CTR 3-9-85-450-1

EFFECTIVENESS OF FLY ASH REPLACEMENT IN THE REDUCTION OF DAMAGE DUE TO ALKALI-AGGREGATE REACTION IN CONCRET

Josef Farbiarz and Ramon L. Carrasquillo

RESEARCH REPORT 450-1

PROJECT 3-9-85-450

CENTER FOR TRANSPORTATION RESEARCH
BUREAU OF ENGINEERING RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN
MAY 1986

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-87/15+450-1		

4. Title and Subtitle
EFFECTIVENESS OF FLY ASH REPLACEMENT IN THE REDUCTION OF DAMAGE DUE TO ALKALI-AGGREGATE REACTION IN CONCRETE

5. Report Date
May 1986

6. Performing Organization Code

7. Author(s)
Josef Farbiarz and Ramon L. Carrasquillo

8. Performing Organization Report No.
Research Report 450-1

9. Performing Organization Name and Address
Center for Transportation Research
The University of Texas at Austin
Austin, Texas 78712-1075

10. Work Unit No.

11. Contract or Grant No.
Research Study 3-9-85-450

12. Sponsoring Agency Name and Address
Texas State Department of Highways and Public Transportation; Transportation Planning Division
P. O. Box 5051
Austin, Texas 78763

13. Type of Report and Period Covered
Interim

14. Sponsoring Agency Code

15. Supplementary Notes
Study conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration
Research Study Title: "Alkali-Aggregate Reaction in Concrete Containing Fly Ash"

16. Abstract

The concrete industry is faced with the urgent need of improving its knowledge about the mechanism by which fly ash helps in the reduction of damage due to alkali-aggregate reaction in concrete to acceptable levels.

The main objective of this research was to identify the most relevant components of fly ash, cement, and concrete aggregates affecting the alkali-aggregate reaction, and to find a relationship between them, indicating type and amount of a given component acceptable for use in concrete to ensure no damage due to alkali-aggregate reaction. The research approach used in this investigation was to conduct a comparative study of the behavior of several mixes made using several aggregate sources in combination with cements with high and low alkali content, and containing different types of fly ash at different replacement percentages.

The variables studied included:

(1) alkali content of the cement,
(2) available alkali content of the fly ash,
(3) degree of alkali reactivity of the aggregate,
(4) type and source of fly ash, and
(5) percentage of cement replaced.

Test results presented in this report are limited to 90-day exposure testing. However, exposure testing of all specimens will continue until the 24-month test age and the results will be included in later reports.

17. Key Words	18. Distribution Statement
fly ash, concrete, damage reduction, alkali-aggregate, 90-day exposure, comparative study	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	202	

Form DOT F 1700.7 (8-69)

EFFECTIVENESS OF FLY ASH REPLACEMENT IN THE REDUCTION OF DAMAGE DUE TO ALKALI-AGGREGATE REACTION IN CONCRETE

by

Josef Farbiarz and Ramon L. Carrasquillo

Research Report No. 450-1

Research Project No. 3-9-85-450

"Alkali-Aggregate Reaction in Concrete Containing Fly Ash"

Conducted for

Texas
State Department of Highways and Public Transportation

In cooperation with the

U. S. Department of Transportation
Federal Highway Administration

by

CENTER FOR TRANSPORTATION RESEARCH
BUREAU OF ENGINEERING RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

May 1986

PREFACE

Since the alkali-aggregate reaction was first recognized more than 40 years ago, extensive literature has been published regarding all aspects of the problem that the reaction represents in the field of concrete durability. A survey of these reports rendered the following summary of means of reducing the alkali-aggregate reaction damage in concrete to acceptable levels:

1. The use of nonreactive aggregate.

2. The use of a cement with less than 0.60% alkalies (Na O equivalent)* in concrete containing reactive aggregate.

3. Use of certain admixtures, such as fly ash or other pozzolans, to replace a portion of the cement.

The first solution is rather vague, as the identification of reactive components in a sample of aggregate is not always an easy task. Furthermore, in many instances, an acceptable source of aggregate is not locally available and transportation may increase the cost of concrete.

The second solution has proved to be insufficient, as the alkali concentration within the concrete in place can be altered by several factors such as moisture migration.

As for the use of pozzolans, fly ash has become the most suitable material mainly because of its availability due to increasing environment protection measures. However, the beneficial effect of fly ash in reducing the damage due to alkali-aggregate reaction depends on both intrinsic and extrinsic characteristics such as, fly ash type and percent of cement being replaced. Thus, much controversy exists today as to the effect of fly ash on the alkali-aggregate reaction in concrete.

The main objective of the work described herein was to study the fundamental mechanisms governing the interaction among the alkalies in both the cement and the fly ash, and the reactive silica in the concrete aggregates and to develop adequate guidelines for proper, economical, and efficient use of fly ash in reducing alkali-aggregate reaction damage in concrete.

---

* Na_2O equivalent = Na_2O + 0.658 K O

S U M M A R Y

The concrete industry is faced with the urgent need of improving its knowledge about the mechanism by which fly ash helps in the reduction of damage due to alkali-aggregate reaction in concrete to acceptable levels.

The main objective of this research was to identify the most relevant components of fly ash, cement, and concrete aggregates affecting the alkali-aggregate reaction, and to find a relationship between them, indicating type and amount of a given component acceptable for use in concrete to ensure no damage due to alkali-aggregate reaction. The research approach used in this investigation was to conduct a comparative study of the behavior of several mixes made using several aggregate sources in combination with cements with high and low alkali content, and containing different types of fly ash at different replacement percentages.

The variables studied included:

1. Alkali content of the cement
2. Available alkali content of the fly ash
3. Degree of alkali reactivity of the aggregate
4. Type and source of fly ash
5. Percentage of cement replaced

Test results presented in this report are limited to 90-day exposure testing. However, exposure testing of all specimens will continue until the 24-month test age and the results will be included in later reports.

IMPLEMENTATION

The test results of this research project clearly indicate that the expansions due to alkali-aggregate reaction in concrete can be reduced with the use of any fly ash, provided it replaces the proper amount of cement in the mix which depends on the properties of each particular fly ash.

This study constitutes the first step toward the much-needed establishment of guidelines for use by engineers in deciding which fly ash to use in combination with available cements and aggregates to ensure adequate performance of the concrete in service. It is only through the understanding of the fundamental mechanisms governing the interaction among the alkalies in the cement and fly ash and the aggregate used in concrete that adequate guidelines for proper, economical, and efficient use of fly ash in concrete can be developed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

CHAPTER 1

INTRODUCTION

1.1 Justification

In the late 1930's several concrete structures in California began to show a disturbing damage in the form of abnormal cracking beyond drying shrinkage or freeze and thaw [1]. Thomas E. Stanton [2] was the first to suggest that this deterioration was due to a reaction between the so called alkalies in the cement and certain responsive siliceous elements of the aggregates within the concrete.

Stanton's article initiated a long series of experiments and investigations in the United States, during the 1940's, and abroad, during the 1950's [1,3]. The first practical result was the establishment of a limit on the alkali content in portland cement in order to prevent the deleterious reaction from occurring. This limit was set at 0.6% by weight of the cement, based mainly on mortar bar test results (ASTM C 227). Cements below that limit are referred to as "low alkali" cements.

The basis for the specification concerning the limit of 0.6% content of alkalies in cement dates back to work done only with reactive opaline materials [5] and subsequently was applied to other reactive aggregate types. Investigators such as D.C. Stark and others [5,6] have proved that the 0.6% cutoff concept can be misleading in many cases. Furthermore, in the last two decades the problem of conservation of energy has been of paramount importance in any field or industry, including the concrete industry. Reducing the alkalies in cement by only 0.15% results in a 300% increment in energy consumption [7]; besides, the Environmental Protection Agency no longer permits alkalies to be vented out the chimney and pollute the atmosphere or to be buried and pollute ground water. As a result, efforts were made to try to demonstrate that portland cement containing higher than the permissible alkali content according to ASTM C150, Standard Specification for portland cement, could be safely used in combination with a reactive aggregate using pozzolans such as pulverized-fuel ash (known as fly ash) [4,8].

Consequently, the use of fly ash in concrete has increased tremendously in the last ten years. However, fly ash also contains alkalies, either naturally (from the coal) or artifically added. An available alkali content limit of 1.5% by weight in fly ash to be used in concrete has been suggested by ASTM C 618, Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for use as a Mineral

2. To establish a relationship, if possible, among relevant components of fly ash, portland cement and concrete aggregates to be used in preventing alkali-aggregate reaction damage in concrete;

3. Provide further information on the adequacy of existing fly ash specifications to ensure satisfactory performance of concretes containing fly ash, especially as related to alkali-aggregate reaction; and

4. To establish guidelines in a form useful to field engineers for the selection and use of fly ash in concrete.

1.3 Definition of Akali-Aggregate Reaction

Prior to 1940 it was assumed that aggregates were, in general, innocuous constituents of concrete. As Stanton [9] pointed out with his investigations in 1940, all aggregates can be considered reactive although only those that actually cause damage to concrete are of concern in concrete practice, from the point of view of durability.

The basic approach to durability studies is to, first, establish the significance and the extent of the different kinds of degradation, characterize the product and establish each of the degradation mechanisms. Second, determine which material property serves as the best indicator of the degradation and how it can be measured. Third, devise a test to simulate the degradation mechanism in the laboratory and finally relate the laboratory test data to field test data and to practice.

It is now well established that the alkalies in mortar or concrete can react with some aggregates giving rise, under certain conditions, to deleterious expansion of the mortar or concrete.

In the early research it was thought that the alkali-aggregate reaction was only caused by the reaction between the alkalies in the cement and the silica that was present in some types of aggregates. However, later investigations indicated the existence of more than one type of alkali-aggregate reaction.

Alkali-Silica Reaction. This involves the reaction between alkalies and the microcrystalline phases of silica that may be found in volcanic, metamorphic and sedimentary rocks. The aggregates that are involved in this type of reaction are those containing amorphous (opal) and metastable (tridymite and cristobalite) forms of silica as well as certain acid, intermediate and volcanic glasses. The reactive constituents are chalcedony, cryptocrystalline quartz, and strained quartz. In general, the reactive forms of silica are randomly arrayed tetrahedral networks with irregular spaces between the molecules.

different mixes being studied. Data from specimens older than three months will be presented in subsequent reports.

An introduction and a brief literature review are presented in Chapters 1 and 2. In Chapter 3, a description of the materials used and the reasons for being selected are presented together with a description of the experimental procedures. Test results and discussion of the results are included in Chapters 4 and 5, respectively. A summary, conclusions, and recommendations for further research are contained in Chapter 6.

More than 800 specimens were cast and tested representing more than 100 mixes. The variables considered included materials, alkali content, alkali source, and percentage of cement replaced with fly ash. For this reason, the use of graphs was the only means of visualizing differences and similarities of the behavior among different specimens. These graphs are shown in Appendix A for all specimens, while material properties and mix proportion data can be found in Appendix B and C, respectively. Only commercially available materials for use by the Texas State Department of Highways and Public Transportation were utilized in this program.

This report contains valuable information regarding type and amount of fly ash to be used in concrete to prevent damage due to alkali aggregate reaction and provides an insight into what the mechanisms are which occur and how they appear in concrete.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Since the alkali-aggregate reaction was first recognized more than 40 years ago, extensive literature has been published regarding all aspects of the problem the reaction represents for concrete construction. This chapter is intended to survey, at least in part, the technical publications dealing with topics of most interest for the present study. Among the subjects treated here are: chemistry of alkali-aggregate reaction, evidences in concrete, the use of fly ash for prevention, and methods for diagnosis of affected concrete.

2.2 Chemistry of Alkali-Aggregate Reaction

Although alkali-aggregate reaction has been under study for a long period of time, very little is known about the details in which the chemical process takes place.

In order to better understand the different mechanisms involved in alkali-aggregate reaction, a look to the origins of alkalies will be examined first.

Alkalies are hydroxides of alkali metals. Alkali metals are the elements in group 1a of the periodic table of the elements: lithium, sodium, potassium, rubidium, celsium and francium. However, sodium and potassium are the sixth most abundant of the elements comprising 2.6 and 2.4% of the earth's crust, while the other alkali metals are considerably more rare comprising 0.03, 0.007 and 0.0007% of the earth's crust for rubidium, lithium and celsium, respectively. Francium, a natural radioactive isotope, is extremely rare and was not discovered until 1939 [34]. Therefore, the existance of alkalies in any compound has been measured only in terms of sodium and potassium oxides (Na_2O and K_2O) and for the purpose of this project the only alkali metals considered will be sodium and potassium.

Alkalies exist in soluble or insoluble form in cements [10]. The soluble portion is mainly derived from the fuel used in the production of cement. It is present as sulphates and as continuous series of potassium-sodium double salts. On the other hand, water insoluble alkalies are derived mainly from clay and other siliceous components of the raw mix. Generally the total amount of potassium and sodium (K_2O and N_2O) in cement does not exceed 1.0% [10]. This total is expressed as Na_2O equivalent, i.e. $Na_2O + 0.658\ K_2O$.

cations are then balanced by the hydroxyl ions, forming the well-known sodium and potassium oxides known as alkalies.

2. Formation of a hydrous alkali-silicate gel: The alkalies then react with certain components of the aggregates, silica being the most reactive. However, the silica is not always a well-crystallized element; it also exists in an amorphous (poorly crystallized) form. Dent, Glasser and Kataoka [14] explain the reaction as follows: attack on well-crystallized or other relatively dense forms of silica takes place mainly at the surface. It is rather slow and produces discrete silicate ions which pass harmlessly into the fluid paste, while the loosened network of a poorly-crystallized silica makes it easier for the hydroxyl and potassium (or sodium) ions to penetrate and disrupt the Si-O-Si bonds, as can be seen in Fig. 1.

3 and 4. Attraction of water by the gel and formation of a fluid solution (as dilute suspension of colloidal particles): The resultant structure becomes a polyelectrolyte with alkali-metal ions that, in contact with water, sets up an osmotic pressure. The partially disrupted silicon-oxygen framework (Fig. 1) acts then elastically and swells. Hobbs [5] states that any gel formed while the mortar is still setting will not develop internal significant stress and, therefore, the cracking is induced only when the volume concentration of gel exceeds a particular value, which depends on the alkali concentration in the pore water at the time the first reaction is complete.

2.3 Evidences of Alkali-Aggregate Reaction

In general, damage in a concrete structure is evident only when its surface cracks or erodes in some way. Unfortunately, different problems can cause the same or very similar surficial evidences. "Map-cracking", accompanied by a white exudation along the cracks as seen in Fig. 2, is typical evidence of alkali-aggregate reaction [15,16,1], although further analysis is necessary to confirm that it is really that reaction which is causing the damage. Petrographic analysis is necessary in order to physically observe, at a microscopic level, the damaged concrete. Some common signs of the presence of alkali-aggregate reactions are: off-white translucent to opaque agglomeration of fluffy gel-type deposits in voids, bordering the aggregates or in the cracks on the aggregates; a dark rim reaction around the aggregates which alter their edges; and cracked aggregates. Each one of these evidences may appear alone or combined with the others.

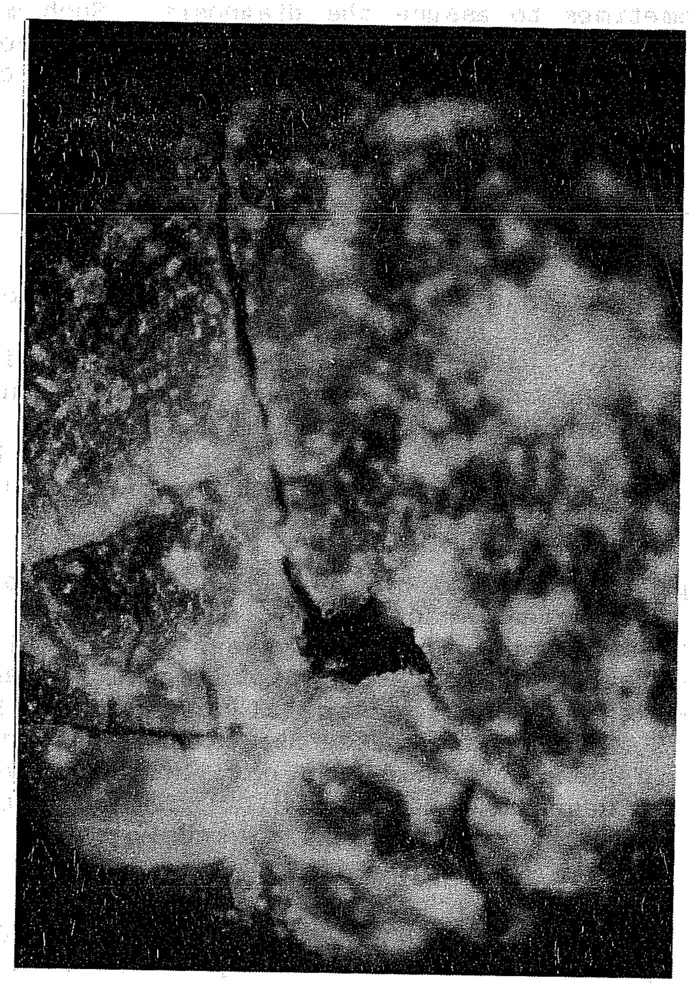


Fig. 2 Enlarged view of a crack in the surface of a concrete member due to alkali-aggregate reaction. Note the gel along the crack.

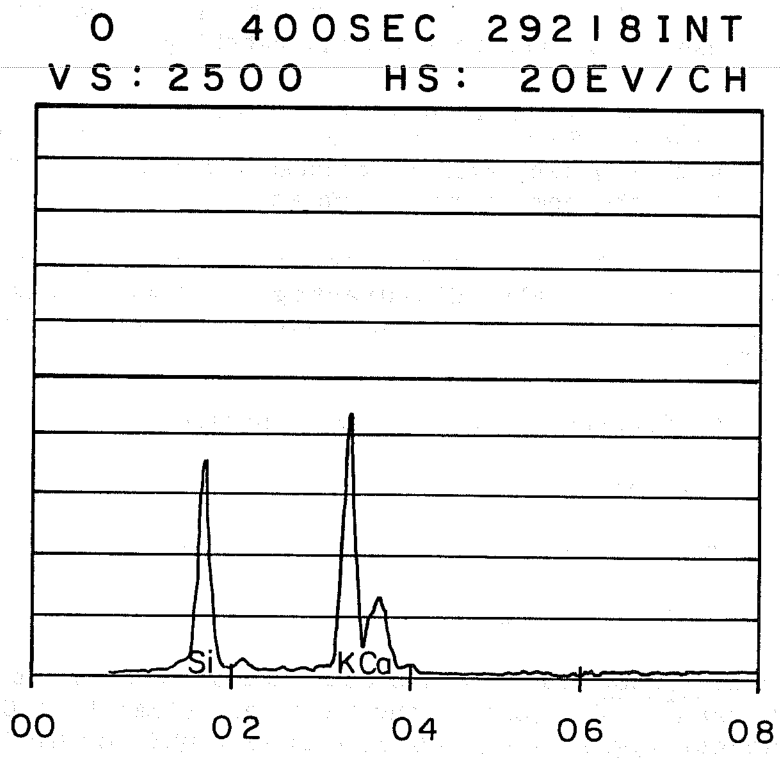


Fig. 3 EDAX spectrum from the gel

workability in concrete. Carbon particles are also more porous affecting the air-void structure of concrete which affects water content and air-entrainment agent requirements. It has been shown [29] that high-carbon fly ash, when used in air-entrained concrete mixes, may adsorb part of the air-entraining agent, thus lowering the air content and thereby reducing the freeze and thaw resistance of the concrete. ASTM sets the maximum permissible loss on ignition for fly ash at 6% by weight. The subdivision made by Cain refers to 3% as the limit between Class F fly ash with low loss on ignition and fly ash with high loss on ignition.

Class C fly ash is a somewhat "newer" type of fly ash that appeared when utilities began using lower sulfur coals, especially the type of coals found in the western regions of the country, such as lignites and subbituminous coal. This class of fly ash has some cementitious properties, besides having pozzolanic properties as well. Although ASTM sets the same maximum limit on loss on ignition for Class C fly ash as for Class F, Cain reports that most of the Class C fly ash have a low loss on ignition. Cain adds that what is relevant with respect to Class C fly ash is the degree of hydraulicity, since it exhibits cementitious properties. The classification of Class C fly ash as highly or moderately cementitious could help in the production of high strength concrete using fly ash.

In an effort to try to classify the fly ash by properties and not by source, the TSDHPT has specified two types, A and B, of fly ash according to their chemical composition as shown in Table 1. The difference between these two types of fly ash is the calcium content as reflected by the total amount of silicone, aluminum and iron oxides. Low-calcium fly ash (high content of oxides) is classified as Type A fly ash, while high calcium (low oxides) fly ash is classified as Type B fly ash. High-calcium fly ash corresponds, most of the time, with ASTM Class C fly ash, while low-calcium fly ash roughly coincides with ASTM Class F fly ash [38].

The fact that low-calcium fly ash comes from anthracite and bituminous coal while high-calcium ash comes from lignites and subbituminous coals is not necessarily true and gives place to confusion. For example, a lignite used in this project, which would be classified as Class C by ASTM, is classified as Type A by the TSDHPT. Since the different types of fly ash used in this project were provided through the Materials and Test Division of the TSDHPT, their classification is used in this report.

2.4.3. <u>Effect of Fly Ash in Preventing Alkali-Aggregate Reaction.</u> Fly ash has been reported to reduce expansion due to alkali-aggregate reaction in mortar bar tests as reported by several researchers [22,23,24,25,26,27]. However, the published literature disagrees on whether fly ash acts only as a diluter of the alkalies in portland cement or whether, through chemical reaction, it has a

TABLE 1. (Continued)

	Type A	Type B
B. Physical Requirements:		
Fineness - retained on 325 sieve (45 cm, max, %	30.0	30.0
Variation in percentage points retained on the 325 sieve from the average of the last ten samples (or less provided ten have not been tested) shall not exceed.	5.0	5.0
Pozzolanic activity index with portland cement as a minimum percentage of the control at 28 days	75	75
Water requirement, maximum percentage of control	100	100
Soundness, autoclave expansion or contraction, max, %	0.8	0.8
Increase of drying shrinkage of mortar bars at 28 days, max, %	0.03	0.03
Reactivity with cement alkalies mortar bars at 28 days, max, %	0.020	0.020
Specific gravity, maximum variation from average, %	5.0	5.0

Drying shrinkage shall be tested in accordance with ASTM C 157.
Alkali reactivity shall be tested in accordance with ASTM C 441.
Specific gravity shall be tested in accordance with ASTM C 188.
All other physical requirements shall be tested in accordance with ASTM C 311.

HCl acid in water. Then the content of sodium and potassium is determined by atomic absorption using the emission mode to make the measurements. This procedure does not follow any specifications and, therefore, should not be recommended as the guide to establish the suitability of a fly ash to be used in concrete.

2.5 Test Methods for Alkali-Aggregate Reactions Identification

There are several approved and suggested methods to evaluate the potential reactivity of an aggregate with respect to alkali-aggregate reaction. The main disagreement between them is the correlation between laboratory test results and the actual concrete to be used in the structure. In the United States, the following tests are most commonly used [29]: ASTM C 289, Test for Potential Reactivity of Aggregates (Chemical Method); ASTM C 227, Test for Potential Alkali Reactivity of Cement-Aggregate Combination (Mortar-Bar Methods); ASTM C 295, Test for Petrographic Examination of Aggregates for Concrete; and ASTM C 586, Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (Rock Cylinder Method). The first three methods are designed to predict alkali-silica reactivity potential in aggregates, while the fourth is only appropriate for the evaluation of alkali-carbonate reactivity potential.

According to Heck [29], none of the first three methods, ASTM C 289, ASTM C 227 and ASTM C 295, are adequate to predict alkali-silica reactivity potential by themselves. He suggests changes on the limits of expansion at six months, from 0.1 to 0.075% to define alkali-silica reactive aggregates. The problem of establishing safe limits of expansion is complicated by the variation in the rates of expansion and the time taken for the main expansive phase of the reaction to occur. Table 2 shows the limits set by different organizations for an aggregate to be considered safe.

Furthermore, the mortar-bar method (ASTM C 227) which is the most used of the three methods for alkali-silica reactive aggregates, is used to predict behavior of the aggregates within concrete based in tests done on mortar mixes using the same aggregates. Such correlation has not been proven to be satisfactory. Therefore, authors such as Grattan-Bellew [30] suggest the use of the Concrete Prism Test of the Canadian Standards Association, CSA A23.2-14A.

Whichever method is used, most authors agree that the use of a petrographical method is essential to determine the probable type of alkali-aggregate reaction likely to be found when using a certain type of aggregate. This is due mainly to the fact that a proper combination of tests done to predict alkali-silica reactivity of an aggregate will not be adequate to predict other types of alkali-aggregate reactivity.

In a world where time is money, a test that takes a minimum of three months to predict (with doubtful accuracy) the harmful potential of an aggregate is regarded as inefficient. In recent years, studies have been made in several parts of the world regarding accelerated methods for accurately predicting alkali-aggregate reactivity in a short period of time.

In California, Brotschi and Metha [31] suggested a modification of the mortar-bar method (ASTM C 227) to give results within a 14 day period. The modifications are mainly with respect to the heat of storage, 110^{o} F instead of the actual 100^{o}F, and a maximum expansion limit of 0.2% at 14 days.

In China, Tang, Han and Zhen [32] allegedly have found a method that only takes two days to identify alkali-aggregate reactive aggregates. This method uses 1x1x4 cm mortar bars with a cement to aggregate (c/a) ratio of 10/1 and a w/c ratio of 0.3 by weight. After demolding the specimens, they are subjected to 100^{o} C steam curing for four hours after which they are immersed in 10% KOH solution and autoclave-treated at 150^{o}C for six hours. The authors do not specify the limit at which an aggregate would be considered unsafe when using this method.

In Denmark, Damgaard et al. [33] studied two accelerated methods used in Europe known as the German Method and the Saturated NaCl Bath Method. The first method is equivalent to the Chemical Method specified by ASTM in C 289, and the second is similar to ASTM C 227.

However, the implementation of faster tests is not easy since many questions remain to be answered about the mechanism of the alkali-aggregate reaction itself. For example, it has been found that certain coarse aggregates that are reported to be nonreactive, become alkali-reactive when ground to finer sizes [10,11]. This is most important when it is realized that most of the tests done today are based on mortar mixes which use only a fine aggregate gradation. As a result, coarse aggregate must be ground to a specified finer gradation in order to be tested using any mortar bar test method.

CHAPTER 3

MATERIALS AND TEST PROCEDURES

3.1 Introduction

The current project represents the most extensive and comprehensive test done so far on alkali-aggregate reaction, at least in terms of number of mortar combinations studied and variables analyzed. This paper reports only on the first part of a broader program in which additional variables are being analyzed.

The need to correlate experimental data with actual concrete practice made it necessary to use for this program only commercially available materials for use in practice. Three types of aggregate were chosen following TSDHPT records according to their alkali-aggregate reactivity. The cements and the fly ashes used were selected according to their available alkali content.

Among the main variables included in this first stage were:

1. Aggregate alkali-silica reactivity
2. Total alkali content of cement
3. Available alkali content of fly ash
4. Fly ash (Types A and B)
5. Percentage of cement replaced with fly ash
6. Exposure time

Temperature, humidity, and mix consistency (rather than w/c ratio), were kept constant or, at least, within the permissible ranges specified by ASTM C 227.

This chapter describes the material properties and the test procedures used.

3.2 Test Specimens

A total number of 108 mixes were studied in this part of the project. Eight mortar bars were made per mix for a total of 864 specimens. All specimens consisted of 1x1x11.75 in. mortar bars,

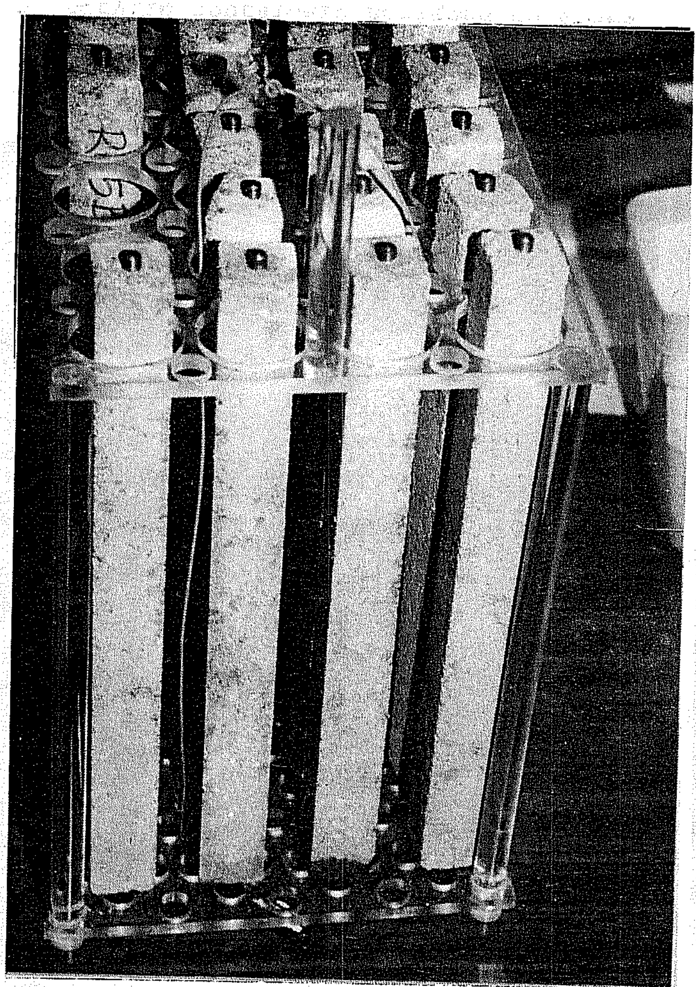


Fig. 4 Photograph of test specimens

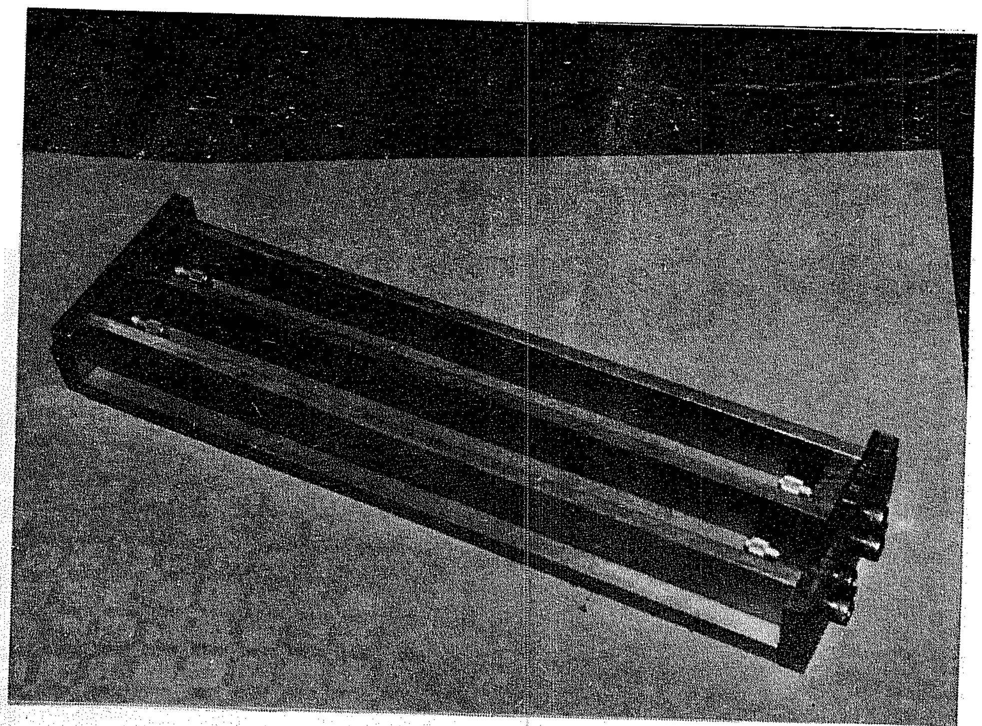


Fig. 5 Photograph of specimen molds

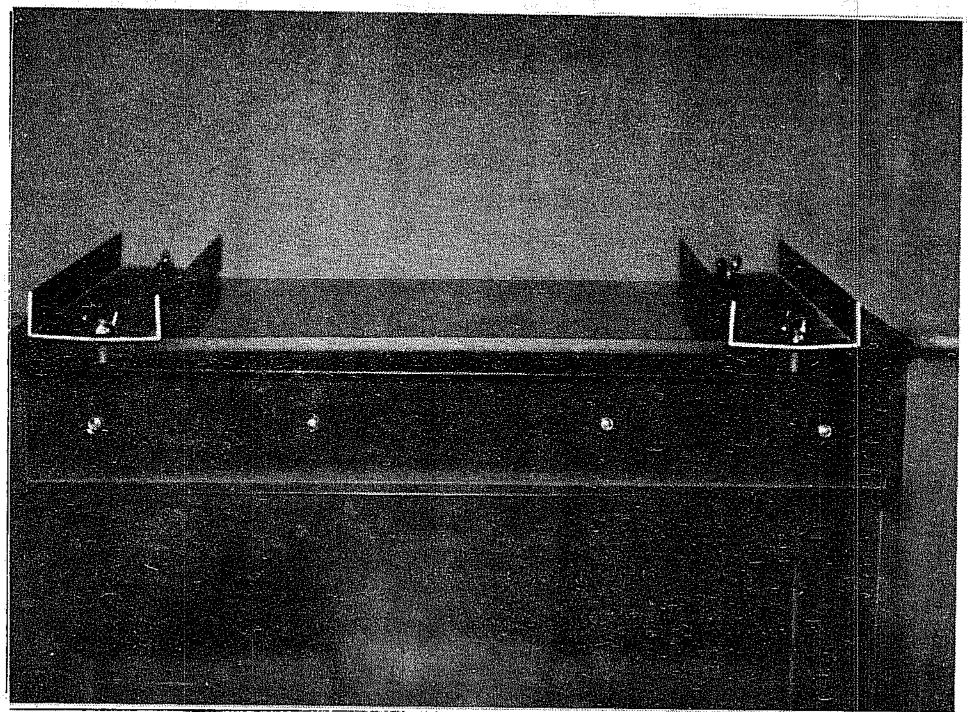


Fig. 8 Photograph of the sealing device for the storage container

data - ASTM C 295): quartz, chert, volcanic rock, and tuff; tests made with this material resulted in mortar bars expansion of 0.2% at 60 days;

2. Medium reactive - Gravel from Laredo, Texas; coarse aggregate containing the following alkali-reactive component (Petrographic data - ASTM C 295): chert, rhyolite, chalcedony, and volcanic rocks; tests made with this material resulted in mortar bars expansion of 0.11% at 60 days;

3) Nonreactive - Limestone from Georgetown, Texas; tests made with this material gave negligible values of expansion of the mortar bars, even at six months; and

4) Control - Pyrex Glass was used as the control aggregate as suggested in ASTM C 441.

Figure 9 shows the graphs for the tests done on the first two aggregate types. The aggregates were measured out and batched in oven-dry conditions.

3.3.3. <u>Fly Ash</u>. Since the current alkali content specifications are being questioned, it followed that at least one fly ash source containing a high percentage of available alkalies and one source having a low available alkali content were to be used for each type of fly ash tested. Also, three different percentages of cement replaced with fly ash were selected: 15, 28 and 37% by weight of portland cement. The sources of fly ash used in this part of the study were as follows:

1. <u>Fly Ash Type A</u>

   A. <u>High alkali content:</u>

      1) power plant - San Miguel

      2) city - Jourdanton, Texas

      3) owner - South Texas Municipalities

      4) fuel - Lignite (lower stratum)

      5) suppliers - Gifford Hill, Dallas

6) coal source - plant area

7) available alkalies - 1.38%

8) ASTM Class F

B. <u>low alkali content:</u>

1) power plant - Big Brown

2) city - Fairfield, Texas

3) owner - Texas Utilities

4) fuel - Lignite (upper stratum)

5) suppliers - General Portland, Inc.

6) coal source - plant area

7) available alkalies - 0.57%

8) ASTM Class C

1. <u>Fly Ash Type B</u>

A. <u>High alkali content:</u>

1) power plant - Seymour Johnston

2) city - LaGrange, Texas

3) owner - LCRA and City of Austin

4) fuel - subbituminous coal

5) suppliers - LCRA

6) coal source - Wyoming and Montana

7) available alkalies - 4.35%

8) ASTM Class C

B. <u>low alkali content:</u>

1) power plant - Harrington Unit 3

2) city - Amarillo, Texas

TABLE 3 Water Chemical Analysis

ANALYSIS RESULTS
in ppm

MSL ID SAMPLE ID	Na	Ca	K	Mg	Sr	Fe	Mn
85-872 NON-DISTILLED WATER	40.3	18.1	3.27	19.0	0.06	0.01	0.01
	Cl	Br	SO_4	I	HCO_3	pH	
	69	0.35	51.6	0.35	57.6	8.14	

QUALITY ASSURANCE

	Na	Ca	K	Mg	Cl	Br	SO_4	I
EPA478 #4X2								
Found	82.7	55.5	13.3	13.8				
Reported	80.0	64.0	14.4	14.2				
Standard Seawater								
Found					19600	70	2820	
Reported					19850	69	2776	
83-200								
Found								35.9
Reported								33.5

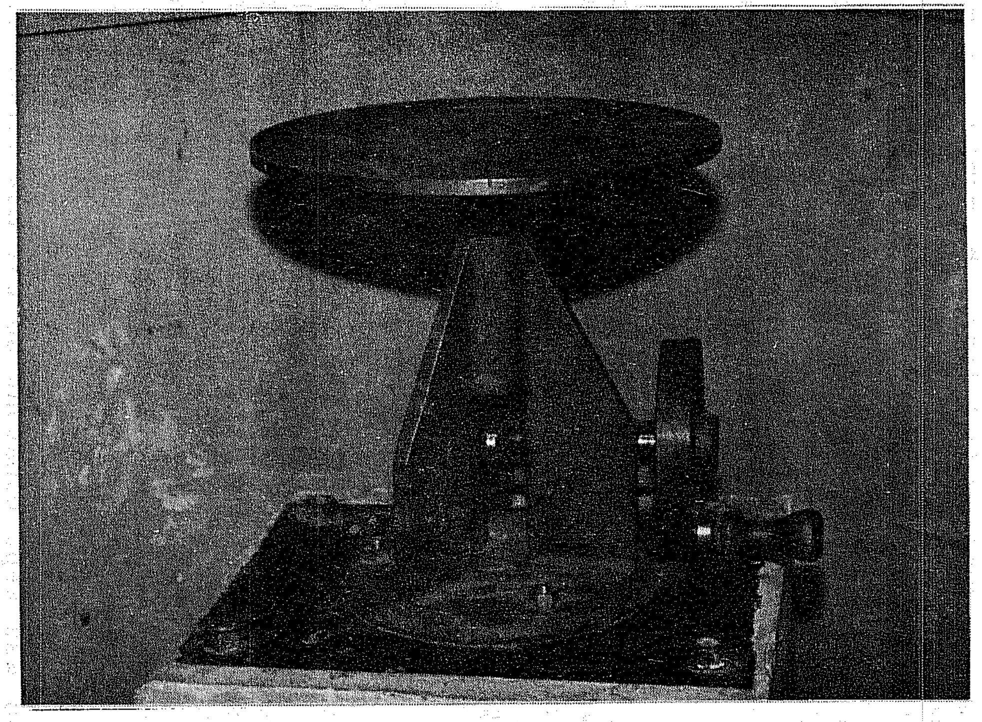


Fig. 10 Flow table used to measure consistency of the mix

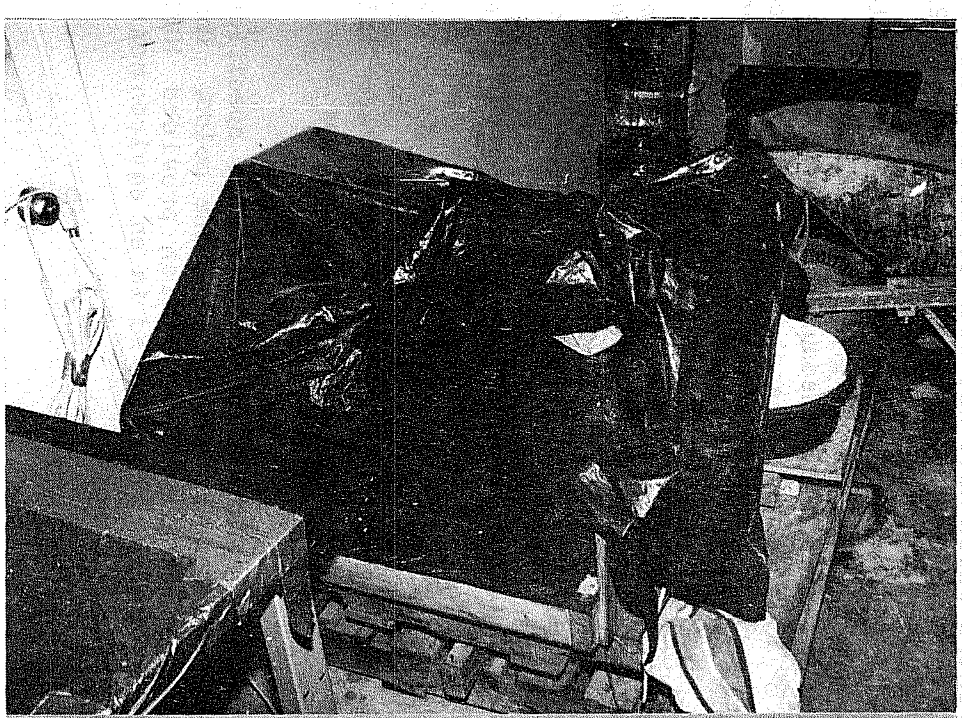


Fig. 11 Curing platform with humidifier

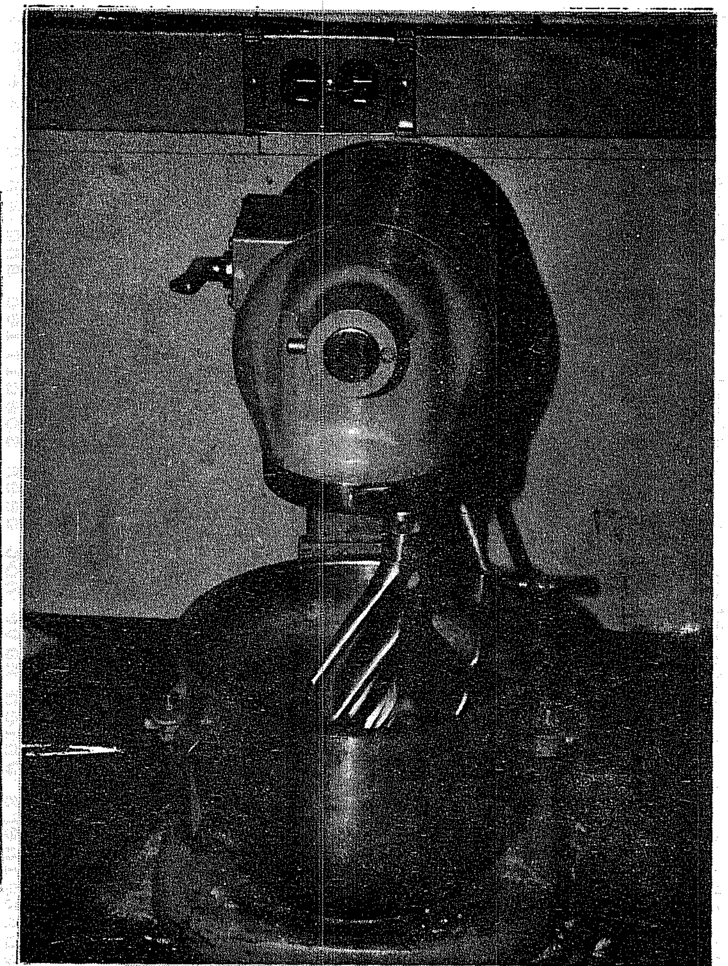


Fig. 12 Mixer, bowl, and paddle used in this investigation

TABLE 5 Grading requirements

Sieve Size		Weight Percent
Passing	Retained on	
No. 4 (4.75 mm)	No. 8 (2.36 mm)	15
No. 8 (2.36 mm)	No. 16 (1.18 mm)	25
No. 16 (11.18 mm)	No. 30 (600 m)	25
No. 30 (600 m)	No. 50 (300 m)	25
No. 50 (100 m)	No. 100 (150 m)	10

which provided a constant temperature of 100°F. From then on, measurements were taken at 14 days, 1, 2, 3, 4, 6, 9, 12, 18, and 24 months. The container with the specimens to be measured each time was removed from the environmental chamber and placed in the measuring room, at least 16 hours before opening the container.

All measurements were made using a Length Comparator as specified in ASTM C 490 and shown in Fig. 13.

The calculation of the expansion for each mortar bar was made to the nearest 0.001% of the effective gage length and the average for each combination is reported to the nearest 0.01%. After each measurement, the specimens were inspected for warping of more than 0.01 in. No apparatus is specified to make this measurement. In this study the device shown in Fig. 14 was used to measure warping.

Visual examination of the mortar bar was made to look for cracks and crack patterns, surficial deposits or exudation, or any other evidence of alkali-aggregate reaction.

3.4.4 Chemical and Petrographical Analysis. Chemical analysis of the raw materials and of certain key mortar bar samples was made in order to try to monitor the main variables and mechanisms involved in alkali-aggregate reaction. The chemical analysis consisted of the breakdown into components and X-ray diffractions of the materials sampled. In order to identify the alkali-aggregate reaction as the cause of any expansion noted, petrographic analysis was made on certain key samples and on any other mortar bar whose behavior was of interest. Two groups of mix combinations were chosen for petrographic analysis: all types of aggregates with low alkali content cement and 15% replacement of high alkali Type B fly ash; and all types of aggregates with high alkali content cement and no cement replacement with fly ash. The petrographical analysis was made on polished stubs analyzed using reflected light through an inverted microscope, as shown in Fig. 15.

3.5 Data

During each measuring session, the length of the mortar bars was measured and then recorded using spreadsheet software. A special format for the spreadsheet was designed so the expansion of each mortar bar and the average expansion of each combination was automatically calculated each time new data were read. Then, the expansion record was plotted. An example of a typical plot is shown in Fig. 16 and the measurement process is shown in Fig. 17.

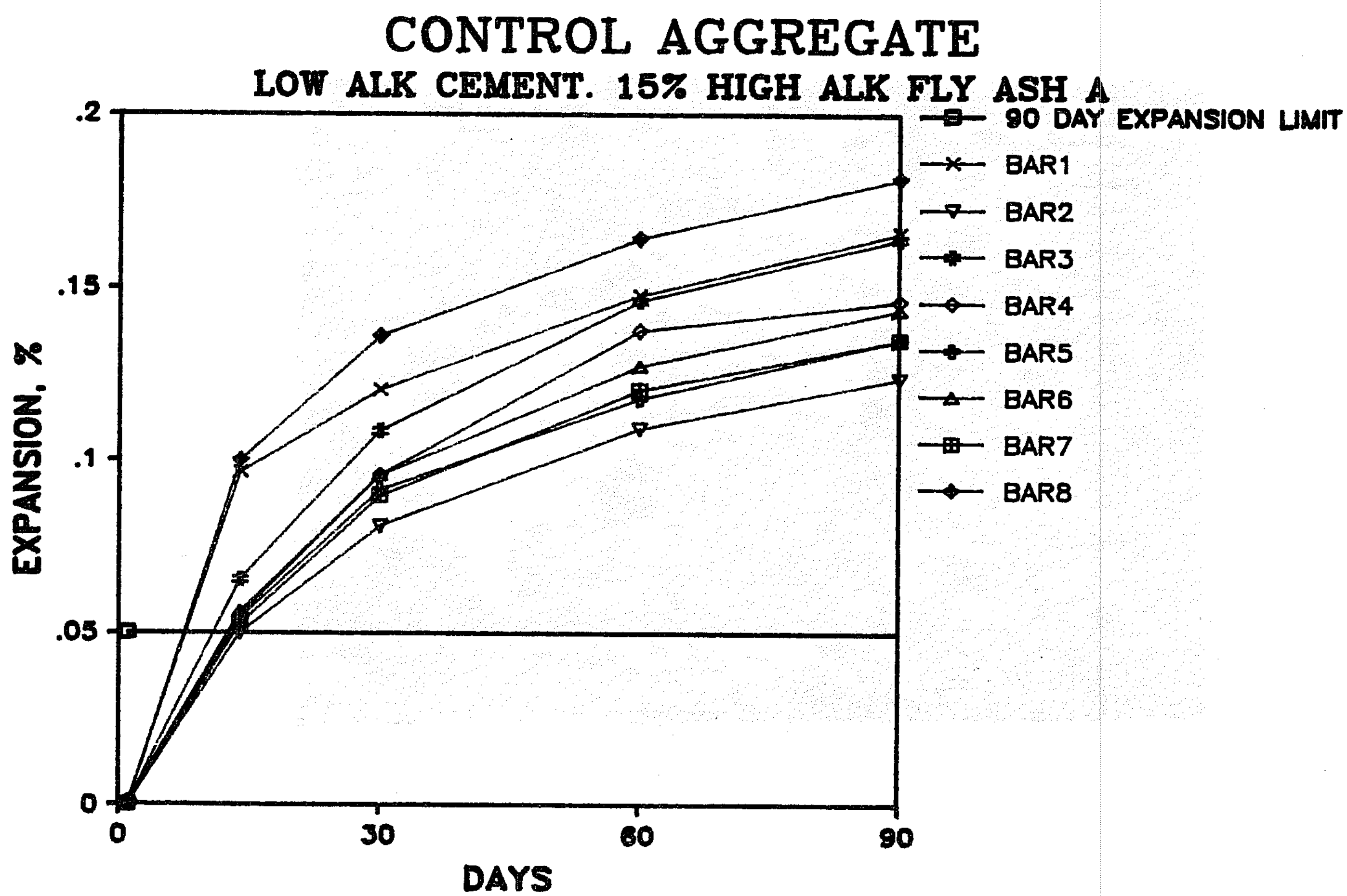


Fig. 16 Typical plot for a mix containing pyrex glass and low alkali cement.
No fly ash

CHAPTER 4

TEST RESULTS

4.1 Introduction

The main objective of the present study was to compare the effect on the alkali-aggregate reaction mechanism of certain sources of aggregates of known alkali-reactivity in combination with different portland cements and different classes of fly ash at several replacement percentages including mixes without fly ash. Mixes using a control aggregate, pyrex glass, were also made for every combination of materials tested, to determine the level of "maximum reactivity," as per ASTM C227 test procedure. Test results presented in this report are limited to 90 days exposure testing. Other variables such as air entrainment, fly ashes with different content of alkalies, cement with a content of alkalies close to 1%, as well as longer exposure testing will be discussed in later reports as part of this research project.

The part of this project discussed herein includes the combination of three types of cement, four aggregate sources and four fly ash sources. Consequently, the test results are grouped according to the variable to be discussed in each section of this chapter.

The test results are based mainly on the percentage of expansion of the mortar bars at 90 days, as determined by ASTM C227, and are presented in detail in Appendix A. The expansions reported are the average expansion of the bars for each mix that fell within the range established by ASTM C227 for satisfactory precision.

4.2 Cement Type

Three types of cement were considered in this study as described in Chapter 3: a Type I cement containing less than 0.6% of alkalies which is denoted in all graphs here as Low Alkali Cement; a Type I cement containing more than 0.6% of alkalies, referred to as High Alkali Cement; and a Type IP cement.

Mortar bar expansion varied with cement alkali content for mixes with no fly ash for all types of aggregate used. A typical plot is shown in Fig. 18.

Test results for the different sources of Type I cement in mixes without fly ash are grouped with the test results of mixes using Type IP cement in four graphs plotting percentage of expansion vs. time, one for each aggregate type; these graphs are shown in Appendix A.

For all aggregates used, mixes using Type IP cement reacted less than the mixes using the other two sources of Type I cement in mixes without fly ash. An example of this is shown in Fig. 19 for mixes containing pyrex glass.

4.3 Aggregate Type

Three aggregate sources were used in this part of the project:

1. An aggregate which had shown negligible expansion when tested using the mortar bar method, denoted in this project as Nonreactive Aggregate

2. An aggregate which showed 0.14% expansion at three months and 0.17% at six months, denoted herein as Medium Reactive Aggregate

3. An aggregate which showed 0.27% expansion at three months and 0.33% at six months, denoted as Highly Reactive Aggregate

These aggregate sources were selected on the basis of results of ASTM C227 mortar bar tests, conducted by TSDHPT, using a cement containing 0.91% alkalies.

In general, the higher the reactivity, the higher the mortar bar expansions, as can be seen in Fig. 20. Repeatability with the test results of TSDHPT was satisfactory: the expansions for the mixes using medium reactive aggregate were indeed considerably smaller than the expansions of the mixes using highly reactive aggregate; the expansions for the mixes using nonreactive aggregate were very small, being for most of the cases close to or smaller than 0.01%. For example, when the aggregates were used in combination with the high alkali cement, the expansions were 0.073%, 0.032% and 0.017% for highly reactive, medium reactive and nonreactive aggregate, respectively. In general, expansions increased with time for all aggregates. Figure 20 is a typical example of this fact.

Test results for the different sources of aggregate in mixes without fly ash are grouped in Appendix A in three graphs plotting percentage of expansion vs. time, one for each cement used. Examples of such graphs are shown in Figs. 20 and 21.

4.4 Fly Ash

4.4.1 Type. Four sources of fly ash were used in this study; two sources of Type A fly ash and two of Type B fly ash. The fly

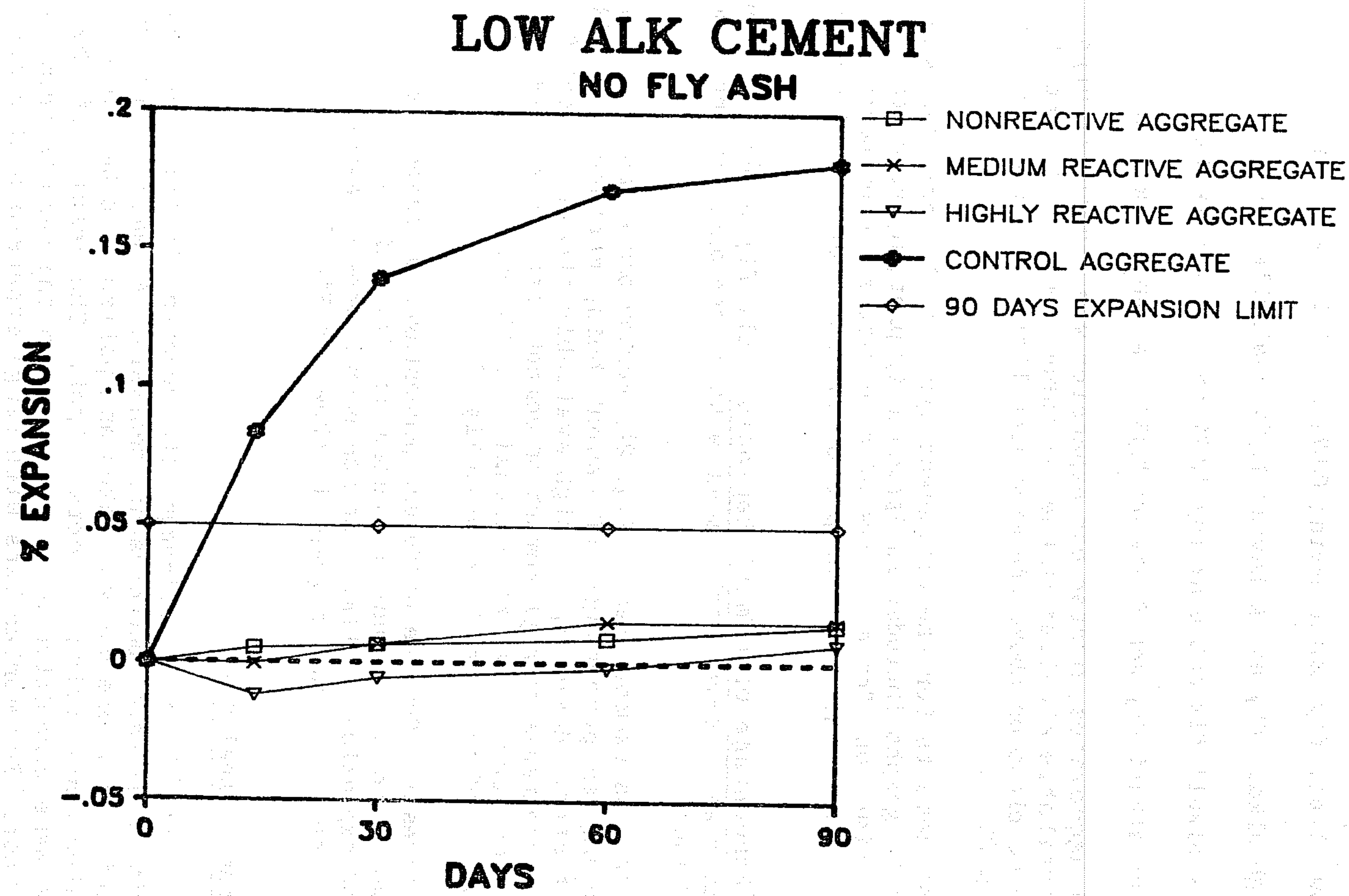


Fig. 21 Percentage of expansion vs time for all mixes made with low alkali cement and without fly ash

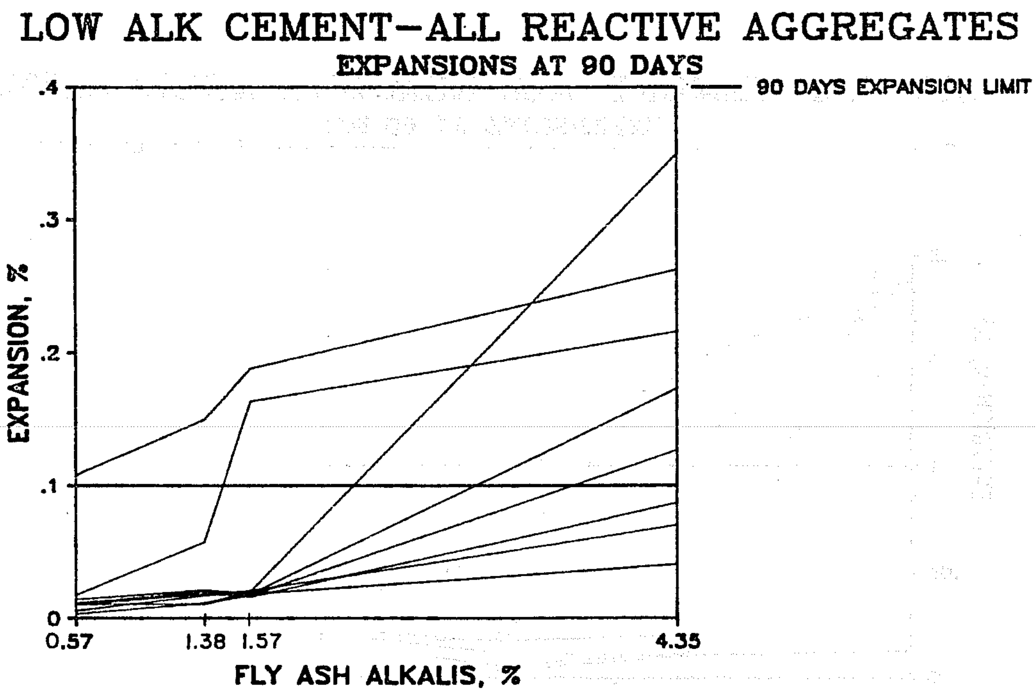


Fig. 22 Percentage of expansion at 90 days vs content of alkalis of fly ash for all mixes made with reactive aggregates and low alkali cement

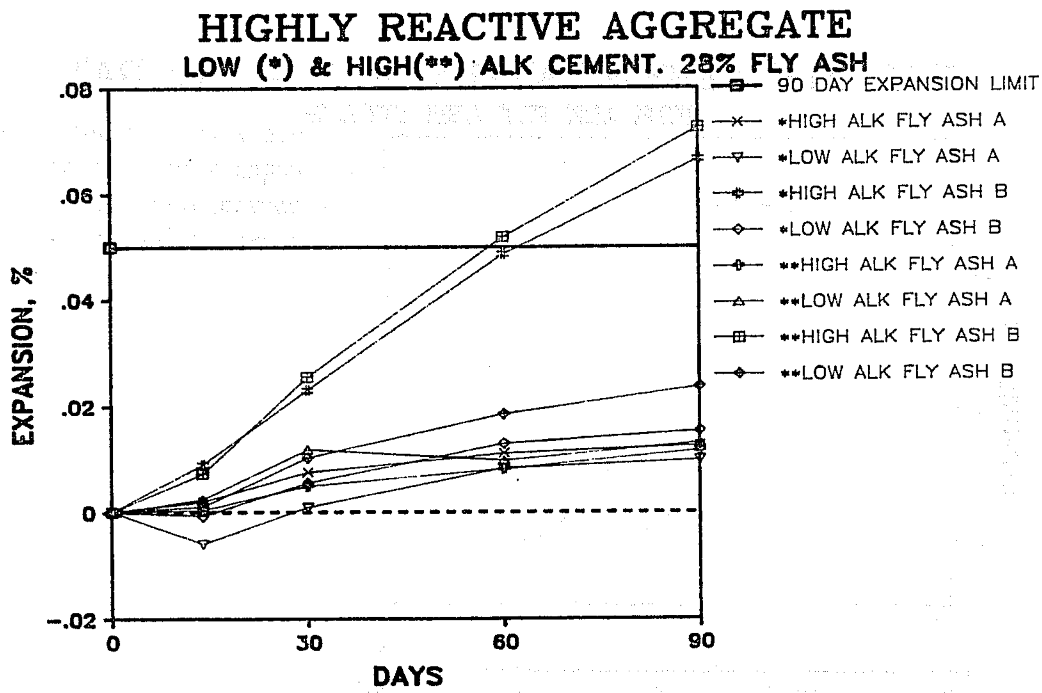


Fig. 23 Percentage of expansion vs time for all mixes made with highly reactive aggregate, containing 28% fly ash

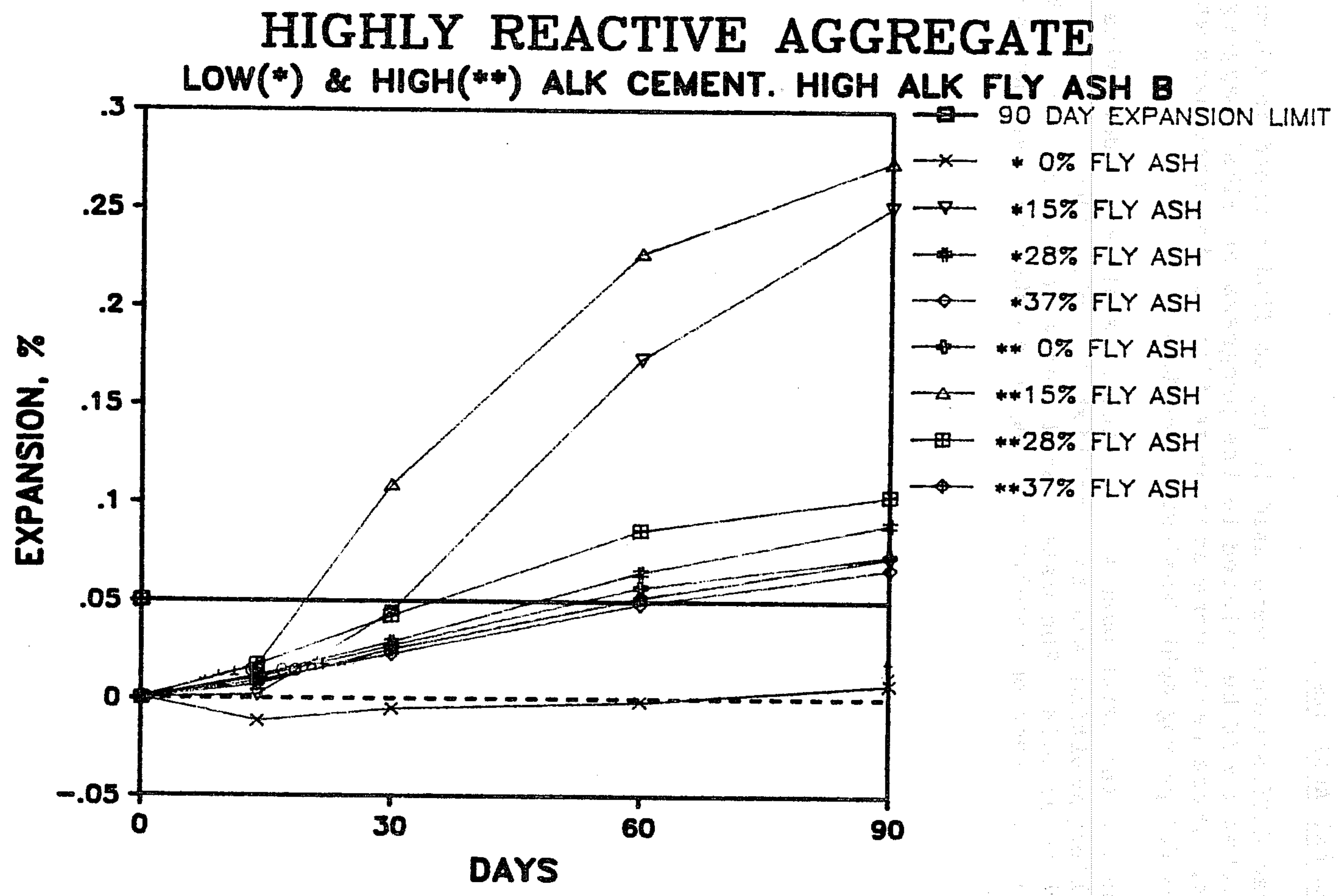


Fig. 26 Percentage of expansion vs time for all mixes made with highly reactive aggregate and high alkali Type B fly ash

CHAPTER 5

DISCUSSION OF TEST RESULTS

5.1 Introduction

The experimental test results presented in Chapter 4 are discussed in this chapter. Explanations for the observed effects of different variables on the alkali-aggregate reaction are examined.

5.2 Cement Type

For all cements used, in any mix containing no fly ash, mortar bar expansion increased with time as shown in Figs. 27 through 30. In general, a similar trend is also observed in mixes with Type IP cement.

When used with a nonreactive aggregate, the alkali content of the different cements does not influence significantly the behavior of the mix with respect to alkali aggregate reaction. Figure 27 shows that, although the expansion is affected by the alkali content and by the presence of fly ash, the variation on the degree of reactivity is almost negligible and its level well below the 0.05% expansion limit as specified in ASTM C227.

When used with medium reactive aggregate, the effect of the type and alkali content of the cement on mortar bar expansion was significant. The trends for each type of cement are well defined, as shown in Fig. 28. For the Type I cements without fly ash, the higher the alkali content of cement, the larger the mortar bar expansions. In the case of Type IP cement, having 20% of the cement replaced with fly ash, the beneficial effect of the blend is such that shrinkage is no longer offset by the expansion as in the case of the Type I cements as can be seen in Fig. 28. Based on the test results at 90 days the use of medium reactive aggregate in combination with high alkali content cement in mixes without fly ash resulted in expansions below the 0.05% limit. The trend of the expansion curve is such that it is probable that mortar bar expansion, for mixes with high alkali cement, will be very close to the limit specified for six months. However, using Type IP cement and low alkali Type I cement in mixes without fly ash made with medium reactive aggregate resulted in negligible expansions at 90 days. Therefore, using low alkali Type I cement and Type IP cement, in mixes containing medium reactive aggregate, results in a lower risk of damage due to alkali-aggregate reaction.

When used with a highly reactive aggregate, high alkali cement produces detrimental effects to the mortar, as observed in the test results at 90 days shown in Fig. 29. Type IP cement and low alkali

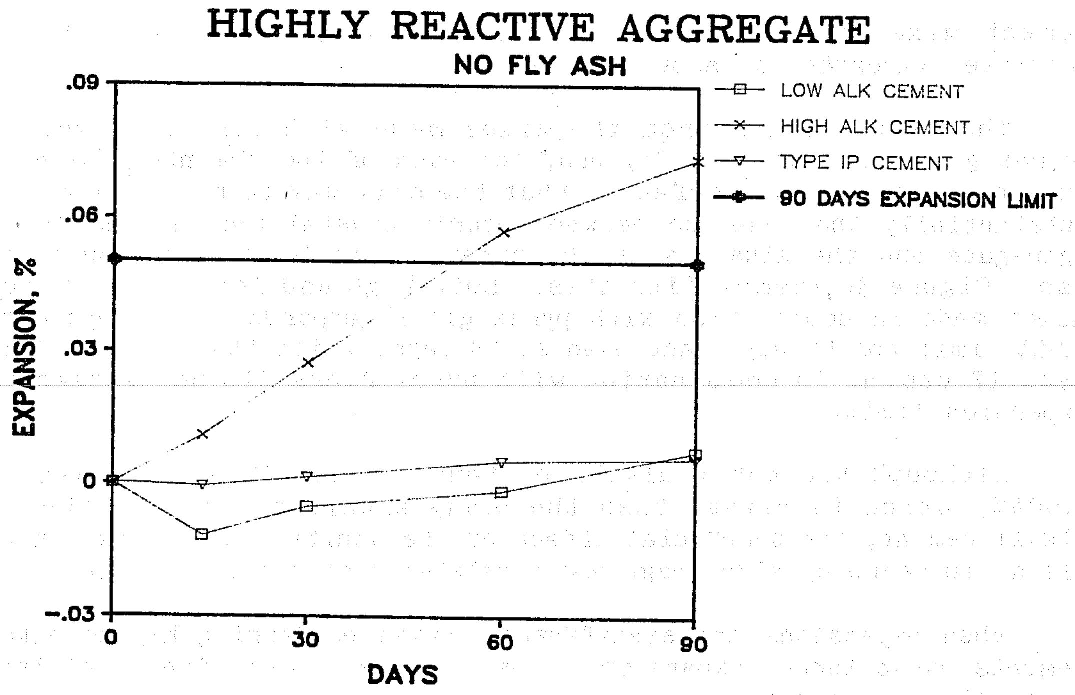


Fig. 29 Percentage of expansion vs time for all highly reactive aggregate mixes without fly ash added during mixing

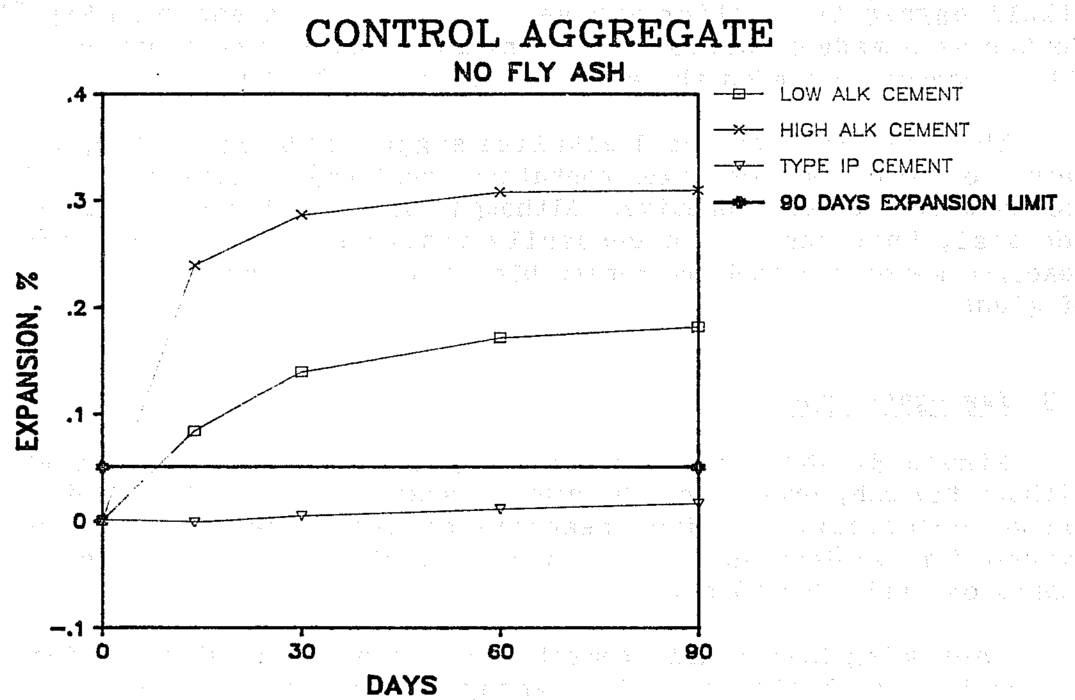


Fig. 30 Percentage of expansion vs time for all control aggregate mixes without fly ash added during mixing

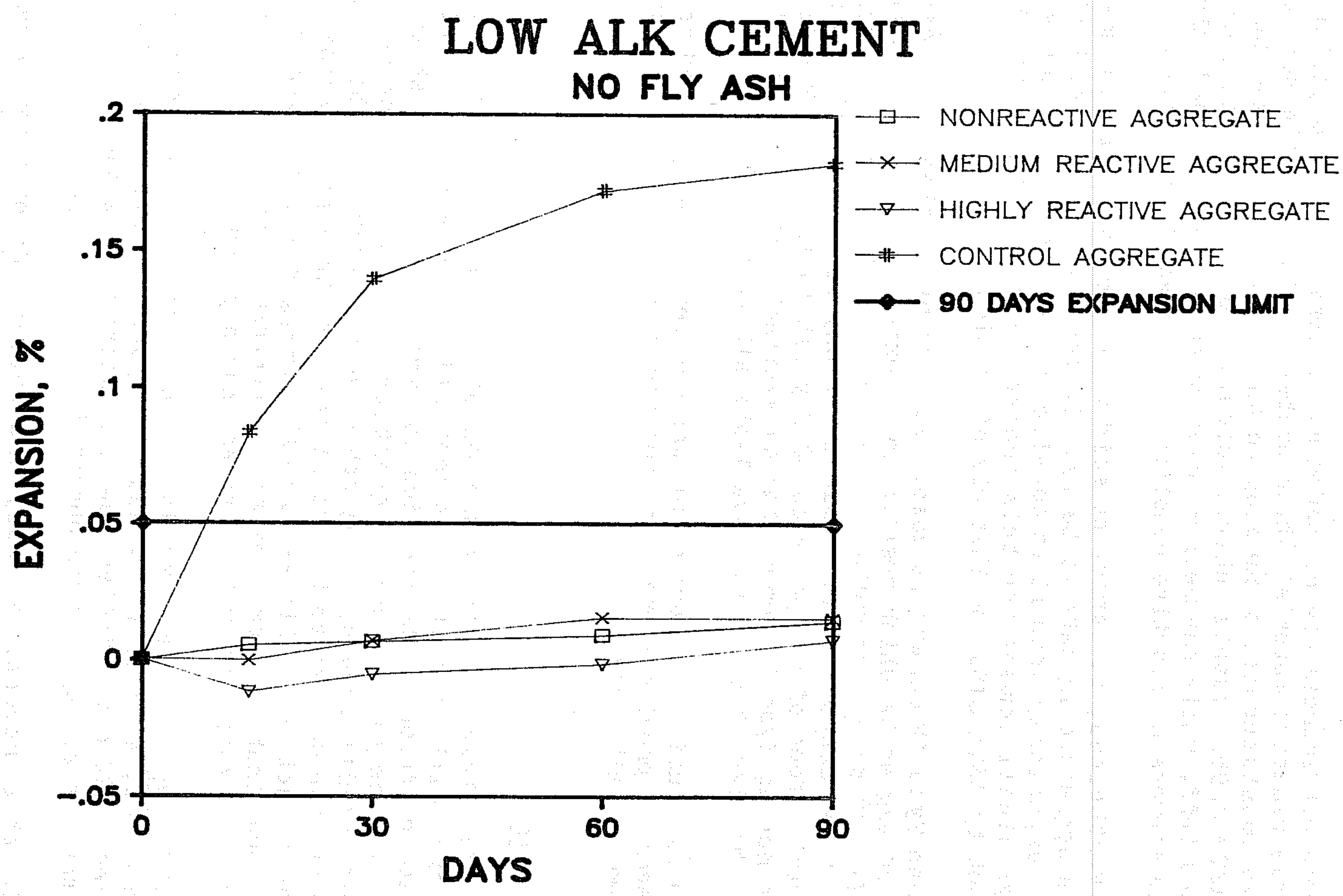


Fig. 31 Percentage of expansion vs time for all low alkali cement mixes without fly ash

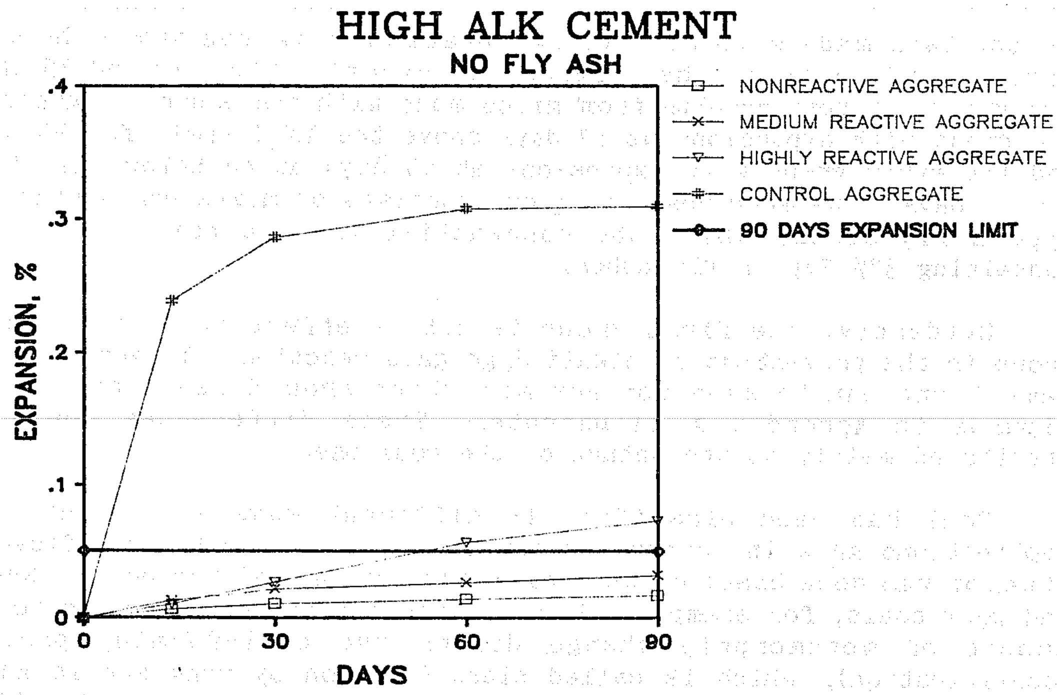


Fig. 32 Percentage of expansion vs time for all high alkali cement mixes without fly ash

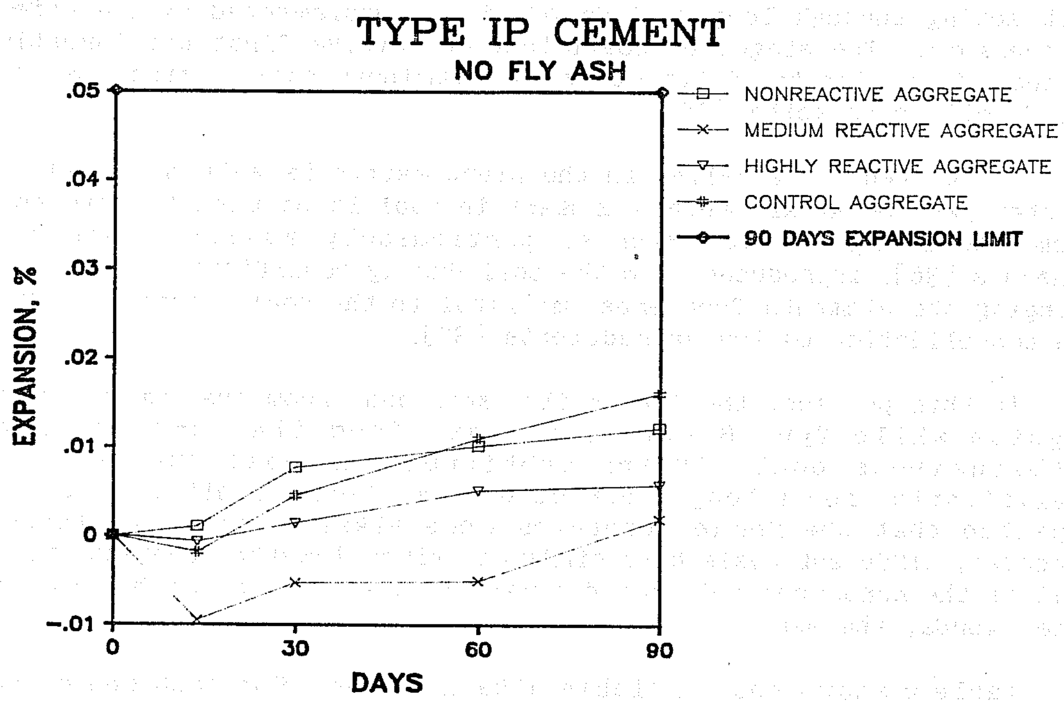


Fig. 33 Percentage of expansion vs time for all Type IP cement mixes

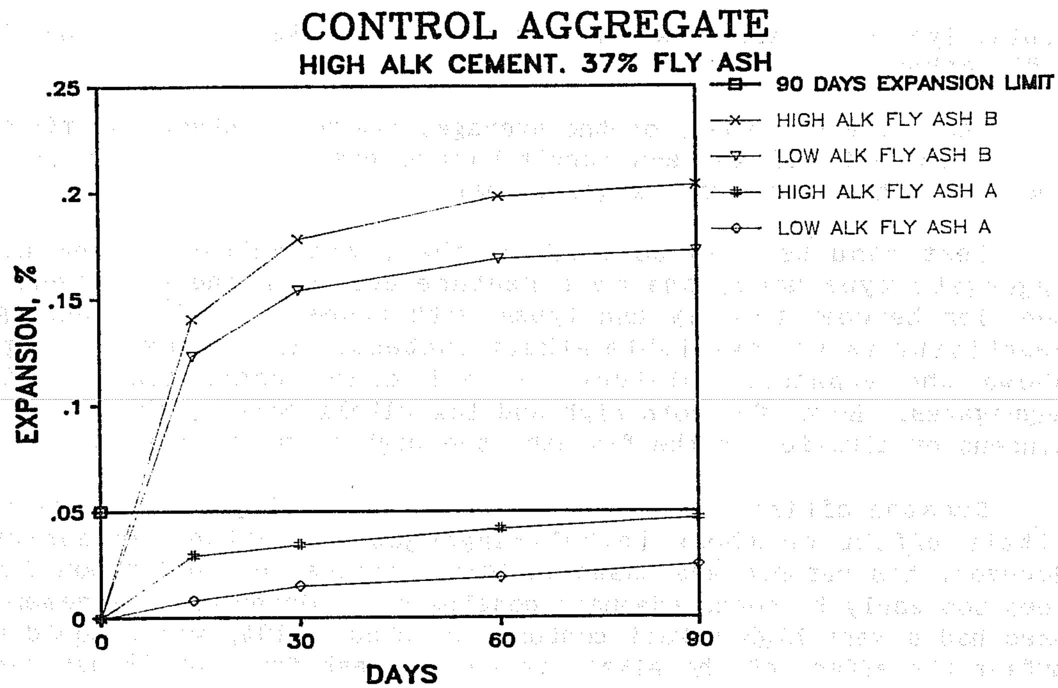


Fig. 34 Percentage of expansion vs time for all control aggregate mixes containing high alkali cement with 37% fly ash

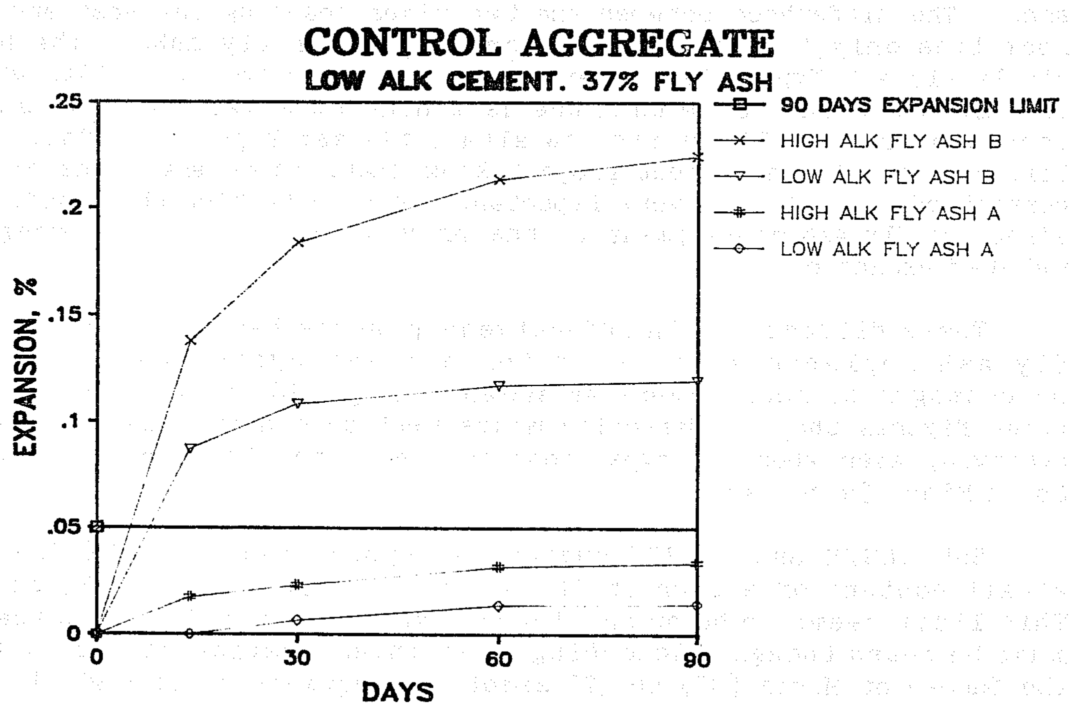


Fig. 35 Percentage of expansion vs time for all control aggregate mixes containing low alkali cement with 37% fly ash

TABLE 6 Available Alkali Content for Fly Ashes Used in this Project

PLANT	TYPE	AV. ALK. %
Big Brown	A	0.57
San Miguel	A	1.38
Harrington, 3	B	1.67
Fayette	B	4.35

TABLE 7 Typical Proximate and Ultimate Analysis and Heating Values of Coal Representative of Major Coal Reserves in the United States

Coal Type	Ultimate analysis (dry) (wt %)						Proximate Analysis (as received)				Heating value as received (Btu/lb)
	C	H	S	N	Ash	O	Volatile Matter	Fixed Carbon	Moisture	Ash	
Lignite	65.7	4.5	1.0	1.2	9.2	18.4	31.4	25.9	35.5	7.2	7,100
Western subbituminous	62.6	4.0	1.0	1.0	13.6	17.8	36.6	42.8	8.1	12.5	9,400
Illinois No. 6	70.0	4.9	3.8	1.4	9.2	10.7	41.1	39.6	11.2	8.1	11,300
Eastern bituminous (high-sulfur)	70.4	4.6	4.6	1.4	10.5	8.5	37.0	46.4	6.9	9.7	11,700
Eastern bituminous (low-sulfur)	79.9	5.5	1.3	1.5	5.4	6.4	36.9	53.9	4.0	5.2	14,000

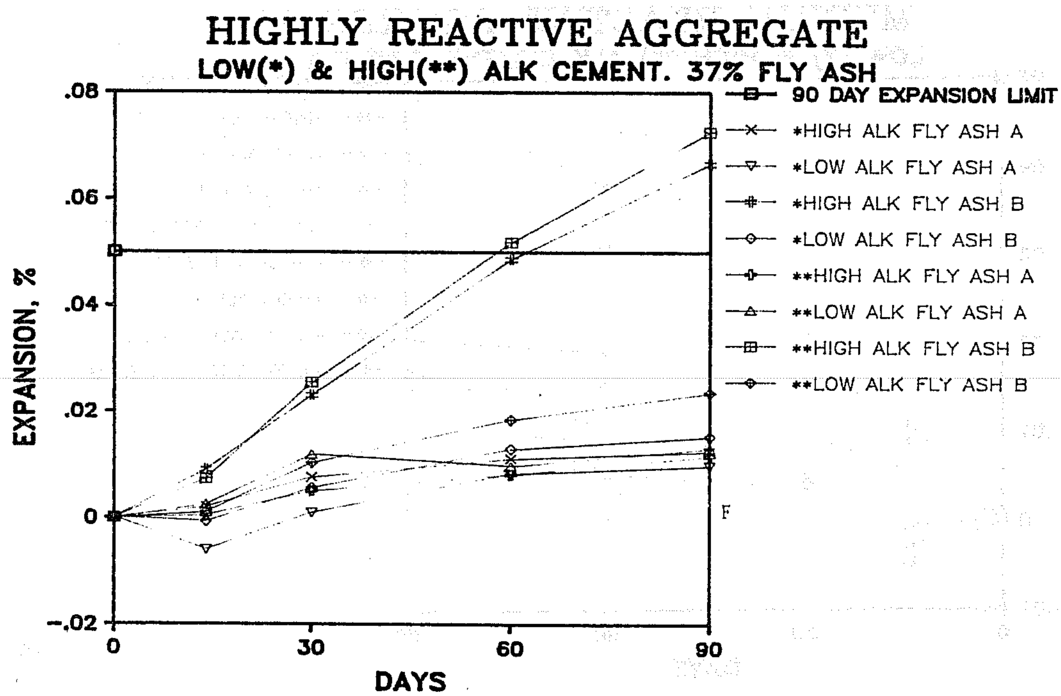


Fig. 37 Percentage of expansion vs time for all highly reactive aggregate mixes containing 37% fly ash

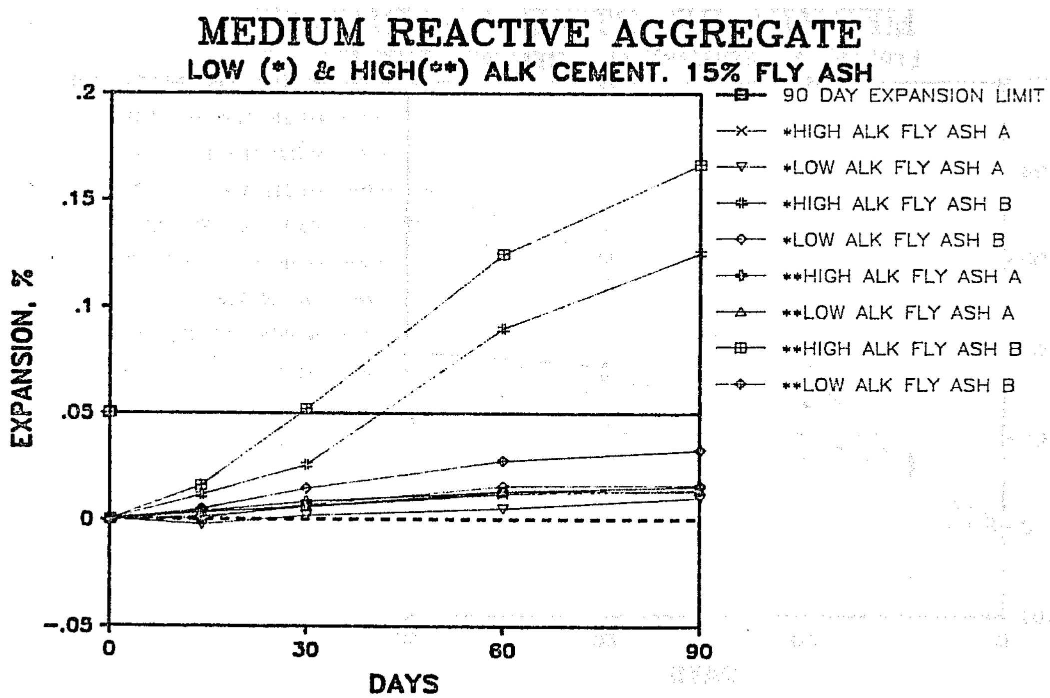


Fig. 38 Percentage of expansion vs time for all medium reactive aggregate mixes containing 15% fly ash

United States, an average value for different constituents of the coal was found. Interestingly enough, the average potassium oxide content was 1.5% and the average sodium oxide content was 0.5%, which gives a total of alkalies in terms of equivalent of 1.5%.

It is obvious, from the test results shown in Figs. 38 through 40, that the 1.5% limit on available alkali content of a fly ash when used with reactive aggregate or high alkali cement could be exceeded without inducing expansions in excess of 0.5% at 90 days depending on the materials used and their proportions.

Another variable in the fly ash possibly affecting the alkali-aggregate reaction in concrete is the calcium oxide content. Ming Shu et al. [22] affirmed that "when the cements have the same alkali content, the lower the basicity of the admixture, the less vigorous is the alkali-silica reaction." Dunstan [21] also suggested the deleterious effect of high content of calcium oxide in the fly ash. However, it seems that the effect of the available alkali content on the alkali-aggregate reaction is more pronounced than the effect of calcium content. Figures 41 and 42 show the expansion of mixes made with high alkali cement and low alkali cement against the CaO content of the fly ash. As can be seen from these graphs, no correlation seems to exist between the CaO content and the mortar bar expansions. The same was true for all mixes tested in this part of the current research project. Table 8 shows the fly ash CaO content.

TABLE 8 Calcium oxide content for fly ashes used in this project

PLANT	TYPE	CaO %	AV. ALK. %
Big Brown	A	14.35	0.57
San Miguel	A	2.52	1.38
Harrington, 3	B	30.47	1.67
Fayette	B	23.43	4.35

In his study, Ming Shu [22] does not report the alkali content of the cement used in his experiments. In addition, his tests were conducted comparing basicity of admixtures made combining cement with fly ash, and then adding to that blend, by artifical means, CaO.

In summary, the test results of this project suggest that the main factor affecting the effectiveness of different fly ash types in

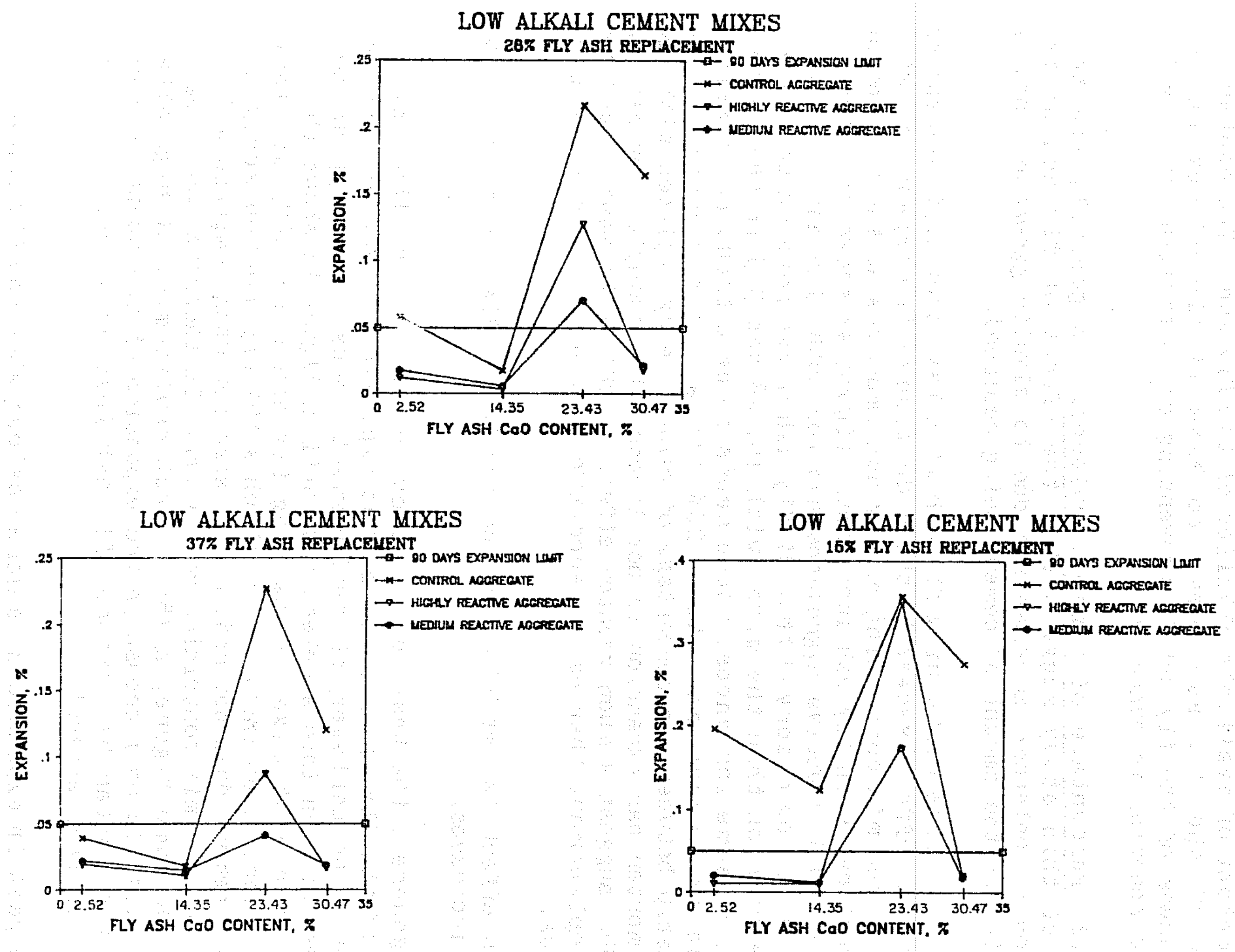


Fig. 42 Percentage of expansion at 90 days vs CaO content of fly ash for all mixes made with reactive aggregates and low alkali cement

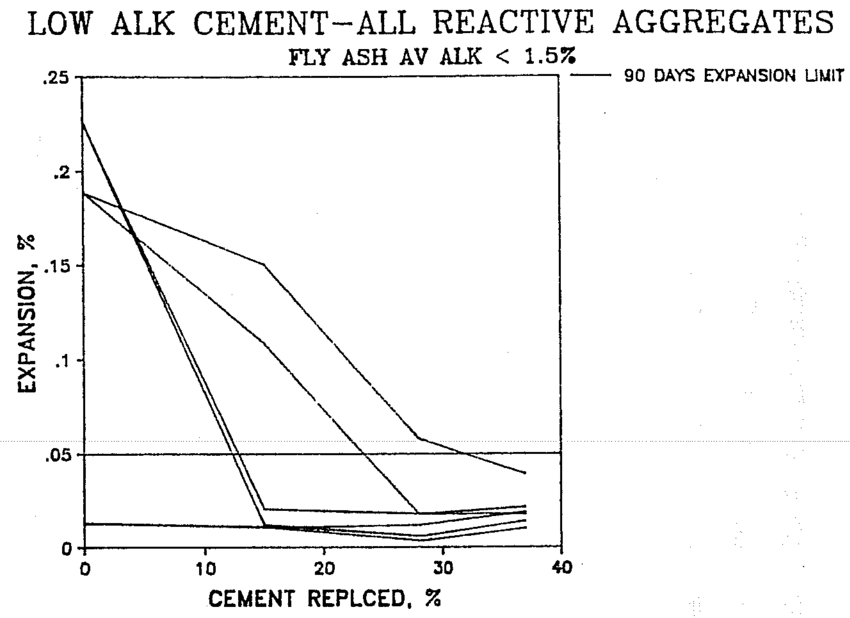


Fig. 43 (a) Percentage of expansion at 90 days vs percentage of cement being replaced, for all mixes made with low alkali cement and with fly ash containing less than 1.5% alkalies

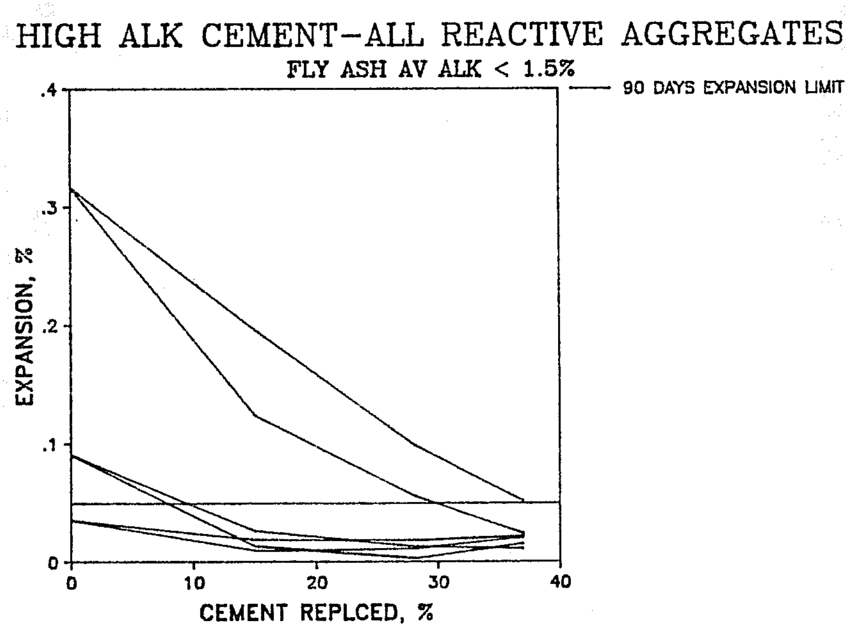


Fig. 43 (b) Percentage of expansion at 90 days vs percentage of cement being replaced, for all mixes made with high alkali cement and with fly ash containing less than 1.5% alkalies

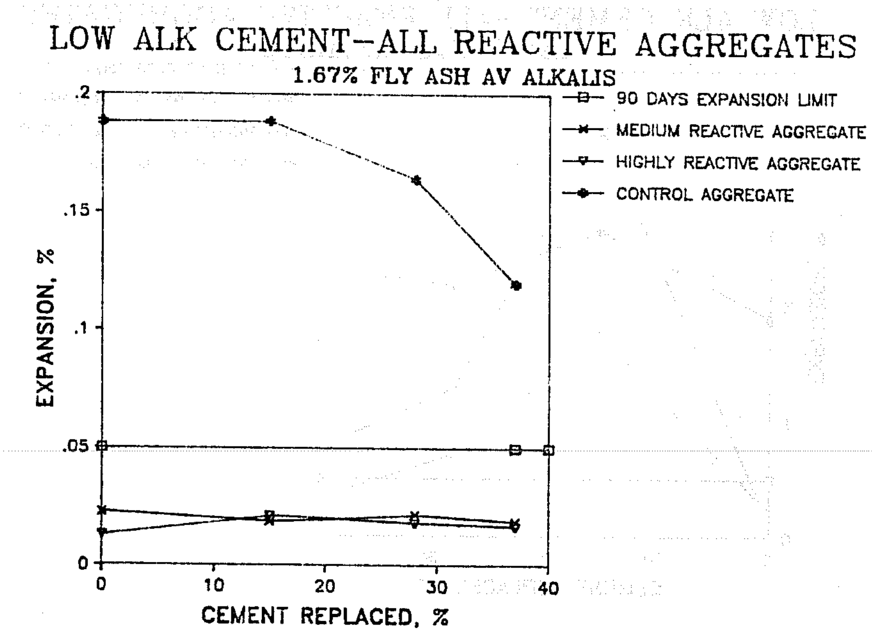


Fig. 45 (a) Percentage of expansion at 90 days vs percentage of cement being replaced, for all mixes made with low alkali cement, reactive aggregates, and fly ash containing 1.67% alkalies

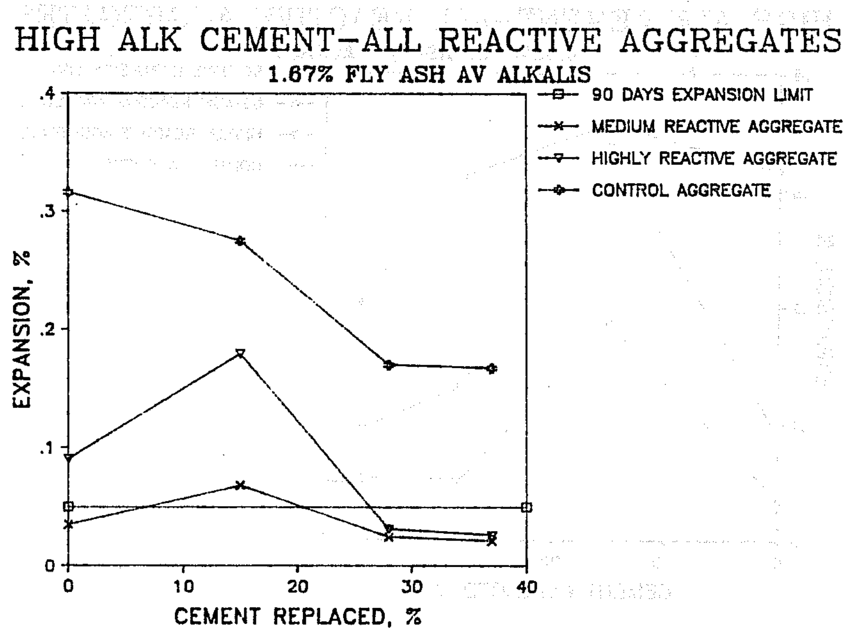


Fig. 45 (b) Percentage of expansion at 90 days vs percentage of cement being replaced, for all mixes made with high alkali cement, reactive aggregates, and fly ash containing 1.67% alkalies

The issue of the existence of a percentage or percentage range with worsening effects, rather than preventive effects, has been already addressed by previous investigators such as Dunstan [21], and is called the "pessimum limit." According to Dunstan, small amounts of certain pozzolans produce an increase of expansion while larger amounts of the same pozzolan result in a decrease in expansion. He also affirms that "regardless of the alkali level, the expansion is reduced if enough fly ash is used," and suggests that the minimum replacement to reduce expansion is very close to the calcium oxide content of the fly ash. The last statement was not confirmed by the test results of this study. As Figs. 45 and 46 illustrate, different combinations of cement and aggregate with the same fly ash can result in different "pessimum limits."

Ming Shu, et al. [22] explain the pessimum limit problem as follows: because of the chemical structure characteristics of the fly ash, it will inevitably absorb alkalies from the pore solution of the cement paste, instead of releasing alkalies, at an early stage of hydration, regardless of the amount of fly ash. However, if there is an insufficient amount of fly ash, and this varies with type of fly ash, calcium hydoxide will gradually react with the fly ash, forming a product from which alkali will be released into the pore solution by ionic exchange.

On the other hand, the test results show that when a fly ash has an alkali content high enough to exhibit a "pessimum limit," the latter is higher for mixes using low alkali cements than for mixes using high alkali cement, as shown in Fig. 46. This remarkable fact is not only peculiar, but has not been reported previously.

One possible explanation can be tentatively drawn. During the hydration process of cement, silicates, aluminates and sulphates react forming ions that are balanced by Ca^{++} [15]. However, in high alkali cement mixes some of those ions are balanced by sodium and potassium ions instead of calcium ions [14]. Thus, the pore fluid pH tends to be abnormally high, a factor which favors alkali-aggregate reaction. When fly ash is added to such mixes, the pozzolanic reaction itself takes care of the abnormal pH, regardless of the available alkali content of the fly ash. On the other hand, this process is not the same for low alkali cements where the pH remains lower and the alkali-aggregate reaction is more dependent only on the alkali content in the pore fluid. Therefore, when fly ash is added to such mixes, its available alkali content does play the main role on its effectiveness in reducing expansion and, therefore in the minimum amount needed to cause a decrease in expansion or pessimum limit. Consequently, although absolute expansions are still larger for high alkali cement mixes than for low alkali cement mixes, the latter could have a higher pessimum limit than the former.

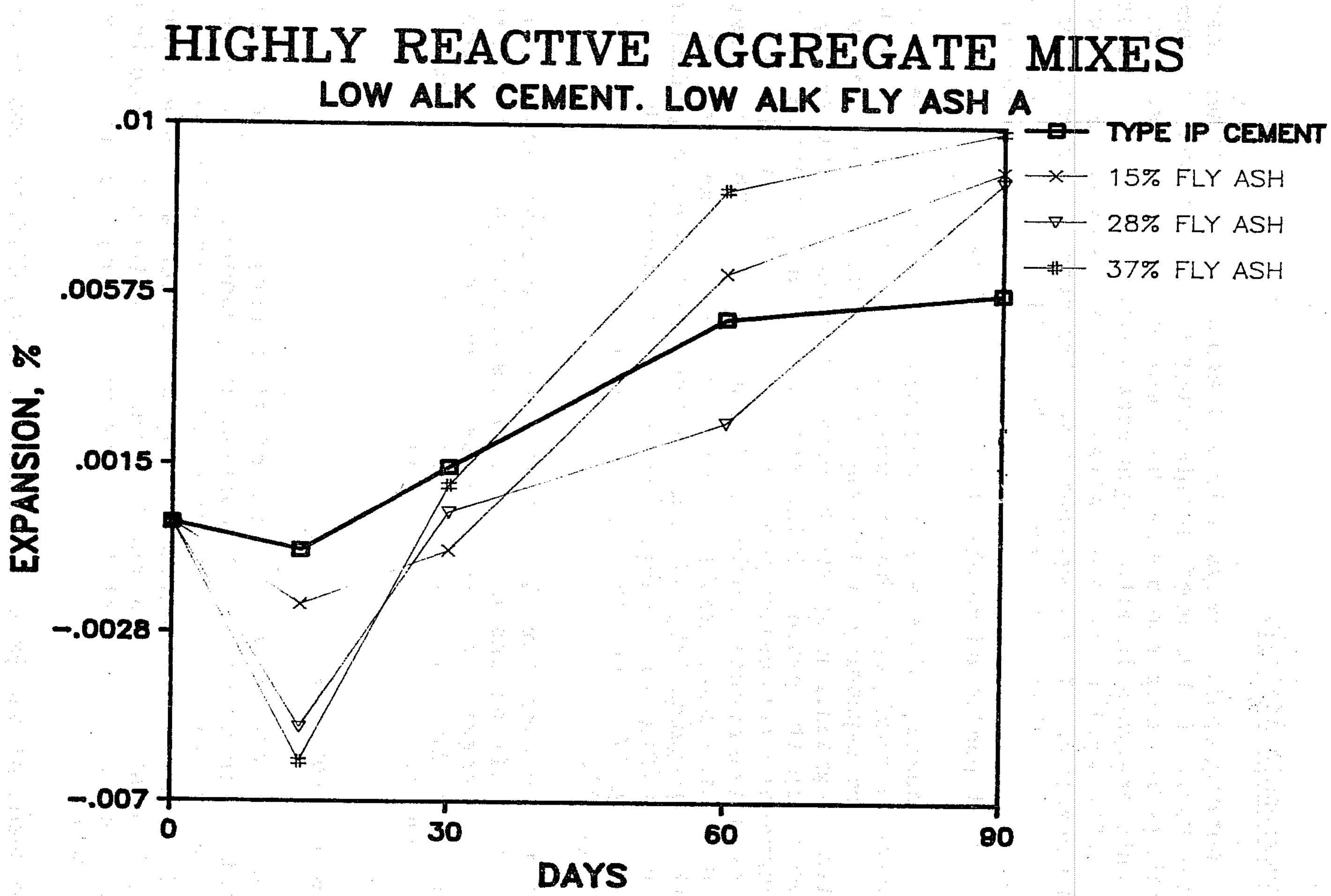


Fig. 47 Percentage of expansion vs time for all highly reactive aggregate mixes containing low alkali cement and Type A fly ash with low content of alkalies

Fig. 48 Aggregate particle surrounded by a reaction rim

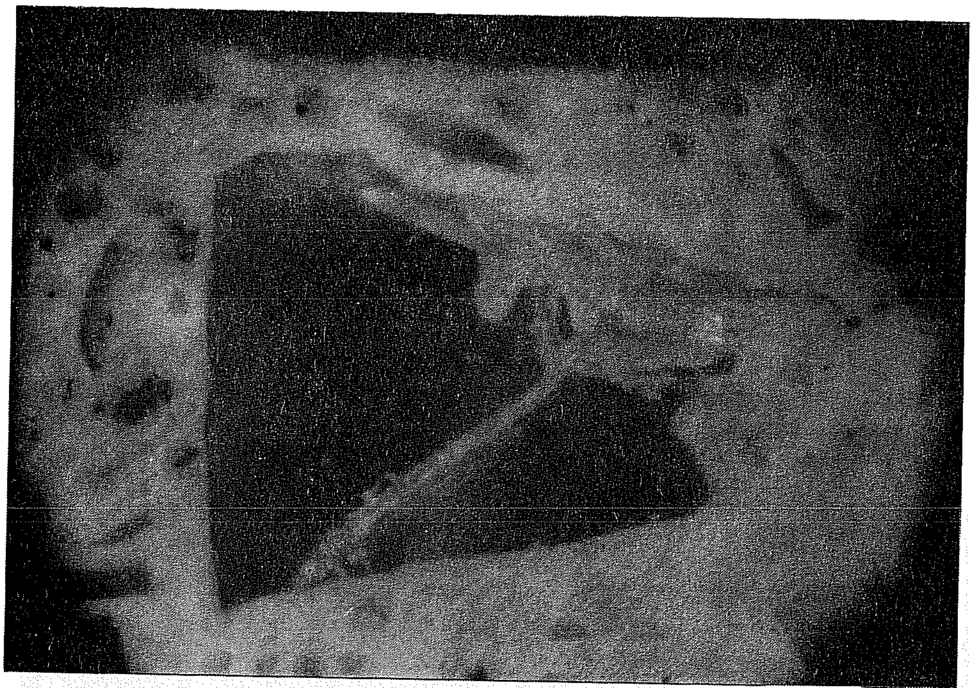


Fig. 49 Aggregate particle with degraded edges

Fig. 52 Cracked mortar bar surface covered with white deposit

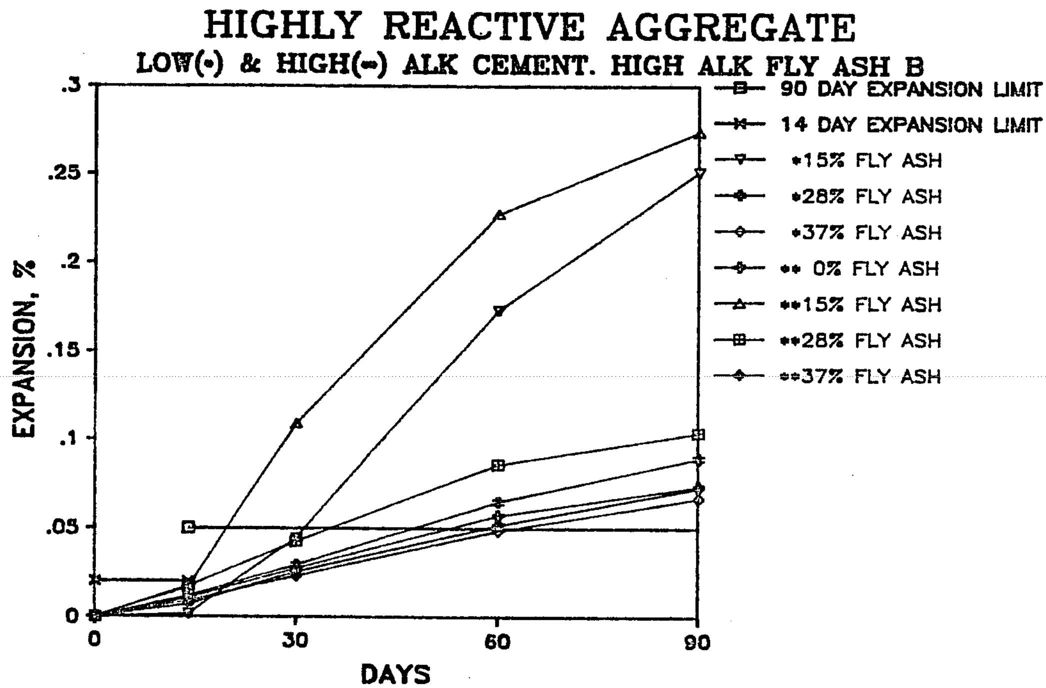


Fig. 53 Percentage of expansion vs time for all mixes made with highly reactive aggregate and high alkali Type B fly ash

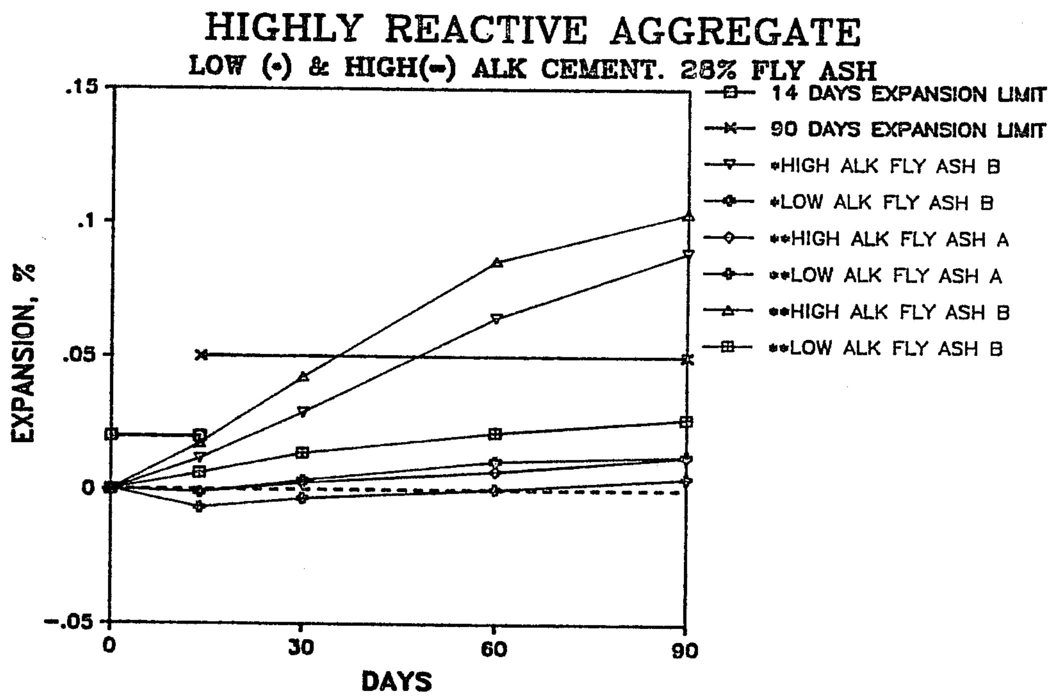


Fig. 54 Percentage of expansion vs time for all mixes made with highly reactive aggregate containing 28% fly ash

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The main objective of this research was to identify the most relevant components of fly ash, cement and concrete aggregates affecting the alkali-aggregate reaction, and to find a relationship between them, indicating type and amount of a given component acceptable for use in concrete to ensure no unacceptable damage due to alkali-aggregate reaction. The variables studied included:

a - Alkali content of cement

b - Available alkali content of fly ash

c - Degree of aggregate alkali reactivity

d - Type and source of fly ash

e - Percentage of cement replaced

Test results presented in this report are limited to 90 days exposure testing.

6.2 Conclusions

The following are the main conclusions deducted from the test results obtained in this study:

1. The 0.6% limit set up by ASTM C150 for the alkali content of cement cannot be used as the only measure to prevent damage to concrete due to alkali-aggregate reaction

2. The main variable affecting alkali-aggregate reaction in concrete containing no fly ash is the amount of alkalies contained in the cement

3. The degree of alkali-aggregate reactivity of concrete mixes increases when the alkali content of the cement increases

4. The replacement of a portion of cement with fly ash is an effective measure to reduce the expansion in concrete due to alkali-aggregate reaction

6.4 Further Research Needed

To continue improving the knowledge gained so far in the field of concrete durability related to alkali-aggregate reaction, the following suggestions for further research are given:

1. A study to find the pessimum limit of fly ashes with available alkali content of more than 1.7%

2. A joint research project is needed between civil and chemical engineering to define and monitor the mechanism by which the alkali-aggregate reaction occurs and the mechanism in which this reaction is prevented by the addition of fly ash

3. A study to determine what influence the procedure for adding fly ash to the concrete mix has on alkali-aggregate reaction

4. A study to correlate the results obtained in mortar bar tests and the results obtained in concrete prism tests, and to correlate those results with the behavior of concrete in real structures

5. A study to find the relationship between alkali-aggregate reaction and other features of concrete constituents such as water pH and air entrainment

6. A study to determine if the blending of fly ash with the cement prior to mixing improves the effectiveness of fly ash replacement in the prevention of deleterious expansion due to alkali-aggregate reaction in concrete

REFERENCES

1. Tuthill, Lewis H. "Alkali-Silica Reaction - 40 Years Later," Concrete International, April 1982, pp. 32-36.

2. Stark, D.C. "Alkali-Silica Reactivite: Some Reconsiderations," Research and Development Bulletin (RD076.01T), Portland Cement Association, 1981.

3. Hobbs, D.W. "Expansion of Concrete Due to Alkali-Silica Reaction," The Structural Engineer, Vol. 62A, No. 1, January 1984, pp. 26-34.

4. Tang, Ming-Shu. "Some Remarks About Alkali-Silica Reactions," Cement and Concrete Research, Vol. 11, No. 3, 1981, pp. 477-478.

5. Hobbs, D.W. "The Alkali-Silica Reaction - A Model for Predicting Expansion in Mortar," Magazine of Concrete Research, Vol. 33, No. 117, December 1981, pp. 208-219.

6. Berry, E.E. and Malhotra, V.M. "Fly Ash for Use in Concrete - A Critical Review," ACI Journal, March-April, 1980, pp. 59-73.

7. Stodola, Paul R. "Performance of Fly Ash in Hardened Concrete," Concrete International, December 1983.

8. Haque, M.N., Langan, B.W. and Ward, M.A. "High Fly Ash Concretes," ACI Journal, January-February 1984, pp. 54-60.

9. Stanton, Thomas E. "Influence of Cement and Aggregate on Concrete Expansion," Engineering News-Record, Feb. 1, 1940.

10. Ramachandran, V.S., et al. Concrete Science, Division of Building Research Council of Canada, Heyden, London, 1981, pp. 340-395.

11. Barnes, P. Structure and Performance of Cements, Applied Science Publishers, Longon, 1983, pp. 365-396.

12. Gillot, J.E. "Practical Implications of the Mechanisms of Alkali-Aggregate Reaction," Symposium on the Alkali-Aggregate Reaction, Reykjavik, August 1975, pp. 213-230.

25. Smith, Robert L. "The Alkali-Aggregate Reaction and Texas Fly Ashes," Texas Civil Engineer, Vol. 54, No. 5, May 1984, pp. 19-21.

26. Mindess, Sidney and Young, J. Francis. Concrete, Prentice-Hall, Inc., New Jersey, 1976.

27. Butler, W.B. "A Critical Look at ASTM C618 and C311," Cement, Concrete and Aggregates, Vol. 4, No. 2, Winter 1982, pp. 68-72.

28. Jones, F.E. and Tarleton, R.D. "Reactions Between Aggregate and Cement, Part I to VI," National Building Studies Research Papers, No. 14, 1952, pp. 23; No. 15, 1952, pp. 20; No. 17, 1952, pp. 30; No. 20, 1958, pp. 43; No. 25, 1958, pp. 17, Her Majesty's Stationery Office, London.

29. Heck, William J. "Study of Alkali-Silica Reactivity Tests to Improve Correlation and Predictability for Aggregates," Cement, Concrete and aggregates, CCAGDP, Vol. 5, No. 1, Summer 1983, pp. 47-53.

30. Grattan-Bellew, P.E. "Re-Evaluation of Standard Mortar Bar and Concrete Prism Tests for Alkali-Aggregate Reactivity," Materiaux et Constructions, Vol. 16, No. 94, pp. 243-249.

31. Brotschi, John and Mehta, Kumar P. "Test Methods for Determining Potential Alkali-Silica rectivity in Cements," Cement and Concrete Research, Vol. 8, No. 2, 1978, pp. 191-200.

32. Tang, Ming-shu, Han, Su-fen and Zhen, Shi-hua. "A Rapid Method for Identification of Alkali Reactivity of Aggregate," Cement and Concrete Resarch, Vol. 13, No. 3, 1983, pp. 417-422.

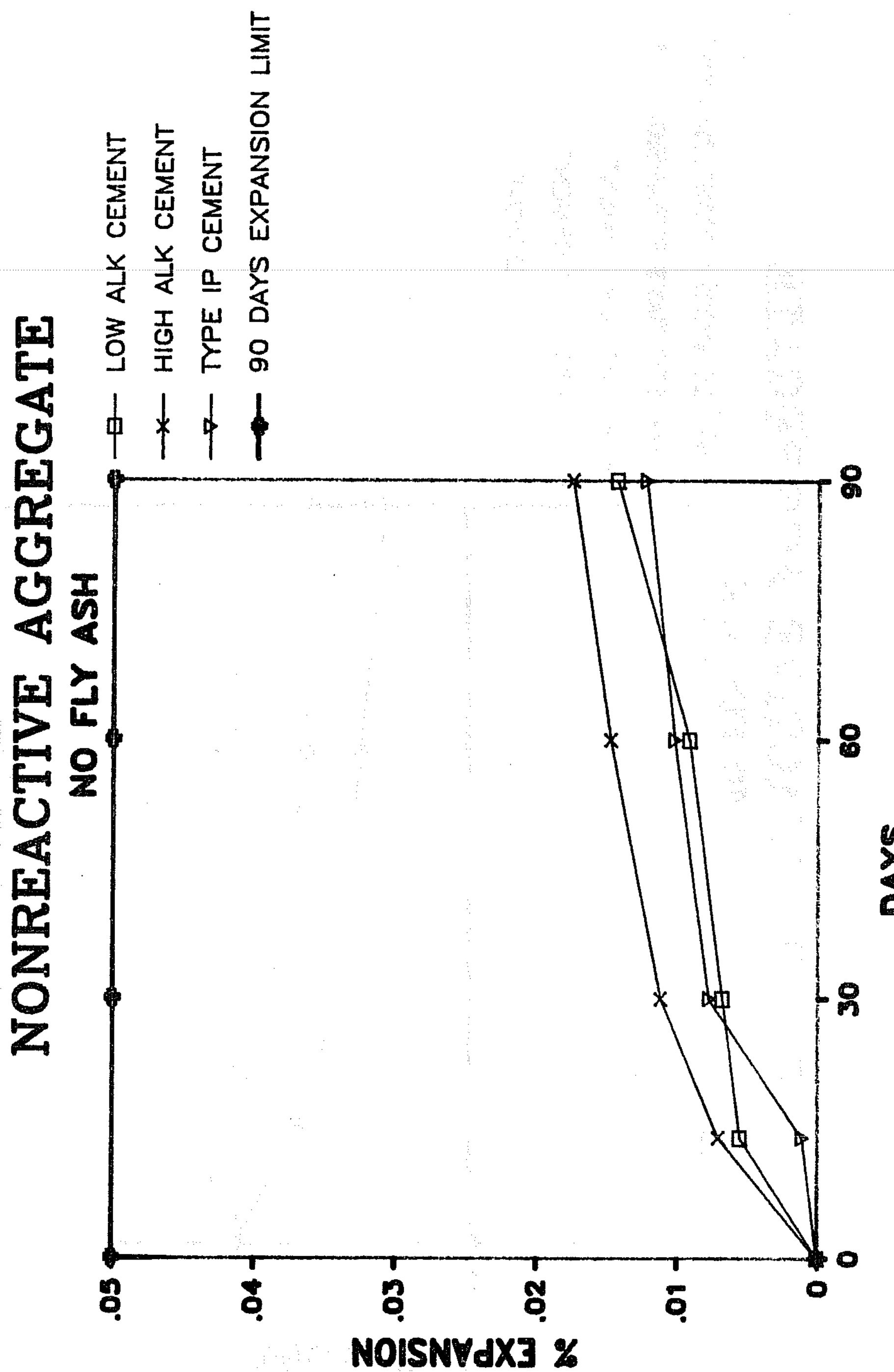
33. Damgaard, A., Chatterji, S. Christensen, P., Thaulow, N. and Gudmundsson, H. "Studies of Alkali-Silica Reaction - Part 1. A Comparison of Two Accelerated Test Methods," Cement and Concrete Research, Vol. 12, No. 5, 1982, pp. 641-647.

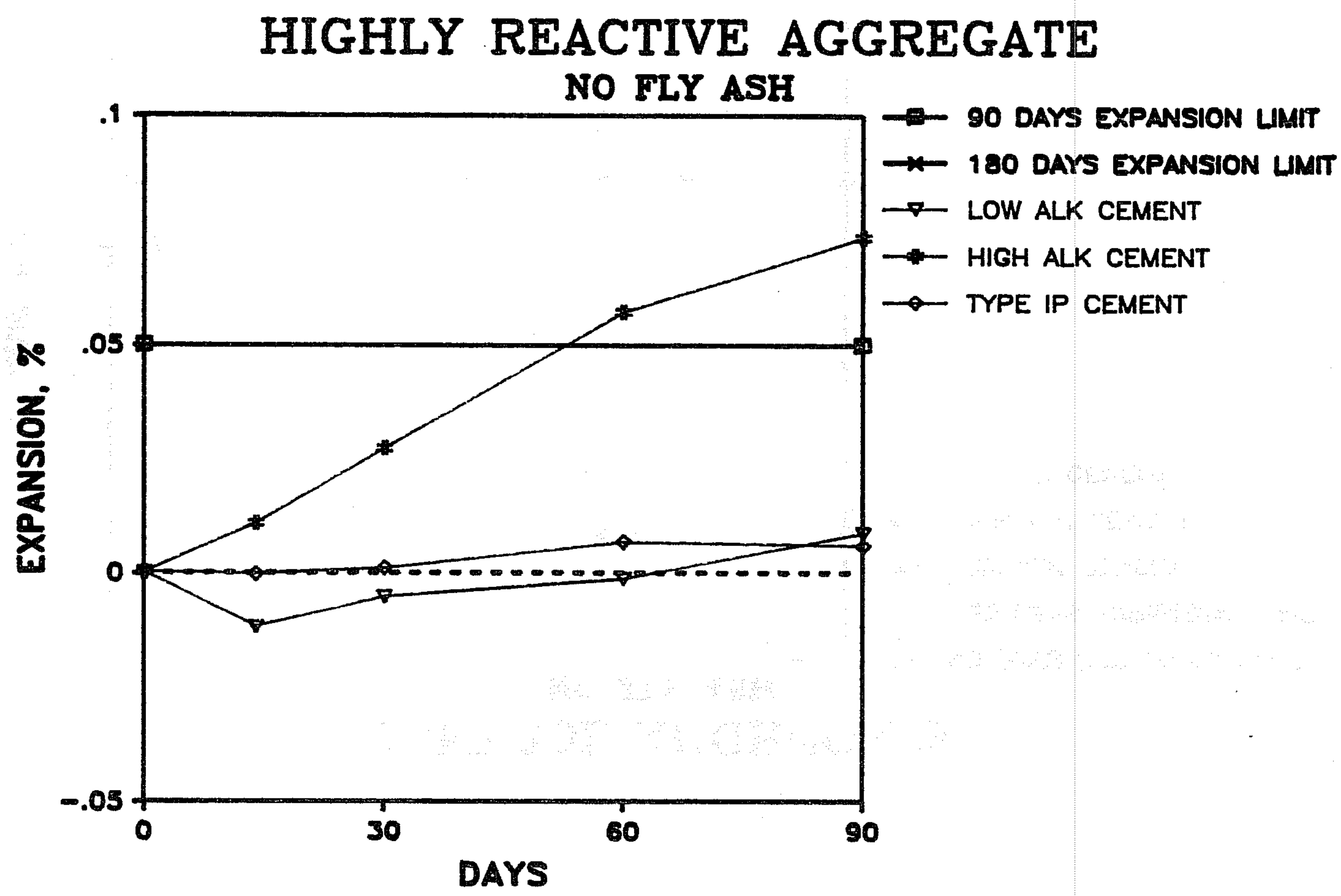
34. Encyclopedia of Chemical Technology, Vol. 6, John Wiley and Sons, NY, 1978, pp. 230.

35. Meyers, Robert A. Coal Handbook, Energy, Power and Environment, Marcel Dekker, Inc., New York, 1978.

APPENDIX A

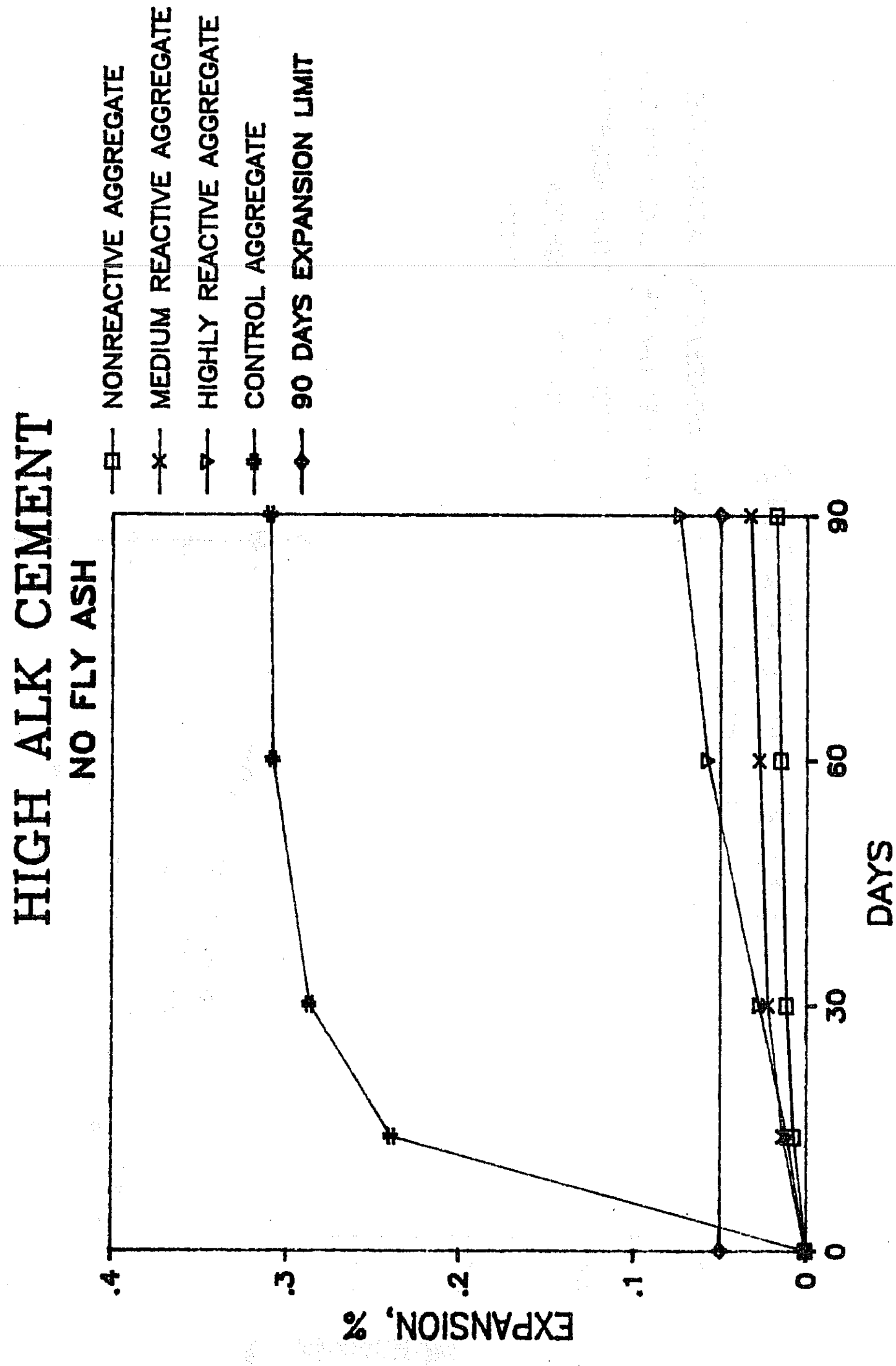
GRAPHS AND TEST RESULT DATA


NONREACTIVE AGGREGATE
NO FLY ASH
LOW ALK CEMENT
HIGH ALK CEMENT
TYPE IP CEMENT
90 DAYS EXPANSION LIMIT
% EXPANSION
.05
.04
.03
.02
.01
0
DAYS
0
30
60
90


HIGHLY REACTIVE AGGREGATE
NO FLY ASH
.1
.05
0
-.05
EXPANSION, %
0
30
60
90
DAYS
90 DAYS EXPANSION LIMIT
180 DAYS EXPANSION LIMIT
LOW ALK CEMENT
HIGH ALK CEMENT
TYPE IP CEMENT

MIXES WITHOUT FLY ASH

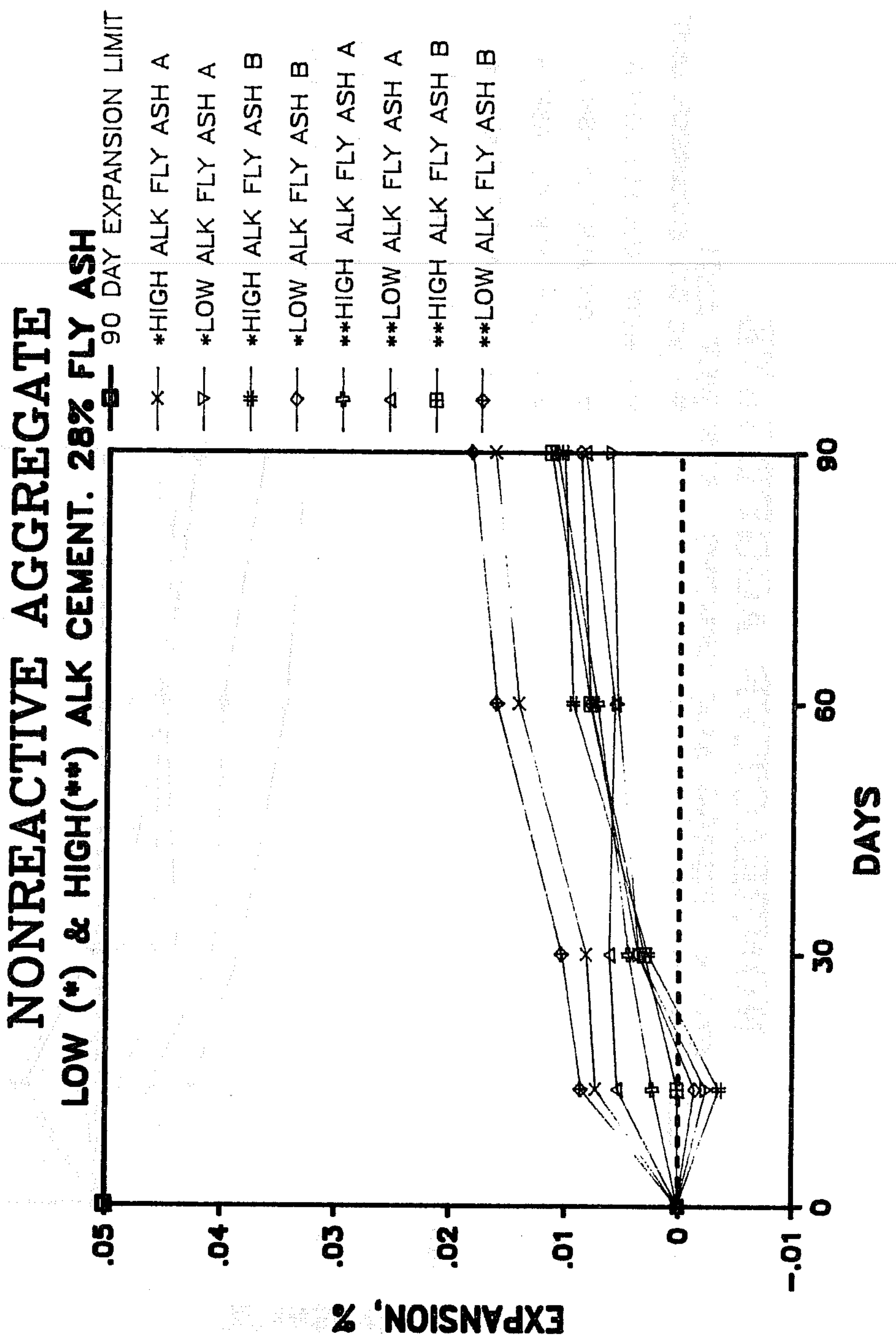
CURVES FOR THE CEMENTS


HIGH ALK CEMENT
NO FLY ASH
NONREACTIVE AGGREGATE
MEDIUM REACTIVE AGGREGATE
HIGHLY REACTIVE AGGREGATE
CONTROL AGGREGATE
90 DAYS EXPANSION LIMIT
EXPANSION, %
.4
.3
.2
.1
0
0
30
60
90
DAYS

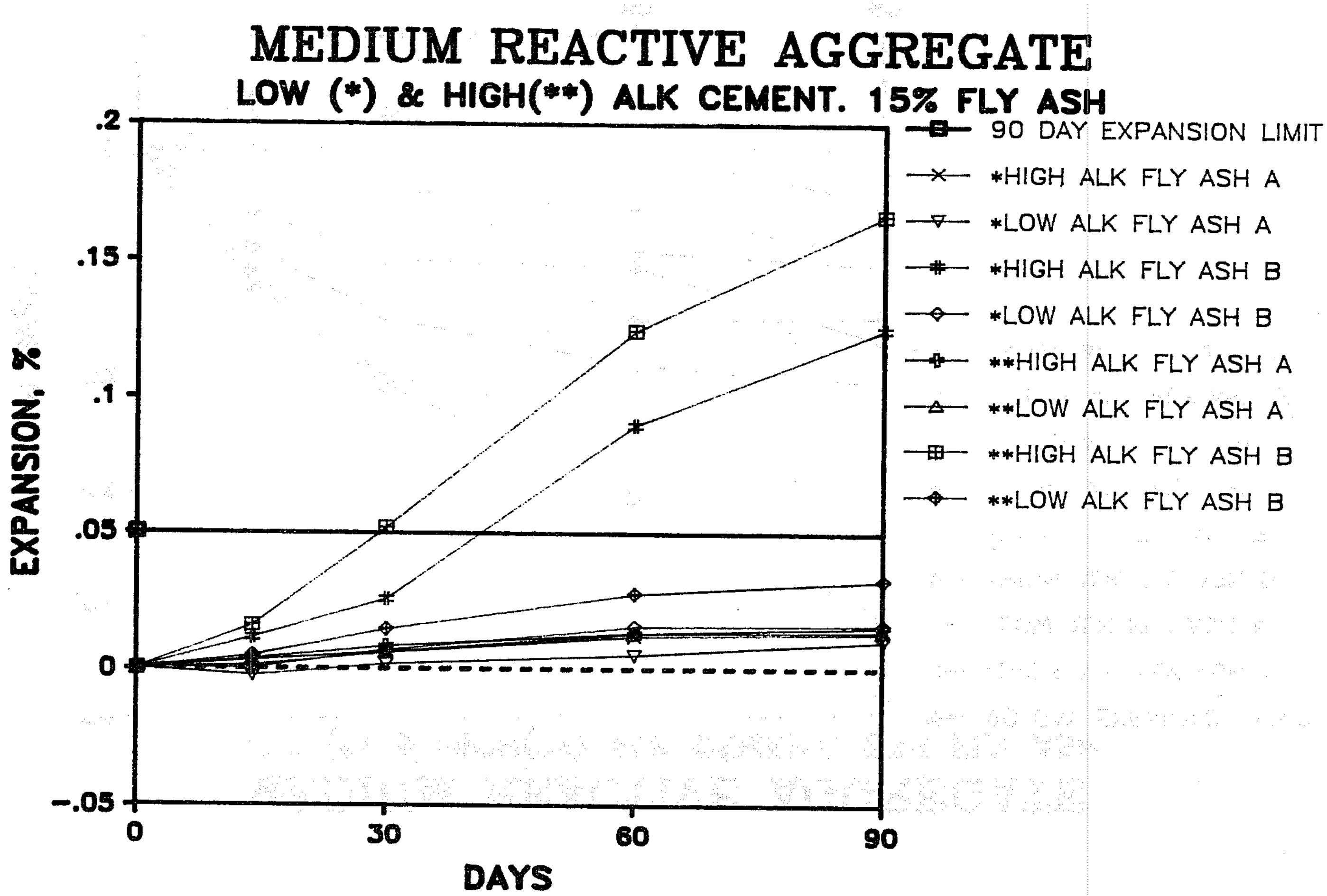
MIXES CONTAINING FLY ASH

ALL TYPES OF FLY ASH FOR EACH AGGREGATE

AND EACH FLY ASH REPLACEMENT

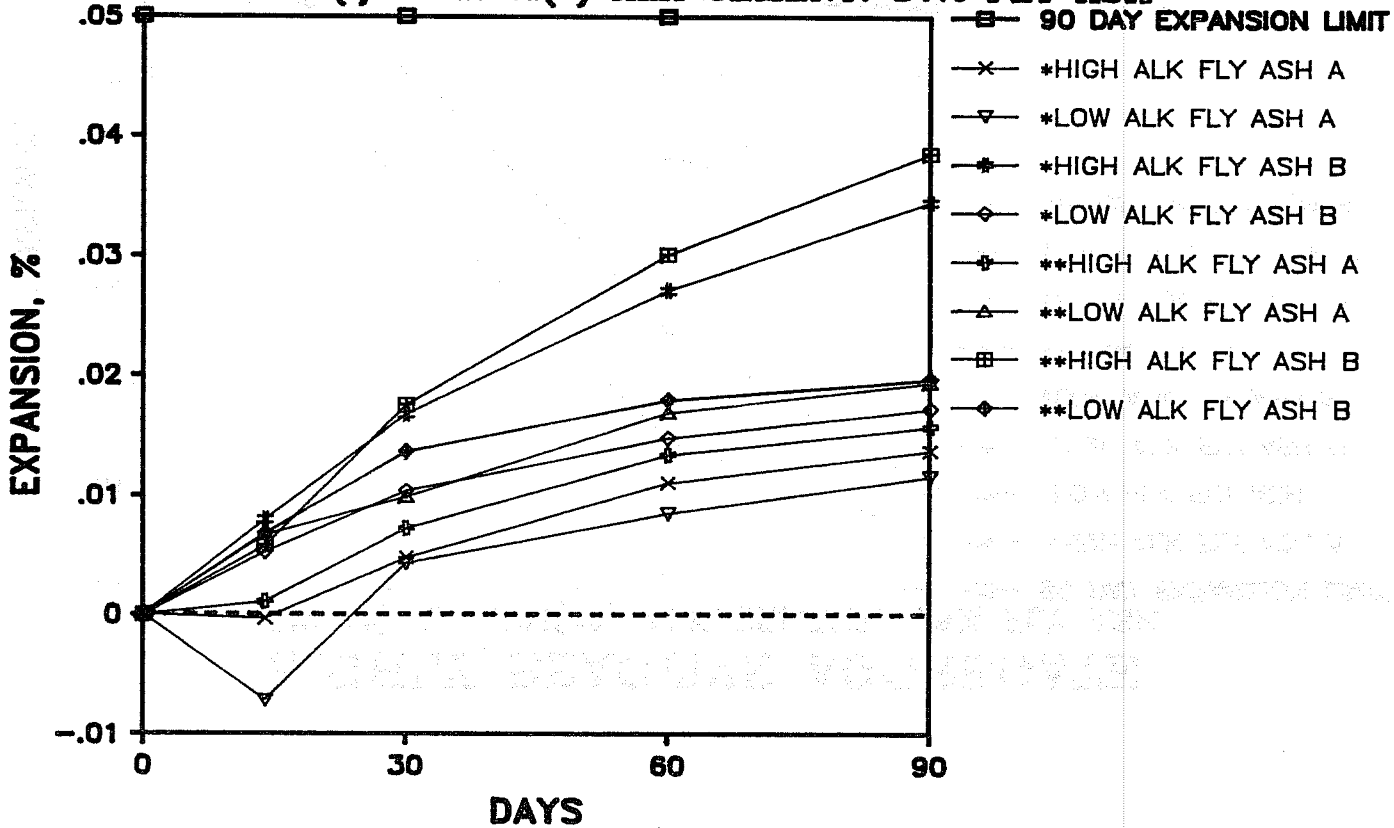


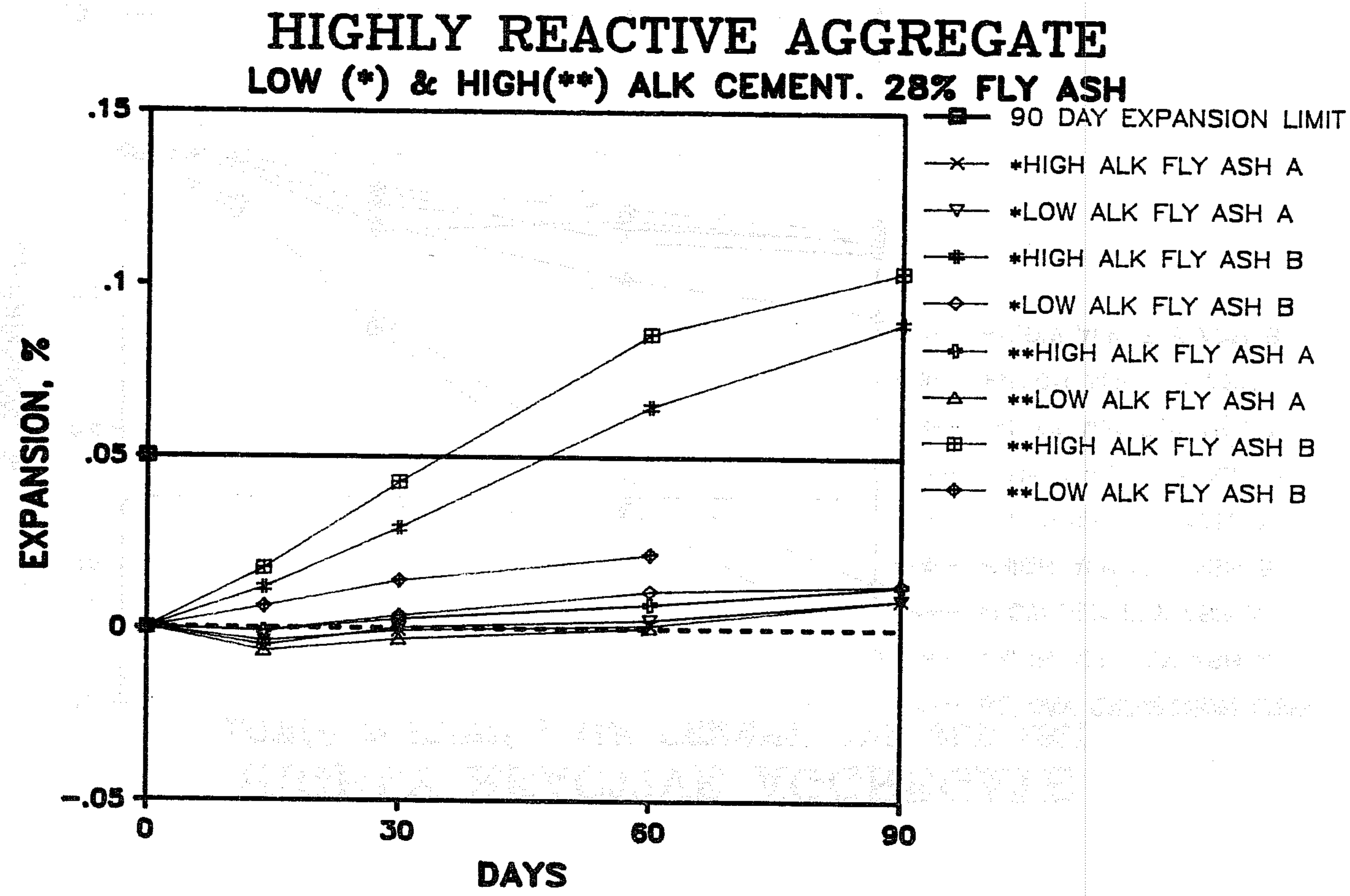
NONREACTIVE AGGREGATE
LOW (*) & HIGH(**) ALK CEMENT. 28% FLY ASH
90 DAY EXPANSION LIMIT
*HIGH ALK FLY ASH A
*LOW ALK FLY ASH A
*HIGH ALK FLY ASH B
*LOW ALK FLY ASH B
**HIGH ALK FLY ASH A
**LOW ALK FLY ASH A
**HIGH ALK FLY ASH B
**LOW ALK FLY ASH B
EXPANSION, %
.05
.04
.03
.02
.01
0
-.01
0
30
60
90
DAYS

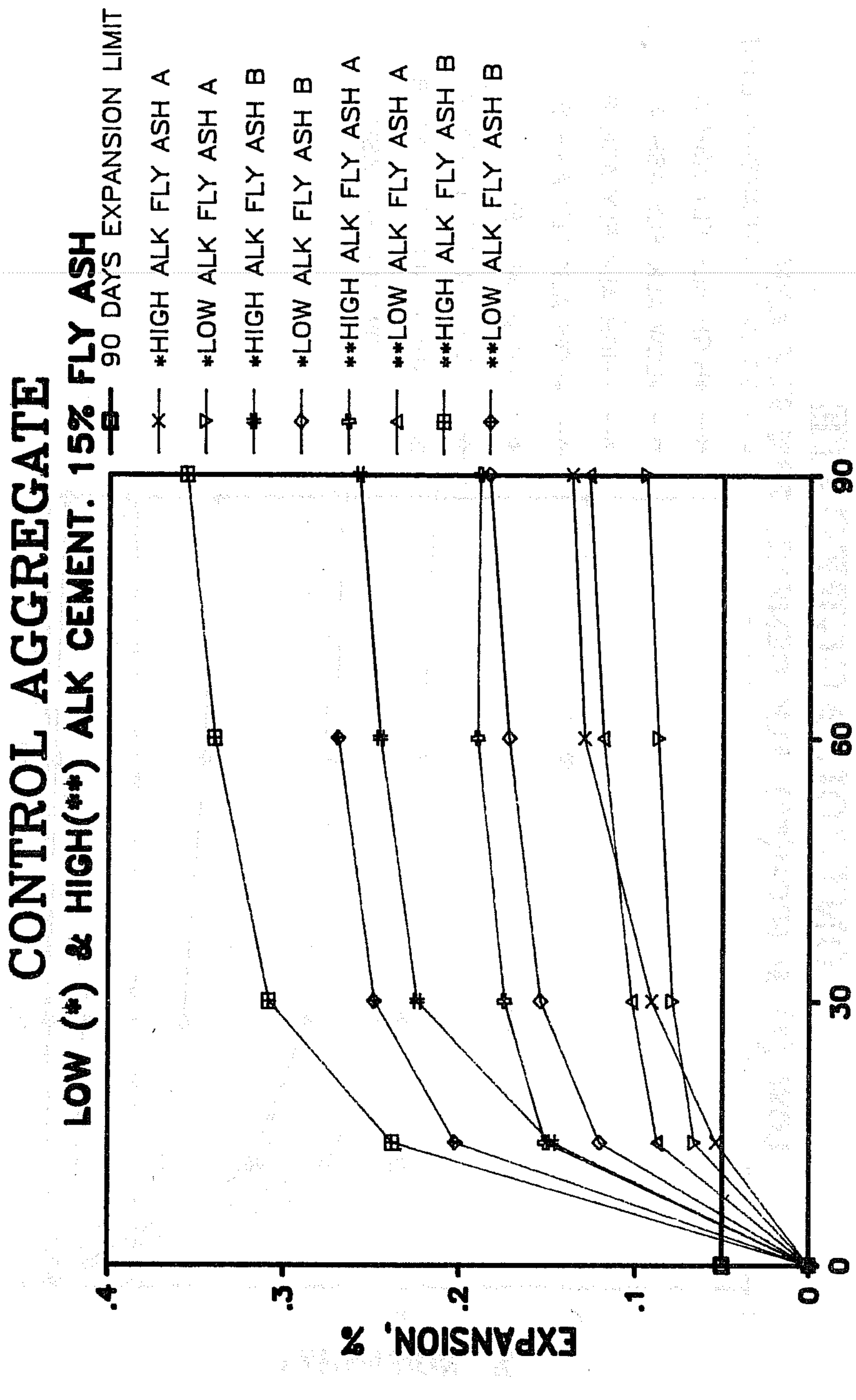

MEDIUM REACTIVE AGGREGATE
LOW (*) & HIGH(**) ALK CEMENT. 15% FLY ASH
EXPANSION, %
.2
.15
.1
.05
0
-.05
DAYS
0
30
60
90
90 DAY EXPANSION LIMIT
*HIGH ALK FLY ASH A
*LOW ALK FLY ASH A
*HIGH ALK FLY ASH B
*LOW ALK FLY ASH B
**HIGH ALK FLY ASH A
**LOW ALK FLY ASH A
**HIGH ALK FLY ASH B
**LOW ALK FLY ASH B

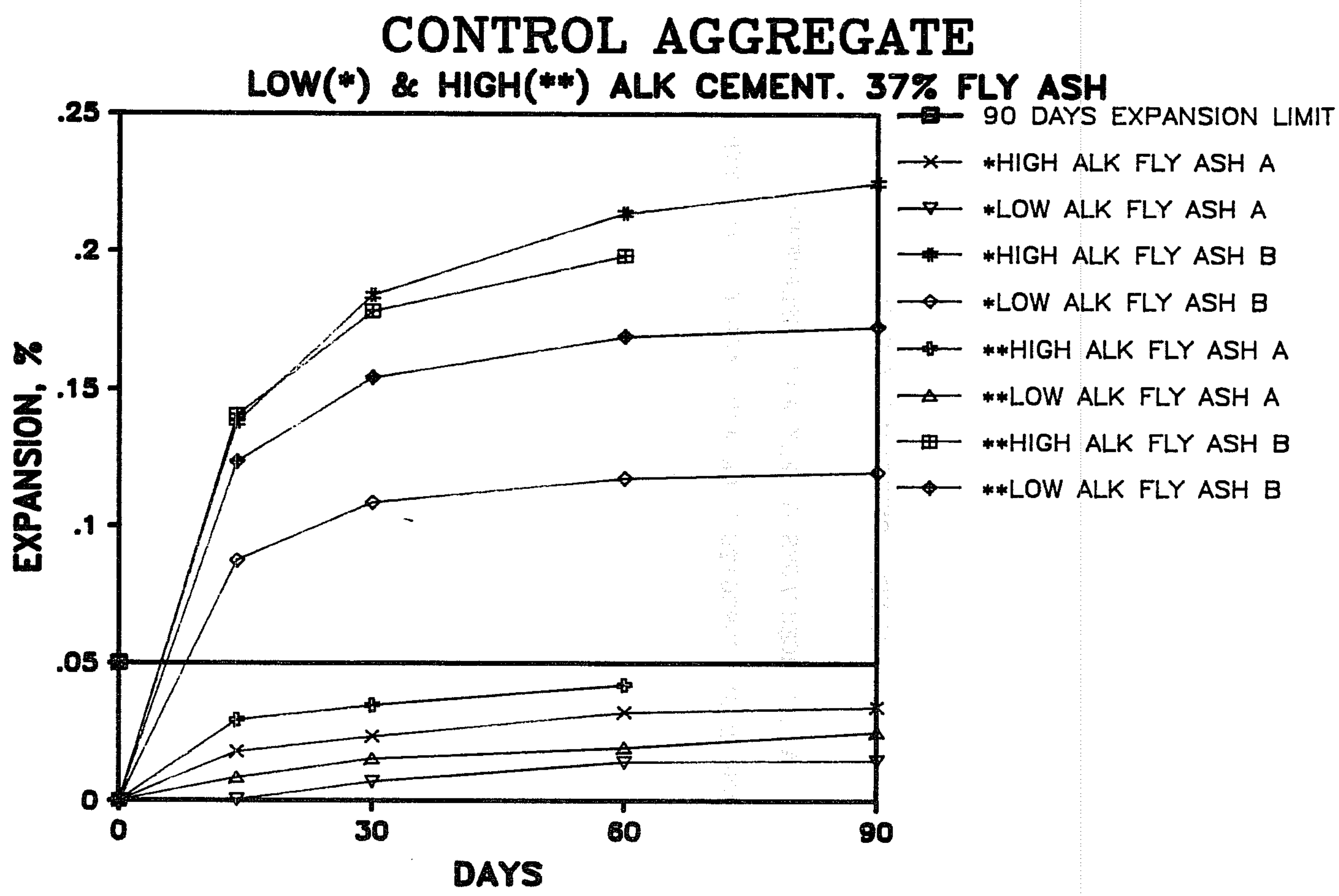
MEDIUM REACTIVE AGGREGATE

LOW(*) & HIGH(**) ALK CEMENT. 37% FLY ASH

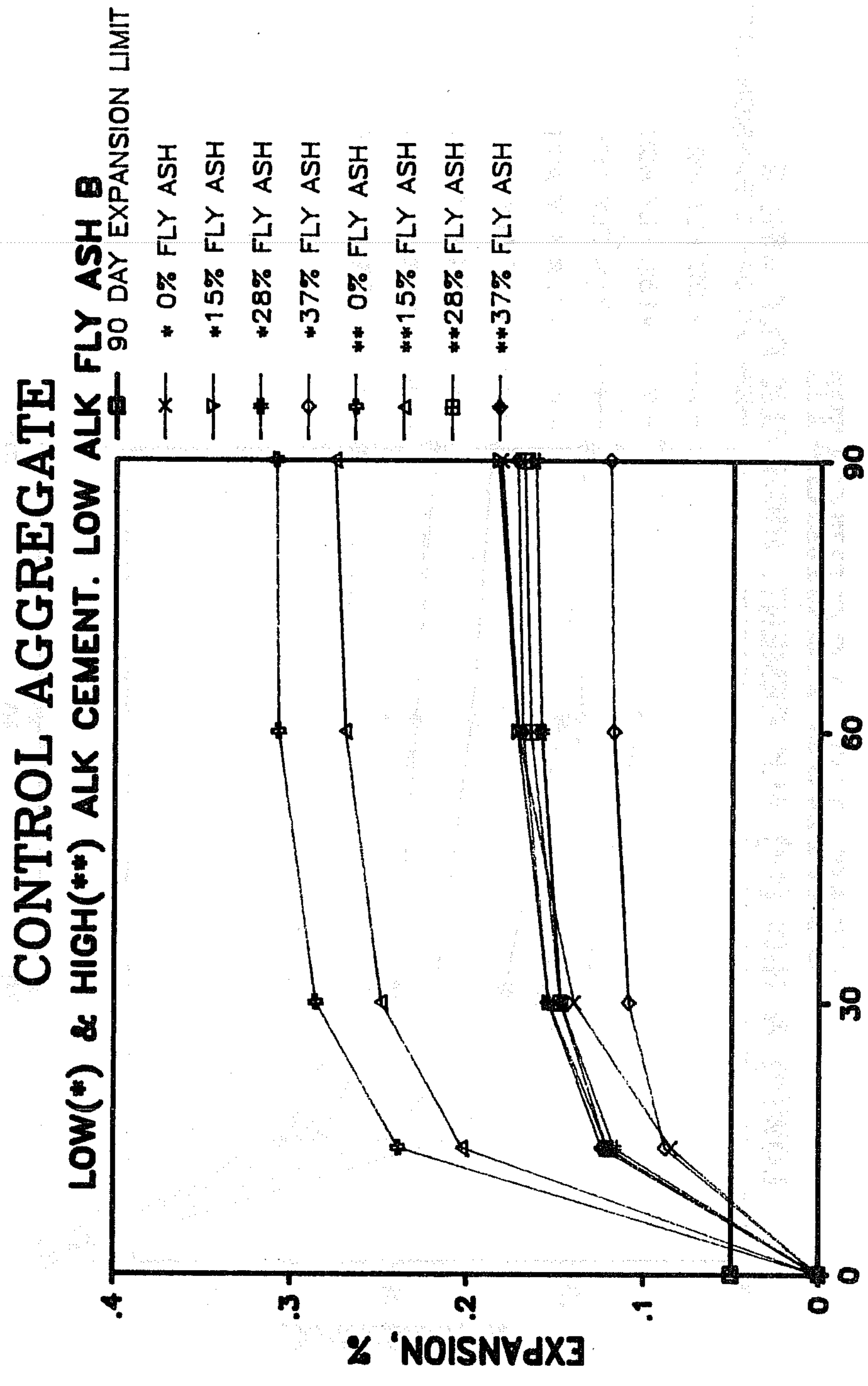



HIGHLY REACTIVE AGGREGATE
LOW (*) & HIGH(**) ALK CEMENT. 28% FLY ASH
EXPANSION, %
.15
.1
.05
0
-.05
0
30
60
90
DAYS
90 DAY EXPANSION LIMIT
*HIGH ALK FLY ASH A
*LOW ALK FLY ASH A
*HIGH ALK FLY ASH B
*LOW ALK FLY ASH B
**HIGH ALK FLY ASH A
**LOW ALK FLY ASH A
**HIGH ALK FLY ASH B
**LOW ALK FLY ASH B

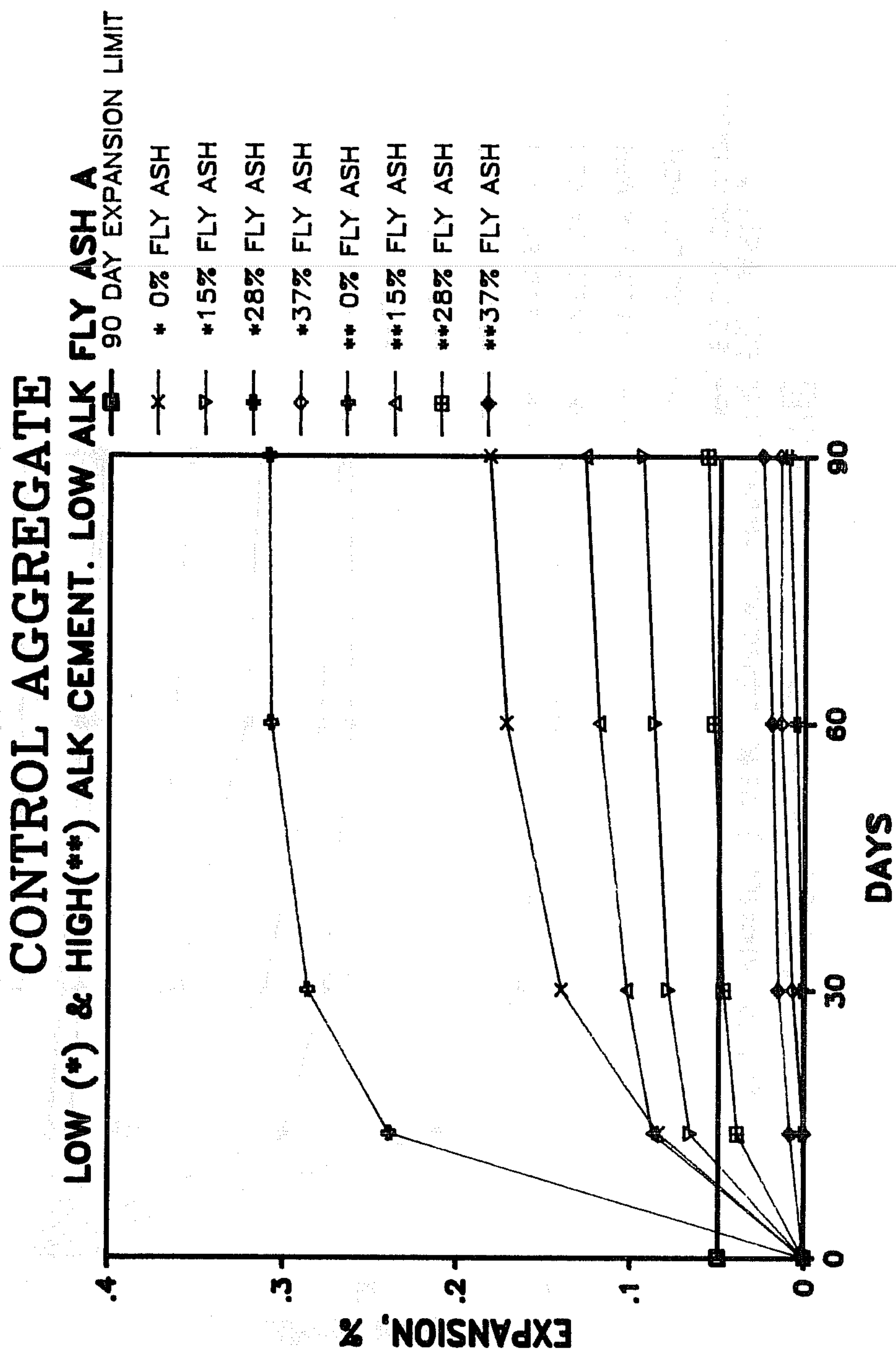

CONTROL AGGREGATE
LOW (*) & HIGH(**) ALK CEMENT. 15% FLY ASH
90 DAYS EXPANSION LIMIT
*HIGH ALK FLY ASH A
*LOW ALK FLY ASH A
*HIGH ALK FLY ASH B
*LOW ALK FLY ASH B
**HIGH ALK FLY ASH A
**LOW ALK FLY ASH A
**HIGH ALK FLY ASH B
**LOW ALK FLY ASH B
EXPANSION, %
.4
.3
.2
.1
0
0
30
60
90
DAYS

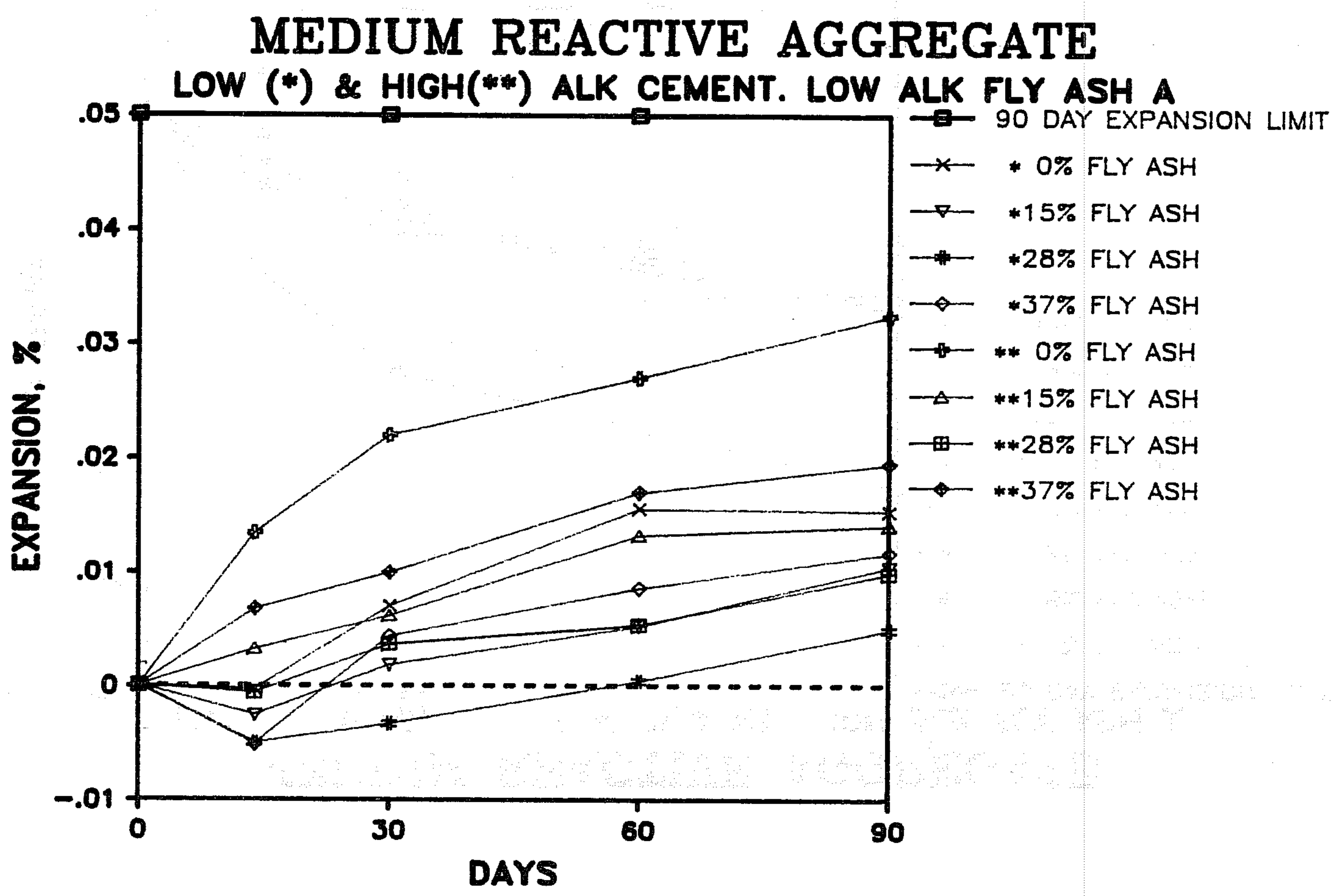


CONTROL AGGREGATE
LOW(*) & HIGH(**) ALK CEMENT. 37% FLY ASH
EXPANSION, %
.25
.2
.15
.1
.05
0
0
30
60
90
DAYS
90 DAYS EXPANSION LIMIT
*HIGH ALK FLY ASH A
*LOW ALK FLY ASH A
*HIGH ALK FLY ASH B
*LOW ALK FLY ASH B
**HIGH ALK FLY ASH A
**LOW ALK FLY ASH A
**HIGH ALK FLY ASH B
**LOW ALK FLY ASH B



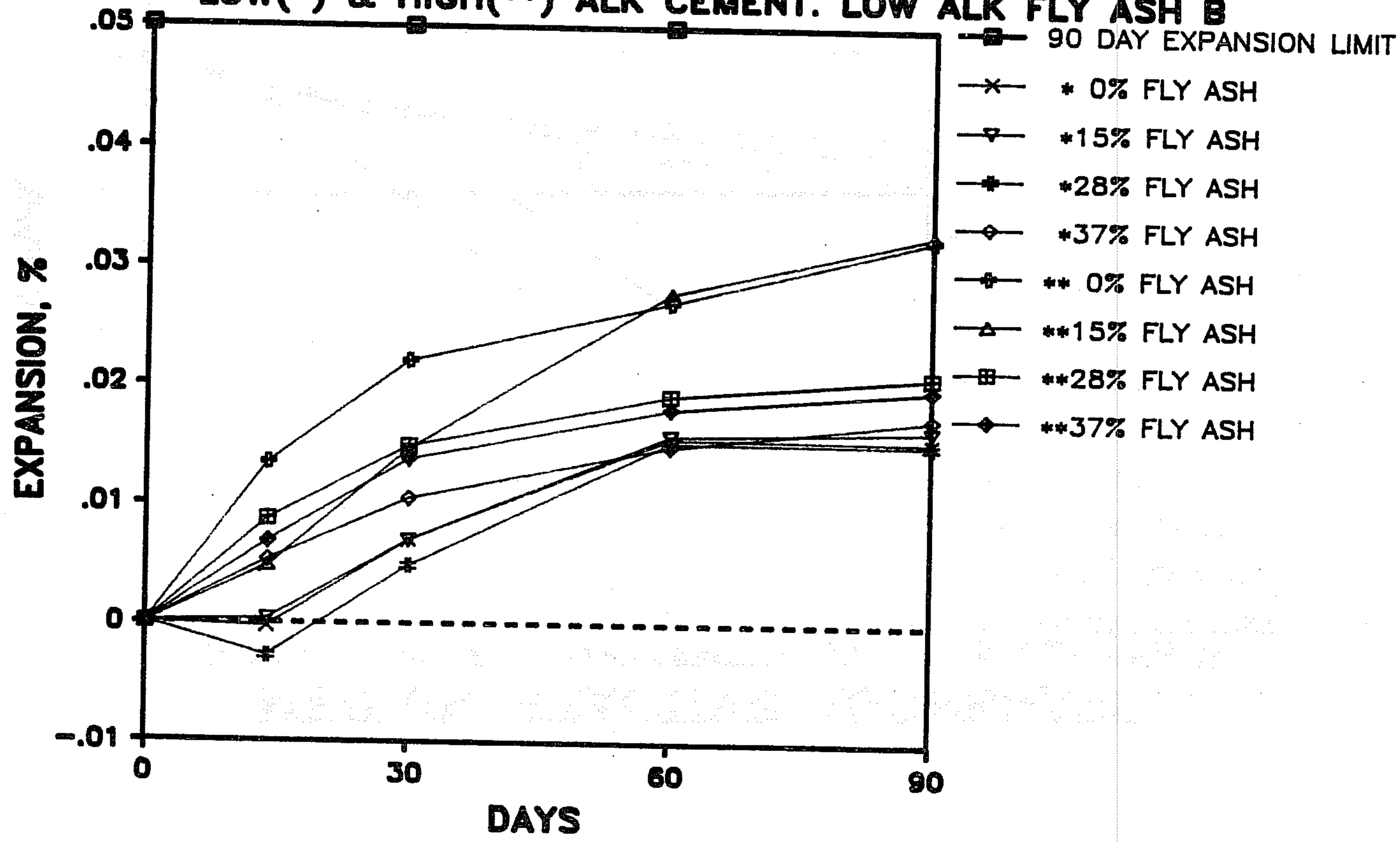
CONTROL AGGREGATE
LOW(*) & HIGH(**) ALK CEMENT. LOW ALK FLY ASH B
90 DAY EXPANSION LIMIT
* 0% FLY ASH
*15% FLY ASH
*28% FLY ASH
*37% FLY ASH
** 0% FLY ASH
**15% FLY ASH
**28% FLY ASH
**37% FLY ASH
EXPANSION, %
.4
.3
.2
.1
0
0
30
60
90
DAYS

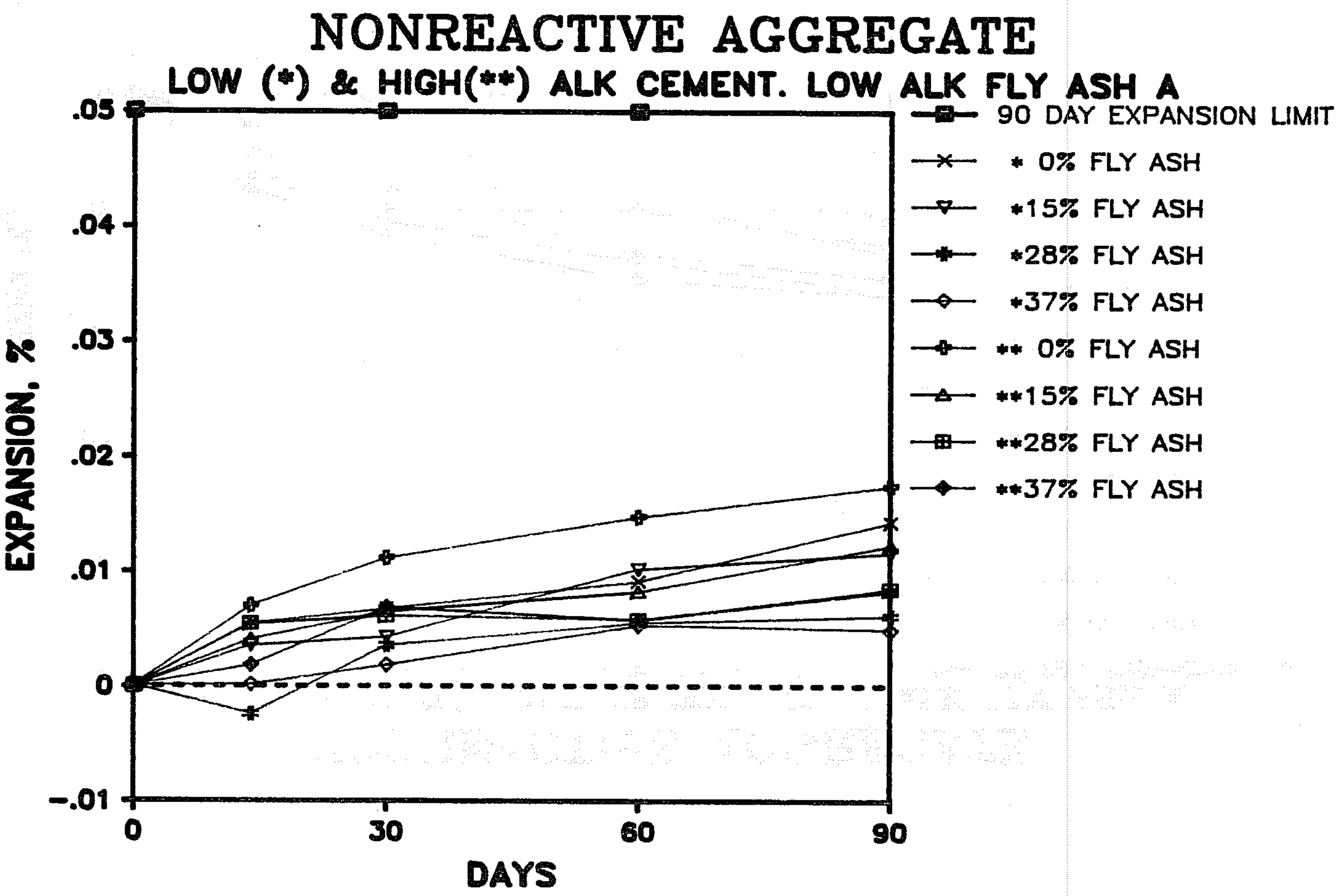

CONTROL AGGREGATE
LOW (*) & HIGH(**) ALK CEMENT. LOW ALK FLY ASH A
EXPANSION, %
.4
.3
.2
.1
0
0
30
60
90
DAYS
90 DAY EXPANSION LIMIT
* 0% FLY ASH
*15% FLY ASH
*28% FLY ASH
*37% FLY ASH
** 0% FLY ASH
**15% FLY ASH
**28% FLY ASH
**37% FLY ASH

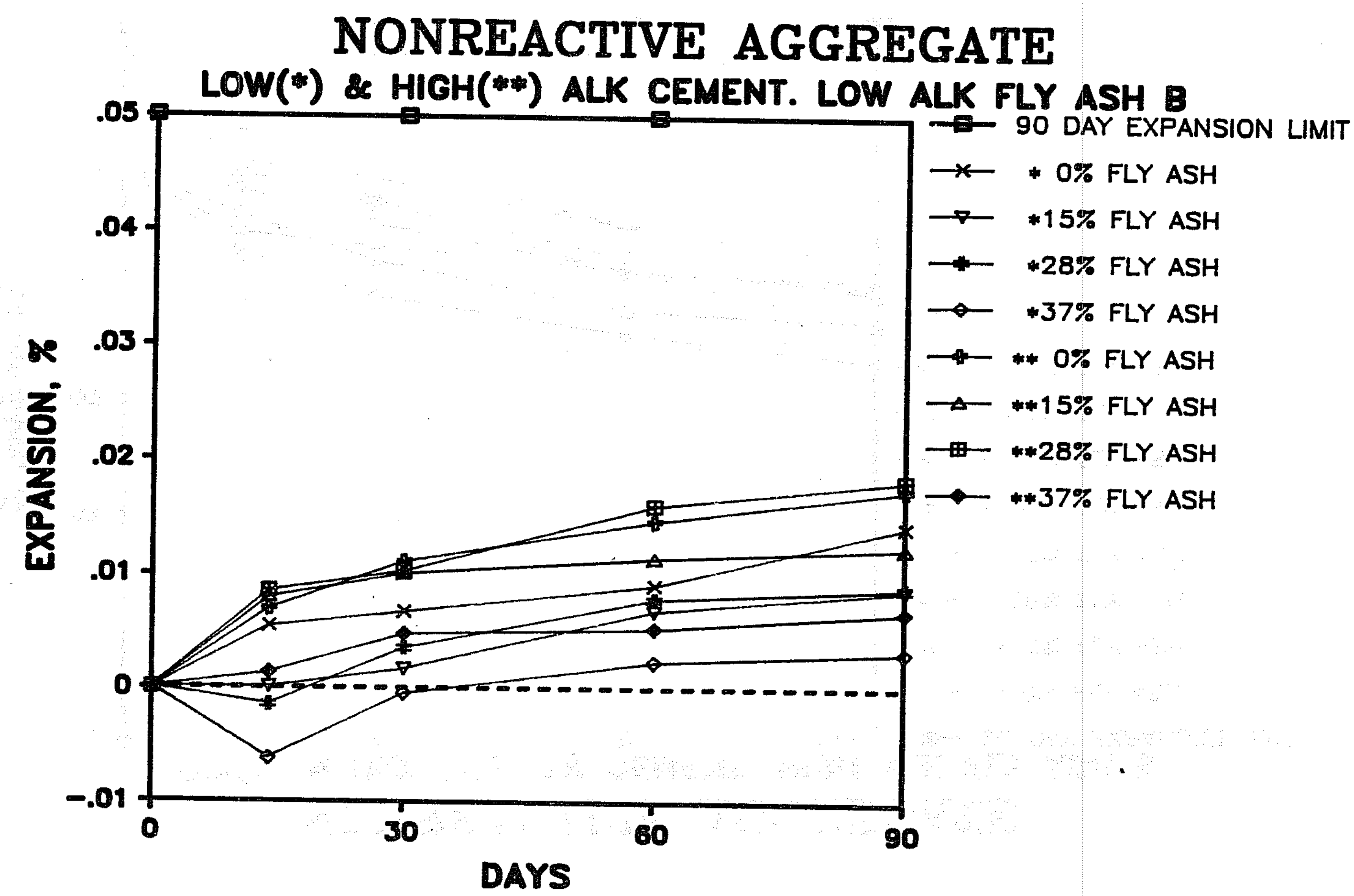

MEDIUM REACTIVE AGGREGATE
LOW (*) & HIGH(**) ALK CEMENT. LOW ALK FLY ASH A
EXPANSION, %
.05
.04
.03
.02
.01
0
-.01
0
30
60
90
DAYS
90 DAY EXPANSION LIMIT
* 0% FLY ASH
*15% FLY ASH
*28% FLY ASH
*37% FLY ASH
** 0% FLY ASH
**15% FLY ASH
**28% FLY ASH
**37% FLY ASH

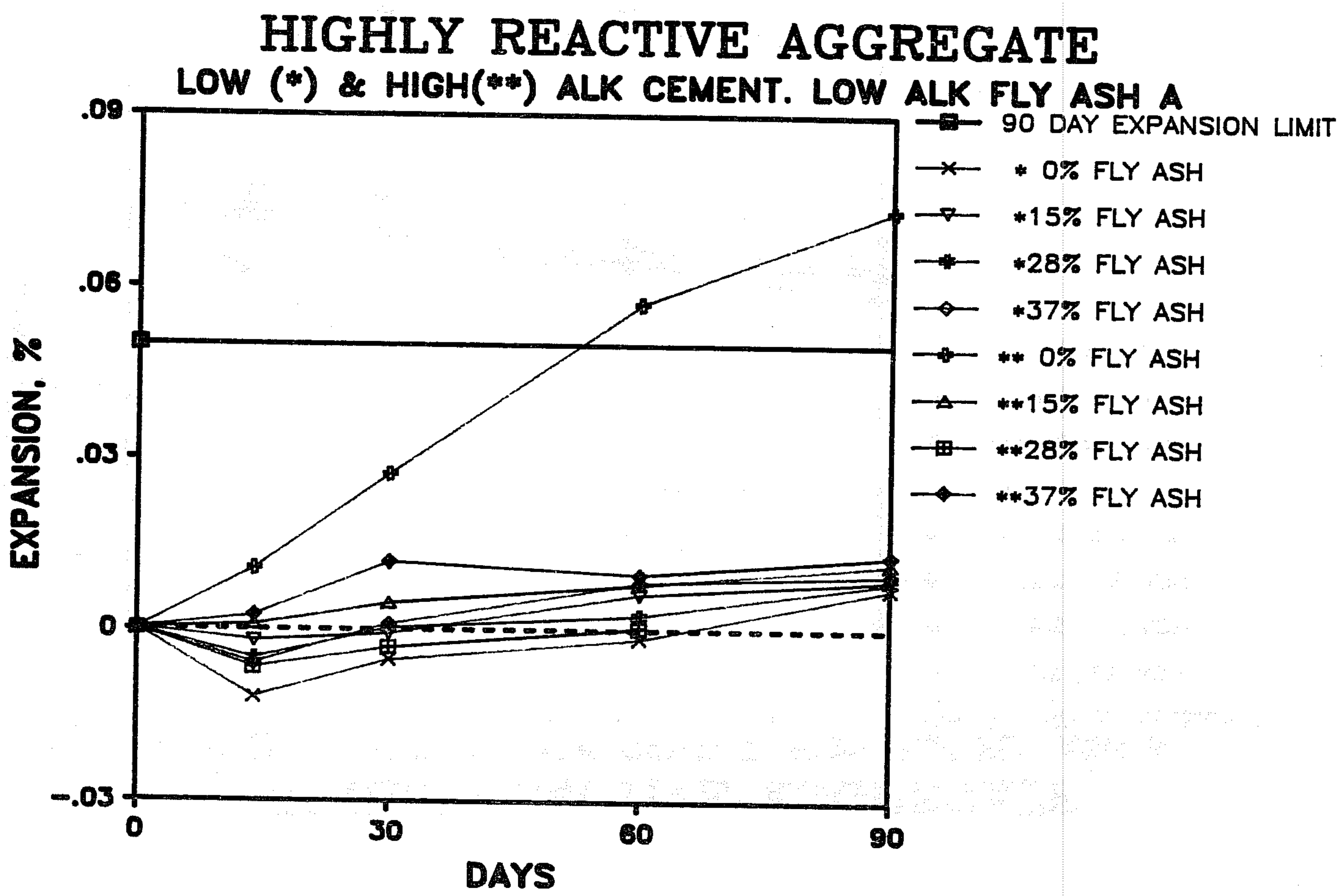
MEDIUM REACTIVE AGGREGATE

LOW(*) & HIGH(**) ALK CEMENT. LOW ALK FLY ASH B



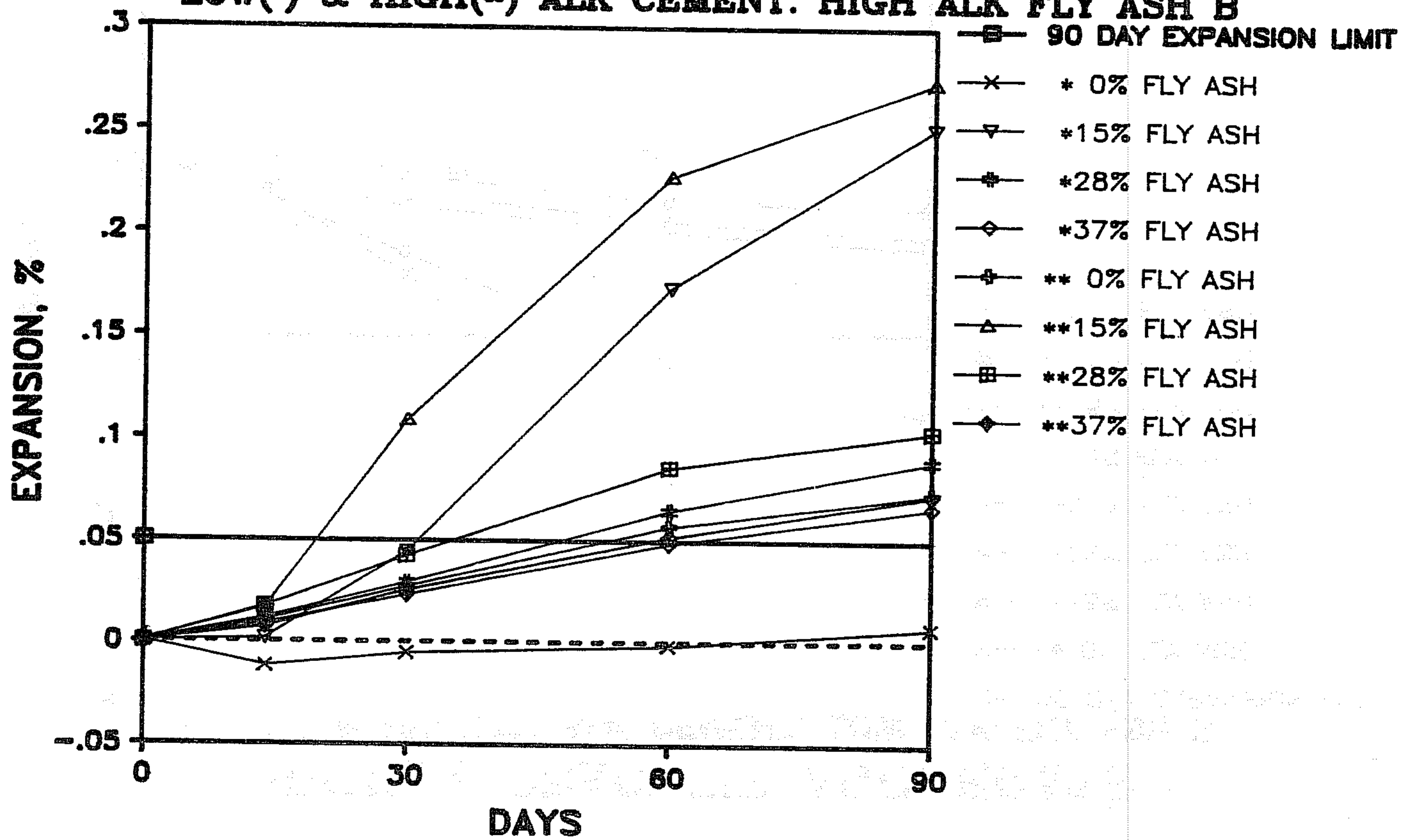

NONREACTIVE AGGREGATE
LOW (*) & HIGH(**) ALK CEMENT. LOW ALK FLY ASH A
EXPANSION, %
.05
.04
.03
.02
.01
0
-.01
0
30
60
90
DAYS
90 DAY EXPANSION LIMIT
* 0% FLY ASH
*15% FLY ASH
*28% FLY ASH
*37% FLY ASH
** 0% FLY ASH
**15% FLY ASH
**28% FLY ASH
**37% FLY ASH


NONREACTIVE AGGREGATE
LOW(*) & HIGH(**) ALK CEMENT. LOW ALK FLY ASH B
EXPANSION, %
.05
.04
.03
.02
.01
0
-.01
0
30
60
90
DAYS
90 DAY EXPANSION LIMIT
* 0% FLY ASH
*15% FLY ASH
*28% FLY ASH
*37% FLY ASH
** 0% FLY ASH
**15% FLY ASH
**28% FLY ASH
**37% FLY ASH


HIGHLY REACTIVE AGGREGATE
LOW (*) & HIGH(**) ALK CEMENT. LOW ALK FLY ASH A
EXPANSION, %
.09
.06
.03
0
-.03
0
30
60
90
DAYS
90 DAY EXPANSION LIMIT
* 0% FLY ASH
*15% FLY ASH
*28% FLY ASH
*37% FLY ASH
** 0% FLY ASH
**15% FLY ASH
**28% FLY ASH
**37% FLY ASH

HIGHLY REACTIVE AGGREGATE

LOW(*) & HIGH(**) ALK CEMENT. HIGH ALK FLY ASH B



-MIX 1-

NONREACTIVE AGGREGATE, LOW ALKALI CEMENT, NO FLY ASH

DAYS: READINGS:

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	274	311	398	378	161	240	251	234
14	282	318	401	381	167	249	259	241
30	282	319	403	384	169	251	260	242
60	282	322	406	387	173	254	263	245
90	290	329	412	393	179	259	268	250

DAYS: % EXPANSION

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.006866	.006005	.002572	.002572	.005154	.007726	.006867	.006009
30	.006866	.006863	.004286	.005145	.006872	.009443	.007725	.006868
60	.006866	.009437	.006858	.007717	.010308	.012018	.010300	.009443
90	.013731	.015443	.012002	.012861	.015462	.016310	.014592	.013736

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.005471	.006759	.009118	.014267

-MIX 2-

NONREACTIVE AGGREGATE, LOW ALKALI CEMENT, 15% HIGH ALKALI FLY ASH A

DAYS: READINGS:

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	266	252	246	220	300	269	237	198
14	269	251	243	214	293	264	234	194
30	274	256	248	223	297	269	240	199
60	283	268	261	230	310	280	248	208
90	286	270	261	235	310	281	247	209

DAYS: % EXPANSION

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.002575	-.00086	-.00258	-.00515	-.00601	-.00429	-.00258	-.00344
30	.006866	.003433	.001717	.002576	-.00257	0	.002575	.000859
60	.014590	.013734	.012876	.008586	.008580	.009441	.009443	.008583
90	.017165	.015450	.012876	.012879	.008580	.010299	.008585	.009446

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00356	.001227	.009787	.010444

-MIX 3-

NONREACTIVE AGGREGATE, LOW ALKALI CEMENT, 15% LOW ALKALI FLY ASH A

DAYS: READINGS:

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	111	198	119	184	185	214	315	332
14	116	204	122	185	190	217	320	337
30	117	205	122	186	190	219	322	337
60	124	212	130	194	197	225	327	344
90	125	213	132	196	199	228	328	345

DAYS: % EXPANSION

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.004297	.005153	.002578	.000859	.004294	.002576	.004289	.004289
30	.005156	.006011	.002578	.001718	.004294	.004293	.006005	.004289
60	.011172	.012023	.009453	.008589	.010306	.009445	.010295	.010293
90	.012032	.012881	.011171	.010306	.012024	.012021	.011153	.011151

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.003542	.004293	.010197	.011592

-MIX 7-

NONREACTIVE AGGREGATE, LOW ALKALI CEMENT, 28% LOW ALKALI FLY ASH A

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	198	167	188	184	193	219	198	142
14	196	167	183	179	189	218	195	146
30	204	172	189	186	198	228	201	149
60	206	175	193	188	200	226	204	153
90	207	176	193	189	200	227	205	153

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	-.00172	0	-.00429	-.00429	-.00344	-.00086	-.00258	.003437
30	.005153	.004295	.000859	.001718	.004294	.007727	.002576	.006014
60	.006870	.006872	.004294	.003435	.006012	.006010	.005153	.009451
90	.007729	.007731	.004294	.004294	.006012	.006869	.006011	.009451

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00245	.003558	.005521	.006134

-MIX 8-

NONREACTIVE AGGREGATE, LOW ALKALI CEMENT, 28% HIGH ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	301	396	352	305	156	246	345	273
14	303	393	348	302	151	239	342	277
30	302	399	355	310	158	250	349	281
60	311	407	362	315	166	259	355	287
90	312	407	366	317	166	257	357	288

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.001716	-.00257	-.00343	-.00257	-.00430	-.00601	-.00257	.003433
30	.000858	.002572	.002573	.004290	.001718	.003434	.003431	.006866
60	.008580	.009430	.008576	.008580	.008591	.011159	.008577	.012015
90	.009438	.009430	.012007	.010296	.008591	.009442	.010292	.012873

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00358	.002696	.009438	.010296

-MIX 9-

NONREACTIVE AGGREGATE, LOW ALKALI CEMENT, 28% LOW ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	259	264	151	227	142	204	215	224
14	260	264	148	225	140	200	213	234
30	267	272	152	229	146	206	219	237
60	271	275	154	233	151	209	223	240
90	271	276	156	234	152	214	226	241

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.000858	0	-.00258	-.00172	-.00172	-.00343	-.00172	.008586
30	.006866	.006866	.000859	.001717	.003437	.001717	.003435	.011161
60	.010300	.009441	.002577	.005151	.007732	.004294	.006869	.013737
90	.010300	.010299	.004295	.006010	.008592	.008587	.009445	.014596

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00147	.003557	.007899	.008872

-MIX 13-

NONREACTIVE AGGREGATE, LOW ALKALI CEMENT, 37% LOW ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	275	190	175	BROKEN	236	235	262	BROKEN
14	276	188	170	BROKEN	227	225	257	BROKEN
30	280	197	177	BROKEN	234	234	261	BROKEN
60	284	202	179	BROKEN	238	237	265	BROKEN
90	285	203	181	BROKEN	239	238	265	BROKEN

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.000858	-.00172	-.00429	0	-.00773	-.00858	-.00429	0
30	.004291	.006012	.001718	0	-.00172	-.00086	-.00086	0
60	.007724	.010306	.003436	0	.001717	.001717	.002575	0
90	.008582	.011165	.005154	0	.002575	.002575	.002575	0

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00622	-.00043	.002361	.003220

-MIX 14-

NONREACTIVE AGGREGATE, HIGH ALKALI CEMENT, NO FLY ASH

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	314	SAMPLE	286	286	272	259	325	260
14	324	SAMPLE	296	SAMPLE	278	265	332	270
30	326	SAMPLE	300	SAMPLE	286	273	337	272
60	329	SAMPLE	305	SAMPLE	290	277	341	277
90	334	SAMPLE	308	SAMPLE	293	280	343	280

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.008579	0	.008581	0	.005149	.005150	.006005	.008583
30	.010295	0	.012013	0	.012015	.012016	.010294	.010300
60	.012868	0	.016304	0	.015448	.015449	.013725	.014591
90	.017158	0	.018878	0	.018022	.018024	.015441	.017166

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.007008	.011155	.014731	.017448

-MIX 15-

NONREACTIVE AGGREGATE, HIGH ALKALI CEMENT, 15% HIGH ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	278	214	-157	197	276	373	371	356
14	271	219	-156	199	280	384	374	360
30	214	222	-152	201	282	383	378	362
60	218	225	-150	206	285	386	379	364
90	218	226	-149	208	285	387	381	365

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	0	.004293	.000861	.001718	.003433	.009432	.002572	.003430
30	0	.006869	.004307	.003435	.005149	.008575	.006002	.005146
60	0	.009445	.006030	.007729	.007724	.011147	.006860	.006861
90	0	.010304	.006891	.009446	.007724	.012004	.008575	.007718

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.002718	.005640	.007441	.008952

-MIX 19-

NONREACTIVE AGGREGATE, HIGH ALKALI CEMENT, 28% HIGH ALKALI FLY ASH A

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	337	272	277	166	256	304	60	228
14	339	274	287	168	260	310	63	231
30	343	276	290	171	261	312	66	233
60	346	279	294	174	265	316	69	237
90	349	282	297	176	268	320	73	237

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.001715	.001716	.008582	.001718	.003433	.005148	.002579	.002576
30	.005146	.003433	.011156	.004295	.004292	.006864	.005159	.004293
60	.007720	.006007	.014589	.006872	.007725	.010296	.007738	.007727
90	.010293	.008582	.017163	.008590	.010300	.013728	.011177	.007727

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.002290	.004436	.007298	.010945

-MIX 20-

NONREACTIVE AGGREGATE, HIGH ALKALI CEMENT, 28% LOW ALKALI FLY ASH A

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	415	459	433	236	243	231	350	268
14	424	466	424	241	244	235	356	275
30	423	467	424	244	247	237	358	276
60	423	467	425	245	246	237	356	275
90	425	471	426	249	249	241	360	276

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.007714	.005998	-.00771	.004292	.000858	.003434	.005146	.006008
30	.006857	.006855	-.00771	.006868	.003434	.005151	.006861	.006866
60	.006857	.006855	-.00686	.007726	.002575	.005151	.005146	.006008
90	.008572	.010282	-.00600	.011160	.005151	.008585	.008576	.006866

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.005432	.006127	.005760	.008456

-MIX 21-

NONREACTIVE AGGREGATE, HIGH ALKALI CEMENT, 28% HIGH ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	322	404	423	398	357	396	331	401
14	328	407	423	398	355	394	331	403
30	330	410	425	401	360	399	336	404
60	334	415	432	406	364	404	341	410
90	337	419	435	412	368	409	344	415

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.005147	.002572	0	0	-.00172	-.00171	0	.001715
30	.006863	.005143	.001714	.002572	.002573	.002572	.004289	.002572
60	.010294	.009430	.007714	.006858	.006003	.006858	.008578	.007715
90	.012868	.012859	.010285	.012002	.009433	.011145	.011151	.012002

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.000122	.003062	.007931	.011468

-MIX 25-

NONREACTIVE AGGREGATE, HIGH ALKALI CEMENT, 37% HIGH ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	349	414	339	385	397	405	190	193
14	349	413	337	384	396	403	188	193
30	353	413	340	386	399	405	191	195
60	356	419	345	391	404	410	197	199
90	361	423	351	394	408	414	198	211

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	0	-.00086	-.00172	-.00086	-.00086	-.00171	-.00172	0
30	.003431	-.00086	.000858	.000857	.001715	0	.000859	.001718
60	.006003	.004286	.005146	.005144	.006001	.004286	.006012	.005153
90	.010292	.007714	.010293	.007716	.009430	.007715	.006870	.015458

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00096	.000736	.005254	.008576

-MIX 26-

NONREACTIVE AGGREGATE, HIGH ALKALI CEMENT, 37% LOW ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	539	330	214	322	236	254	267	335
14	541	327	218	324	236	254	268	337
30	543	329	221	328	241	259	273	341
60	541	331	222	329	241	260	273	340
90	545	331	225	331	243	260	276	342

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.001712	-.00257	.003435	.001716	0	0	.000858	.001715
30	.003425	-.00086	.006010	.005147	.004292	.004292	.005149	.005146
60	.001712	.000858	.006869	.006005	.004292	.005150	.005149	.004289
90	.005137	.000858	.009445	.007721	.006009	.005150	.007724	.006004

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.001348	.004780	.005292	.006742

-MIX 27-

NONREACTIVE AGGREGATE, CEMENT TYPE IP

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	188	114	293	277	371	340	251	239
14	193	117	294	275	370	340	251	243
30	198	124	301	285	379	348	260	250
60	201	127	304	288	381	351	263	253
90	205	129	306	289	382	353	266	257

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.004294	.002578	.000858	-.00172	-.00086	0	0	.003434
30	.008588	.008594	.006864	.006865	.006860	.006862	.007725	.009443
60	.011165	.011172	.009439	.009440	.008575	.009435	.010300	.012018
90	.014600	.012891	.011155	.010298	.009432	.011150	.012875	.015452

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.001074	.007725	.010193	.012232

-MIX 31-

MEDIUM REACTIVE AGGREGATE, LOW ALKALI CEMENT, 15% HIGH ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	136	SAMPLE	203	189	139	218	220	119
14	153	SAMPLE	213	201	151	233	233	134
30	166	SAMPLE	SAMPLE	216	169	252	250	148
60	210	SAMPLE	SAMPLE	285	240	330	329	189
90	232	SAMPLE	SAMPLE	322	292	370	365	214

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.014607	0	.008587	.010306	.010310	.012879	.011162	.012890
30	.025776	0	0	.023188	.025776	.029193	.025758	.024921
60	.063582	0	0	.082447	.086778	.096164	.093586	.060153
90	.082484	0	0	.114223	.131456	.130508	.124496	.081637

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.011534	.025769	.089744	.125171

-MIX 32-

MEDIUM REACTIVE AGGREGATE, LOW ALKALI CEMENT, 15% LOW ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	260	218	175	170	187	260	0	179
14	262	215	160	162	182	258	1	183
30	272	224	180	172	192	267	11	190
60	279	230	188	180	203	280	18	198
90	281	234	191	184	205	288	22	200

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.001717	-.00258	-.01288	-.00687	-.00429	-.00172	.000860	.003436
30	.010300	.005152	.004295	.001718	.004294	.006008	.009462	.009448
60	.016308	.010303	.011166	.008590	.013741	.017166	.015484	.016319
90	.018024	.013738	.013743	.012025	.015459	.024032	.018925	.018037

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.000344	.006994	.015804	.016321

-MIX 33-

MEDIUM REACTIVE AGGREGATE, LOW ALKALI CEMENT, 28% HIGH ALKALI FLY ASH A

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	361	282	241	248	206	258	460	470
14	362	278	233	241	200	254	457	470
30	365	284	242	247	204	258	463	474
60	373	293	251	258	214	268	474	481
90	372	296	254	260	215	270	474	484

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.000858	-.00343	-.00687	-.00601	-.00515	-.00343	-.00257	0
30	.003430	.001716	.000858	-.00086	-.00172	0	.002570	.003427
60	.010291	.009439	.008584	.008584	.006870	.008583	.011996	.009424
90	.009433	.012014	.011160	.010301	.007728	.010300	.011996	.011995

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00458	.001178	.009221	.010616

-MIX 37-

MEDIUM REACTIVE AGGREGATE, LOW ALKALI CEMENT, 37% HIGH ALKALI FLY ASH A

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	192	176	243	315	249	380	248	274
14	194	176	243	315	247	378	246	275
30	200	181	248	321	253	384	252	283
60	207	188	258	330	260	391	259	288
90	208	192	259	335	263	397	262	290

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.001718	0	0	0	-.00172	-.00171	-.00172	.000858
30	.006870	.004295	.004292	.005147	.003434	.003430	.003434	.007724
60	.012882	.010307	.012876	.012868	.009442	.009432	.009442	.012015
90	.013741	.013743	.013735	.017158	.012017	.014576	.012017	.013731

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00032	.004828	.011158	.013840

-MIX 38-

MEDIUM REACTIVE AGGREGATE, LOW ALKALI CEMENT, 37% LOW ALKALI FLY ASH A

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	186	252	203	281	325	274	370	276
14	190	247	196	270	315	264	363	276
30	191	258	206	284	330	279	375	285
60	194	264	210	290	336	284	379	290
90	200	268	214	294	335	288	384	293

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.003435	-.00429	-.00601	-.00944	-.00858	-.00858	-.00600	0
30	.004294	.005150	.002576	.002574	.004289	.004291	.004287	.007724
60	.006871	.010300	.006011	.007723	.009436	.008582	.007717	.012014
90	.012024	.013734	.009446	.011156	.008578	.012015	.012005	.014589

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00515	.004398	.008582	.011693

-MIX 39-

MEDIUM REACTIVE AGGREGATE, LOW ALKALI CEMENT, 37% HIGH ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	296	261	270	190	518	380	174	99
14	306	271	281	200	525	390	180	110
30	313	281	292	212	536	401	191	119
60	326	291	302	227	552	416	206	131
90	332	299	311	233	560	424	214	137

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.008580	.008583	.009440	.008588	.005995	.008574	.005154	.009454
30	.014587	.017166	.018881	.018894	.015415	.018006	.014602	.017190
60	.025741	.025749	.027463	.031776	.029118	.030867	.027486	.027503
90	.030889	.032615	.035187	.036929	.035969	.037726	.034357	.032660

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.008046	.016842	.027177	.034542

-MIX 43-

MEDIUM REACTIVE AGGREGATE, HIGH ALKALI CEMENT, 15% LOW ALKALI FLY ASH A

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	225	168	370	536	332	330	294	302
14	236	177	375	540	335	334	297	310
30	238	179	378	545	338	336	301	314
60	243	188	386	551	346	344	308	319
90	242	188	387	552	348	346	310	319

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.009444	.007731	.004287	.003425	.002573	.003431	.002574	.006864
30	.011161	.009449	.006860	.007706	.005147	.005147	.006006	.010296
60	.015454	.017179	.013720	.012844	.012009	.012009	.012013	.014586
90	.014595	.017179	.014577	.013700	.013724	.013724	.013729	.014586

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.003258	.006173	.013233	.014091

-MIX 44-

MEDIUM REACTIVE AGGREGATE, HIGH ALKALI CEMENT, 15% HIGH ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	207	244	405	349	311	237	268	360
14	231	260	421	364	331	253	290	382
30	274	320	462	406	370	298	333	417
60	350	435	566	499	452	385	414	486
90	360	SAMPLE	612	557	493	429	450	512

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.020608	.013735	.013716	.012865	.017158	.013735	.018881	.018866
30	.057532	.065239	.048862	.048885	.050617	.052366	.055785	.048881
60	.122792	.163957	.138014	.128646	.120967	.127053	.125303	.108052
90	.131379	0	.177446	.178389	.156141	.164825	.156199	.130349

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.016015	.051847	.124404	.166600

-MIX 45-

MEDIUM REACTIVE AGGREGATE, HIGH ALKALI CEMENT, 15% LOW ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	318	319	306	339	263	256	183	215
14	330	327	311	344	259	259	182	222
30	338	337	323	354	272	274	189	229
60	351	354	332	369	293	290	204	241
90	358	376	345	379	320	320	219	251

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.010294	.006863	.004290	.004289	-.00343	.002575	-.00086	.006010
30	.017157	.015441	.014585	.012866	.007724	.015450	.005153	.012021
60	.028310	.030025	.022307	.025731	.025748	.029183	.018036	.022324
90	.034315	.048898	.033460	.034309	.048922	.054933	.030919	.030911

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.004805	.014587	.027799	.032783

-MIX 49-

MEDIUM REACTIVE AGGREGATE, HIGH ALKALI CEMENT, 28% LOW ALKALI FLY ASH B

DAYS: READINGS:

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	225	266	255	279	349	301	467	438
14	235	276	265	281	357	312	470	450
30	242	282	273	289	366	318	476	457
60	246	287	278	295	372	324	481	461
90	247	288	280	300	376	329	486	463

DAYS: % EXPANSION

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.008586	.008583	.008583	.001716	.006861	.009438	.002570	.010284
30	.014595	.013732	.015450	.008582	.014580	.014586	.007711	.016283
60	.018030	.018023	.019742	.013730	.019726	.019734	.011995	.019711
90	.018888	.018882	.021458	.018021	.023156	.024024	.016279	.021425

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.008722	.014871	.019161	.020836

-MIX 50-

MEDIUM REACTIVE AGGREGATE, HIGH ALKALI CEMENT, 37% HIGH ALKALI FLY ASH A

DAYS: READINGS:

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	248	244	185	164	279	302	384	365
14	255	247	186	166	279	304	384	371
30	259	253	191	171	285	311	392	377
60	266	262	196	176	293	318	398	383
90	268	263	202	180	296	323	403	389

DAYS: % EXPANSION

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.006009	.002575	.000859	.001718	0	.001716	0	.005145
30	.009442	.007726	.005153	.006013	.005149	.007722	.006859	.010290
60	.015451	.015451	.009447	.010308	.012014	.013728	.012003	.015435
90	.017168	.016310	.014600	.013744	.014589	.018018	.016290	.020581

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.001145	.007294	.013484	.015817

-MIX 51-

MEDIUM REACTIVE AGGREGATE, HIGH ALKALI CEMENT, 37% LOW ALKALI FLY ASH A

DAYS: READINGS:

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	273	160	395	283	318	294	314	302
14	283	165	401	289	328	304	320	312
30	287	167	405	293	331	306	323	315
60	291	169	414	303	332	321	333	325
90	299	180	418	305	342	322	334	326

DAYS: % EXPANSION

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.008582	.004295	.005144	.005149	.008579	.008580	.005147	.008580
30	.012015	.006013	.008573	.008581	.011152	.010297	.007721	.011154
60	.015448	.007731	.016289	.017163	.012010	.023167	.016300	.019734
90	.022313	.017181	.019718	.018879	.020589	.024025	.017158	.020592

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.006757	.009928	.016987	.019490

-MIX 55-

HIGHLY REACTIVE AGGREGATE, LOW ALKALI CEMENT, NO FLY ASH

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	277	302	178	164	171	252	338	206
14	268	289	162	149	157	238	327	199
30	272	298	169	156	166	246	332	207
60	280	302	177	162	168	250	337	210
90	286	SAMPLE	187	174	179	260	345	215

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	-.00772	-.01115	-.01374	-.01289	-.01203	-.01202	-.00943	-.00601
30	-.00429	-.00343	-.00773	-.00687	-.00429	-.00515	-.00515	.000859
60	.002575	0	-.00086	-.00172	-.00258	-.00172	-.00086	.003435
90	.007724	0	.007730	.008590	.006872	.006867	.006004	.007728

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.01188	-.00527	-.00155	.007359

-MIX 56-

HIGHLY REACTIVE AGGREGATE, LOW ALKALI CEMENT, 15% HIGH ALKALI FLY ASH A

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	-280	150	77	181	206	214	225	-568
14	-282	144	67	171	197	205	220	-568
30	-280	147	73	173	203	209	222	-568
60	-275	150	76	180	205	210	226	-563
90	-269	157	83	185	212	218	231	-557

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	-.00172	-.00515	-.00860	-.00859	-.00773	-.00773	-.00429	0
30	0	-.00258	-.00344	-.00687	-.00258	-.00429	-.00258	0
60	.004311	0	-.00086	-.00086	-.00086	-.00343	.000859	.004322
90	.009485	.006014	.005158	.003436	.005152	.003435	.005151	.009509

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00701	-.00279	-.00086	.004724

-MIX 57-

HIGHLY REACTIVE AGGREGATE, LOW ALKALI CEMENT, 15% LOW ALKALI FLY ASH A

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	442	450	251	316	214	402	241	345
14	442	447	247	313	218	395	239	349
30	446	451	248	314	224	401	242	352
60	453	457	256	323	230	406	251	360
90	455	460	260	325	234	410	254	364

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	0	-.00257	-.00343	-.00257	.003435	-.00600	-.00172	.003431
30	.003428	.000857	-.00258	-.00172	.008586	-.00086	.000858	.006004
60	.009427	.005998	.004292	.006005	.013738	.003429	.008584	.012865
90	.011140	.008569	.007725	.007721	.017173	.006858	.011160	.016296

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00206	-.00069	.006289	.008862

-MIX 61-

HIGHLY REACTIVE AGGREGATE, LOW ALKALI CEMENT, 28% LOW ALKALI FLY ASH A

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	223	231	328	340	262	266	122	286
14	224	228	320	334	257	257	117	287
30	229	232	327	341	262	265	124	293
60	231	236	331	342	264	267	127	295
90	234	241	338	350	267	270	130	297

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.000859	-.00258	-.00686	-.00515	-.00429	-.00772	-.00430	.000858
30	.005151	.000859	-.00086	.000858	0	-.00086	.001719	.006007
60	.006869	.004293	.002573	.001715	.001717	.000858	.004297	.007723
90	.009444	.008585	.008578	.008577	.004291	.003433	.006875	.009439

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00515	.000286	.002575	.004866

-MIX 62-

HIGHLY REACTIVE AGGREGATE, LOW ALKALI CEMENT, 28% HIGH ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	78	164	289	286	288	338	257	156
14	95	196	302	296	300	350	274	171
30	117	199	322	320	321	370	292	187
60	162	242	365	362	365	414	328	221
90	185	273	390	392	390	442	354	244

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.014614	.027488	.011155	.008581	.010297	.010293	.014591	.012886
30	.033526	.030065	.028317	.029176	.028317	.027447	.030041	.026631
60	.072210	.067002	.065214	.065216	.066073	.065187	.060941	.055839
90	.091981	.093631	.086666	.090959	.087525	.089203	.083257	.075597

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.011774	.029190	.064710	.089032

-MIX 63-

HIGHLY REACTIVE AGGREGATE, LOW ALKALI CEMENT, 28% LOW ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	347	BROKEN	300	276	312	290	225	130
14	347	BROKEN	297	274	311	287	224	132
30	353	BROKEN	304	280	316	292	227	138
60	361	BROKEN	314	288	323	302	235	146
90	365	BROKEN	318	290	325	304	239	144

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	0	0	-.00257	-.00172	-.00086	-.00257	-.00086	.001719
30	.005146	0	.003432	.003433	.003432	.001716	.001717	.006874
60	.012007	0	.012012	.010298	.009437	.010297	.008586	.013748
90	.015438	0	.015444	.012014	.011153	.012013	.012020	.012030

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00098	.003679	.010912	.012873

-MIX 67-

HIGHLY REACTIVE AGGREGATE, LOW ALKALI CEMENT, 37% LOW ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	218	208	251	295	-444	271	246	158
14	225	207	253	296	-448	268	245	158
30	227	212	260	304	-440	276	253	163
60	235	222	269	310	-429	284	262	171
90	241	229	272	310	-428	285	262	175

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.006010	-.00086	.001717	.000858	-.00345	-.00257	-.00086	0
30	.007727	.003435	.007725	.007722	.003454	.004291	.006009	.004295
60	.014596	.012022	.015451	.012871	.012953	.011157	.013734	.011168
90	.019748	.018032	.018026	.012871	.013816	.012015	.013734	.014604

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00074	.005582	.012994	.015356

-MIX 68-

HIGHLY REACTIVE AGGREGATE, HIGH ALKALI CEMENT, NO FLY ASH

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	184	183	216	200	333	SAMPLE	306	283
14	200	196	228	209	342	SAMPLE	SAMPLE	299
30	215	218	247	228	365	SAMPLE	SAMPLE	316
60	223	254	275	264	405	SAMPLE	SAMPLE	332
90	228	271	290	294	438	SAMPLE	SAMPLE	339

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.013742	.011165	.010303	.007729	.007720	0	0	.013730
30	.026625	.030060	.026617	.024045	.027448	0	0	.028318
60	.033495	.060979	.050659	.054959	.061759	0	0	.042048
90	.037790	.075580	.063538	.080721	.090065	0	0	.048055

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.010731	.027186	.057089	.073280

-MIX 69-

HIGHLY REACTIVE AGGREGATE, HIGH ALKALI CEMENT, 15% HIGH ALKALI FLY ASH A

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	244	224	370	329	362	246	217	191
14	250	227	372	328	361	246	217	195
30	256	231	376	333	369	253	221	197
60	261	236	384	341	376	258	228	202
90	267	244	390	348	387	268	234	212

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.005150	.002576	.001715	-.00086	-.00086	0	0	.003435
30	.010301	.006010	.005145	.003431	.006003	.006009	.003434	.005153
60	.014593	.010303	.012005	.010293	.012006	.010301	.009445	.009447
90	.019744	.017171	.017150	.016298	.021439	.018885	.014596	.018035

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.000859	.005026	.010543	.017411

-MIX 73-

HIGHLY REACTIVE AGGREGATE, HIGH ALKALI CEMENT, 28% HIGH ALKALI FLY ASH A

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	456	689	309	311	214	289	302	268
14	461	690	305	309	216	286	301	274
30	464	696	310	312	220	291	304	277
60	471	700	316	318	227	297	310	282
90	474	705	321	323	230	303	314	286

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.004284	.000855	-.00343	-.00172	.001717	-.00257	-.00086	.005149
30	.006855	.005986	.000858	.000858	.005152	.001716	.001716	.007724
60	.012853	.009407	.006006	.006005	.011162	.006865	.006864	.012015
90	.015423	.013682	.010295	.010295	.013738	.012013	.010296	.015448

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00100	.002714	.007029	.012649

-MIX 74-

HIGHLY REACTIVE AGGREGATE, HIGH ALKALI CEMENT, 28% LOW ALKALI FLY ASH A

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	259	434	257	240	123	245	402	323
14	261	429	252	234	112	235	392	323
30	263	432	255	238	117	239	398	325
60	266	440	259	243	122	244	401	329
90	267	441	261	245	126	245	405	330

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.001717	-.00429	-.00429	-.00515	-.00945	-.00858	-.00857	0
30	.003433	-.00171	-.00172	-.00172	-.00516	-.00515	-.00343	.001716
60	.006008	.005142	.001717	.002575	-.00086	-.00086	-.00086	.005147
90	.006866	.005999	.003433	.004292	.002578	0	.002572	.006005

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00672	-.00315	.000343	.004535

-MIX 75-

HIGHLY REACTIVE AGGREGATE, HIGH ALKALI CEMENT, 28% HIGH ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	256	389	214	213	128	283	255	303
14	275	408	235	234	149	300	275	327
30	301	433	260	267	186	332	308	358
60	344	476	307	326	241	386	358	402
90	365	499	332	SAMPLE	276	421	383	424

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.016308	.016290	.018031	.018031	.018045	.014588	.017167	.020591
30	.038625	.037723	.039497	.046367	.049838	.042048	.045492	.047189
60	.075533	.074589	.079853	.097027	.097097	.088387	.088408	.084940
90	.093557	.094308	.101319	0	.127172	.118421	.109867	.103815

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.017381	.042420	.085729	.103548

-MIX 79-

HIGHLY REACTIVE AGGREGATE, HIGH ALKALI CEMENT, 37% HIGH ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	356	325	274	324	268	264	334	230
14	370	337	283	330	278	271	341	243
30	387	355	305	350	303	294	364	268
60	413	385	336	380	334	326	388	296
90	430	407	368	405	358	350	413	320

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.012006	.010294	.007724	.005147	.008582	.006008	.006004	.011161
30	.026585	.025735	.026604	.022303	.030038	.025748	.025733	.032624
60	.048883	.051469	.053208	.048038	.056644	.053212	.046319	.056662
90	.063462	.070341	.080670	.069484	.077241	.073811	.067762	.077266

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.007293	.025451	.051804	.072505

-MIX 80-

HIGHLY REACTIVE AGGREGATE, HIGH ALKALI CEMENT, 37% LOW ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	357	364	272	265	382	302	227	341
14	365	368	272	264	384	304	227	349
30	372	379	282	275	394	313	238	358
60	380	388	291	281	404	322	246	365
90	385	395	297	290	411	328	252	372

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.006861	.003430	0	-.00086	.001715	.001716	0	.006862
30	.012864	.012863	.008582	.008583	.010289	.009438	.009444	.014581
60	.019724	.020581	.016306	.013732	.018863	.017160	.016312	.020585
90	.024012	.026583	.021455	.021456	.024865	.022308	.021463	.026589

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.001000	.010295	.018504	.023591

-MIX 81-

HIGHLY REACTIVE AGGREGATE, CEMENT TYPE IP, NO FLY ASH

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	246	229	285	290	211	252	188	210
14	251	230	285	287	207	247	187	211
30	254	232	289	292	209	250	189	212
60	259	236	294	298	216	255	197	219
90	257	238	294	295	217	255	196	217

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.004292	.000859	0	-.00257	-.00343	-.00429	-.00086	.000859
30	.006867	.002576	.003432	.001716	-.00172	-.00172	.000859	.001717
60	.011159	.006010	.007723	.006865	.004293	.002575	.007729	.007728
90	.009442	.007727	.007723	.004290	.005152	.002575	.006871	.006011

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00069	.001431	.005150	.005794

-MIX 85-

CONTROL AGGREGATE, LOW ALKALI CEMENT, 15% HIGH ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	285	SAMPLE	284	260	172	194	283	285
14	567	SAMPLE	462	423	340	359	467	516
30	645	SAMPLE	SAMPLE	512	428	443	547	570
60	670	SAMPLE	SAMPLE	537	452	466	574	596
90	688	SAMPLE	SAMPLE	547	469	482	588	609

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.241987	0	.152745	.139902	.144303	.141699	.157895	.198224
30	.308920	0	0	.216290	.219890	.213837	.226545	.244562
60	.330373	0	0	.237748	.240504	.233589	.249715	.266873
90	.345819	0	0	.246331	.255106	.247329	.261728	.278028

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.147309	.224225	.245686	.257705

-MIX 86-

CONTROL AGGREGATE, LOW ALKALI CEMENT, 15% LOW ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	238	276	334	363	237	269	257	259
14	448	432	472	494	382	404	393	467
30	470	468	512	540	423	441	428	487
60	496	488	534	566	442	462	447	515
90	501	498	551	579	454	475	461	522

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.180276	.133876	.118370	.112337	.124477	.115861	.116731	.178527
30	.199162	.164770	.152680	.151784	.159674	.147615	.146772	.195693
60	.221482	.181934	.171550	.174080	.175985	.165638	.163080	.219726
90	.225774	.190515	.186132	.185228	.186287	.176795	.175097	.225734

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.120275	.153883	.172045	.183342

-MIX 87-

CONTROL AGGREGATE, LOW ALKALI CEMENT, 28% HIGH ALKALI FLY ASH A

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	116	-50	178	89	28	150	188	179
14	158	-33	195	100	49	168	211	219
30	160	-27	200	107	55	179	224	225
60	170	-19	211	116	73	190	237	238
90	173	-13	218	125	86	198	249	248

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.036093	.014630	.014601	.009455	.018060	.015464	.019753	.034356
30	.037812	.019793	.018896	.015472	.023220	.024914	.030918	.039509
60	.046405	.026678	.028344	.023208	.038700	.034364	.042082	.050675
90	.048983	.031842	.034356	.030944	.049880	.041237	.052388	.059264

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.016502	.021706	.036307	.043612

-MIX 91-

CONTROL AGGREGATE, LOW ALKALI CEMENT, 37% HIGH ALKALI FLY ASH A

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	194	239	225	142	354	170	177	102
14	220	263	244	145	372	192	193	135
30	222	271	252	161	381	197	198	141
60	230	279	261	170	390	209	210	148
90	234	281	261	174	393	211	211	151

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.022328	.020603	.016313	.002577	.015437	.018897	.013743	.028362
30	.024046	.027470	.023181	.016324	.023155	.023192	.018037	.033519
60	.030916	.034338	.030908	.024057	.030874	.033499	.028344	.039535
90	.034351	.036055	.030908	.027493	.033447	.035217	.029203	.042114

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.017887	.023394	.032107	.033996

-MIX 92-

CONTROL AGGREGATE, LOW ALKALI CEMENT, 37% LOW ALKALI FLY ASH A

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	384	312	273	341	158	234	352	260
14	397	312	274	340	160	236	349	263
30	401	320	283	346	165	243	353	270
60	411	327	293	354	175	252	362	276
90	412	328	293	356	174	252	361	278

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.011146	0	.000858	-.00086	.001718	.001717	-.00257	.002575
30	.014576	.006863	.008582	.004288	.006013	.007726	.000858	.008583
60	.023149	.012869	.017164	.011150	.014604	.015453	.008576	.013733
90	.024007	.013727	.017164	.012865	.013745	.015453	.007719	.015449

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.000491	.007009	.014162	.014734

-MIX 93-

CONTROL AGGREGATE, LOW ALKALI CEMENT, 37% HIGH ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	295	336	222	130	120	179	199	184
14	498	504	384	285	260	343	374	382
30	535	547	432	331	296	380	409	410
60	571	585	471	370	323	413	442	436
90	582	599	488	385	334	424	455	445

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.174182	.144100	.139089	.133184	.120306	.140858	.150280	.170053
30	.205929	.180982	.180301	.172710	.151242	.172637	.180336	.194101
60	.236818	.213576	.213785	.206221	.174444	.200981	.208675	.216432
90	.246257	.225585	.228381	.219110	.183896	.210429	.219839	.224161

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.137970	.183857	.213784	.224823

-MIX 97-

CONTROL AGGREGATE, HIGH ALKALI CEMENT, 15% LOW ALKALI FLY ASH A

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	244	266	-313	191	352	344	189	228
14	378	376	-214	289	451	446	312	391
30	397	418	-194	310	469	464	332	410
60	411	417	-183	323	480	474	346	422
90	413	415	-176	332	489	481	353	426

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.115027	.094408	.085391	.084163	.084904	.087483	.105635	.139941
30	.131337	.130454	.102642	.102198	.100341	.102921	.122811	.156253
60	.143355	.129596	.112130	.113362	.109775	.111498	.134835	.166555
90	.145072	.127879	.118168	.121091	.117494	.117502	.140846	.169989

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.087270	.102026	.118533	.126865

-MIX 98-

CONTROL AGGREGATE, HIGH ALKALI CEMENT, 15% HIGH ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	325	447	195	145	282	378	435	530
14	640	733	450	399	536	646	711	844
30	715	828	527	469	622	733	792	930
60	742	864	556	496	662	779	837	973
90	763	883	571	510	681	801	859	991

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.270212	.245079	.218988	.218222	.217966	.229790	.236534	.268882
30	.334549	.326487	.285113	.278362	.291765	.304387	.305952	.342524
60	.357710	.357336	.310018	.301559	.326091	.343828	.344517	.379346
90	.375724	.373617	.322899	.313587	.342395	.362692	.363371	.394759

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.238209	.308642	.340051	.356131

-MIX 99-

CONTROL AGGREGATE, HIGH ALKALI CEMENT, 15% LOW ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	250	138	297	303	233	313	366	232
14	535	372	531	536	477	542	583	491
30	572	417	585	583	535	590	637	530
60	596	441	609	606	561	618	661	552
90	600	446	617	613	572	630	668	558

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.244635	.201052	.200777	.199909	.209473	.196460	.186081	.222352
30	.276395	.239715	.247111	.240234	.259265	.237640	.232387	.255834
60	.296996	.260336	.267703	.259968	.281586	.261661	.252967	.274721
90	.300429	.264632	.274567	.265973	.291030	.271956	.258970	.279872

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.202301	.248573	.269492	.275929

-MIX 106-

CONTROL AGGREGATE, HIGH ALKALI CEMENT, 37% HIGH ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	242	240	335	341	289	275	296	308
14	427	402	492	498	437	437	452	491
30	475	446	535	540	479	482	494	534
60	496	470	559	565	501	509	517	556
90	502	475	566	569	509	516	525	560

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.158809	.139068	.134666	.134659	.126996	.139026	.133853	.157003
30	.200014	.176839	.171549	.170682	.163036	.177644	.169890	.193895
60	.218041	.197442	.192134	.192125	.181913	.200815	.189625	.212770
90	.223191	.201734	.198139	.195555	.188778	.206823	.196489	.216201

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.140510	.177944	.198108	.203364

-MIX 107-

CONTROL AGGREGATE, HIGH ALKALI CEMENT, 37% LOW ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	297	353	438	335	238	330	119	311
14	519	530	601	477	375	470	256	503
30	544	556	628	508	405	505	289	529
60	548	570	640	520	418	517	300	538
90	551	575	642	526	420	522	305	542

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.190481	.151797	.139689	.121800	.117609	.120089	.117729	.164721
30	.211932	.174095	.162827	.148390	.143362	.150112	.146087	.187027
60	.215364	.186102	.173111	.158683	.154522	.160405	.155540	.194748
90	.217938	.190390	.174825	.163829	.156239	.164694	.159836	.198179

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.123383	.154145	.169016	.172570

-MIX 108-

CONTROL AGGREGATE, CEMENT TYPE IP, NO FLY ASH

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	130	206	256	314	291	156	232	229
14	139	208	254	307	287	153	228	235
30	144	213	246	314	293	162	238	242
60	149	221	254	324	304	168	246	251
90	150	226	260	327	307	168	251	256

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.007733	.001717	-.00172	-.00601	-.00343	-.00258	-.00343	.005151
30	.012030	.006011	-.00858	0	.001716	.005154	.005151	.011161
60	.016326	.012880	-.00172	.008579	.011155	.010309	.012019	.018888
90	.017185	.017174	.003433	.011153	.013729	.010309	.016312	.023180

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00189	.004508	.010988	.016100

APPENDIX B

MATERIAL PROPERTIES

MATERIAL: Cement Type I
PRODUCER: Capitol Portland Cement Company, San Antonio, Texas

PHYSICAL PROPERTIES

COMPRESSIVE STRENGTH:	3 Day: 3605 psi 7 Day: 4272 psi 28 Day: 5528 psi
SPECIFIC SURFACE AREA:	1825 cm^2/gr
SOUNDNESS (Autoclave Expansion):	0.02%
TIME OF SETTING (Gillmore):	Initial: 2.33 hrs Final: 4.33 hrs
AIR CONTENT:	10.5%
NORMAL CONSISTENCY:	26.0%

CHEMICAL PROPERTIES

METAL OXIDES:	CaO: 64.41% Al_2O_3: 5.50% Fe_2O_3: 1.90% SiO_2: 20.11% SO_3: 3.01% MgO: 1.31%
ALKALI OXIDES:	Na_2O: 0.07% K_2O: 0.54%
TOTAL ALKALIS ($Na_2O + 0.6K_2O$):	0.43%
PHASE ANALYSIS:	C_3S: 61.14% C_2S: 11.54% C_3A: 11.35% C_4AF: 5.78%
TOTAL OXIDES:	96.24%
TOTAL PHASES:	89.81%
LOSS ON IGNITION:	2.13%
INSOLUBLE RESIDUE:	0.07%

MATERIAL: Fly Ash Type A
PRODUCER: San Miguel Plant, Texas

PHYSICAL PROPERTIES

WATER REQUIREMENT:	93.33%
FINENESS:	16.70%
SOUNDNESS (Autoclave Expansion):	0.03%
SPECIFIC GRAVITY:	1.86
INCREASE OF DRYING SHRINKAGE:	-0.01%

CHEMICAL PROPERTIES

SUM OF SiO_2, Al_2O_3, AND Fe_2O_3:	82.17%
CaO:	2.52%
SO_3:	0.48%
MgO:	0.00%
MOISTURE CONTENT:	0.19%
LOSS ON IGNITION:	0.30%
AVAILABLE ALKALIS ($Na_2O + 0.6K_2O$):	1.38%

MATERIAL: Fly Ash Type B
PRODUCER: Fayette Plant, Texas

PHYSICAL PROPERTIES

WATER REQUIREMENT:	90.32%
FINENESS:	14.30%
SOUNDNESS (Autoclave Expansion):	0.005%
SPECIFIC GRAVITY:	2.71%
INCREASE OF DRYING SHRINKAGE:	0.01%

CHEMICAL PROPERTIES

SUM OF SiO_2, Al_2O_3, AND Fe_2O_3:	62.49%
CaO:	23.43%
SO_3:	2.59%
MgO:	4.30%
MOISTURE CONTENT:	0.12%
LOSS ON IGNITION:	0.34%
AVAILABLE ALKALIS ($Na_2O + 0.6K_2O$):	4.35%

APPENDIX C

MIX DATA

MIX No.	MATERIALS WEIGHTS[b] (lb)				W/(C+F)[d]	FLY ASH CONTENT[e] (%)		TOTAL VOLUME (ft^3)		
	CEMENT	FLY ASH	AGGREGATE	WATER[c]		BY WEIGHT	BY VOLUME	C+F	AGGREGGATE	WATER
25	23.74	10.21	80.89	20.00	0.59	28	34	.0183	0.497	0.320
26	20.19	13.45	81.61	19.62	0.58	37	44	0.185	0.501	0.314
27	38.99	0.00	87.95	17.2	0.44	0	0	0.198	0.526	0.276
28	32.04	5.64	87.02	16.73	0.44	15	22	0.212	0.520	0.268
29	25.21	10.84	85.91	16.52	0.46	28	41	0.221	0.514	0.265
30	21.17	14.10	85.59	16.16	0.46	37	52	0.229	0.512	0.259
31-Batch1	32.27	5.68	87.64	16.55	0.44	15	18	0.201	0.524	0.275
31-Batch2	31.30	5.51	85.00	18.68	0.51	15	18	0.194	0.508	0.298
32	25.80	11.09	87.91	16.90	0.46	28	35	0.203	0.526	0.271
33	21.71	14.47	87.78	16.88	0.47	37	46	0.205	0.525	0.270
34	32.38	5.70	87.94	17.21	0.45	15	17	0.198	0.526	0.276
35	25.97	11.17	88.50	17.02	0.46	28	33	0.198	0.529	0.273
36	21.90	14.59	88.55	17.03	0.47	37	44	0.198	0.529	0.273
37	32.66	5.75	88.71	16.75	0.44	15	17	0.201	0.530	0.269
38	25.92	11.14	88.32	16.98	0.46	28	34	0.200	0.528	0.272
39	21.85	14.55	88.32	16.98	0.47	37	44	0.200	0.528	0.272
40	38.79	0.00	87.52	17.43	0.45	0	0	0.197	0.523	0.280
41	31.74	5.58	56.19	17.17	0.46	15	22	0.210	0.515	0.275
42	25.21	10.84	85.91	16.52	0.46	28	41	0.221	0.514	0.265
43	21.07	14.04	85.19	16.38	0.47	37	52	0.228	0.509	0.263
44	32.11	5.65	87.22	17.37	0.46	15	18	0.200	0.521	0.279
45	25.80	11.09	87.91	16.91	0.46	15	18	0.203	0.526	0.271
46	21.71	14.47	87.78	16.88	0.47	28	35	0.205	0.525	0.270
47	32.22	5.67	87.51	17.43	0.46	37	46	0.198	0.523	0.279
48	25.97	11.17	88.50	17.02	0.46	15	17	0.198	0.529	0.273

MIX No.	MATERIALS WEIGHTS[b] (lb)				W/(C+F)[d]	FLY ASH CONTENT[e] (%)		TOTAL VOLUME (ft^3)		
	CEMENT	FLY ASH	AGGREGATE	WATER[c]		BY WEIGHT	BY VOLUME	C+F	AGGREGGATE	WATER
71	26.69	11.48	90.96	14.68	0.38	28	35	0.211	0.554	0.235
72	22.58	15.04	91.28	14.42	0.38	37	46	0.213	0.556	0.231
73	33.34	5.87	90.54	15.23	0.39	15	17	0.204	0.552	0.244
74	27.01	11.61	92.06	14.54	0.38	28	33	0.206	0.561	0.233
75	22.78	15.18	92.11	14.55	0.38	37	44	0.206	0.561	0.233
76	33.30	5.86	90.44	15.22	0.39	15	17	0.205	0.551	0.244
77	26.82	11.53	91.40	14.75	0.38	28	34	0.207	0.557	0.236
78	22.49	14.99	90.94	14.99	0.40	37	44	0.206	0.554	0.240
79	35.03	0.00	79.03	17.37	0.50	0	0	0.178	0.544	0.278
80	29.20	5.14	79.30	16.34	0.48	15	22	0.193	0.545	0.262
81	23.00	9.89	78.38	16.15	0.49	28	41	0.202	0.539	0.259
82	19.57	13.04	79.13	15.22	0.47	37	52	0.212	0.544	0.244
83	29.52	5.19	80.17	16.52	0.49	15	18	0.184	0.551	0.265
84	23.70	10.19	80.75	16.08	0.47	28	35	0.187	0.555	0.258
85	20.04	13.35	81.00	15.86	0.47	37	46	0.189	0.557	0.254
86	29.74	5.23	80.78	16.37	0.47	15	17	0.182	0.556	0.262
87	24.06	10.34	81.98	15.77	0.46	28	33	0.184	0.564	0.252
88	20.20	13.46	81.66	15.98	0.47	37	44	0.182	0.562	0.256
89	29.85	5.25	81.06	16.15	0.46	15	17	0.184	0.557	0.259
90	24.01	10.32	81.83	15.74	0.46	28	34	0.185	0.563	0.252
91	20.15	13.42	81.46	15.94	0.47	37	44	0.184	0.560	0.256
92	35.65	0.00	80.43	16.57	0.46	0	0	0.181	0.553	0.266
93	29.33	5.16	79.65	16.14	0.47	15	22	0.194	0.548	0.258
94	23.10	9.93	78.72	15.95	0.48	28	41	0.203	0.541	0.256

(Continued from inside front cover)

183-8 "The Resilient and Fatigue Characteristics of Asphalt Mixtures Processed by the Dryer-Drum Mixer," by Manuel Rodriguez and Thomas W. Kennedy, December 1976.

183-9 "Fatigue and Repeated-Load Elastic Characteristics of Inservice Portland Cement Concrete," by John A. Crumley and Thomas W. Kennedy, June 1977.

183-10 "Development of a Mixture Design Procedure for Recycled Asphalt Mixtures," by Ignacio Perez, Thomas W. Kennedy, and Adedare S. Adedimila, November 1978.

183-11 "An Evaluation of the Texas Blackbase Mix Design Procedure Using the Indirect Tensile Test," by David B. Peters and Thomas W. Kennedy, March 1979.

183-12 "The Effects of Soil Binder and Moisture on Blackbase Mixtures," by Wei-Chou V. Ping and Thomas W. Kennedy, May 1979.

184-1 "The TEXAS Model for Intersection Traffic—Development," by Clyde E. Lee, Thomas W. Rioux, and Charlie R. Copeland, December 1977.

184-2 "The TEXAS Model for Intersection Traffic — Programmer's Guide," by Clyde E. Lee, Thomas W. Rioux, Vivek S. Savur, and Charlie R. Copeland, December 1977.

184-3 "The TEXAS Model for Intersection Traffic—User's Guide," by Clyde E. Lee, Glenn E. Grayson, Charlie R. Copeland, Jeff W. Miller, Thomas W. Rioux, and Vivek S. Savur, July 1977.

184-4F "Application of the TEXAS Model for Analysis of Intersection Capacity and Evaluation of Traffic Control Warrants," by Clyde E. Lee, Vivek S. Savur, and Glenn E. Grayson, July 1978.

188-1 "Behavior of Stage-Cast Inverted T-Beams with the Precast Flange in Tension," by S. A. A. Wahidi and R. W. Furlong, August 1976.

188-2F "Strength and Behavior of Stage-Cast Inverted T-Beams," by Richard W. Furlong, August 1978.

196-1F "Design of Reinforcement for Notched Ends of Prestressed Concrete Girders," by Gangadharan Menon and Richard W. Furlong, August 1977.

198-1F "Control of Cracking on the Side Faces of Large Reinforced Concrete Beams," by G. C. Frantz and J. E. Breen, September 1978.

209-1F "Fatigue Loading of Cantilever Sign Structures from Truck Wind Gusts," by Bruce M. Creamer, Karl H. Frank, and Richard E. Klingner, April 1979.

212-1F "Design Criteria for Median Turn Lanes," by C. Michael Walton, Thomas W. Horne, and William K. Fung, March 1978.

244-1 "Analysis of Single Piles Under Lateral Loading," by Barry J. Meyer and Lymon C. Reese, December 1979.

245-1F "Texas Traffic Data Acquisition Program," by Han-Jei Lin, Clyde E. Lee, and Randy Machemehl, February 1980.

514-1F "Effects of Temperature Change on Plastic Crash Cushions," by Victor N. Toth and Clyde E. Lee, January 1976.

1053-1F "Social Service Agency Transportation Services: Current Operations and the Potential for the Increased Involvement of the Taxi Industry," by Walter L. Cox and Sandra Rosenbloom, August 1977.

RR 16 "The Prediction of Passenger Riding Comfort from Acceleration Data," by Craig C. Smith, David Y. McGehee, and Anthony J. Healey, March 1976.

RR 35 "Perceived Environmental Utility Under Alternative Transportation Systems: A Framework for Analysis," by Pat Burnett, March 1976.

RR 36 "Monitoring the Effects of the Dallas/Fort Worth Regional Airport — Volume I: Ground Transportation Impacts," by William J. Dunlay, Jr., Lyndon Henry, Thomas G. Caffery, Douglas W. Wiersig, and Waldo A. Zambrano, December 1976.

RR 37 "Monitoring the Effects of the Dallas/Fort Worth Regional Airport — Volume II: Land Use and Travel Behavior," by Pat Burnett, David Chang, Carl Gregory, Arthur Friedman, Jose Montemayor, and Donna Prestwood, July 1976.

RR 38 "The Influence on Rural Communities of Interurban Transportation Systems, Volume II: Transportation and Community Development: A Manual for Small Communities," by C. Michael Walton, John Huddleston, Richard Dodge, Charles Heimsath, Ron Linehan, and John Betak, August 1977.

RR 39 "An Evaluation of Promotional Tactics and Utility Measurement Methods for Public Transportation Systems," by Mark Alpert, Linda Golden, John Betak, James Story, and C. Shane Davies, March 1977.

RR 40 "A Survey of Longitudinal Acceleration Comfort Studies in Ground Transportation Vehicles," by L. L. Hoberock, July 1976.

RR 43 "A Pavement Design and Management System for Forest Service Roads — A Working Model," by Freddy L. Roberts, B. Frank McCullough, Hugh J. Williamson, and William R. Wallin, February 1977.

RR 45 "Characteristics of Local Passenger Transportation Providers in Texas," by Ronald Briggs, January 1977.

RR 46 "The Influence on Rural Communities of Interurban Transportation Systems, Volume I: The Influence on Rural Communities of Interurban Transportation Systems," by C. Michael Walton, Richard Dodge, John Huddleston, John Betak, Ron Linehan, and Charles Heimsath, August 1977.

RR 47 "Effects of Visual Distraction on Reaction Time in a Simulated Traffic Environment," by C. Josh Holahan, March 1977.

RR 48 "Personality Factors in Accident Causation," by Deborah Valentine, Martha Williams, and Robert K. Young, March 1977.

RR 49 "Alcohol and Accidents," by Robert K. Young, Deborah Valentine, and Martha S. Williams, March 1977.

RR 50 "Alcohol Countermeasures," by Gary D. Hales, Martha S. Williams, and Robert K. Young, July 1977.

RR 51 "Drugs and Their Effect on Driving Performance," by Deborah Valentine, Martha S. Williams, and Robert K. Young, May 1977.

RR 52 "Seat Belts: Safety Ignored," by Gary D. Hales, Robert K. Young, and Martha S. Williams, June 1978.

RR 53 "Age-Related Factors in Driving Safety," by Deborah Valentine, Martha Williams, and Robert K. Young, February 1978.

RR 54 "Relationships Between Roadside Signs and Traffic Accidents: A Field Investigation," by Charles J. Holahan, November 1977.

RR 55 "Demographic Variables and Accidents," by Deborah Valentine, Martha Williams, and Robert K. Young, January 1978.

RR 56 "Feasibility of Multidisciplinary Accident Investigation in Texas," by Hal L. Fitzpatrick, Craig C. Smith, and Walter S. Reed, September 1977.

RR 60 "A Pavement Design and Management System for Forest Service Roads — Implementation," by B. Frank McCullough and David R. Luhr, January 1979.

RR 61 "Multidisciplinary Accident Investigation," by Deborah Valentine, Gary D. Hales, Martha S. Williams, and Robert K. Young, October 1978.

RR 62 "Psychological Analysis of Degree of Safety in Traffic Environment Design," by Charles J. Holahan, February 1979.

RR 63 "Automobile Collision Reconstruction: A Literature Survey," by Barry D. Olson and Craig C. Smith, December 1979.

RR 64 "An Evaluation of the Utilization of Psychological Knowledge Concerning Potential Roadside Distractors," by Charles J. Holahan, December 1979.