

A RECOMMENDED SYNTHETIC COARSE AGGREGATE
CLASSIFICATION SYSTEM

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Submitted to:

The Texas Highway Department

October, 1966

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INTRODUCTION

The Texas Transportation Institute, in cooperation with the Texas Highway Department and U. S. Bureau of Public Roads, is conducting research on synthetic aggregates for highway use. We are involved in facets of the use of synthetic aggregates from structural grade portland cement concrete to asphaltic concrete and to flexible base. Several research reports have been published on the various studies undertaken.

At this time, it appears desirable to present our best judgement concerning a recommended synthetic aggregate classification system for highway construction, based on the results of our research studies to date. While research in this area is being continued, the judgements presented herein are subject to revision as additional knowledge is gained.

CLASSIFICATION SYSTEM

The classification system for coarse synthetic aggregate* is presented in Table 1. The table divides the material into two classes (I and II), and each class is subdivided into three groups (A, B, and C) of descending physical requirements.

A functional grouping of coarse synthetic aggregates is presented in Table 2. In this table, the permissible coarse aggregate group defined in Table 1 is shown for each highway function, from surface treatments to base materials. Summaries of each quality test are given in the following section of this report.

*Coarse synthetic aggregates are those synthetic aggregates with a minimum of 95 percent retained on the No. 4 sieve.

Table 1

A CLASSIFICATION SYSTEM FOR
COARSE SYNTHETIC AGGREGATE

Class	Group	Dry Loose Unit Weight (pcf) ¹		Aggregate Absorption Factor ²	Aggregate Freeze-Thaw Loss-% ³
		Max.	Min.		Max.
I (Bloated)	A	55	30	3	7
	B	55	30	5	15
	C	55	30	-	-
II (Nonbloated)	A		55	3	7
	B		55	5	15
	C		55	-	-

¹Dry loose unit weight determination should be made in accordance with ASTM Designation C29, utilizing the shoveling procedure, except that the aggregate shall be tested in an oven-dry condition.

²The aggregate absorption factor (AAF) is defined as the percent absorption at 1000 minutes of soaking minus the percent absorption at 100 minutes of soaking (from oven-dry weight). The absorption-time curve shall be obtained according to the Bryant Method (Appendix 1).

³The average freeze-thaw loss, after 50 cycles, in accordance with the Gallaway Method (Appendix 2).

Table 2

FUNCTIONAL GROUPING OF SYNTHETIC AGGREGATES

Function	Permissible Aggregate Group ¹	Aggregate Requirements		
		Abrasion Loss-% Max. (ASTM C131)	Potential Reactivity (ASTM C289)	Decomposable Sulfide Odor ²
Surface Treatments	IA	35	--	--
Asphaltic Conc. Surfaces	IA, IIA	35	--	--
Asphaltic Conc. Bases	IA, IB, IIA, IIB	40	--	--
Lt. Wt. P. C. Concrete Structures	IA	35 ³	Innocuous	None to slight
P. C. Concrete	IA, IB IIA, IIB	35 ³	Innocuous	None to slight
Base Materials	IA, B, C IIA, B, C	45	--	--

¹For explanation of aggregate group designations, see Coarse Synthetic Aggregate Classification System (Table 1).

²Qualitative test based on immersion of aggregate particles in a hot dilute solution of HCl and noting release of H₂S gas odor (in accordance with the Blank Method) (Appendix 3).

³For concrete not subjected to abrasion, this requirement may be waived.

TEST SUMMARIES

Dry Loose Unit Weight

The maximum values used for Group I (55 pcf) were taken directly from ASTM designation C330-64T.^{1*} In order to delineate Group II from Group I, the minimum unit weights for Group II were set at 55 pcf. The use of the 30 pcf minimum weight for Group I is to insure that only structural quality coarse aggregates will be used.

Aggregate Absorption Factor (AAF)

The AAF was introduced and compared in research report 81-3.^{2*} Those aggregates with an AAF greater than 3 indicated poor durability in aggregate freeze-thaw tests and also in concrete freeze-thaw tests. Therefore, an AAF of 3 is selected as the maximum acceptable value for Group A aggregates, whether bloated or non-bloated. The use of an AAF of 5 as the maximum allowable for Group B is arbitrary at this time and subject to verification by further research. Since this was a special test, the tentative procedure is given in Appendix 1.

Aggregate Freeze-Thaw Loss

This test was introduced in research report 51-2.³ The results obtained in report 51-2 were also used in research report 81-3. The results from this test correlate reasonably well with the aggregate absorption factor (AAF). Aggregates with a high freeze-thaw loss are suspect in environments where they would be exposed to the weather and climate. We believe that aggregates which meet this specification will be durable in all environments. The maximum allowable value of 7% for Group A is based upon the concrete freeze-thaw results reported in research reports 81-1⁴ and 81-3.² The maximum allowable value of 15% for Group B is based on our best judgement at this time.

This test is also special and the tentative procedures are given in Appendix 2.

* Superscript numbers refer to references contained at the close of this report.

The running of the aggregate freeze-thaw test requires time and equipment. In report 81-3², a tentative relation was reported between the aggregate freeze-thaw loss and the aggregate absorption factor. If further research verifies this relationship it may be possible to drop the aggregate freeze-thaw loss and rely only on the aggregate absorption factor. However, at this time both tests should be run.

Permissible Aggregate Group

The permissible coarse aggregate group to be allowed for a given function is given in order that only suitable aggregates might be used for a specific function. As further research data are obtained and analyzed, this grouping may change.

Los Angeles Abrasion Loss

The values reported in Table 2 are substantially the same as those now specified for natural aggregate by the Texas Highway Department for the various functions involved.

ASTM designation C131 is specified rather than the Texas modification (Tex-410-A part II)⁵ because research report 51-2³ indicates no substantial difference in the results of the two tests for lightweight synthetic aggregates.

Potential Reactivity

Potential reactivity has long been an important test in indicating possible deleterious reactions between the portland cement alkalies and the aggregate (ASTM designation C289).¹ Since synthetic aggregates are predominantly a poor glass in the form of fused silicates,⁴ they sometimes react with cement alkalies. Therefore, such a test is desirable to insure that no aggregates are used in portland cement concrete which exhibit a potential reactivity.

Decomposable Sulfide Odor

Synthetic aggregates which have been improperly burned are difficult to detect using standard test methods. And if these aggregates contain decomposable sulfides, they will react with water and weaken the concrete. Therefore, a test for decomposable sulfides is recommended for those aggregates which are to be used in portland cement concrete.

Recommended test procedures for this special test are given in Appendix 3.

CONCLUSION

A classification system for coarse synthetic aggregate is offered and we believe it will delineate between groups of aggregates and insure high quality aggregates for various highway functions. This system is preliminary and subject to revision as additional knowledge is gained through our continuing research efforts in this area.

REFERENCES

1. 1965 Book of ASTM Standards, Part 10, Concrete and Mineral Aggregates, ASTM, Philadelphia, Pa., September 1965.
2. Ledbetter, W. B., and Eugene Buth, "Aggregate Absorption Factor as an Indicator of the Freeze-Thaw Durability of Structural Lightweight Concrete," Research Report 81-3, Texas Transportation Institute, Texas A&M University, (pending publication).
3. Gallaway, Bob M., and W. J. Harper, "A Laboratory and Field Evaluation of lightweight Aggregates as Coverstone for Seal Coats and Surface Treatments," Research Report 51-2, Texas Transportation Institute, Texas A&M University, April 1966.
4. Ledbetter, W. B., "Correlation Studies of Fundamental Aggregate Properties with Freeze-Thaw Durability of Structural Lightweight Concrete," Research Report 81-1, Texas Transportation Institute, Texas A&M University, August 1965.
5. Manual of Testing Procedures, Volumes 1 and 2, Texas Highway Department, revised February 1963.

Appendix 1

DETERMINATION OF ABSORPTION, SPECIFIC GRAVITY, AND AGGREGATE ABSORPTION FACTOR OF SYNTHETIC AGGREGATE

The test method that follows was excerpted from "The Determination of Moisture Absorption Characteristics of Lightweight Concrete Aggregates," a thesis by Julian Stephen Bryant, Texas A&M University, January 1959. A more nearly complete discussion of the test method, including the theory involved, is included in Reference 1. The authors have made some changes in Bryant's original test method and they think these will add to its value in practical application.

The test method and calculations are not as complicated as they appear to be and tabulation of the data similar to that shown in the example makes the calculations rather straightforward.

DETERMINATION OF ABSORPTION, SPECIFIC GRAVITY
AND AGGREGATE ABSORPTION FACTOR OF SYNTHETIC AGGREGATE

Scope. This method of test is intended for use in determining the bulk specific gravity both dry and saturated surface dry, apparent specific gravity, absorption, rate of absorption and aggregate absorption factor of both coarse and fine lightweight synthetic aggregates.

Apparatus. The apparatus shall consist of the following:

- (a) Balance--A balance having a capacity of 3 kilograms or more and a sensitivity of 0.1 gram or less.
- (b) 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.

- (a) The test shall be conducted in an environmental temperature of $72 \pm 5^{\circ}$ F.
- (b) The sample shall be dried in an oven at a temperature of 105° C for a minimum of 24 hours. The sample shall then be allowed to cool to room temperature in a desiccator.
- (c) The weight of the pycnometer jar and cap shall be determined to the nearest 0.1 gram.
- (d) The weight of the pycnometer completely filled with distilled water shall be obtained to the nearest 0.1 gram. Match marks shall be used on the jar and cap to insure that the same volume is obtained throughout the test.
- (e) The dry sample shall be placed in the pycnometer and the total weight determined to the nearest 0.1 gram.
- (f) The jar shall be filled with distilled water. The top shall then be placed on the jar with the match mark coinciding and water added to fill the jar and top completely. The pycnometer with sample and water shall then be weighed to the nearest 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 and each 24 hours thereafter, taking care to agitate the sample by rolling and shaking the jar so that a constant volume is maintained before each weighing is made.

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. The weight of pycnometer plus sample plus initial water shall be subtracted from each of the weighings made to determine the weight of absorbed water. The weight of absorbed water shall be divided by the dry weight of the sample to determine the percent absorption for each reading. A curve with time (in days) as the abscissa and percent absorption as the ordinate shall be plotted on rectangular coordinate paper. The percent absorption at any time can then be read from the curve. Another curve with time in minutes (to at least 1440 minutes - 24 hours) as the abscissa and percent absorption as the ordinate shall be plotted on rectangular coordinate paper. The percent absorption at 1000 minutes and 100 minutes shall be read from this curve and used in determining the aggregate absorption factor.

The aggregate absorption factor is defined as the percent absorption at 1000 minutes minus the percent absorption at 100 minutes based on dry weight.

The bulk specific gravity (dry) shall be calculated by dividing the over-dry weight of the sample by the bulk volume of the sample.

The bulk specific gravity (saturated surface dry) varies with the length of time the sample has been immersed in water and shall be calculated by dividing the sum of the oven-dry weight of the sample and the weight of absorbed water (at any given time) by the bulk volume of the sample.

The apparent specific gravity also varies with the length of time the sample has been immersed in water and shall be calculated by dividing the oven-dry weight of the sample by the apparent volume of the sample (at any given time).

Example Data and Calculations

DATA SHEET 1

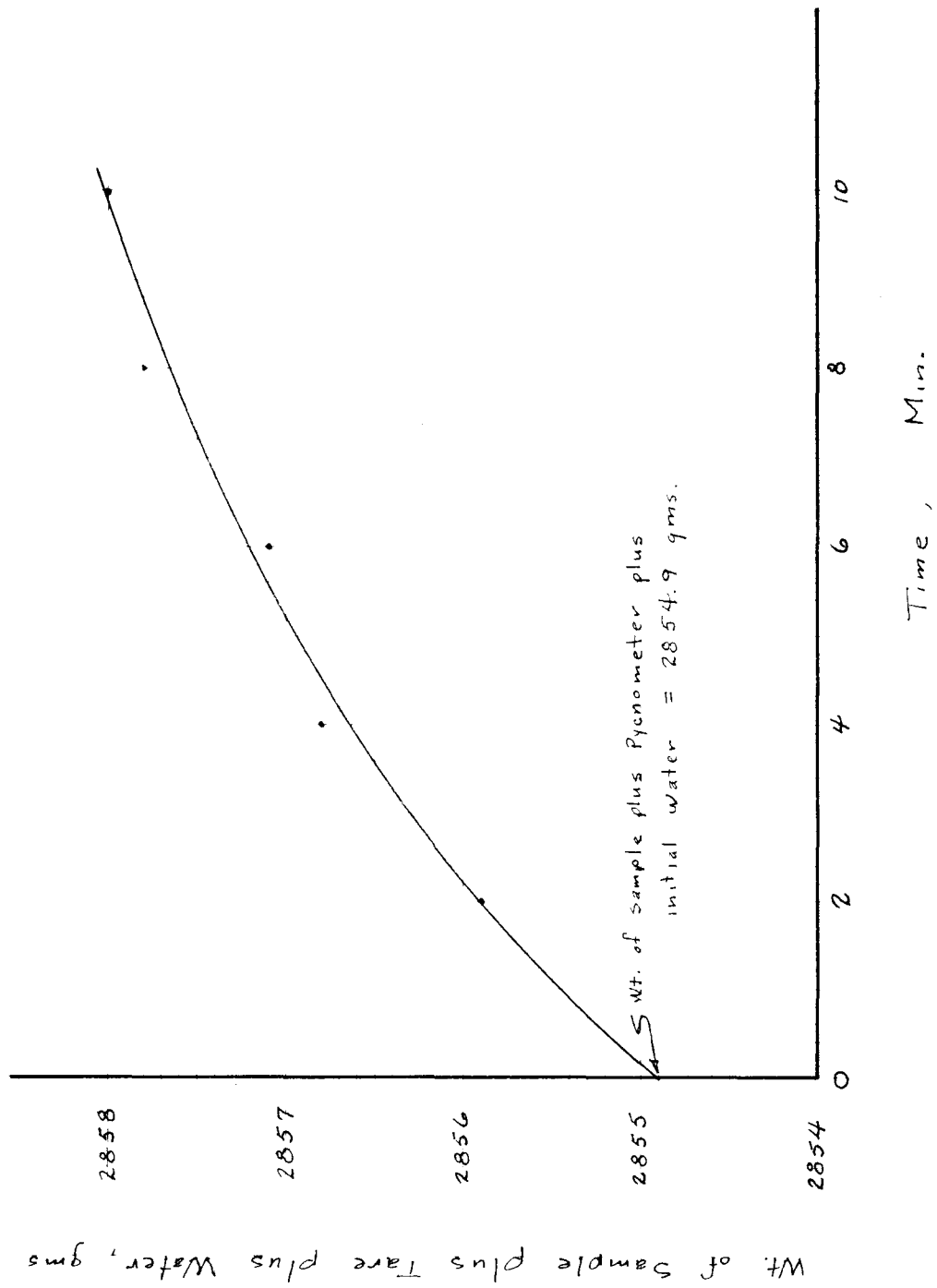
Absorption and Specific Gravity

Study 1081 Aggregate RCA #2 Date 3-2-66

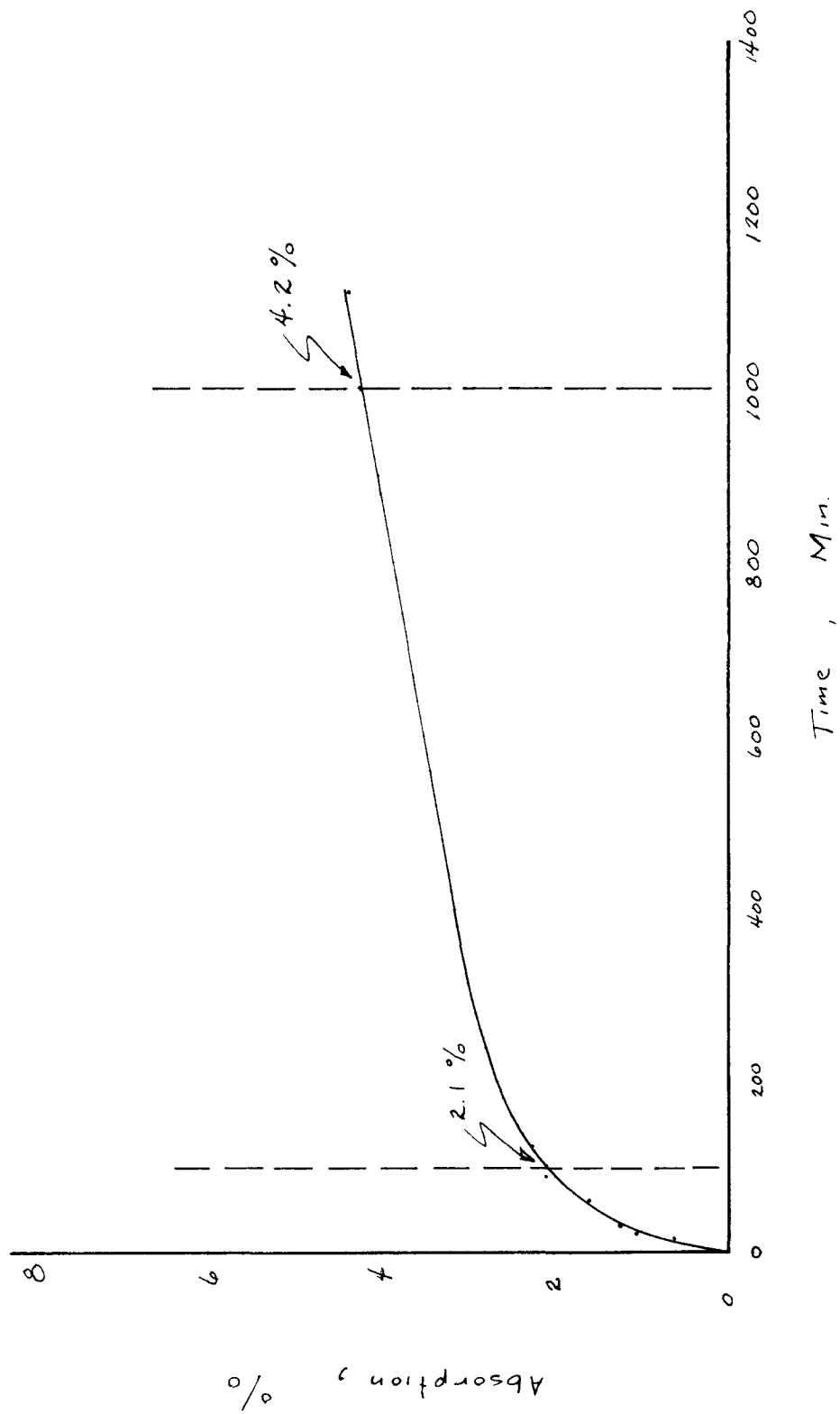
Performed by _____

Weight of pycnometer filled with water	<u>2723.8</u>
Weight of pycnometer	<u>795.1</u>
Weight of water (volume of pycnometer)	<u>1928.7</u>
Weight of pycnometer and dry sample	<u>1194.9</u>
Weight of dry sample	<u>399.8</u>

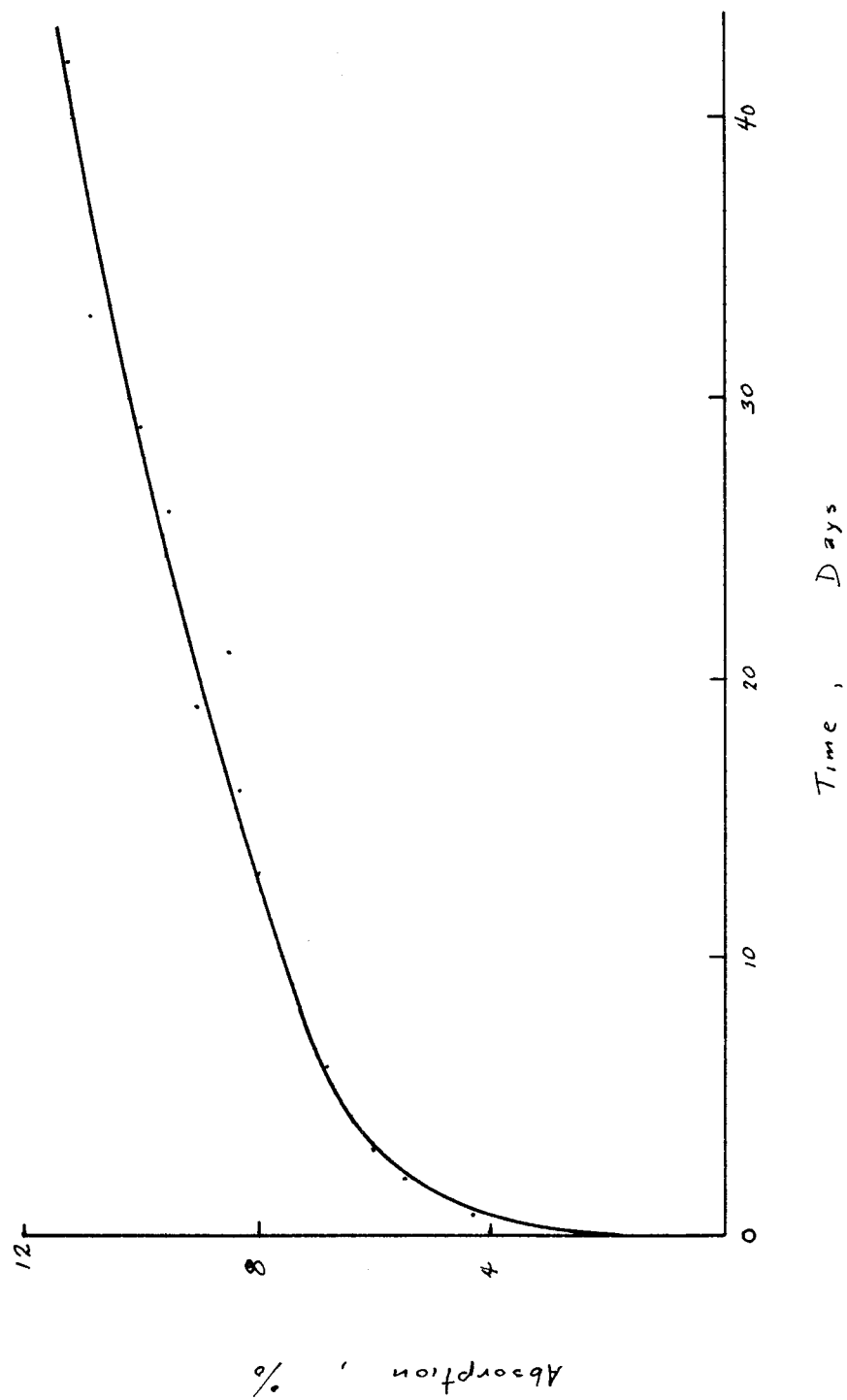
Date and Time	Time Since Start	Weight of Pycnometer Sample and Water	Weight of Absorbed Water	Percent Absorption
	0 min.	2854.9		
3/2 8:30	2	2855.9	1.0	0.2
8:32	4	2856.8	1.9	0.5
8:34	6	2857.1	2.2	0.6
8:36	8	2857.8	2.9	0.7
8:38	10	2858.0	3.1	0.8
8:48	20	2859.2	4.3	1.1
8:58	30	2860.1	5.2	1.3
9:28	60	2861.3	6.4	1.6
9:58	90	2863.5	8.6	2.2
10:28	120	2864.1	9.2	2.3
3/3 15:00	1110	2872.1	17.2	4.3
3/4 8:15	2 days	2876.8	21.9	5.5
3/5 8:17	3	2878.8	23.9	6.0
3/8 9:00	6	2882.0	27.1	6.8
3/11 9:07	9	2884.5	29.6	7.4
3/12 8:10	10	2884.8	29.9	7.5
3/15 8:40	13	2887.0	32.1	8.0
3/18 8:26	16	2888.1	33.2	8.3
3/21 8:30	19	2891.0	36.1	9.0
3/23 8:12	21	2888.8	33.9	8.5
3/28 9:17	26	2893.8	38.9	9.7
3/31 9:00	29	2894.9	40.0	10.0
4/4 8:05	33	2898.0	43.1	10.8
4/13 8:20	42	2898.5	43.6	10.9
4/14 9:00	43	2900.0	45.1	11.3



Example Absorption-Time Curve for Coarse Synthetic Aggregate



Example Absorption-Time Curve for Coarse Synthetic Aggregate



Example Absorption - Time Curve for Coarse Synthetic Aggregate

DATA SHEET 2

Absorption and Specific Gravity
After 3 days soaking

- (a) Weight of sample plus pycnometer plus Initial Water 2854.9
- (b) Weight of sample plus pycnometer 1194.9
- (c) Weight of Initial Water (Free water) (a) - (b) = 1660.0
- (d) Percent absorption (from curve) 6.0%
- (e) Weight of dry sample 399.8
- (f) Volume of pycnometer 1928.7
- (g) Weight of absorbed water = (e) 399.8 x (d) 0.06 = 24.0
- (h) Weight of saturated sample = (e) 399.8 + (g) 24.0 = 423.8
- (i) Weight of total water = (c) 1660.0 + (g) 24.0 = 1684.0
- (j) Bulk volume of sample = (f) 1928.7 - (c) 1660.0 = 268.7
- (k) Apparent volume of sample = (f) 1928.7 - (i) 1684.0 = 244.7
- (l) Bulk Specific Gravity (dry) = $\frac{(e) \ 399.8}{(j) \ 268.7} = 1.49$
- (m) Bulk Specific Gravity (SSD) = $\frac{(h) \ 423.8}{(j) \ 268.7} = 1.58$
- (n) Apparent Specific Gravity = $\frac{(e) \ 399.8}{(k) \ 244.7} = 1.63$
- (o) Aggregate Absorption Factor = $\frac{4.2}{1000 \text{ min.}} - \frac{2.1}{100 \text{ min.}} = 2.1$

Appendix 2

COARSE AGGREGATE FREEZE-THAW TEST

Scope. This method of test describes a procedure to be followed in testing synthetic coarse aggregates* to determine their resistance to desintegration 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:

(a) 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.

(b) Trays and Containers -- the sample of aggregate shall be placed in shallow metal trays approximately two (2) inches in depth. The trays shall be of suitable dimensions to contain the aggregate sample in a single layer.

(c) Sieves -- sizes $5/8$ inch, $1/2$ inch, $3/8$ inch, and No. 4 conforming to the Specifications for Sieves for Testing Purposes (ASTM Designation: E 11).

(d) Balance -- a balance sensitive to 0.1 gram and having a capacity of at least 1000 grams shall be used.

(e) Drying Oven -- the drying oven shall provide a free circulation of air through the oven and shall be capable of maintaining a temperature of 105°C to 110°C .

Sample. The graded coarse aggregate for the test shall be separated into the different sizes as follows:

Passing $5/8$ inch sieve, retained on $1/2$ inch sieve -- 100 particles.

Passing $1/2$ inch sieve, retained on $3/8$ inch sieve -- 200 particles.

Passing $3/8$ inch sieve, retained on No. 4 inch sieve -- 300 particles.

Preparation of the Sample. The sample, consisting of the three (3) fractions listed above, shall be thoroughly washed and dried to constant weight at 105°C to 110°C .

Procedure.

(a) The oven-dry weight of each fraction of the prepared sample shall

* Coarse aggregates are defined as aggregates with 95 percent retained on the No. 4 sieve.

be obtained to the nearest 0.1 gram.

(b) 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.

(c) The trays shall be immediately placed in the freezing chamber and allowed to remain there until the water is completely frozen (about two hours).

(d) The trays containing the sample shall be removed from the freezing chamber and allowed to thaw at $25^{\circ}\text{C} \pm 5^{\circ}\text{C}$ until no ice is evident in the water. Distilled water shall be added to each tray when required to maintain the proper water level.

(e) Steps (c) and (d) shall be repeated until the required number of cycles have been obtained. One cycle shall be defined as one series of freezing and thawing.

(f) After the required number of cycles, the sample (remaining in the trays) shall be dried to a constant weight at 105°C to 110°C .

(g) 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 0.1 gram. The number of particles retained on sieve shall also be obtained for qualitative examination.

Report. The report shall include the following data:

(a) Weight and number of each fraction of each sample before test.

(b) Weight and number of each fraction of each sample after test.

(c) The percentage loss of each fraction of each sample as a percent of the original dry weight.

(d) 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.

*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 ASTM tolerance between different sieves of the same size cannot be accepted in this test.

Exhibit 3
Example Data and Calculations
for
Synthetic Aggregate Freeze-Thaw Test

Study No. 2051 Operator John Doe
 Identification No. E-3-1 Date April 4, 1965
 Material Lightweight Aggregate Source of Material Eastland
 Remarks _____

Sample	Size Range	Before Test		After Test, 50 Cycles	
		No. Particles	dry wt. grams	No. Particles	dry wt. grams
A	5/8 - 1/2 inch	100	246.9	99	242.0
A'	5/8 - 1/2 inch	100	267.5	90	245.0
B	1/2 - 3/8 inch	200	239.3	177	213.0
B'	1/2 - 3/8 inch	200	260.8	183	241.0
C	3/8 inch - No. 4	300	190.3	300	188.0
C'	3/8 inch - No. 4	300	176.5	300	171.0

Exhibit 3

Example Data and Calculations

for

Corrected Percentage Loss After 40 Cycles of Freezing and Thawing

Study No. 2051 Operator John Doe
Identification No. E-3-1 Date April 4, 1965
Material Lightweight Aggregate Source of Material Eastland
Remarks _____

<u>Sieve Size</u>	<u>Grading of Original Sample</u>	<u>Actual Loss Percent</u>	<u>Weighted Loss Percent</u>
5/8 - 1/2 in.	11.2	5.2	0.58
1/2 - 3/8 in.	37.3	9.3	3.73
3/8 in. - No. 4	51.8	2.2	1.12
TOTAL LOSS			5.43

APPENDIX 3

QUALITATIVE TEST FOR DECOMPOSABLE SULFIDES

by

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Research Geologist

Scope. This method of test describes a procedure to be followed in testing synthetic coarse aggregates for decomposable sulfides. It furnishes information helpful in identifying the presence of decomposable sulfides which may be detrimental when contained in concrete.

Apparatus. The apparatus shall consist of the following:

- (a) 3 or 4 six-inch test tubes.
- (b) Test-tube holder
- (c) Test-tube rack.
- (d) Bunsen burner.
- (e) Qualitative filter paper.
- (f) Glass-stoppered bottles (2 or more) for reagents.
- (g) Small, air-tight containers for ground samples.
- (h) Steel anvils, hammer, "diamond" mortar, or other suitable apparatus for crushing samples.

Reagents.

- (a) Dilute hydrochloric acid (one part concentrated [36%] HCL to five parts distilled water, by volume). Need not be too exact provided the same dilution is used each time.
- (b) Lead acetate, $\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2 \cdot 3\text{H}_2\text{O}$, crystalline.
- (c) Distilled water.

Sample. A representative sample of the aggregate, about 200 gms., obtained by repeated quartering in the usual way.

Sample Preparation. Crush the representative sample to about the size of coarse sand, but do not screen it. Thoroughly mix and quarter down to a bulk of about 50 cc., being careful to get both coarse and fine particles in each quarter retained and discarded. Then grind all of the final

quarter to pass 100-mesh, and thoroughly mix. If not to be tested at once, keep a tightly closed container to prevent oxidation.

Procedure.

(a) Prepare a concentrated solution of lead acetate by shaking the crystalline salt with distilled water and allowing to stand overnight. Protect both the solid and the solution from the laboratory atmosphere in closed containers.

(b) Prepare strips of qualitative filter paper about 1/2 inch wide and 3 or 4 inches long. Fold them double lengthwise, then fold one end back about 1 inch to form a hook.

(c) Place enough of the powdered sample to form about 1/4 inch layer at the bottom of a dry, 6-inch test tube. Add about 1 inch of dilute HCl. Warm, and finally bring just to boiling, but do not allow to boil violently. Cautiously smell the vapor as soon as the acid is added and at frequent intervals thereafter.

(d) If decomposable sulfides are present, H_2S will be evolved, and may be recognized by its characteristic rotten-egg odor. If much sulfide is present the reaction may begin before heating.

Results. The results are qualitative only and should be reported, in terms of the odor developed, as none, slight, moderate, or heavy.

The hydrogen sulfide (H_2S) may be confirmed, especially for small amounts where the odor may be doubtful, by dipping one of the folded strips of filter paper into the lead acetate solution and then hanging it wet (but not dripping) in the mouth of the test tube. Do not allow it to fall into the acid. Make this test before the acid boils; prolonged exposure of the paper to HCl vapor will prevent the reaction. A very little H_2S will turn the lead acetate paper brown; more will turn it iridescent black. For small amounts of decomposable sulfides the intensity of the colors give a rough comparison of the amounts present in the aggregate.

NOTE: H_2S is poisonous. A few sniffs will do no harm, but if a long series tests is made the laboratory should be well ventilated and the sniffer should clear his lungs with fresh air at frequent intervals.