THE DEVELOPMENT OF TEST PROCEDURES TO IDENTIFY THE ABILITY OF SYNTHETIC AGGREGATES TO RESIST TRAFFIC DEGRADATION

by

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ABSTRACT

This investigation basically concerns the resistance of synthetic aggregates to degradation. It is a project that investigates various methods of testing aggregates with respect to particle strength. These test methods include some of the "accepted" standard methods of test, modifications of these procedures and some new approaches to degrading aggregates. The synthetic aggregates involved in this investigation represent both source sampled materials and job sampled materials.

SUMMARY

Although many tests have been made and considerable data collected, only a few samples of aggregate from the major sources in production have been tested. This limitation of samples prevents the establishment of a definite specification and test procedure for eliminating undesirable synthetic aggregates.

IMPLEMENTATION

In an attempt to select a test procedure and develop a specification, two or possibly three procedures that appear to be promising from this investigation will be utilized in testing samples submitted to the Materials and Tests Laboratory. More data is necessary for the establishment of specification requirements that will result in the elimination of only the undesirable aggregates and qualify only those that are desirable with respect to particle strengths.

CONTENTS

ERRATA

On page 7, third paragraph was erroneously duplicated.

On page 30, Table IV, under R3-71-660, "Eastland" should read "Dallas*." Under R3-71-661, Eastland should have "*".

I. PURPOSE

This investigation was initiated for the purpose of developing a test method and corresponding specification that would control the degrading properties of synthetic aggregates. The procedure was to determine the aggregate's ability to resist degradation and develop specifications for acceptable limits.

II. CONCLUSIONS

At this point, the primary benefit has been the elimination of many of the original proposed test methods that have been found to be inconclusive. While none of the test methods have been found to be acceptable for the definition of an aggregate with satisfactory particle strength, there are several which do indicate trends sufficient to warrant further testing in this project.

III. RECOMMENDATIONS

The only recommendation that could be offered as a result of this investigation is that more tests with many different materials be made utilizing two or possibly three of the test methods that showed promise. This should be done in conjunction with active projects, for performance in the field is an absolute essential in the development of a test method and specification.

IV. MATERIALS

Laboratory No. R3-70-535: Synthetic aggregate produced by Texas Industries, Inc. plant near Clodine, Texas, sampled from stockpile in Polk County.

Laboratory No. R3-70-1363: Synthetic aggregate produced by Texas Industries, Inc. plant in Eastland, Texas, sampled from stockpile in Tom Green County.

Laboratory No. R3-71-139: Synthetic aggregate from the Featherlite Corporation's plant in Ranger, Texas.

Laboratory No. R3-71-513: Synthetic aggregate from Texas Industries, Inc. Dallas Lightweight Aggregate Company's plant near Dallas, Texas.

Laboratory No. R3-71-649: Synthetic aggregate from Bay Prairie Aggregate Corporation's plant near Wharton, Texas.

Laboratory No. R3-71-659: Texas Industries Clodine synthetic aggregate sampled from stockpile at job site of Texas Transportation Institute's Research Study 2-6-71-83 on S.H. 95 South of Elgin, Texas.

Laboratory No. R3-71-660: Texas Industries-Dallas synthetic aggregate sampled from stockpile at job site of Texas Transportation Institute's Research Study 2-6-71-83 on S.H. 95 South of Elgin, Texas.

Laboratory No. R3-71-661: Texas Industries-Eastland synthetic aggregate sampled from stockpile at job site of Texas Transportation Institute's Research Study 2-6-71-83 on S.H. 95 South of Elgin, Texas.

Laboratory No. R3-71-663: Featherlite-Ranger synthetic aggregate sampled from stockpile at job site of Texas Transportation Institute's Research Study 2-6-71-83 on S.H. 95 South of Elgin, Texas.

Complete information and petrographic analysis of the above listed aggregates may be found in the "Appendix."

Miscellaneous aggregates tested for comparative purposes (not included in the current Project Proposal):

Laboratory No. R3-70-1362: A hard, dense, igneous, black nephaline basalt aggregate, commonly referred to as "trap rock," from the White's Mines, Inc. plant at Knippa, Texas.

Laboratory No. R3-70-210: A very porous, fossiliferous, fine-grained, chalky, sedimentary limestone aggregate, sometimes referred to as "soft rock;" a select sample from the Texas Crushed Stone Company near Georgetown, Texas.

V. TEST METHODS AND EQUIPMENT

1. Sieve Analysis: All sieve analyses in Table I were performed according to Test Method Tex-200-F.

2. Specific Gravity and Water Absorption: The first figures for specific gravity and water absorption listed in Table II were determined according to Test Method Tex-201-F. The water absorption was determined after 24 hours inundation.

The second pair of figures for specific gravity and water absorption were determined as described in Test Method Tex-433-A, the water absorption being determined after 24 hours inundation.

The third set of figures represent the specific gravity and 24 hour water

absorption determined according to Test Method Tex-433-A, with the exception that instead of tap water as the inundation media a 0.01% aerosol solution was used. Due to its ineffectiveness, this procedure was discontinued after use with R3-71-139, Featherlite-Ranger aggregate.

The last set of data in Table II is the specific gravity and water absorption as determined utilizing Test Method Tex-109-E. All results are the average of two or more tests.

3. Unit Weight: Table III contains both the "standard" and "rodded" unit weight values, as determined by Test Method Tex-404-A. The first figures are for the 3/8" - 1/4" sized aggregate, chosen as the standard aggregate size for this investigation. The second set of figures are the unit weights of the aggregates in the gradations "as received," these gradations being recorded in Table I. All results are the average of two tests.

4. Pressure Slaking: The first row of figures in Table IV contains the pressure slaking value for each material as determined by Test Method Tex-431-A using the equipoise shaker. The second row of pressure slaking values are those values determined with the same procedure for the 3/8" - 1/4" standard size aggregate for this investigation.

The second group of figures in Table IV were determined in accordance with the "Modified" method of Test Method Tex-431-A. At the time the tests were made, the procedure was referred to as the Texas Transportation Institute "Modified I" method with a specified shaker speed of 285 $\pm$ 10 r.p.m. The combination of pulleys and motor speeds available in the

laboratory resulted in a shaker speed of approximately 296 r.p.m. for this procedure. The results of this procedure appeared repetitious to the equipoise shaker method and the procedure was discontinued early in the investigation. The results are averages of two tests each.

It was decided to experiment with the development of a pressure slaking procedure that would duplicate the equipoise shaker results without conversion, as required in Tex-431-A. The bottles were placed horizontal and stacked one on top of the other in the Bain Marie pot, the procedure being the same as "Modified I" above. It was discovered that the top bottle always degraded measurably less than the bottom bottle. The procedure was discontinued as indicated by the dashes in Table IV.

Another attempt was made to duplicate the equipoise shaker results with available, standard field laboratory equipment. A bracket was made for the Tyler Sieve Shaker that would clamp the pressure slaking bottles side-by-side in the shaker. After brief experimentations, a shaking speed of approximately 259 r.p.m. (this is the standard combination of pulley's and motors presently used in all D-9 Field Laboratories) for 35 minutes was selected. The results of this procedure are recorded as the last group of data in Table IV. All results are the average of two tests.

5. Soundness Test: Both the magnesium sulfate and sodium sulfate soundness tests were made with the aggregate sizes required according to Test Method Tex-411-A. The tests were also made with the investigation standard size 3/8" - 1/4" aggregate. It was decided that for comparative purposes and as a method of evaluating degradation, materials would be sieved,

after test, over the 1/4", No. 10 and No. 40 sieves, recording the passing sieve values. This was established as a standard procedure and practiced throughout the investigation. All results in Table V are the average of two tests. The soundness tests were discontinued, after several check tests, due to erratic test results.

6. Freeze and Thaw Test: The freeze and thaw test results in Table VI were determined according to Test Method Tex-432-A. Each aggregate was sieved over the sieves indicated, after exposure to the freeze and thaw test. All values are the average of two tests. (Due to unrealistic Total Weighted Loss values, all of these values are in the process of being re-determined by re-testing.)

7. Los Angeles Abrasion Test: The first row of figures in Table VII contains the Los Angeles abrasion value of each material tested, as determined by Test Method Tex-410-A. Each Los Angeles Abrasion value is followed by the standard sieving procedure results as described previously.

The second group of data is the result of Test Method Tex-410-A using the standard 3/8" - 1/4" sample. The next set of degradation data resulted from the testing of a 5,000 gram sample for 1,000 revolutions of the Los Angeles drum.

The third group in Table VII contains test results from 3,000 gram samples after 500 revolutions of the Los Angeles drum.

The last sets of data are the result of 3,000 gram samples after 1,000 revolutions. All values are the results of two tests. Some of the

procedures were discontinued, as indicated, after evaluation of the previous results did not warrant continuation.

8. Wet Ball Mill Test: The first group in Table VIII contains the standard sieve analysis values for the materials after subjection to Test Method Tex-116-E. This group includes the tests on aggregates graded as received and on the investigation standard 3/8" - 1/4" size aggregates.

The second set of results are values after subjecting standard size samples to the wet ball procedure using 12 steel balls and 600 revolutions of the mill.

The second set of results are values after subjecting standard size samples to the wet ball procedure using 12 steel balls and 600 revolutions of the mill.

The last group of values in Table VIII result from standard size samples being tested by the wet ball procedure for 300 revolutions of the mill with 12 steel balls. All values are the average of two tests.

9. Bituminous Section Mill Test: The Bituminous Section mill consists of a Bain Marie pot clamped horizontally in a variable speed, rotating collar. In the beginning, two Bain Marie pots were used, one a conventional smooth pot, the other, a pot with four 1/2 inch square steel ribs running lengthwise of the pot. The smooth pot did not abrade the materials sufficiently to justify continuance and thus was deleted from the investigation program after use with the first material.

The speed of rotation, the time period of rotation and the condition of the sample during rotation are all indicated with their respective data in Table IX.

The procedure consisted of simply rotating a weighed sample of aggregate for the given period of time and speed, removing the material, drying those involving water and then sieving the sample.

The standard 3/8" - 1/4" size aggregates were used with this test method.

Many of these procedures were judged unnecessary and discontinued in an effort to reduce the volume of testing involved in the overall investigation. All results are the average of two tests.

10. Bituminous Section Motorized Press Test: This procedure utilizes the Bituminous Section gyratory-shear motorized molding press. For the first series of tests in Table X, the sample of aggregate was placed in the mold, the pressure increased to 150 p.s.i. gauge pressure, and the aggregate gyrated for ten sets of three gyrations, readjusting the pressure between each set of three gyrations.

The first group of tests in each series in Table X (the very last series being an exception) was made with thin neoprene discs placed as pads on the base plate of the mold, between the material and the base plate and on top of the material between the material and the ram. The second group of tests in each series was made without these pads. The materials were gyrated and then sieved through the standard sieves as recorded in Table X.

For the second series of tests, the mold was permitted to gyrate continuously for 30 gyrations, while the pressure was maintained at 150 p.s.i. gauge pressure with the hand pump. The third and fourth series of tests followed the same procedure permitting the mold to gyrate continuously for 50 and 75 gyrations respectively.

For all tests to this point in Table X, the aggregates were dry during test. The last set of data in this table results from experimentation with aggregates in a saturated, surface dry condition after 24 hours of inundation. These aggregates were gyrated continuously for 50 gyrations with a constant gauge pressure of 150 p.s.i.

The standard 3/8" - 1/4" aggregate size was used for all tests in Table X. All values are the average of two tests.

After initial experiments, procedures were eliminated to reduce the volume of testing.

11. Soils Section Motorized Press Test: This procedure was identical to the Bituminous Section Motorized Press Test just described, the only variation being that it was necessary to apply 300 p.s.i. gauge pressure to approximate the Bituminous Section press gauge pressure of 150 p.s.i.

All values are the results of two tests in Table XI.

After experimentation with the first two materials, this test was discontinued.

12. Sandblast Test: The "standard procedure" for the sandblast test data in Table XII was the test method described in "A Sandblast Abrasion Test for Synthetic Aggregate Evaluation" by James T. Houston, Asst. Professor, University of Texas at Austin and W. B. Ledbetter, Assoc. Research Engineer, Texas Transportation Institute, Research Report 81-8. The first row of figures in Table XII is the result of testing the size of aggregate required by the test method. The remaining test samples were all the standard 3/8" - 1/4" size aggregates.

The second group of tests in Table XII exposed the aggregates to 2,400 grams of sand during the sandblast and the last, 3,600 grams of sand.

All results are the average of two tests.

13. Bain Marie Pot Tests: This series of tests utilizes the 8-1/4 quart, stainless steel Bain Marie pot (described under "Apparatus" in Test Method Tex-217-F, Page 3).

The first four groups of tests in Table XIII were made with the Tyler Sieve Shaker operating at approximately 296 r.p.m. The first set of results was obtained by sieving the sample of aggregate after it had been exposed to 15 minutes of shaking. The samples were dry. The second set of tests was made by shaking the aggregates for 15 minutes while inundated. No soaking period was involved. The third set of data resulted from a 15 minute inundated shake after the aggregate had soaked for 24 hours. The fourth group of tests was made after the aggregate had soaked for 24 hours and was allowed to drain in a No. 40 sieve for 10 minutes prior to shaking.

The aggregates were shook for 15 minutes in this "drip-dry" condition.

The next series of tests were made with the equipoise shaker. The first data resulted from sieving aggregates after placing the dry samples in the Bain Marie pot and shaking it in the equipoise shaker for 15 minutes. The next two tests were identical except for the increased shaking times of 30 to 60 minutes as indicated. These 15, 30 and 60 minute shaking tests were repeated, the aggregates being inundated during test with no soaking period.

It was then decided to expose the aggregates to 30 and 60 minute shaking periods in the Tyler Sieve Shaker. The aggregates were dry during test. The results from these tests are found at the bottom of Table XIII.

The 3/8" - 1/4" standard size aggregates were used throughout these tests. All results are the average of two.

14. Direct Compression Tests: The first test in Table XIV consisted of subjecting the sample of dry aggregate to direct compression by placing the sample in a manual gyratory-shear molding press mold and applying the load at a rate of 0.20 in./min. until a total load of 5,000 lbs. was attained. The dry material was then removed and sieved.

The second bit of data resulted from taking the material retained on the 1/4" sieve from the first test, placing it in a motorized gyratory-shear molding press mold and gyrating it for 50 gyrations with a constant gauge pressure of 150 p.s.i. The aggregate was removed and sieved.

The third set of test results was obtained by sieving aggregates that had been subjected first to the direct compression procedure described for the first set of tests above and then, after this direct compression, the entire sample placed in the Bituminous Section motorized press mold and gyrated for 50 gyrations with constant 150 p.s.i. gauge pressure.

The fourth set of data resulted from sieving the aggregates after subjection to direct compression following the same procedure as the first test given above but using the double plunger mold of the immersion-compression test method.

The last data in Table XIV are the test results following the degradation of the aggregates by the British Aggregate Crushing Value Test procedure. This test method is found in "Methods for Sampling and Testing of Mineral Aggregates, Sands and Fillers," British Standard 812:1960 of the British Standards Institution. The procedure was slightly modified to fit existing laboratory equipment.

The dry aggregate was placed in a manual gyratory-shear molding press mold. A total load of 35,555 pounds is applied at a rate such that the total load is attained in 10 minutes. The aggregate is then sieved through the standard sieves for this investigation.

All results in Table XIV are the average of two tests. Many of these tests were discontinued when the data indicated that they were of little significance in evaluating the materials.

15. The New Washington Degradation Test: The first figures in Table XV are the New Washington Degradation Factors for each of the materials tested. The New Washington Test can be found in the report, "Modification of the Standard Los Angeles Abrasion Test," by Lorys J. Larson, R. P. Mathiowetz and Joe H. Smith.

The dry aggregate sample was placed in the Bain Marie pot with 200 ml. of water and shaken in the Tyler Sieve Shaker at the rate of approximately 259 r.p.m. for 20 minutes. At the conclusion of the shaking time, the pot is emptied into nested No. 10 and No. 20 sieves placed in a funnel over a 500 ml. graduate. The pot is washed out and the aggregate washed with fresh water until the graduate is filled to the 500 ml. mark.

The 500 ml. graduate with its contents are agitated by hand shaking and the contents then poured into a sand equivalent cylinder containing 7 ml. of sand equivalent stock solution. The sand equivalent cylinder is stoppered and agitated in a prescribed manner 20 times in 35 seconds. The cylinder is then placed on a table undisturbed for 20 minutes and the height of the sediment column is read and recorded. This value is used in a given formula to calculate the New Washington Degradation Factor.

The significance of this test is questionable, and it is a difficult test to perform. It was therefore discontinued after the fourth material.

British Aggregate Impact Value: The British Aggregate Impact test involves the dropping of a 30 pound "hammer" 15 inches upon a confined aggregate sample. Fifteen blows completes the test. The aggregate is dry. The complete procedure may be found in "Methods for Sampling and

Testing Mineral Aggregates, Sands and Fillers," British Standard 812:1960 of the British Standards Institution.

The Aggregate Impact Value is the percent by weight of material passing the No. 7 British Sieve (U.S. Standard No. 8).

The Aggregate Impact Value and the standard sieve analysis for each aggregate along with some check tests are recorded in Table XV. All results are the average of two tests.

VI. PROCEDURE

This investigation was officially proposed March 26, 1970. The first several months were concerned with the selection of aggregates to be submitted for test. The Materials and Tests Division of the Texas Highway Department was aware of a synthetic aggregate that had been reported as a "problem aggregate." This aggregate had yielded poor performance from a degradation standpoint and thus became a desirable material for this investigation.

The aggregate stockpile sample (R3-70-535) was brought to the laboratory, dried and prepared for testing. All synthetic aggregates involved in this investigation were prepared in the same manner.

A second aggregate (R3-70-1363) that had been reported as performing poorly in the field was sampled, delivered and processed for testing.

Samples from the major producers currently active in the production of synthetic aggregates were requested and delivered. The materials were processed for testing. All are described under materials.

As tests with these initial samples were nearing completion, the decision was made to cooperate with the Texas Transportation Institute in their Research Study 2-6-71-83. In response to this decision, samples were taken from the Research Study project site. The description of these materials is found under "Materials" in this report.

It should be noted that after considerable testing had been done with the first material, R3-70-535, a number of procedures had been discontinued and the whole test program reorganized, requiring much smaller field samples. Samples of one cubic yard proved adequate unless the particular material was very shy of a size fraction needed for the selected test methods. The preparation of the laboratory test samples was greatly simplified by this reduction of field sample size.

Throughout this period of testing new test methods, not listed in the original proposal, were added as they were discovered or developed and other tests were deleted or discontinued when it appeared that they would contribute little or nothing to the objective of the investigation.

VII. DISCUSSION

An ever increasing complaint registered with personnel of the Materials and Tests Division of the Texas Highway Department concerned the degradation and abrasion of synthetic surface treatment aggregates. Since natural aggregates are not immune to these conditions, a number of samples from some of the major natural aggregate sources were prepared and some preliminary testing done prior to the issuance of a proposal for this investigation. The purpose for this testing of natural aggregates was to

provide "standards" to which to compare later test results from the synthetic aggregates. This experimental testing was just begun when on March 26, 1970, the proposal for this investigation was issued specifying a test program. In accordance with the proposal, materials were obtained. The aggregates were prepared and tested.

A few tests were made with two natural aggregates available in the laboratory at the time of testing. These two aggregates were chosen because they are examples of the extremes in natural aggregates with respect to hardness or abrasiveness, R3-70-1362 and R3-70-210 are described under "Materials" and data from tests with these aggregates is scattered throughout the tables of data. These results provide comparative information of a sort.

Table I contains the sieve analyses of the aggregates as received, R3-70-535 was identified as a Grade 3 aggregate. All the others were identified as Grade 4 or Grade 4 Modified.

Table II lists the various specific gravities and corresponding water absorption percentages of the 3/8" - 1/4" size for each material. (The 3/8" - 1/4" size aggregate was chosen as the "standard" size for all tests in this investigation.) The table shows the comparison between specific gravity and water absorption determined by Tex-201-F and Tex-433-A. Experiments were made using a 0.01% aerosol solution instead of water with the Tex-433-A test method. The results were not altered by use of this solution, so it was discontinued. Tex-109-E provides more insight into the absorptive qualities of these synthetic aggregates.

Table III includes the standard and rodded unit weights of both the 3/8" - 1/4" size aggregate and the aggregate in its original condition, as received. These are oven dry unit weights.

Pressure slaking test values are found in Table IV. The first figures are the pressure slaking values of Test Method Tex-431-A samples size 3/4" - No. 10 and the investigation standard sample size 3/8" - 1/4" as determined with the equipoise shaker. In some instances the particle size of the sample made considerable difference in the pressure slaking value.

The "Modified I" converted value is the pressure slaking value determined according to the second portion of Tex-431-A. Preliminary tests revealed that for all practical purposes it was a duplication of the equipoise shaker method and thus discontinued.

It was decided to experiment with other methods that would duplicate the equipoise shaker results without conversion. The first effort was to stack the two pressure slaking bottles of aggregate on top of each other in a horizontal position in the Bain Marie pot. This horizontal position was to assimulate the action of the equipoise shaker. This method was unsatisfactory, for the top bottle in the pot received less agitation than the bottom bottle and consistently yielded unrealistic results. The method was discontinued.

The last experiment with pressure slaking was a second effort to duplicate the equipoise shaking action; this time giving consideration to field

laboratory use. A bracket was made to hold the pressure slaking bottles of aggregate side-by-side in the Tyler Sieve Shaker and the shaker was run at the rate of speed equal to those found in all Materials and Tests (D-9) Field Laboratories, id. est. approximately 259 r.p.m. The results in Table IV indicate that this test method may prove of value in duplicating the equipoise shaker test results with existing equipment.

In the search for a method to degrade and/or abrade synthetic aggregates, it was decided to subject the aggregates to the soundness tests. Table V contains results from both the magnesium sulfate ($MgSO_4$) and sodium sulfate (Na_2SO_4) tests, as determined by Tex-411-A. The individual values from these tests and their check tests were erratic and this coupled with some real difficulties in testing justified discontinuance of the test.

The Freeze and Thaw Test results are recorded in Table VI. A study of both the standard sieve analyses and the Total Weighted Loss values reveals inconsistancies and such extreme results that the value of this data becomes questionable. For this reason the freeze and thaw tests on the synthetic aggregates are being rerun.

The test results from the Los Angeles Abrasion test and various modifications of this test are listed in Table VII. In order to reduce the amount of testing, procedures were eliminated after the completion of tests with several materials, two test methods being retained and continued; the standard procedure, Tex-410-A, and the modification involving a sample of 3,000 gms. subjected to 500 revolutions of the drum. The modified methods do not appear to differentiate between materials any better

than the standard test method. Due to the brevity of the investigation, this statement cannot be conclusive.

Table VIII contains results from the wet ball mill test and variations of this test method. The lack of degradation by these procedures led to the discontinuance of the test method as part of the investigation.

The results from the many variations of the Bituminous Section mill tests are recorded in Table IX. This test method (described under "Test Methods and Equipment") is, for all practical purposes, a pure abrasion test. Many experiments were made with this new test method before a procedure was chosen to follow throughout the investigation. The one hour at 72 r.p.m. procedure with a dry sample was selected. Though degradation is minimal, the test does appear to separate synthetic aggregates. Its value as an accepted procedure remains to be proven by extensive testing.

The Bituminous Section motorized press test subjects the aggregate to a "grinding action," a combination of abrasion and fracture under pressure. The degradation is considerable, as can be seen from the data in Table X.

After experimenting with various procedures, the 50 gyrations at constant 150 p.s.i. gauge pressure was chosen as the test method to continue. Further testing is required to ascertain its worth in evaluating the degradable characteristics of aggregates.

It was thought that some improvement might result by subjecting a larger sample of aggregate to the gyratory-shear action, therefore, a number of experiments were made with the large gyratory-shear molding press of the

Soils Section. This procedure proved very cumbersome and was detrimental to the molding press. It was not an improvement over the Bituminous Section motorized press test method and was thus discontinued. Test results from this procedure are found in Table XI.

The sandblast test is a pure abrasion test, exposing the aggregate sample to an 80 p.s.i. blast of sand. Due to the limited degradation, the charge of sand was doubled and then tripled. Further testing is essential if the merits of this test are to be determined. From the data of this investigation, repeatability is questioned. Table XII contains the results of the sandblast tests.

Previous experience of aggregate abrasion with the Bain Marie pot led to its addition to the list of experimental tests for the investigation. A number of experimentations were made with this equipment, the results recorded in Table XIII. There was not sufficient degradation to warrant the continuation of this test after the initial work was completed.

Several methods of test involving direct compression are included in Table XIV, all being described in detail under "Test Methods and Equipment." Most of these were deleted from the investigation due to the fact that they revealed little or nothing that other tests were not already acomplishing in a better manner.

One direct compression test is believed to show merit, worthy of continuation; the British Aggregate Crushing Value Test. Some abrasion may contribute to the degradation achieved by this test method, but on the

whole, the above average degradation indicated by the results at the bottom of Table XIV, is most likely a result of particle fracture. The slow application of the rather large load causes the aggregate particles to break and re-break. This test method may prove useful, but lack of data prevents further comment.

Two test methods are included in Table XV as "Miscellaneous Tests." The first is the New Washington Degradation Test and is described under "Test Methods and Equipment." It does not differentiate between aggregates. Further work with this test method does not seem justifiable. It was discontinued early in the investigation.

The second test method in Table XV is the British Aggregate Impact Value Test. The results from this test method are encouraging with respect to judging an aggregate's particle strength. It is a very simple test utilizing a very practical piece of portable test equipment. On the negative side is the sample size. It is small. However, due to the brevity of the test procedure, a number of tests can be made in a brief period of time, somewhat overcoming the disadvantages of a small test sample. Extended experimentation with this test method is necessary for proper evaluation of its merit.

Statistical analysis of the data from this investigation is inappropriate. The amount of data for any given test or series of tests is insufficient for definite, positive conclusions. One can only attempt to visualize a "trend," which may or may not be misleading. Therefore, Table XVI has been titled "Statistical Analysis for Trends" and should be considered as such.

In order to establish a "common ground" only those test methods in which the results were evaluated by the investigation standard sieve analysis were considered for the statistical study. This study was further limited to only those test methods that were of interest for future consideration. These limitations resulted in the statistical analysis of the thirteen test procedures listed in Table XVI. The passing No. 10 sieve values were the figures chosen for statistical consideration. The individual test results were used rather than the average values recorded in all the Tables. For analysis of a particular material source, like materials from the Research Study field project and those from districts or sources were grouped. Since the Bay Prairie-Wharton (R3-71-649) material was not included in the Research Study field project, it was not included in the statistical analysis. The arithmetic mean, the standard deviation, the coefficient of variation and the range were computed for each material source for each test. The arithmetic mean ($\bar{x}$) and the coefficient of variation, Cv(%), are listed in Table XVI for consideration as indicative of statistical trends.

From a numerical standpoint, the coefficient of variation defines repeatability, therefore, from a purely numerical analysis of the data the freeze and thaw test is totally unacceptable as a control test method for synthetic aggregates. Table XVI contains some excessively high coefficients of variation leading to the assumption that those particular tests have poor repetitive characteristics. In some instances, these coefficients of variation are out of proportion with reality. Due to the non-homogeneousness of aggregates and aggregate sources, and due to the all but impossible

task of selecting test samples that truly represent the whole, many variables are introduced into test results for which the test procedure is not responsible. For accurate analysis of these procedures much more data is deemed necessary. However, if trends are indicative of fact, the freeze and thaw test must be suspect with regard to repeatability, for the poor performance is rather consistant.

The results of the arithmetic mean recorded in Table XVI have been plotted on graph paper, the points being connected with straight lines. This provides for a visual analysis of these statistical results. This plot shows the order or relationship of one material to another with respect to its response to a given test method. From this plot and this data, it becomes obvious that, except for one or two exceptions, the four materials are "paired off;" two of them responding to the abuse of most test methods considerably better than the other two. Though the order sometimes changes between abrasive tests and fracture tests, more times than not the aggregates respond in pairs. This justifies a conclusion: The Clodine and Dallas source materials are similar with regard to particle strength and resistance to abrasion and the Eastland and Ranger source materials are similar in like manner, as determined from analysis of this brief data. The future may completely disqualify this conclusion, for it is rather premature, being based upon a minimal of information.

APPENDIX

TABLE I

SIEVE ANALYSIS

(% By Wt.)

Test Method & Size	R3-70-535 T.I., Clodine	R3-70-1363 T.I., Eastland	R3-71-139 Feath.-Ranger	R3-71-513 T.I., Dallas	R3-71-649 Bay Prairie-Wharton	R3-71-659 T.I., Clodine*	R3-71-660 T.I., Dallas*	R3-71-661 T.I., Eastland*	R3-71-663 Feath.-Ranger*
Tex-200-F									
Ret. 5/8"	0	0	0	0	0	0	0	0	0
Ret. 1/2"	3.9	0.3	2.3	4.3	0	0	0.8	0	0
Ret. 3/8"	72.6	21.1	38.5	35.1	48.8	8.7	55.5	52.8	46.6
Ret. 1/4"	95.8	74.8	82.2	77.8	98.3	59.4	92.6	97.0	92.7
Ret. No. 4	97.7	91.0	94.6	88.7	99.2	86.2	96.5	97.9	97.7
Ret. No. 10	99.0	98.1	99.7	97.1	99.4	97.4	99.1	98.7	99.0

*Research Study 2-6-71-83 (Dist. 14)

TABLE II

SPECIFIC GRAVITY & WATER ABSORPTION

Aggregate Size = 3/8" - 1/4"

Test Method	R3-70-535 T.I., Clodine	R3-70-1363 T.I., Eastland	R3-71-139 Feath.-Ranger	R3-71-513 T.I., Dallas	R3-71-649 Bay Prairie-Wharton	R3-71-659 T.I., Clodine*	R3-71-660 T.I., Dallas*	R3-71-661 T.I., Eastland*	R3-71-663 Feath.-Ranger*
Tex-201-F									
Sp. Gravity	1.409	1.588	1.528	1.082	1.800	1.630	1.113	1.493	1.556
Absorp. (% By Wt.)	19.2	6.3	8.3	21.9	9.4	12.7	21.4	7.0	6.6
Tex-433-A									
Sp. Gravity	1.576	1.627	1.575	1.163	1.985	1.788	1.202	1.516	1.611
Absorp. (% By Wt.)	10.8	5.3	5.9	15.7	3.7	6.9	14.5	5.4	4.8
0.01% Aerosol Solution									
Sp. Gravity	1.562	1.624	1.572	--	--	--	--	--	--
Absorp. (% By Wt.)	10.7	4.5	5.4	--	--	--	--	--	--
Tex-109-E									
Sp. Gravity	2.223	2.163	2.236	2.073	2.346	2.301	2.039	2.127	2.170
Absorp. (% By Wt.)	27.9	16.0	16.3	34.7	12.4	15.5	32.4	17.3	15.8

*Research Study 2-6-71-83 (Dist. 14)

TABLE III

UNIT WEIGHT

(lbs./ft.^{3})

Test Method & Size	R3-70-535 T.I., Clodine	R3-70-1363 T.I., Eastland	R3-71-139 Feath.-Ranger	R3-71-513 T.I., Dallas	R3-71-649 Bay Prairie-Wharton	R3-71-659 T.I., Clodine*	R3-71-660 T.I., Dallas*	R3-71-661 T.I., Eastland*	R3-71-663 Feath.-Ranger*
Tex-404-A									
Standard 3/8" - 1/4"	46.25	52.87	51.22	35.60	57.85	54.36	35.75	49.58	52.17
Rodded 3/8" - 1/4"	47.71	54.70	52.69	37.99	60.78	56.30	36.71	51.67	53.66
Standard-as received	47.45	53.61	52.17	38.72	58.11	56.60	36.54	49.49	52.63
Rodded-as received	48.87	55.76	54.34	40.11	60.89	58.15	38.40	51.59	54.76

*Research Study 2-6-71-83 (Dist. 14)

TABLE IV

PRESSURE SLAKING TEST

(Loss, % By Wt.)

Test Method & Size	R3-70-535 T.I., Clodine	R3-70-1363 T.I., Eastland	R3-71-139 Feath.-Ranger	R3-71-513 T.I., Dallas	R3-71-649 Bay Prairie-Wharton	R3-71-659 T.I., Clodine*	R3-71-660 T.I., Dallas*	R3-71-661 T.I., Eastland*	R3-71-663 Feath.-Ranger*
Tex-431-A Equipoise Shaker									
3/4" - No. 10	3.1	1.4	1.9	3.9	4.3	2.9	1.8	1.8	2.4
3/8" - 1/4"	2.7	1.1	1.9	2.5	3.7	2.4	2.5	1.9	1.8
Mod. I; Converted Value									
3/4" - No. 10.	1.9	1.5	---	---	---	---	---	---	---
3/8" - 1/4"	2.8	0.9	---	---	---	---	---	---	---
Mod. I; Bottles Horizontal, stacked vertically. (Value not converted)									
3/4" - No. 10	2.2	0.9	---	---	---	---	---	---	---
3/8" - 1/4"	1.9	0.6	---	---	---	---	---	---	---
Mod. I., Bottles Horizontal side-by-side 35 min. shake (Value not converted)									
3/4" - No. 10	3.6	1.4	1.8	3.6	4.8	3.1	2.7	1.6	2.3
3/8" - 1/4"	3.3	1.5	1.5	2.8	4.1	3.1	3.0	1.5	1.5

*Research Study 2-6-71-83 (Dist. 14)

TABLE V
SOUNDNESS TEST
(% By Wt.)

Test Method & Size	R3-70-535 T.I., Clodine		R3-70-1363 T.I., Eastland		R3-71-139 Feath.-Ranger		R3-71-513 T.I., Dallas	R3-71-649 Bay Prairie-Wharton	R3-71-659 T.I., Clodine*	R3-71-660 T.I., Dallas*	R3-71-661 T.I., Eastland*	R3-71-663 Feath.-Ranger*
	$MgSO_4$	Na_2SO_4	$MgSO_4$	Na_2SO_4	$MgSO_4$	Na_2SO_4						
Tex-411-A												
3/4" - 3/8" Sample												
Soundness Value	3.9	26.1	0.8	0.4	1.0	0.6						
Pass 1/4"	3.5	21.4	0.4	0.3	0.6	0.3	-	-	-	-	-	-
Pass No. 10	2.6	15.2	0.2	0.2	0.2	0.1						
Pass No. 40	1.7	12.1	0	0	0	0						
3/8" - No. 4 Sample												
Soundness Value	4.5	12.2	1.2	0.7	3.2	1.4						
Pass 1/4"	14.2	28.7	75.9	82.0	42.2	41.6	-	-	-	-	-	-
Pass No. 10	4.0	5.4	0.7	0.3	0.5	0.7						
Pass No. 40	3.0	2.2	0.3	0	0.4	0.2						
3/8" - 1/4" Sample												
Soundness Value	4.5	13.4	1.8	1.2	1.5	0.9						
Pass 1/4"	7.8	27.8	8.4	15.1	3.2	2.2	-	-	-	-	-	-
Pass No. 10	3.9	6.2	1.0	0.7	0.9	0.3						
Pass No. 40	2.7	2.7	0.7	0.4	0	0						
Check Test												
3/8" - 1/4" Sample												
Soundness Value	3.5	0.5	-	-	-	-						
Pass 1/4"	6.5	1.8	-	-	-	-	-	-	-	-	-	-
Pass No. 10	3.0	0.3	-	-	-	-						
Pass No. 40	2.2	0	-	-	-	-						
Second Check Test												
3/8" - 1/4" Sample												
Soundness Value	-	1.0	-	-	-	-						
Pass 1/4"	-	11.7	-	-	-	-	-	-	-	-	-	-
Pass No. 10	-	11.1	-	-	-	-						
Pass No. 40	-	0	-	-	-	-						
Third Check Test												
3/4" - 3/8" Sample												
Soundness Value	-	0.3	-	-	-	-						
Pass 1/4"	-	0.3	-	-	-	-	-	-	-	-	-	-
Pass No. 10	-	0.2	-	-	-	-						
Pass No. 40	-	0	-	-	-	-						
3/8" - No. 4 Sample												
Soundness Value	-	1.2	-	-	-	-						
Pass 1/4"	-	5.5	-	-	-	-	-	-	-	-	-	-
Pass No. 10	-	0.5	-	-	-	-						
Pass No. 40	-	0	-	-	-	-						

*Research Study 2-6-71-83 (Dist. 14)

TABLE VI

FREEZE & THAW TEST

(% By Wt.)

Test Method & Size	R3-70-535 T.I., Clodine	R3-70-1363 T.I., Eastland	R3-71-139 Feath.-Ranger	R3-71-513 T.I., Dallas	R3-71-649 Bay Prairie-Wharton	R3-71-659 T.I., Clodine*	R3-71-660 T.I., [illegible]	R3-71-661 T.I., Eastland	R3-71-663 Feath.-Ranger*	R3-70-1362 Trap Rock	R3-70-210 T.C.S., "Soft Rock"
Tex-432-A											
5/8" - 1/2" Sample					Size not	Size not		Size not	Size not		
Actual Loss, Pass 1/2"	75.6	27.9	34.1	69.2	available	available	72.1	available	available		
Pass 1/4"	37.1	14.9	1.8	23.8	in sample	in sample	26.8	in sample	in sample	-	-
Pass No. 10	19.7	2.5	0.9	8.3			10.3				
Pass No. 40	7.2	0.8	0.3	2.0			3.2				
1/2" - 3/8" Sample											
Actual Loss, Pass 3/8"	67.2	6.5	11.5	72.8	20.4	47.3	60.9	31.9	9.7		
Pass 1/4"	46.4	3.5	2.2	34.2	7.9	7.7	27.3	2.9	1.4		
Pass No. 10	23.9	1.8	1.1	12.4	4.6	3.6	10.4	1.8	0.9		
Pass No. 40	9.2	0.5	0	4.0	1.6	1.4	3.3	0.6	0.3		
3/8" - No. 4 Sample											
Actual Loss, Pass No. 4	43.4	8.4	5.2	34.8	9.6	8.1	22.0	3.6	1.8		
Pass 1/4"	53.2	96.6	100.0	55.1	11.6	40.8	35.6	6.1	8.6		
Pass No. 10	29.9	3.6	2.0	15.2	6.4	3.4	9.5	1.8	0.5		
Pass No. 40	15.5	1.2	0	6.9	2.1	1.4	3.2	0.7	0		
Total Weighted Loss	61.4	8.1	8.3	49.7	14.9	12.1	44.5	18.9	5.5		
3/8" - 1/4" Sample											
Actual Loss, Pass 1/4"	55.4	5.1	15.0	54.3	10.9	19.1	35.4	1.6	7.1	4.8	10.0
Pass 1/4"	55.4	5.1	15.0	54.3	10.9	19.1	35.4	1.6	7.1	4.8	10.0
Pass No. 10	33.9	1.4	4.3	12.7	6.6	4.2	10.3	1.5	1.0	0.8	3.0
Pass No. 40	13.8	0	0.5	4.9	0.7	1.0	5.7	0.3	0	0	1.5
Check Tests											
5/8" - 1/2" Sample											
Actual Loss, Pass 1/2"	44.8										
Pass 1/4"	17.1	-	-	-	-	-	-	-	-	-	-
Pass No. 10	8.8										
Pass No. 40	4.6										
1/2" - 3/8" Sample											
Actual Loss, Pass 3/8"	48.9										
Pass 1/4"	28.0	-	-	-	-	-	-	-	-	-	-
Pass No. 10	14.4										
Pass No. 40	6.4										
3/8" - No. 4 Sample											
Actual Loss, Pass No. 4	22.2										
Pass 1/4"	37.0	-	-	-	-	-	-	-	-	-	-
Pass No. 10	14.8										
Pass No. 40	7.4										
Total Weighted Loss	41.9										
3/8" - 1/4" Sample											
Actual Loss, Pass 1/4"	33.8										
Pass 1/4"	33.8	-	-	-	-	-	-	-	-	-	-
Pass No. 10	15.3										
Pass No. 40	8.8										

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TABLE VII

LOS ANGELES ABRASION TEST

(% By. Wt.)

Test Method & Size	R3-70-535 T.I., Clodine	R3-70-1363 T.I., Eastland	R3-71-139 Feath.-Ranger	R3-71-513 T.I., Dallas	R3-71-649 Bay Prairie-Wharton	R3-71-659 T.I., Clodine*	R3-71-660 T.I., Dallas*	R3-71-661 T.I., Eastland*	R3-71-663 Feath.-Ranger*	R3-70-1362 Trap Rock	R3-70-210 T.C.S., "Soft Rock"
Tex-410-A											
3/8" - No. 4 Sample											
Los Angeles Abrasion Value	28.2	22.3	21.7	20.6	Size not	26.0	20.8	20.8	22.2		
Pass 1/4"	89.7	85.4	86.1	87.0	available	91.0	86.6	81.2	85.4		
Pass No. 10	31.8	25.5	24.7	24.6	in sample	30.8	24.9	24.0	25.9		
Pass No. 40	13.9	9.8	10.8	8.1		11.9	8.0	9.5	11.4		
3/8" - 1/4" Sample											
Los Angeles Abrasion Value	28.7	22.2	20.3	19.8	31.0	26.6	20.1	20.1	21.4	8.9	34.9
Pass 1/4"	79.7	73.3	71.9	74.3	84.0	84.3	76.0	64.4	70.1	35.9	81.3
Pass No. 10	32.0	25.4	23.6	23.9	35.1	31.2	24.9	23.4	25.0	10.0	37.8
Pass No. 40	14.4	10.2	19.8	7.1	15.2	12.2	8.1	9.8	11.5	4.8	23.1
5,000 gms.-1,000 rev.											
3/8" - No. 4 Sample											
Los Angeles Abrasion	47.4	39.9	37.1	36.8							
Pass 1/4"	97.9	92.6	96.1	96.6	-	-	-	-	-	-	-
Pass No. 10	52.8	45.2	42.8	43.3							
Pass No. 40	24.1	18.7	17.0	14.4							
3/8" - 1/4" Sample											
Los Angeles Abrasion Value	47.7	39.7	37.3	36.9						15.8	56.5
Pass 1/4"	96.5	92.5	92.2	92.4	-	-	-	-	-	54.2	96.8
Pass No. 10	53.7	45.3	42.7	43.2						19.5	60.7
Pass No. 40	24.8	17.8	17.7	15.1						8.8	39.4
3,000 gms.-500 rev.											
3/8" - No. 4 Sample											
Los Angeles Abrasion Value	42.2	31.2	29.6	31.8	Size not	32.0	31.3	30.2	31.2		
Pass 1/4"	97.9	93.2	93.3	95.3	available	97.0	94.7	90.1	92.5	-	-
Pass No. 10	47.4	35.6	34.3	38.0	in sample	39.3	36.8	35.4	36.7		
Pass No. 40	19.9	14.1	13.2	13.4		13.3	9.0	13.3	15.5		
3/8" - 1/4" Sample											
Los Angeles Abrasion Value	41.7	31.8	28.7	31.8	34.1	32.7	31.6	28.	30.5	9.5	33.5
Pass 1/4"	94.5	86.0	85.6	90.4	89.5	92.9	89.8	77.9	83.3	33.8	72.9
Pass No. 10	45.9	35.5	33.5	37.9	39.4	38.4	37.3	33.4	35.0	10.9	35.6
Pass No. 40	19.7	14.1	13.1	11.8	16.6	14.7	10.1	12.8	15.5	5.5	24.4
3,000 gms.-1,000 rev.											
3/8" - No. 4 Sample											
Los Angeles Abrasion Value	69.7	53.7	51.1	56.3							
Pass 1/4"	100.0	98.9	98.9	99.6	-	-	-	-	-	-	-
Pass No. 10	75.8	60.9	58.2	64.0							
Pass No. 40	34.6	23.7	23.3	22.6							
3/8" - 1/4" Sample											
Los Angeles Abrasion Value	67.6	52.8	49.6	61.3						16.9	68.5
Pass 1/4"	99.8	97.5	97.2	99.4	-	-	-	-	-	50.3	98.3
Pass No. 10	74.2	58.7	56.3	69.2						19.4	73.2
Pass No. 40	33.9	24.7	23.2	28.2						10.4	45.0

*Research Study 2-6-71-83 (Dist. 14)

TABLE VIII

WET BALL MILL TEST

(% By Wt.)

Test Method & Size	R3-70-535 T.I., Clodine	R3-70-1363 T.I., Eastland	R3-71-139 Feath.-Ranger	R3-71-513 T.I., Dallas	R3-71-649 Bay Prairie-Wharton	R3-70-1362 Trap Rock	R3-70-210 T.C.S., "Soft Rock"
Tex-116-E							
Standard-as received							
Pass 1/4"	20.6	42.7	38.8	35.9			
Pass No. 10	7.1	6.3	5.7	7.1	-	-	-
Pass No. 40	4.7	2.8	2.9	3.6			
3/8" - 1/4" Sample							
Pass 1/4"	25.6	33.8	33.2	41.2		35.1	45.5
Pass No. 10	6.8	4.8	4.7	5.5	-	3.5	13.9
Pass No. 40	4.3	2.4	2.6	2.8		1.7	10.2
600 rev.- 12 steel balls							
3/8" - 1/4" Sample							
Pass 1/4"	51.6	50.4	47.1	56.4		46.9	64.2
Pass No. 10	13.7	9.9	9.0	9.6	-	6.4	25.4
Pass No. 40	7.0	4.1	4.3	4.0		2.8	16.8
300 rev.-12 steel balls							
Pass 1/4"	33.8	39.7	35.2	38.1		35.7	44.0
Pass No. 10	7.4	5.5	4.9	5.1	-	3.7	13.0
Pass No. 40	3.8	2.3	2.3	2.2		1.7	8.7

TABLE IX

BITUMINOUS SECTION MILL TEST

Aggregate Size = 3/8" - 1/4"

(% By Wt.)

Test Method & Size	R3-70-535 T.I., Clodine		R3-70-1363 T.I., Eastland	R3-71-139 Feath.-Ranger	R3-71-513 T.I., Dallas	R3-71-649 Bay Prairie-Wharton	R3-71-659 T.I., Clodine*	R3-71-660 T.I., Dallas*	R3-71-661 T.I., Eastland*	R3-71-663 Feath.-Ranger*
1 hr. @48 rpm-Dry	Ribbed	Smooth	Ribbed Pot	Ribbed Pot	Ribbed Pot	Ribbed Pot	Ribbed Pot	Ribbed Pot	Ribbed Pot	Ribbed Pot
Pass 1/4"	11.0	3.4	21.1	16.0	13.0					
Pass No. 10	6.2	0.9	4.2	3.4	1.7	-	-	-	-	-
Pass No. 40	5.7	0.8	3.5	3.1	1.3					
1 hr. @48 rpm-Inundated										
Pass 1/4"	7.5	2.8	7.5							
Pass No. 10	3.3	0.9	1.4	-	-	-	-	-	-	-
Pass No. 40	1.8	0.8	1.3							
2 hrs. @48 rpm-Dry										
Pass 1/4"	14.9	3.4	16.1	18.8	12.7					
Pass No. 10	7.2	1.0	2.5	4.2	1.7	-	-	-	-	-
Pass No. 40	6.5	0.8	1.9	3.8	1.2					
2 hrs. @48 rpm-Inundated										
Pass 1/4"	9.4	3.3	11.1							
Pass No. 10	6.1	1.7	3.2	-	-	-	-	-	-	-
Pass No. 40	5.2	1.6	2.9							
1 hr. @72 rpm-Dry										
Pass 1/4"	13.8	4.6	24.1	22.2	19.0	15.2	28.1	14.6	7.5	20.2
Pass No. 10	8.0	1.6	4.9	5.9	3.2	9.6	7.4	4.0	5.3	5.8
Pass No. 40	7.3	1.4	4.2	5.4	2.5	8.6	6.3	3.0	4.7	5.4
1 hr. @72 rpm-Inundated										
Pass 1/4"	11.8	2.8	8.3							
Pass No. 10	5.8	1.1	2.5	-	-	-	-	-	-	-
Pass No. 40	5.5	1.1	2.4							
2 hrs. @72 rpm-Dry										
Pass 1/4"	19.1	3.5	17.5	27.4	22.8					
Pass No. 10	11.8	1.4	7.0	8.1	4.3	-	-	-	-	-
Pass No. 40	11.0	1.2	6.2	7.5	3.5					
2 hrs. @72 rpm-Inundated										
Pass 1/4"	16.0	4.4	18.5							
Pass No. 10	10.8	2.7	4.2	-	-	-	-	-	-	-
Pass No. 40	10.4	2.6	4.0							
1 hr. @92 rpm-Dry										
Pass 1/4"	11.8	3.2	21.9	19.7	16.9					
Pass No. 10	7.1	1.7	4.7	5.1	2.7	-	-	-	-	-
Pass No. 40	6.4	1.5	4.0	4.6	1.8					
1 hr. @92 rpm-Inundated										
Pass 1/4"	13.8	2.9	11.2							
Pass No. 10	7.8	1.6	4.0	-	-	-	-	-	-	-
Pass No. 40	4.6	1.4	3.7							
2 hrs. @92 rpm-Dry										
Pass 1/4"	18.4	4.9	20.2	30.1	22.3					
Pass No. 10	10.3	1.8	6.4	8.2	5.2	-	-	-	-	-
Pass No. 40	9.4	1.5	5.6	7.6	4.3					
2 hrs. @92 rpm-Inundated										
Pass 1/4"	18.9	5.5	20.0							
Pass No. 10	12.3	3.9	6.7	-	-	-	-	-	-	-
Pass No. 40	11.9	3.7	6.5							

*Research Study 2-6-71-83 (Dist. 14)

TABLE X

BITUMINOUS SECTION MOTORIZED PRESS TEST

Aggregate Size = 3/8" - 1/4"

(% By Wt.)

Test Method & Size	R3-70-535 T.I., Clodine	R3-70-1363 T.I., Eastland	R3-71-139 Feath.-Ranger	R3-71-513 T.I., Dallas	R3-71-649 Bay Prairie-Wharton	R3-71-659 T.I., Clodine*	R3-71-660 T.I., Dallas*	R3-71-661 T.I., Eastland*	R3-71-663 Feath.-Ranger*	R3-70-1362 Trap Rock	R3-70-210 T.C.S., "Soft Rock"
10 sets of 3 gyr. @150 psi											
With neoprene pads											
Pass 1/4"	53.2	40.3	48.1	58.8						18.7	28.5
Pass No. 10	19.7	12.6	15.1	17.9	-	-	-	-	-	5.8	11.8
Pass No. 40	8.0	4.4	5.7	5.4						2.2	6.1
Without neoprene pads											
Pass 1/4"	54.1	35.8	43.9	56.6						17.6	27.6
Pass No. 10	19.5	11.3	13.8	17.0	-	-	-	-	-	4.7	11.1
Pass No. 40	8.0	3.9	4.9	5.0						1.8	5.9
30 gyr. @ constant 150 psi											
With neoprene pads											
Pass 1/4"	58.3	48.5	54.3	70.1						17.9	38.7
Pass No. 10	24.7	17.9	18.5	27.9	-	-	-	-	-	4.5	18.9
Pass No. 40	10.8	6.3	7.4	9.8						1.6	10.0
Without neoprene pads											
Pass 1/4"	64.8	55.9	57.5	71.6						20.9	45.7
Pass No. 10	26.8	23.1	21.6	30.9	-	-	-	-	-	5.6	23.2
Pass No. 40	12.0	9.0	9.0	11.8						2.1	13.0
50 gyr. @ constant 150 psi											
With neoprene pads											
Pass 1/4"	66.4	56.2	61.7	75.6	59.6	71.5	76.3	48.0	58.7	23.9	46.1
Pass No. 10	31.5	24.1	25.0	34.1	29.1	28.5	35.3	26.3	26.2	7.2	25.5
Pass No. 40	15.8	10.5	11.4	13.7	15.1	13.7	13.9	13.0	12.8	3.0	15.4
Without neoprene pads											
Pass 1/4"	67.3	66.9	65.0	77.1	65.2	72.6	77.6	51.1	57.9	26.7	48.4
Pass No. 10	32.1	29.5	28.0	37.1	33.6	31.4	37.5	28.3	28.0	8.2	26.1
Pass No. 40	16.1	14.0	13.5	16.9	18.0	15.5	15.4	13.8	14.1	3.3	15.6
75 gyr. @ constant 150 psi											
With neoprene pads											
Pass 1/4"	67.3										
Pass No. 10	34.6	-	-	-	-	-	-	-	-	-	-
Pass No. 40	18.9										
Without neoprene pads											
Pass 1/4"	70.9										52.8
Pass No. 10	38.8	-	-	-	-	-	-	-	-	-	29.8
Pass No. 40	21.9										18.8
50 gyr. @constant 150 psi											
Without neoprene pads											
Sample S.S.D. after 24 hr. soak											
Pass 1/4"	72.3	63.5	67.9								
Pass No. 10	35.5	29.2	27.0	-	-	-	-	-	-	-	-
Pass No. 40	16.2	11.8	11.1								

*Research Study 2-6-71-83 (Dist. 14)

TABLE XI

SOILS SECTION MOTORIZED PRESS TEST

Aggregate Size = 3/8" - 1/4"

(% By Wt.)

Test Method & Size	R3-70-535 T.I., Clodine	R3-70-1363 T.I., Eastland	R3-71-139 Feath.-Ranger	R3-71-513 T.I., Dallas	R3-71-649 Bay Prairie-Wharton	R3-70-1362 Trap Rock
10 sets of 3 gyr. @ 300 psi						
With neoprene pads						
Pass 1/4"	44.5	33.7				10.7
Pass No. 10	13.4	8.1	-	-	-	1.9
Pass No. 40	4.9	2.5				0.7
Without neoprene pads						
Pass 1/4"	47.3	34.6				10.2
Pass No. 10	14.4	9.0	-	-	-	2.0
Pass No. 40	5.4	2.9				0.8
30 gyr. @ constant 300 psi						
With neoprene pads						
Pass 1/4"	56.5	46.1				13.0
Pass No. 10	20.3	14.2	-	-	-	3.2
Pass No. 40	8.1	4.6				1.1
Without neoprene pads						
Pass 1/4"	59.0	49.2				16.6
Pass No. 10	22.2	16.8	-	-	-	4.4
Pass No. 40	9.0	5.8				1.6
50 gyr. @ constant 300 psi						
With neoprene pads						
Pass 1/4"	58.8	50.0				14.1
Pass No. 10	22.7	18.1	-	-	-	3.9
Pass No. 40	9.7	6.4				1.5
Without neoprene pads						
Pass 1/4"	61.1	53.5				20.6
Pass No. 10	25.3	20.2	-	-	-	6.0
Pass No. 40	11.4	8.1				2.4
75 gyr. @ constant 300 psi						
With neoprene pads						
Pass 1/4"	60.3					
Pass No. 10	25.0	-	-	-	-	-
Pass No. 40	11.0					
Without neoprene pads						
Pass 1/4"	66.0					
Pass No. 10	30.5	-	-	-	-	-
Pass No. 40	15.1					

TABLE XII

SANDBLAST TEST

(% By Wt.)

Test Method & Size	R3-70-535 T.I., Clodine	R3-70-1363 T.I., Eastland	R3-71-139 Feath.-Ranger	R3-71-513 T.I., Dallas	R3-71-649 Bay Prairie-Wharton	R3-71-659 T.I., Clodine*	R3-71-660 T.I., Dallas*	R3-71-661 T.I., Eastland*	R3-71-663 Feath.-Ranger*
Standard Procedure									
1/2" - No. 4 Sample	3.6	1.3	1.2	3.1	7.7	2.3	2.7	1.8	2.3
3/8" - 1/4" Sample	3.3	2.4	1.8	3.0	4.2	2.5	2.1	2.3	2.9
2,400 gms. sand									
3/8" - 1/4" Sample	6.6	3.6	2.5	5.7	7.7	4.6	7.1	4.0	7.4
3,600 gms. Sand									
3/8" - 1/4" Sample	7.7	6.2	4.9	6.9	9.6	5.9	9.7	5.5	9.8

*Research Study 2-6-71-83 (Dist. 14)

TABLE XIII

BAIN MARIE POT TESTS

Aggregate Size - 3/8" - 1/4"

(% By Wt.)

Test Method & Size	R3-70-535 T.I., Clodine	R3-70-1363 T.I., Eastland	R3-71-139 Feath.-Ranger	R3-71-513 T.I., Dallas	R3-71-649 Bay Prairie-Wharton
Tyler Sieve Shaker					
15 min. Shake-Sample dry					
Pass 1/4"	5.4	9.8	10.6	6.9	
Pass No. 10	2.3	1.0	1.4	0.5	-
Pass No. 40	2.1	0.8	1.3	0.3	
15 min. Shake- Sample inundated- no soak					
Pass 1/4"	4.9	9.6	6.6		
Pass No. 10	2.2	0.8	1.2	-	-
Pass No. 40	1.8	0.7	1.1		
15 min. Shake-Sample inundated- 24 hr. soak					
Pass 1/4"	4.7	7.5	4.8		
Pass No. 10	2.0	0.9	1.0	-	-
Pass No. 40	1.8	0.7	0.9		
15 min. shake-Sample "drip dry"- 24 hr. soak, 10 min. drain					
Pass 1/4"	5.6	6.6	7.1		
Pass No. 10	2.9	0.7	1.6	-	-
Pass No. 40	2.8	0.6	1.5		
Equipoise Shaker					
15 min. Shake-Sample dry					
Pass 1/4"	5.2	11.0	8.5	6.3	
Pass No. 10	1.9	0.7	1.1	0.6	-
Pass No. 40	1.7	0.4	1.0	0.4	
30 min. Shake-Sample dry					
Pass 1/4"	6.1	13.5	9.1	6.6	
Pass No. 10	2.7	0.9	1.5	0.5	-
Pass No. 40	2.4	0.6	1.3	0.3	
60 min. Shake-Sample Dry					
Pass 1/4"	7.1	17.6	9.4	7.4	
Pass No. 10	3.4	0.8	1.4	0.6	-
Pass No. 40	3.1	0.5	1.2	0.3	
15 min. Shake-Sample inundated- no soak					
Pass 1/4"	5.0	12.9	7.6		
Pass No. 10	2.2	0.8	0.8	-	-
Pass No. 40	2.0	0.7	0.7		
30 min. Shake-Sample inundated- no soak					
Pass 1/4"	8.6	11.4	7.7		
Pass No. 10	4.3	1.3	1.9	-	-
Pass No. 40	4.0	1.1	1.7		
60 min. Shake-Sample inundated- no soak					
Pass 1/4"	10.6	13.7	10.0		
Pass No. 10	6.0	2.3	3.2	-	-
Pass No. 40	5.7	2.1	2.9		
Tyler Sieve Shaker					
30 min. Shake-Sample Dry					
Pass 1/4"	5.0	10.7	9.3	6.4	
Pass No. 10	2.9	1.2	1.7	0.5	-
Pass No. 40	2.5	1.0	1.5	0.2	
60 min. Shake-Sample Dry					
Pass 1/4"	6.1	11.9	10.8	6.3	
Pass No. 10	3.4	1.1	1.5	0.6	-
Pass No. 40	3.0	0.7	1.1	0.2	

TABLE XIV

DIRECT COMPRESSION TESTS

Aggregate Size = 3/8" - 1/4"

(% By Wt.)

Test Method & Size	R3-70-535 T.I., Clodine	R3-70-1363 T.I., Eastland	R3-71-139 Feath.-Ranger	R3-71-513 T.I., Dallas	R3-71-649 Bay Prairie-Wharton	R3-71-659 T.I., Clodine*	R3-71-660 T.I., Dallas*	R3-71-661 T.I., Eastland*	R3-71-663 Feath.-Ranger*	R3-70-210 T.C.S., "Soft Rock"
Manual press mold-direct compr. @0.2 in./min. to 5,000 lbs.										
Pass 1/4"	38.6	34.0	34.3	49.3						72.1
Pass No. 10	8.6	4.1	5.2	9.9	-	-	-	-	-	3.9
Pass No. 40	2.1	0.8	1.1	1.6						1.3
Ret. 1/4" from above-Bit. Sec. motorized press- 50 gyr.-constant 150 psi										
Pass 1/4"	51.5									46.6
Pass No. 10	19.2	-	-	-	-	-	-	-	-	25.3
Pass No. 40	7.9									14.7
Same as first sample above, then after direct compr. total sample placed in Bit. Sec. motorized press mold-50 gyr.-constant 150 psi										
Pass 1/4"	74.6	66.2	62.4	82.4						55.0
Pass No. 10	38.2	28.8	29.8	40.4	-	-	-	-	-	30.8
Pass No. 40	19.3	13.2	13.9	16.1						18.9
Same procedure as first sample above but using immers.-compr. equipment										
Pass 1/4"	37.7	35.8								
Pass No. 10	7.8	5.0	-	-	-	-	-	-	-	-
Pass No. 40	2.1	1.0								
British Aggr. Crushing Value Test										
Pass 1/4"	75.5	76.9	79.0	89.9	83.4	80.0	84.6	75.0	73.4	
Pass No. 10	38.9	33.9	33.6	49.4	40.5	36.5	49.7	34.2	31.7	
Pass No. 40	14.7	10.4	11.2	16.6	14.6	12.6	15.6	11.1	11.2	

*Research Study 2-6-71-83 (Dist. 14)

TABLE XV

MISCELLANEOUS TESTS

(% By Wt.)

Test Method & Size	R3-70-535 T.I., Clodine	R3-70-1363 T.I., Eastland	R3-71-139 Feath.-Ranger	R3-71-513 T.I., Dallas	R3-71-649 Bay Prairie-Wharton	R3-71-659 T.I., Clodine*	R3-71-660 T.I., Dallas*	R3-71-661 T.I., Eastland	R3-71-663 Feath.-Ranger*	R3-70-210 T.C.S., "Soft Rock"
The New Washington Degradation Factor	88	96	96	88	-	-	-	-	-	35
British Aggregate Impact Value										
1/2"-3/8" Sample										
Aggr. Impact Value	38	26	25	45	34	37	44	31	36	19
Pass 1/4"	69.4	52.3	53.4	75.1	64.9	65.8	74.7	56.4	63.3	38.9
Pass No. 10	34.0	22.9	22.3	39.4	30.8	33.2	39.3	27.5	32.7	17.7
Pass No. 40	11.7	7.3	6.7	14.3	11.9	12.0	12.7	9.2	12.5	7.8
3/8"-1/4" Sample										
Aggr. Impact Value	41	34	33	49	37	36	42	34	35	32
Pass 1/4"	76.3	73.0	76.2	82.4	73.7	80.4	83.5	65.4	73.7	66.3
Pass No. 10	37.2	30.3	29.1	41.8	33.5	33.3	39.4	30.2	32.7	29.1
Pass No. 40	14.1	9.6	9.5	14.4	13.4	11.5	12.1	10.8	12.1	13.3
Check Test										
1/2"-3/8" Sample										
Aggr. Impact Value	29								37	
Pass 1/4"	57.6								67.4	
Pass No. 10	26.1								34.4	
Pass No. 40	8.8								13.0	
3/8"-1/4" Sample										
Aggr. Impact Value	36								24	
Pass 1/4"	75.0								61.1	
Pass No. 10	32.7								21.0	
Pass No. 40	11.7								6.6	
Second Check Test										
1/2"-3/8" Sample										
Aggr. Impact Value	36									
Pass 1/4"	61.8									
Pass No. 10	31.9									
Pass No. 40	11.9									
3/8"-1/4" Sample										
Aggr. Impact Value									36	
Pass 1/4"									75.9	
Pass No. 10									32.7	
Pass No. 40									11.5	

*Research Study 2-6-71-83 (Dist. 14)

TABLE XVI

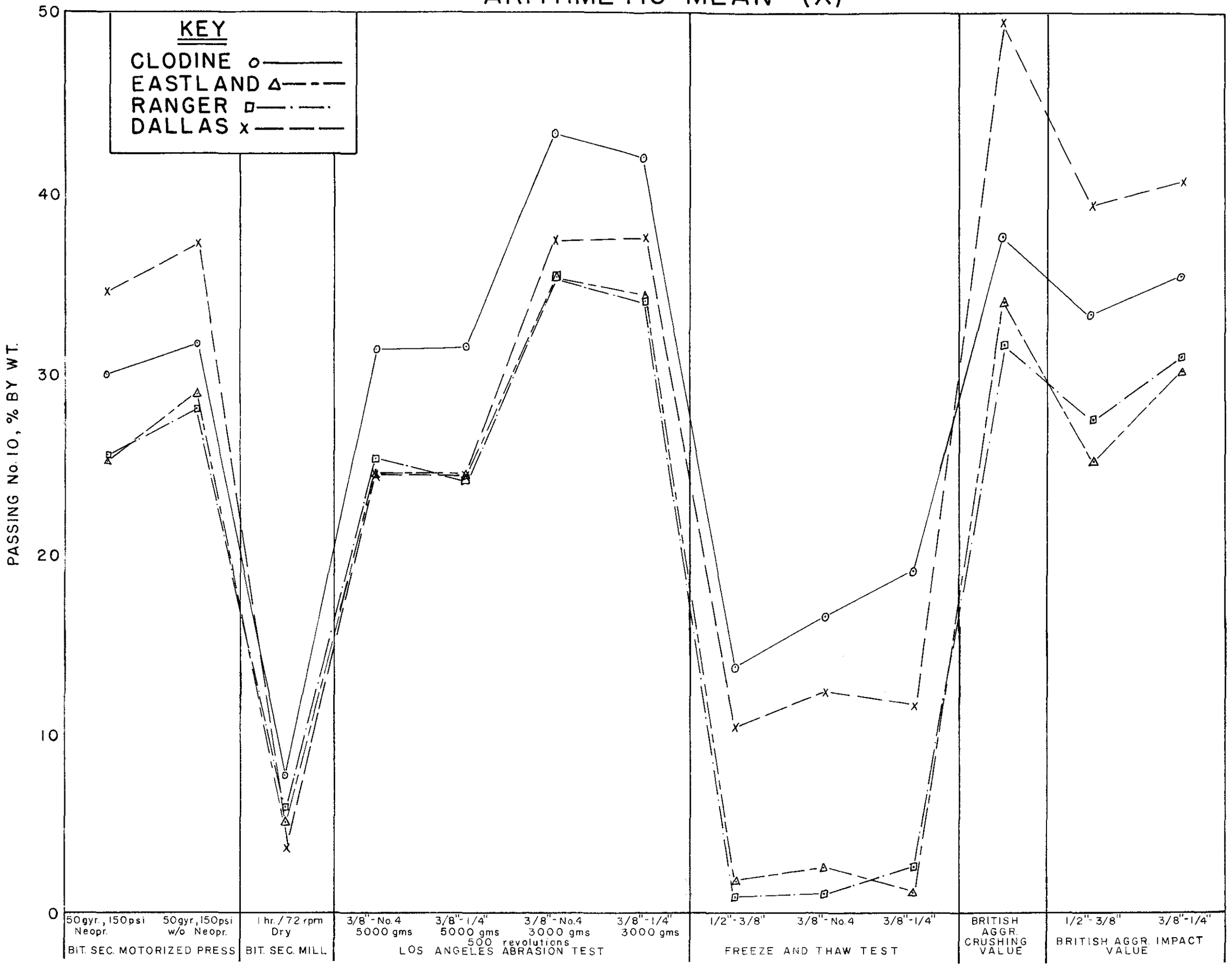
STATISTICAL ANALYSIS FOR TRENDS

(Passing No. 10 sieve values used for this data)

Test Method & Size	T.I., Clodine R3-70-535 & R3-71-659*		T.I., Eastland R3-70-1363 & R3-71-661*		Featherlite-Ranger R3-71-139 & R3-71-663*		T.I., Dallas R3-71-513 & R3-71-660*	
	$\bar{X}$	Cv(%)	$\bar{X}$	Cv(%)	$\bar{X}$	Cv(%)	$\bar{X}$	Cv(%)
Bituminous Section Motorized Press - 3/8"-1/4"								
50 gyrations with constant 150 psi gauge pressure, with neoprene pads	30.0	5.7	25.2	5.2	25.6	3.4	34.7	2.1
50 gyrations with constant 150 psi gauge pressure, without neoprene pads	31.7	3.0	28.9	4.8	28.0	3.7	37.3	1.0
Bituminous Section Mill Test-3/8"-1/4"								
1 hr. @ 72 rpm - Dry	7.7	4.6	5.1	4.1	5.9	1.7	3.6	13.2
Los Angeles Abrasion Test - 500 revolutions								
3/8"-No. 4-5,000 gms.	31.3	1.8	24.7	3.5	25.3	2.7	24.7	0.7
3/8"-1/4"-5,000 gms.	31.6	1.6	24.4	4.6	24.3	3.2	24.4	2.4
3/8"-No. 4-3,000 gms.	43.3	10.9	35.5	0.8	35.5	3.8	37.4	1.8
3/8"-1/4"-3,000 gms.	42.1	10.4	34.4	3.6	34.2	2.6	37.6	0.9
Freeze & Thaw Test								
1/2"-3/8"	13.8	91.3	1.8	11.6	1.0	25.6	11.4	10.3
3/8"-No. 4	16.6	92.9	2.7	56.8	1.2	86.9	12.3	27.7
3/8"-1/4"	19.0	91.2	1.2	36.5	2.6	76.1	11.5	13.3
British Aggregate Crushing Value Test								
3/8"-1/4"	37.7	4.4	34.0	1.5	32.7	3.8	49.5	0.4
British Aggregate Impact Value Test								
1/2"-3/8"	33.4	3.7	25.2	12.1	27.5	22.1	39.3	2.0
3/8"-1/4"	35.3	6.7	30.2	2.8	30.9	7.3	40.6	5.3

*Research Study 2-6-71-83 (Dist.14)

ARITHMETIC MEAN ($\bar{X}$)



IP-8-70-F: Petrography and Polish Value Determinations for TXI Clodine Synthetic Aggregate Sample R3-70-535

The above studies, conducted on the TXI Clodine aggregate sample as outlined in IP-8-70-F, are summarized as follows:

PETROGRAPHIC ANALYSIS

1. General:

Texas Industries' plant located near Clodine, Fort Bend County, utilizes clay from the Beaumont Formation as raw material for their rotary kiln process. The clay is generally brown in color and contains varying amounts of silt, sand and caliche. This variation in composition is vividly reflected in the fired product, in the form of particles having varying hardnesses (H=4-7, Moh's Scale) and abrasion resistance.

2. Polished-Section Examinations:

The color of "typical" Clodine production ranges from a pale olive gray to black with a small percentage of yellowish brown particles. Internally the colors are generally light gray to black. Degrees of bloating (expansion due to void formation during firing) range from only slight to high. In some particles, a very thin rind or crust can be noted, generally of a darker color than the portion immediately below, however, a well-formed rind is not characteristic of the Clodine material. Internal cracks (caused by shrinkage), common to about 50% of the particles, are generally, but not always, expressed at the surface (See Figs. 1 and 2). Sand grain distribution appears to be relatively uniform. The grains are mainly clear

and glassy, but some opaque grains associated with mineral inclusions, such as, calcite and several metallic oxides.

3. Thin-Section Examinations:

Thin sections of the Clodine material were fabricated and examined under plane and polarized light. The clay minerals show relatively uniform degrees of fusion with no un-burned portions noted. The crystalline mineral inclusions, especially the quartz sand, retained their integrity and were not altered during firing. Whereas, the carbonate fractions calcined sufficiently to form an amorphous matrix along with the clay minerals.

ACCELERATED POLISH VALUE DETERMINATIONS

Samples of the subject aggregate were subjected to an accelerated polishing action, by means of the British Polishing Machine for a period of 9 hours. Frictional readings were taken before and after the polishing process by means of the British Portable Tester. The average of the final readings, expressed as the Polish Value, was 55.4 (or 55). The average initial reading for the samples (n=5) was found to be 56.6 (or 57). Figures 3-5 show surface characteristic after 9 hours of polishing. Mineral inclusions and textural features are indicated. Surface roughness, which results from differential abrasion between mineral inclusions and the fused matrix, coupled with textural heterogeneity, are the major factors influencing the relatively high polish value obtained.

Fig. 1 Surface view of a particle exhibiting irregular surface features, cracks, and unfused mineral inclusions. Some inclusions are indicated. (Mag. 7.5X)

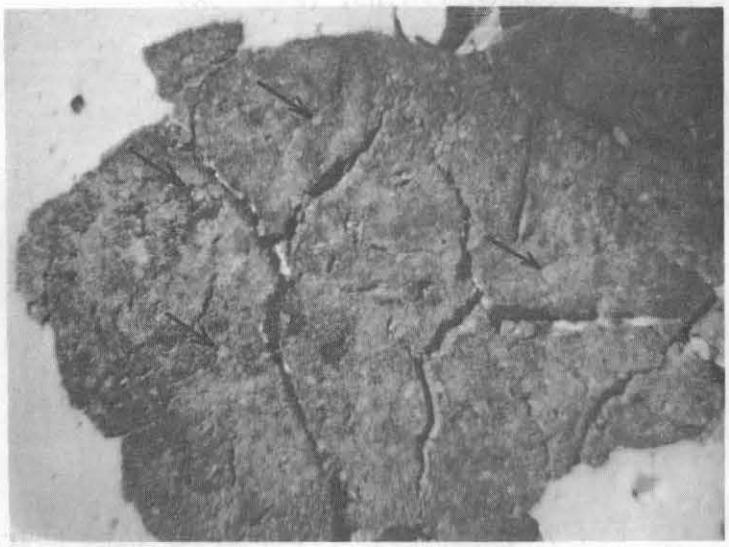


Fig. 2 Internal cracking and mineral inclusions revealed by polished-section techniques. Aggregate particle is embedded in plaster matrix. Some quartz grains are indicated. (Mag. 7.5X)

Fig. 3 Particles exhibiting abrasion characteristics after nine hours in the British Polishing Machine. A darker interior color in particle on left can be noted. Sand grains and other mineral inclusions are indicated. (Mag. 7.5X)

Fig. 4 Particle surface after nine hours of polishing showing irregular surface resulting from irregular wearing rates, protruding sand grains, and cavities left by plucked grains. (Mag 23X)

Fig 5 Particle surface after nine hours of polishing showing microvesicular texture formed by trapped gases. Included sand grains are noted. (Mag. 23X)

IP-8-70-F: Petrography and Polish Value Determinations for TXI-Eastland Synthetic Aggregate Sample R3-70-1363

The above studies conducted on the TXI-Eastland lightweight aggregate sample as outlined in IP-8-70-F, are summarized as follows:

PETROGRAPHIC ANALYSIS

1. General:

Texas Industries, Inc., Eastland Plant, located on the northwest edge of that town (See map) utilizes a shale from the upper Caddo Creek Formation (Pennsylvanian Age) which crops out along an almost north-south line through middle Eastland County. Presently, the shale pit is located some 5 miles south of the plant, one-half mile southwest of IH 20-SH 6 intersection off a county road.

The olive green shale is quarried by open pit methods, then trucked to and stockpiled at the plant. The raw material is reduced by a roller mill and screened (-4 size removed) before being sent to silo storage as kiln feed.

TXI operates three 60' X 6' and one 100' X 7' rotary kilns at a temperature of 2000°F. The commercial product is known as "Haydite."

Published chemical analysis of the shales in the Eastland area indicated that the clay minerals illite, kaolinite, chlorite and vermiculite are predominate; with quartz, gypsum, organic material, iron oxides and pyrite as common accessory minerals.

2. Polished-Section Examination:

A sampling of TXI-Eastland's production, when sectioned and viewed internally, shows that 90-95% of the particles have a color range from gray to black; the remaining percentage varies in color from yellow-brown to reddish-brown.

The bloating characteristics of the Eastland material have been determined statistically and can be described as ranging from Class II to V.* Some 95% of the aggregate particles fall into Classes III to V (44% in Class IV). Rind development is common to about half the particles but it is generally thin and often very non-distinct.

The hardness of the outer surface of the particles was measured as being 7 on the Moh's Scale. The inner structure appeared softer but actually was more easily crushed because of its brittle nature. Particle wear, resulting from the action of the British Accelerated Polish Machine, was differiential because of the difference in ability to withstand abrasion between the particle's outer skin and its inner vesicular structure (See photos). Irregularities in apparent wear rates were also reflected in slight differences in degrees of bloating and mineral inclusions, especially quartz grains. The relative rate in which a particle abrades is reflected in part by its bloating class (Class I and II abrades relatively fast) and amount of rind exposed to the wearing surface (a particle lying flat with a large rind area exposed will polish until the rind wears through, then,

*Class I has the greatest index of bloating with Class V essentially representing a burnt, stabilized and non-bloated material.

as the inner structure is exposed, its frictional value increases). Particles oriented to where very little rind area is exposed (end or edgewise) or has a very thin rind (or none at all) will begin to wear faster than others is, in itself, a contributing factor to high frictional properties, common to bloated materials.

ACCELERATED POLISH VALUE DETERMINATIONS

Samples of the subject aggregate were subjected to an accelerated polishing action by means of the British Polishing Machine for a period of 9 hours. Frictional readings were taken before and after the polishing process by means of the British Portable Tester.

The average initial reading for the Eastland samples was 52.4. The average final reading, expressed as the polish value, was 51.0. Figures 2-4 illustrate the type of surface abrasion exhibited by some of the tested particles.


T E P H E N S C O U N T Y
TEXAS INDUSTRIES, INC
EASTLAND PLANT
TXI Raw Material Pit
EASTLAND
POP. 3,292
CISCO
POP. 4,499
CARBON
POP. 309
OLDEN
MORTON VALLEY
Colony
Reagan
Pleasant Grove
LULA NEAL OIL FIELD
Ringling Lake
Lake Brelsford
HARRIMAN OIL FIELD
EASTLAND MUNICIPAL AIRFIELD
INSET NO 2
INSET NO 3
KLEINER OIL FIELD
BANKLINE OWENS OIL FIELD
CISCO (N.E.) OIL FIELD
TEXAS AND PACIFIC RAILWAY
GIPE OIL FIELD
RAY OIL AND GAS FIELD
Corinth
Lake Olden
Leon River
Middle Fork
Freedom
Mountain
PUNKIN CENTER
Pleasant Valley
Flatwood
Church
Bear Springs
PLEASANT HILL
Hearn
Murray
WOODSON-HALL OIL FIELD
ROMNEY
New Hope
Nash

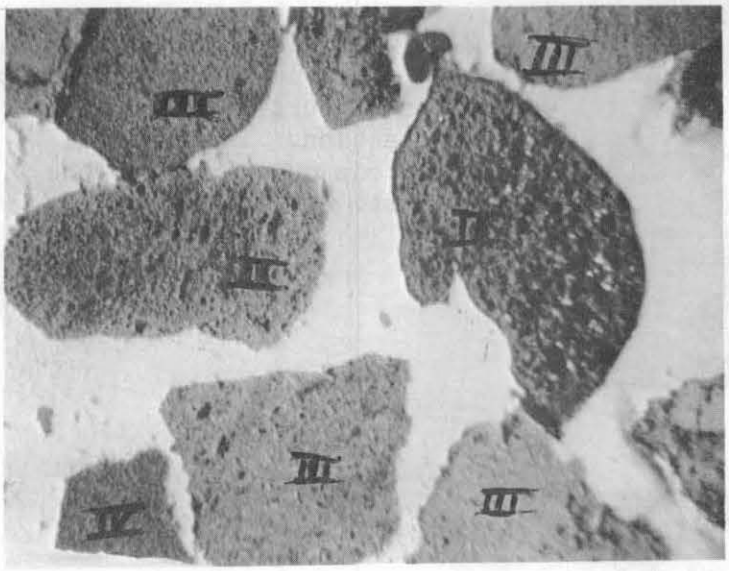


Fig. 1a Particles of TXI-Eastland sample illustrating the range of bloating. The middle-right particle is typed as Class II but in part grades into a fully expanded Class I. The middle-left grain is a Class II and the others are classed as marked. (Mag. 7.5X)

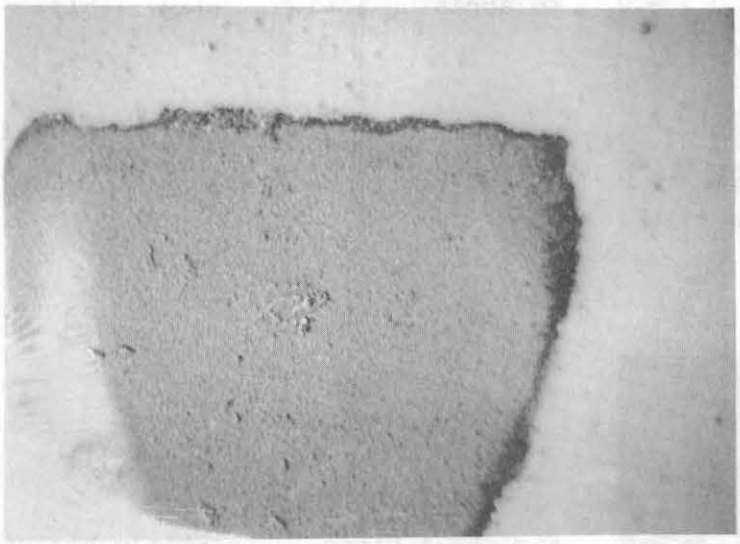


Fig. 1b Rind development in a Class IV particle. (Mag. 7.5X)

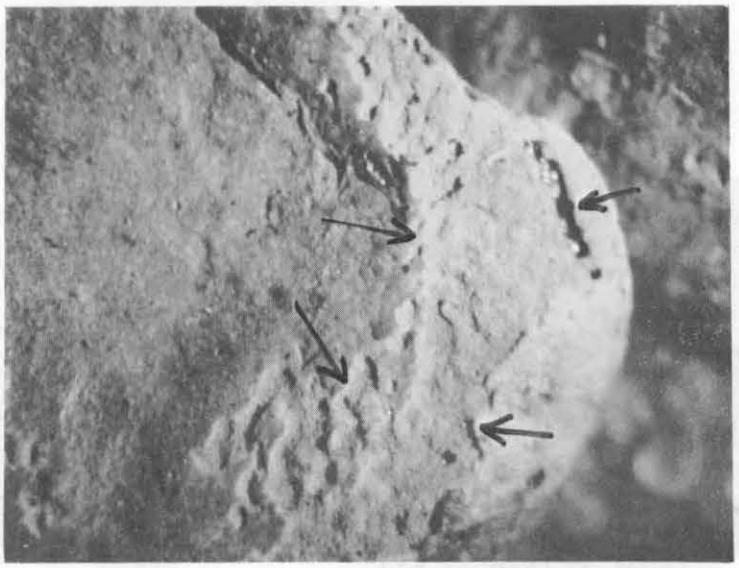


Fig. 2 A Class IV particle with a well defined rind showing abrasion wear after 9 hours of accelerated polishing action. The internal portions erode quickly after the rind is lost. (Mag. 10X)

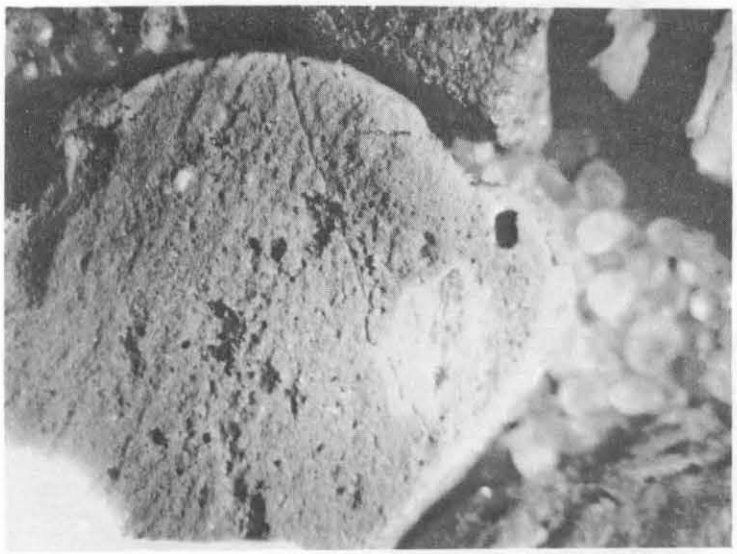


Fig. 3 A Class III particle showing extensive wear after 9 hours of polishing action. The particle has an ill-defined rind which yielded readily to abrasion action. (Mag. 7.5X)

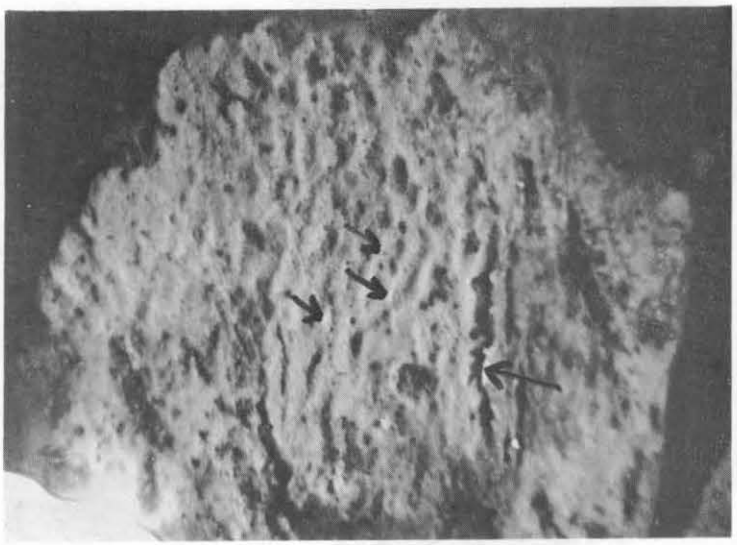


Fig. 4 A Class III particle beginning to show internal wear just after the loss of its thin rind(9 hrs. of abrasion). Note irregularities in wearing surface due to incomplete loss of rind and variation in void sizes. The false "ripple mark" features are common to many types of aggregates when subjected to the accelerated polishing action. (Mag. 7.5X)

IP-8-70-F: Petrography and Polish Value Determinations for Featherlite-Ranger Synthetic Aggregate Sample (R3-71-139).

The above studies conducted on the Featherlite-Ranger lightweight aggregate sample as outlined in IP-8-70-F, are summarized as follows:

1. General:

The Featherlite Corporation, Ranger Plant, is located on the north edge of the city limits of Ranger in northeastern Eastland County (See map). The plant, operating at its present site since about 1952, utilizes a shale from the Brad Formation (Pennsylvanian Age) which has been quarried from open pits just north of the plant. More recently, in view of depleting reserves, raw shale has been quarried from a new source some 6 miles south of town and trucked to the plant. Featherlite now operates three 10' X 150' and four 6' X 50' rotary kilns; the latter ones are being phased out.

Published studies indicate that the clay minerals illitie, kaolinite and chlorite are predominate with orgainic material, iron oxides and quartz present as minor accessory minerals.

2. Petrographic Analysis:

Sliced and ground sections through several hundred particles of the Ranger sample show that about 95% of the particles are gray to black in color; the others are generally shades of yellow-brown to reddish-brown. The same can be said about samples collected since 1968. These ground sections also reveal that the bloating character ranges from fully expanded (essentially composed of large voids with very thin walls) to non-bloated

(clay minerals stabilized but no gas voids formed), however, less than 10% of the particles fall into these two extremes. Between 60-70% of the particles examined are composed of relatively minute but fairly uniform sized voids closely spaced in a well defined amorphous matrix and typically with a pronounced rind such as that illustrated in Figure 1. Particles which have been crushed or fractured during screening or handling exhibit only a partial rind or none at all. About half the particles show no lineation features; others have their voids aligned parallel to the original bedding planes of the shale formation. In many of the particles expansion is preferential and occurs perpendicular to the bedding planes, thus, rifts or splits occur in the sides of the grain which are parallel to the original bedding (see Fig. 2). In general these splits do not penetrate the grain but are contained within the zone of rind development.

Thin-section analysis indicates that a fairly uniform amorphous matrix characterizes the Ranger material. Minor amounts of birefringent minerals do occur but infrequently, and some opaque minerals were noted (probably iron oxides). Grain hardness was measured as being 7 on the Moh's Scale for particles having a rind; the interior could not be measured adequately on well bloated grains due to their brittle nature. The burnt, but non-bloated grains, ranged from 6 to 7 on the Moh's Scale.

3. Accelerated Polish Value Determinations:

Samples of the subject aggregate were subjected to an accelerated polishing action by means of the British Polishing Machine for a period of 9

hours. Frictional readings were taken before and after the polishing process by means of a British Portable Tester.

The results of this test are summarized as follows:

Sample #	Initial Reading	Final
3-30-71A	57	57
3-30-71B	58	60
3-30-71C	57	60
3-30-71D	57	60
3-30-71E	58	57
3-30-71F	56	57
3-30-71G	57	58
Average	57	58*

* Polish Value

As can be seen in above table, the frictional values actually increased slightly; a common occurrence with most lightweight aggregates. Compared to other lightweight aggregate samples previously tested, the Ranger sample shows (and measures) a relatively low weight loss per particle due to mechanical abrasion by the polishing machine.

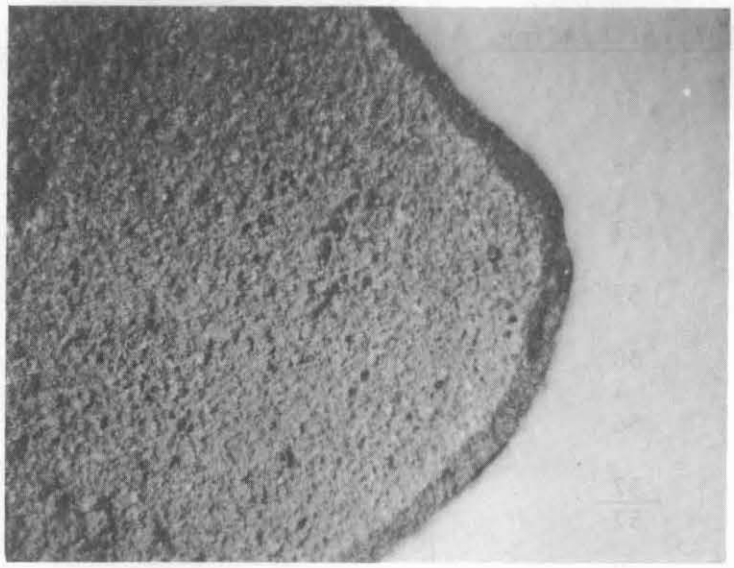
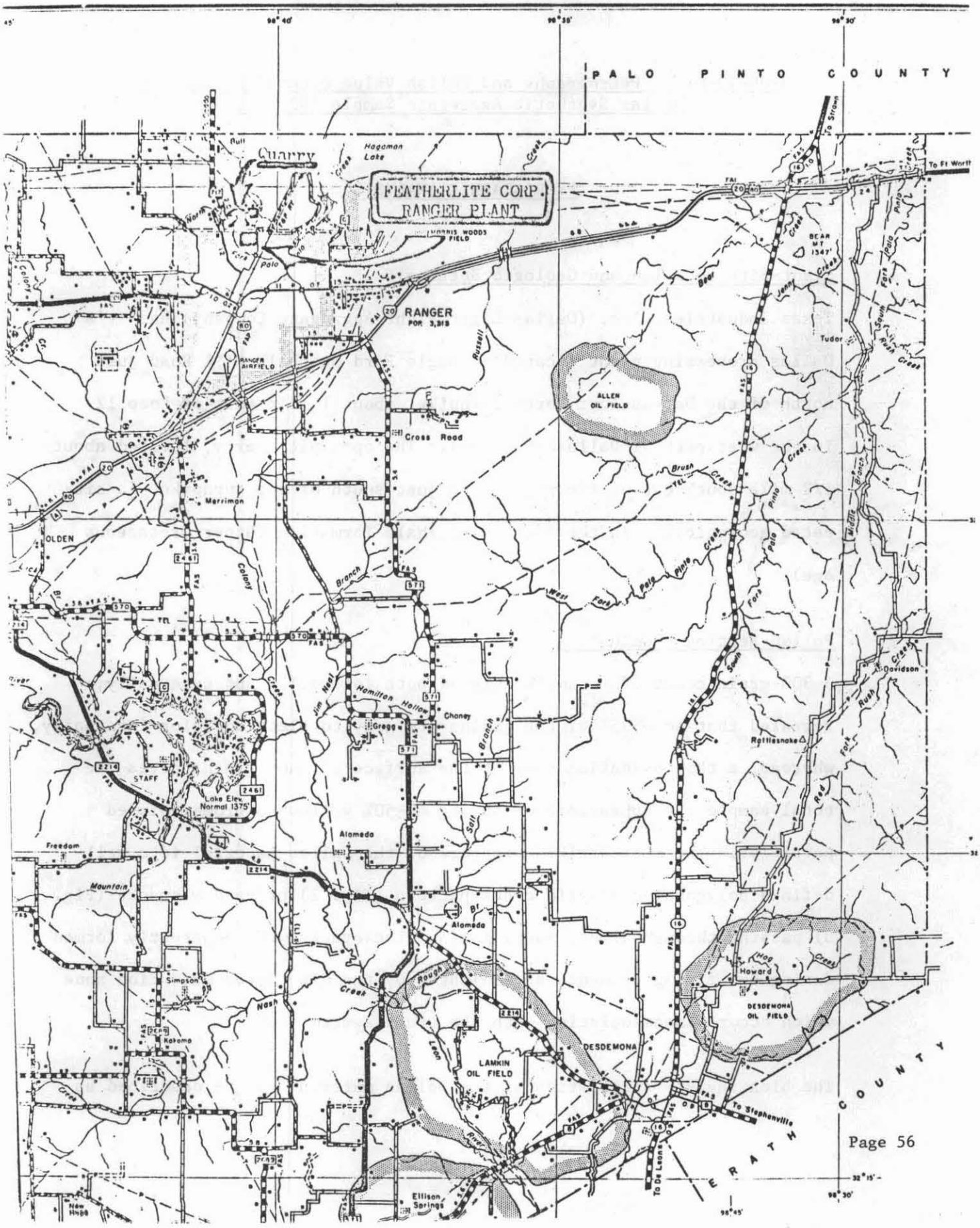


Fig. 1 A particle showing relatively uniform bloating and rind development. Uncrushed Featherlite-Ranger sample (R3-71-139) (Mag. 15X)

Fig. 2 Pull-apart features formed along or parallel to bedding planes. These features result from preferred directional expansion perpendicular to bedding planes. (Mag. 7.5X)


PALO PINTO COUNTY
FEATHERLITE CORP.
RANGER PLANT
Quarry
Hagaman Lake
Harris Woods Field
RANGER
POP. 3,313
Ranger Airfield
Bear Mt. 1347'
Tudor
Allen Oil Field
Cross Road
Merriman
Olden
Colony Creek
Jim Neal Branch
Hamilton Hollow
Chaney
Gregg
Staff
Lake Eleo
Normal 1375'
Alameda
Freedom
Mountain
Simpson
Nash Creek
Kokomo
New Hope
Rough Creek
Lamkin Oil Field
Desdemona
Desdemona Oil Field
Howard
Rattlesnake
Davidson
Ellison Springs
To Stephenville
To De Leon
To Strawn
To Ft Worth
ERATH COUNTY

3-06-70-017: Petrography and Polish Value Determinations for TXI-Dallas Synthetic Aggregate Sample (R3-71-513)

PETROGRAPHIC ANALYSIS

1. Plant-Site Location and Geologic Setting:

Texas Industries, Inc. (Dallas Lightweight Aggregate Company) has it's Dallas processing plant located at Eagle Ford on Chalk Hill Road just north of the Dallas-Fort Worth Turnpike, about 1 mile east of Loop 12 in the west part of Dallas (See Map). The open-pit quarry, located about 1/2 mile southwest of the plant area just south of the turnpike, is situated geologically in the Eagle Ford shale formation (Upper Cretaceous Age).

2. Polish-Section Examination:

A 300-grain count of a sample, viewed both internally and externally, revealed that some 95% of the grains are gray to black in color internally, whereas, a thin oxidation zone at the surface of many grains gives the total sample the appearance of having 40-50% yellow to brown-colored particles. The most striking feature of the Dallas material is a well-defined polygonal or mosaic crack pattern (Fig. 2) or random cracks (Fig. 3) passing through almost every grain. The cracks were apparently formed during the firing sequence as indicated by the discolored oxidation zone which occurs in association with the crack system.

The bloating characteristics of the Dallas material can be described as

ranging from Class II to V* with some 90% of the grains falling into Classes III and IV. No Class I particles were observed in the 300 grain count; the remaining percentage was composed of Class II and V grains. No rind development was observed.

The hardness of a number of particles (exterior surface) was measured as being 3.5 on the Moh's Scale. The relatively low reading (as compared to Ranger or Eastland material) is apparently due to lack of rind development. Because of the extreme brittle nature of the grain interior, no internal hardness measurements could be taken.

Although hardness measurements were only obtained on exterior surfaces, it was apparent that slight differences in "toughness" existed for different parts of a particle, especially along the oxidation zones which were associated with the internal crack systems. However, this observed feature showed to have little effect on the noted differential-particle wear as brought out by the abrasive action of the British Accelerated Polish Test (Tex-438). Close examination reveals that slight differences in degrees of bloating from particle to particle coupled with the general vesicular nature of the material has the greatest influence on the relatively high skid-resistance (compared to many other aggregate types) as measured by the British Portable Tester.

3. Thin-Section Examination:

Thin sections fabricated by standard petrographic techniques of the Dallas

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* Particle bloating Class I has the greatest index of bloating with Class V essentially representing a burnt and stabilized but a non-bloated material.

sample have been analyzed and placed on file. The particles show relatively uniform degrees of fusion. Transformation of the clay minerals appeared complete, whereas, quartz inclusions remained unaltered by the firing process. No other crystalline material was observed. The matrix showed to be amorphous and glass-like; typical for expanded shale.

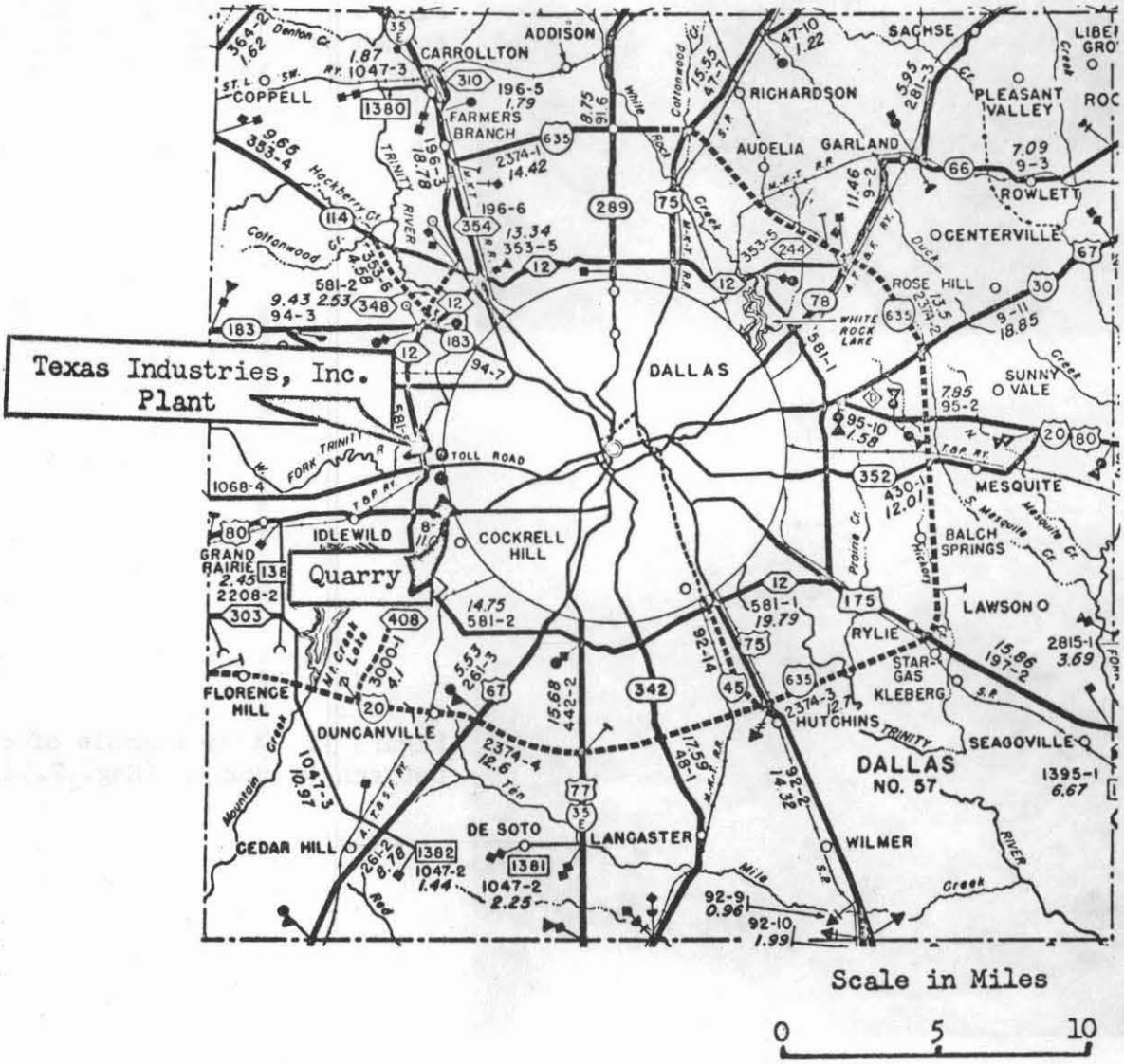
ACCELERATED POLISH VALUE DETERMINATIONS

Samples of the subject aggregate were subjected to an accelerated polishing action by means of the British Accelerated Polish Machine for a period of 9 hours. Frictional readings were taken before and after the polishing action by means of the British Portable Tester in accordance to Test Method Tex-438.

The measured polish value for the Dallas sample was 62. The average initial frictional value for the seven specimens examined for this study was 57. This value when compared to the final average reading points out that, as the "polishing" action was taking place, the particle micro-texture actually gained in frictional character and, thusly, increased in skid resistance. However, along with a fairly high rate of particle attrition (common to vesicular aggregates), there was an observed high loss of particles due to breakage stemming from fracture planes initiated by the internal crack system.

FIGURE 1.

General highway map of Dallas County
showing location of TXI-Dallas plant.



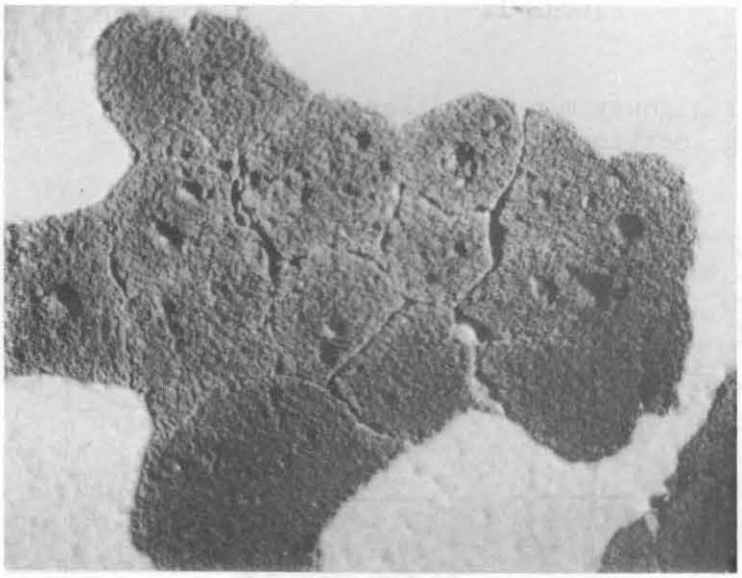


Figure 2. Polygonal crack system common to most of the TXI-Dallas material. (Mag. 7.5X)

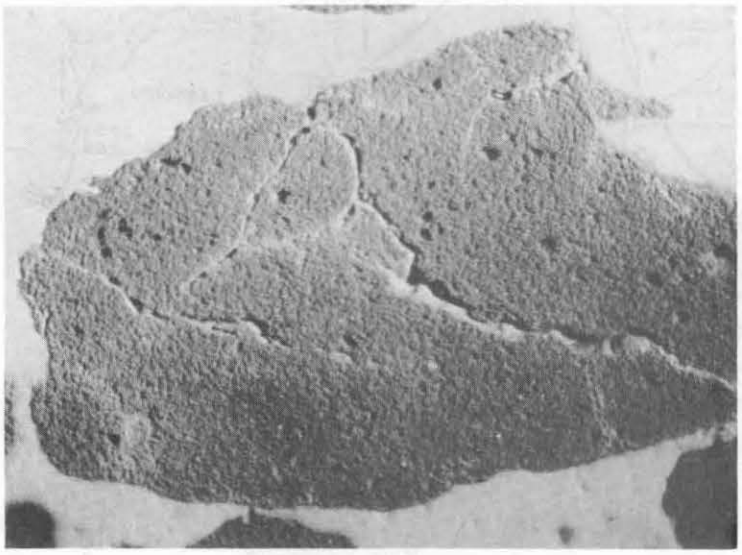


Figure 3. Other example of crack pattern (random). (Mag. 7.5X)

3-06-70-017: Petrography and Polish Value Determinations for Bay Prairie Aggregate Corporation Synthetic Aggregate Sample (R3-71-649)

PETROGRAPHIC ANALYSIS

1. Plant-Site Location and Geologic Setting:

Bay Prairie Aggregate Corporation has its synthetic aggregate processing plant located 3 miles northeast of Lane City, off FM 1096, in eastern Wharton County. Open-pit quarry methods are utilized in obtaining clay from the Beaumont Formation (late Cenozoic Age). Firing is by rotary-kiln techniques and the prepared aggregate carries the trade name "B-Pac."

2. Polished-Section Examination:

Based on a 200 grain count, approximately 94% of the particles can be characterized as being non-bloated or Class V on the tentative bloated classification scheme. About 3% fell in Class IV, 2% in the Class III, 1% in Class II, and no Class I particles (the highest index of bloating) were observed at all. Roughly 20% exhibited mineral inclusions foreign to the normally fused amorphous matrix (See Figures 1, 2 and 3). As can be seen in all attached photomicrographs, the particles shown are void of any vesicular texture.

In terms of color, about 10-12% of the particles are yellowish-brown to brownish-red, the remaining are about half and half dark to light gray and shades of olive green. The pale olive-green colored grains make the Bay Prairie material easily recognizable from the other synthetic aggregates examined for this project.

Although somewhat noticeable to the unaided eye, under low magnification, a well developed internal random-crack system is prevalent in this material (Figs. 3, 4 and 5).

Hardness of particles, as measured on the Moh's Scale, is somewhat variable; the outer glazed crust on some particles was measured to be 5.5 and on fresh broken particles portions of the interior was found to be about 4.0. However, the white mineral inclusions were measured to be 2.0 (Gypsum has a hardness of 2.0 and is also white in a powder form). Some of the black-mineral inclusions were brittle and broke with the appearance of a charred material or oxidized metal. Although on some grains a well-glazed ceramic-looking surface occurred, no rind development was apparent as a rule. A few grains were extremely sandy and had the appearance of a clastic (fragmental) sedimentary rock (Fig. 3). Quartz sand grains were prevalent, and loosely fused together by the amorphous matrix. As expected, the quartz grains remained unaltered during the firing process (probably at no more than about 1950°-2000°F).

3. Thin-Section Examination:

Thin sections of the Bay Prairie material fabricated by standard petrographic techniques have been analyzed and placed on file. Transmitted-light examinations reveal that the aggregate has a very heterogeneous matrix. In some sections un-fused mineral matter, consisting of silt-to-sand-sized quartz grains, made up 70-80% of the particle. Other particles had a lesser percentage of sand grains present. Interestingly, many quartz grains contained minute microfractures which may have resulted

from a rapid quenching after the firing process. This feature of the sand grains was not observed in the Dallas, Eastland or Ranger material. The matrix appeared in general to be amorphous, however, because of so much un-fused silt-size inclusions, it was difficult to examine adequately. However, heavy staining of the matrix, probably from iron oxides, was observed.

ACCELERATED POLISH VALUE DETERMINATIONS

Samples of the subject aggregate were subjected to an accelerated polishing action by means of the British Accelerated Polish Machine for a period of 9 hours (Tex-438). Frictional readings were taken before and after the polishing action by means of the British Portable Tester.

The initial frictional reading (average of seven specimens) was 63 and the final polish value (average) was found to be 59. The value of 59 seems to be somewhat high considering that the material is non-vesicular. However, this sample has very irregular surface features; no flat particles or smooth surfaces, were observed even when broken. This character along with the high quartz grain content probably contribute highly to the polish value. Although the sample exhibited internal crack features, there was no particle loss due to breakage during the polish test.

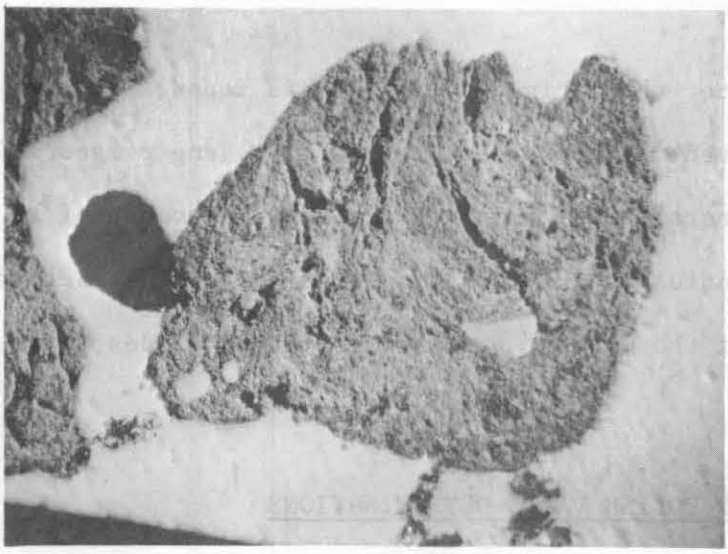


Fig. 1

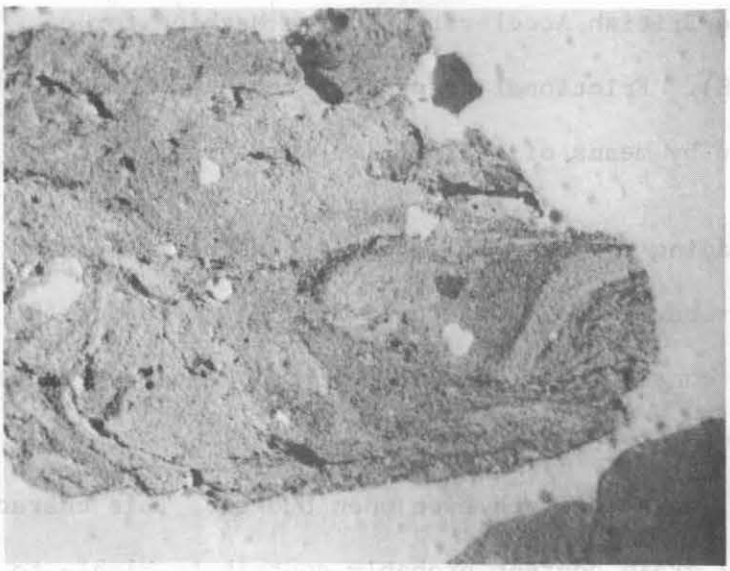


Fig. 2

Fig. 3

(All at 7.5X)

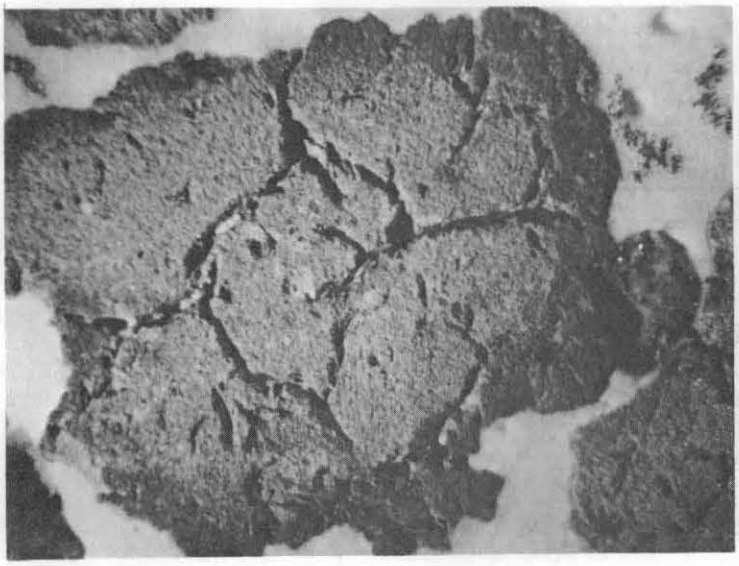


Fig. 4

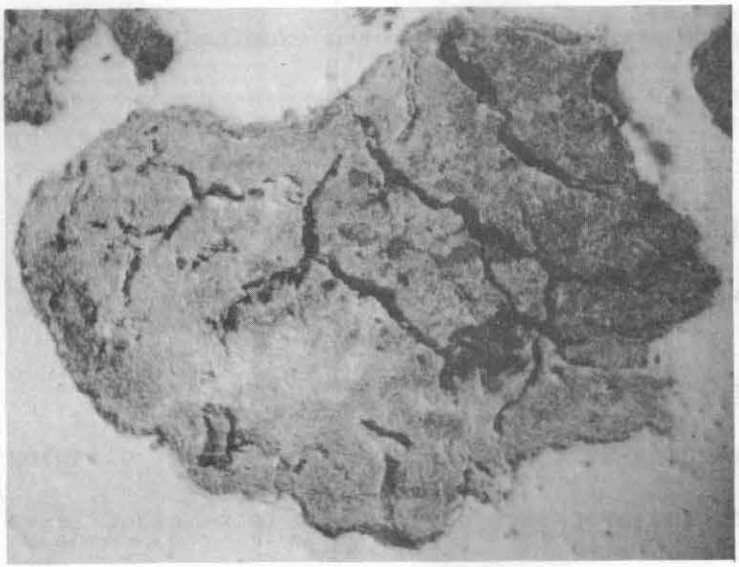


Fig. 5

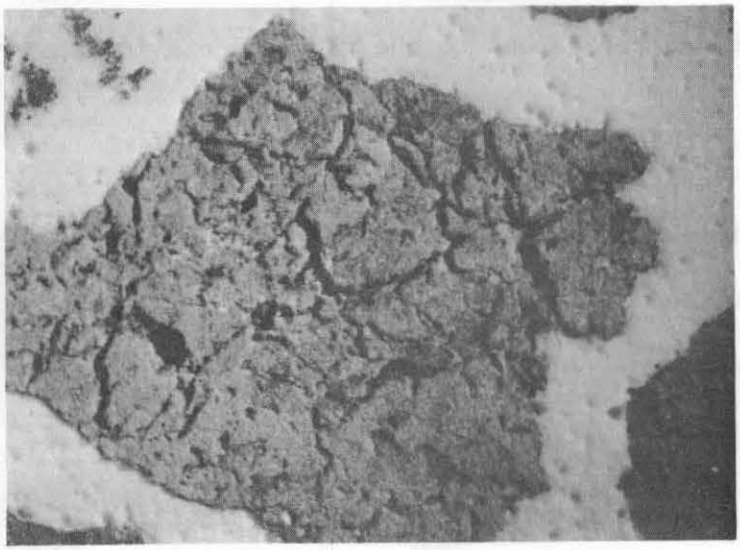


Fig. 6

Status Report on District 14 Lightweight Aggregate Samples (3-06-70-017)

TXI - Clodine	#R3-71-659
TXI - Dallas	#R3-71-660
TXI - Eastland	#R3-71-661
Featherlite-Ranger	#R3-71-663

1. Petrography:

Each of the above listed aggregate samples have been examined petrographically by means of polished and thin-section techniques. In general, both techniques showed that the material represented compares in all respects with samples previously examined from the sources and reported to Section F. (See Progress Report dated September 14, 1972.)

2. Polish Value Determinations:

Samples of the subject aggregates were examined for respective polishing characteristics according to the procedure outlined in Test Method Tex-438-A. The following values were obtained with a new British Portable Tester. The second set of values is based on correlation curves developed from a statistical analysis and correspond to the range of previously reported values.

Clodine	48	(58)
Dallas	51	(61)
Eastland	41	(49)
Ranger	42	(51)

Test Method Tex-109-E
Rev: January 1, 1971

Texas Highway Department

Materials and Tests Division

PRESSURE PYCNOMETER METHODS FOR DETERMINATION OF SPECIFIC GRAVITY, MOISTURE CONTENT AND FOR SLAKING OR WETTING MATERIALS

Scope

(This procedure consists of four parts.)

In Part I the pressure pycnometer is used to find the percent moisture and the specific gravities of soils by weighing and measuring the volume of soil solids and moisture by elimination of air voids through the use of pressure and absorption. If a sufficient number of specific gravities have been predetermined to justify assignment of a value, the use of a high pressure pycnometer will expedite moisture density control tests because oven drying of samples will not be required. When neither specific gravity nor moisture content are known, both can be found from the same sample, but oven drying will be required.

As described in Part II, this device or a pressure vessel may also be used to saturate and slake a sample of soil and water by forcing water under high pressure into the voids, thereby reducing the time required for air drying and saturation of samples subjected to the wet method of preparation of soil binder.

In Part III, the pressure vessel is also used to saturate a specimen of soil-bituminous material by forcing water into the voids under high pressure in a very short period of time. Protection is given the specimen during this pressurization procedure to prevent its loss of structure.

Part IV has been added to give the method of pressure wetting bituminous hot mix stabilized base (black base) in which the pressure restrainers from Part III are not used. The specimen is pressure wetted using hot water that is forced into the voids, which wets the material in a very short time. The pressure apparatus is protected from scratches and dents through the use of plastic bags or buckets.

PART I

DETERMINATION OF ABSOLUTE SPECIFIC GRAVITY AND MOISTURE CONTENT

Apparatus

1. Suitable high pressure pycnometer and pump, see Figure 1.

2. Same as listed in Test Method Tex-103-E.

3. A supply of plastic bags.

4. Butcher knife, syringe, etc.

5. A source of compressed air, or other suitable gas capable of furnishing 100 pounds pressure during tests.

Procedure

1. Select an adequate representative sample, ranging from 5 to 15 pounds*.

2. Slice any clay lumps, which might exist in the sample, to a maximum thickness of 1/4-inch. In this operation, precautions should be taken to avoid the loss of any more moisture than is absolutely necessary.

3. Place sample in plastic bag, weigh, and subtract weight of plastic bag, and record as W. If the sample is weighed out to an exact ten pounds or any convenient percent thereof, then the calculations under step 16 can be replaced by available tables.

ZERO DETERMINATION FOR WATER ONLY***

4. Fill lower portion with ample amount of zeroing water to cover sample (which will be introduced in step 12) usually about 6 to 8 inches.

5. Place piston, with vent plug removed, in pressure pycnometer. Press gently until water is barely visible in vent plug opening.

6. When water level in opening is properly adjusted, screw in plug tightly.

7. Fill remainder of pressure pycnometer with water to the shoulder and insert head of pycnometer with release valve open so that water overflows. Then fasten head securely.

8. Apply pressure to water reservoir with high pressure water pump** with water reservoir valve open. When pressure gauge indicates line pressure, close water reservoir valve. Move air pressure line to bottom stem on Prespump. Pump to 1200 psi.

*Such as might be obtained from digging a hole for density tests.

**See manufacturer's instructions for operation.

***Although almost any convenient temperature may be used for running tests in Part I, precautions should be taken to prevent any significant change in temperature during any single test.

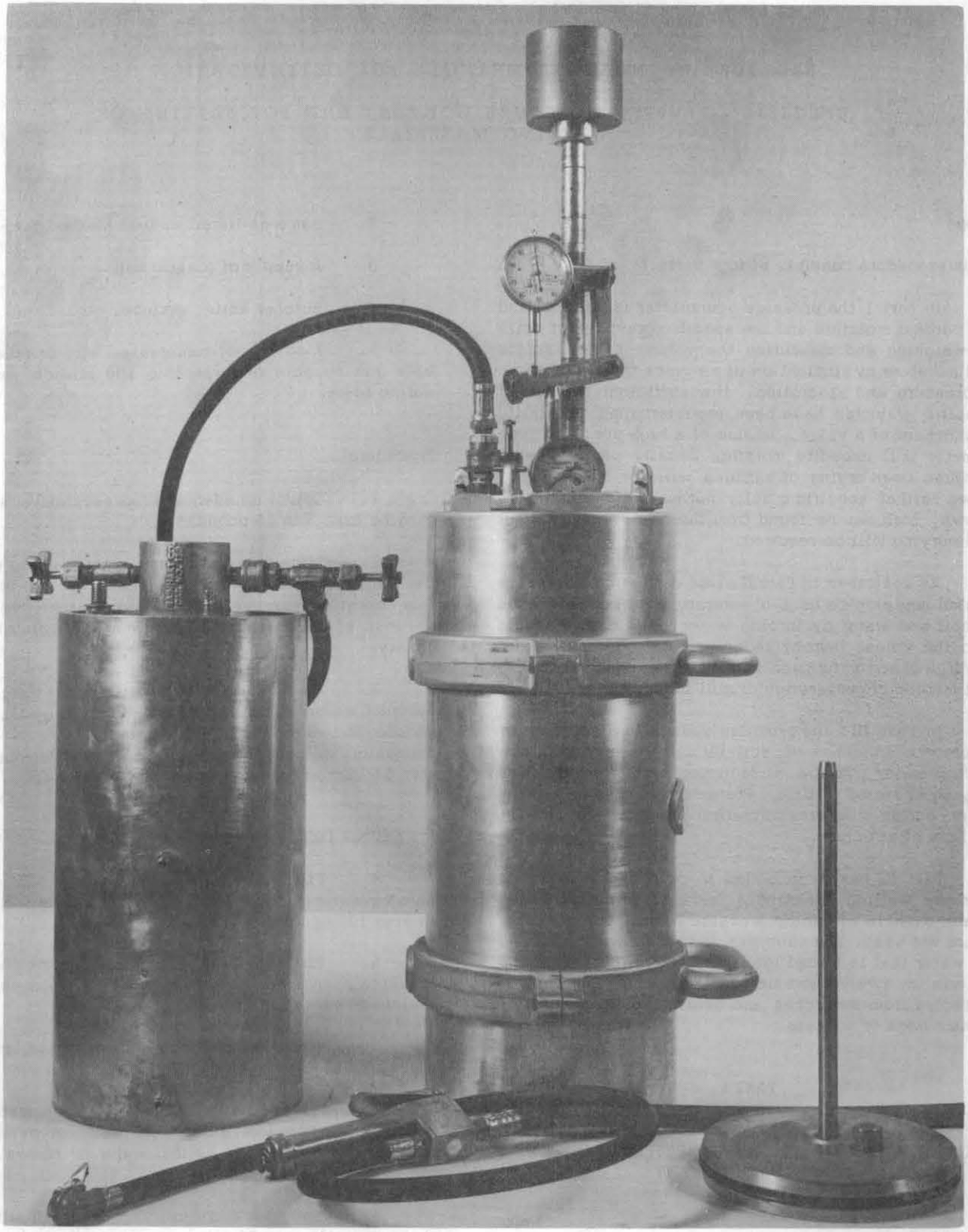


Figure 1

9. Set dial indicator on piston rod at zero by selection of calibrated spacers for coarse adjustment and micrometer screw for fine adjustment and lock adjustment.** Carefully recheck pressure and readjust, if necessary, then remove dial indicator.

NOTE: In determining the zero setting in using the pressure pycnometer, the dial indicator lever arm must always be zeroed below the horizontal or in the "down" position. Zeroing with the arm above the horizontal gives erroneous results.

10. Release pressure and remove head. Drain water and wipe all parts until dry.

11. Extrude piston** and remove vent plug and set aside without losing any zeroing water from bottom of piston or pycnometer.

VOLUMETRIC DETERMINATION OF SAMPLE***

12. Place sample, mentioned in step 3, in water in pressure pycnometer so that water overflows into the bag without washing out soil.

13. Replace piston in pressure pycnometer as indicated in steps 5 and 6. If water overflows, raise piston and by use of a pre-wetted syringe, suck up water and return through vent opening.

14. Fill remainder of pressure pycnometer with water and pump to 1200 psi. as set forth in steps 7 and 8. Maintain this pressure for a minimum of 15 minutes. Care must be taken to reproduce exact pressure gauge reading that was used in setting zero dial indicator in step 9.

15. By selection of calibrated spacers, etc.** (see step 9), set dial indicator on piston rod and record volume of solids and moisture displaced in pycnometer as V_1 from which the volume of the plastic bag must be subtracted to obtain V. The volume of the bag can be determined using the bag as the sample in steps 1 to 15 in Part I. The use of plastic bags of uniform volume or weight is highly desirable in order to avoid repetitious volume determinations.

16. Calculations (The use of high pressure pycnometer tables will replace most calculations as expressed in the formulas given below.)

$$DW = W - \frac{GV - W}{G - 1}$$

and

$$M = \left(\frac{GV - W}{G - 1} \Big/ DW\right) 100$$

Where:

W = Total weight of sample

DW = Oven-dry weight of sample. If sample is from density determination, divide DW in lbs. by volume of hole in cu. ft. for density in lbs./cu.ft.

V = Volume displaced by sample (solids and water).

G = Specific Gravity of solids

M = Moisture content expressed as a percentage of dry weight.

If specific gravity has not been previously determined, remove sample from pressure pycnometer and oven dry at 230° F. and determine DW.

Then $G = \frac{DW}{V - (W - DW)}$ or if a separate representative moisture content sample is used to find M and DW, $G = \frac{W}{V - (W - DW)\left(1 + \frac{M}{100}\right)}$ and $DW = \frac{W}{1 + \frac{M}{100}}$

Conventional C and D scales of slide rules may be used for calculation where weight of moisture =

$$\frac{GV - W}{G - 1} = \left(\frac{W}{G - 1}\right)\left(\frac{GV}{W} - 1\right)$$

(1) Set C scale index to G on D scale.

(2) Move cursor to V on C scale. $\frac{GV}{W}$

(3) Set W on C scale under cursor.

(4) Record value (1 to 2) on D scale and subtract one.

(5) Set cursor at W on D scale. $\frac{W}{G-1}$

(6) Move C scale until G-1 is at cursor.

(7) Move cursor over C scale to value found in step 4.

(8) Read answer under cursor on D scale. Subtract this weight of water from W to obtain DW or dry weight.

$\left(\frac{W}{G-1}\right)\left(\frac{GV}{W} - 1\right)$ For (7) & (8) above

17. Record data on Pressure Pycnometer Work Sheet, Figure 6.

Note: The use of the pressure pycnometer for determining specific gravities is based on the fact that air, and any other gases in the material being tested, is absorbed in the water at pressures well below the 1200 psi being applied. Also at 1200 psi, water is forced into the voids of the material to completely saturate it. This occurs much faster in some materials than others and is particularly noticeable in specific gravity determinations when the dial indicator needle continues to move while under 1200 psi pressure, even after 15 minutes. Therefore, in order to expedite the determination of the combined specific gravity (or asphalt determination) of a fresh field or plant mix of bituminous mixture (or a core taken from the pavement), it may be important that the material be well broken up and placed loose in a plastic bag in the pycnometer. The final reading on the dial indicator should not be taken until movement of the dial hand stops, even though fifteen minutes has been exceeded.

When determining the percent asphalt through the use of the pressure pycnometer, it is suggested that the sample, pycnometer and water be at, or near, 90°F. More accuracy can be obtained by mixing test size batches of aggregate and known asphalt content and determining the combined specific gravity (and asphalt content) at, say, 75°F, 90°F and 110°F. From these data the temperature giving the most accuracy can be extrapolated.

PART II

SATURATION FOR SLAKING OF SOILS

Apparatus

1. Pump and pressure vessel as shown in Figure 2. It is possible to use the pressure pycnometer instead of the pressure vessel, except volumetric measuring equipment (piston, dial indicator, etc.) are eliminated.

Procedure

1. Select suitable size sample for soil constants and gradation (see Test Method Tex-100-E).

2. Prepare sample by chopping or breaking clay lumps into minus 1/4-inch thick slices and place in plastic bag.

3. Place bag in pressure vessel and fill both with water to the shoulder so as to avoid washing soil out of plastic bag.

Figure 2

4. Place head in pressure vessel and press down until water flows out of release valve.

5. Fasten head securely and apply the line pressure (approximately 80 pounds) with the high pressure water pump, then close the valve.

6. Apply pressure until 1200 psi. is read on the gauge and maintain this pressure for at least 15 minutes.

7. Release pressure, remove head and remove sample for washing and preparing as set forth in Test Method Tex-101-E.

PART III

WETTING OF BITUMINOUS MIXTURES FOR COHESIOMETER TESTS

NOTE: Details for wetting triaxial specimens are given in Test Method Tex-119-E.

Prespump

Presves

Specimen in Restrainer

Cohesiometer Specimens

Figure 3

Soil Asphalt Specimen

PRESSURE RESTRAINER ASSEMBLY USED IN WETTING OF BITUMINOUS TREATED SPECIMENS BY PRESSURE VESSEL

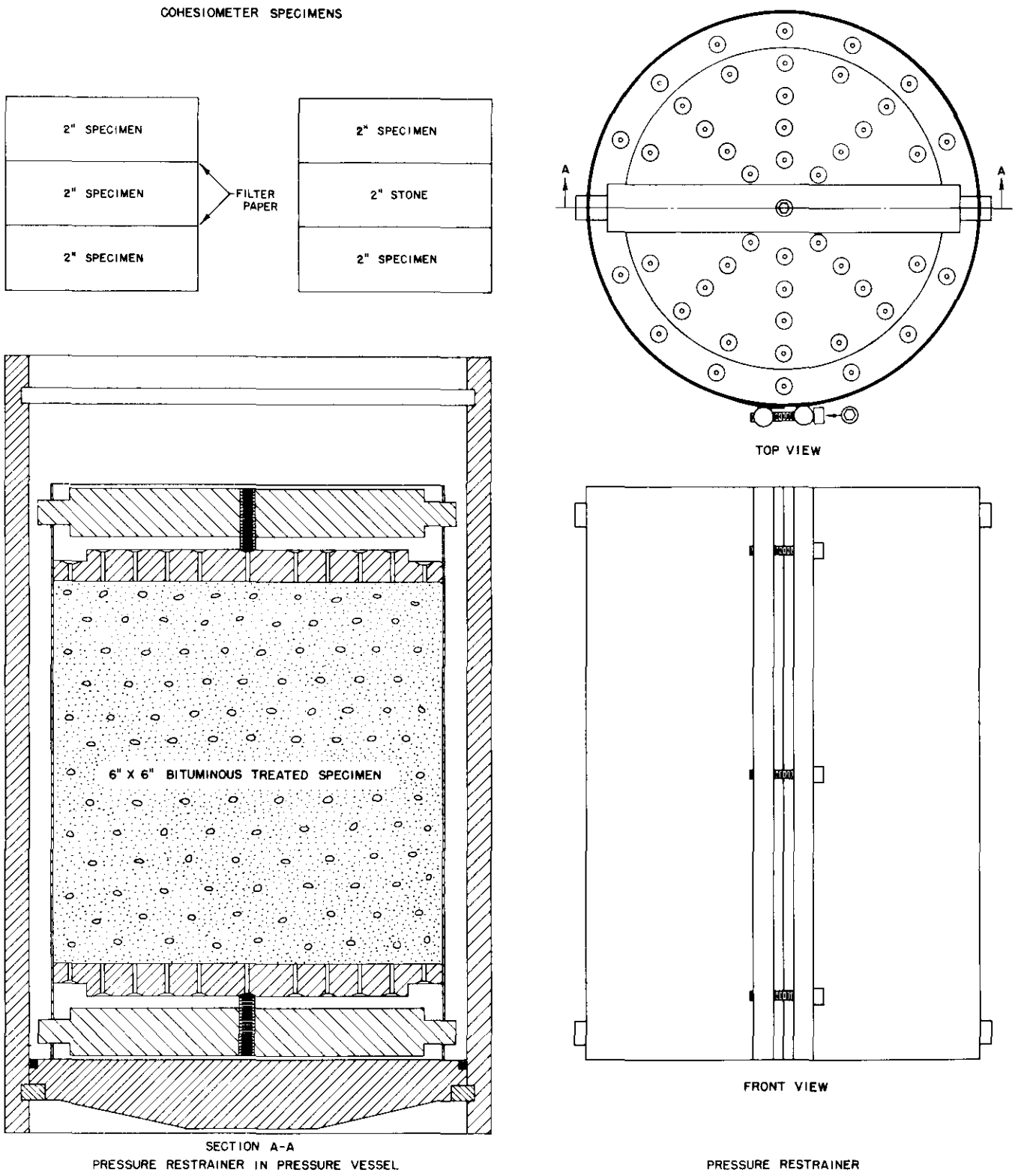


Figure 4

Apparatus

1. Same as Part II.

2. Pressure restrainers. See Figures 3 and 4.

3. A source of hot water.

4. A suitable size 140° F. oven.

Procedure

1. After specimens for cohesiometer tests (see Test Method Tex-122-E) have been dry-cured, weigh and measure height and circumference.

2. Place specimen in pressure restrainer as shown in Figure 4 and tighten screws securely.

3. Fill pressure vessel with hot water and apply pressure as indicated in steps 5 and 6 of Part II, except use 150° F. plus or minus 10° F. water.

4. Release pressure slowly and remove head.

5. Leave pressure restrainer assembly in hot water until bubbling of escaping gas ceases. Remove pressure restrainer assembly from water. If other specimens are to be pressurized, remove pressure restrainer assembly from pressure vessel and place in hot water tank at same temperature. This change allows the bubbling of escaping gases to continue but does not tie up the pressurizing equipment.

6. Remove specimen from pressure restrainer, weigh and measure height and circumference.*

7. Place a plastic disk slightly larger than the top and bottom stones; then the stones, and finally the triaxial cell around the specimen and return to the 140° F. oven. Specimen is now ready for cohesiometer tests (see Test Method Tex-122-E).

NOTE: Paragraphs 17 through 21, Test Method Tex-119-E, are applicable to pressurization of cohesiometer specimens, except that porous stones may be used as spacers to fill the restrainer.

PART IV

PRESSURE WETTING OF BLACK BASE SPECIMENS

*This measurement of circumference is necessary in the case of cohesiometer specimens wetted by submerged-capillary conditions at 1 psi. lateral pressure confinement.

NOTE: Pressure wetting of black base specimens differs from the testing details given in Part III, herein, or Test Method Tex-119-E in that specimens are not pressurized in metal restrainers.

Apparatus

1. Same as Part III, except that pressure restrainers are not used.

2. A supply of plastic bags 10-1/2 inches by 18 inches, or a plastic or metal bucket with bail, which slide into the pressure vessel or pycnometer.

Procedure

At this point the specimens should have been molded previously and should be in the 140° F. oven awaiting further handling. Proceed as follows:

1. Fill the pressure pump and pressure vessel with hot water (150° F. ± 10° F.).

2. Remove the first specimen from the oven and obtain the weight to the nearest estimated 0.001 pound.

3. Carefully place the specimen in a plastic bag that has been perforated, or the bucket, and lower into the hot water in the pressure vessel (or pycnometer, if used) making sure the mouth of the bag is opened and allowing water to fill the bag also. (Figure 5)

4. Place head in pressure vessel and press down until water flows out of release valve.

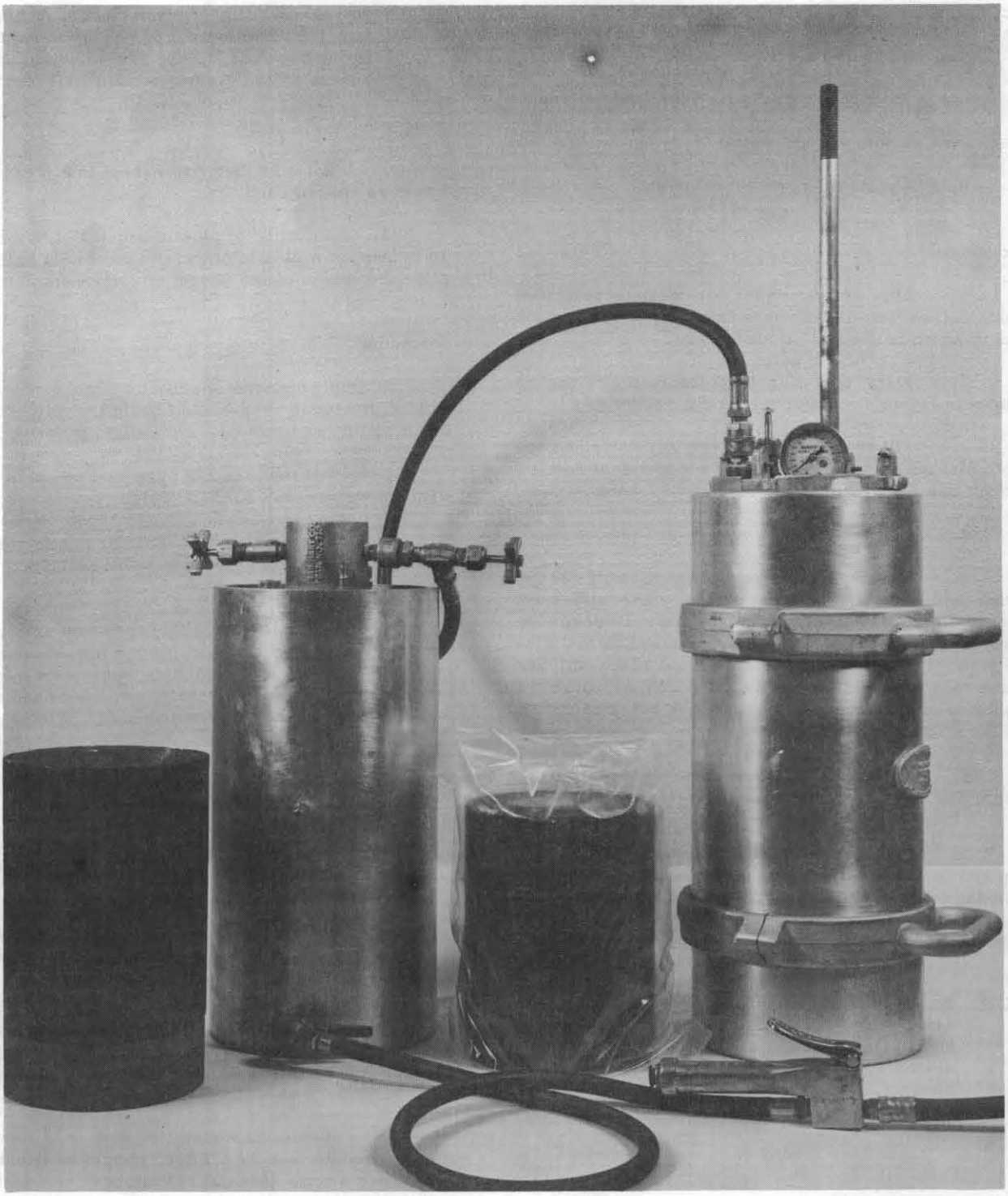
5. Fasten head securely, and using the manufacturer's instructions, apply 1200 psi. on the specimen, as indicated by the gauge, for fifteen minutes.

6. Release the pressure, carefully remove the specimen to the scales, blot, and obtain its wet saturated weight. Record data on Pressure Pycnometer Work Sheet, Figure 6.

7. Specimens near 140° F. may be removed to the testing area and tested as described under Procedure for Testing Black Base Specimens in Unconfined Compression, Test Method Tex-126-E, Part III.

8. Specimens whose temperature is low, or if it is desired to test them later, should be fitted with two porous stones (triaxial test stones) and a triaxial cell. The stones and cell should have been pre-heated to 140° F., and a plastic disk placed between the specimen and stones for moisture preservation and keeping stones freer from asphalt.

9. Store the specimen in the 140° F. oven for later testing.



Black Base Specimen | Pump | Specimen in Plastic Bag | Pycnometer Used as a Pressure Vessel

Figure 5

PRESSURE PYCNOMETER WORK SHEET

ABSOLUTE VOLUME, SPECIFIC GRAVITY, AND MOISTURE

CONTENT TEST DATA

DATE: _____

SAMPLE NO.						
PRES.-PYC. VOLUME (LBS.)						
VOLUME PLASTIC BAG (LBS.)						
VOLUME SAMPLE (LBS.)						
WET WT. SAMPLE (LBS.)						
* DRY WT. SAMPLE (LBS.)						
WT. WATER IN SAMPLE (LBS.)						
** % WATER IN SAMPLE						
CORR. PRES.-PYC. VOL.(LBS.)						
*** SPECIFIC GRAVITY						

* DRY WEIGHT FORMULA

$$\text{DRY WT.} = \text{WET WT.} - \frac{\text{SP. GR. X VOL.} - \text{WET WT.}}{\text{SP. GR.} - 1}$$

** MOISTURE CONTENT FORMULA

$$\% \text{ MOIST.} = \left\{ \frac{\text{SP. GR. X VOL.} - \text{WET WT.}}{\text{SP. GR.} - 1} \Big/ \text{DRY WT.} \right\} 100$$

*** SPECIFIC GRAVITY FORMULA

$$\text{SP. GR.} = \frac{\text{DRY WT.}}{\text{VOL.} - (\text{WET WT.} - \text{DRY WT.})}$$

File 9.400

Figure 6

Test Method Tex-116-E
Rev: September 1966

Texas Highway Department

Materials and Tests Division

BALL MILL METHOD FOR DETERMINATION OF THE DISINTEGRATION OF FLEXIBLE BASE MATERIAL

Scope

This test method describes a procedure for determining the resistance of the aggregate in flexible base material to disintegration in the presence of water. The test provides a measure of the ability of the material to withstand degradation in the road base and detects soft aggregate which is subject to weathering. This test is known as the Texas Ball Mill value.

Apparatus

1. Texas Ball Mill: The mill shall conform in all its essential dimensions to the design shown in Figure 1. The machine consists of a watertight steel cylinder, closed at one end, having inside dimensions of 10-3/16 inches diameter and 10-3/4 inches in length. The cylinder is fitted with a removable lid with watertight gasket attached. The cylinder is mounted in a rigid support in such a manner that it is rotated about the central axis in a horizontal position. A steel baffle, projecting radially 3-1/4 inches into the cylinder and 10-3/4 inches in length, is welded along one element of the interior surface of the cylinder. The baffle shall be of such thickness and so mounted as to be rigid. The machine should be operated at a uniform speed of approximately 60 r.p.m.

2. Metallic Spheres: The abrasive charge consists of 6 steel spheres approximately 1-7/8 inches in diameter, weighing between .9 lb. and 1.0 lb. each. (409 and 454 gms.)

3. Toledo Scales, or equivalent, of 30 lbs. capacity sensitive to .01 lbs. or less.

4. Sieves, No. 40 mesh and 1-3/4 inch

5. Oven, an air-dryer with temperature range of 120°F to 140°F.

6. Crusher

7. Miscellaneous equipment includes large pans, wash bottles, etc.

Test Record Form

Each sample shall be given an identification number and a card bearing the number should be placed with each portion of the sample throughout the processing and testing of the material. Record the test data on Work Card, Form 359.

Procedure

1. Secure a representative sample of the total material of sufficient size to yield more than the quantity required, in paragraph 4, (7 3/4 lbs.) of air dry material. Sixteen to eighteen pounds is a convenient size.

2. Crush oversize particles to pass a 1-3/4 inch sieve

3. Air dry the sample at a temperature not to exceed 140°F.

4. Reduce air dry sample of total material by sample splitter, or quartering methods to approximately 7 3/4 pounds. Adjust weight to 7 3/4 pounds plus or minus 0.1 pound of air dried sample. Place sample in pan and cover with water for 1 hour. (One-half gallon is usually sufficient.)

Note:

a. When testing borderline materials for compliance with specifications or running referee tests requiring accurate determinations, the minus No. 40 portion of the Wet Ball Mill Test should be in conformity with the amount of minus No. 40 material in the screen analysis sample. A check of the minus No. 40 in the sample can be done by screening the air dry material over the No. 40 sieve. When the Wet Ball Mill Test fines have been adjusted properly then recombine the sample and continue.

b. Air dry materials prepared for triaxial test (Test Method Tex-101-E, Part II) may be weighed accumulatively from the prepared separated sample.

5. Decant all free water from sample into a 1/2 gallon container, finish filling container with clear water and use to wash sample into ball mill.

6. Place the 6 steel spheres in the ball mill, fasten the watertight lid securely and rotate 600 revolutions at the rate of approximately 60 r.p.m.

7. When the 600 revolutions are completed, remove the cover and carefully empty the cylinder contents into a pan.

8. Remove the steel spheres and separate the sample by washing over the No. 40 sieve.

9. Dry the aggregate portion retained on sieve to constant weight at 140°F rescreen over the No. 40 sieve and weigh.

Calculations

Calculate the percentage of soil binder from the Texas Ball Mill test as follows:

$$\text{Texas Ball Mill Value} = \frac{A - B}{A} \times 100$$

Where: A = dry weight of total sample (step 4)

B = weight of retained material (step 9)

Precautions

1. Always use dry material in performing test.
2. Avoid the loss of portions of sample in transferring into or out of cylinder.
3. Use only 1/2 gallon of water in cylinder with wet sample from which free water has been decanted.
4. Check weight of steel spheres periodically for loss due to wear.

Charts

Figure 2 and Table I show typical test data.

Reporting Test Results

Report the Texas Ball Mill value on Form 476-A.

Notes

This procedure is not a substitute for Test Method Tex-101-E and should not be used generally for the preparation of soil samples for determination of standard soil constants and hydrometer analysis. The test furnishes valuable supplementary data pertaining to the quality of the aggregate portion of flexible base material. The Texas Ball Mill test is more reliable than the Los Angeles abrasion test in evaluating the quality of base materials.

TABLE I

Lab. No.	Percent Soil Binder: Standard Soil Test	Percent Soil Binder: Texas Ball Mill Value	Los Angeles Wear Test	Type of Material
41-83-R	5	10	28	Hall Bros. Cr. Limestone
42-425-E	1	6	28	Chico Cr. Limestone
42-426-E	1	6	16	Trap Rock
42-427-E	6	17	30	Servtex Cr. Limestone
41-49-R	9	70	55	Austin Chalk (poor quality)
42-354-E	17	36	78	Cr. Limestone (good quality)
41-125-E	**4**	22	40	Cr. Limestone (good quality)

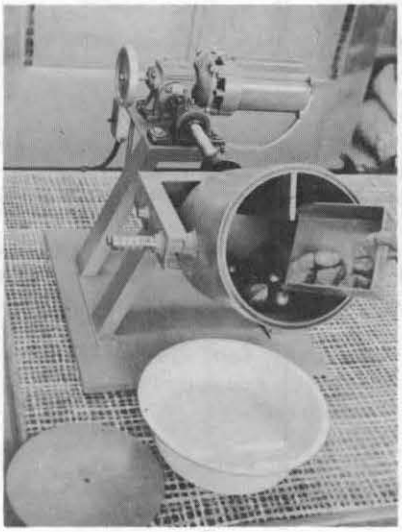


Figure 1a
Wet Ball Mill Showing Baffle and Charge

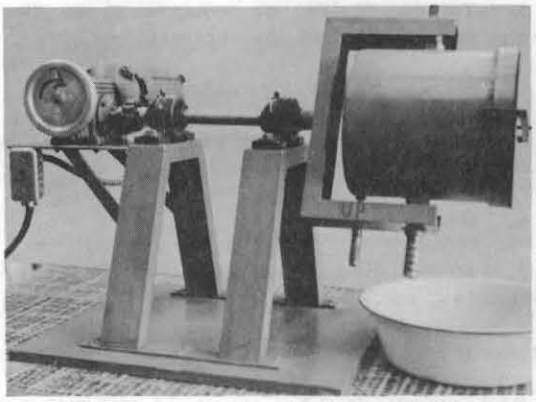


Figure 1b
Wet Ball Mill - Cantilevered Type

RELATION BETWEEN PERCENT SOIL BINDER FROM TEXAS BALL MACHINE AND PERCENT SOIL BINDERS BEFORE AND AFTER ROLLING

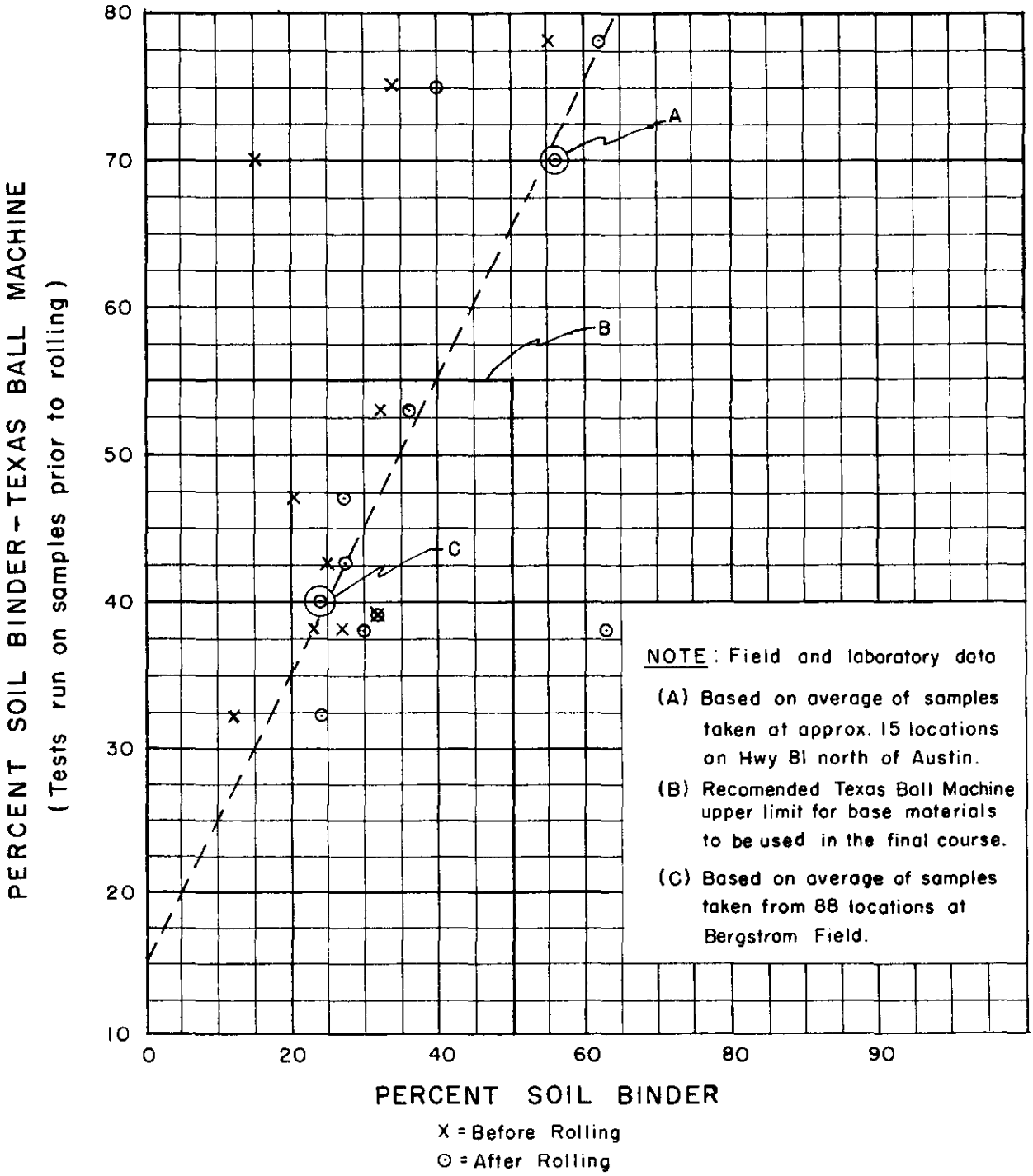


Figure 2

Texas Highway Department

Materials and Tests Division

SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES

Scope

This test method, which is a modification of A. S. T. M. Designation: C 136, covers a procedure for the determination of the particle size distribution of fine and coarse aggregate samples, using sieves with square openings. The method is also applicable for use to obtain the sieve analysis of aggregate recovered from bituminous mixtures obtained from plant or roadway.

Apparatus

1. Sample-splitter (Figure 1), quartering cloth (Figure 2), shoveling method on clean surface (Figure 3 and 4), or quartering machine (Not shown).

2. Set of Standard U. S. Sieves - woven wire with square openings (A.S.T.M. E-11)

3. Mechanical sieve shaker (Figure 5)

4. Scale or balance with at least 4500 grams capacity and sensitive to 0.1 gram.

5. Drying oven capable of attaining a temperature of 200°F. or more.

Figure 1

6. Various pans as needed

7. Scoop, brass wire brush and hair brush

Test Record Forms

Identify sample with a laboratory number and record test data on the appropriate work card as follows: Forms D-9-F14, D-9-F23, D-9-F2.

Preparation of Sample

1. Select a representative portion of processed aggregates for test.

2. Place aggregate in oven and dry to constant weight at a temperature of 100° to 300° F. (aggregates may be dried in a pan over open flame with frequent stirring.) Drying to a "constant weight" may be accomplished by drying for a specific period of time that has proven by experiment to be adequate or drying to the point that by observation, based on experience, the aggregate is sufficiently dry for testing.

When drying rock asphalt samples prior to testing, care must be taken to adjust oven temperatures so that native bitumen is not fluxed from aggregate. (For control testing, rock asphalt aggregate need not be dried)

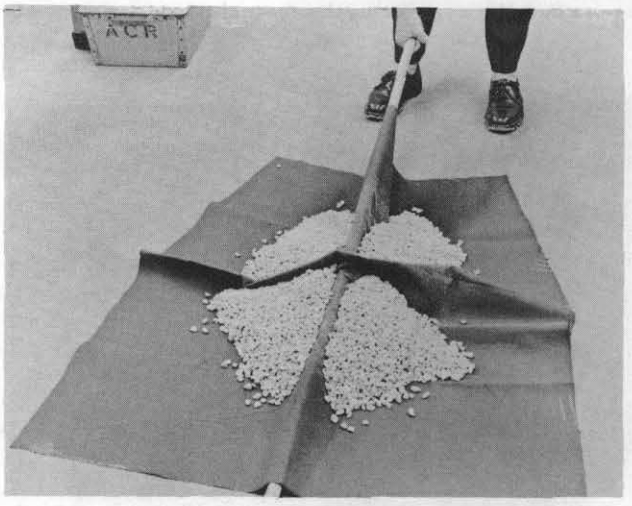


Figure 2

Remove samples from oven and allow to cool to room temperature. (For control testing, samples need not be cooled to room temperature prior to testing.)

3. To quarter the material use either the sample splitter, the quartering cloth, quartering machine, or the method of manipulating the aggregate with a large flat scoop or shovel blending it back and forth on a smooth clean surface until blended and then quartering mechanically with some straight-edge, thus reducing the dry aggregate sample to laboratory testing size. (Figure 4). It is permissible for fine materials (major portion passing No. 10 sieve) to thoroughly blend the material and take small portions form several places covering the entire area of the pan to make up the test sample. (For control testing it is permissible to make up the test sample for all size aggregates by blending small portions taken from several places in the pan.) See Tex-221-F. Table 1 for size of sample.

PART I
DRY SIEVE ANALYSIS

Procedure

1. Accurately weigh the total sample to the nearest estimated 0.1 gm. When testing surface treatment aggregates, this weight may be omitted, the total sample weight being the summation of the individual weights of the analysis.

2. Place the set of sieves, with the largest opening on top, into a pan and pour the aggregate onto the top sieve. Perform a sieve analysis on the aggregate sample by separating the material into a series of particle sizes using such sieves as are necessary to determine compliance with specifications for the material. The hand sieving operation is done by means of a lateral and vertical motion of the sieves, accompanied by a jarring action so as to keep the material moving continuously over the surface of the sieves. Continue hand sieving until by visual observation no material continues to pass through the sieves in use. When mechanical sieving is used, shaking time should be established that will assure proper sieving of the material without degradation. Check the thoroughness of the sieving by the above described method.

3. Remove any particles clinging to sieves with a brush taking care to lose none of the material. Determine the weights to the nearest estimated 0.1 gram of aggregate retained on each sieve in succession, record these weights along with the respective passing and retained sieve sizes. Also, record the weight of material passing the smallest size sieve used. If the sieve analysis of a material is desired on a "total retained" basis, one of two methods may be chosen. A "passing and retained" sieve analysis may be made and then converted mathematically to a "total retained" analysis by adding accumulatively the weights of all material retained on sieves larger than the particular sieve size under consideration to the material retained on that sieve. The second method is to make the original sieve analysis a "total retained" analysis by weighing material cumulatively, placing the material retained on one sieve directly on top of the previously weighed material on the balance from the larger size sieve. At the completion of this analysis all material, with the exception of that portion passing the smallest opening sieve will be on the balance pan.

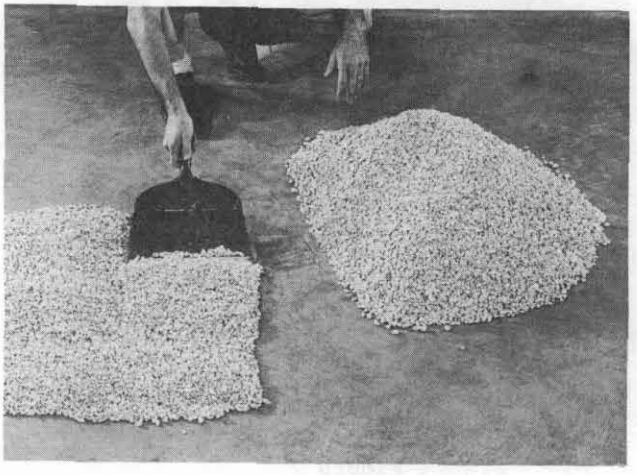


Figure 3

Figure 4

PART II

WASHED SIEVE ANALYSIS
(When Specified)

Follow the same steps as indicated under Tex-200-F "Preparation of Sample."

Procedure

1. Weigh the total dry sample to the nearest estimated 0.1 gm. and record the weight.

2. Place a set of sieves consisting of the sizes required in a pan with the largest opening on top. Pour the complete sample of material onto the top sieve. Shake gently so that the majority of the material passes through this sieve onto the next smaller sieve. Mechanical shaking for a brief period is permissible.

3. Remove the top sieve and place in a clean pan. Run or spray clean tap water over the material in the sieve until the pan is approximately one third full. Then shake the sieve vigorously back and forth, and up and down in the water, washing the finer material into the wash water.

4. After considerable shaking, hold the sieve above the pan and pour or spray clean water over the material, observing the water as it drips from the sieve into the pan. If it appears dirty, continue the shaking in the water until the sample is washed clean.

5. Pour the wash water into the stack of sieves washing all the fine material from the pan onto the next sieve.

6. Remove the clean material from the sieve and place in a tared pan to dry. (For fine materials this will require water to wash the material from the sieve into the drying pan. The pan should be allowed to sit undisturbed until the material has settled. The water can then be carefully decanted, and the material placed in an oven, min. 200 F, to dry). Statement in parentheses may be omitted when testing surface treatment aggregates. Any fine material washed through the smallest sieve will be counted as material passing the smallest sieve.

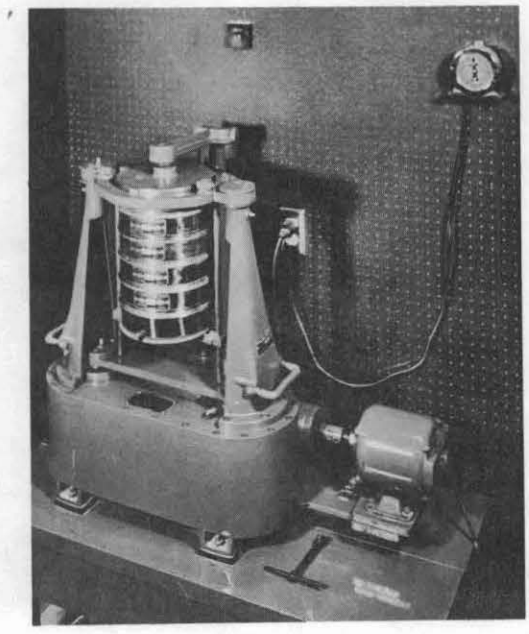


Figure 5

7. After dry, weigh the material to the nearest estimated 0.1 gm. and record the weight.

8. This procedure is repeated for each sieve size.

9. The per cent by weight of each sieve size is based on the original dry sample weight determined in step 1.

Reporting Test Results

Report the percentages to the nearest 0.1 percent for each size of aggregate passing and retained between consecutive sieves, retained on each sieve, or passing each sieve as set forth by specification requirements.

Notes

1. The term "sieve" as used in this procedure shall apply to an apparatus in which the aperatures are square.

2. In performing the sieve analysis, be careful to lose none of the sample during the sieving operations. However, if there is an insignificant discrepancy between the original dry weight of sample and the sum of the weights of the various parts, assume the small amount as particles passing the smallest size sieve and use the original weight. If the discrepancy is large, check the weights of the various sizes or re-run analysis with new sample to correct error.

Calculations

Calculate the percentages retained between consecutive sieves depending upon the specifications for the use of the material tested as follows:

$$W = \frac{X_1}{W_T} \times 100$$

Where:

W = Percentage of aggregate retained between consecutive sieves

X_1 = Weight of oven-dry aggregate passing one size sieve and retained on a smaller size sieve.

W_T = Total weight of original sample which equals the sum ($X_1 + X_2$, etc.) of all the weights of aggregate retained on sieve sizes and includes the portion which passes the smallest size sieve used.

Texas Highway Department

Materials and Tests Division

BULK SPECIFIC GRAVITY AND WATER ABSORPTION OF AGGREGATE

Scope

This test method describes a procedure for determining the bulk specific gravity and water absorption of aggregate. The test is performed by obtaining the oven-dry weight of a quantity of aggregate and measuring the volume of the material in a saturated surface-dry condition by displacement of water. This bulk specific gravity is the value used in calculating the theoretical gravity of a bituminous mixture. The water absorption may be used to determine the amount of free moisture in aggregate which is an indication of the porosity of the material. Figure 1 demonstrates the theory of the bulk specific gravity determination.

Definitions

Bulk Volume: The bulk volume of an aggregate includes both the volume of the impermeable portion of the aggregate particles and the volume of the permeable voids in the particles. The bulk volume of the aggregate is equal to the volume of water displaced by the aggregate in a saturated, surface-dry condition.

Bulk Specific Gravity: This term is defined as the ratio of the oven-dry weight of the aggregate to the bulk volume of the aggregate particles.

Apparatus

1. Scale or balance: A balance with at least 4500 gram capacity, sensitive to 0.1 gram.

2. Half-gallon glass fruit jar and pycnometer cap

3. Drying oven capable of attaining a temperature of 200°F. or more, hot plate or gas burner.

4. Wide-mouth funnel

5. Sieve, set of U. S. Standard sieves with square openings

6. Round pans, 7-3/4 quart capacity

7. Small masonry pointing trowel

8. Small ear syringe

9. Sample-splitter, quartering machine, or quartering cloth (unless shoveling method on clean surface is used)

Materials

1. Lint-free cotton cloth

2. Fine carborundum cloth

3. Turpentine

4. Clean tap water

Test Record Form

Record test data on work card, Form No. D-9-F15 and report test values on Form No. 231.

Calibration of Pycnometer

It is necessary to prepare and calibrate the pycnometer to assure that it is of definite and constant volume. Select a half-gallon fruit jar with good threads on neck and with rim free from cracks or broken places. Clean the jar and fill with clean tap water. With the gasket seated smoothly in place, screw the metal pycnometer cap snugly on the jar. Use ear syringe, Figure 3, and fill with water, leaving a rounded bead of water on top of the cap. If the pycnometer leaks water, place a piece of fine grain carborundum cloth on a smooth, solid, plane surface and pour a small amount of turpentine on the cloth. Hold the jar as shown in Figure 2, smooth and true the rim by rotating the jar. Apply force and continue the grinding action until the rim of the jar appears to

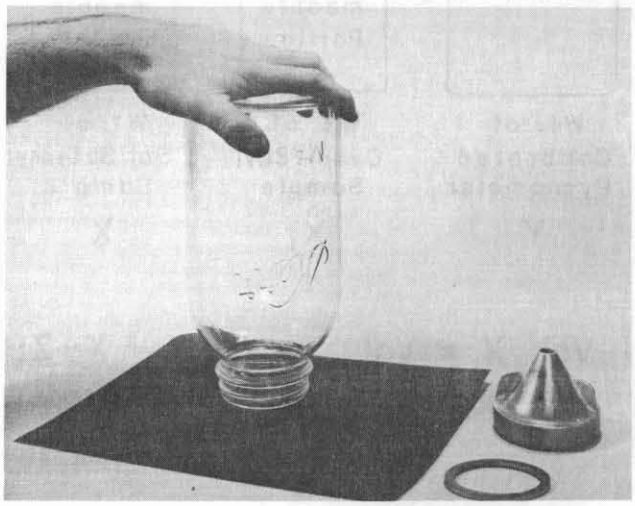
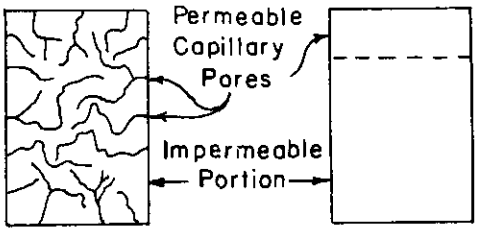
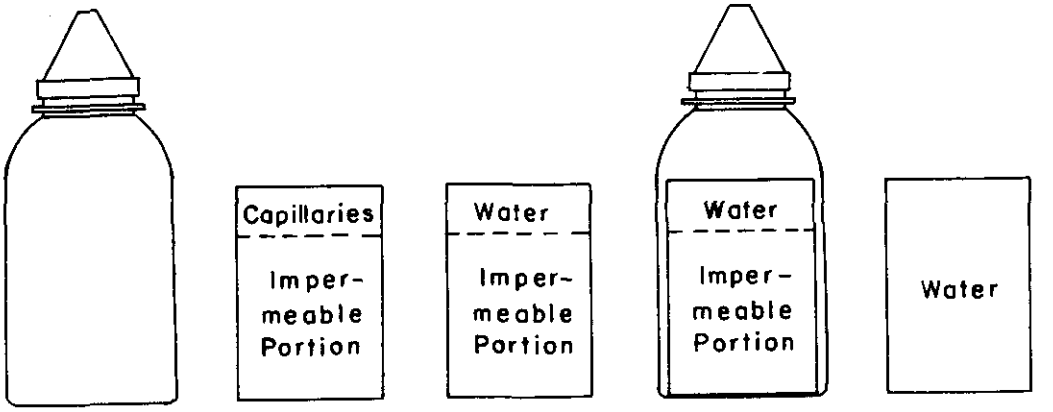


Figure 2



Aggregate Particle

Figure 1a



Wt. of Calibrated Pycnometer	Wt. of Oven-dry Sample	Wt. of Sat. Sur.-dry Sample	Wt of Pyc. + Ssd. Sample + Water to Fill	Wt. of Water Displaced by X
Y	X_1	X	Z	Y + X − Z

$$\text{Vol. } X_1 = \text{Vol. } X = \text{Vol. } Y + X - Z; \quad \text{Bulk Sp. Gr.} = \frac{X_1}{Y + X - Z}$$

Figure 1b

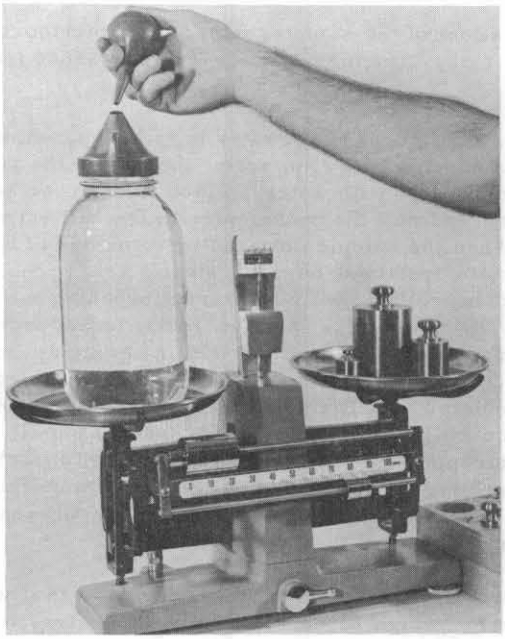


Figure 3

be perfectly smooth. Weigh the pycnometer filled with water to the nearest estimated 0.1 gram, Figure 3, and record weight as Y each time pycnometer is used.

Preparation of Sample

1. Secure a quantity of representative material proposed for use and reduce to laboratory test size by quartering.

2. Use the procedure outlined in Test Method Tex-200-F for sieve analysis and divide the material classified as coarse aggregate (material retained on the No. 10 sieve) into sizes to conform with the requirements of the specification. Sieve the fine aggregate (material passing the No. 10 sieve) over the No. 80 sieve. Save the material passing the No. 80 sieve and determine the specific gravity in accordance with Test Method Tex-202-F.

3. After the aggregates have been separated into the proper sizes, rinse or wash with clean water to remove any fine materials that might have existed as a coating on particles or in the form of lumps. The coarse aggregates are washed over a No. 10 sieve.

4. Place approximately 1500 - 2000 grams of each size aggregate, obtained from step 2 above, in separate milk pans; cover with water and saturate for 24 hours, or boil the aggregate for four hours. Keep the aggregate inundated throughout the soaking period or while boiling to thoroughly saturate all of the material with water. After this period of saturation, re-wash the coarse aggregates over the No. 10 sieve to remove slaked material.

BULK SPECIFIC GRAVITY

Procedure

1. Surface-dry each aggregate portion as follows:

a. Surface-dry all aggregate particles retained on the No. 10 sieve by means of the lint-free cloth. Drain the water from the sample, transfer a portion of the material to the cloth and roll in the cloth until all surface moisture has been removed. Do not dry past the surface-dry condition. Place the surface-dry aggregate in a small pan and cover with lid. Continue this operation until the total sample has been surface-dried and weigh immediately to prevent loss of moisture by evaporation.

b. Carefully drain the water from the aggregate passing the No. 10 sieve and retained on the No. 80 sieve. Then place the wet material on a smooth non-absorbent surface, such as a metal or tile topped work bench, and allow to air dry (Figure 4). An air circulating type fan may be used as an aid in decreasing time required for drying but do not apply artificial heat or sunlight. Use a small trowel to stir and mix the sample frequently so that the particles on top will not become drier than the surface-dry condition. Determine the saturated, surface-dry condition as follows:

Method (1): Place a small amount of aggregate of the same grading as that being tested, which is obviously drier than surface-dry, into a dry milk pan with smooth bottom. Tilt the pan to an approximately 45° angle with table and tap lightly on the bottom observing the manner in which the dry material slides down the bottom of the tilted pan. Place a portion of the sample which is near to surface-dry condition in another dry milk pan, tilt and tap while observing how the material flows or slides (Figure 5). When the aggregate being tested ceases to adhere to the bottom of the pan and flows freely, as the dry sample did, it is judged to be surface dry.

Method (2): Scoop up on a small masonry pointing trowel some of the same aggregate that is being tested that is obviously drier than surface-dry. Tilt the trowel slowly to one side, observing how the dry material flows freely from the trowel. Then scoop up the same amount of the nearly surface-dry sample being tested and tilt the trowel in the same manner watching it flow from the edge of the trowel. When the material being tested ceases to adhere to the trowel surface and flows off freely as individual particles, as the dry sample did, it is said to be in a saturated, surface-dry condition.

Note: Be certain that the trowel is completely dry before each check on the material.

2. Transfer the saturated, surface-dry material to the balance and weigh immediately to prevent the loss of moisture by evaporation. Weigh the sample to the nearest estimated 0.1 gram and record weight as X.

3. Place the saturated, surface-dry sample into the pycnometer jar approximately one-fourth full of water by means of the wide-mouth funnel, taking care to lose none of the sample. Rinse the funnel thoroughly so that any clinging particles will be washed into the jar.

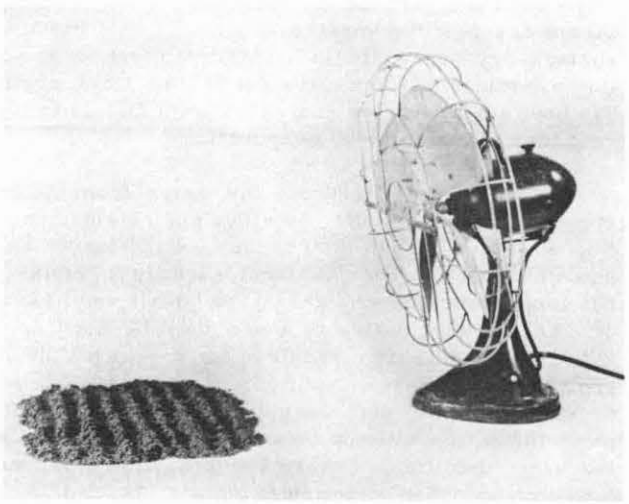


Figure 4

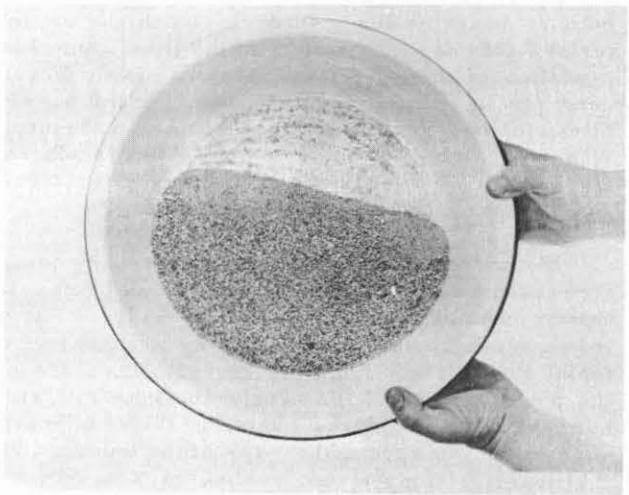


Figure 5

4. Fill the jar with water to within approximately one-half inch of the rim, screw the cap on the jar and fill completely with water. Place finger over hole in the cap and roll the pycnometer to free all entrapped air. When the sample contains large pieces of coarse aggregate (retained on 3/8" sieve), the pycnometer should be rolled gently to prevent breaking the glass jar. The material should be gently tossed from one end of the jar to the other with a swinging motion while rolling. When a quantity of air bubbles has accumulated, refill the pycnometer, washing out the air and roll again. Repeat this process until all of the entrapped air has been removed. To facilitate the removal of the air, a water-aspirator may be used, but care should be exercised to prevent siphoning out any of the finer particles.

5. Dry the outside of the pycnometer thoroughly, use ear syringe to carefully fill with water, leaving a rounded bead of water on top of pycnometer cap, and weigh to nearest estimated 0.1 gram. (Figure 3). Record weight as Z.

6. Remove the cap from the pycnometer and pour the sample into a clean, tared milk pan. Use plenty of water to rinse jar, cap and hands thoroughly. Allow the material to remain undisturbed until the water becomes perfectly clear, then decant or siphon the water from the sample. Take care to lose none of the material while pouring or draining the water from sample.

7. Dry the aggregate to constant weight at a temperature of 220° to 400°F. and cool to room temperature before weighing. Record the net oven-dry weight of sample to the nearest estimated 0.1 gram as X_1.

Calculations

1. Calculate the bulk specific gravity of the aggregate by the following formula:

$$G = \frac{X_1}{X + Y - Z}$$

Where:

G = Bulk (oven-dry) specific gravity of aggregate
X_1 = Weight (grams) of oven-dry sample
X = Weight (grams) of saturated, surface-dry sample
Y = Weight (grams) of calibrated pycnometer filled with water

Z = Weight (grams) of pycnometer containing saturated, surface-dry sample and water to fill at approximately the same temperature at which the pycnometer was calibrated.

2. Calculate the average bulk specific gravity of combined sizes of aggregate or combination of materials as follows:

$$G = \frac{100}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \text{etc.}}$$

Where:

G = Average bulk specific gravity of combination

G_1 = Bulk specific gravity of Material No. 1

G_2 = Bulk specific gravity of Material No. 2

W_1 = Percentage of Material No. 1 from screen analysis or based on total weight of combination

W_2 = Percentage of Material No. 2 from screen analysis or based on total weight of combination

$W_1 + W_2 + W_3$, etc., should total 100%

3. Using the test data secured in determining the bulk specific gravity, calculate the water absorption of the aggregate as follows:

$$A = 100\,\frac{X - X_1}{X_1}$$

Where:

A = Percent water absorption (24 hours) of aggregate based on the oven-dry weight of sample

X = Weight (grams) of saturated, surface-dry sample

X_1 = Weight (grams) of oven-dry aggregate

4. Calculate the average percent water absorption of combined materials as follows:

$$A = \frac{A_1W_1 + A_2W_2 + \text{etc.}}{100}$$

Where:

A = Average percent water absorption (24 hours) of combined materials based on the total weight of oven-dry combination

A_1 = Percent water absorption of Material No. 1

A_2 = Percent water absorption of Material No. 2

W_1 and W_2 are the same as defined under step 2

Notes

Water temperature for weights Y and Z should be approximately the same. Repeated results should check within $\pm$ 0.02.

Test Method Tex-404-A
Rev: January 1, 1972

Texas Highway Department

Materials and Tests Division

DETERMINATION FOR UNIT WEIGHT OF AGGREGATE

Scope

This method of test, which is a modification of A.S.T.M. Designation: C 29 , describes a procedure for determining the loose weight per cubic foot of both coarse and fine aggregates. The unit weight of aggregate in a saturated surface-dry loose condition is intended for use in portland cement concrete mix design.

Apparatus

1. A small square-point scoop
2. Quartering cloth or large flat metal pan
3. A scale of 106 pounds capacity, sensitive to 0.01 pound meeting requirements of Class IV-C scales of Test Method Tex-901-K.
4. A metal straight edge

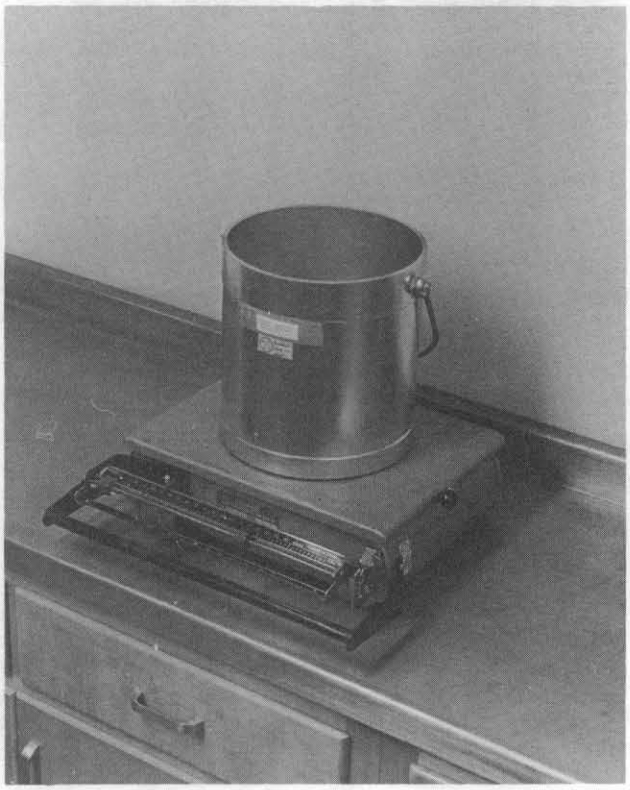


Figure 1

5. Two, metal measures, cylindrical in form and provided with handles. The containers shall be watertight with the top and bottom true and even, preferably machined to accurate dimensions on the inside, and of sufficient rididity to retain their form under rough usage. The measures required shall have capacities (volume) of 1/2 and 1/10 cubic foot and shall conform to the following requirements:

Capacity cu. ft.	Inside Diam. in Inches	Inside Height in Inches	Size Aggregate
1/2	10.0 ± 0.1	11.0 ± 0.1	Coarse
1/10	6.0 ± 0.1	6.1 ± 0.1	Fine

6. A piece of plate glass large enough to cover the top of measure.
7. Rubber bulb or wash bottle.
8. A denim cloth sleeve 8-1/2 in. by 30 in. long (flat measurement)
9. Fahrenheit thermometer calibrated by Test Method Tex-906-K.

Calibration of Measure

Calibrate the measure by accurately determining the weight of water at a convenient temperature (degrees F) that is required to fill the measure as follows:

1. Place the measure on the scale and cover with a piece of plate glass. Use a spirit level to perfectly level the measure.
2. Obtain the weight of the measure and glass cover to the nearest 0.01 pound and record the weight as W_M.
3. Fill the measure with water until the water level barely reaches the rim of the measure. Then use the piece of glass as a cover plate. If the measure is almost full, the surface tension will cause the water to adhere to the cover plate. Start the glass plate at one side and carefully slide it over the measure. While the cover plate is moved across the measure, use the rubber bulb or a wash bottle and continue adding water enough to fill the large air bubble which forms under the edge of the cover plate. When the operation is nearly complete, fill the small remaining air space with a few drops of water to exactly fill the measure.
4. Weigh the measure filled with water to the nearest 0.01 pound and record the weight as W_W. Use the Fahrenheit thermometer to obtain the temperature of the water at T_F.

5. Calculate the volume of the water which is also the volume of the measure from temperature-density relation of the water and obtain the factor for the measure as follows:

$$V = \frac{W_W - W_M}{U_W}$$

$$F = \frac{1}{V} = \frac{U_W}{W_W - W_M}$$

Where:

F = Factor for measure (reciprocal of volume
V = Volume of measure in cu. ft.
W_W = Weight of measure filled with water and glass cover
W_M = Weight of measure empty and glass plate
U_W = Unit weight of water at temperature T_F from Table I
T_F = Temperature of the water in the measure

6. Secure the tare weight of the measure and record the weight as T to the nearest 0.01 pound.

Sample Preparation

Secure a representative sample of sufficient quantity to fill measure and either air dry at room temperature to the saturated surface-dry condition or dry in oven to constant weight at a temperature of 230 $\pm$ 9°F. depending on whether oven-dry or saturated surface-dry unit weight per cubic foot value is desired. Place the sample on a quartering canvas or in the large flat pan and thoroughly mix.

Procedure

A. Coarse Aggregate

1. Place the 1/2 cubic foot measure on a level surface near the aggregate sample. Take a scoop full of the aggregate from the thoroughly mixed sample pile and holding the scoop two inches above the measure, pour the aggregate into the measure. Pour the material uniformly over the entire area in such a manner that each layer placed is nearly level and the surface of the material when the measure is full will be practically level with the rim of the measure.

2. Level off the surface of the aggregate with the fingers, taking care not to jar the measure, in such a way that slight projections of the larger particles above the rim shall balance the larger voids in the surface below the top of measure (Figure 4).

3. Weigh the measure full of aggregate, and subtract the tare weight of the empty measure to obtain the net weight of material required to fill the measure. Repeat the above steps two additional times to obtain an average weight. Record the average net weight of aggregate as W.

Figure 4

B. Fine Aggregate

1. The fine aggregate sample should be of sufficient size (after drying) to fill the 1/10 cubic foot measure to overflowing. A slight amount of free moisture causes sand to bulk, thus introducing an error in the test result. Use the small scoop to place the sample of sand into the denim sleeve.

2. Place the 1/10 cubic foot measure in a large flat pan so that the excess material may be recovered for check tests.

3. Thoroughly mix the fine aggregate in the sleeve by closing the ends with both hands and then alternately raising and lowering one end of the sleeve and then the other. Close the open end of the sleeve with one hand, allowing several inches of the empty part of the sleeve to extend beyond the hand, place this end on the bottom of the measure and remove the hand (Figure 2). Hold the measure firmly with one hand while steadily withdrawing the sleeve with the other hand.

4. Use the straight edge to strike off the excess material even with the top of the measure. Tap the side of the measure lightly to settle the material slightly to prevent loss of any material when weighing (Figure 3).

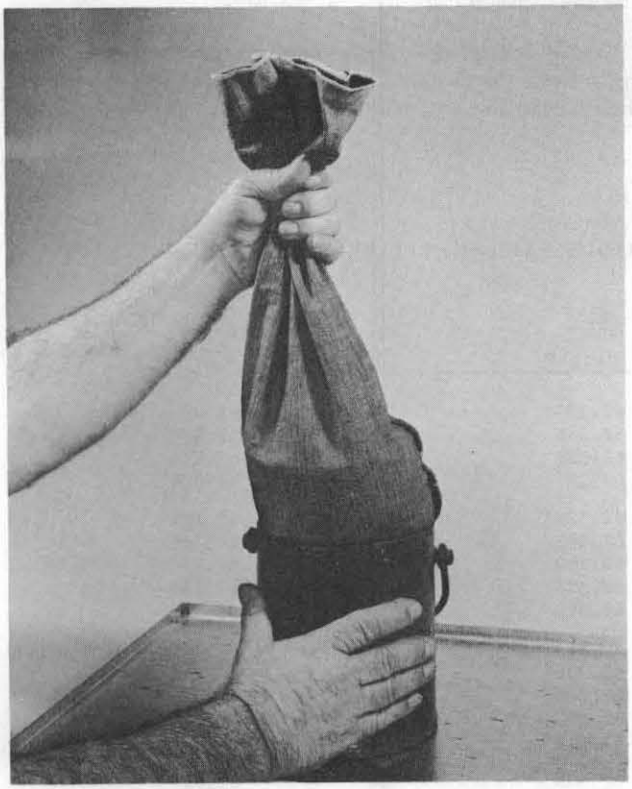


Figure 2

5. Obtain the weight of the measure filled with fine aggregate and record the net weight as W to the nearest estimated 0.01 pound. Repeat this process to obtain an average net weight for the aggregate.

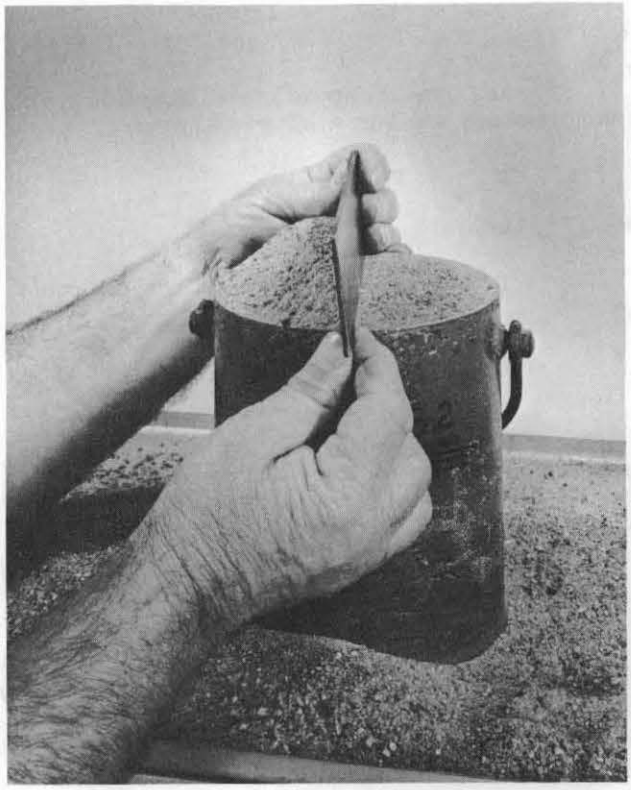


Figure 3

C. Lightweight Aggregate, Coarse

TENTATIVE, December 1970

It is desirable to standardize the gradation on which the dry loose unit weight determination is made when this unit weight is used as a quality acceptance criteria as noted under the Article "Materials" in the governing specification.

When used as a volume measure for weight–volume conversion, distribution rate, pay item or when the standardized grading cannot be obtained, the dry loose unit weight determination shall be made on the total sample as received.

1. Dry the material to a constant weight at a temperature of 230 ± 9°F.

2. Standard Gradation: Material, more than sufficient to fill the 1/2 cubic foot measure, shall be sized as follows:

Size	Retained, Percent by Wt.
1/2	0
3/8	40 - 60
No. 4	100

3. The remainder of this procedure shall be in accordance with Part A, Coarse Aggregate.

1. $U = FW$

Where:

U = Unit weight in pounds per cubic foot
F = Factor for the measure (1/V)
W = Average net weight of aggregate to fill measure

2. If the aggregate was dry when tested and the saturated surface-dry loose unit weight is desired, determine the absorption A as specified in Test Method Tex-403-A and calculate the unit weight as follows:

$$U = FW\left(1+\frac{A}{100}\right)$$ = saturated surface-dry unit weight

3. If the free moisture has been removed but the aggregate still contains some absorbed moisture when tested and the oven-dry unit weight is desired, calculate the value by the following expression:

$$U = \frac{FW}{1+\frac{A_1}{100}}$$

Where:

A_1 = Absorbed moisture at the test condition of the aggregate

Notes

1. Avoid unnecessary delays when testing saturated surface-dry material in order to prevent excessive loss of moisture by evaporation.

2. Mix the aggregates thoroughly and take precautions to prevent segregation of the particles when filling the unit weight measures.

TABLE I

UNIT WEIGHT OF DISTILLED WATER AT VARIOUS FAHRENHEIT TEMPERATURES

Temp. °F.	Unit Weight	Temp. °F.	Unit Weight	Temp. °F.	Unit Weight
32	62.418	55	62.390	78	62.234
33	62.420	56	62.386	79	62.225
34	62.422	57	62.382	80	62.216
35	62.423	58	62.377	81	62.206
36	62.424	59	62.372	82	62.196
37	62.425	60	62.366	83	62.186
38	62.425	61	62.360	84	62.176
39	62.426	62	62.355	85	62.166
40	62.426	63	62.349	86	62.156
41	62.425	64	62.342	87	62.145
42	62.425	65	62.336	88	62.134
43	62.424	66	62.329	89	62.124
44	62.423	67	62.322	90	62.113
45	62.421	68	62.316	91	62.101
46	62.419	69	62.308	92	62.090
47	62.417	70	62.301	93	62.079
48	62.415	71	62.294	94	62.067
49	62.412	72	62.286	95	62.055
50	62.409	73	62.277	96	62.043
51	62.406	74	62.269	97	62.031
52	62.402	75	62.261	98	62.018
53	62.399	76	62.252	99	62.006
54	62.395	77	62.243	100	61.993

Texas Highway Department

Materials and Tests Division

ABRASION OF COARSE AGGREGATE BY USE OF THE LOS ANGELES MACHINE

Scope

This Test Method covers the procedure for testing conventional and lightweight coarse aggregate for resistance to abrasion in the Los Angeles testing machine with an abrasive charge. The apparatus and procedure used in this test are identical with A.S.T.M. Designation: C 131.

Procedure

Use the apparatus specified to prepare and test the required gradings of aggregate in accordance with the procedure described in A.S.T.M. Designation: C 131.

Reporting Test Results

Report the test data and type grading and the wear to the nearest 0.1 percent on Form No. 272.

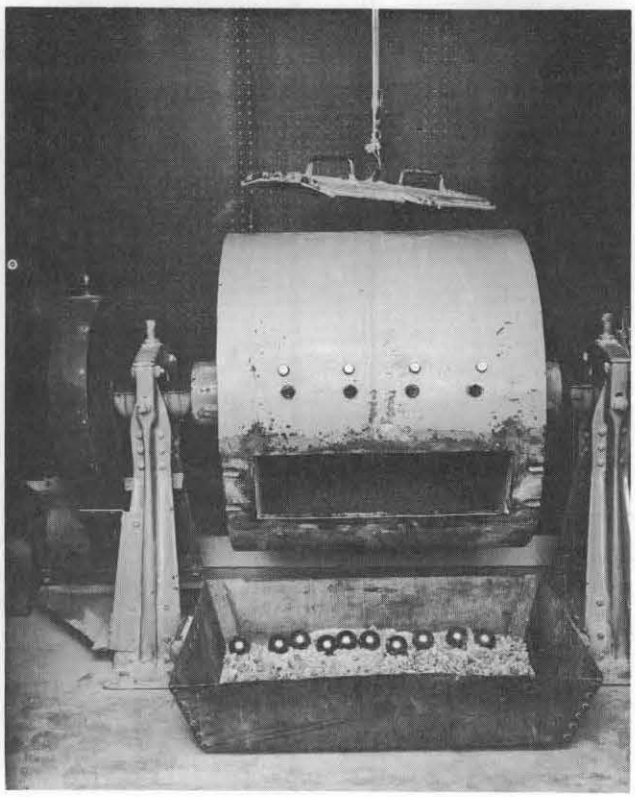


Figure 1

Test Method Tex-411-A
Rev: September 1965

Texas Highway Department

Materials and Tests Division

SOUNDNESS OF AGGREGATE BY USE OF SODIUM SULPHATE OR MAGNESIUM SULPHATE

Scope

This test method covers the procedure to be followed in testing aggregates to determine their resistance to disintegration by saturated solutions of magnesium sulphate or sodium sulphate. Attention is called to the fact that test results by the use of the two salts differ considerably and care must be exercised in fixing proper limits in any specification which may include requirements for these tests. The test as performed is identical with A. S. T. M. Designation: C 88 and the results are determined after 5 cycles of the aggregate in a saturated solution of magnesium sulphate or sodium sulphate.

Procedure

Use the apparatus to prepare and test samples of aggregate as specified in A. S. T. M. Designation: C 88. Prepare the saturated magnesium sulphate or sodium sulphate solution several days prior to testing to regulate the temperature and specific gravity of the solution. Determine the percent loss of aggregate after 5 complete cycles of wetting in solution and drying.

Reporting Test Results

Report the weighted average percent loss calculated on the basis of the total sample on Form No. 272.

Notes

1. Check both the temperature and the specific gravity of the solution daily as test reproducibility will be affected if these factors are allowed to vary from the test requirements.

2. The aggregate must be completely dried and then cooled to room temperature to prevent any disintegration which may be caused by sudden temperature changes in the aggregate.

Test Method Tex-431-A, TENTATIVE
Rev: April 1, 1970

Texas Highway Department

Materials and Tests Division

PRESSURE-SLAKING TEST OF SYNTHETIC COARSE AGGREGATE

Scope

The test method described here is intended to be used to evaluate the amount of dehydration that has occurred in the production of synthetic aggregates fired in a Rotary Kiln.

Apparatus

The apparatus shall consist of the following:

1. Pressure cooker (common kitchen type with 6 quart capacity with 15 psi pressure regulator)

Note: Centrifuge bottles will require a pan depth of approximately 7 inches. Presto Stainless Steel Pressure Cooker Model PCS6 has been found to have a satisfactory inside height.

2. Centrifuge bottles - 500 ml. Pyrex

3. Balance - having capacity of at least 4500 grams and accurate within 0.1 percent of the test load at any point within the range of use and sensitive to 0.1 gram

4. Heavy duty shaker - Equipoise Model No. 5855

5. Sieves - U. S. Standard woven wire—sizes 3/4-inch, No. 10, and No. 40. (Conforming to ASTM Designation E-11)

6. Drying oven maintained at 220° F. ± 9° F.

Sample

An unwashed representative sample of sufficient volume to half fill the centrifuge bottle should be chosen. The sample material is that which passes a 3/4" sieve and is retained on a No. 10 sieve. Any material retained on the 3/4" sieve should be crushed to pass this sieve using a minimum amount of crushing. Since synthetic aggregates vary widely as to specific gravity, a volumetric measure of the sample is used rather than weight.

Procedure

1. Place the sample into the centrifuge bottle and add 200 ml. of distilled water. It is not necessary to determine the initial weight of the sample.

2. Place the centrifuge bottles containing the aggregates into the pressure cooker, adding approximately 1/2" of distilled water to the pressure cooker and seal the lid tightly.

3. Heat the pressure cooker until full pressure is indicated by the pressure regulator.

4. Adjust heat to allow only a slight escape of steam and maintain pressure for 15 minutes. Remove the heat, release the pressure, and remove the centrifuge bottles.

5. After cooling to approximately 100°F., place corks in the centrifuge bottles and place the bottles in the Equipoise shaker. Shake the aggregates for 15 minutes.

6. Upon removing the bottles from the shaker, wash the sample over a No. 40 sieve, taking care not to lose any of either fraction.

7. Dry both fractions to a constant weight at 105°C. (220°F.). Due to rehydration, the final total weight of the sample may be greater than the initial weight.

MODIFIED PRESSURE SLAKING TEST

Apparatus

The apparatus shall consist of the following:

1. Pressure cooker (common kitchen type with 6 quart capacity with 15 psi pressure regulator)

Note: Centrifuge bottles will require a pan depth of approximately 7 inches. Presto Stainless Steel Pressure Cooker Model PCS6 has been found to have a satisfactory inside height.

2. Centrifuge bottles - 500 ml. Pyrex

3. Balance - having capacity of at least 4500 grams and accurate within 0.1 percent of the test load at any point within the range of use and sensitive to 0.1 gram

4. Sieve Shaker - Tyler Portable Sieve Shaker or equivalent—motor driven. General Warehouse Stock No. 212305

5. Sieves - U. S. Standard woven wire—sizes 3/4-inch, No. 10, and No. 40. (Conforming to ASTM Designation E-11)

6. Drying oven maintained at 220° F. ± 9° F.

7. Stainless Steel Pot—Bain Marie with cover. Body diameter of 8 inches, depth 9-3/4 inches. General Warehouse Stock No. 210425.

8. Spacer (7-3/4 inch diameter x 2 inch thick) Rubber Cushion (7-3/4 inch diameter x 1/8 inch thick), and miscellaneous rubber sheeting or rags.

Sample

An unwashed representative sample of sufficient volume to half fill the centrifuge bottle should be chosen. The sample material is that which passes a 3/4" sieve and is retained on a No. 10 sieve. Any material retained on the 3/4" sieve should be crushed to pass this sieve using a minimum amount of crushing. Since synthetic aggregates vary widely as to specific gravity, a volumetric measure of the sample is used rather than weight.

Procedure

1. Place the sample into the centrifuge bottle and add 200 ml. of distilled water. It is not necessary to determine the initial weight of the sample.

2. Place the centrifuge bottles containing the aggregates into the pressure cooker, adding approximately 1/2" of distilled water to the pressure cooker and seal the lid tightly.

3. Heat the pressure cooker until full pressure is indicated by the pressure regulator.

4. Adjust heat to allow only a slight escape of steam and maintain pressure for 15 minutes. Remove the heat, release the pressure, and remove the centrifuge bottles.

5. After cooling to approximately 100° F., place stoppers in the centrifuge bottles and place the bottles vertically in the stainless steel pot. (The rubber cushion should be placed beneath the bottles and the rubber sheeting or rags inserted between the bottles to press them firmly against the side of the bucket.

6. Place the spacer over the rubber stoppers in the bottles and fasten the cover to press the bottles against the bottom of the bucket.

7. Place the stainless steel pot in the sieve shaker and shake for 15 minutes.

8. Upon removing the bottles from the shaker, wash the sample over a No. 40 sieve, taking care not to lose any of either fraction.

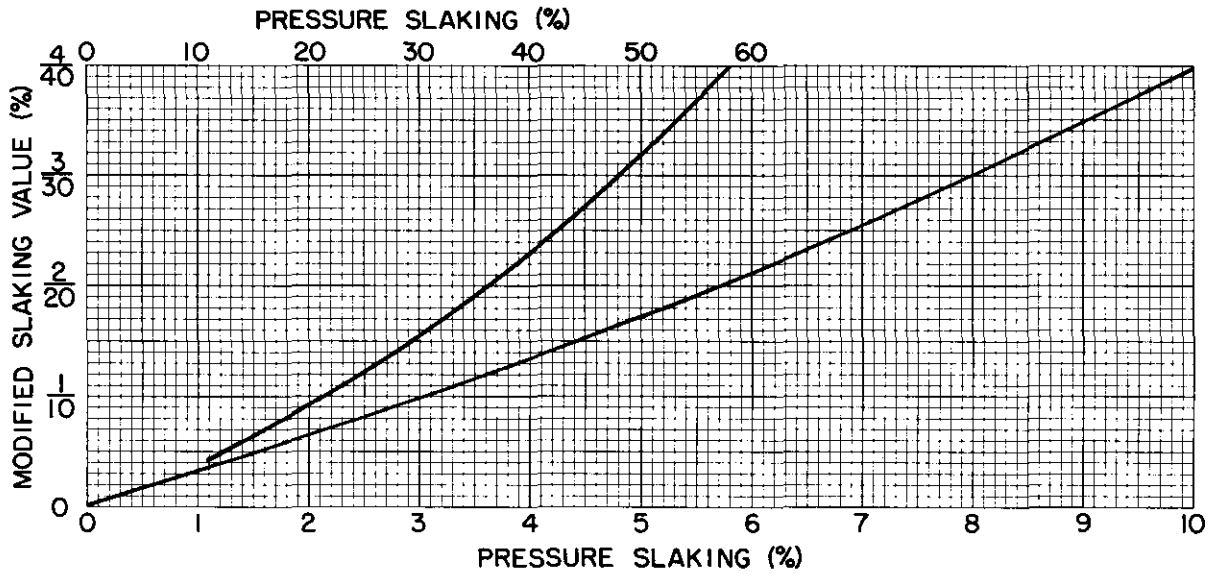
9. Dry both fractions to a constant weight at 105° C. (220° F.) Due to rehydration, the final total weight of the sample may be greater than the initial weight.

Calculations

The modified slaking value is expressed as the percent passing the No. 40 sieve and is calculated by the following equation:

$$\text{Modified slaking value (\%)} = \frac{\text{Weight of minus 40 material}}{\text{Total weight of material}} \times 100$$

Note: The Modified Procedure has been correlated with the initial procedure and the Modified Slaking Value must be converted by use of the curve below in order to compare with specification requirements.



Texas Highway Department

Materials and Tests Division

COARSE AGGREGATE FREEZE-THAW TEST

Scope

This method of test describes a procedure to be followed in testing synthetic coarse aggregate to determine their resistance to disintegration by freezing and thawing. It furnishes information helpful in judging the soundness of aggregates subjected to weathering action.

Apparatus

The apparatus shall consist of the following:

1. The freezing chamber - the freezing chamber shall be any commercial type freezer of suitable dimensions and shall be capable of maintaining a constant temperature of -10°C. or lower.
2. Trays and containers - shallow metal trays approximately two (2) inches in depth and of suitable dimensions to contain the aggregate sample in a single layer.
3. Sieves - sizes 3/4 inch, 5/8 inch, 1/2 inch, 3/8 inch, No. 4, and No. 10 conforming to the Specifications for Sieves for Testing Purposes (A.S.T.M. Designation: E 11).
4. Balance - with a capacity of 1000 grams and accurate within 0.1 percent of the test load at any point within the range of use and sensitive to 0.1 gram.
5. Drying oven - the drying oven shall provide a free circulation of air through the oven and shall be capable of maintaining a temperature of 230°F.

Sample

The test sample shall be prepared from aggregate representative of that being furnished. The aggregate shall be washed and dried at 230°F ± 9° to constant weight, separated into individual size fractions as follows:

Size of Aggregate		Weight of Individual Sizes - grams Test Grade			
Passing -	Ret'd	A	B	C	D
3/4 in.	5/8 in.	400 ± 10			
5/8 in.	1/2 in.	250 ± 10	250 ± 10		
1/2 in.	3.8 in.	200 ± 10	200 ± 10	200 ± 10	
3/8 in.	#4	100 ± 5	100 ± 5	100 ± 5	100 ± 5
#4	#10	30 ± 5		30 ± 5	30 ± 5

Should the sample contain less than 5 percent of any of the sizes specified in grades above, that size shall not be tested, but for the purpose of calculating the test results, it shall be considered to have the same loss during the treatment as the next smaller size.

Procedure

1. The oven-dry weight of each fraction of the prepared sample shall be obtained to the nearest estimated 0.1 gram.
2. Each fraction of the sample shall then be placed in a separate tray, and enough distilled water shall be added to each tray to adjust the water level to approximately three-fourths (3/4) of the average stone depth.
3. The trays shall be immediately placed in the freezing chamber and allowed to remain there until the water is completely frozen (about two hours).
4. The trays containing the sample shall be removed from the freezing chamber and allowed to thaw at room temperature until no ice is evident in the water. Distilled water shall be added to each tray when required to maintain the proper water level.
5. Steps 3 and 4 shall be repeated until 50 cycles have been obtained. One cycle shall be defined as one series of freezing and thawing.
6. After 50 cycles, the sample (remaining in the trays) shall be dried to a constant weight at 230°F.
7. The oven-dry fraction in each tray shall be passed over the same sieve used in the original separation and the weight retained on each sieve obtained to the nearest estimated 0.1 gram. The number of par-

ticles retained on sieve shall also be obtained for qualitative examination.

Report

The report shall include the following data:

1. Weight of each fraction of each sample before test.

2. Weight of each fraction of each sample after test.

3. The percentage loss of each fraction of each sample as a percent of the original dry weight.

4. Weighted average calculated from the percent loss for each fraction, based on the grading of the sample received for examination or, preferably on the average grading of the material from that portion of the supply of which the sample is representative.

Note:

The sieve used to separate the original fractions for test must be the identical sieve used to examine the same fractions after the test. This is necessary since sieve sizes include a tolerance in mesh openings. For example, all sieves of a given size, say 3/8 inch, do not have exactly the same size opening. The A.S.T.M. tolerance between different sieves of the same size cannot be accepted in this test.

Sieve Size	Grading of Original Sample	Actual Loss Percent	Weighted Loss Percent
5/8-1/2 in.	11.2	5.2	0.58
1/2-3/8 in.	37.0	9.3	3.44
3/8 in.-No. 4	51.8	2.2	1.14
TOTAL WEIGHTED LOSS			5.16

Test Method Tex-433-A
TENTATIVE Rev: January 1, 1972

Texas Highway Department

Materials and Tests Division

ABSORPTION AND DRY BULK SPECIFIC GRAVITY OF SYNTHETIC COARSE AGGREGATE

Scope

This method of test is intended for use in determining the absorption and dry bulk specific gravity of lightweight coarse aggregate.

Apparatus

The apparatus shall consist of the following:

1. Balance - having a capacity of at least 4500 grams and accurate within 0.1 percent of the test load at any point within the range of use and sensitive to 0.1 gram.

2. Container - a glass Mason jar fitted with a pycnometer cap.

Sample

A sample of sufficient size to yield approximately 400 grams after being oven dried shall be selected, by the method of quartering, from the aggregate to be tested.

Procedure

1. The test shall be conducted in an environmental temperature of 72 $\pm$ 5°F.

2. The sample shall be dried in an oven at a temperature of 230°F. to constant weight. The sample shall then be allowed to cool to room temperature in a desiccator and weight to the nearest estimated 0.1 gram. Record as X.

3. The weight of the pycnometer completely filled with distilled water shall be obtained to the nearest estimated 0.1 gram. Record as Y.

4. The jar shall be filled with distilled water. The top shall then be placed on the jar and water added to fill the jar and top completely. The pycnometer with sample and water shall then be weighed to the nearest estimated 0.1 gram. With a little practice, the first weighing can be accomplished two minutes after the water is first introduced into the container. Weighings shall then be made at intervals of 4, 6, 8, 10, 20, 30, 60, 90, and 120 minutes from the beginning of the test, taking care to agitate the sample by rolling and shaking the jar and adding water so that a constant volume is maintained before each weighing is made. Record as Z_2, Z_4, Z_6, etc.

Calculations

A curve with time (to at least 10 minutes) as the abscissa and weight of pycnometer plus sample plus water as the ordinate shall be plotted on rectangular coordinate paper. This curve shall be extended back to include zero time and the weight of pycnometer plus sample plus initial water read from the curve. A curve with time as the abscissa and percent absorption as the ordinate shall be plotted on rectangular coordinate paper. The percent absorption at 100-minutes can then be read from the curve.

$$A_t, \text{ \% absorption at given time} = \frac{Z_t - Z_0}{X} 100$$

$$G_b, \text{ Dry bulk specific gravity} = \frac{X}{X + Y - Z_0}$$

Where:

X = Weight of oven-dry sample

Y = Weight of calibrated pycnometer filled with water.

Z_t = Weight of pycnometer containing sample and water to fill (t = time from beginning of test in minutes).

100-Minute Saturation

The 100-minute saturation value is calculated from absorption, dry bulk specific gravity and absolute specific gravity. The absolute specific gravity (G_a) is determined by Test Method Tex-109-E, Part I.

$$S_{100}, \text{ \% 100-minute saturation} = \frac{A_{100} \circ G_b}{1 - \frac{G_b}{G_a}}$$

A_{100} = 100-minute absorption in percent.

G_a = Absolute specific gravity.

G_b = Dry bulk specific gravity.

The porosity of the aggregate is determined by the following equation:

$$N = 1 - \frac{G_b}{G_a}$$

Where:

N = Porosity of the aggregate expressed as a decimal

1/ 3K