TECHNICAL MEMORANDUM NO. 6-368

TESTS FOR CHEMICAL REACTIVITY BETWEEN ALKALIES AND AGGREGATE

Report 3

FURTHER INVESTIGATION OF THE MORTAR-BAR TEST

by

B. J. Houston

October 1967

Sponsored by

Office, Chief of Engineers
U. S. Army

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ARMY-MRC VICKSBURG, MISS.

FOREWORD

This investigation was authorized by the Office, Chief of Engineers, by first indorsement, dated 25 August 1964, to letter, dated 11 August 1964, subject, "Project Plan for Alkali-Aggregate Reaction - Investigation of Mortar Bar Test," from the U. S. Army Engineer Waterways Experiment Station (WES), and forms a part of Item 603 of the Civil Works Engineering Studies Program.

The work was conducted at WES under the direction of Messrs. Thomas B. Kennedy, B. Mather, James M. Polatty, R. L. Curry, and Mrs. K. Mather, by Mr. Billy J. Houston, who prepared this report. Mr. L. Pepper advised in the statistical analysis of the data.

Directors of WES during the investigations, preparation, and publication of this report were COL Alex G. Sutton, Jr., CE, and COL John R. Oswalt, Jr., CE. Mr. J. B. Tiffany was Technical Director.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	25.4	millimeters
pounds per square inch	0.070307	kilograms per square centimeter

SUMMARY

This report gives the results of an investigation to determine the effect of the differences between the Corps of Engineers mortar-bar method (CRD-C 123) and American Society for Testing Materials mortar-bar method (ASTM C 227) for determining alkali-aggregate reactivity.

The principal differences between the methods are (a) the grading of the aggregate used in the mortar, (b) the age of the bars when the initial measurement is taken, and (c) the number of times the bars are measured. The ASTM grading has slightly less particle surface area than the CRD grading and has 15 percent more material larger than the No. 16 screen. The ASTM method specifies that the test bars be stripped and measured initially at 24 ± 2 hr age and that subsequent measurements be made at 1, 2, 3, 6, 9, and 12 months; the CRD bars are measured initially at 44 ± 4 hr and then at 8 and 28 days age, and at 28-day intervals thereafter until the bars are 1 yr old.

Test bars were made using both a high- and a medium-alkali cement, each in combination with Pyrex glass, a reactive natural silica sand, and a nonreactive natural silica sand. Each of the six cement-aggregate combinations was tested using the (a) CRD grading and measuring sequence with initial measurements made at both 24 ± 2 hr and 44 ± 4 hr age and (b) ASTM grading and measuring sequence with initial measurements made at both 24 ± 2 hr and 44 ± 4 hr age. In addition, blotting paper liners were placed in the plastic exposure containers, extending through the 1 in. of water at the bottom of the containers, when the bars were removed for the 6-month measurements to increase the area from which water vapor could escape into the container. This was done because it was suspected that the air surrounding the bars in the containers was not of the desired relative humidity.

The results indicate the following:

<u>a</u>. There was a significant difference, in some cases, between the 1-yr expansions of mortar bars containing ASTM graded reactive aggregates that were measured according to the ASTM specified measuring sequence and bars containing CRD graded aggregates that were measured according to the CRD specified measuring sequence. Where there was a significant difference, the ASTM bars expanded more than the CRD bars.

b. There was no significant difference in the 1-yr expansions of mortar bars measured initially at 24 ± 2 hr and those measured at 44 ± 4 hr age.

c. Subsequent measurement of bars after absorptive liners were placed in the exposure containers showed an abrupt increase in expansion of the bars in most cases. It is evident that the air surrounding the bars is not always of the desired relative humidity when bars are exposed in plastic containers of the type prescribed in method CRD-C 123.

It is recommended that CRD-C 123 be revised to conform to ASTM C 227, and that absorptive liners be placed in all containers where the relative humidity inside the container is questionable.

TEST FOR CHEMICAL REACTIVITY BETWEEN ALKALIES AND AGGREGATE

FURTHER INVESTIGATION OF THE MORTAR-BAR TEST

PART I: INTRODUCTION

Background

1. A proposal was made in January 1964 to revise U. S. Army Corps of Engineers Methods CRD-C 123 and CRD-C 128[1] for mortar-bar and quick-chemical tests, respectively, for determining alkali-aggregate reaction so that they would agree with the comparable American Society for Testing and Materials (ASTM) Methods C 227 and C 289.[2] (The ASTM methods had been revised prior to 1964 to bring them into relatively close agreement with the CRD methods* and to include certain desirable features not in the CRD methods.) This proposal was discussed at a conference held at the U. S. Army Engineer Waterways Experiment Station in February 1964 and it was concluded that the mortar-bar test should be modified first, and then the quick-chemical test should be revised. It was also concluded that a study should be made to determine the effects of the differences in the ASTM and CRD mortar-bar test methods before consideration was given to changing the CRD method. The differences between these methods are (a) differences in grading of the aggregate used in fabricating the bars, (b) differences in age of the bars when the initial measurements are taken, (c) differences in number of times the bars are measured, and (d) number of specimens tested.

Differences Between CRD and ASTM Test Methods

Aggregate gradings

2. CRD-C 123. The aggregate grading initially proposed for

* The CRD methods were established, in principle, by the studies reported in Reports 1 and 2 of this series.[3,4]

CRD-C 123 was one suggested by the Bureau of Reclamation, but this grading was never adopted officially by the Corps of Engineers. In August 1947 a grading suggested by the U. S. Army Engineer District, Omaha, was adopted. This grading was designed to closely approximate the fine aggregate grading then being used in concrete mixtures for Corps of Engineers structures. In 1958 the Omaha District grading was modified to that shown in the fourth column of the tabulation below. The primary reason for this modification was to eliminate the material finer than the No. 100 sieve as there was strong evidence that the fine reactive material functioned as an effective pozzolan and reduced expansion due to the alkali-silica reaction. This is the grading currently specified in CRD-C 123. The development of the aggregate gradings specified in CRD-C 123 is shown below.

Sieve Sizes	Percent, by Weight, Retained on Sieve		
	As Suggested by Bureau of Reclamation	As Suggested by Omaha District 1947-1958*	As Modified 1958 to Date
3/8-in.** to No. 4	0	2.5	2
No. 4 to No. 8	19	7.5	8
No. 8 to No. 16	19	10.0	10
No. 16 to No. 30	19	35.0	37
No. 30 to No. 50	19	30.5	32
No. 50 to No. 100	19	11.0	11
Passing No. 100	5	3.5	0

* Used in studies reported in Report 2 of this series.

** A table of factors for converting British units of measurement to metric units is presented on page ix.

3. ASTM C 227. The aggregate grading initially specified in ASTM C 227 was that shown in the third column of the tabulation below. In 1960 this grading was modified to that shown in the fourth column.

Sieve Size		Percent, by Weight, Retained on Sieve	
Passing	Retained on	C 227-58T	C 227-65, 1960 to Date
No. 4	No. 8	20	10
No. 8	No. 16	20	25
No. 16	No. 30	20	25
No. 30	No. 50	20	25
No. 50	No. 100	20	15

The initial grading was also a Bureau of Reclamation grading but was a later version than the one suggested for CRD-C 123. The 1960 revision was made to bring the grading more in line with fine aggregate gradings actually being used in concrete mixtures, and also to eliminate the sieving of excessively large quantities of fine aggregate that is deficient in No. 8 or No. 100 material, or both, to obtain sufficient quantities of these sizes for testing.

Age of mortar bars at time
of initial length measurement

4. The CRD method has consistently specified that bars be stripped from the molds and initial length measurements taken at 44 ± 4 hr age to avoid the excessive breakage that often occurs when bars are stripped at 24 hr age. However, breakage is still a problem, especially with bars containing Pyrex aggregate. The ASTM method, on the other hand, has consistently required that bars be stripped at 24 ± 2 hr age. With this method, breakage is an even worse problem; however, it has been informally reported that breakage in one laboratory was greatly reduced when it was directed that all bars broken in stripping be remade.

Number of times bars are measured

5. The ASTM method specifies that the bars be measured initially at 24 ± 2 hr and that subsequent measurements be made at 1, 2, 3, 6, 9, and 12 months, or a total of seven measurements. The CRD method specifies that bars be measured initially at 44 ± 4 hr and then at 8 and 28 days age and at 28-day intervals thereafter until the bars are 1 yr old, or a total of fifteen measurements. After the initial measurement, each time the bars were measured they were removed from the 100 F storage, placed in a room having a temperature of 73.4 ± 2 F for at least 16 hr, then measured and returned to 100 F storage. The effect of the number of times measured was not isolated in this program but the combined effect of measuring times and aggregate grading was studied by comparing the measurements of the bars containing ASTM graded aggregate measured seven times during the year and those containing CRD graded aggregate measured fifteen times.

Number of specimens tested

6. Another difference between the two test methods is the number of bars tested. The ASTM method states that at least four test specimens, two from each of two batches, for each cement-aggregate combination shall be made. The CRD method states that "Each cement-aggregate combination to be tested shall be represented by three rounds of three bars each." This particular difference is a statistical consideration and was not investigated in this program.

Purpose and Scope

7. This investigation was conducted to determine the effects of the differences between the ASTM and the CRD mortar-bar methods of test for alkali-aggregate reactivity before consideration was given to revising the CRD method to correspond to the ASTM method. For the investigation test bars were made using both a high- and a medium-alkali cement, each in combination with Pyrex glass, a reactive natural silica sand, and a nonreactive natural silica sand. Each of the six cement-aggregate combinations was tested using (a) both the CRD grading and measuring sequence and the ASTM grading and measuring sequence with initial measurements made at 24 ± 2 hr age, and (b) both the CRD grading and measuring sequence and the ASTM grading and measuring sequence with initial measurements made at 44 ± 4 hr age. In addition, the effect of blotting paper liners, placed in the bar storage containers at the time of the 6-month measurements, in maintaining the desired relative humidity in the containers was investigated.

PART II: MATERIALS, MIXTURES, AND TESTS

Materials

8. The following materials were used to fabricate 1- by 1- by 11-1/4-in. mortar bars for evaluating the differences between ASTM C 227 and CRD-C 123 test methods.

a. Cement. The chemical and physical properties of the cements used in this study are given in detail in table 1. The cements were:

(1) High alkali, RC-167, type I portland cement from Canada; total alkalies as Na_2O, 1.02 percent.

(2) Medium-alkali, RC-546, type II cement from Alabama; total alkalies as Na_2O, 0.54 percent.

b. Aggregates.

(1) Pyrex glass, CRD G-22(4), from New York. Pyrex glass is used as a standard reactive fine aggregate by the ASTM and Corps of Engineers in tests for effectiveness of pozzolans in reducing expansion due to alkali-silica reactivity (see ASTM C 441, CRD-C 263).

(2) Republican River reactive natural sand, CRD S-22, from Nebraska, obtained through the Bureau of Reclamation, Denver, Colorado.

(3) Natural silica sand, No. 7S-1(3), from Louisiana. A sample of sand from the same pit as the sample used in this study was tested for reactivity several years ago to determine its acceptability for use in Corps of Engineers construction in that area, and was found to be highly reactive. A shipment of this sand that was to be used in another investigation was received while the study reported herein was being planned, so it, too, was included in this program.

Mixtures

9. Each of the two cements was mixed with each of the three aggregates, which gave six cement-aggregate combinations as follows:

a. High-alkali cement and Pyrex glass.

b. High-alkali cement and Republican River sand.

c. High-alkali cement and natural Louisiana sand.

d. Medium-alkali cement and Pyrex glass.

e. Medium-alkali cement and Republican River sand.

f. Medium-alkali cement and natural Louisiana sand.

Twenty-four sets of test bars were made, with each set consisting of three rounds of three bars per round per cement-aggregate combination, which involved 72 mortar batches, or a total of 216 bars. The 72 batches were made in random order except that in no case was more than one round, of the three rounds representing a set of test bars, made on the same day. Table 2 shows the sequence of batch making and randomization of batches.

Tests

10. Effects of 24- or 44-hr initial measurements of length, from which expansion of bars is computed, were determined for each of the six cement-aggregate combinations, as listed below.

a. CRD aggregate grading, initial measurement made at 24 ± 2 hr age.

b. CRD aggregate grading, initial measurement made at 44 ± 4 hr age.

c. ASTM aggregate grading, initial measurement made at 24 ± 2 hr age.

d. ASTM aggregate grading, initial measurement made at 44 ± 4 hr age.

11. After the initial measurements, all bars containing the CRD graded aggregate were measured at the intervals specified in the CRD method which are at 8 and 28 days age and at 28-day intervals thereafter until the bars are 1 yr old. All bars containing the ASTM graded aggregate were measured at the intervals specified in the ASTM method which, not including the initial measurement, are at 1, 2, 3, 6, 9, and 12 months. A month was considered to be 30 days except when this caused measurements to fall on weekends or holidays. The CRD bars were measured a total of fourteen times, and the ASTM bars a total of six; neither total includes the initial measurement. Hereafter, a reference to "effect of grading" actually means the combined effect of grading plus measuring times as explained above.

Investigation of Container Liners for Improving Humidity

12. Another influence on alkali-silica reaction was investigated to some extent in this program, although this was not part of the project plan. It had been suspected for some time that when nine bars are exposed in plastic containers of the type prescribed in method CRD-C 123, the air surrounding the bars is not of the desired humidity even though water to a depth of 1 in. is maintained in the bottom of the container below the false bottom on which the bars rest. To correct this condition liners were placed in the containers, extending to the bottom as shown in fig. 1. This arrangement provides much more area for escape of water vapor into the air, and hence higher relative humidity within the containers. The liners were placed in the containers at the time the bars were measured at 6 months age.

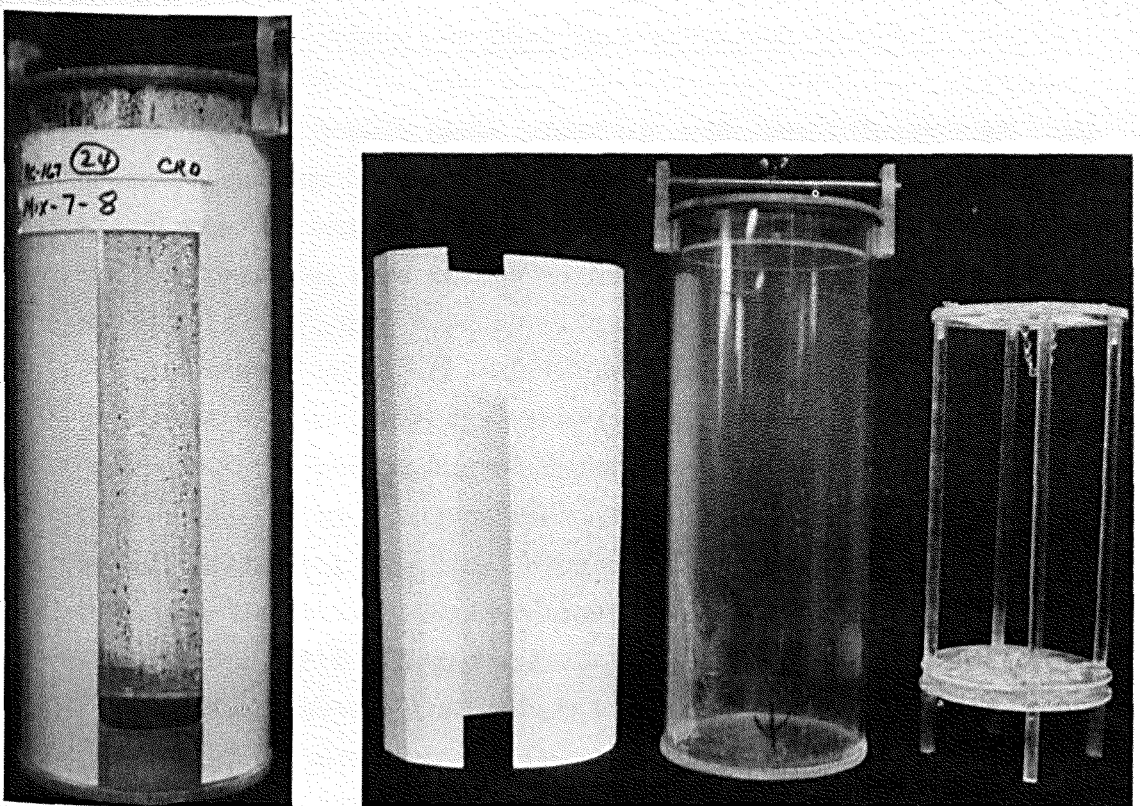

Fig. 1. Plastic storage container and absorbent liner

PART III: TEST RESULTS AND DISCUSSION

Effect of Aggregate Grading on Alkali-Aggregate Reactivity

13. Test results are summarized in table 3 and plotted in plates 1-6. These results show that bars containing Pyrex or Republican River aggregate graded according to ASTM requirements expanded more than comparable bars containing these aggregates graded according to CRD requirements. Bars containing the Louisiana natural sand graded according to CRD requirements expanded slightly more than comparable ASTM bars in three of four comparisons. However, it was found that this shipment of the sand was nonreactive. Consequently, there was very little expansion in any of the bars containing the Louisiana sand, and the slight differences in expansion can probably be attributed to random variations inherent in the test methods.

Effect of Age of Mortar Bars at Time of Initial Measurement

14. Test results are shown in table 4 and plates 7-12. These results indicate that consistently higher expansions of the bars cannot be attributed to either age of initial measurement. There was no significant difference in the 1-yr expansion of mortar bars measured initially at 24 $\pm$ 2 hr and those measured initially at 44 $\pm$ 4 hr. Of the twelve comparisons made, seven showed greater expansion of the bars measured initially at 44 hr age, four showed greater expansion of the bars measured initially at 24 hr age, and one showed no difference. It might be reasoned that any difference between making the initial measurement at 24 or 44 hr age would be that the expansion taking place between 24 and 44 hr would not be shown by bars measured initially at 44 hr age. The results show, however, that if alkali-silica expansion did occur between 24 and 44 hr age, it was compensated for, or perhaps even overcompensated for, by shrinkage caused by bleeding, drying, etc., during this period.

Statistical Calculations

Method of analysis

15. The experimental design for this investigation was purposely selected to be a nested factorial experiment as can be seen in table 2. However, since the aggregate from Louisiana was nonreactive, bars containing this aggregate did not expand to any extent, and therefore would not be expected to exhibit either a grading or initial measurement effect, should there be one. The inclusion of these data in the analysis of variance would tend to hide the effects exhibited by bars containing the reactive aggregates. It is also true that bars containing high-alkali cement and a reactive aggregate should exhibit a more pronounced grading and initial reading effect, if either exists, than bars containing that reactive aggregate and a medium-alkali cement. The inclusion of these data in the analysis might also minimize any effect exhibited by the bars containing the high-alkali cement. Therefore, six separate analyses of the 1-yr data were made using the groupings shown in table 2.

16. The variations that made up the model were (a) aggregate grading (actually, grading plus measuring sequence); (b) age of bars when measured initially; (c) interaction of gradings and initial measurements; (d) batches nested within grading and initial measurement; and (e) error term.

Results

17. Table 5 shows the results of the three analyses where a significant effect was exhibited. Basically, these results show that the aggregate gradings had an effect in bars containing (a) high-alkali cement and Pyrex glass, although the significance in this analysis was questionable; (b) medium-alkali cement and Pyrex glass; and (c) high-alkali cement and Republican River sand. Examination of plate 1, which shows graphically the effect of gradings of the questionable data, indicates that the grading effect would probably be significant if only that data used in plate 1b were analyzed and insignificant if the data used in plate 1a were analyzed. The grading effect was insignificant in the

other three aggregate-cement combinations used in this investigation.

18. There was no significant difference between 1-yr expansion of bars measured initially at 24 ± 2 hr age and those measured initially at 44 ± 4 hr age in any of the six aggregate-cement combinations.

Theoretical Considerations of the Effect of Gradings

19. In the alkali-silica reaction, the degree of reaction depends on the silica content, the metastability of the silica, and the fineness (particle diameter and specific surface) of the particles of reactive silica. In an attempt to explain why the bars containing reactive silica graded according to ASTM requirements expanded significantly more than bars containing the same silica graded according to CRD requirements, the two gradings were considered:

Retained on Sieve No.	Percent CRD-C 123		Percent ASTM C 227	
4	2	20	0	35
8	8		10	
16	10		25	
30	37	80	25	65
50	32		25	
100	11		15	
	100		100	

A calculation of surface area, considering spherical particles, revealed that CRD graded material has 1.012 times more surface area than ASTM graded material. Also to be noted, the ASTM grading has 15 percent more material larger than the No. 16 screen than has the CRD grading.

20. According to Powers and Steinour,[5] the attack by alkalies on reactive silica in the presence of excess lime produces a nonswelling "lime-alkali-silica complex" (gel) if chemical equilibrium is reached. If lime is not available or cannot reach the reaction site, an alkali-silica complex is formed which will imbibe water and hence will swell, thereby causing pressures that will crack concrete. In affected concrete, both of these complexes are produced, but it is the alkali-silica complex that causes excessive expansion. In the initial reaction, alkalies

(sodium and potassium hydroxide derived from the cement) attack the surface of reactive silica particles and gradually penetrate the particle. This produces a surface layer of the lime-alkali-silica complex. When alkali in immediate contact with a reactive particle is used up in the reaction, diffusion brings more alkali to the particle and carries it on into the particle as the attack proceeds radially. As long as lime is available and takes part in the reaction, the nonswelling lime-alkali-silica complex will be formed. The liquid phase in portland cement paste is normally saturated with lime; however, there are factors that hinder the availability of sufficient lime as the reaction penetrates the larger reactive particles. They are

a. The lime concentration in the nonswelling gel is at least four times as great as the alkali concentration; therefore, the lime must reach the reaction site much faster than the alkali for the nonswelling gel to be formed.

b. Alkali hydroxides depress the calcium ion concentrations.

c. After a sufficient thickness of reaction layer of lime-alkali-silica complex has formed on the larger particles, this layer can no longer be penetrated by hydrated calcium ions but can be penetrated by hydrated alkali ions.

This last factor is directly related to particle size and was a conclusion reached by Van der Burgh[6] in 1932, and more recently by Vivian.[6]

21. When high-alkali cement and reactive silica are combined, expansion will occur unless there is enough reactive silica of small particle size to react with the alkalies forming the nonswelling gel, thereby reducing the alkali concentration to a safe level before the radial penetration of the reaction layer forming on the larger particles has progressed very far.

22. It has been shown experimentally[5] that with low-alkali cement even reactive particles as large as those passing the No. 16 sieve and retained on the No. 30 sieve may be converted to the lime-alkali-silica complex; but at higher alkali concentrations the lime is apparently not able to diffuse into the larger particles at the required rate, and the swelling alkali-silica complex is formed. This would tend to indicate that the greater amount (15 percent) of particles larger than the No. 16 sieve in the ASTM grading could have been the factor that caused the bars

containing ASTM graded aggregate to expand significantly more than comparable bars containing CRD graded aggregate.

23. The above discussion is based on the assumption that the different aggregate grading was the factor that caused the difference in expansion. It could be that the difference in measuring times could also have had its effect. Each time the bars were measured they were taken from a room where the temperature was maintained at 100 F and placed in a room at 73.4 ± 2 F for a minimum of 16 hr before the containers were opened and the bars measured. The bars were then resealed in the containers and returned to the 100 F room. The bars containing the ASTM graded aggregate went through the cooling and then reheating cycle 6 times, whereas those containing the CRD graded aggregate went through the cycle 14 times. This effect, if any, was not isolated in this program so it is not known. One line of reasoning is that alkali-silica reaction, being a chemical reaction, would be inhibited or slowed by cooling which would have caused the bars containing CRD graded aggregate to expand less than like bars containing ASTM graded aggregate. Conversely, it might be reasoned that the additional cycling might reduce internal resistance to expansion, thus causing the bars containing CRD graded aggregate to expand <u>more</u> than like bars containing ASTM graded aggregate.

24. Another factor is that the mortar batches containing ASTM graded aggregate required less water than comparable batches containing CRD graded aggregate for equal consistency, as shown in table 4. However, it is doubtful that this had any effect on expansion, as earlier work by E. G. Swenson[7] of the National Research Council of Canada showed that water-cement ratio has no influence.

Effect of Absorptive Liners for Exposure Containers

25. The effect of the absorptive liners, which were placed in the containers when the bars were 6 months old, can be seen in plates 1-12. The effect is noticeable in practically all instances, and is very pronounced in some. If the liners had been in the containers from the beginning of the tests, it is probable that the expansions of all bars

would have been greater. The small amount of space between bars when nine are stored in the container, coupled with the further restrictions of the splash baffle (the disk below the plate upon which the bars rest, as shown in fig. 1) probably had an effect in deterring the moisture in the bottom of the containers from saturating the air.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

26. The data developed in this investigation indicate that there is a significant difference in certain cases between the 1-yr expansion of bars containing ASTM graded reactive aggregates and measured as specified in the ASTM test method and comparable bars containing CRD graded reactive aggregates measured as specified in the CRD test method when the bars also contain either high- or medium-alkali cement. In the cases where there is a significant difference, the bars containing the ASTM graded aggregates will expand more than those containing CRD graded aggregates.

27. It is also apparent from data reported herein that bars exposed in containers of the type specified in CRD-C 123 are, during much or all of their storage period, exposed to a relative humidity materially lower than was intended and, as a result, moisture evaporates from the bars into the air. The drying of the bars apparently causes them to expand less than they would have if stored at a higher humidity. Absorptive liners of the type shown in fig. 1 are beneficial in preventing drying of the bars.

28. There is no significant difference in 1-yr expansions of mortar bars measured initially at 24 $\pm$ 2 hr age and like bars measured initially at 44 $\pm$ 4 hr.

Recommendations

29. It is recommended that CRD-C 123-63, "Method of Test for Length Change of Mortar Bars Caused by Alkali-Silica Reaction," be replaced in the <u>Handbook for Concrete and Cement</u>[1] by ASTM C 227-65, "Standard Method of Test for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar Bar Method)."

30. It is also recommended that absorptive liners of the type used

in this investigation be used in containers where the humidity in the air surrounding the bars may be insufficient.*

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* At the June 1966 meeting of the subcommittee of ASTM Committee C-9 that is in charge of method C 227, it was agreed to revise C 227 to include a note in the section on "containers" reading as follows:

> Note 2 - Experience has shown that some containers, with water in the bottom, are so constructed with supporting plates, spacers and splash baffles that, even with water in the bottom, the air surrounding the specimens seldom, if ever, achieved a high relative humidity. This condition can be corrected by inserting blotting paper liners in the containers, positioned so that the lower edge of the blotting paper is immersed and the upper edge extends to the elevation of the top of the specimen.

This revision was put to ballot of the subcommittee on 19 July 1966. There were no negative votes on this revision.

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Table 1

Chemical and Physical Properties of Cements

Component or Test	(RC-167) High-Alkali, Type I Portland Cement	(RC-546) Medium-Alkali, Type II Portland Cement
Chemical Properties		
iO_2, %	20.7	23.2
l_2O_3, %	6.3	3.8
e_2O_3, %	2.7	3.0
aO, %	63.2	63.1
gO, %	2.5	3.2
O_3, %	1.8	2.0
Loss on ignition, %	1.1	0.94
Na_2O, %	0.49	0.25
K_2O, %	0.81	0.44
Insoluble residue, %	0.13	0.18
Water soluble Na_2O, %	--	0.54
Total alkalies as Na_2O, %	1.02	0.54
C_3S, %	--	44
C_2S, %	--	33
C_3A, %	12.1	5
C_4AF, %	--	9
Physical Properties		
Fineness (Blaine), sq cm/g	2240	3290
Normal consistency, %	--	25.4
Gillmore time of setting, hr:min		
Initial	5:20	4:35
Final	9:40	7:20
Autoclave expansion, %	0.22	0.13
Heat of hydration, cal/g		
7 days	--	82.5
28 days	--	92.4
Air content of mortar, %	11.5	11.4
Compressive strength, psi		
3 days	1585	1820
7 days	2500	2880
28 days	--	4690

Table 2

Test Arrangement, Sequence of Batch Making, and Randomization of Batches

Aggregate Grading Used	Initial Reading hr	High-Alkali Cement			Medium-Alkali Cement		
		Pyrex Glass	Republican River Sand	Louisiana Sand	Pyrex Glass	Republican River Sand	Louisiana Sand
CRD-C 123	24	3	17	24	7	8	11
		56	32	33	40	19	36
		69	65	52	67	27	45
	44	54	25	9	4	10	16
		64	34	35	44	43	30
		68	72	53	70	62	58
ASTM 227	24	21	6	2	5	13	1
		42	39	14	20	48	26
		71	49	59	31	60	51
	44	18	15	37	12	23	28
		47	22	41	38	29	63
		55	57	50	61	46	66

Note: The numbers in the blocks denote the numerical order in which the 72 batches were mixed.

The mixing order was completely randomized except that in no case was more than one round, of the three rounds representing a set of test bars, made on the same day.

Bars containing different cement were not placed in the same storage container.

Table 3

Effects of Aggregate Grading on Alkali-Aggregate Reactivity

Cement	Aggregate	Age at Initial Measurement, hr	Mix No.	Length Change, Percent, at Various Ages of Test Bars: 8 days	28 days	30 days	56 days	62 days	84 days	90 days	112 days	140 days	168 days	182 days	196 days	224 days	252 days	274 days	280 days	308 days	336 days	364 days	365 days
										ASTM Method													
High-alkali	Pyrex glass	24	19			0.114		0.135		0.145				0.150				0.177					0.191
		44	13			0.110		0.135		0.147				0.154				0.192					0.207
Medium-alkali	Pyrex glass	24	22			0.021		0.038		0.057				0.071				0.126					0.149
		44	16			0.012		0.028		0.049				0.068				0.134					0.162
High-alkali	Republican River sand	24	21			0.010		0.061		0.101				0.133				0.156					0.161
		44	15			0.017		0.097		0.135				0.172				0.194					0.200
Medium-alkali	Republican River sand	24	18			-0.003		0.003		0.011				0.034				0.114					0.137
		44	24			0.001		0.004		0.008				0.031				0.109					0.133
High-alkali	Louisiana sand	24	20			-0.001		0.001		0.012				0.031				0.067					0.074
		44	14			0.000		0.001		0.004				0.013				0.041					0.047
Medium-alkali	Louisiana sand	24	23			0.000		0.004		0.006				0.019				0.024					0.028
		44	17			0.000		0.003		0.008				0.014				0.023					0.028
										CRD Method													
High-alkali	Pyrex glass	24	7	0.067	0.115		0.131		0.145		0.148	0.149	0.151		0.151	0.163	0.165		0.169	0.172	0.175	0.177	
		44	1	0.050	0.091		0.111		0.123		0.126	0.127	0.129		0.128	0.141	0.145		0.148	0.151	0.153	0.153	
Medium-alkali	Pyrex glass	24	10	0.006	0.013		0.021		0.027		0.037	0.037	0.040		0.042	0.054	0.058		0.063	0.066	0.070	0.071	
		44	4	0.006	0.011		0.021		0.034		0.043	0.048	0.053		0.056	0.080	0.091		0.103	0.110	0.112	0.115	
High-alkali	Republican River sand	24	9	-0.001	0.004		0.018		0.055		0.072	0.086	0.095		0.106	0.126	0.128		0.131	0.133	0.134	0.135	
		44	3	0.000	0.004		0.025		0.055		0.072	0.084	0.089		0.093	0.113	0.117		0.119	0.122	0.122	0.123	
Medium-alkali	Republican River sand	24	6	-0.002	0.001		0.004		0.010		0.014	0.018	0.027		0.038	0.083	0.105		0.113	0.118	0.120	0.124	
		44	12	0.001	0.003		0.006		0.013		0.017	0.025	0.037		0.038	0.085	0.101		0.116	0.124	0.125	0.127	
High-alkali	Louisiana sand	24	8	-0.001	-0.002		-0.001		0.006		0.011	0.016	0.019		0.023	0.045	0.048		0.050	0.053	0.053	0.054	
		44	2	-0.002	-0.004		-0.004		0.002		0.007	0.011	0.016		0.020	0.052	0.057		0.060	0.063	0.063	0.063	
Medium-alkali	Louisiana sand	24	11	0.001	0.005		0.004		0.007		0.011	0.012	0.014		0.015	0.022	0.024		0.026	0.028	0.028	0.029	
		44	5	0.002	0.004		0.007		0.010		0.011	0.013	0.016		0.018	0.025	0.025		0.028	0.029	0.030	0.032	

Note: Each expansion value shown is the average of nine bars (three rounds of three bars each).

Table 4

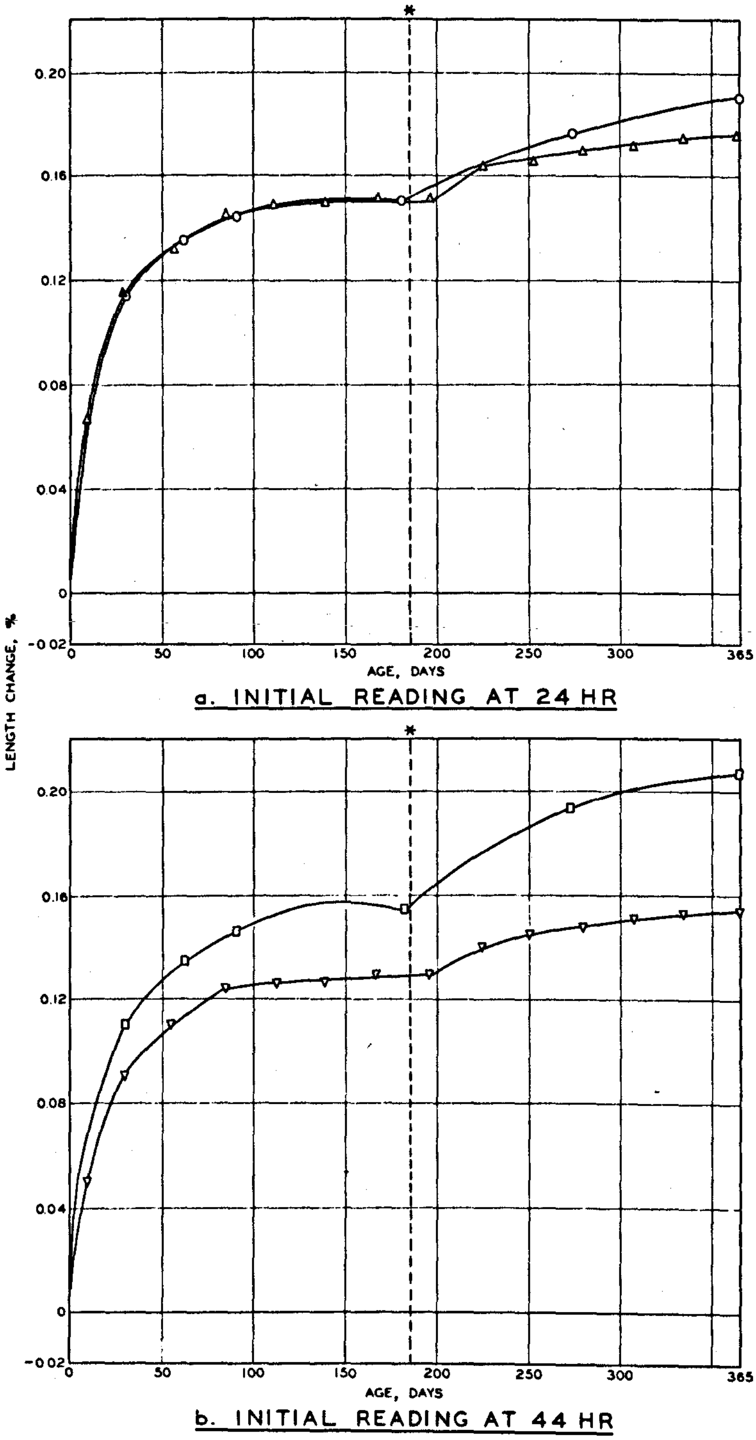
Effect of Age of Mortar Bar at Time of Initial Measurement

Grading Method	Cement	Aggregate	Mixture No.	Age at Time of Initial Measurement hr	Expansion Percent (Avg of 9 Bars) at 1-yr Age	Water, ml Used in Each 3-Bar Batch
ASTM	High-alkali	Pyrex glass	19	24	0.191	248
			13	44	0.207	248
CRD			7	24	0.177	260
			1	44	0.153	260
ASTM	Medium-alkali	Pyrex glass	22	24	0.149	248
			16	44	0.162	248
CRD			10	24	0.071	260
			4	44	0.115	260
ASTM	High-alkali	Republican River sand	21	24	0.161	190
			15	44	0.200	190
CRD			9	24	0.135	194
			3	44	0.123	194
ASTM	Medium-alkali	Republican River sand	18	24	0.137	194
			24	44	0.133	194
CRD			6	24	0.124	196
			12	44	0.127	196
ASTM	High-alkali	Louisiana sand	20	24	0.074	190
			14	44	0.047	190
CRD			8	24	0.054	198
			2	44	0.063	198
ASTM	Medium-alkali	Louisiana sand	23	24	0.028	204
			17	44	0.028	204
CRD			11	24	0.029	206
			5	44	0.032	206
			Total	24	1.33	
				44	1.39	

Table 5

Analysis of Variance

Variations	Degrees of Freedom	Mean Square Value	F No.	Significant Difference
High-Alkali Cement and Pyrex Glass Aggregate				
Aggregate grading	1	0.010370	3.54	Significant at 90 percent
Age at initial measurement	1	0.000103	0.03	Not significant
Grading and initial measurement	1	0.003661	1.25	Not significant
Batches	8	0.002928	3.05	Significant at 97.5 percent
Error term	24	0.000960		
Total	35			
Medium-Alkali Cement and Pyrex Glass Aggregate				
Aggregate grading	1	0.035784	8.34	Significant at 97.5 percent
Age at initial measurement	1	0.007310	1.70	Not significant
Grading and initial measurement	1	0.002418	0.56	Not significant
Batches	8	0.004292	5.45	Significant at 99.5 percent
Error term	24	0.000787		
Total	35			
High-Alkali Cement and Republican River Sand Aggregate				
Aggregate grading	1	0.023154	5.54	Significant at 95 percent
Age at initial measurement	1	0.002100	0.50	Not significant
Grading and initial measurement	1	0.005956	1.42	Not significant
Batches	8	0.004183	3.21	Significant at 97.5 percent
Error term	24	0.001302		
Total	35			



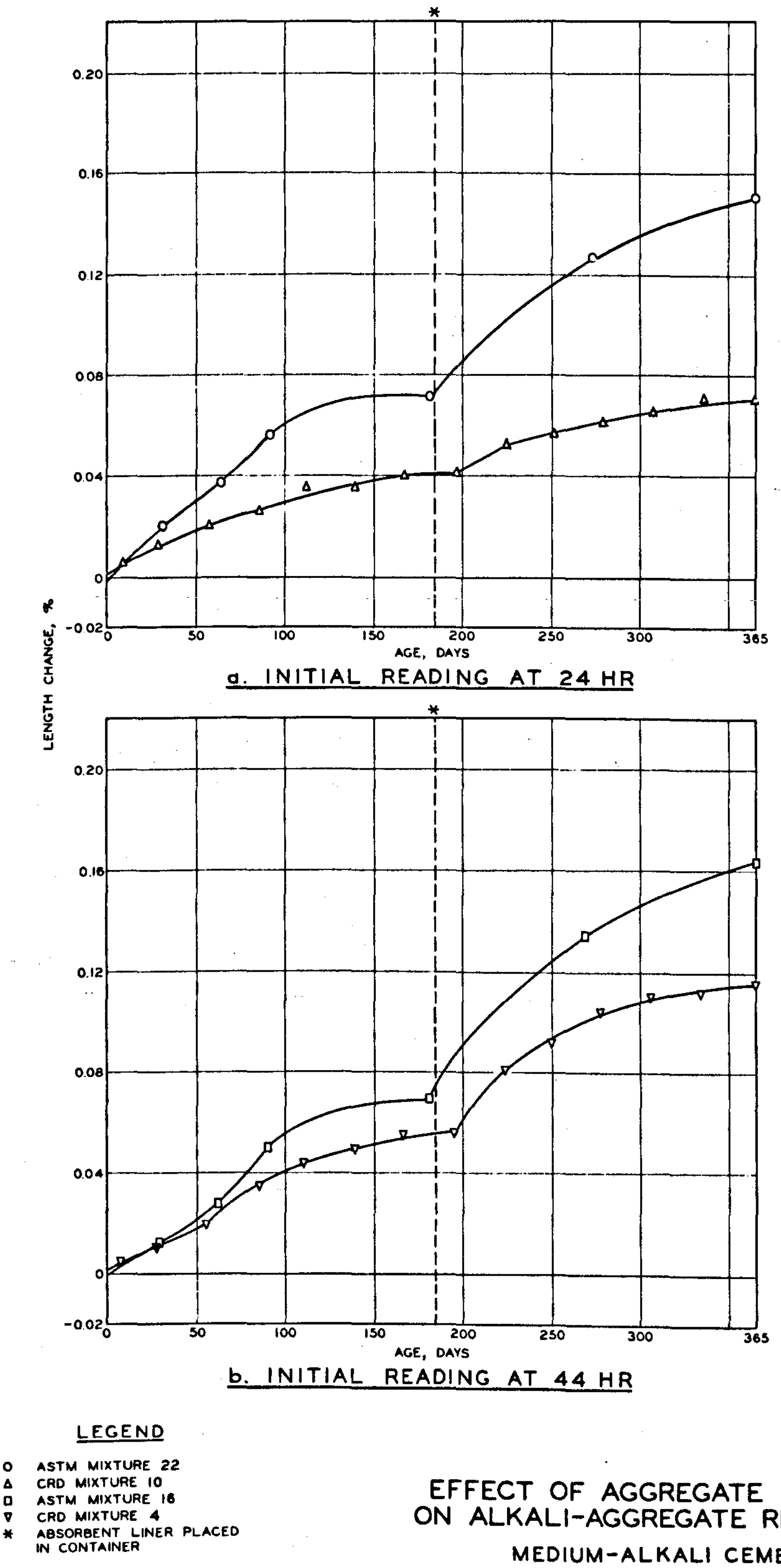
LEGEND

- ○ ASTM MIXTURE 19
- △ CRD MIXTURE 7
- □ ASTM MIXTURE 13
- ▽ CRD MIXTURE 1
- * ABSORBENT LINER PLACED IN CONTAINER

EFFECT OF AGGREGATE GRADING ON ALKALI-AGGREGATE REACTIVITY

HIGH-ALKALI CEMENT

PYREX GLASS AGGREGATE

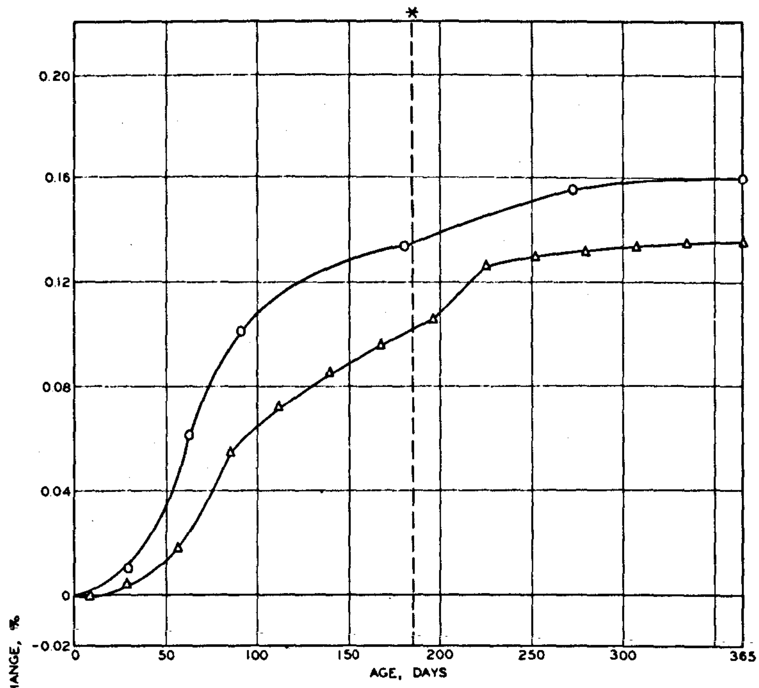


EFFECT OF AGGREGATE GRADING ON ALKALI-AGGREGATE REACTIVITY

MEDIUM-ALKALI CEMENT

PYREX GLASS AGGREGATE

PLATE 2



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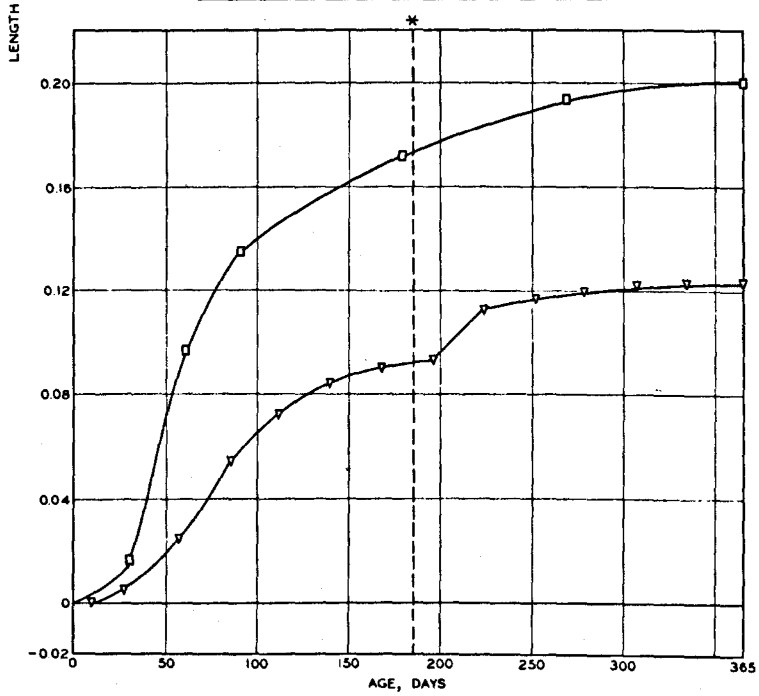

b. INITIAL READING AT 44 HR

LEGEND

- O ASTM MIXTURE 21
- Δ CRD MIXTURE 9
- □ ASTM MIXTURE 15
- ∇ CRD MIXTURE 3
- * ABSORBENT LINER PLACED IN CONTAINER

EFFECT OF AGGREGATE GRADING ON ALKALI-AGGREGATE REACTIVITY

HIGH-ALKALI CEMENT

REPUBLICAN RIVER NATURAL SAND

PLATE 3

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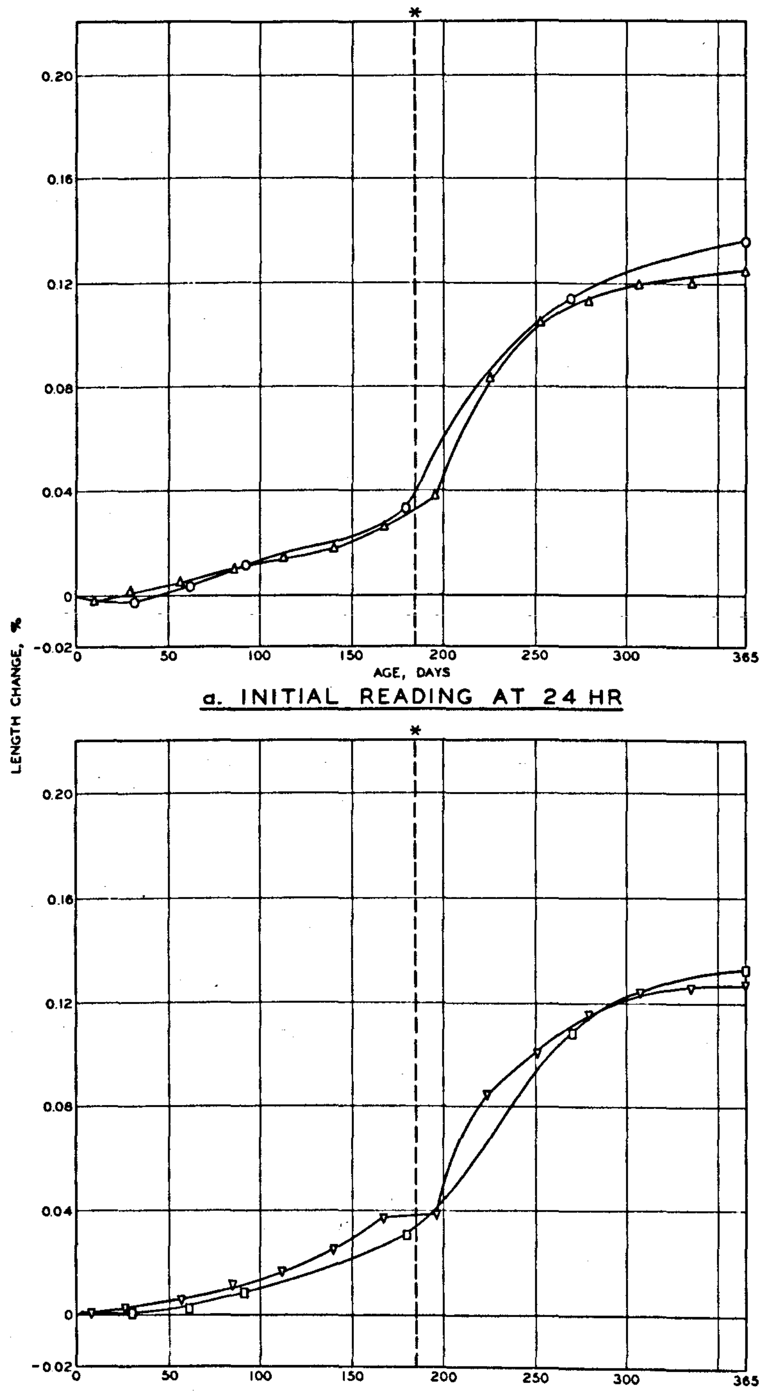


a. INITIAL READING AT 24 HR

b. INITIAL READING AT 44 HR

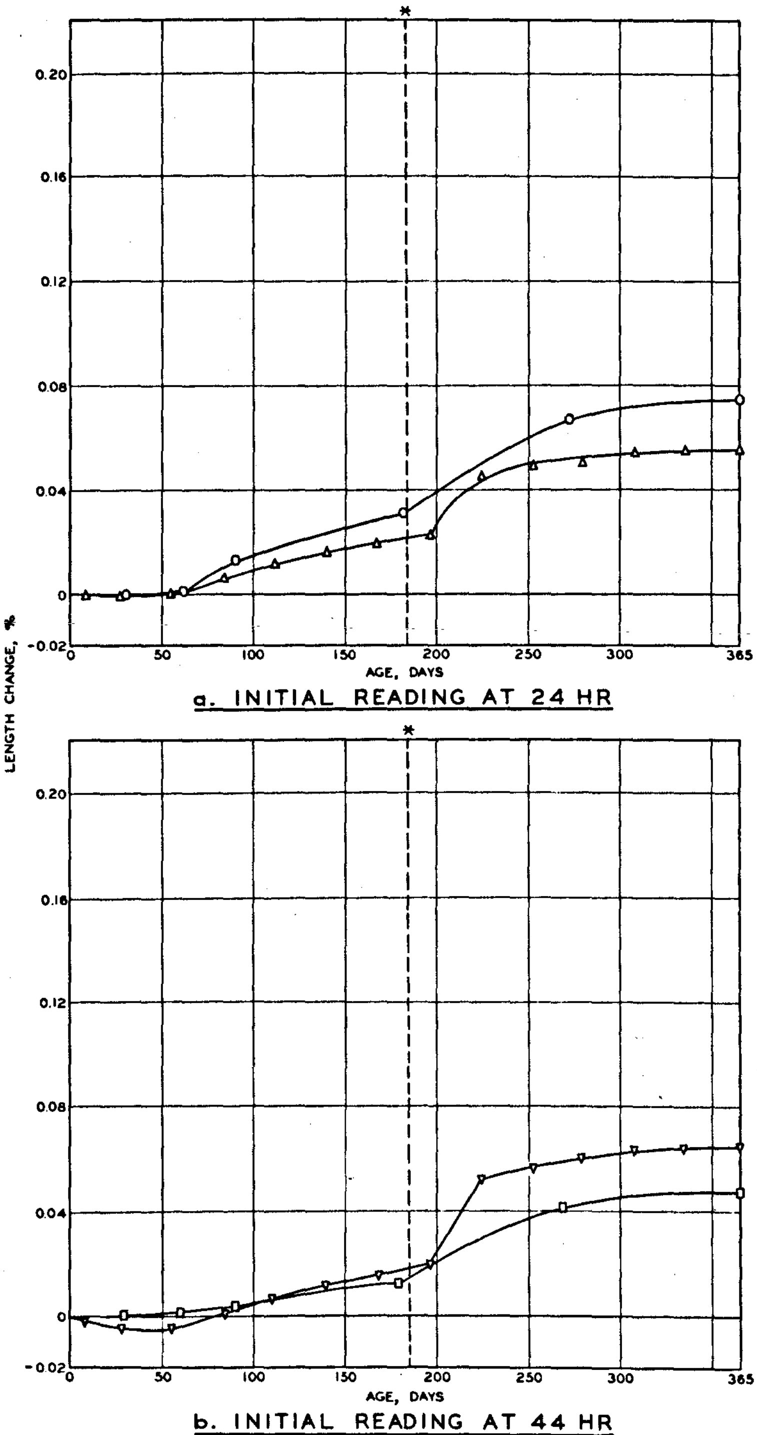
LEGEND

- O ASTM MIXTURE 18
- Δ CRD MIXTURE 6
- □ ASTM MIXTURE 24
- ∇ CRD MIXTURE 12
- * ABSORBENT LINER PLACED IN CONTAINER

EFFECT OF AGGREGATE GRADING ON ALKALI-AGGREGATE REACTIVITY

MEDIUM-ALKALI CEMENT

REPUBLICAN RIVER NATURAL SAND



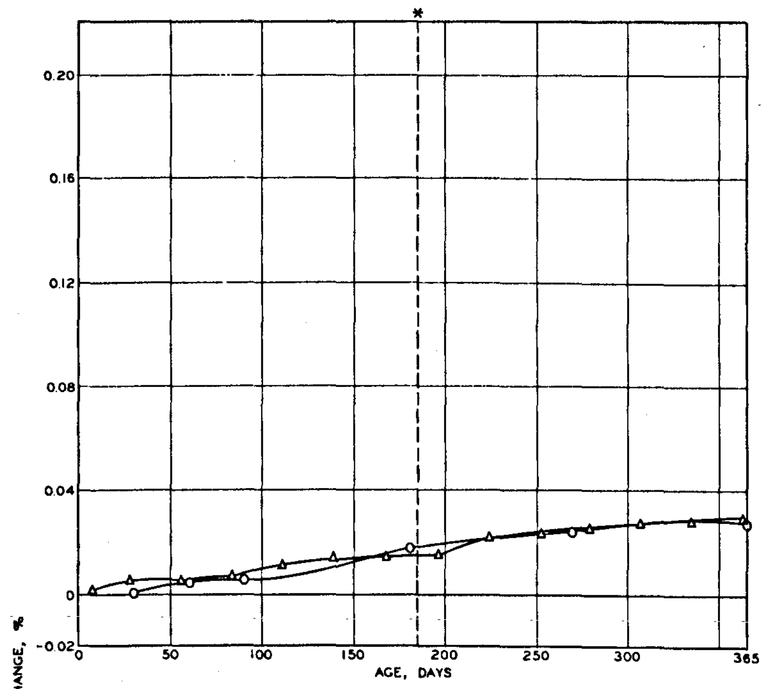
LEGEND

- O ASTM MIXTURE 20
- Δ CRD MIXTURE 8
- □ ASTM MIXTURE 14
- ∇ CRD MIXTURE 2
- * ABSORBENT LINER PLACED IN CONTAINER

EFFECT OF AGGREGATE GRADING ON ALKALI-AGGREGATE REACTIVITY

HIGH-ALKALI CEMENT

LOUISIANA NATURAL SAND



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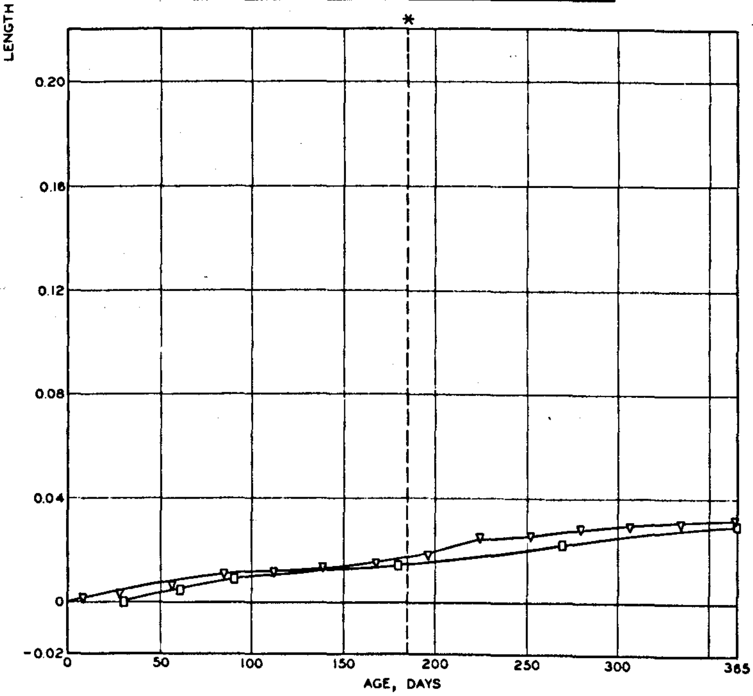


b. INITIAL READING AT 44 HR

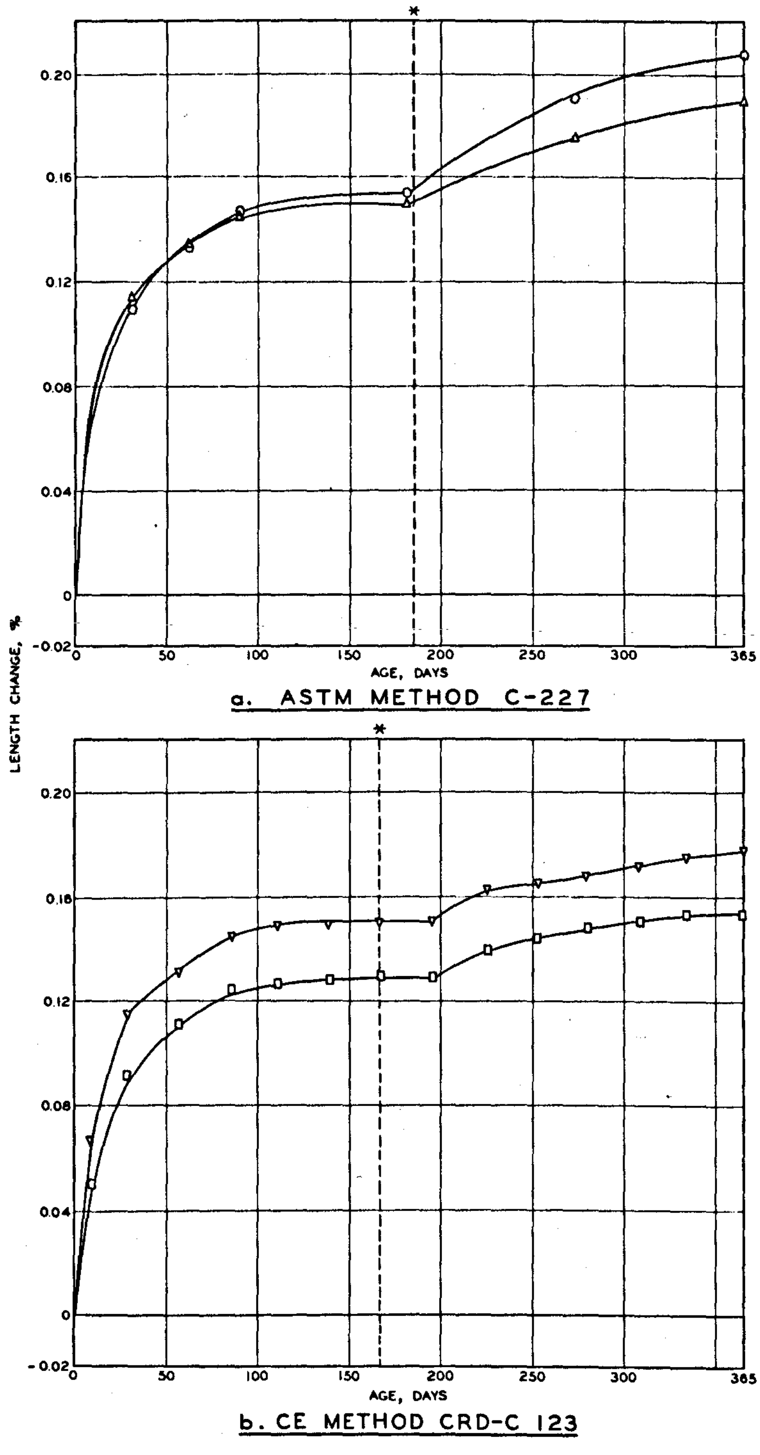
LEGEND

- O ASTM MIXTURE 23
- Δ CRD MIXTURE 11
- □ ASTM MIXTURE 17
- ∇ CRD MIXTURE 5
- * ABSORBENT LINER PLACED IN CONTAINER

EFFECT OF AGGREGATE GRADING ON ALKALI-AGGREGATE REACTIVITY

MEDIUM-ALKALI CEMENT

LOUISIANA NATURAL SAND



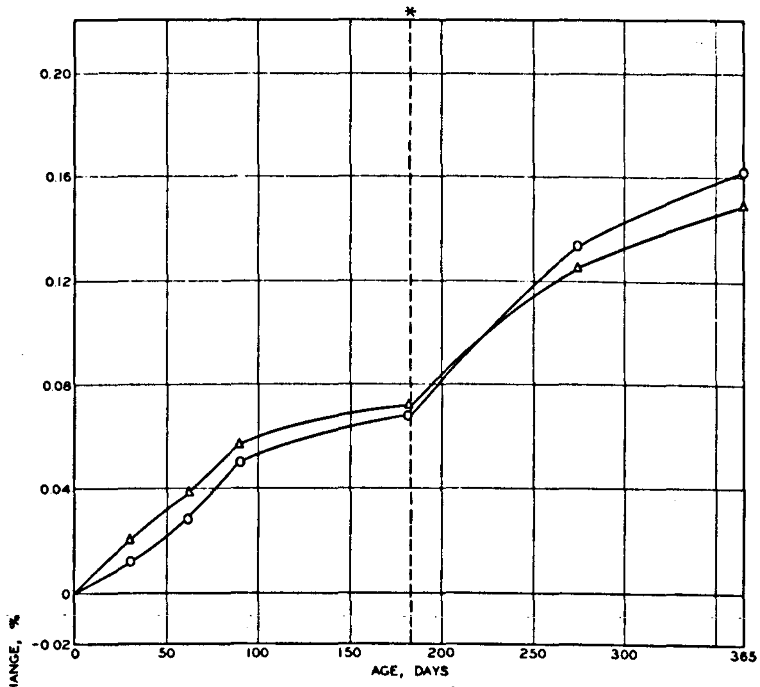
LEGEND

- O MIXTURE 13, 44 HR
- Δ MIXTURE 19, 24 HR
- □ MIXTURE 1, 44 HR
- ∇ MIXTURE 7, 24 HR
- * ABSORBENT LINER PLACED IN CONTAINER

EFFECT OF AGE OF MORTAR BAR AT TIME OF INITIAL MEASUREMENT

HIGH-ALKALI CEMENT

PYREX GLASS AGGREGATE



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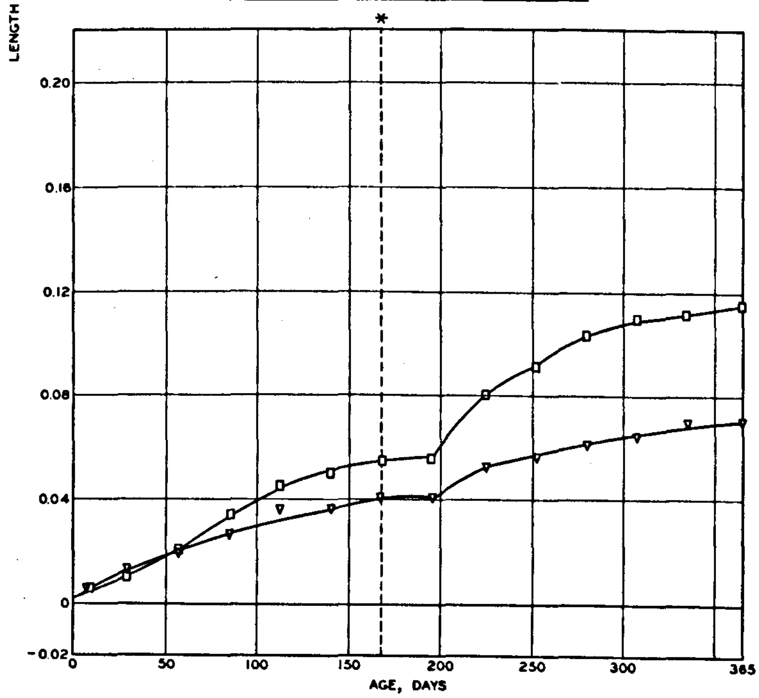


b. CE METHOD CRD-C 123

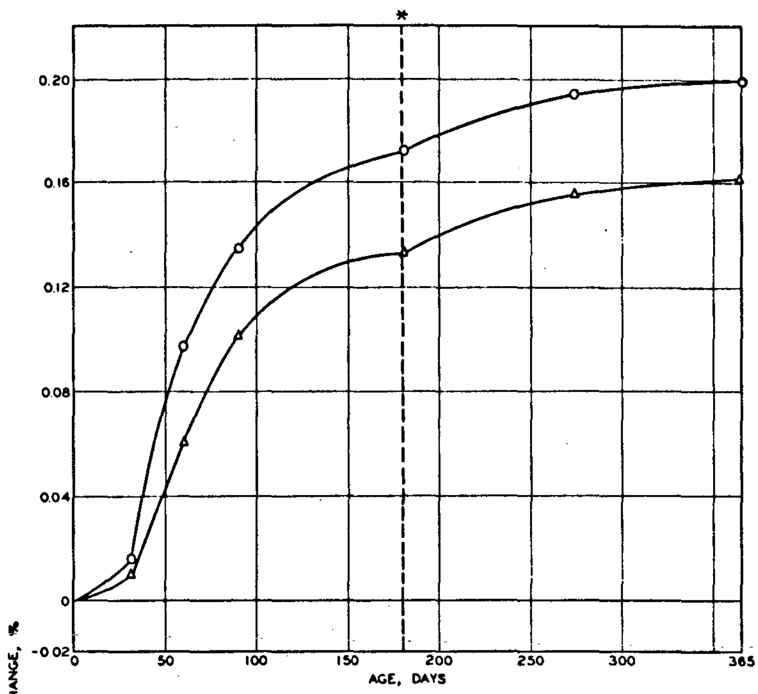
LEGEND

- O MIXTURE 16, 44 HR
- Δ MIXTURE 22, 24 HR
- □ MIXTURE 4, 44 HR
- ▽ MIXTURE 10, 24 HR
- * ABSORBENT LINER PLACED IN CONTAINER

EFFECT OF AGE OF MORTAR BAR AT TIME OF INITIAL MEASUREMENT

MEDIUM-ALKALI CEMENT

PYREX GLASS AGGREGATE



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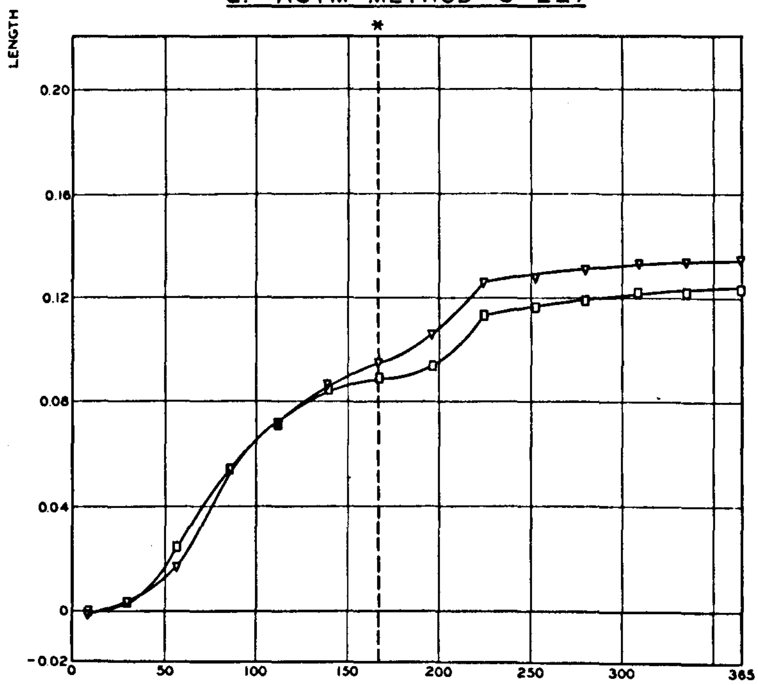


b. CE METHOD CRD-C 123

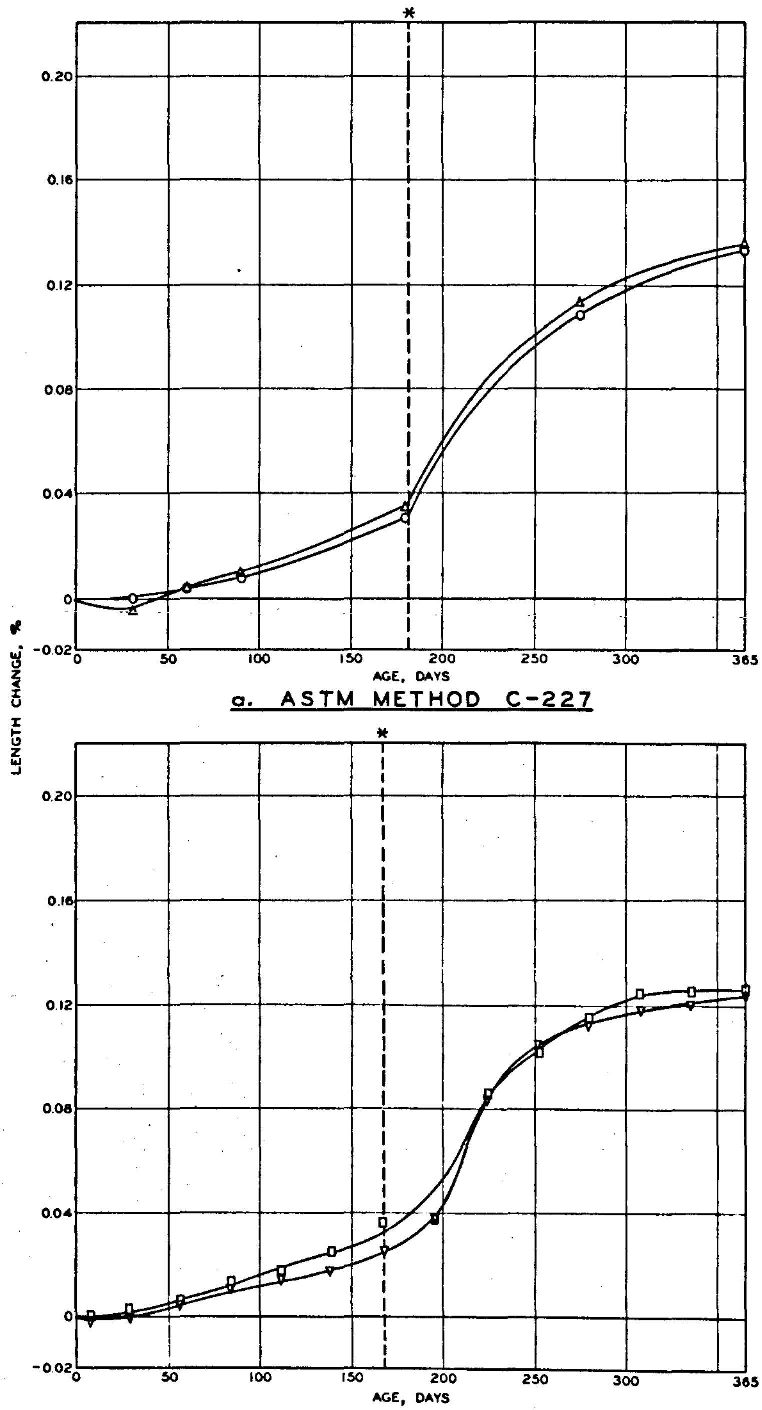
LEGEND

- O MIXTURE 15, 44 HR
- Δ MIXTURE 21, 24 HR
- □ MIXTURE 3, 44 HR
- ▽ MIXTURE 9, 24 HR
- * ABSORBENT LINER PLACED IN CONTAINER

EFFECT OF AGE OF MORTAR BAR AT TIME OF INITIAL MEASUREMENT

HIGH-ALKALI CEMENT

REPUBLICAN RIVER NATURAL SAND



a. ASTM METHOD C-227

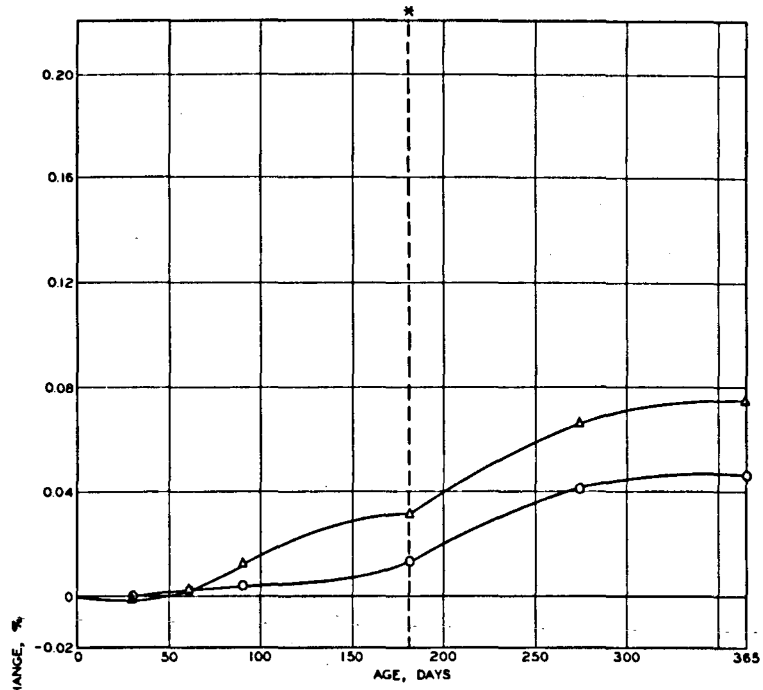
b. CE METHOD CRD-C 123

LEGEND

- O MIXTURE 24, 44 HR
- Δ MIXTURE 18, 24 HR
- □ MIXTURE 12, 44 HR
- ▽ MIXTURE 6, 24 HR
- * ABSORBENT LINER PLACED IN CONTAINER

EFFECT OF AGE OF MORTAR BAR AT TIME OF INITIAL MEASUREMENT

MEDIUM-ALKALI CEMENT
REPUBLICAN RIVER NATURAL SAND



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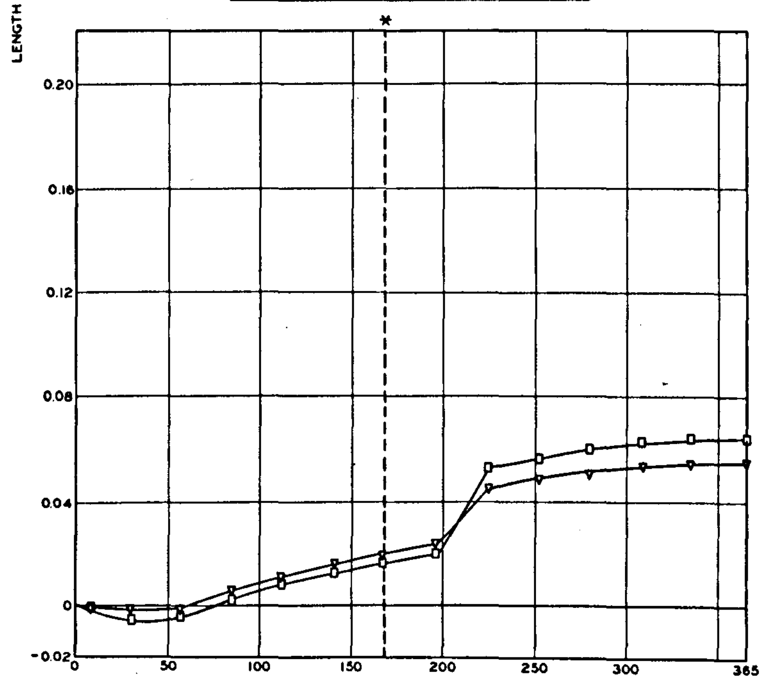


b. CE METHOD CRD-C 123

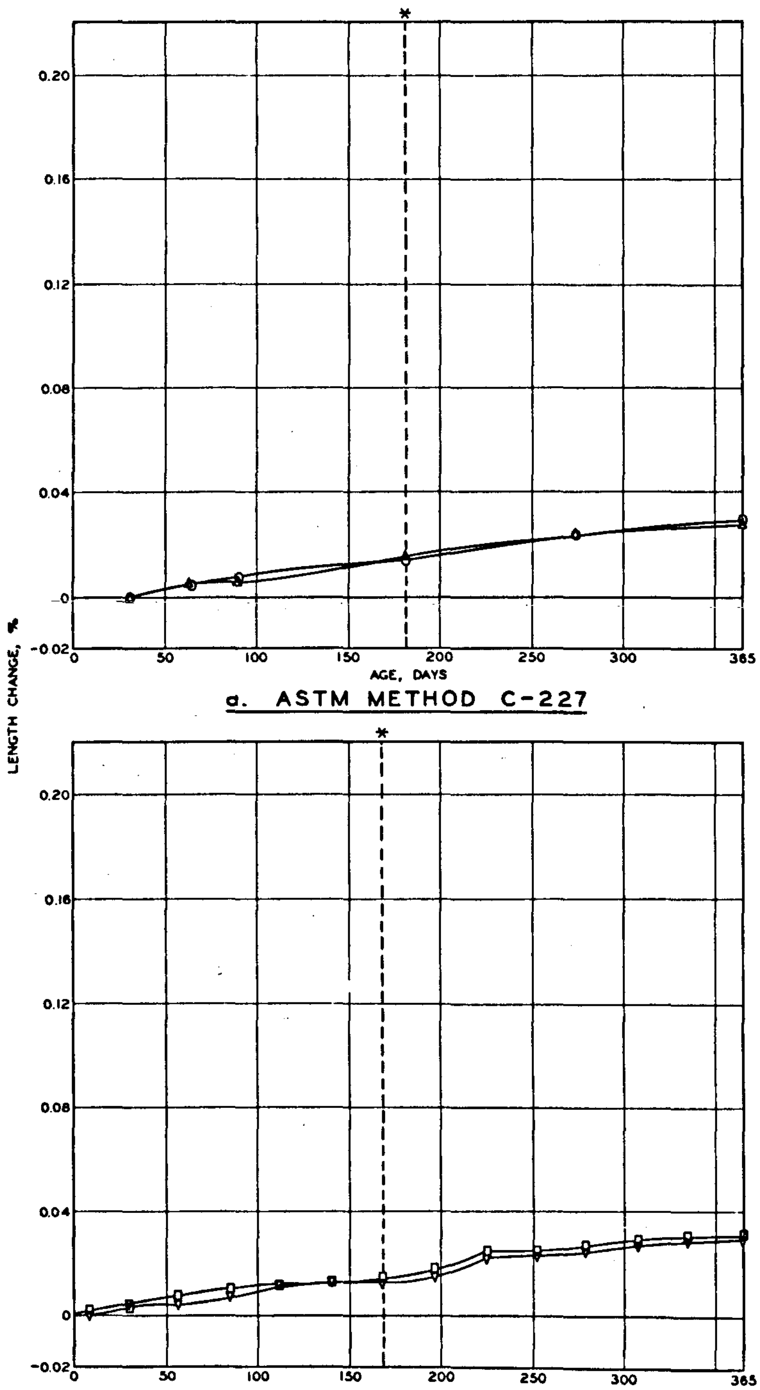
LEGEND

- O MIXTURE 14, 44 HR
- Δ MIXTURE 20, 24 HR
- □ MIXTURE 2, 44 HR
- ▽ MIXTURE 8, 24 HR
- * ABSORBENT LINER PLACED IN CONTAINER

EFFECT OF AGE OF MORTAR BAR AT TIME OF INITIAL MEASUREMENT

HIGH-ALKALI CEMENT

LOUISIANA NATURAL SAND



a. ASTM METHOD C-227

b. CE METHOD CRD-C 123

LEGEND

- O MIXTURE 17, 44 HR
- Δ MIXTURE 23, 24 HR
- □ MIXTURE 5, 44 HR
- ∇ MIXTURE 11, 24 HR
- * ABSORBENT LINER PLACED IN CONTAINER

EFFECT OF AGE OF MORTAR BAR AT TIME OF INITIAL MEASUREMENT

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13. ABSTRACT Tests were conducted to ascertain the effect of the differences between Corps of Engineers method (CRD-C 123) and American Society for Testing Materials method (ASTM C-227) for determining alkali-aggregate reactivity in mortar bars. Principal differences are (a) grading of aggregate used in the mortar; (b) age of bars at time of initial measurement; and (c) number of times bars are measured. Test bars made of six cement-aggregate combinations were tested using CRD and ASTM gradings and measuring sequences. Also, blotting paper liners were placed in the exposure containers to improve the relative humidity of the air surrounding the bars in the containers. Results indicate: (a) There was a significant difference, in some cases, between the 1-yr expansion of bars containing ASTM graded reactive aggregates that were measured according to the ASTM specified measuring sequence and bars containing CRD graded aggregate that were measured according to the CRD specified measuring sequence. Where there was a significant difference, the ASTM bars expanded more than the CRD bars. (b) There was no significant difference in the 1-yr expansion of bars measured initially at 24 + 2 hr and those measured at 44 + 4 hr age. (c) Subsequent measurement of bars after absorptive liners were placed in the exposure containers showed an abrupt increase in expansion of the bars in most cases. It is evident that the air surrounding the bars is not always of the desired relative humidity when bars are exposed in plastic containers of the type prescribed in CRD-C 123. It is recommended that CRD-C 123 be revised to conform to ASTM C-227, and that absorptive liners be placed in all containers where the relative humidity inside the container is questionable.

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