difference between them. In the case illustrated by this investigation, if the test values found were within 5 per cent on each the shaley limestone and the grey limestone, at the extreme there would be a percentage loss difference of 12.44 per cent. Therefore, the Magnesium Sulfate Soundness Test could be used to detect the presence of the shaley limestone in the coarse aggregate of this investigation providing it were present in a large percentage. It was demonstrated, however, that the test is not acceptable for detecting argillaceous material in a sample of coarse aggregate.

CHAPTER V

SUMMARY OF SAND-EQUIVALENT TESTS

Correlation of Test Values with Aggregate Field Service

The Sand-Equivalent Test was first used, in this investigation, to establish a correlation between sand-equivalent test values and the condition of a given pavement in service. Aggregate samples recovered by the Abson method (5) from sawed pieces of a badly raveled and popped-out asphaltic concrete pavement were available. The sawed samples had been judged and separated into two groups on the basis of the condition of the surface of the pavement from which they were taken.

Table III is a tabulation of the sieve analyses of the recovered aggregate samples. Samples 2, 3, and 4, were rated as being representative of a pavement that has not failed due to raveling or popping-out of its surface. Samples 20, 10, 11, 12, and 13, were taken as representative samples of a pavement surface that showed a considerable amount of raveling and popping-out. The difference in gradation of the samples within the two rated groups illustrates the fact that there was actually a considerable difference in the condition of the samples composing either group.

TABLE III

SIEVE ANALYSIS OF RECOVERED SAMPLES

(Per Cent Passing)

Sample No.	Sieve Size (U. S. Standard Sieve)							
	1/2	3/8	#4	#10	#40	#80	#200	Pan
2	96.3	85.8	63.5	47.8	31.4	11.1	5.0	0
3	93.6	85.9	62.8	48.3	31.6	12.1	6.7	0
4	96.7	89.6	61.8	45.7	29.8	10.9	4.3	0
20	98.6	92.6	73.0	53.3	32.5	15.8	8.8	0
10	97.2	86.1	61.9	43.2	26.5	11.4	6.1	0
11	93.0	83.4	55.7	39.5	23.3	8.3	3.1	0
12	97.1	83.0	58.8	42.3	26.9	11.2	6.7	0
13	95.9	84.2	60.5	43.5	27.8	13.0	7.6	0

Theoretically, since the samples were from the same roadway and the same asphaltic concrete mix design, the per cent passing each sieve size for any sample would be, correspondingly, the same for any other sample that had been exposed to the same weather conditions and traffic. However, the volume and weight of traffic that a roadway is exposed to is not constant, even over small sections of the pavement.

An arithmetic average of the percentage passing each sieve size of both groups of rated samples is tabulated in Table IV. From this data, it may be seen that there was an increase in the amount of material passing the smaller sieve sizes of the bad samples as compared to the good samples. Also, the increase would be more pronounced if the fine material obtained by centrifuge had been added to the samples. The increase in percentage passing indicated that degradation was more pronounced in the portions of the roadway surface that had failed.

The correlation of Sand-Equivalent Test values with the condition of the pavement from which the samples were taken, is tabulated in Table V. The test values indicate that a mixture of aggregate with a test value of 75, or larger was representative of an aggregate that had given satisfactory field service, while an aggregate mixture that tested below 75 represented an aggregate that had permitted a raveled and popped-out surface condition in service. The difference in test values would have been more pronounced had the centrifuged fines been added.

TABLE IV

AVERAGE GRADATION OF RATED SAMPLES

(Per Cent Passing)

Sieve Size	Samples Rated "Good"	Samples Rated "Bad"
1/2	95.5	96.4
3/8	87.1	85.9
#4	62.7	62.0
#10	47.1	44.4
#40	34.3	27.4
#80	11.4	11.9
#200	5.3	6.5
Pan	0	0

TABLE V

CORRELTATION OF SAND-EQUIVALENT VALUES WITH RECOVERED AGGREGATE SAMPLES

Sample No.	Rating as to Raveling and Popping-out	Sand-Equivalent Value
2	Good	76
3	Good	77
4	Good	81
20	Bad	60
10	Bad	67
11	Bad	73
12	Bad	59
13	Bad	62

Relation of Test Values to Content of Clay-dervied Material

The Sand-Equivalent Test was next used in this investigation in an attempt to establish a relation between the test values and the percentage of a clay-derived material contained in a sample of coarse aggregate. The shaley limestone portion of the coarse aggregate used in this investigation was used as the clay-derived material in the samples. This was done because the Magnesium Sulfate Soundness Test had indicated it to be more susceptible to the actions of freezing and thawing than the argillaceous limestone portion of the aggregate.

Samples composed of varying percentages of shaley limestone and grey limestone were prepared to meet the specifications of the Oklahoma State Highway Commission for Class "A" Asphaltic Concrete Aggregate (22). The results of the Sand-Equivalent Tests run on these samples are given in Table VI. Also, the results of these tests are shown graphically in Figure 1. It was desired to determine a smooth curve, such as Curve "A", from a plot of the Sand-Equivalent Test values against the per cent shaley limestone in corresponding samples. However, Figure 1 illustrates that such a plot would not produce a smooth curve from the results of this investigation. As for the other tests, it is possible that the manner in which the materials were identified and separated from the original aggregate was the reason a curve, similar to curve "A", was not more clearly defined by the results of this investigation.

TABLE VI

RESULTS OF SAND-EQUIVALENT TESTS ON SAMPLES HAVING VARYING PER CENT SHALEY LIMESTONE

Sample (3-ounce)		
Shaley Limestone (%)	Grey Limestone (%)	Sand-Equivalent Value
0	100	41.1
10	90	41.0
20	80	39.0
25	75	27.4
40	60	27.9
50	50	29.7
75	25	25.7
100	10	22.8

Relation of Sand-Equivalent Values
To
Per Cent Shaley Limestone

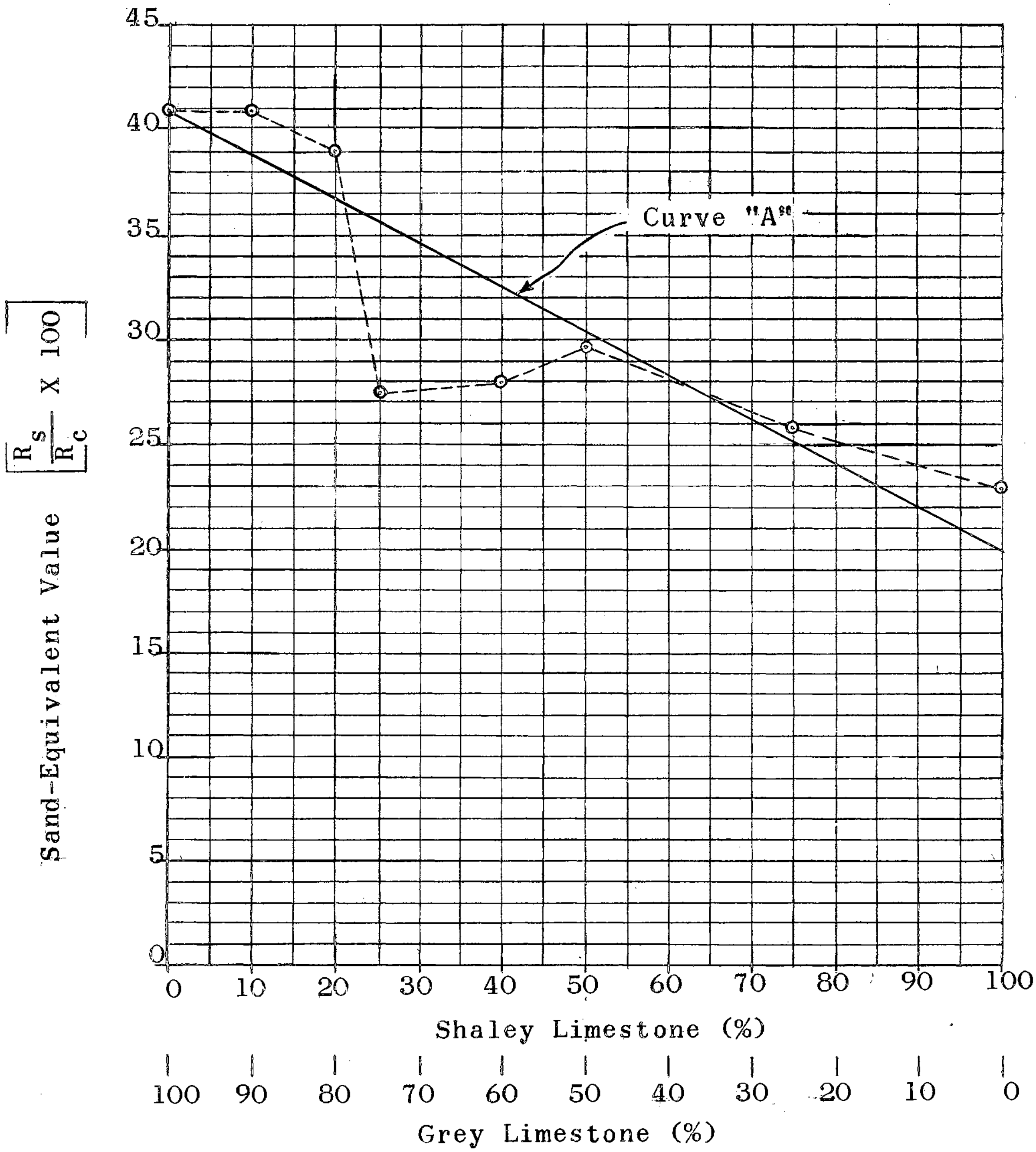

Figure I

Evaluation of Sand-Equivalent Tests

By using the Sand-Equivalent Test along with a more scientific means of identifying and separating the basic constituents of a coarse aggregate than was used in this investigation, it may be possible to construct a "calibration curve" similar to curve "A", Figure 1. However, the feasibility of this method is rather doubtful because of the fact that the material to be tested would have to be crushed and sized in the same manner as the calibration samples. This would necessarily entail a considerable amount of field laboratory equipment.

It appears that the Sand-Equivalent Test does warrant further investigation to correlate its results with the field service of aggregate mixtures. It may be possible, with the establishment of some criteria, to predict the durability of an aggregate mixture to be used in asphaltic concrete.

The Sand-Equivalent Test values may be correlated with the condition of the pavement when it is run on recovered aggregate samples. When the fines of the centrifuge process were not present in the test sample, a Sand-Equivalent Test value of 75 or larger indicated that the recovered aggregate was from a pavement that was in good surface condition. When the test value was below 75, the recovered aggregate represented a sample of pavement that had a bad surface condition.

CHAPTER VI

SUMMARY OF WET BALL MILL TESTS

The results of the Wet Ball Mill Tests used in this investigation are tabulated in Table VII, and were taken as the precentage of material passing the Standard U. S. No. 10 sieve after the test.

The test value for argillaceous limestone was 20.3 per cent, while the test value of the grey limestone sample was 26.7 per cent (see Table VII). Like the Magnesium Sulfate Soundness Tests on the same materials, the Wet Ball Mill Test results indicate the argillaceous limestone to be the better of the two materials. However, in the case of the Wet Ball Mill Test, the results are taken as a measure of the resistance of the aggregate to degradation. As before, the results of the tests on the two materials are contrary to what was expected. The test values in both cases could be erroneous because of the method used to separate and identify the two materials. However, the closeness of the two test values is important because it indicates that the resistance to degradation of the argillaceous limestone and the grey limestone is very similar.

Again from Table VII, a test value of 60.2 per cent was indicated for a sample of 100 per cent shaley limestone.

TABLE VII

RESULTS OF WET BALL MILL TESTS ON VARIOUS COARSE AGGREGATE SAMPLES

Material	Original Sample Weight Gms	After Test (Passing #10) Gms	Test Value (Per Cent Passing #10 Sieve)
Grey Limestone	602	441	26.7
Argillaceous Limestone	600	478	20.3
Shaley Limestone	600	239	60.2
75% Grey Limestone plus 25% Argillaceous Limestone	614	451	26.6
50% Grey Limestone plus 50% Shaley Limestone	604	419	30.6

This value, compared with the corresponding values for argillaceous limestone and grey limestone, suggested that the shaley limestone portion of the coarse aggregate used in this investigation had much less resistance to degradation than the other portions. This, in turn, suggests the shaley limestone to be more deleterious than argillaceous limestone in an asphaltic concrete roadway.

Evaluation of Wet Ball Mill Tests

From the results of the Wet Ball Mill Tests of this investigation, it appears that the test has a definite place in materials testing. Though the test is based on a different property of the aggregate, the same aggregate samples tested by both the Wet Ball Mill Test and the Magnesium Sulfate Soundness Test gave similar results. However, the results of a Wet Ball Mill Test was obtained within 24 hours after the beginning of the test. The results of a Magnesium Sulfate Soundness Test were obtained after about 7 days from the beginning of the test.

Also, it was demonstrated that the Wet Ball Mill Test may be used to detect the presence of shaley limestone, if it is present in sufficient quantity in a sample of coarse aggregate. However, the test results indicate that it could not be used to give an indication of agrillaceous limestone in a sample. A scientific method of identification and separation must be used before the test may be used as a quantitative test for shaley limestone.

CHAPTER VII

CONCLUSIONS

Four highway material tests of aggregate have been evaluated in this investigation to determine if any of them may be used to give a quantitative measure of the amount of clay-derived material in a sample of coarse aggregate. It has been shown that the Specific Gravity and Adsorption Test and the Magnesium Sulfate Soundness Test are not suitable for this purpose. However, with a more scientific means of identification and separation, the Sand-Equivalent Test and the Wet Ball Mill Test show promise of being acceptable for such a quantitative test.

The Sand-Equivalent Test, to be useful as a quantitative test, would entail the presence of extensive aggregate crushing equipment for the preparation of samples. This would make the test highly impractical.

The Wet Ball Mill Test, however, is a simple, quick test that may be used as a quantitative test without the use of other equipment. When used with a good method of separation and indentification, the test should give an accurate measure of the amount of shaley material in a sample of coarse aggregate. The Wet Ball Mill Test will, undoubtedly, become one of the more useful highway materials tests.

Only one specific crusher run coarse aggregate was used to evaluate the tests for this investigation. Therefore, the conclusions drawn from the different tests are considered to be applicable, only, to this material. Subsequent investigations, using the tests on other coarse aggregates, will be necessary before any general conclusions may be made about these tests.

Specific Gravity and Adsorption Test

1. The difference in specific gravities, both saturated surface-dry and apparent, of the materials that composed a sample of the coarse aggregate used in this investigation is very small. Further investigation of this property of the materials as the basis for a quantitative test is not warranted.

2. Though there is some difference in the adsorption values of the three materials used, a quantitative test based on this property is not considered feasible because of the variability in composition of the materials and the manner in which adsorption values may be obtained.

Magnesium Sulfate Soundness Test

1. The shaley limestone portion, of the aggregate used in the evaluation of this test, has more loss than either the grey limestone portion or the argillaceous limestone according to the test results.

2. The test is too lengthy and time consuming to be feasible as a quantitative test.

3. If the inherent variability of the results of this test is less than the difference of percentage loss of the grey limestone and the shaley limestone, then the test may be used to indicate the presence of shaley limestone in a coarse aggregate sample.

4. The test is not extensive enough to give an indication of the presence of argillaceous limestone in a sample.

Sand-Equivalent Test

1. There is a good possibility that with proper correlation the Sand-Equivalent Test may be used to predict the effect of a given aggregate mixture on the durability of an asphaltic concrete roadway.

2. When the test is run on recovered aggregate samples from an asphaltic concrete pavement, a test value of 75 or larger, indicates that the sample was from a part of the roadway with no surface failure; a test value of less than 75 indicates the sample was from a part of the roadway that had moderate to extensive surface failure.

3. It is doubtful that a simple method of measuring the amount of clay-derived material, quantitatively, would be practical by using this test because of the extensive crushing equipment that is required to prepare a sample from coarse aggregate.

Wet Ball Mill Test

1. The results from the Wet Ball Mill Test indicate that the shaley limestone portion of the coarse aggregate

used in this investigation is highly susceptible to degradation.

2. Though based on a different property of the aggregate than the Magnesium Sulfate Soundness Test, the Wet Ball Mill gives comparable results for these aggregate.

3. This comparatively new test has a definite place in the field of highway materials testing. The test requires little expensive equipment and gives results within 24 hours from the beginning of the test. The action of the mill on shaley limestone is sufficient to cause it to break down during the test, thereby giving an indication of its presence in the test sample. By using a proper method of indentification and separation, this test may be readily adapted to measure the amount of shaley limestone in a sample of coarse aggregate.

4. The results of this test do not give an indication of the presence of argillaceous limestone.

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APPENDIX

DATE SHEETS

SPECIFIC GRAVITY AND ADSORPTION TESTS

Material	Oven-Dry Weight in Air (Gms.)	Saturated Surface-Dry Weight in Air (Gms.)	Weight in Water (Gms.)
Grey Limestone	2751.5 2846.0	2786.0 2877.0	1732.0 1795.0
Argillaceous Limestone	1946.5 1342.5	2002.0 1380.5	1227.0 846.5
Shaley Limestone	2592.0 1866.0	2363.0 1897.0	1637.5 1182.0
50% Argillaceous Limestone plus 50% Grey Limestone	2650.5 2801.5 2801.0 2649.0 2799.0 2651.0	2715.0 2863.0 2861.5 2718.0 2862.5 2716.0	1679.5 1772.0 1771.5 1678.5 1680.0 1680.0
50% Shaley Limestone plus 50% Grey Limestone	2970.5	3025.5	1876.0

MAGNESIUM SULFATE SOUNDNESS TESTS

Grey Limestone

Sieve Size		Original Sample		After 5 Cycles		Weighted Average (Corrected Percentage Loss)
Passing	Retained	Retain (Gms.)	Number Pieces	Retain (Gms.)	Number Pieces	
1-1/2	1	1000	26	819	22	6.46
1	3/4	503	21	453	20	1.78
3/4	1/2	669		539		4.64
1/2	3/8	330		300		1.72
3/8	#4	300		270		1.07
				Total		15.67

Argillaceous Limestone

Sieve Size		Original Sample		After 5 Cycles		Weighted Average (Corrected Percentage Loss)
Passing	Retained	Retain (Gms.)	Number Pieces	Retain (Gms.)	Number Pieces	
1-1/2	1	438	12	380	11	2.35
1	3/4	748	41	665	38	3.35
3/4	1/2	635		518		4.75
1/2	3/8	380		324		2.28
3/8	#4	265		257		0.33
				Total		13.06

Shaley Limestone

Sieve Size		Original Sample		After 5 Cycles		Weighted Average (Corrected Percentage Loss)
Passing	Retained	Retain (Gms.)	Number Pieces	Retain (Gms.)	Number Pieces	
1-1/2	1	625	17	231	6	15.25
1	3/4	533	33	364	26	6.53
3/4	1/2	702		453		9.65
1/2	3/8	396		283		4.36
3/8	#4	330		270		2.32
				Total		38.11

50% Grey Limestone Plus 50% Shaley Limestone

Sieve Size		Original Sample		After 5 Cycles		Weighted Average (Corrected Percentage Loss)
Passing	Retained	Retain (Gms.)	Number Pieces	Retain (Gms.)	Number Pieces	
1-1/2	1	1000	28	663	11	12.07
1	3/4	501	30	371	16	4.62
3/4	1/2	670		571		3.52
1/2	3/8	330		274		2.04
3/8	#4	300		245		2.01
				Total		24.26

50% Grey Limestone Plus 50% Argillaceous Limestone

Sieve Passing	Size Retained	Original Retain (Gms.)	Sample Number Pieces	After 5 Cycles Retain (Gms.)	After 5 Cycles Number Pieces	Weighted Average (Corrected Percentage Loss)
1-1/2	1	998	27	856	21	5.05
1	3/4	499	20	394	14	3.72
3/4	1/2	670		563		3.78
1/2	3/8	350		266		3.00
3/8	#4	298		258		1.42
				Total		16.97

SAND-EQUIVALENT TEST DATA

Sand-Equivalent Values of Recovered Samples

Sample No.	Reading at Top of the Suspension (R_c)	Reading at Bottom of the Foot (R_c)	Test No.
2	5.1 5.1	3.9 3.8	1 2
3	5.0 5.1	3.9 3.8	1 2
4	4.4 4.6	3.8 3.5	1 2
20	6.3 6.6	3.9 3.9	1 2
10	6.0 6.3	4.0 4.2	1 2
11	5.0 5.0	3.7 3.6	1 2
12	6.2 6.2	3.6 3.7	1 2
13	5.9 5.4	3.3 3.5	1 2

Sand-Equivalent Values Vs. Shaley Limestone

Sample No.	Shaley Limestone (%)	Grey Limestone (%)	Reading at Top of the Suspension (R_c)	Reading at Bottom of the Foot (R_s)
1	0	100	7.3	3.0
2	10	90	7.4	3.1
3	20	80	7.7	3.0
4	25	75	10.2	2.8
5	40	60	10.4	2.9
6	50	50	10.1	3.0
7	75	25	10.9	2.8
8	100	0	12.3	2.8

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