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16. ABSTRACT

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Using aggregate samples from a single pit, it was found that in mixing mortar or concrete to a given consistency the quantity of water increased as the sand equivalent decreased. In both mortar and concrete the compressive strength was related inversely and the drying shrinkage directly, to the water-cement ratio. The sand equivalent, therefore, measured the quality of the sand in both respects.

As a result of tests of 248 samples of sand from 142 sources in California it was found that a high degree of correlation exists between the drying shrinkage of Portland cement mortar and the sand equivalent of the constituent sand. Departures from the general equation expressing the relationship evidently are connected with the degree of compressibility of the sand particles and more specifically in this investigation were found to be related to the porosity as measured by the absorption test.

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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

A report on

THE SAND EQUIVALENT TEST

AS A MEASURE OF

THE QUALITY OF CONCRETE SAND

State of California
Department of Public Works
Division of Highways
Materials and Research Department

August 1, 1955

Lab. W. O. 5004-S-51

Mr. E. Withycombe
Assistant State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is:

A report on

THE SAND EQUIVALENT TEST

AS A MEASURE OF

THE QUALITY OF CONCRETE SAND

Study made by .... Technical Section
Under general direction of .... Bailey Tremper
Report prepared by .... Bailey Tremper and W. E. Haskell

Very truly yours,

F. N. Hveem
Materials and Research Engineer

cc: Dept. Heads
District Engineers
District Materials Engineers

THE SAND EQUIVALENT TEST AS A MEASURE OF THE QUALITY OF CONCRETE SAND

SYNOPSIS

The sand equivalent test was developed in the Materials and Research Department as a measure of the quantity and activity of clay-like fractions in aggregates. Lower numerical values of "sand equivalent" indicate higher amounts or higher activity of clay-like fractions.

Using aggregate samples from a single pit, it was found that in mixing mortar or concrete to a given consistency the quantity of water increased as the sand equivalent decreased. In both mortar and concrete the compressive strength was related inversely and the drying shrinkage directly, to the water-cement ratio. The sand equivalent, therefore, measured the quality of the sand in both respects.

As a result of tests of 248 samples of sand from 142 sources in California, it was found that a high degree of correlation exists between the drying shrinkage of portland cement mortar and the sand equivalent of the constituent sand. Departures from the general equation expressing the relationship evidently are connected with the degree of compressibility of the sand particles and more specifically in this investigation were found to be related to the porosity as measured by the absorption test.

The relationship between drying shrinkage and sand equivalent and absorption can be expressed by an equation of the form:

$$Y = aX_1 + bX_2 + c$$

Values of the coefficients and the constant are given in the following text.

In general, sources of sand that produce high drying shrinkage with respect to sand equivalent are located in Northern California.

The limitation on minimum sand equivalent of concrete sand in the Standard Specifications serves a useful purpose in improving the quality of mortar and concrete. A further improvement would result from a limitation on maximum absorption.

INTRODUCTION

The sand equivalent test was first developed in the Materials and Research Department as a rapid method, suitable for both field and laboratory use, of indicating the amount and activity of clay-like fractions in base and subbase materials (Reference 1). Its successful use for this purpose led to a study of the test in connection with fine aggregates for bituminous mixtures and other purposes. This report deals with the significance of the test with respect to the quality of fine aggregate for portland cement concrete.

It has long been the practice to restrict the percentage of silt and clay in concrete sands by means of a limitation on the maximum percentage passing the No. 200 or No. 270 sieve by wet sieving. The procedure is frequently referred to locally as "wash grading". Objections to the test are the difficulty in determining the end point in washing and the elapsed time required in completing the test due to the necessity of oven-drying the test sample to constant weight both before and after washing through the sieve. The No. 270 sieve, and to a lesser extent the No. 200 sieve, is impractical for field use because of its cost and fragile nature. A further objection, for specification purposes, lies in the fact that in order to admit the inevitable fraction of fine particles such as rock dust or inert particles just smaller than the test sieve, percentage tolerances must be set so high as to impair the quality of the sand seriously if the particles are of the nature of clay.

The sand equivalent test has the advantage over the wash grading test of using simple, less fragile equipment and requiring a much shorter elapsed time for completion together with its ability to furnish a measure or index of both the quantity and activity of clay-like materials that may be present, usually as a coating on the sand grains.

Sand equivalent tests of sands for concrete were adopted as routine procedure in the laboratory of the Division of Highways in January, 1954. Sufficient data were obtained in a few months to indicate a practical minimum value from the standpoint of the ability of producers to manufacture material to meet the requirement. As a result of this information and preliminary data relating to the quality of the product, the Standard Specifications dated August, 1954 contain a requirement that the sand equivalent of fine aggregate for portland cement concrete shall not be less than 80. The method of test for sand equivalent is published as Test Method No. Calif. 217 of the Materials and Research Department.

SCOPE OF TESTS

The data used in this report consist of sand equivalent, drying shrinkage and compressive strength tests of mortar and concrete made with sands from a single source and sand equivalent, absorption and drying shrinkage tests of mortars made with sands from 142 sources.

TEST PROCEDURES

Although following substantially the procedure set forth in Test Method No. Calif. 217-A, a great many of the values reported for sand equivalent were the result of single tests only. It is now recognized that the test for materials of high sand equivalent is not highly reproducible* and the standard method for concrete sands now requires that at least three tests be averaged to determine the result.

Details of making the drying shrinkage test of mortars are given in the appendix. Briefly the test bars, after moist-curing for 7 days are stored in an oven which is maintained at

*When sand equivalent results are high, it means that only a very small amount of clay is present and such things as temperature, soluble salts, etc. can noticeably affect the rate of settling or flocculation.

100° F. and 70 per cent relative humidity. The change in length is measured after 7, 14 and 28 days of drying. A storage temperature of 100° F. was adopted because it was the lowest temperature at which available equipment could be made to operate with any degree of constancy. Even at this temperature there are times during the summer months when it is doubtful that conditions of temperature and humidity are controlled within desirable tolerances. Under well controlled oven conditions, the increase in shrinkage is found to be proportional to the logarithm of drying time up to at least 28 days. In a few of the tests included in this study the observed shrinkage departed measurably from the logarithmic relationship with drying time.

It is known that the composition of the cement can affect drying shrinkage. The cement used during this period of tests was of the same brand but from several lots. Control tests of the test cement and graded Ottawa sand were made at frequent intervals. The results were so nearly constant that it is concluded that the effect of the cement could be dismissed as a factor in variations in the test results reported here.

Tests for compressive strength of mortars were made in accordance with Test Method No. Calif. 515-A. The compressive strength of concrete was determined in accordance with standard ASTM methods. Drying shrinkage tests of concrete were similar to those described in the appendix for mortar except that the test specimens were 3" x 3" x 10" effective gage length.

Part of the original data leading to the inclusion of the sand equivalent requirement in the Standard Specifications were obtained from samples of aggregate from a pit in Alameda County. Samples of pit-run, partially processed and commercially processed materials were secured from this pit. By thorough scrubbing of the latter sample and by blending parts of the first two samples, five lots of sand were prepared in which the sand equivalent varied from 18 to 95. Tests for drying shrinkage and compressive strength of mortars were made on these sands. Three of the sands in combination with the corresponding thoroughly sieved coarse aggregate were made into concrete and tested for compressive strength and drying shrinkage.

The results of these tests are shown diagramatically in Figures 1 to 4 inclusive.

Figure 1 shows that the mixing water required for a given consistency increases with decreasing sand equivalent. A sharp increase is indicated for the mortar as the sand equivalent decreases from 24 to 18.

Figure 2 shows that the logarithm of compressive strength is inversely proportional to the water-cement ratio and thus conforms to the water-cement ratio law. This figure also shows that the logarithm of drying shrinkage is directly proportional to the water-cement ratio.

Figure 3 shows that compressive strength is directly proportional to sand equivalent, except possibly for sand equivalents less than about 20.

Figure 4 shows that drying shrinkage increases with decreasing sand equivalent. The indicated relationship is curvilinear with a sharp increase between sand equivalents of 24 and 18 which is a reflection of the sharp increase in water requirement found between these two values.

Starting in January, 1954 and continuing into 1955, each sample of concrete sand received in the laboratory has been made into mortar and molded into three 1" x 1" x 11¼" bars upon which drying shrinkage has been determined.

At the present time there are available for study and statistical analysis the results of sand equivalent and drying shrinkage tests of 248 samples from 142 sources in California including a few from nearby locations in Nevada and Arizona.

At the time the test program was started the sand equivalent requirement was not included in the specifications for concrete sand. Many of the routine samples of sand had sand equivalents less than the presently specified value of 80 with the result that there was a substantial proportion of sands in the range of 60 to 80.

It was desired to express the drying shrinkage as a single value with respect to time of drying. After considerable study it was concluded that the 14-day value was slightly more dependable than those obtained at 7 or 28 days. Accordingly all values of drying shrinkage, except where otherwise noted in this report, are those of linear shrinkage after 14 days of drying, expressed as a percentage of the length at the end of the 7-day moist curing period.

Figure 5 is a histogram of the percentage frequency and drying shrinkage of mortars in class intervals of 0.010 per cent for individual samples. It will be noted that shrinkage of the majority of the samples was within the range of 0.08 to 0.12 per cent.

Figure 6 is a scatter diagram of the correlation between sand equivalent and drying shrinkage considering each sample separately. The regression line for the data of this figure

was computed by the product moment method for grouped data. The equation of the curve is

$$S_{14} = 0.0024 \ (100 - SE) + 0.0588 \pm 0.0168 \qquad (1)$$

in which S_{14} = per cent drying shrinkage after 14 days

SE = sand equivalent

The constant, 0.0588, is the theoretical drying shrinkage for a sand equivalent of 100.

The value, 0.0168, is the standard error of estimate (shown as dashed lines in Fig. 2). It is the standard deviation about a line of average relationships and is a measure of the accuracy of the estimate.

The coefficient of correlation between sand equivalent and drying shrinkage is 0.66, a value indicative of rather high correlation.

Equation (1) indicates that the drying shrinkage attributable to a change in sand equivalent of 24 is as great as that contributed to the mortar by the cement paste itself. The shrinkage resulting from a sand equivalent of 60 is double that resulting from a sand equivalent of 92.

Shrinkage of concrete during drying is an important factor in the performance of pavements and structures. It is of particular significance in prestressed concrete. The importance of controlling sand equivalent above a reasonable minimum is clearly apparent.

During the course of the investigation samples from some of the sources were received and tested from two to six times. In some cases it was found that the results of one sample were "wild", that is, the departure from the general equation was relatively great whereas the remainder of the samples from that source conformed quite closely. The average results for those sources for which several samples were available can be accepted with greater confidence.

Figure 7 is a plot in which average results of each source are shown. Single samples are indicated by open circles. The average results of two or more samples are shown by solid dots. It will be noted that the majority of points that fall outside of the dashed lines, indicating the standard error of estimate, represent single tests only. It may be assumed that had tests from multiple samples been available for these sources some of the results would have conformed more nearly to equation (1).

There are, nevertheless, several sands on which tests of repeat samples are available for which the drying shrinkage departs from equation (1) by more than the standard error of estimate. Many of these are related to each other by geographical proximity of the pit locations and the departures may be related to the mineral composition of the sand grains.

In general, those sources yielding sand of high drying shrinkage with respect to sand equivalent are located in Northern California. Examples of such pits are listed below by county and geological province. The extent of departure in drying shrinkage from equation (1) is shown in percentage points.

Del Norte and Humboldt Counties
Northern Coast Range Province

Pit	No. of Samples	Departure
A	1	+0.023
B	1	+0.046
C	1	+0.013
D	2	+0.010
E	3	+0.037
F	1	-0.006

Lake and Sonoma Counties
Northern Coast Range Province

Pit	No. of Samples	Departure
A	1	+0.045
B	1	+0.033
C	2	+0.027
D	1	+0.006
E	6	+0.005
F	2	+0.044

Santa Clara and San Benito Counties
Southern Coast Range Province

Pit	No. of Samples	Departure
A	2	+0.030
B	1	+0.049
C	1	+0.021

Shasta County, Vicinity of Redding
Great Valley Province, Northern End

Pit	No. of Samples	Departure
A	1	+0.020
B	1	+0.010
C	3	-0.002
D	1	+0.021

Merced and Kings Counties
Great Valley Province,
West Side Southern End

Pit	No. of Samples	Departure
A	2	+0.021
B	4	+0.013
C	2	+0.026

Modoc, Lassen and Plumas Counties
Modoc Lava Plain Province

Pit	No. of Samples	Departure
A	1	+0.025
B	2	+0.015
C	1	+0.045
D	2	-0.006

On the other hand, in one important area for which a considerable number of tests are available the drying shrinkage tends to be less than that indicated by equation (1). The results follow:

Alameda County
Southern Coast Range Province

Pit	No. of Samples	Departure
A	1	+0.016
B	6	-0.011
C	4	-0.016
D	4	-0.012
E	4	-0.022
F	1	-0.004

Degrees [illegible]

[illegible]

[illegible] Counties [illegible]
[illegible] Valley Province [illegible]
[illegible] Side [illegible]

[illegible] Degrees [illegible]

[illegible]

[illegible] Plumas County [illegible]
[illegible] Province

[illegible] Degrees [illegible]

[illegible]

[illegible] are available for these stations [illegible] (1) [illegible]

[illegible] County [illegible]
[illegible] Coast Range Province

[illegible] Degrees [illegible]

[illegible]

Other pits for which the mortar shrinkage evidently is low with respect to the sand equivalent are:

(1) A pit near Maricopa in Kern County. Departure, -0.023 (average of 3 samples).

(2) A pit near Blythe in Riverside County. Departure, -0.025 (average of 2 samples).

(3) A pit near East Highline Canal in Imperial County. Departure -0.025 (average of 3 samples).

DISCUSSION

The effect of the rock types or minerals in aggregates on drying shrinkage has been discussed by R. W. Carlson (Reference 2) who concluded that the cement paste in attempting to shrink introduced compressive stresses into the aggregate particles and that the relative rigidity or compressibility of the aggregate was a factor in the restraint of shrinkage. He states:

> "Among the pure mineral aggregates that have been tested, hornblende and pyroxene are notable in producing high shrinkage. On the other hand, quartz, feldspar, dolomite and limestone are outstanding in producing concrete of low shrinkage.
>
> "Among the aggregates of mixed composition, sandstone and slate produce concrete of high shrinkage while a dense grade of granite produces concrete of less than average shrinkage.
>
> "The relative compressibility of aggregate appears to be the most important factor causing different aggregates to produce concretes of different shrinkage."

It should be understood that Carlson was referring to characteristics of the aggregates *per se* and did not consider the effects of contaminants such as clay and silt which are determined by the sand equivalent method. Carlson's results thus offer a reasonable explanation of the causes leading to departures from average behavior of sands produced in certain areas within the State.

In Reference 2 and also in an earlier paper (Reference 3), Carlson found that among the relatively few aggregates tested, drying shrinkage increased with the percentage of absorption as determined by the standard test method. This finding is borne out by the results of our study. Twenty pits for which the shrinkage exceeded that of equation (1) by 0.017 percentage points or more, with one exception, had absorptions between 1.8 and 4.7 per cent with an average value of 2.6 per cent. On the other hand 16 pits for which the expansion was less than equation (1) by 0.017 percentage points or more had absorptions between 0.8 and 1.8 per cent and averaged 1.2 per cent. It should be noted however, that among the sands tested, three having absorptions of 3.5, 4.6 and 5.5 per cent respectively all produced mortars having drying shrinkage close to or less than that indicated by equation (1). These sands all originated in the northeastern corner of the state. Although petrographic data are not available, it is probable that the porosity is due to the vesicular character of lava that is common to this region. In this connection, Richart and Keranen (Reference 4) reported that haydite produced less drying shrinkage than normal sand and gravel at early ages although it eventually equalled and finally exceeded that of sand and gravel.

The above discussion strongly suggests that a relationship exists between absorption (i.e., presence of pores) and drying shrinkage. Using the data of the tests it was found that the relationship can be expressed by equation (2) as given below. For purposes of comparison, equation (1) is also shown.

$$S_{14} = 0.0024\ (100 - SE) + 0.0588 \qquad (1)$$

$$S_{14} = 0.0198\ A + 0.0723 \qquad (2)$$

where A = per cent absorption of the sand

The combined relationship between sand equivalent and absorption and drying shrinkage has been computed and is as follows:

$$S_{14} = 0.0013\ (100 - SE) + 0.0155\ A + 0.0561 \qquad (3)$$

The correlation and relative accuracy of the three equations may be summarized as follows:

Equation Number	Variables	Coefficient of Correlation	Standard Error of Estimate
(1)	SE	0.66	0.0168
(2)	Absorption	0.65	0.0516
(3)	SE and Absorption	0.83	0.0121

Good correlation exists between drying shrinkage and both sand equivalent and absorption taken individually, however the standard error of estimate is high for absorption. The multiple correlation between drying shrinkage and sand equivalent and absorption together is very high. The standard error of estimate of the multiple correlation is considerably lower than for either function taken separately.

These results demonstrate that a maximum limitation on absorption, together with a minimum limitation on sand equivalent, would result in lower shrinkage than is obtainable by the sand equivalent requirement alone.

The sand equivalent value of an aggregate can be improved by manufacturing processes but reduction of absorption of an aggregate from a given pit would be difficult, if not impractical, to accomplish. A specification that limited the absorption to a maximum of, say 3 per cent, would virtually eliminate some pits as potential sources. Some of the eliminated sources would be those that produce undesirably high shrinkage but others would be those that produce normal shrinkage.

CONCLUSIONS

The sand equivalent test is a useful measure of the properties of fine aggregate that affect the quality of mortar and concrete.

The water-cement ratio required in mortar or concrete of a given consistency increases as the sand equivalent decreases. As a result the compressive strength is decreased and the drying shrinkage is increased as the sand equivalent becomes lower.

The drying shrinkage of mortars made with the majority of California sands can be expressed by a linear equation of the following form:

$$S = a(100 - SE) + c$$

where S = drying shrinkage in per cent

SE = sand equivalent

a = a coefficient varying with the conditions of test and age of test

c = a constant

For the remainder of the sands tested an adjustment in the value of "c" is required depending on the compressibility of the aggregate particles. The compressibility evidently is related to the porosity as measured by the absorption test. The value of "c" is greater for aggregates of high absorption and lower for those of low absorption.

For all sands investigated, the multiple relationship between drying shrinkage and sand equivalent and absorption can be expressed by a linear equation of the form:

$$S = a(100 - SE) + bA + c$$

where A = per cent absorption of the sand and the remaining symbols represent the factors given before.

The minimum value of 80 for sand equivalent of concrete sands in the standard specifications requires more thorough washing during manufacture than did the previous limitation by the wash grading test but results in a definite improvement in the quality of mortar and concrete.

A requirement for maximum absorption would eliminate a number of sands the quality of which cannot be controlled effectively by the sand equivalent test alone. Such a requirement, however, would also eliminate a few sands of normal shrinkage characteristics.

Serious consideration will need to be given to the economic effect of virtually eliminating certain sources of supply before adopting a restriction on maximum absorption of mineral aggregates for concrete.

REFERENCES

1. "Sand Equivalent Test for Control of Materials During Construction" by F. N. Hveem, Proc. Highway Research Board, Vol. 32, p. 238 (1953)

2. "Drying Shrinkage of Concrete as Affected by Many Factors" by R. W. Carlson, Proc. ASTM, Vol. 38, Part II, p. 419 (1938)

3. "Chemistry and Physics of Concrete Shrinkage" by R. W. Carlson, Proc. ASTM, Vol. 35, Part II, p. 370 (1935)

4. "Shrinkage of Haydite and Sand-Gravel Concrete" by F. E. Richart and J. E. Keranen, Proc. ASTM, Vol. 36, Part I, p. 339 (1936)

APPENDIX

Drying Shrinkage Test

The standard or reference mix for the drying shrinkage test consists of 1 part (500 grams) of portland cement, and 2.75 parts (1375 grams) of graded Ottawa Sand. This mix is identical to the mix employed for the compressive strength test of portland cement, ASTM Designation: C 109-52. Sufficient water to produce a flow between 100 and 115 as determined according to the above specification is added to the materials, and the mixing is done by hand as directed by ASTM Designation: C 109-52. Three test specimens or bars are fabricated from each batch of mortar. The test specimens are 1 in. by 1 in. by 11-1/4 in. with an effective gage length of 10 inches.

The proportions of the materials used in the test mix are 500 grams of cement and an absolute volume of the saturated surface dry sand equal to the absolute volume of the graded Ottawa sand used in the reference mix. Sufficient water to produce a flow between 100 and 115 is added to the materials and three test specimens are fabricated, exactly as is done in fabricating the reference mix.

After fabrication, the specimens are stored in a moist room at 73.4 F. ± 3 F. for one day. They are then removed from the molds and cured in water at 73.4 F. ± 3 F. for six days.

At the end of the 7-day curing period the bars are measured and placed in an oven at a temperature of 100 F. ± 5 F., and a relative humidity of 70 per cent ± 5 per cent.

At the end of 7, 14 and 28 days in the oven, the bars are removed and measured for length, after cooling to room temperature for 6 hours in a closed container over a saturated solution of sodium dichromate (which produces a relative humidity of approximately 50 per cent). The measurements are performed as rapidly as possible in a room at a temperature of about 74 F. ± 3 F. All measurements are made in a comparator reading to 0.0001 inch.

The average length change of the three specimens is taken as the length change of the sample. The variation between three specimens of the same mix is almost invariably small.

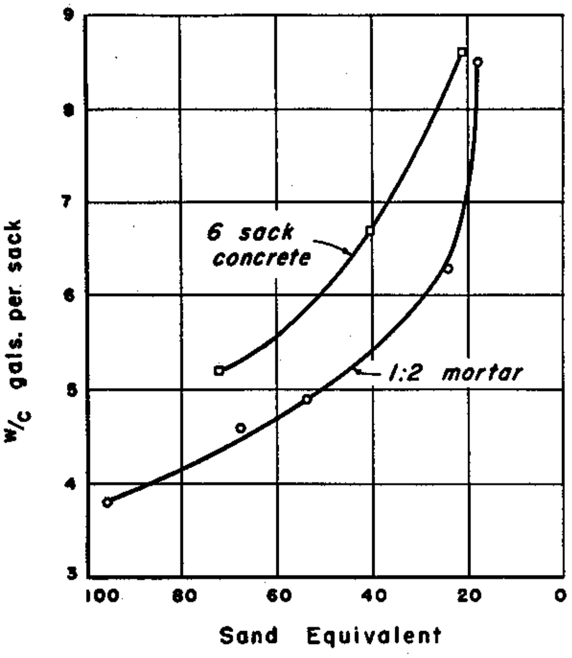


Fig. 1

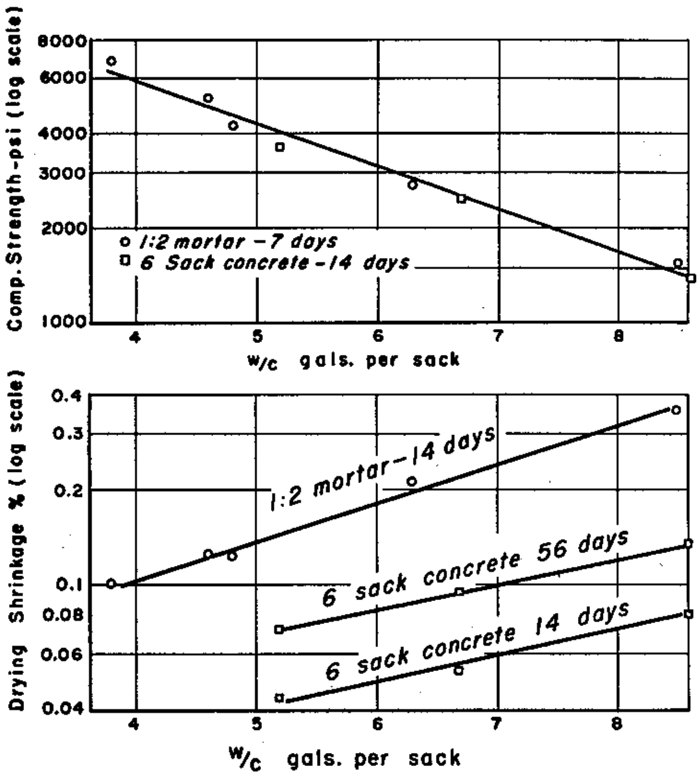


Fig. 2

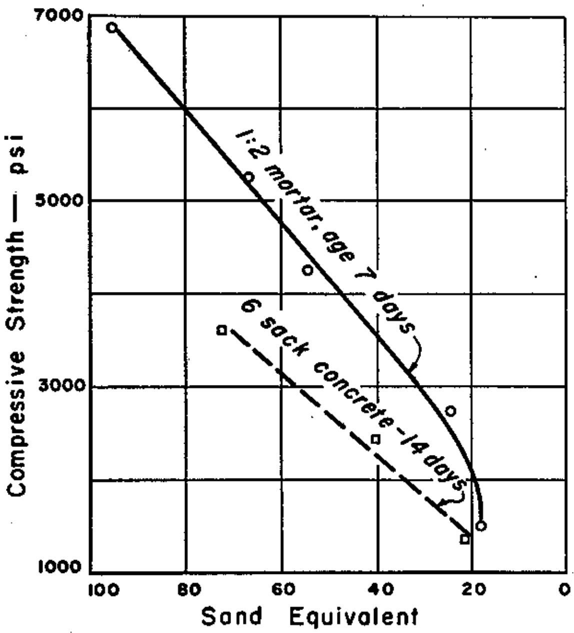


Fig. 3

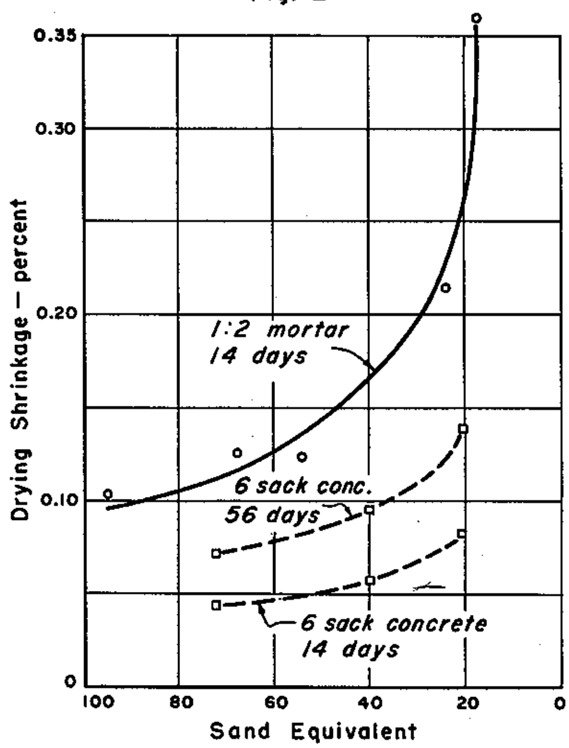
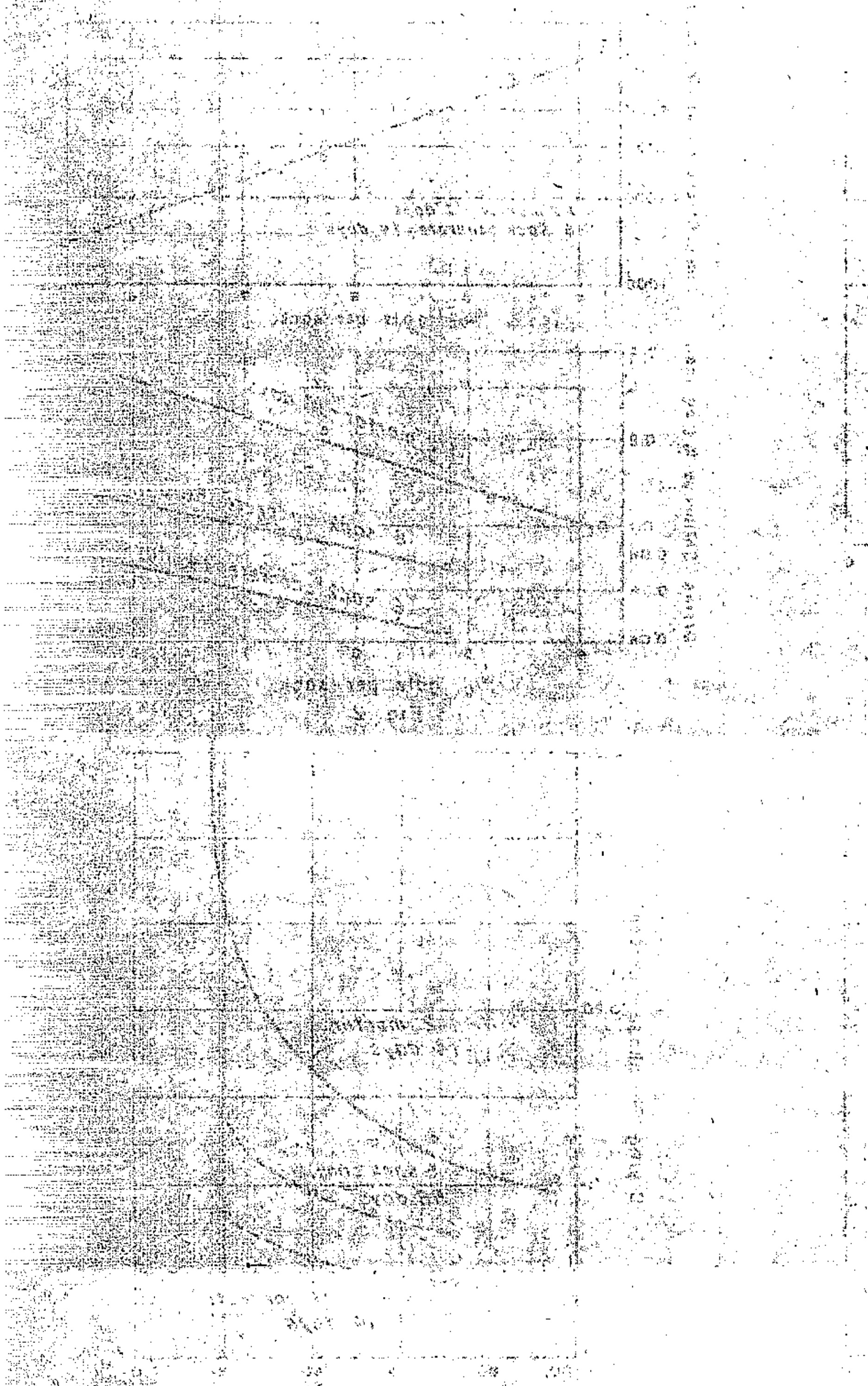


Fig.4

Relationships between Sand Equivalent, Water-Cement Ratio, compressive strength and drying shrinkage of mortar and concrete for sand from one pit



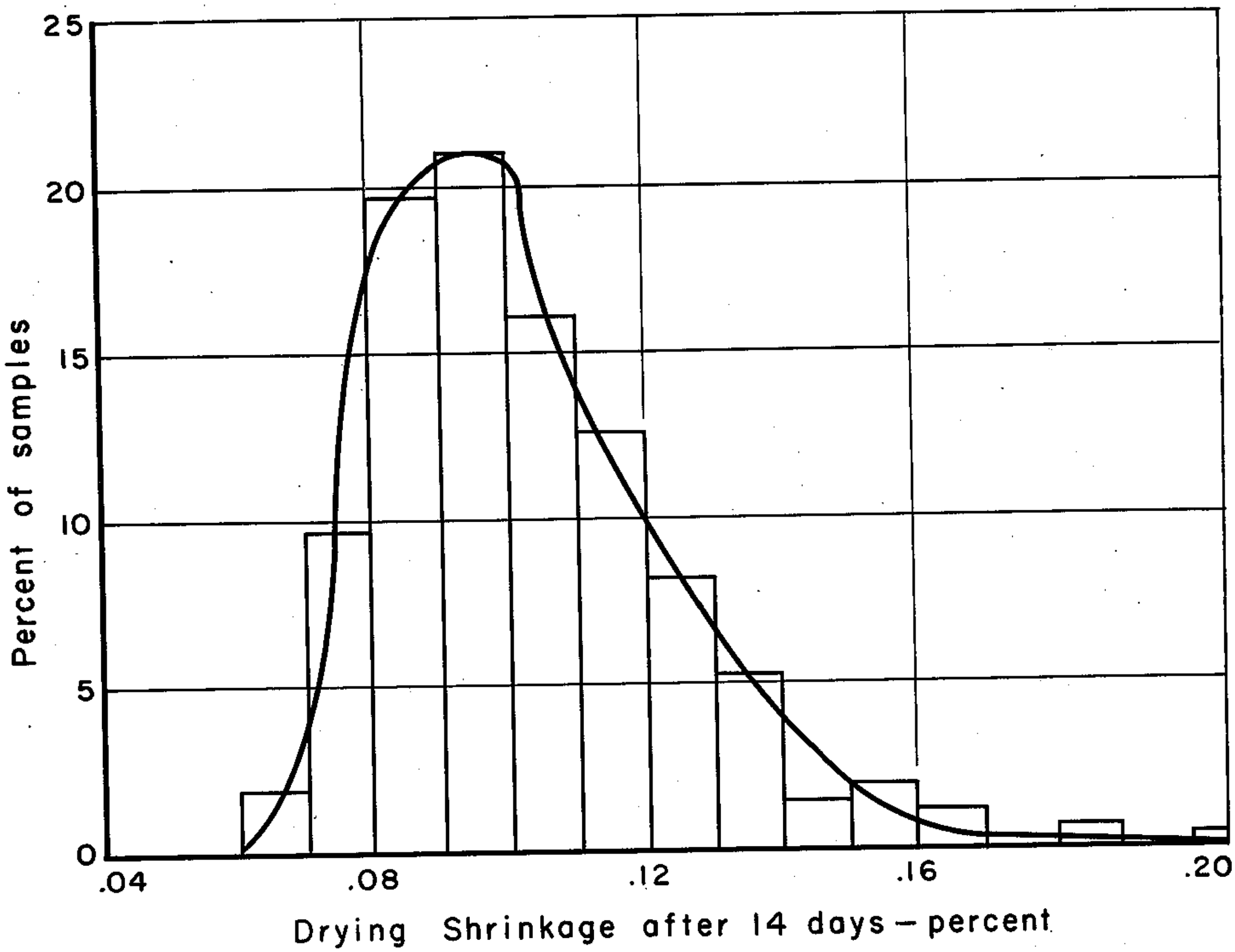
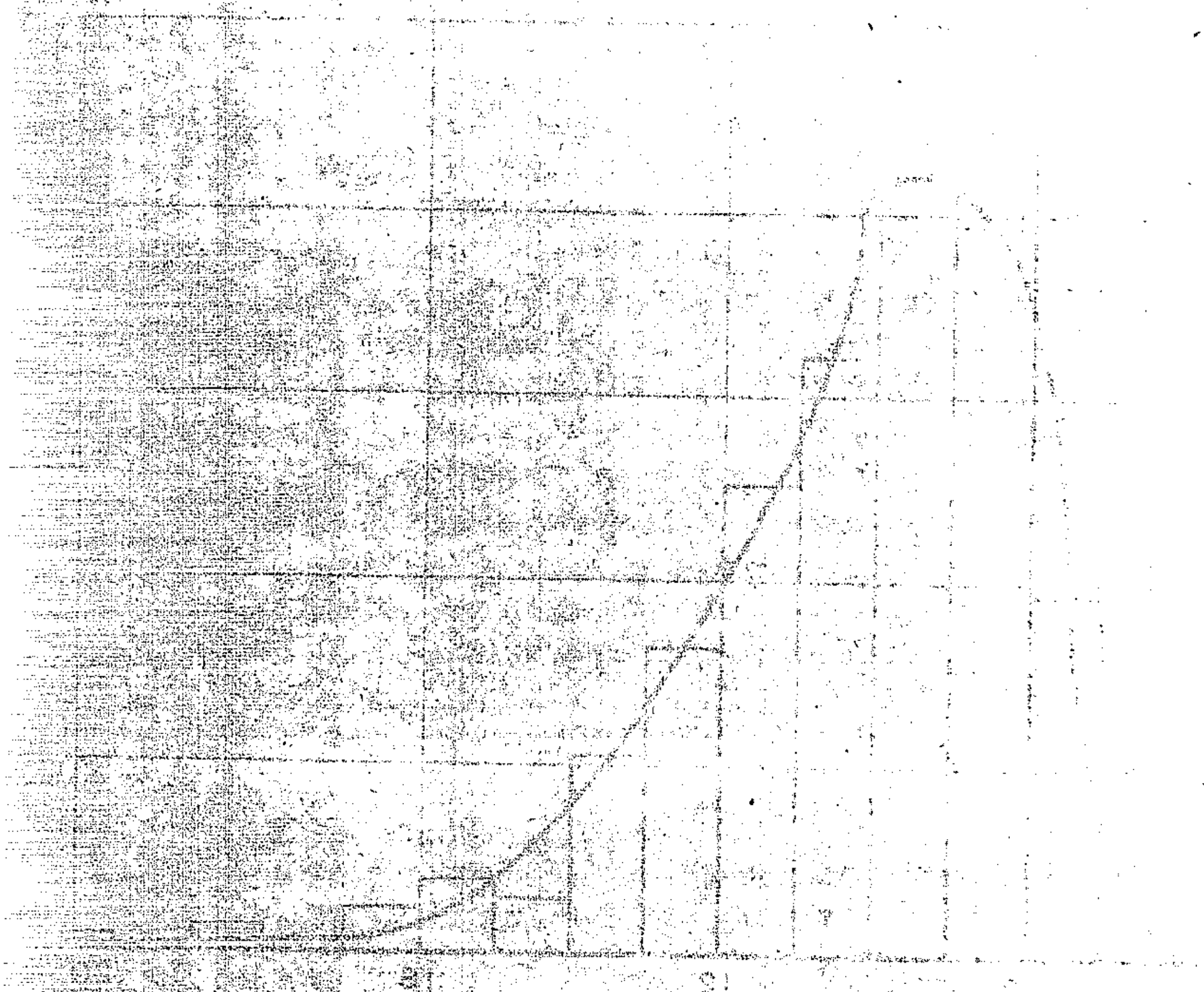


Fig. 5

Distribution of Samples
according to
Drying Shrinkage



... phase after 10 days in percent

Fig. 5

Distribution of Samples
according to ...

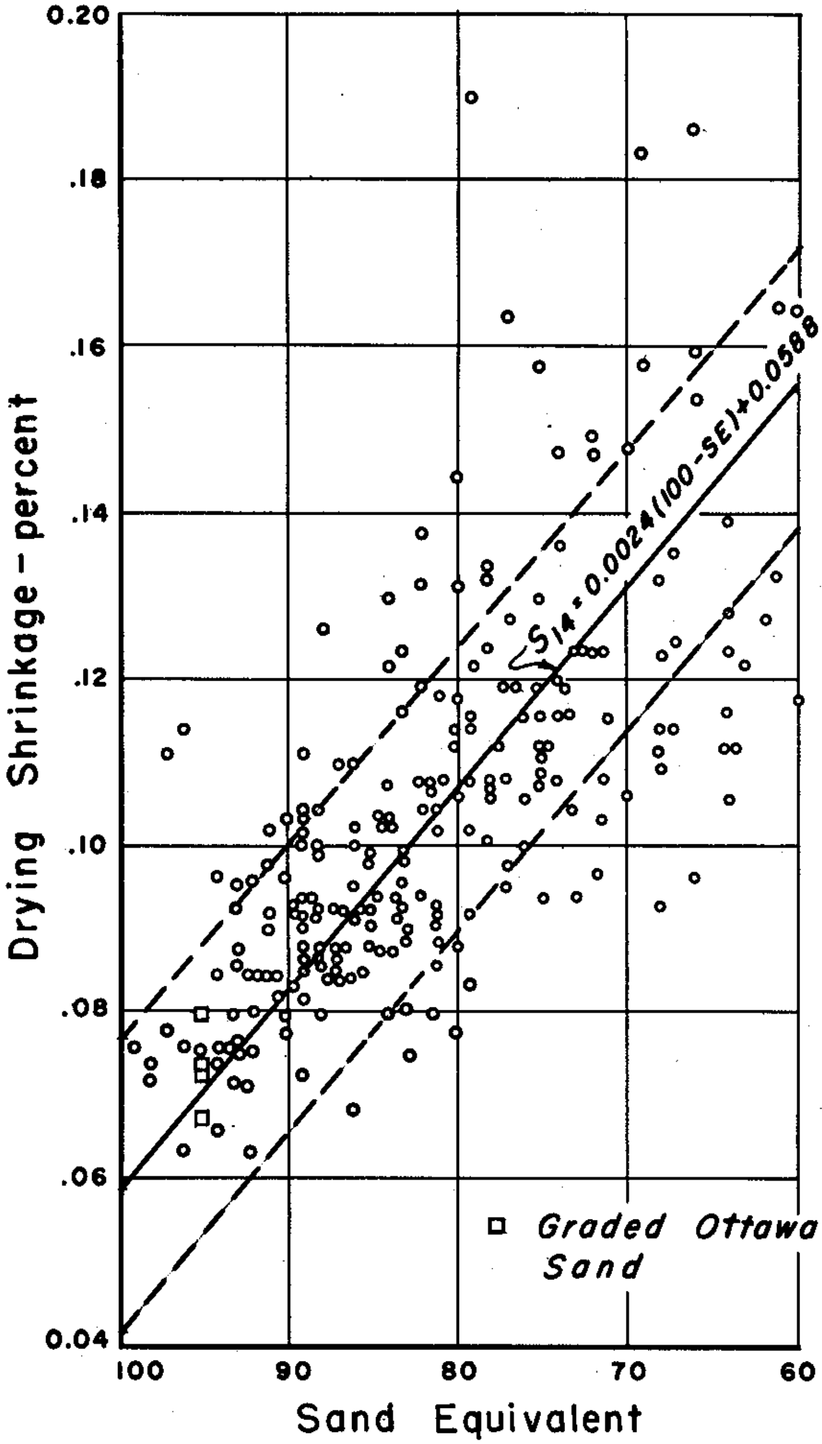


Fig. 6

Relationship between Sand Equivalent and Drying Shrinkage of Mortar

(Individual Samples)

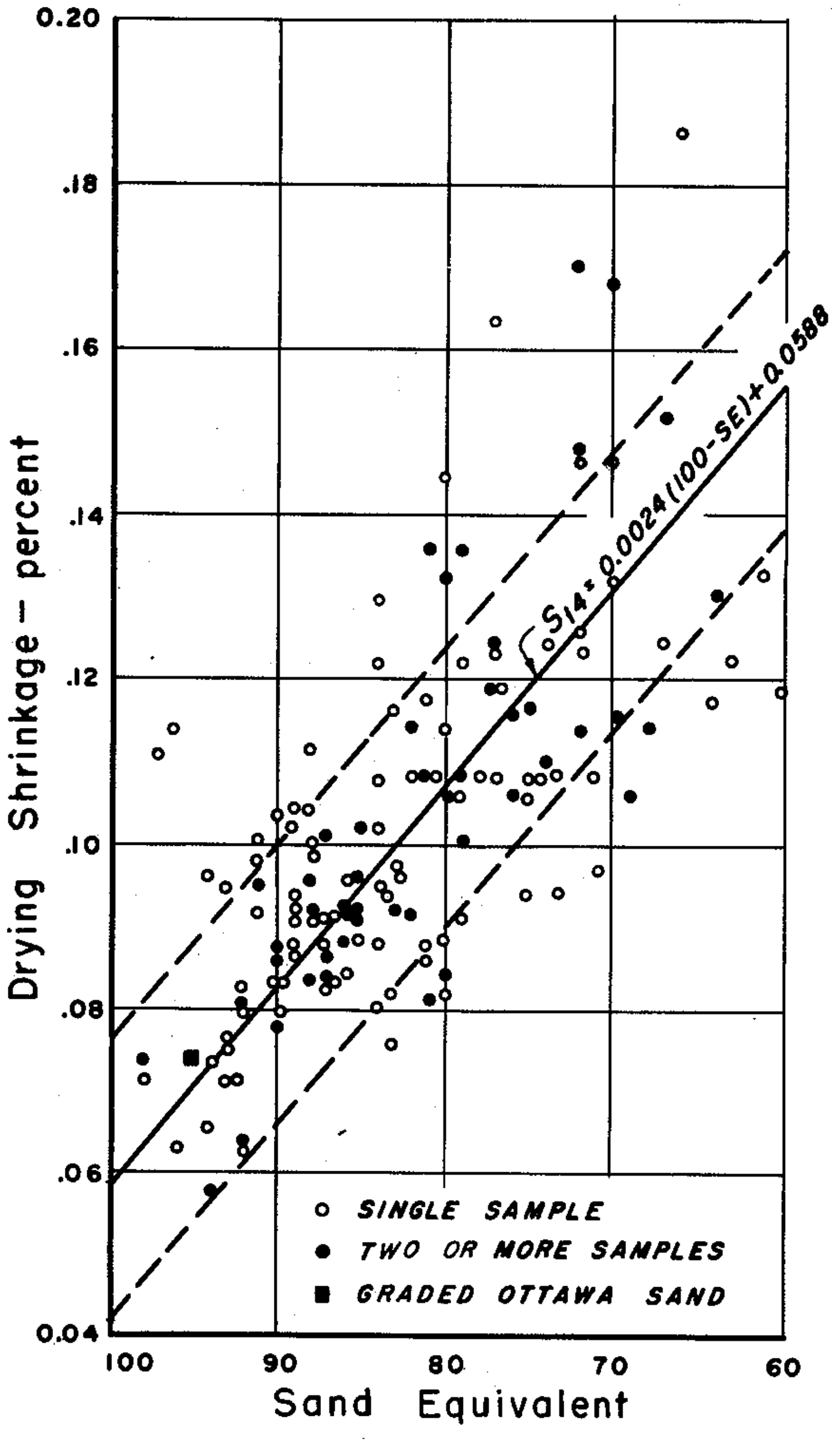


Fig. 7

Relationship between Sand Equivalent and Drying Shrinkage of Mortar

(Pit Averages)