AGGREGATE ABSORPTION FACTOR AS AN INDICATOR OF THE FREEZE-THAW DURABILITY OF STRUCTURAL LIGHTWEIGHT CONCRETE

by

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Research Report 81-3

Synthetic Aggregate Research

Research Study Number 2-8-65-81

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Texas A&M University
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PREFACE

This is the third report of a research study carried out in the Structural Research Department of the Texas Transportation Institute as part of the cooperative research program with the Texas Highway Department in cooperation with the U. S. Bureau of Public Roads. The first two reports are:

> "Correlation Studies of Fundamental Aggregate Properties with Freeze-Thaw Durability of Structural Lightweight Concrete," by W. B. Ledbetter, Research Report 81-1, Texas Transportation Institute, August 1965.
>
> "Effect of Degree of Synthetic Lightweight Aggregate Prewetting on the Freeze-thaw Durability of Lightweight Concrete," by C. N. Kanabar and W. B. Ledbetter, Research Report 81-2, Texas Transportation Institute, December 1966.

The following staff personnel were actively engaged in the study.

W. B. Ledbetter, Assistant Research Engineer
Eugene Buth, Research Associate
Horace R. Blank, Research Geologist
Subodh K. Das, Research Assistant
James T. Houston, Research Assistant.

In addition, several part-time personnel were employed on various phases.

The authors are indebted to these people for their contribution to this research effort.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

Figures — Page

Tables — Page

1. Introduction

1.1 Purpose

The purpose of this phase of investigation was twofold.

1. Correlation of freeze-thaw research results at the Texas Transportation Institute with ASTM Standard freeze-thaw results.

2. Develop preliminary durability acceptance criteria for concrete using synthetic aggregates based on freeze-thaw test.

1.2 Background

The research reported herein represents a portion of a study undertaken in cooperation with the Texas Highway Department and U. S. Bureau of Public Roads.

Two formal reports have been prepared to date. Complete information concerning the over-all purpose, scope, limitations, and background of this research study is given in these two reports (1, 2).*

1.3 Conclusions

From the results obtained in this phase of investigation, the following conclusions are suggested:

1. The Aggregate Absorption Factor (AAF) of the synthetic lightweight coarse aggregates studied is a readily obtainable property which can be used to predict the coarse aggregate's resistance to freezing and thawing and the resulting concrete's durability against freezing and thawing.

2. A relationship was established between the Texas Transportation Institute and ASTM Standard (C290) concrete freeze-thaw tests.

1.4 Recommendations

From the findings of this study, the following recommendations are suggested:

1. Continued attempts should be made to relate fundamental aggregate properties with the durability of the resulting concrete.

2. The relationship developed between the two concrete freeze-thaw tests should not be universally applied without further substantiating data.

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*Numbers in parentheses refer to references contained in Section 4.3 of this report.

2. Experimental Program

2.1 General

Synthetic lightweight aggregate from five sources, commercially available in Texas, were selected for investigation. All aggregates selected were structural lightweight aggregates manufactured by the rotary kiln process from shale (Fig. 2.1). The engineering properties of these aggregates, which were given originally in report 81-1, are reproduced in Table 2-1 for ready reference.

2.2 Coarse Aggregate Freeze-Thaw Test

Coarse aggregates from each source were sized into three groupings and placed in a shallow pan of distilled water, with the water level at about one-half the depth of the stone. The prepared samples were then subjected to 50 cycles of alternate freezing and thawing in accordance with the Gallaway aggregate freeze-thaw test (3). After completion of the cycling, the samples were dried and weighed, and any particles passing the sieve on which they were retained before the test began were removed. The resulting weight losses were corrected by weighted averages, in accordance with the Texas Highway Department Grade 3 aggregate grouping (4). Results of the corrected weight losses after both 50 cycles and 100 cycles of freezing and thawing are given in Table 2-2.

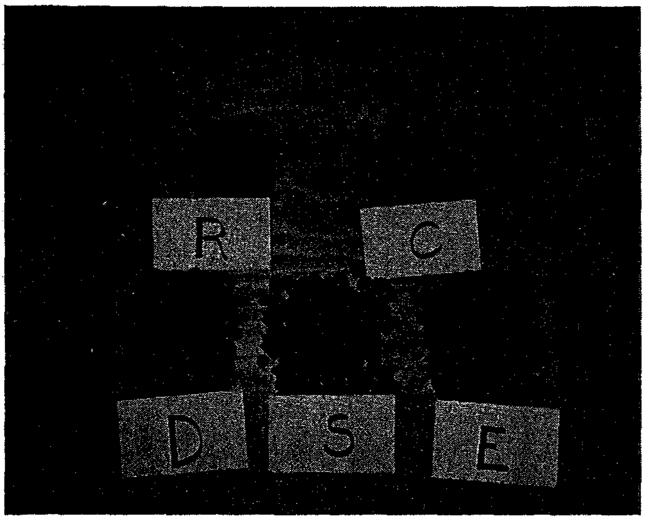

Fig. 2-1. Photograph of the Five Structural Lightweight Aggregates.

2.3 Coarse Aggregate Absorption Factor (AAF)

The freeze-thaw durability of concrete has long been of concern to engineers. In using synthetic, lightweight, aggregates, the fact that these aggregates have a relatively high absorption may make resulting concretes nondurable when subjected to freezing and thawing. Therefore, various aggregates were tested and the aggregate absorption was compared with the resulting concrete's freeze-thaw durability. The results indicated no apparent relationship between the two (1).

Although the aggregate absorption itself did not correlate with concrete durability, it was still believed that some facet of absorption may be important. It has been found that synthetic lightweight aggregates differ not only in total absorption, but also in rate of absorption. Therefore an absorption factor was defined which would include the latter property (see section 3.1). For the purposes of this investigation, a Coarse Aggregate Absorption Factor (AAF) is defined as the change in percent absorption of the coarse aggregate between 100 minutes and 1000 minutes of elapsed immersion time, based on dry weight. The selection of this interval of time is somewhat arbitrary, although it does represent a time interval during the hardening of concrete when water is still available for absorption.

The absorption-time data are obtained in accordance with the Bryant Method (5) which is reproduced in Section 4.1 for ready reference. The aggregate absorption factors for each aggregate and lot are given in Table 2-3.

2.4 Concrete Properties

Structural quality concretes were made using each of the five selected synthetic coarse aggregates. All mixes employed natural fine aggregate from the same source (designated H (fine) in this report). Concretes were batched with a nominal cement factor of five sacks per cubic yard. Concretes prepared for the Texas Transportation Institute freeze-thaw test (which were reported previously in research reports 81-1 and 81-2), and concretes prepared for the ASTM freeze-thaw test are described in Section 4.2. The laboratory mixing proce-

TABLE 2-1. SYNTHETIC COARSE AGGREGATE ENGINEERING PROPERTIES

Coarse Aggregate Designation	Absorption[1] 3 Days Percent	Absorption[1] 14 Days Percent	Bulk Specific Gravity[1] (SSD) 3 Days	Bulk Specific Gravity[1] (SSD) 14 Days	Dry Unit Wt (pcf)	Fineness Modulus[2]
R	4.7	8.0	1.47	1.50	46.8	7.0
C	8.0	12.1	1.37	1.41	38.1	6.7
E	6.5	8.6	1.42	1.46	43.8	6.5
S	10.9	16.6	1.78	1.85	48.5	6.9
D	22.5	28.0	1.35	1.42	34.4	6.7
H (Fine)[3]	0.8		2.61		99	2.57

[1] Immersed in water for the period indicated, then determined by Bryant Method (see Section 4.1).
[2] As defined in ASTM Designation: C125-58.
[3] Regular-weight control aggregate.

TABLE 2-2. COARSE AGGREGATE WEIGHT LOSS (CORRECTED FOR GRADE 3)[1] AFTER FREEZING AND THAWING[2]

Coarse Aggregate Designation	Percentage Weight Loss After 50 Cycles	After 100 Cycles
R	4.7	6.5
C	6.6	13.4
E	5.4	8.2
S	8.5	18.8
D	24.8	41.9

[1] Texas Highway Department Specification Item 302.
[2] Data taken from page 71 of reference 3.

dures followed were also reported in research report 81-1 and are not repeated here (1).

2.5 Concrete Freeze-Thaw Tests

Two concrete freeze-thaw tests were performed on selected concretes. The first test, designated the Texas Transportation Institute (TTI) Freeze-Thaw Test, consisted of freezing the specimens in air at approximately 0°F in a commercial chest-type freezer for 10 hours, followed by thawing the specimen in water at approximately 75°F for four hours. This test was reported fully in research report 81-1 (1). Standard 3 x 4 x 16 in. specimens were cured in the moist room at approximately 75°F and 100 percent relative humidity prior to testing.

Starting with an initial measurement prior to commencing the freeze-thaw tests, and continuing at the end of the thaw cycle, fundamental-flexural-frequency of vibration (f) measurements were taken.** These values were then squared. This f^2 value yielded a nondestructive measure of the soundness of concrete.

This value of f^2 can be easily converted to sonic modulus of elasticity. When subjecting concrete specimens to this test, the specimens exhibited almost no deterioration until, rather suddenly structural cracks appeared which caused almost complete loss of structural integrity in the concrete within a very few freeze-thaw cycles. Thus, concrete failure from this particular test was easily discernible and readily definable as complete loss of structural integrity. A typical set of concrete specimens after failure in this test is pictured in Fig. 2-2.

TABLE 2-3. AGGREGATE ABSORPTION FACTORS (AAF)

Coarse Aggregate Designation	Aggregate Lot No.	AAF[1]
R	1	1.8
	2	1.8
C	1	2.3
	2	1.6
E	1	3.5
	4	2.5
	6	2.3
S	1	4.9
	3	3.5
D	1	6.3
	2	5.5

[1] Change in percent absorption of the coarse aggregate between 100 minutes and 1000 minutes of elapsed immersion time, based on dry weight.

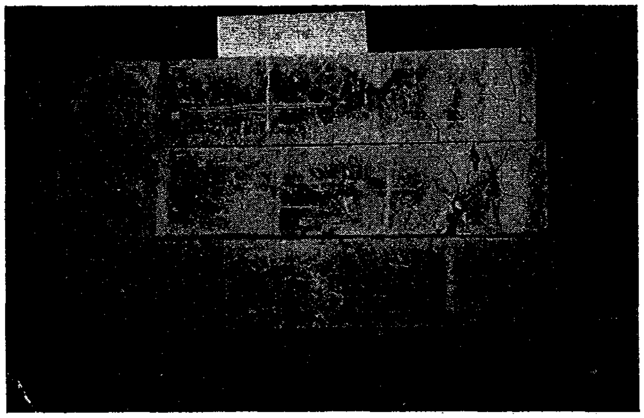

Fig. 2-2. Typical Concrete Specimens after Failure under Texas Transportation Institute (TTI) Freeze-Thaw Test.

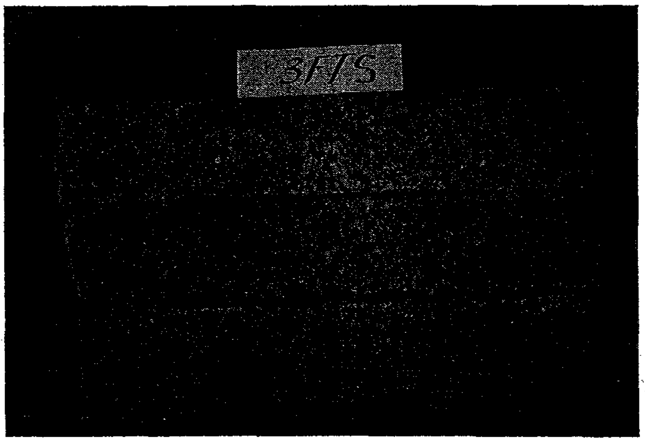

Fig. 2-3. Typical Concrete Specimens after Failure under the ASTM Standard Freeze-Thaw Test.

The second test employed was the standard ASTM test for rapid freezing and thawing of concrete in water (ASTM Designation C-290-63T). In this test, 3 x 3 x 16 in. specimens, cured exactly the same as the concrete used in the TTI test, were subjected to rapid freezing and thawing in water (about eight cycles per day). The deterioration of the concrete from this type of test was different from the TTI test in that the predominate mode of deterioration consisted of surface scaling (Fig. 2-3). A typical f^2 versus number of freeze-thaw cycles for one concrete is shown in Fig. 2-4. Note here that the drop in f^2 is not sudden and that difficulty arises when a number-of-cycles-to-failure is selected. In ASTM Test Designation C290-63T, failure is arbitrarily defined as when the relative modulus of elasticity of each specimen reaches 60 percent of the initial modulus. Therefore, for the purposes of this investigation, failure is defined as when the f^2 value reaches 60 percent of the original f^2 value. This is approximately the same as the ASTM definition of failure.

It should be noted that all the concretes tested were batched and cured similarly in that each had approximately the same cement factor and percent coarse aggregate; and each coarse aggregate was soaked for two

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**See ASTM Designation: C215 for an explanation of this property.

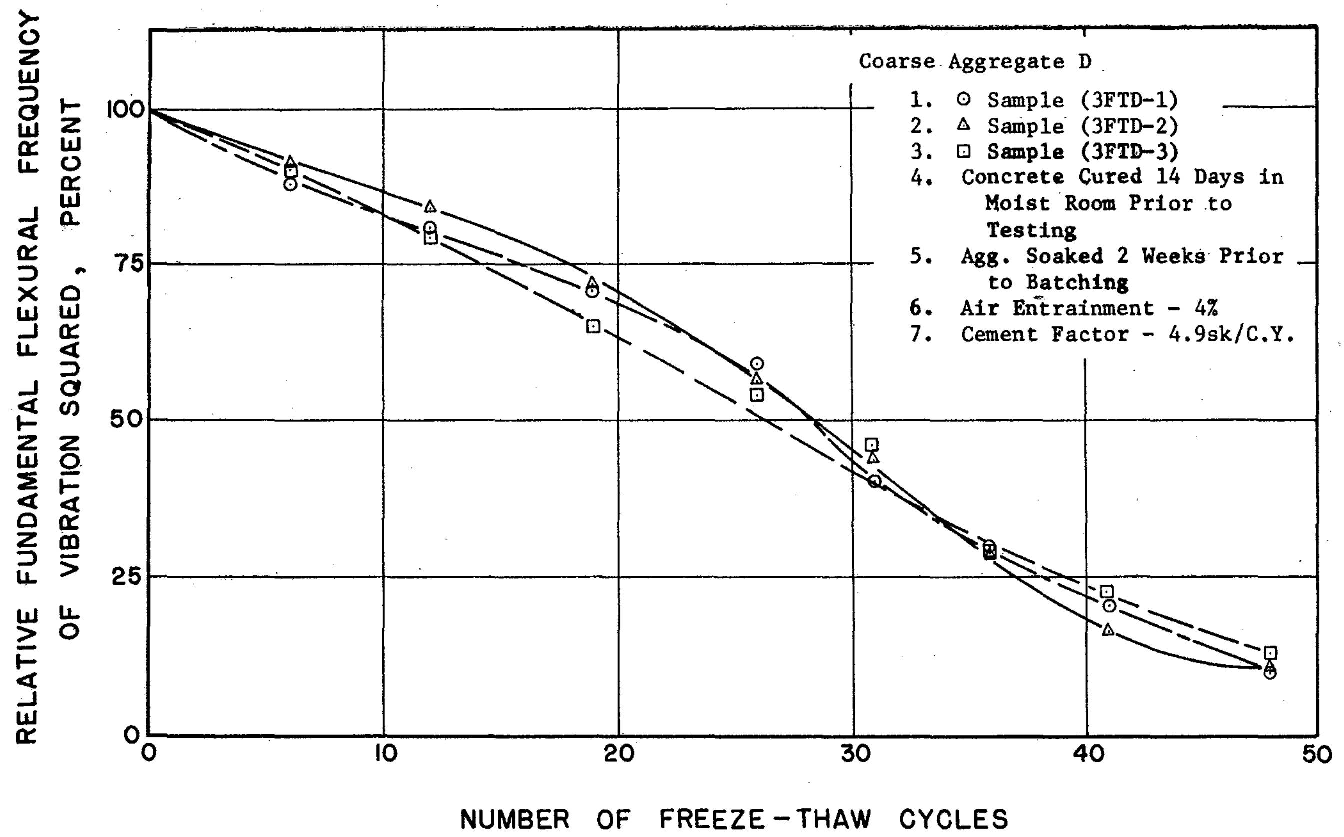

Fig. 2-4. Relative Fundamental Flexural Frequency of Vibration Squared (f^2) Versus Number of ASTM Standard Freeze-Thaw Cycles for Synthetic Lightweight Concrete made with Coarse Aggregate D.

TABLE 2-4. CONCRETE PROPERTIES AND FREEZE-THAW RESULTS

Coarse Aggregate Designation and Lot No.	Cement Factor (sks/cy)	Air Entrainment (%)	28 Day Compressive Strength (psi)[3]	Number of Freeze-Thaw Cycles to Failure		Concrete Batch Code No.
				TTI Test	ASTM Test	
R1	5.0	2.5	4120	228		5R
R1	4.6	4.3	3650		*[4]	3FTR
R1	4.9	5.4	4330		*[4]	4FTR
R2	4.9	6.0[2]	4190		*[4]	5FTR
C1	4.7	2.0[1]	3760	60		5C
C1	4.7	4.3[2]	3780		95	3FTC
C1	4.7	4.8[2]	3540		65	4FTC
E1	4.6	2.1[1]	4060	14		5E
E4	4.7	2.0[2]	4280	105		5E2
E4	4.9	2.1[2]	5600	**[5]		5E3
E4	4.7	5.9[2]	3770		44	3FTE
E4	4.7	5.0[2]	3930		*[4]	4FTE
E6	4.6	6.0[2]	3570		*[4]	5FTE
S1	4.9	1.9[1]	4360	18		5S
S1	4.9	5.3[2]	3740		15	3FTS
S1	4.9	4.3[2]	3900		37	4FTS
S3	5.0	4.5[2]	3930		11	5FTS
D1	4.9	2.0[1]	3580	12		5D
D1	5.0	4.8[2]	3810		25	3FTD
D1	4.9	4.8[2]	3980		30	4FTD
D2	5.0	5.0[1]	4260		27	5FTD

[1] Determined in accordance with ASTM Designation C231.
[2] Determined in accordance with ASTM Designation C173.
[3] Determined in accordance with ASTM Designation C39.
[4] This concrete was still sound after 100 cycles of freezing and thawing, at which time the test was terminated.
[5] This concrete was still sound after 200 cycles of freezing and thawing, at which time the test was terminated.

weeks in water prior to batching. The major difference between the concretes used for the TTI test and those used for the ASTM test was that the TTI test concrete contained *no* entrained air while the ASTM test concrete contained 4 to 5 percent entrained air (as measured by ASTM Designation C173). This difference in air content was deliberate. If air were used with the TTI test concrete, no failures would occur (6). On the other hand, if air had not been used for the ASTM test concrete, the concrete would fail immediately. (On preliminary ASTM freeze-thaw tests conducted on these same concretes without air, all specimens failed in less than six cycles.)

The results of the above two tests, together with the compressive strengths of the concretes used, are given in Table 2-4. Notice that in all cases, structural quality concrete was made.

The analysis and discussion of the results presented here are contained in Chapter 3 of this report.

3. Discussion of Results

3.1 Aggregate Absorption Factor (AAF) as a Durability Acceptance Criterion

In analyzing the aggregate data presented in Chapter 2, the aggregate absorption factor (AAF) is compared with aggregate freeze-thaw loss in Fig. 3-1. Note that a clear trend is exhibited: the higher the AAF, the greater the percent loss after freeze-thaw cycling. Thus, a hypothesis can be formed that the AAF is a good indicator of the potential durability of aggregates to the disruptive action of freezing and thawing while in the presence of water.

The relationship between AAF and the freeze-thaw durability of structural concretes made with these same aggregates is given in Fig. 3-2. The TTI test results are shown in the upper portion of the Figure and the ASTM test results are shown in the lower portion of the Figure. Note that either test indicates that when the AAF is greater than about 2.5, the resulting concretes are not durable. This is an important finding in that now a readily obtainable aggregate property can be used to predict the resulting concrete's durability against freezing and thawing. These data are for only five different aggregates which are all rotary kiln products. However, these aggregates do exhibit a rather wide range of values of AAF which lends confidence in the conclusion. Additional research is needed to verify this finding and explore its validity on other synthetic aggregates.

3.2 Correlation of TTI with ASTM Concrete Freeze-Thaw Test Results

As discussed in Section 1.1, one of the objectives of this phase of the study was to determine the relationship between the two concrete freeze-thaw tests. This relationship can best be made by using Fig. 3-2. Note that

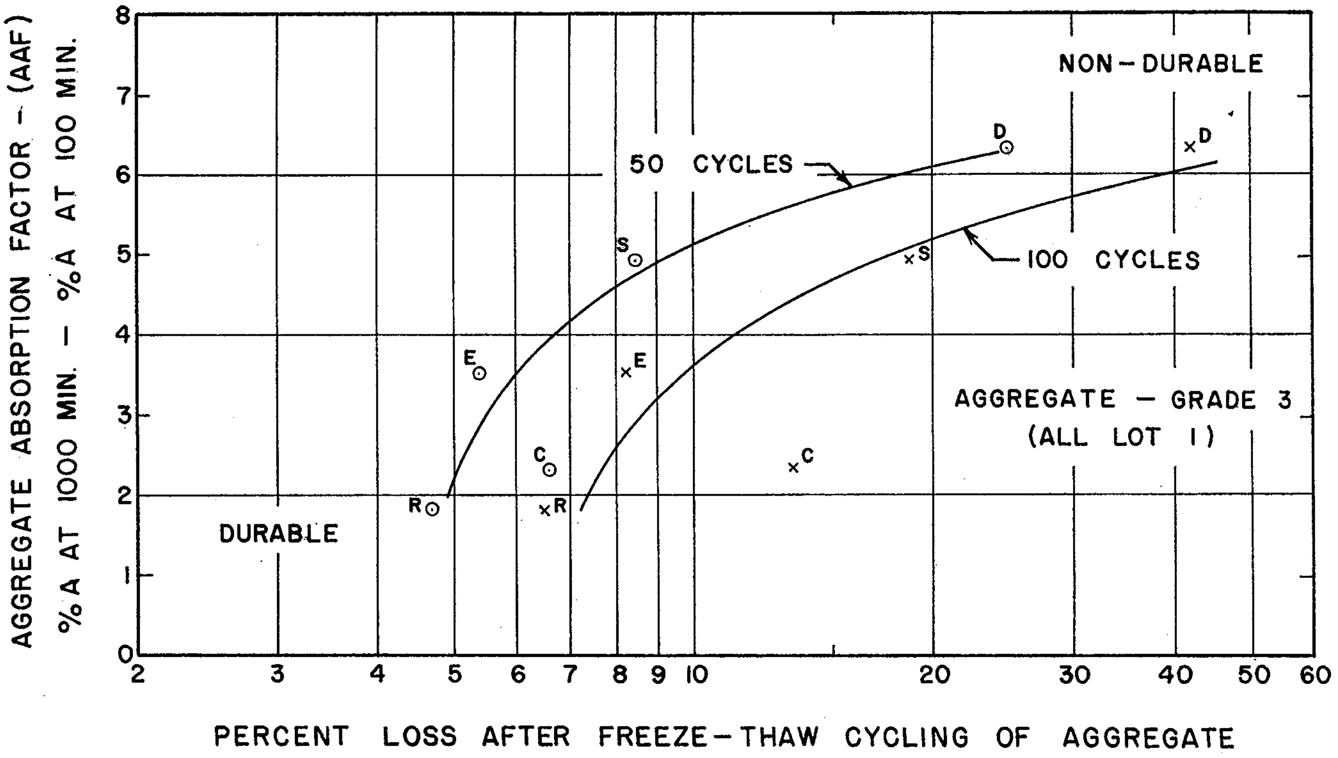

Fig. 3-1. Relationship between AAF and Aggregate Freeze-Thaw Loss for Five Synthetic Lightweight Aggregates.

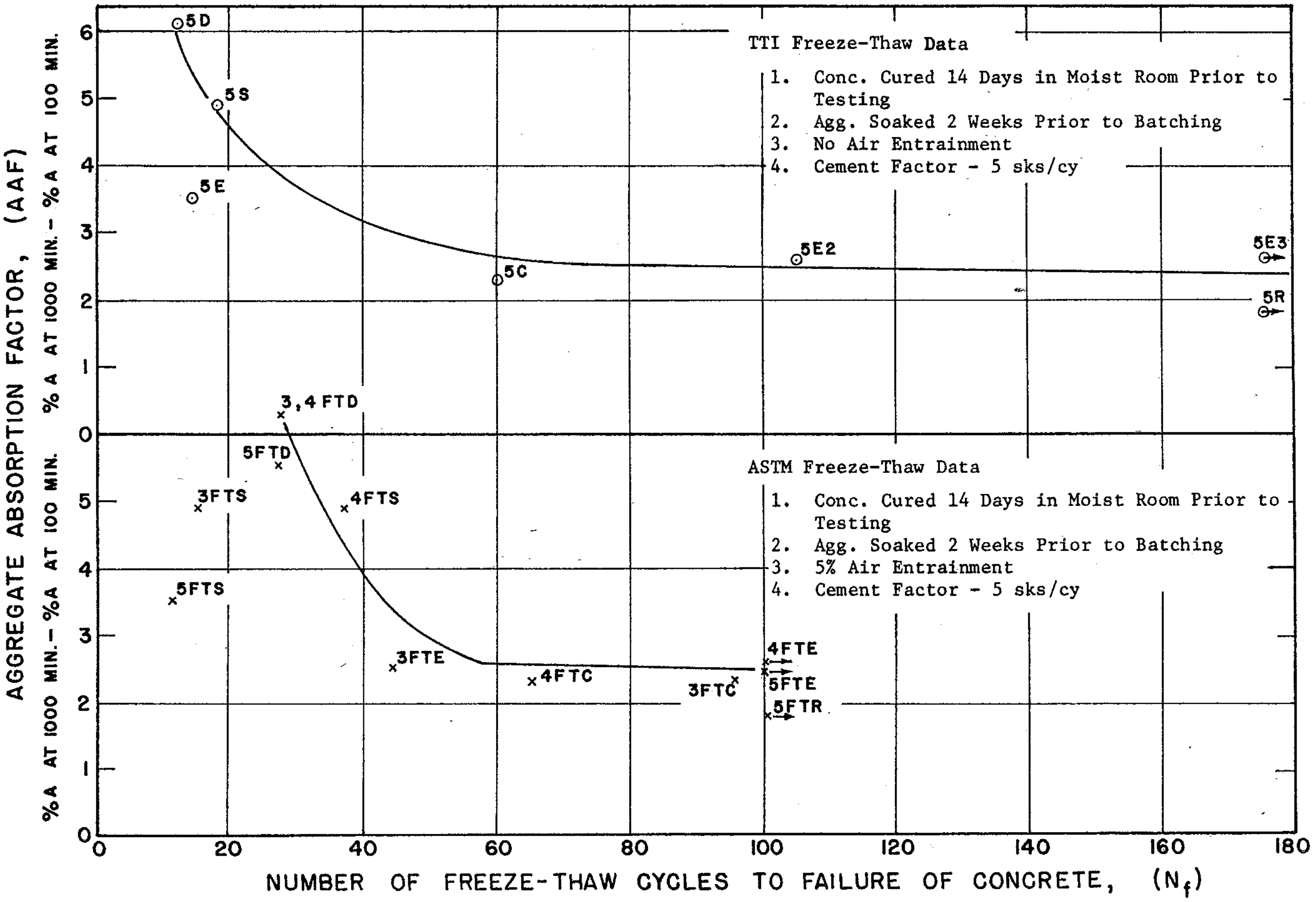

Fig. 3-2. Freeze-Thaw Durability as a Function of AAF for Selected Synthetic Lightweight Concretes, by Code Number.

the shape of the curves relating AAF to N_f (number of freeze-thaw cycles to failure) is similar for the two tests. Therefore, by assuming the curves drawn are the correct relationships and comparing the N_f's for a given AAF from each test, a definite relationship exists (Fig. 3-3). In this Figure, the points represent actual comparisons; data taken from Fig. 3-2. The curves drawn represent parabolic equations which relate the two tests. These equations are:

$$\text{TTI} = 0.016\,(\text{ASTM})^2 \text{ for } N_f < 25 \quad \text{(Eq. 1)}$$

and

$$\text{TTI} = 0.018\,(\text{ASTM})^2 \text{ for } N_f > 25 \quad \text{(Eq. 2)}$$

where: TTI = N_f under the TTI freeze-thaw test
ASTM = N_f under the ASTM C290 freeze-thaw test.

No attempt should be made to apply Eq. 1 and Eq. 2 universally, or to expect individual values to fit the equations exactly. Rather, these equations indicate the general relationship between the two tests on the concretes used in this program *only*, and will be valuable primarily in future research conducted at the Texas Transportation Institute.

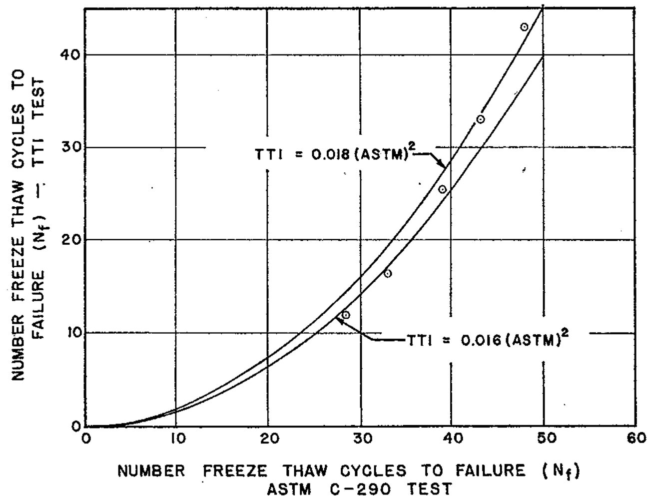

Fig. 3-3. Relationship between TTI Freeze-Thaw Test and ASTM Freeze-Thaw Test for Five Synthetic Lightweight concretes.

4. Appendix

4.1 Absorption-Time Text (Bryant Method) (5)

EXCERPT FROM
"THE DETERMINATION OF THE MOISTURE ABSORPTION CHARACTERISTICS OF LIGHTWEIGHT CONCRETE AGGREGATES"

A THESIS
BY
JULIAN STEPHEN BRYANT

TEXAS A&M UNIVERSITY

JANUARY 1959

A NEW METHOD OF TEST

The purpose of this research was to devise a simple, reliable method of test that would determine values of absorption, rate of absorption, and specific gravities for both fine and coarse fractions of lightweight aggregates.

The Theory

It was necessary to devise a method of test which did not require handling of the sample or obtaining a saturated, surface-dry condition physically in the sample, and also one which would determine the rate of absorption. The approach was to devise a method that would give the saturated weight of the sample and the surface-dry volume without actually obtaining this condition at the same time.

If the sample is immersed in water in a container of known volume and the water is maintained at a constant level by adding water as the sample absorbs it, then the rate of absorption can be measured by weighing the container at specific time intervals during the test. Then if a rate curve can be established and extrapolated to include zero time, the total amount of absorption can be obtained. Also, the surface-dry volume of the sample can be obtained by subtracting the volume of water at zero time from the volume of the container.

The Test

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, and rate of absorption of both the coarse and fine lightweight concrete aggregates. The specific gravity values are as defined in the Standard Definitions of Terms Relating to Specific Gravity (ASTM Designation: E 12) of the American Society for Testing Materials.

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 conical brass cap with a hole one-quarter inch in diameter in the top, as illustrated in Fig. 4-1.

Sample. Approximately 400 grams of the aggregate shall be selected by the method of quartering from the sample to be tested.

Procedure. The procedure shall be as follows:

(a) The jar and cap shall be weighed to the nearest 0.1 gram. The jar shall then be filled completely with distilled water and weighed to the nearest 0.1 gram and the temperature of the water recorded. The test shall be conducted in an environment temperature of 72 ± 5° F.

(b) The sample shall be dried in an oven at a temperature of 105°C for 24 hours. It shall then be allowed to cool to room temperature in a dessicator and the weight determined to the nearest 0.1 gram.

(c) After weighing, the sample shall be placed in the Mason jar and the jar filled with distilled water. The cap shall then be placed on the jar and water added to fill the jar and cap completely. The jar with sample and water shall then be weighed to the nearest 0.1 gram and the temperature recorded. With a little practice, this first weighing can be accomplished two minutes after the water is first introduced into the container. Weighings shall then be made at intervals of 2, 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 to remove any air trapped between the particles and refilling the jar so that a constant volume is maintained before each weighing is made.

Calculations. The weight of total water in the container at any time can be obtained by subtracting the weight of the container and the oven-dry weight of the sample from the total weight of the sample, container and water at that time. The weight of total water for each of the time intervals shall be calculated. Then, if the time intervals are represented by t_1, t_2, t_3, . . . t_t and the weights of total water corresponding to those intervals are represented by w_1, w_2, w_3, . . . w_t, a curve can be plotted with time as the abscissa and total water as the ordinate. This curve should be extended to a minimum time of 60 seconds. The total water at zero time shall be referred to as the free water. The curve shall be extended to time zero to determine the amount of free water. For purposes of this test, free water is defined as all water in the container which is not absorbed by

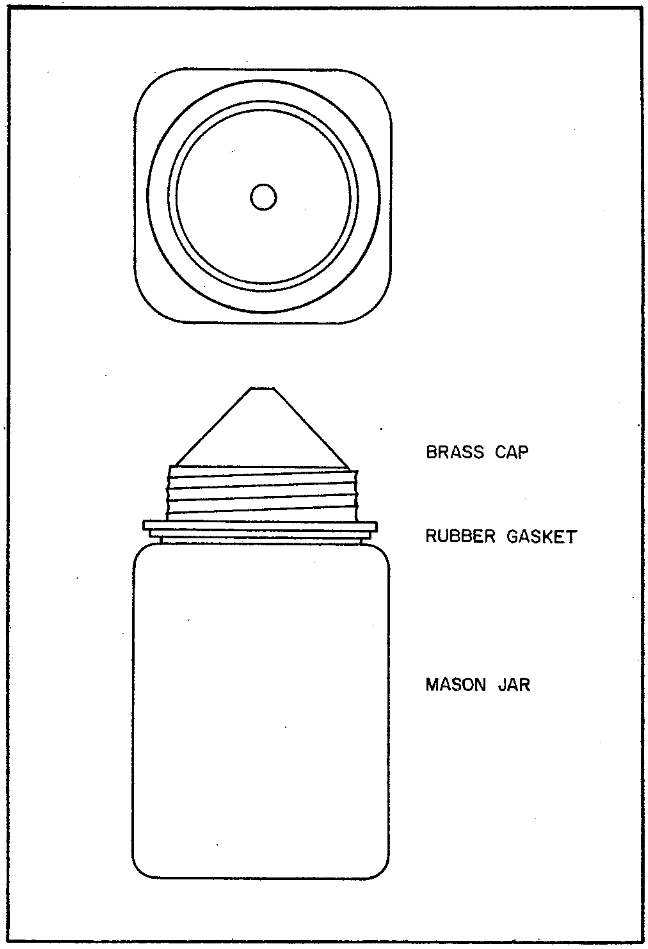

Fig. 4-1. Pycnometer Bottle Used in Tests.

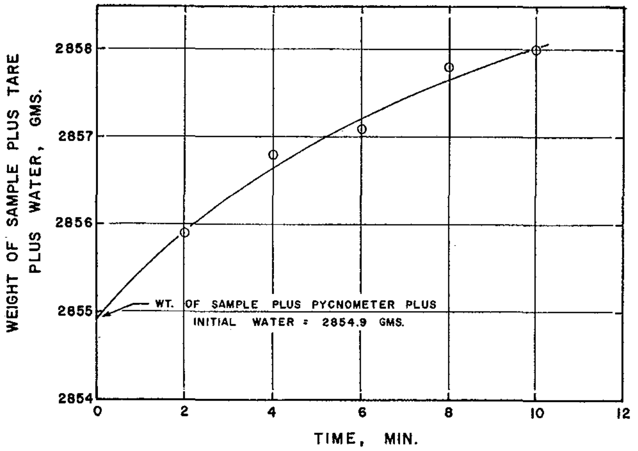

Fig. 4-2. Example Data Plot of Total Water Absorbed Versus Time of Immersion.

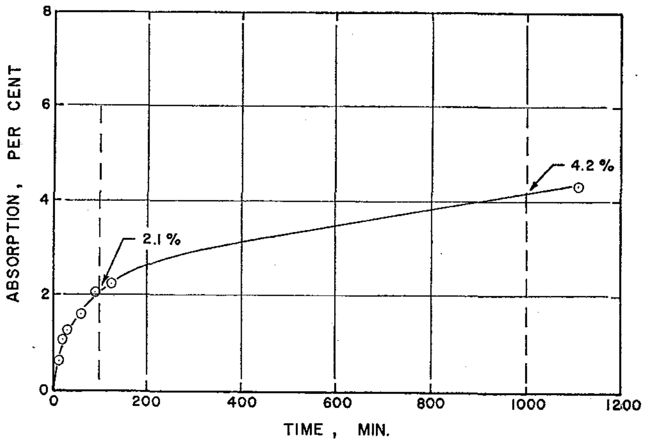

Fig. 4-3. Example Absorption-Time Curve.

the sample. Assuming that the volume of the sample remains constant, then the amount of free water is constant through the test. The volume of free water can then be calculated by dividing the weight of free water by the specific gravity of water at the temperature recorded when the test began. The bulk volume of the sample shall be calculated by subtracting the volume of free water from the volume of the container. The volume of total water at any time, t, shall be calculated by dividing the weight of total water at time, t, by the specific gravity of water at the temperature recorded when the test began. The apparent volume of the sample at any time, t, can then be calculated by subtracting the volume of total water at time, t, from the volume of the container. The absorbed water at any time can be calculated by subtracting the free water from the total water at that time.

Absorption. The percent absorption shall be calculated for each time interval by dividing the weight of absorbed water at each time interval by the oven-dry weight of the sample. The percent absorption versus time shall be plotted on rectangular coordinate graph paper and a smooth curve drawn through these points to establish the rate of absorption.

Bulk Specific Gravity (Dry). The bulk specific gravity shall be calculated by dividing the oven-dry weight of the sample by the bulk volume of the sample.

Bulk Specific Gravity (Saturated Surface-Dry). The bulk specific gravity on a saturated, surface-dry basis at any time, t, shall be calculated by dividing the sum of the oven-dry weight of the sample and the weight of absorbed water at time, t, by the bulk volume of the sample.

TABLE 4-1. EXAMPLE DATA AND CALCULATIONS
ABSORPTION AND SPECIFIC GRAVITY

Date and Time		Time Since Start	Wt. Tare Sample & Water	Weight Total Water	Weight Free Water	Weight Absorbed Water	Percent Absorption
				1660.0	1660.0		
3/2	8:30	2 min	2855.9	1661.0	"	1.0	0.2
	8:32	4	2856.8	1661.9	"	1.9	0.5
	8:34	6	2857.1	1662.2	"	2.2	0.6
	8:36	8	2857.8	1662.9	"	2.9	0.7
	8:38	10	2858.0	1663.1	"	3.1	0.8
	8:48	20	2859.2	1664.3	"	4.3	1.1
	8:58	30	2860.1	1665.2	"	5.2	1.3
	9:28	60	2861.3	1666.4	"	6.4	1.6
	9:58	90	2863.5	1668.6	"	8.6	2.2
	10:28	120	2864.1	1669.2	"	9.2	2.3
3/3	15:00	1110	2872.1	1677.2	"	17.2	4.3
3/4	8:15	2 days	2876.8	1681.9	"	21.9	5.5
3/5	8:17	3	2878.8	1683.9	"	23.9	6.0
3/8	9:00	6	2882.0	1687.1	"	27.9	6.8
3/11	9:07	9	2884.5	1689.6	"	29.6	7.4
3/12	8:10	10	2884.8	1689.9	"	29.9	7.5
3/15	8:40	13	2887.0	1692.1	"	32.1	8.0
3/18	8:26	16	2888.1	1693.2	"	33.2	8.3
3/21	8:30	19	2891.0	1696.1	"	36.1	9.0
3/23	8:12	21	2888.8	1693.9	"	33.9	8.5
3/28	9:17	26	2893.8	1698.9	"	38.9	9.7
3/31	9:00	29	2894.9	1700.0	"	40.0	10.0
4/4	8:05	33	2898.0	1703.1	"	43.1	10.8
4/13	8:20	42	2898.5	1703.6	"	43.6	10.9
4/14	9:00	43	2900.0	1705.1	"	45.1	11.3

TABLE 4-2. TYPICAL DATA SHEET

DATA SHEET

Absorption and Specific Gravity

Project 1081 Aggregate RCA #2 Date 3/2/66

Performed by

(a) Tare Wt. 795.1 Wt. of Bottle and Water 2723.8

Weight of Water 2723.8 - 795.1 = 1928.7

Temp. of Water 24°C Volume of Bottle $\frac{1928.7}{0.7793}$ = 1933.9

(b) Wt. of bottle & dry sample 1194.9 Wt. Dry Sample 1194.9 - 795.1 =

399.8

(c) Wt. of free water. 1660.0 Vol. of Free Water $\frac{1660.0}{0.9973}$ = 1664.5

Bulk Volume of Sample 1933.9 - 1664.5 = 269.4

Wt. Total Water @ 3 days 1683.9 Vol. Total Water $\frac{1683.9}{0.9973}$ = 1688.4

Apparent Vol. Sample 1933.9 - 1688.4 = 245.5

Saturated Wt. Sample 399.8 + 23.9 = 423.7

Absorption (Percent) $\frac{23.9}{399.8}$ = 6.0%

Bulk Specific Gravity (Dry) $\frac{399.8}{269.4}$ = 1.48

Bulk Specific Gravity (SSD) $\frac{423.7}{269.4}$ = 1.57

Apparent Specific Gravity $\frac{399.8}{245.5}$ = 1.63

Aggregate Absorption Factor 4.2 - 2.1 = 2.1

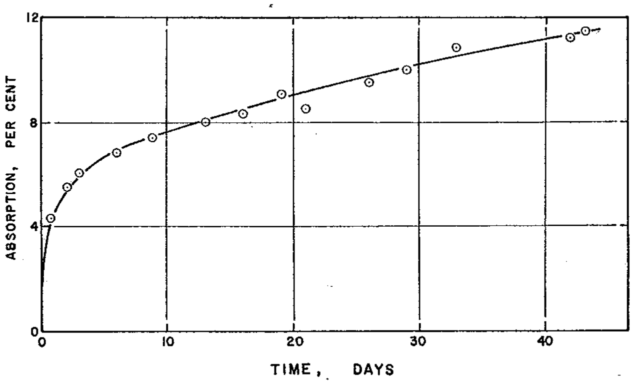

Fig. 4-4. Example Absorption-Time Curve.

Apparent Specific Gravity. The apparent specific gravity at any time, t, shall be calculated by dividing the oven dry weight of the sample by the apparent volume at that time.

4.2 Concrete Mix Design Data

The mix design data for concrete mixes employed in this study are given in Table 4-3.

4.3 References

1. 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.
2. Kanabar, C. N. and Ledbetter, W. B., "Effects of Degree of Synthetic Lightweight Aggregate Pre-Wetting on the Freeze-Thaw Durability of Lightweight Concrete," Research Report 81-2, Texas Transportation Institute, Texas A&M University, December 1966.
3. Gallaway, Bob M. and Harper, William J., "A Laboratory and Field Investigation 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. *Standard Specifications for Road and Bridge Construction*, adopted by the State Highway Department of Texas, Item 302, pp. 207, January 2, 1962.
5. Bryant, J. S., "The Determination of the Moisture Absorption Characteristics of Lightweight Concrete Aggregates," M. S. Thesis, Texas A&M University, 1959.
6. Ledbetter, W. B., Hirsch, T. J., and Ivey, Don L., "Selected Durability Studies of Structural Lightweight Concrete," Research Report 35-2, Texas Transportation Institute, Texas A&M University, December, 1964 (Revised April, 1966).

TABLE 4-3. CONCRETE MIX DESIGN DATA

Coarse Aggregate Designator and Lot No.	Concrete Batch Code No.	Cement Factor (sks/cy)	PERCENT ABSOLUTE VOLUME					Slump (in)	Initial Unit Wt (pcf)
			Cement	Water	FA	CA	Air		
R1	5R	5.0	8.7	20.4	34.7	33.7	2.5	3½	118.8
R1	3FTR	4.6	8.2	20.9	34.9	31.7	4.3	4	114.4
R1	4FTR	4.9	8.7	19.0	33.1	33.8	5.4	3	113.2
R2	5FTR	4.9	8.7	18.7	33.0	33.6	6.0	3¾	115.1
C1	5C	4.7	8.4	22.8	35.1	31.7	2.0	4½	115.7
C1	3FTC	4.7	8.3	21.0	34.3	32.1	4.3	3½	117.6
C1	4FTC	4.7	8.4	20.2	34.4	32.2	4.8	4	115.2
E1	5E	4.6	8.2	21.1	36.8	31.8	2.1	3¾	118.0
E4	5E2	4.7	8.3	20.2	37.2	32.3	2.0	4½	128.0
E4	5E3	4.9	8.7	22.0	33.7	33.5	2.1	3	118.2
E4	3FTE	4.7	8.3	17.6	36.0	32.2	5.9	4½	125.2
E4	4FTE	4.7	8.3	17.1	37.4	32.2	5.0	3	120.8
E6	5FTE	4.6	8.2	16.6	37.1	32.1	6.0	3½	117.1
S1	5S	4.9	8.6	23.6	32.7	33.2	1.9	4½	126.8
S1	3FTS	4.9	8.7	20.7	31.7	33.6	5.3	3	116.8
S1	4FTS	4.9	8.7	21.0	32.4	33.6	4.3	3½	118.0
S3	5FTS	5.0	8.8	20.3	32.6	33.8	4.5	3¾	118.2
D1	5D	4.9	8.7	22.9	35.5	30.9	2.0	4¼	118.4
D1	3FTD	5.0	9.0	18.9	35.4	31.9	4.8	3¼	113.6
D1	4FTD	4.9	8.7	19.2	36.2	31.1	4.8	3¾	115.2
D2	5FTD	5.0	8.9	17.8	36.7	31.6	5.0	3¼	116.1