Influence of the Degree of Saturation of Coarse Aggregate on the Resistance of Structural Lightweight Concrete to Freezing and Thawing

EUGENE BUTH and W. B. LEDBETTER,
Texas Transportation Institute, Texas A&M University

Six selected commercially produced and 7 TTI kiln-produced lightweight coarse aggregates were used in 69 batches of lightweight concrete. These batches of concrete, containing these coarse aggregates, air entrainment, Type 1 cement, and natural sand, were mixed and subjected to freezing and thawing in accordance with ASTM C 290. Absorption characteristics and porosity values were determined for each of the aggregates. Various degrees of saturation of the coarse aggregate at the time of mixing were obtained by immersing the aggregates in water for periods ranging up to 180 days prior to mixing. The results indicate a failure envelope exists between the number of freeze-thaw cycles to failure and the degree of saturation of the coarse aggregate. The "critical" degree of saturation by volume was found to be 0.25 (or 25 percent), below which the concrete will generally withstand 300 cycles of freeze-thaw. It was also determined that some of these aggregates reached this initial saturation after only 30 minutes of immersion, while other aggregates had to be immersed for several days before becoming critically saturated. The practical implications of the test results are discussed.

•INTERNAL STRESSING OF CONCRETE due to the repeated action of internal water freezing and thawing has long been recognized as a detrimental influence on the performance of concrete. This water is present both in the aggregate voids and in the cement paste matrix. Improvements in mix designs and the use of entrained air have significantly reduced the detrimental effects of water in the paste matrix. However, the problem of handling the water in the aggregate voids has not been solved, especially when lightweight aggregates are used that have a relatively large void volume. The research program reported here was concerned with the effects of water in lightweight aggregate used in concrete and subjected to freezing and thawing.

Six selected commercially produced and 7 TTI produced lightweight coarse aggregates were used in the program. The TTI research kiln, which was used to produce the TTI aggregate, is a 25-ft long by 2-ft inside diameter rotary kiln that allows the processing of synthetic aggregates to be closely controlled. The kiln is located at Texas A&M University. A total of 69 batches of concrete using these coarse aggregates and natural sand were mixed and tested in accordance with ASTM C 290. Absorption characteristics and porosity values were determined for each of the aggregates. Various degrees of saturation of the coarse aggregates at the time of mixing were obtained by immersing them in water for periods ranging from 6 hours to 180 days.

Paper sponsored by Committee on Performance of Concrete—Physical Aspects.

BACKGROUND

Deterioration of concrete caused by freezing and thawing is a result of excessive stresses created by the expansion of water being frozen in the void system of the concrete. This void system may exist in the cement paste or in the aggregate. As water expands some 9 percent upon freezing, this expansion is accommodated either by water expansion into pores and capillaries or by elastic dilation of the concrete, or the concrete is ruptured. The factors influencing the amount of stress created are many. Porosity, permeability, void size distribution, degree of saturation of the aggregate and the paste, freezing rate, and the ability of the paste to accommodate water being expelled from the aggregate all combine to influence the stresses created during freezing temperatures.

The effects of the more influential aggregate parameters involved in the durability of concrete may be briefly summarized as follows. For an aggregate to be potentially nondurable in a freezing and thawing environment, it must have sufficiently large porosity and must have been saturated to a degree that is greater than some critical value. If these conditions exist, the expansion of the water during freezing may create excessive stresses and, in turn, cause deterioration of the concrete. Theoretically, the critical degree of saturation is 0.917. However, experiments have failed to verify this value. Reasons for the lack of experimental verification given by Powers (1) are nonuniform distribution of water in particle, pore size distribution (macropores that protect saturated capillaries), and nonhomogeneity of particles. A lower limit of critical saturation exists, above which excessive stresses will be created.

Two types of deterioration may be caused by nondurable aggregates. Combinations of pore size distribution or permeability and freezing rate exist for which excessive stresses may be created if the aggregates were frozen, even if they were unconfined. The other possibility that exists in this respect is that of a high permeability that will allow the expanding water to escape the aggregate particle during freezing. In this instance excessive stresses may be created in the surrounding cement paste if its air content is such that it cannot accommodate the excess water (2). Dolch (3) has summarized as follows: "Therefore, while the type of failure one gets depends on the permeability, whether or not one gets failure will depend on the several factors that determine the degree of saturation of the aggregate."

An aggregate may be saturated beyond the critical value at the time it is mixed and placed or may become critically saturated in the hardened concrete if placed where free drainage is not provided. The major factors that appear to influence the time required for an aggregate to become critically saturated in concrete after being placed are the absorption characteristics of the aggregate and the permeability and thickness of the paste cover separating the aggregate from the external supply of water (2). In any case, the important point is whether the aggregate is critically saturated at the time freezing occurs.

The objective of the investigation reported here was to provide information on the resistance of structural lightweight concrete to freezing and thawing as a function of the degree of aggregate saturation.

COARSE AGGREGATES

Sources

Structural lightweight concrete coarse aggregates from 6 commercial sources and 7 aggregates produced with the TTI kiln were investigated in this program. All commercial sources of aggregate were produced in rotary kilns. The properties of weight and specific gravity for the various aggregates are given in Table 1. The properties of absorption, porosity, and degree of saturation are discussed in the following sections.

Absorption

The Bryant method (4) was used to determine the absorption-time relationships of the various coarse aggregates (Appendix A). Curves of the first 24-hour absorption-time relationships are shown in Figures 1 and 2; curves for periods of up to 40 days

TABLE 1

PROPERTIES OF LIGHTWEIGHT COARSE AGGREGATES

Aggregate and Lot No.	Unit Weight	Dry Bulk Specific Gravity	Apparent Specific Gravity[a]	Production
R1	46.8	1.39	2.11	Commercial
R2	48.1	1.43	2.17	Commercial
C2	38.5	1.40	2.02	Commercial
C3	38.1	1.27	1.99	Commercial
C5A1	37.4	1.19	1.98	TTI[b]
S3	42.0	1.41	2.32	Commercial
E4	45.3	1.36	2.11	Commercial
E6	44.9	1.40	2.06	Commercial
D2	35.8	1.18	2.20	Commercial
D3	39.4	1.24	2.16	Commercial
W3	40.8	1.48	2.24	Commercial
W6D1	40.6	1.11	2.14	TTI[c]
W7B1	47.8	1.31	1.74	TTI[c]
M2B2	42.5	1.20	2.07	TTI
M2C2	37.6	1.12	2.07	TTI
M3C2	33.9	1.09	2.02	TTI
M3D2	37.9	1.21	2.04	TTI

[a]Obtained by using the pressure pycnometer.
[b]From same raw material as aggregate C.
[c]From same raw material as aggregate W.

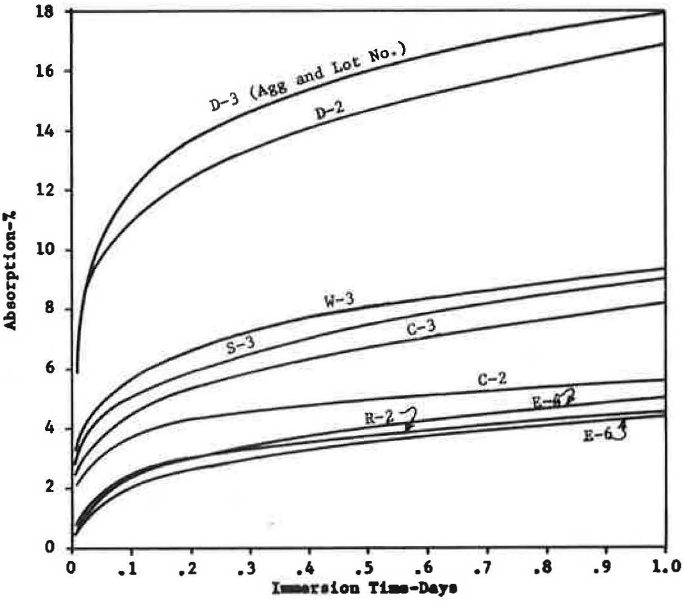

Figure 1. Absorption-time relationships for commercially produced coarse aggregates for first 24 hours.

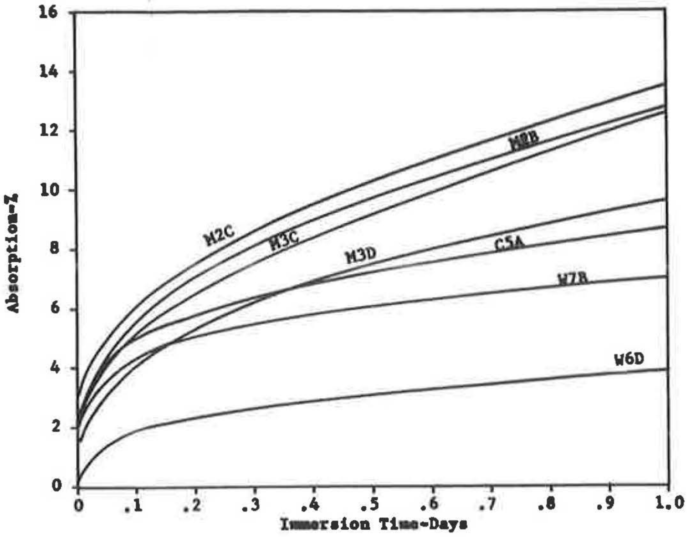

Figure 2. Absorption-time relationships for TTI produced coarse aggregates for first 24 hours.

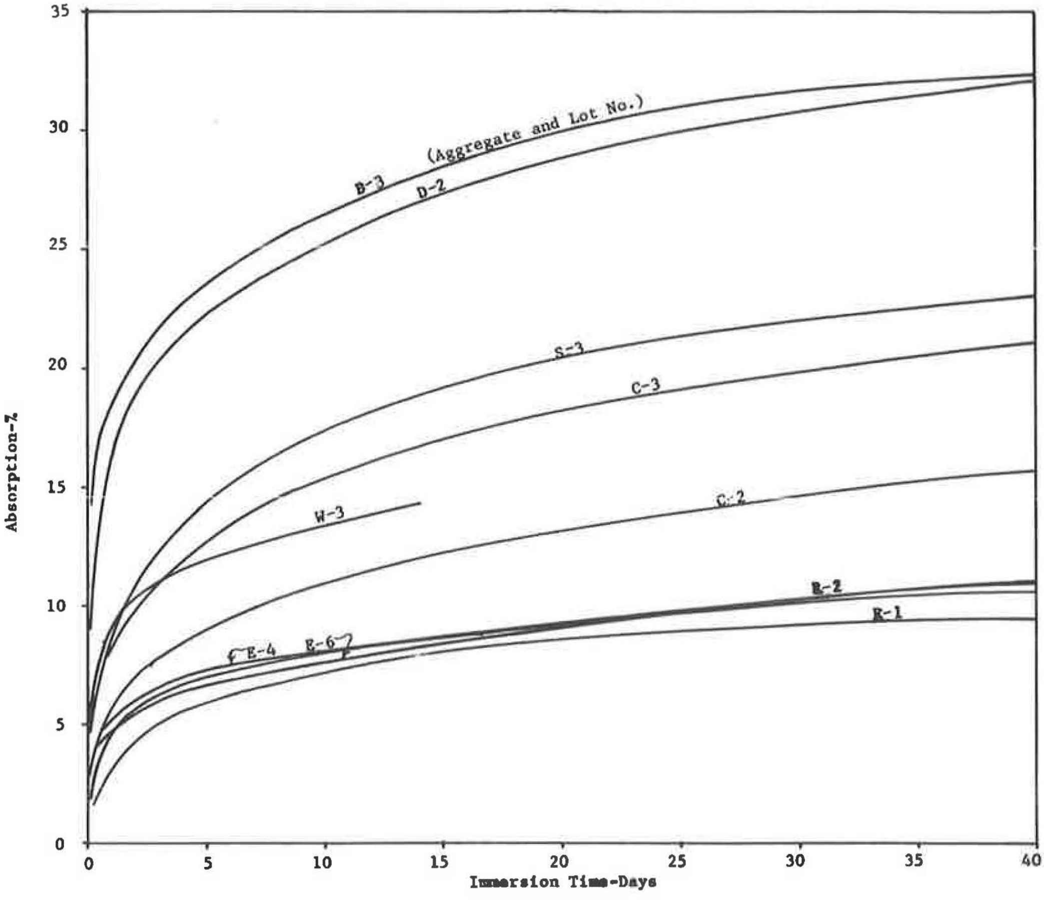

Figure 3. Absorption-time relationships for commercially produced coarse aggregates for 40 hours.

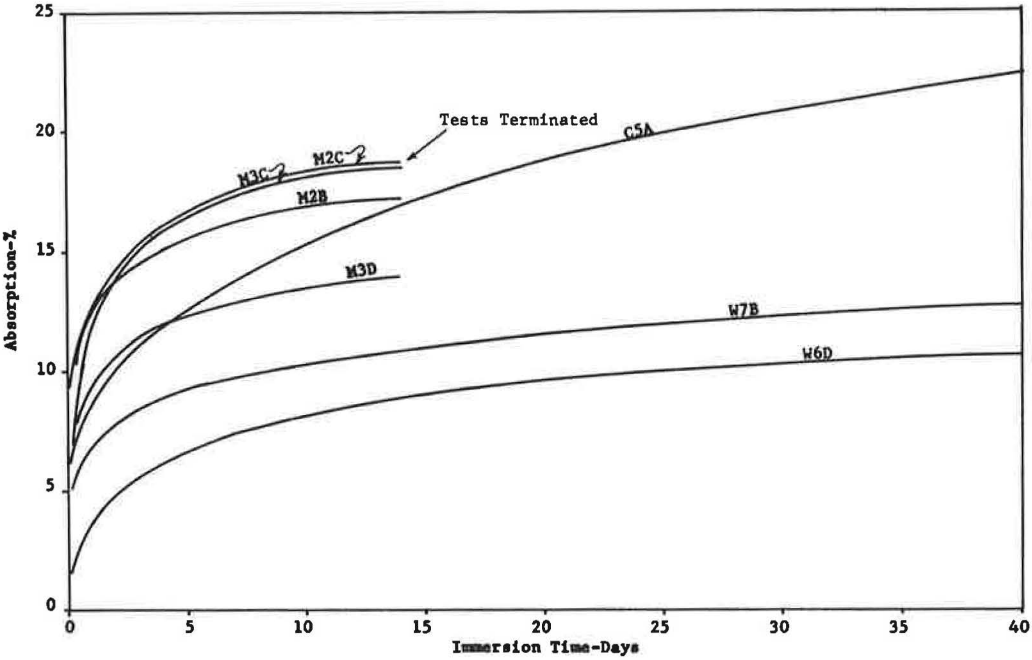

Figure 4. Absorption-time relationships for TTI produced coarse aggregates for 40 hours.

are shown in Figures 3 and 4. The wide range in absorption values is one of the most obvious differences noticed among the lightweight aggregates. Most of these aggregates continue to absorb water for long periods of time, and their final absorption values may be many times their 24-hour values. However, in terms of freeze-thaw durability, the important difference among the aggregates is not a particular value of absorption, but rather the rate at which the aggregates absorb water and become saturated. Thus, the slope of the absorption-time curve, a value that changes with time or degree of saturation, is the more influential parameter as it is a measure of the rate at which the aggregate is "soaking up" water, which in turn influences the ease with which an aggregate may become critically saturated.

Porosity

The porosity of each of the aggregates was calculated by using the dry bulk and apparent specific gravities.

The dry bulk specific gravity used to determine the porosity by this method is that obtained from the Bryant absorption and specific gravity test (Appendix A). The apparent specific gravity was determined by using a pressure pycnometer, which is capable of rapidly saturating an aggregate under 1,200-psi pressure. The porosity was determined by the equation

$$N = 1 - \frac{G_B}{Gpp}$$

where

G_B = dry bulk specific gravity,
Gpp = apparent specific gravity (using pressure pycnometer), and
N = porosity.

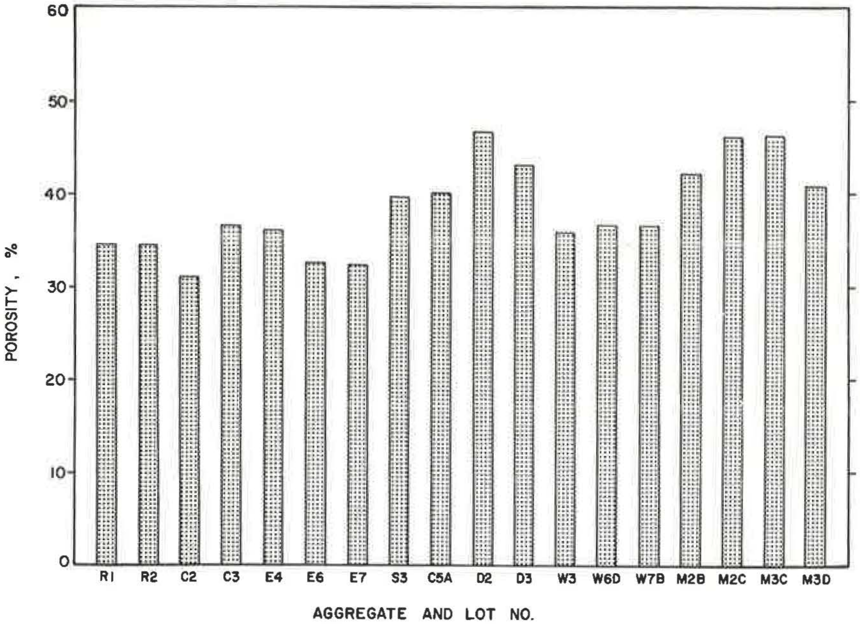

Figure 5. Porosity of aggregates.

The values of porosity are shown in Figure 5. These aggregates are very definitely porous enough (in all cases, over 30 percent) to accommodate sufficient water to cause disruption when frozen. However, as shown by the foregoing absorption-time curves, some of the voids contained in these aggregates apparently are isolated and not subject to saturation under atmospheric pressure, even after long periods of wetting.

Degree of Saturation

Absorption-time relationships and porosities can be combined and presented in the form of degree of saturation-time relationships. Curves illustrating such relationships are shown in Figures 6 through 9. Obviously, the degree of saturation obtained after a given immersion time is much greater for some aggregates than for others. This is in agreement with the following statement by Powers (1): "Various observations... suggest that a principal difference among different kinds of rock particles is the rate at which they become saturated when given free access to water."

CONCRETE

Mixtures

Sixty-nine batches of concrete were mixed and cast using the 6 selected lightweight coarse aggregates produced commercially and the 7 produced in the TTI kiln. Various degrees of prewetting of the coarse aggregates were obtained by immersing the aggregates in water for periods ranging from 6 hours to 180 days prior to mixing. All concrete mixtures had a nominal cement factor of 5 sacks/cu yd, a 3- to 4-in. slump, and 5 to 6 percent entrained air. A natural sand was used in all mixtures. The proportions of coarse and fine aggregate did not vary significantly. The various coarse aggregates and the amount of prewetting they received were the only parameters varied. Mixture proportions and properties of the concrete are given in Appendix B[1]. Three

[1]The original manuscript of the paper included Appendix B, which is available in Xerox form at cost of reproduction and handling from the Highway Research Board. When ordering, refer to XS-32, Highway Research Record 328.

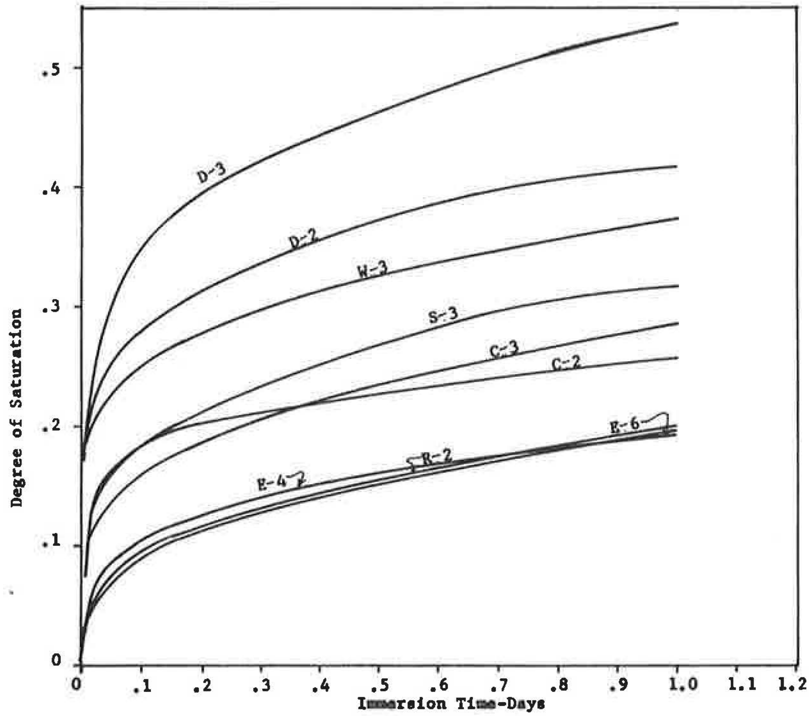

Figure 6. Relationship between degree of saturation and immersion time for commercially produced coarse aggregates for first 24 hours.

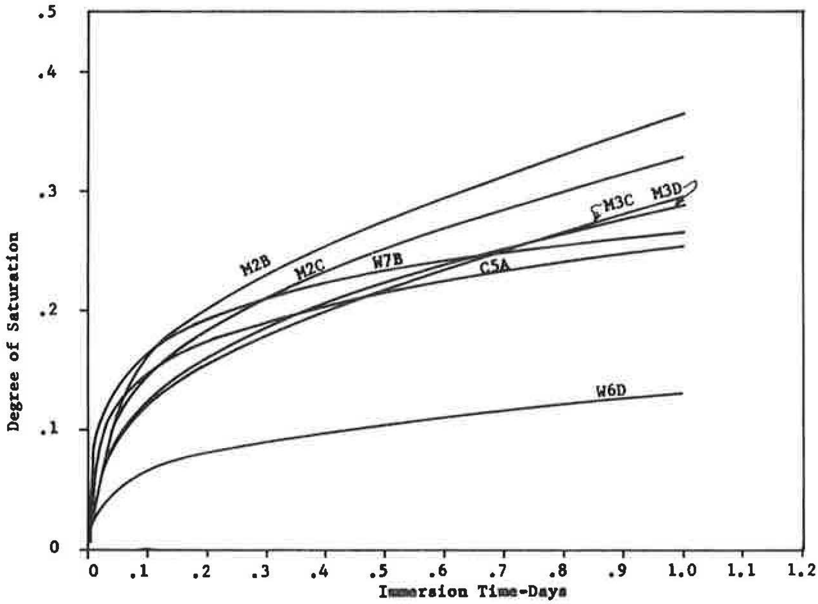

Figure 7. Relationship between degree of saturation and immersion time for TTI produced coarse aggregates for first 24 hours.

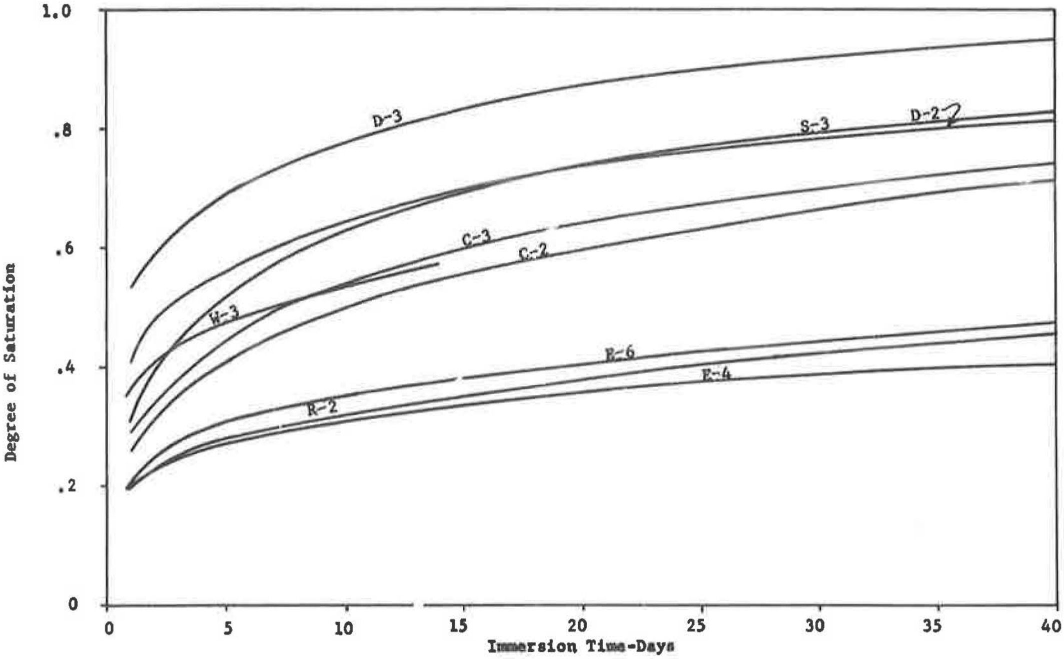

Figure 8. Relationship between degree of saturation and immersion time for commercially produced coarse aggregates for 40 days.

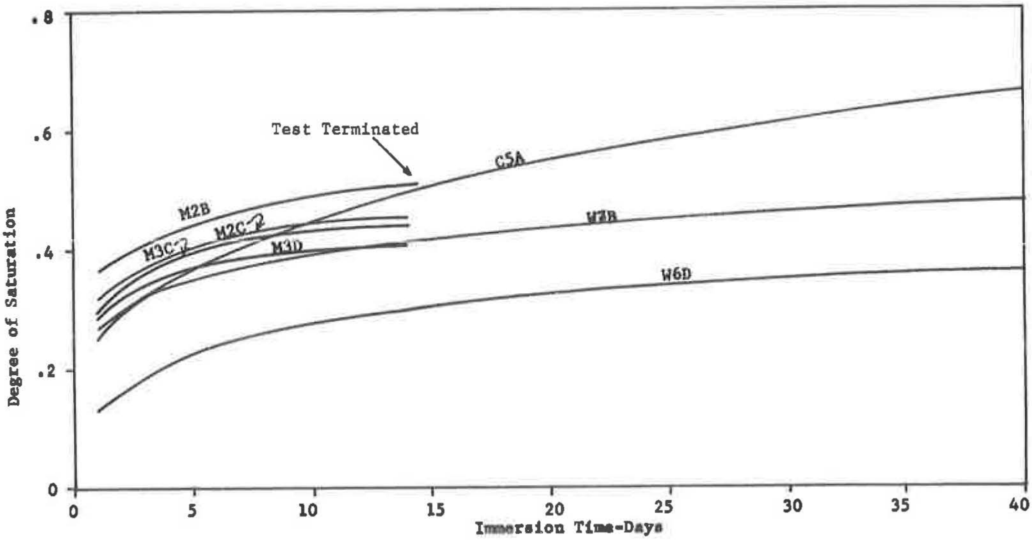

Figure 9. Relationship between degree of saturation and immersion time for TTI produced coarse aggregates for 40 days.

3-in. by 3-in. by 16-in. specimens for freeze-thaw testing were cast from each batch. These specimens were moist-cured until 14 days of age at which time they were subjected to cycles of freezing and thawing in water in accordance with ASTM C 290. Automatic cabinets with a capacity of 17 specimens and a capability of approximately 8 cycles per day were used in conducting these tests. Standard cylinders were cast and moist-cured for compressive strength determination at 14 and 28 days of age (strength values are given in Appendix B[1]).

Freezing and Thawing

The number of cycles to failure of the concrete specimens subjected to freezing and thawing is defined here as the number of cycles at which the square of the fundamental transverse frequency of vibration of the specimen decreased to 60 percent of its original value. This is substantially in accordance with ASTM C 215. Data obtained from these tests compared with degree of saturation of the coarse aggregate at the time of mixing are shown in Figure 10; a failure envelope is suggested. As each point (without an arrow attached) represents a failure, a failure envelope was drawn indicating the safe-unsafe areas. For example, according to the failure envelope, a concrete containing a coarse lightweight aggregate with a degree of saturation of 0.4 would withstand at least 80 cycles of freezing and thawing before failure. A concrete containing a coarse lightweight aggregate with a degree of saturation of 0.25 would withstand at least 300 cycles of freezing and thawing before failure. Four batches failed to the left of the failure envelope. One batch of aggregate E concrete failed at 44

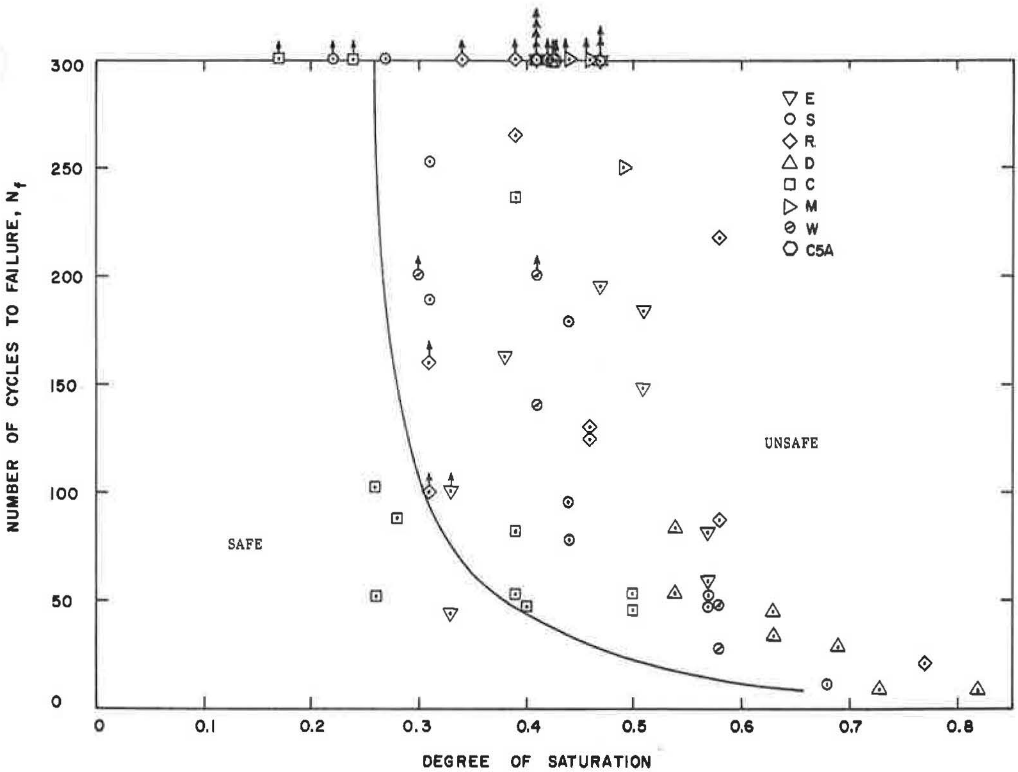

Figure 10. Relationship between number of cycles to failure (ASTM C 290) and degree of saturation of the coarse aggregate at the time of mixing.

cycles but, as it was the only one to fail prematurely, it was not considered representative and thus was ignored. The other 3 batches were made with aggregate C. Aggregate C, which is commercially produced, is made up of small particles partially fused together (Fig. 11) and has always been somewhat of a maverick in experimental work (4, 5). Aggregate C5A (Fig. 11), TTI produced from the same raw material as commercial aggregate C, yielded aggregate properties similar to aggregate C but behaved in the manner predicted by the failure envelope. For this reason, it was believed that the results from aggregate C concrete should also be disregarded when constructing the failure envelope. However, the fact remains that a commercially produced aggregate (aggregate C) did not behave as predicted. Even though this can be at least partially explained, the disparity, or maverick behavior of 1 out of 13 aggregates serves as a warning that the freezing-thawing mechanisms at work are extremely complex and experimental results must be interpreted in the light of the best available engineering judgment.

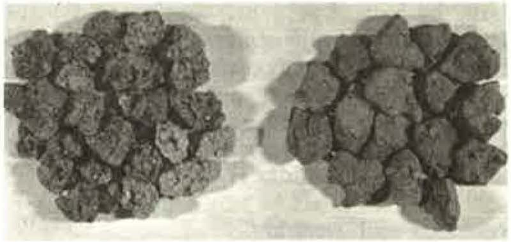

Figure 11. Aggregate C (left) and aggregate C5A (right).

If the failure envelope suggested by the data shown in Figure 10 is accepted, then judgment indicates that a lightweight aggregate with less than a 0.25 degree of satura-

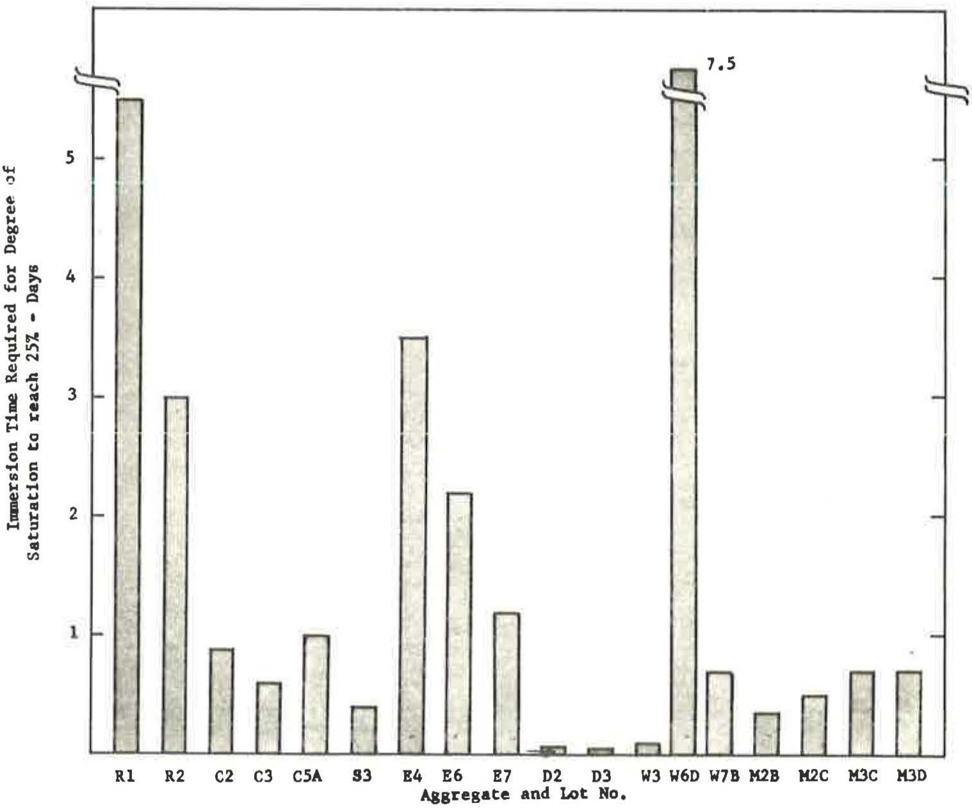

Figure 12. Immersion time required for degree of saturation of the coarse aggregates to reach 25 percent.

tion should produce a durable concrete. What does this mean in terms of the ease with which a given aggregate will reach this "critical" saturation? For the aggregates investigated, this question is answered by the data shown in Figure 12. When immersed in water, aggregate D will reach this critical value almost immediately (actually about 30 minutes), while aggregate W6D will not reach a critical saturation for over 7 days. The conclusion is obvious. Although almost any aggregate will produce durable concrete, extreme care must be exercised with some because of their rapid rate of water absorption.

CONCLUSIONS

Based on the experimental program reported here, the following conclusions are drawn:

1. Lightweight aggregates, when immersed, continue to absorb water for long periods of time (far in excess of 24 hours).
2. A failure envelope has been established between the number of lightweight concrete freeze-thaw cycles to failure and degree of saturation of the coarse aggregate. Lightweight concrete containing lightweight coarse aggregate with a degree of saturation less than 0.25 will generally withstand 300 cycles of freezing and thawing. Conversely, if the aggregate has a degree of saturation in excess of 0.25, the concrete may or may not fail in 300 cycles of freezing and thawing.
3. The time required for some lightweight aggregates to reach the critical degree of saturation of 0.25 can be extremely short (30 minutes immersion in one case), and thus the engineer should fully explore this property with any aggregates he has under consideration.

PRACTICAL IMPLICATION OF TEST RESULTS

Durability in a given environment such as ASTM C 290 can be reasonably predicted. However, the infinite number of environments encountered in the field make accurate predictions an impossibility. The best one can do is to assume that the most severe environment expected will occur and to design accordingly.

A lightweight concrete may be made potentially nondurable (when tested by ASTM C 290 after 14 days of moist-curing) if the coarse aggregate is more than about 25 percent saturated at the time of mixing. As always, it is very difficult to interpret the meaning of these results for field use. The quantitative effect of a drying period prior to freezing temperatures has not been determined. If drying will reduce the degree of saturation of the aggregate sufficiently below 25 percent prior to the occurrence of freezing temperatures, the concrete would be expected to be durable. Also, if the aggregate is less than 25 percent saturated at the time of mixing, it appears reasonable that the aggregate would not reach a critical degree of saturation after being cast in any location where free drainage is provided.

If concrete should not be mixed and placed with the aggregate above critical saturation (a degree of saturation of about 25 percent for the aggregates studied), a field test method for determining the degree of aggregate saturation at the time of mixing must be developed. Consideration should be given to the expected environment and the effect of drying period in establishing any limits on the degree of saturation. Additional information is needed on this subject.

REFERENCES

1. Powers, T. C. Basic Considerations Pertaining to Freezing and Thawing Tests. Proc. ASTM, Vol. 55, 1955, p. 1132.
2. Verbeck, G., and Landgren, R. Influence of Physical Characteristics of Aggregates on Frost Resistance of Concrete. Proc. ASTM, Vol. 60, 1960, pp. 1063-1079.
3. Dolch, W. L. Porosity. In Significance of Test and Properties of Concrete Aggregate, ASTM, Spec. Publication 169, 1956, pp. 443-461.

4. Ledbetter, W. B., and Buth, E. Aggregate Absorption Factor as an Indicator of the Freeze-Thaw Durability of Structural Lightweight Concrete. Texas Transportation Institute, Texas A&M Univ., Research Rept. 81-3, Feb. 1967.
5. Ledbetter, W. B. Correlation Studies of Fundamental Aggregate Properties With Freeze-Thaw Durability of Structural Lightweight Concrete. Texas Transportation Institute, Texas A&M Univ., Research Rept. 81-1, Aug. 1965.
6. Bryant, J. S. The Determination of the Moisture Absorption Characteristics of Lightweight Concrete Aggregates. Texas A&M Univ., Thesis, Jan. 1959.

Appendix A

ABSORPTION-TIME TEST (BRYANT METHOD)

The purpose of this research (4, 6) 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 that 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 the fine lightweight concrete aggregates. The specific gravity values are as defined in ASTM Designation E 12.

Apparatus—The apparatus shall consist of the following:

1. A balance having a capacity of 3 kg or more and a sensitivity of 0.1 gram or less, and
2. A glass mason jar fitted with a conical brass cap with a hole ¼ in. in diameter in the top.

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:

1. 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.
2. 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 desiccator and the weight determined to the nearest 0.1 gram.

3. After it is weighed, 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 2 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 for 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 10 minutes. 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 that is not absorbed by 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 percentage of 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 percentage of 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 adsorbed water at time, t, by the bulk volume of the sample.

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.

Discussion

W. P. CHAMBERLIN, New York State Department of Transportation—The authors conclude that 0.25 is the level of saturation prior to mixing below which a lightweight aggregate will not attain its critical degree of saturation when mixed in concrete and subjected to 300 cycles of ASTM C 290 after 14 days of immersion. Further, they suggest that a field acceptance test based on this value be developed.

It is interesting to look at their data also from the point of view of what can be learned about the water sorption of lightweight aggregate in concrete. For instance, if the number of freeze-thaw cycles to failure is looked upon as a measure of the time required for the aggregates to attain critical saturation in "wet" concrete, then the authors' data may be organized in such a way as to yield a similar but more generalized interpretation. Specifically, if the aggregates (Fig. 10) for which there are sufficient data are plotted separately, they appear to reflect a common trend (Fig. 13a and 13b) that can be stated as follows: The length of time required for any particular lightweight aggregate to attain its critical degree of saturation in concrete decreases at a decreasing rate as the level of saturation prior to mixing is increased above some minimum value. This minimum value is different for different lightweight aggregates. These minimum values for the exposure cited are approximately the following:

Aggregate	Value
C	0.24
D	0.46
E	0.47
R	0.40
S	0.27

In this sense, lightweight aggregates perform as do other aggregates; only the numbers are different.

The curves shown in Figure 13 also help to illustrate the fact that 0.25 is a conservative value (3 of the minimum values cited above exceed 0.25 by 60 to 80 percent) and, perhaps, very conservative for most uses of structural lightweight concrete, considering the severity of the ASTM C 290 exposure.

A second point that may be worth exploring is the feasibility of using degree of aggregate saturation under some standard conditions as a method of prejudging (that is, prior to mixing and testing in concrete) potential performance. Such a test could be useful in identifying at least (a) those lightweight aggregates with a very high probability of acceptable performance under any exposure, and (b) those with a high proba-

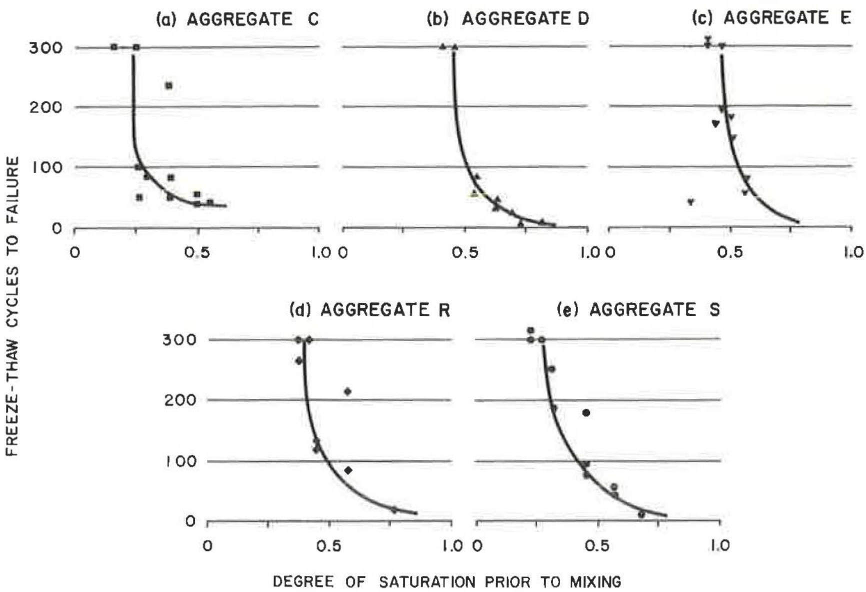

Figure 13. Experimental results for individual aggregates.

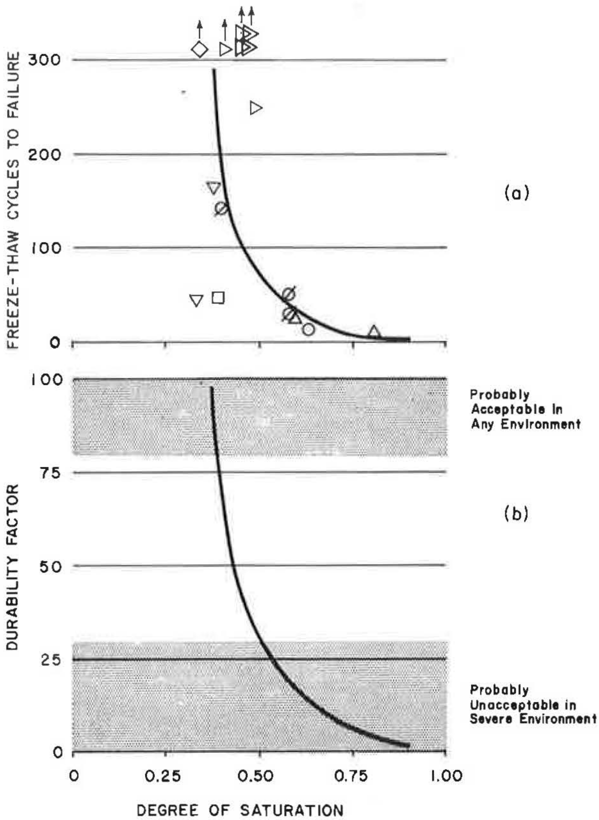

Figure 14. All aggregates after 14 days of immersion.

bility of failure under severe exposure. This is shown in Figure 14 in which the authors' data for 14 days of aggregate immersion are plotted.

If the apparent relationship described by the solid line in Figure 14a is valid (and this could be explored through a carefully designed experiment) and the ordinate were expressed in terms of durability factor (DF) as defined by ASTM C 290, there would then be a basis for making some absolute judgments about quality. For instance, Walker et al. (7) have suggested a DF ≥ 80 as indicating condition a, and a DF ≤ 30 as indicating condition b. Accordingly, it could be reasoned that a lightweight aggregate with a 14-day degree of saturation less than some particular value (about 0.38 in the schematic example of Figure 14b) would probably perform acceptably in any environment and one with a 14-day degree of saturation in excess of some other particular value (0.50 in the example) would probably fail in a severe environment.

Reference

7. Walker, R. D., et al. One Cycle Slow-Freeze Test for Evaluating Aggregate Performance in Frozen Concrete. NCHRP Rept. 65, 1969.

EUGENE BUTH and W. B. LEDBETTER, Closure—Mr. Chamberlin raises 2 points in his discussion. In considering the first point, the authors agree that the limiting value

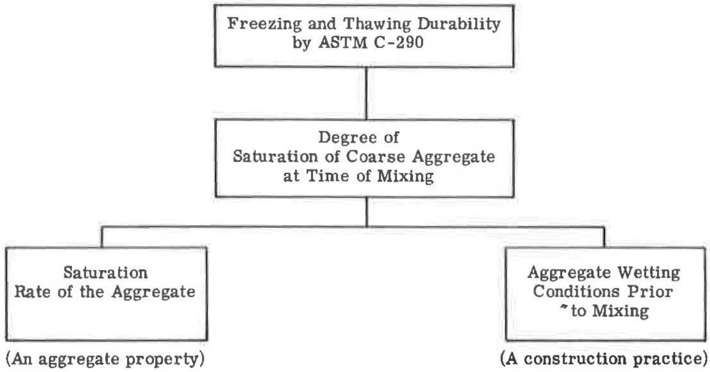

Figure 15. Parameters affecting degree of saturation of aggregates.

of degree of saturation of 0.25 is conservative for aggregates R, E, and D but not conservative for aggregates C and S. The value of 0.25 was chosen as a number applicable to all lightweight aggregates tested and must therefore be conservative for some.

Mr. Chamberlin's second point, concerning the feasibility of using aggregate degree of saturation under some standard conditions as a method of prejudging potential performance, warrants additional discussion. The test results indicate the minimum values of degree of saturation that Mr. Chamberlin states and correctly interprets. However, these values, which can be used to predict performance as determined by freezing and thawing durability, are a function of 2 parameters: the saturation rate of the aggregate (an aggregate property) and the length of time that water is available (a construction practice) to the aggregate (Fig. 15). By controlling the amount of pre-wetting time, any of the aggregates studied (and perhaps all lightweight aggregates) can be conditioned to have a degree of saturation that is less than the minimum values stated. The test results show that, when the degrees of saturation are below these minimum values, the concrete proved to be durable even in the severe exposure of ASTM C 290.

The authors are therefore forced to conclude that the use of degree of saturation under standard conditions as a method of prejudging performance is a slight oversimplification in that it does not account for the influence of amount of prewetting that will take place on the job.