TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA/TX-87/15+450-1	2. Government Accession No.	3. Recipient's Catalog No.
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 13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation; Transportation Planning Division P. O. Box 5051 Austin, Texas 78763		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 fly ash, concrete, damage reduction, alkali-aggregate, 90-day exposure, comparative study		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 202	22. Price

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

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the view or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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

The present work is part of a larger project dealing with the mechanisms and control of alkali-aggregate reaction in concrete, sponsored by the Texas State Department of Highways and Public Transportation, the Federal Highway Administration, and private industry, and administered by the Center for Transportation Research at The University of Texas at Austin.

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

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

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

Admixture in Portland Cement Concrete, and adopted by the TSDHPT (State Department of Highways and Public Transportation) with the Departmental Materials Specification D-9-8900. However, the available alkali content of fly ash has been found in many cases to be higher than the 1.5% limit. Restrictions due to environmental protection measures have forced the use of special admixtures, mostly sodium based, to better collect all ash and any potentially harmful elements that could escape to the atmosphere with the burning of coal. This resulted in an increase in the percentage of available alkalies present in fly ash and created a new variable in the problem of alkali-aggregate reaction, the source and type of available alkalies in fly ash.

Under these circumstances, the concrete industry is faced with the urgent need of improving its knowledge about the mechanism in which fly ash helps prevent damage due to alkali-aggregate reaction. Actually, there are no guidelines available for use by engineers in deciding which fly ash is to be used 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 mechanism 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 could be developed.

1.2 Objectives

Comprehensive investigations of various measures to prevent damage to concrete due to alkali-aggregate reaction have been carried out, but until now, the most effective measure that can be widely used in practice is the addition of mineral admixtures, such as fly ash, to concrete.

The main objective of this study is to develop a relationship between relevant components of fly ash, portland cement, and concrete aggregates as these affect and could prevent damage due to alkali-aggregate reaction in concrete. This research should identify the type and amount of a given component in fly ash acceptable for use in concrete made using a given source of cement and aggregates to ensure no damage due to alkali-aggregate reaction.

As a result, the following objectives were outlined for the present study:

1. Identify the most relevant components of fly ash, including type and amount affecting the mechanism of alkali-aggregate reaction in concrete;

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.

Their large surface areas and randomly arranged networks are susceptible to attack by alkalies [10]. The expansion is said to be caused by the uptake of water by the alkali-silica gel which forms. The reaction is rapidly expansive and is the more common occurring type of alkali-aggregate reaction.

Alkali-Carbonate Rock Reaction. This involves the reaction between alkalies and certain carbonate rocks such as argillaceous dolomitic limestones, argillaceous calcitic dolostones and quartz-bearing argillaceous calcitic dolostones. This type of reaction is different from the alkali-silica reaction, because of the absence of characteristic reaction products normally detected by visual or microscopic methods [10]. The expansive dolomites are composed of illite and chlorite clay minerals. The expansion is thought to result from deodolomitization (disruption of dolomite crystals), which occurs when the dolomite is exposed to alkalies. The expansion can vary from slow to rapid and is less frequent than the alkali-silica reaction.

Alkali-Silicate Reaction. This is the more recent classification of alkali-aggregate reaction and has not yet received general acceptance. Proposed by Gillot [12], no correlation has been found between the expansion of test specimens and the amount of gel formed. Another striking feature is the absence of constituents known as promoters of alkali-aggregate reaction. Its mechanism is still even more obscure than the mechanisms for the other types of reactions depicted above. It is known however, that it involves greywackes, argillites and phyllites containing vermicullite. This reaction differs from the others by its very slow rate of expansion and has been reported only in a few places in Canada.

1.4 Scope of this Research

Since damage due to alkali-carbonate and alkali-silicate reactions is rather scarce and its rate relatively slow (meaning that from the point of view of durability, attack from these two types of alkali-aggregate reactions may be, in some instances, considered negligible), this study will concentrate on the analysis of alkali-silica reaction as the most important and deleterious type of alkali-aggregate reaction.

The research approach used in this study was to investigate in a comparative manner the behavior of several mixes using different types of fly ashes, using cements with high and low alkali content and aggregate sources from non-reactive to highly-reactive. This report will discuss the test results for only part of a broader research program being conducted at the University of Texas at Austin. The initial stages of the reaction, up to three months of age of the specimens, will be monitored herein upon 108 out of approximately 200 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.

This implies that the effect of similar equivalent alkali concentrations in the cement have the same effect on the aggregates. However, there is some evidence that sodium causes more expansion than potassium [10]. Furthermore, cements containing the same percentage of total alkalies may behave differently because the amount of "available" alkalies (water soluble alkalies) may be different from one cement to the other. Moreover, the amount of available alkalies also changes with time [11]. The procedure to determine the amount of alkalies, both total and water soluble, in a cement is described in ASTM C 114, Standard Method for Chemical Analysis of Hydraulic Cement.

Many theories have been proposed for the mechanism of alkali-aggregate reaction, consisting mainly of schematic outlines like the one proposed by Diamond [13] which consists of the following four steps:

1. Initial alkaline depolymerization and dissolution of reactive silica

2. Formation of a hydrous alkali-silicate gel

3. Attraction of water by the gel

4. Formation of a fluid solution (a dilute suspension of colloidal particles)

For each one of these steps, the following explanation is given:

1. Initial alkaline depolymerization and dissolution of reactive silica: Although in the initial stages of hydration alkalies are present as sulphates, as noted before, after a few days the solution contains as many hydroxide ions, OH^- (also called hydroxyl ions) as the combined concentration of potassium and sodium ions. These hydroxyl ions can be formed by two types of reactions [14]:

   a) hydrolysis of silicates,

      silicates + H_2O -----> hydrolized anions + OH^-

   b) formation of insoluble calcium salts rather than calcium hydroxide,

      acid anions + calcium hydroxide ----->

      insoluble Ca salt + $2OH^-$

   On the other hand, the sodium and potassium cations form as a product of the formation of ettringite by the reaction between the sulphates and the tricalcium aluminate. These 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.

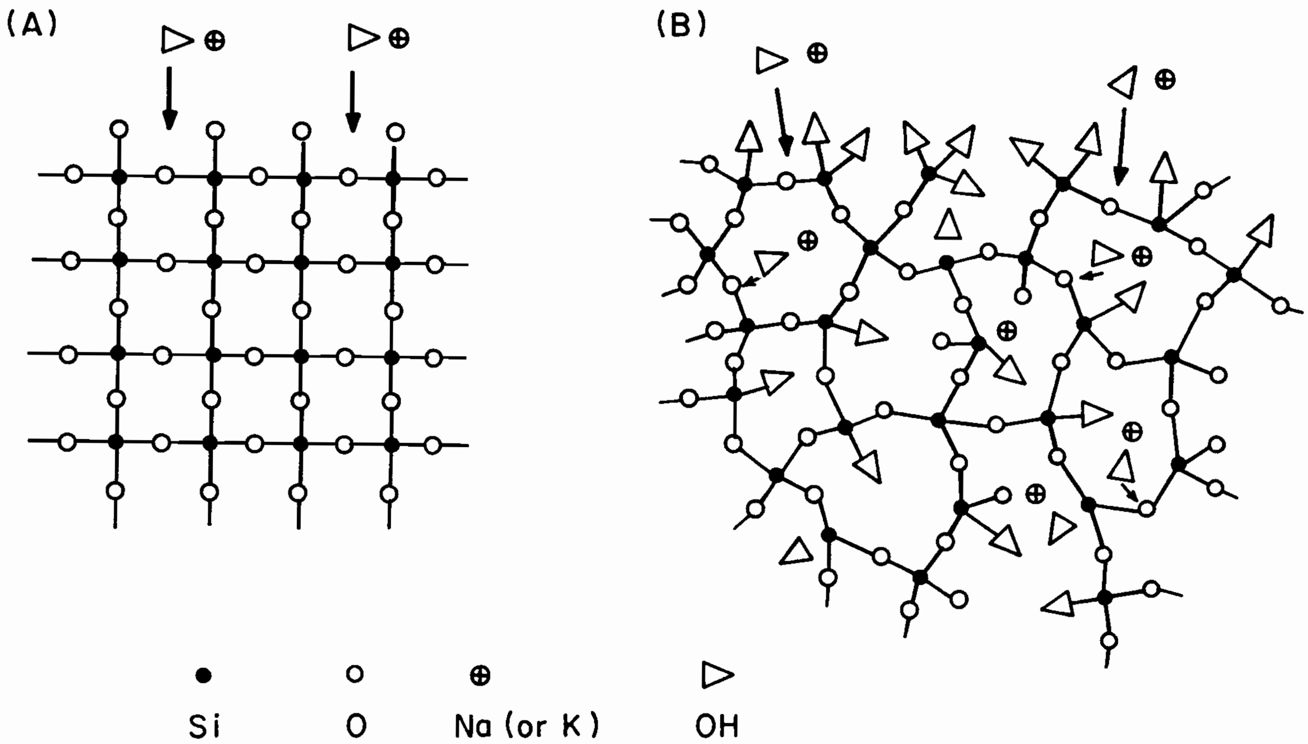


Fig. 1 (a) Attack on well-crystallized silica network is surficial
(b) Attack on poorly-crystallized silica network is deeper

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.

As it was explained previously, the formation of ettringite forms part of the process of formation of the alkali-silica gel. Therefore, in many instances, ettringite is present in such large quantities that it seems to obscure the isotropic gel and makes difficult the identification of alkali attack [17]. As a result, more sophisticated methods are needed sometimes to assure the diagnosis. Such methods are, for example, x-ray diffraction and scanning electron microscopy, with which the actual presence of potassium and sodium can be identified in a spectrum taken of the gel [16]. An example of such a spectrum using SEM is shown in Fig. 3.

2.4 Fly Ash

Coal combustion results in a residue consisting of the inorganic mineral constituents in the coal and the organic matter which is not fully burned. The inorganic mineral constituents, whose residue is ash, make up from 3 to 30% of coal [37]. During combustion, this ash is distributed into two parts; ash collected from the bottom of the boiler unit, so called bottom ash, and ash collected mostly by air pollution control equipment through which stack gases pass, called fly ash.

Fly ash makes up from 10 to 85% of the coal ash residue and its particles are typically spherical, ranging in diameter from 1 to 150 microns [6]. They are removed from exhaust gases by mechanical or electrostatic precipitators. The latter capture the preferable, finer-sized particles that escape mechanical collectors. Recent measures taken by the EPA [18] in the United States and by governments of several countries in order to protect the environment, have made fly ash a more available material. Having similar characteristics to natural pozzolans, it is being increasingly used in the concrete industry.

Chemical characteristics of ash depend largely on geologic and geographic factors related to the coal deposit. The major constituents of ash-primarily silicon, aluminum, iron and calcium-make up 95 to 99% of the total composition. Minor constituents, such as magnesium, titanium, sodium, potassium, sulfur and phosphorus comprise most of the remainder. Ash also contains trace concentrations of 20 to 50 elements.

2.4.1. Applications. Fly ash has several beneficial effects when used in concrete.

1. As reported by many authors [6,7,19,20,21], fly ash may reduce the amount of water required for a given degree of workability and reduces segregation and bleeding compared with an equivalent paste made without fly ash.

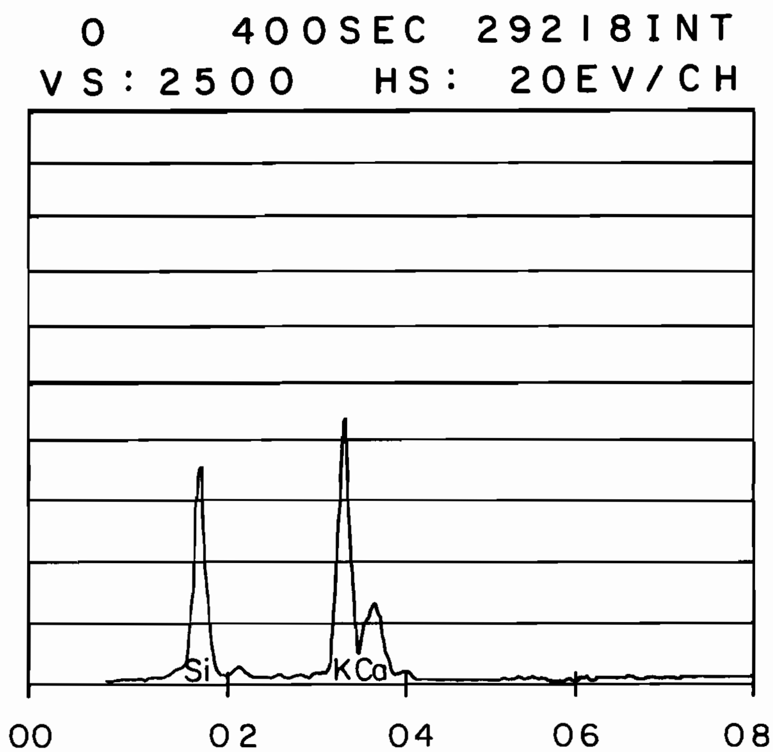


Fig. 3 EDAX spectrum from the gel

Consequently, as the w/c ratio is reduced, ultimate strength is increased, permeability improved, and shrinkage reduced.

2. Since fly ash is generally used as a replacement of a portion of cement rather than as an additive, concrete having less cement has lower heat of hydration, even when using fly ash with cementitious properties, because such fly ash induces less heat of hydration than the cement it replaces.

3. Some studies are being done at the present time dealing with use of fly ash in pavement patching.

4. Fly ash is generally substantially less expensive than cement. So concrete mixes are usually less costly when made with fly ash, even if greater quantities of fly ash are used than the cement being replaced.

But, not only are there advantages to the use of fly ash in concrete, there are also disadvantages. Some of the main problems encountered when fly ash is added to concrete mixes are reported by Butler [27].

1. Difficulty in controlling concrete air content

2. Slow rate of early strength gain

3. Possible reduced freeze-thaw durability

4. Problems of quality control

2.4.2. Types. Fly ash has been classified into two types by the American Society for Testing and Materials (Committee C-09 on Concrete and Concrete Aggregates, subcommittee C 09.03 on Methods of Testing and Specifications for Admixtures). The two types are Class F fly ash and Class C fly ash. The current basis of definition of pozzolans is done based on the pozzolan source, and it has proven to be unsatisfactory [27]. Many authors suggest that classification should be made based on pozzolan properties, rather than source.

Class F fly ash was the first material produced in the U.S. [28], in the eastern part of the country, where the power plants burn anthracite and bituminous coal. This class of fly ash is characterized by its pozzolanic properties. Cain [17] has divided Class F fly ashes into two subtypes, according to their percentage of loss on ignition. Loss on ignition represents the unburned coal or the carbon content in the ash sample, therefore, the lower the loss on ignition, the lower the carbon content. Cain notes that since carbon particles are generally the coarse constituent of fly ash, low carbon content implies higher fineness which contributes to improve the 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. Effect of Fly Ash in Preventing Alkali-Aggregate Reaction. 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. Texas SDHPT Fly Ash Specifications

	Type A	Type B
A. Chemical Requirements		
Silicon dioxide (SiO_2) plus aluminum oxide (Al_2O_3) plus iron oxide (Fe_2O_3), min, %	65.0	50.0
Sulfur trioxide (SO_3), max, %	5.0	5.0
Calcium oxide (CaO), variation in percentage points of CaO from the average of the last ten samples (or less provided ten have not been tested) shall not exceed plus or minus	4.0	4.0
Magnesium oxide (MgO), max, %	5.0*	5.0*
Available alkalies, as Na_2O, max, % (when used in conjunction with reactive or potentially reactive aggregates)	1.5	1.5
Moisture content, max, %	2.0	2.0
Loss on ignition, max, %	3.0	3.0

*When the autoclave expansion or contraction limit is not exceeded, and MgO content above 5.0% may be acceptable.

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.

greater effect than this. Hobbs [24] reports that fly ash acts as an alkali diluter while other authors [25], based on studies where the alkali content of mortar bars under investigation was kept constant, report that the effect of fly-ash on alkali-aggregate reaction was more effective than can be accounted for by alkali dilution only.

Ming-shu et al. [22] report that when a cement has low basicity (low CaO content) the expansion due to alkali-aggregate reaction is lower than the expansion of mixes made with cements with high basicity. Now, the definition of "pozzolanic activity" [15] implies the reaction with calcium hydroxide. All types of fly ash exhibit pozzolanic properties, as noted before, and therefore, they reduce the basicity of the hydration products. On the other hand, fly ash contributes to reduce the permeability of concrete [6,7,18,19,21] while reducing its w/c ratio and therefore, reduces the expansion due to alkali-aggregate reaction, since the latter is a function of humidity.

Gaze and Nixon [24] affirm that in practice, since both chemical and physical effects may occur, the use of fly ash in concrete should be an effective means of preventing alkali-aggregate reaction. However, that effectiveness varies with type and source of the fly ash. Both ASTM and TSDHPT have adopted a limit on the alkali content of fly ash to be used in concrete of 1.5% available alkalies. However, Dunstan reports that there seems to be no relation between the amount of available alkalies in fly ash and the expansion due to alkali-aggregate reaction in a concrete made using fly ash [22]. Smith [25] suggests that a possible explanation is the rate at which alkalies are released into the pore solution. Smith points out that in fly ash the alkalies are trapped within a glassy matrix and are usually released more slowly than the alkalies in cement, particularly within bituminous fly ash (ASTM Class F).

2.4.4. Determination of Alkali Content in Fly Ash. Unlike for cement, there is no specification for the determination of total alkalies in fly ash. Only the available alkalies determination is covered by ASTM C 311, Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement and Concrete. In this 28-day test, the fly ash is mixed with calcium hydroxide (Ca(OH)) and after 28 days the amount of sodium and potassium is determined using a similar flame photometric procedure used in ASTM C 114 for the determination of available alkalies in cement. This means that besides the amount of alkalies detected in this test there is an extra undetected quantity that is thought not to have reacted during those 28 days.

Fly ash can be dissolved completely in order to find out the total alkalies. To do this it is necessary to fuse the fly ash with lithium metaborate (LiBO4). After the fusion is done, it is rapidly cooled to form a glass. The glass is then dissolved in a solution of

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.

TABLE 2. Expansion Limits for Different Methods of Measuring Alkali-Aggregate Reactivity of an Aggregate

Test Method	Limits Set %	Time (months)
Mortar Bar Test (ASTM C 227)	0.05	3
ASTM C 33, App. XI.1.3	0.10	6
	(demarcation between non-reactive and reactive combinations not clearly defined)	
CAN3 A23.1-M77, App. B3.4	0.04	any age
	(limits must be developed for each type of reaction)	
Corps of Engineers EM 1110-2-2000 (Mortar bar test)	0.05	6
	0.10	12
	(slope and trend of expansion to be taken into consideration)	
Bureau of Reclamation (Mortar bar test)	$\geq$0.20	12
	marginal 0.10%-0.20	12
Rate method (mortar bar test)	$\geq$ 7 (provisional)	any age
Concrete Prism Test, (CSA A23.2-14A)		
CSA CAN3 A23.1-M77,1 App. B3.5	0.03%	any age
	0.02% moist conditions	3
	0.04% dry conditions	3
	(limits to be developed for each type of reaction)	
Rate Method (Concrete prism test)	$\geq$ 7 alkali silica and late expansive siliceous aggregates	any age
	$\geq$ 4 (tentative) for carbonate aggregates	any age

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° F instead of the actual 100°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° C steam curing for four hours after which they are immersed in 10% KOH solution and autoclave-treated at 150°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, being different only in the mix composition. Typical specimens are illustrated in Fig. 4.

The molds used in the casting of the specimens complied with ASTM C 490, Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete, and are shown in Fig. 5.

The specimens were cast in groups of 32 per casting day which represents four mixes. Then, each group was stored in specially designed acrylic containers as shown in Fig. 6.

The container consisted of a box made of acrylic panels glued together. The bottom of the container was filled with 2 in. of water. The walls of the box were lined with blotting paper so that water on the bottom provided the necessary humidity to all specimens. Ata distance of 2-1/2 in. from the bottom, a fiber glass mesh was placed in order to prevent any splashing of water on the specimens. On top of the mesh, the rack which actually held the specimens was placed. It was made of two acrylic panels connected with four acrylic rods as shown in Fig. 7.

The holes drilled in the panels had two purposes: (1) to support the specimens directly on the mortar surface so gage studs do not experience any loads (or force); and, (2) to let the humidity from the bottom pass through and saturate the air in the box.

Weather stripping material was used as a seal between the cover lid and the top of the box walls.

Figure 8 shows the system used to seal the box. The aluminum channels at the top of the box play a double roll; besides serving as support for the sealing device, they provide rigidity to the top of the box walls that otherwise would warp when subjected to the constant 100° F specified for this test in ASTM C 227.

The boxes were waterproof tested and then a humidity recorder was placed in each box for 24 hours while in the environmental chamber to assure that a level of 100% relative humidity was reached in each box.

3.3 Materials

3.3.1 Cement. Three sources of cement were selected:

1. Cement with an alkali content lower than the amount specified by ASTM C 150 as the limit for alkali-aggregate reaction to occur

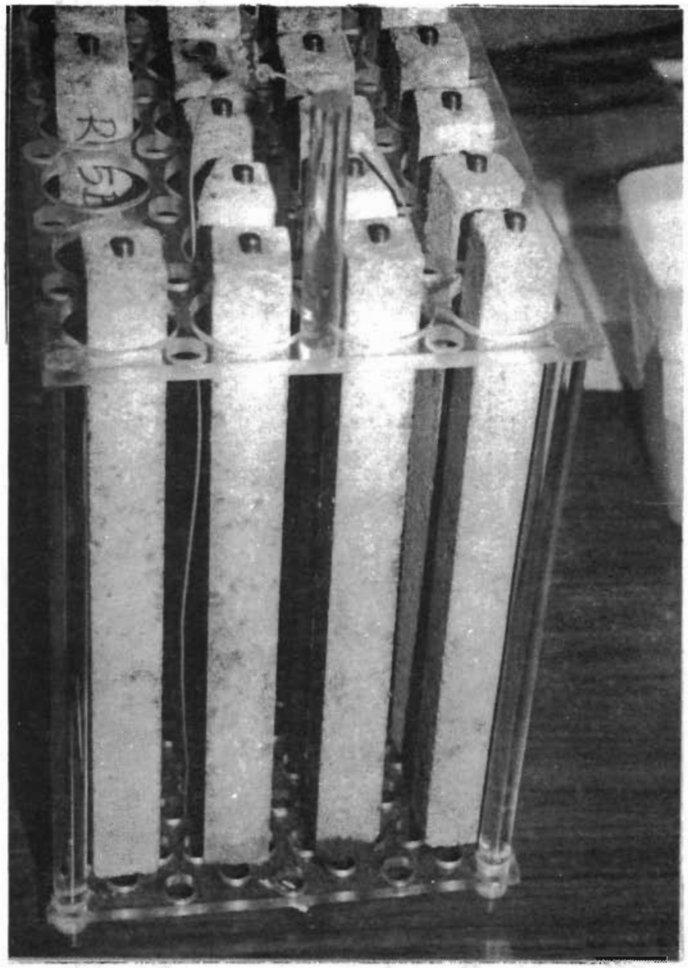


Fig. 4 Photograph of test specimens

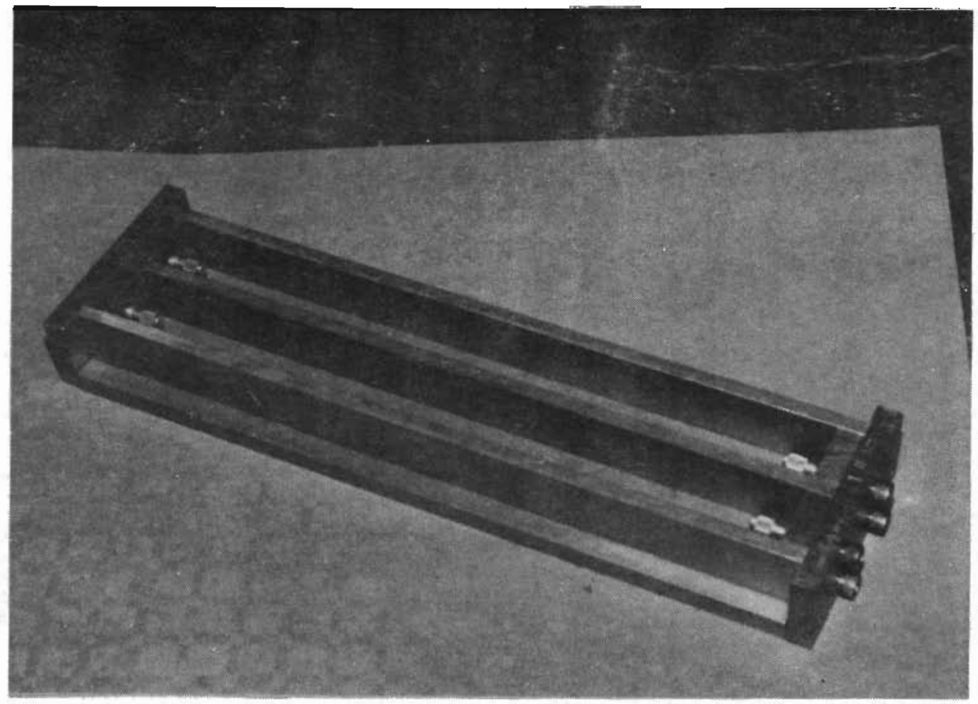


Fig. 5 Photograph of specimen molds

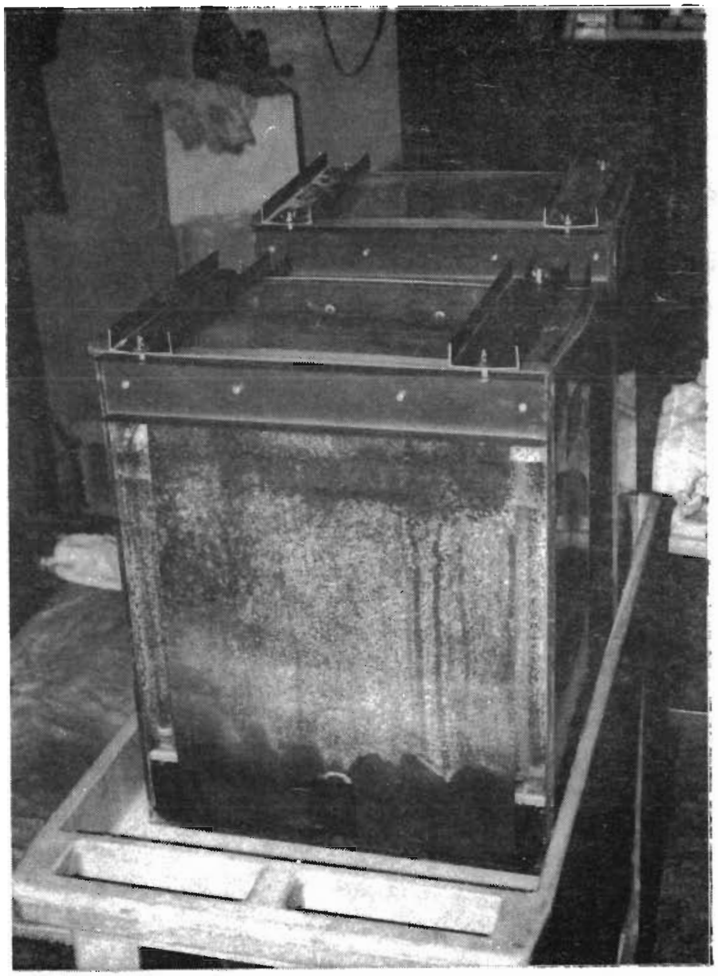


Fig. 6 Acrylic containers designed to store specimens at 100% RH

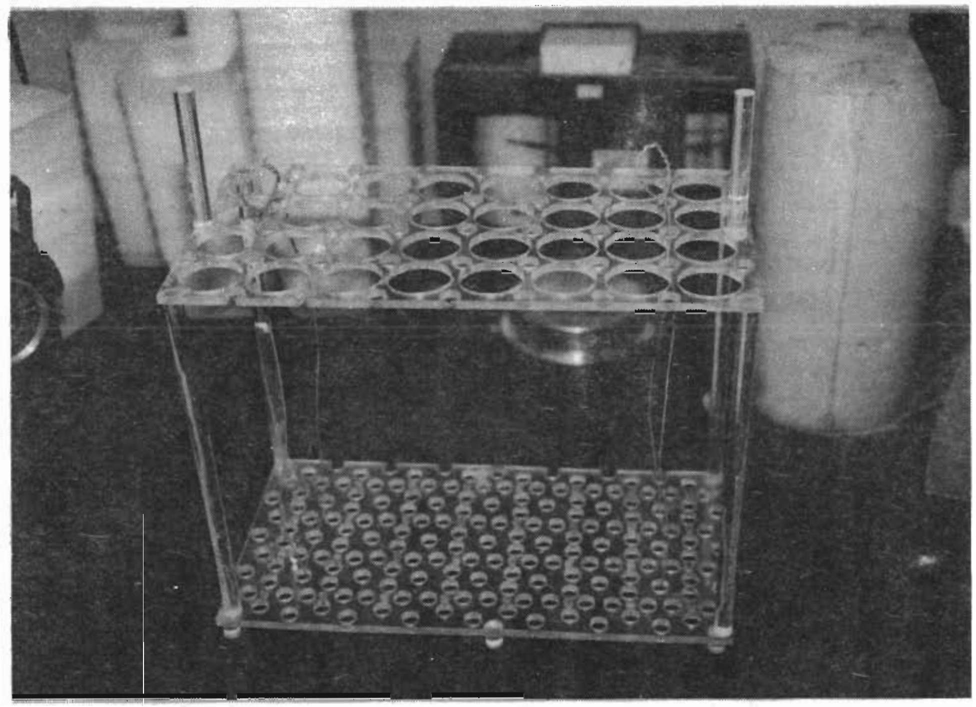


Fig. 7 Photograph of rack used to support test specimens

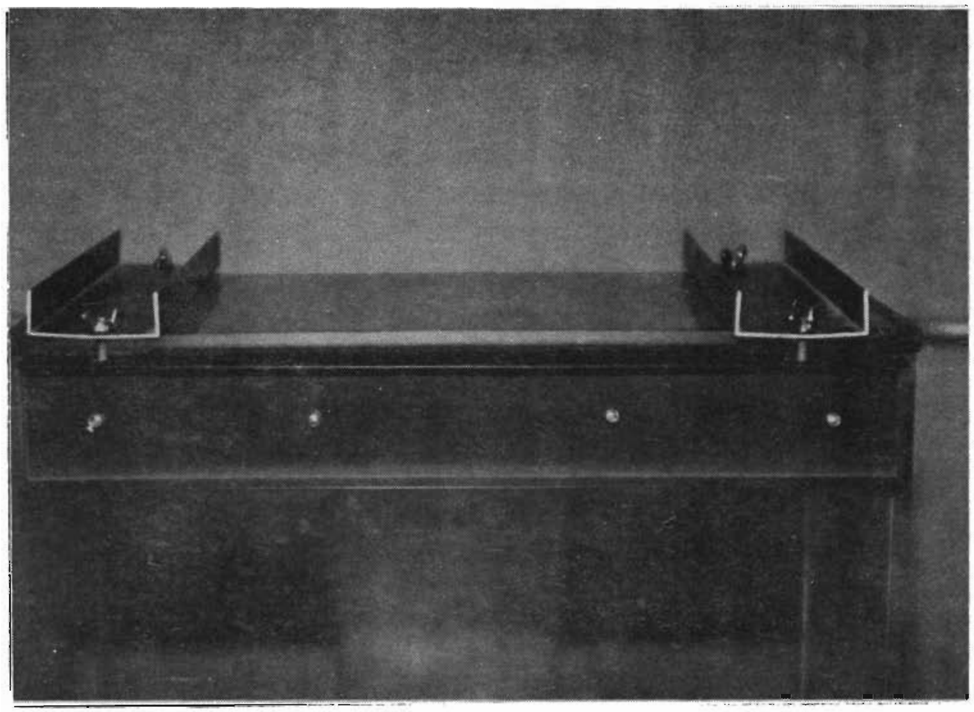


Fig. 8 Photograph of the sealing device for the storage container

2. Cement with an alkali content higher than the ASTM limit

3. A cement type IP which already contains fly ash

Using records from the TSDHPT it was found that a cement having 0.66% of equivalent Na_2O (Na_2O + 0.6 K_2O) was among the highest alkali content cements produced in the state. This source provided the high alkali content cement.

The second source of cement having an alkali content of 0.43% of equivalent Na_2O, was used as a low alkali content source of cement.

The source of cement Type IP used had an 0.504% of combined alkalies, including the alkalies from the pozzolans.

As can be noted, the percentage of alkalies for the high alkali content cement, 0.66% is very close to the 0.6% limit specified in ASTM C 150. For the purpose of this project, 0.7% is about the highest alkali content cement found in Texas.

Most researchers have found that cements with 0.4% or less alkali content represent no danger when used with reactive material; therefore, the low alkali cement used in this study is well suited for the designation of low alkali content cement.

The specific gravity of each cement was reported to be 3.15 by the cement manufacturers, and that value was used for mix design purposes.

All material properties can be found in Appendix B.

3.3.2 Aggregate. Four different aggregates were used for this project. Three were selected according to their performance in previous mortar bar tests done by the TSDHPT: One of them was reported as not reactive and the other two were reported as reactive; the reactive aggregates exhibited different levels of mortar bars expansion. For the purposes of this project, the reactive aggregate which caused the largest expansions was denominated as "highly reactive"; the other reactive aggregate was denominated as "medium reactive" and the not reactive aggregate was denominated as "nonreactive." In addition pyrex glass was used in the control mixes and, consequently, it was denominated as "control" aggregate.

From the records of the TSHPTD, based on ASTM C 227 (Mortar Bar Test) results, these are the sources that produce such materials:

1. Highly Reactive - Sand from El Paso, Texas; fine aggregate containing the following alkali-reactive components (Petrographic

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. Fly Ash. 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. Fly Ash Type A

   A. High alkali content:

      1) power plant - San Miguel

      2) city - Jourdanton, Texas

      3) owner - South Texas Municipalities

      4) fuel - Lignite (lower stratum)

      5) suppliers - Gifford Hill, Dallas

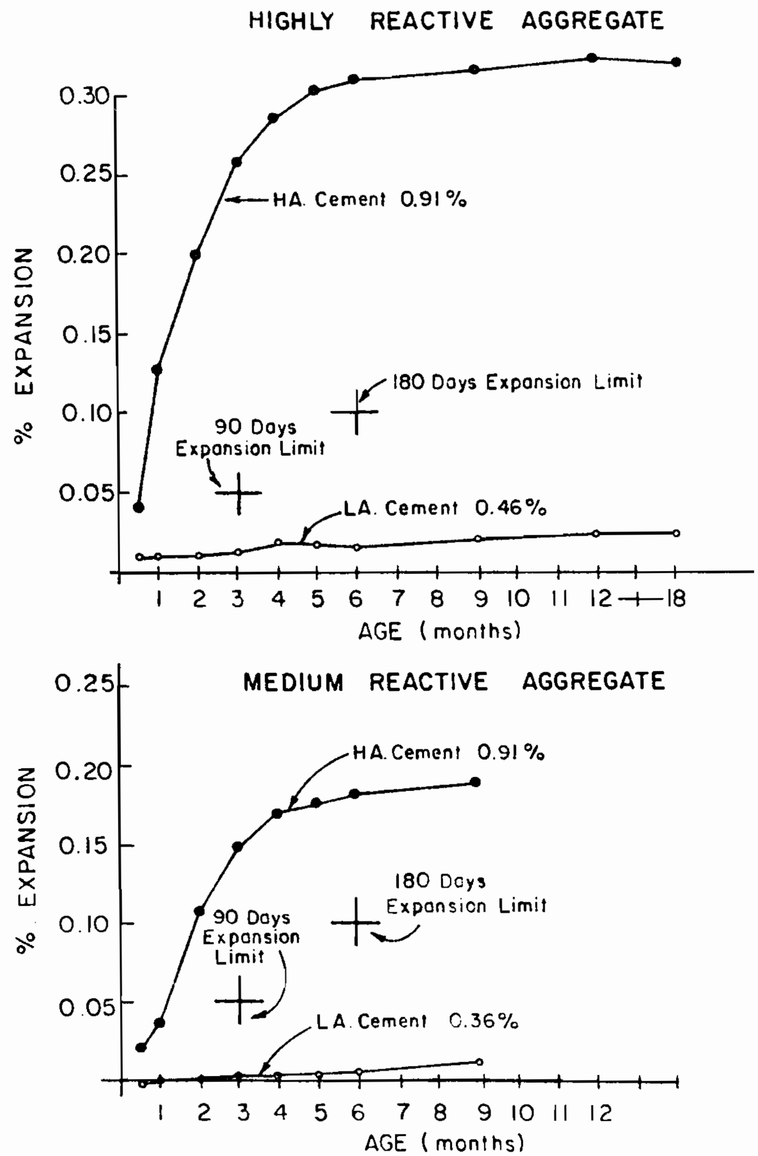


Fig. 9 Test results for the selected aggregates from the Texas SDHPT

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

3) owner - Southwest Public Service

4) fuel - subbituminous coal

5) suppliers - DePauw Construction Co.

6) coal source - Gillette, Wyoming

7) available alkalies - 1.67%

8) ASTM Class C

All the plants named above use electrostatic precipitators to collect the fly ash. None of them use additives to improve the precipitator's efficiency. As it can be seen, there is certain irregularity in the classification of the fly ashes. While the fly ash from the San Miguel power plant comes from lignite coal, it is classified by its producers as Class F, because of its chemical composition. This fly ash has an unusually high available alkali content, for a fly ash of its type, collected without the use of additives. Another striking feature of this fly ash is that the fuel used is a "lower stratum" lignite. Most of the lignites in current use come from a higher, less deep stratum. It has been said that lignite fly ashes that comply with ASTM Class C are those from North and South Dakota but those from Texas and Louisiana do not meet that specification. However, the fly ash from the Big Brown power plant is classified as Class C, based on the fuel source although its chemical properties meet the specifications for ASTM Class F. All the properties and chemical composition of these fly ashes are given in Appendix B.

3.3.4 Water. One variable affecting alkali-aggregate reaction is the alkalinity of the pore solution and, therefore, the water pH [22, 27]. This variable has been kept constant during this first stage of the project. Tap water having a pH of 8.14 was used for this portion of the study. The water temperature was 73 ± 3^{o} F. The value of 62.4 lb/cu.ft. was taken for any calculation involving the unit weight of water. The chemical analysis for this water is shown in Table 3.

3.4 Mixing and Testing

3.4.1 Introduction. Table 4 shows how the materials were combined into the 108 mixes cast. The only variable considered in mix proportioning was the water/cement, or the water/binder, ratio required to give a certain consistency of the mortar, as measured by the flow determination specified in ASTM C 109, Standard Test Method for Compressive Strength of Hydraulic Cement Mortars. The flow table used, shown in Fig. 10, meets the requirements in ASTM C 230, Standard Specification for Flow Table for Use in Tests of Hydraulic Cement. In

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

EPA478 #4X2	Na	Ca	K	Mg	Cl	Br	SO_4	I
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

TABLE 4 List of Mixes

	CEMENTS			AGGREGATES				FLY ASH			
								TYPE A		TYPE B	
MIX NO.	LOW ALKALI CONTENT	HIGH ALKALI CONTENT	IP	NON REACTIVE	MEDIUM REACTIVE	HIGHLY REACTIVE	PYREX	HIGH ALK. CONT.	LOW ALK. CONT.	HIGH ALK. CONT.	LOW ALK. CONT.
1	X			X							
2-4	X			X				X			
5-7	X			X					X		
6-10	X			X						X	
11-13	X			X							X
14	X				X						
15-17	X				X			X			
18-20	X				X				X		
21-23	X				X					X	
24-26	X				X						X
27	X					X					
28-30	X					X		X			
31-33	X					X			X		
34-36	X					X				X	
37-39	X					X					X
40	X						X				
41-43	X						X	X			
44-46	X						X		X		
47-49	X						X			X	
50-52	X						X				X
53		X		X							
54-56		X		X				X			
57-59		X		X					X		
60-62		X		X						X	
63-65		X		X							X
66		X			X						
67-69		X			X			X			
70-72		X			X				X		
73-75		X			X					X	
76-78		X			X						X
79		X				X					
80-82		X				X		X			
83-85		X				X			X		
86-88		X				X				X	
89-91		X				X					X
92		X					X				
93-95		X					X	X			
96-98		X					X		X		
98-101		X					X			X	
102-104		X					X				X
105			X	X							
106			X		X						
107			X			X					
108			X				X				

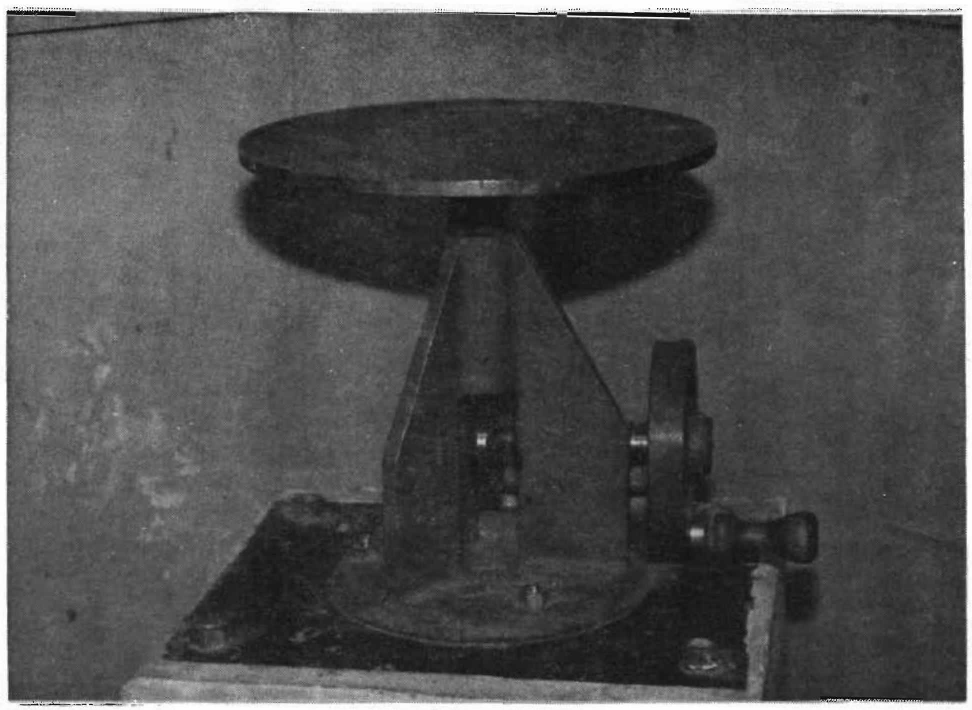


Fig. 10 Flow table used to measure consistency of the mix

this report, the term "binder" refers to the total cementitious material, combination of portland cement and fly ash, within the mix. Both w/c and w/b refer to ratios by weight. The amount of water required was calculated by trial and error for a typical batch and then adjusted as needed for each mix to give the specified flow. The corresponding ratios obtained during mixing are given in Appendix C.

Consistency of the mixes was maintained within the range specified in ASTM C 227.

Due to mixing equipment availability, the mortar was mixed in batches of 0.014 cu.ft, which corresponds to the volume of four mortar bars. Therefore, each mix combination needed two batches to be completed. The second batch was considered a replica of the first and the flow test was then omitted. In some cases, the first batch gave a consistency too close to either the upper or the lower range limits, and in those cases the second batch was made with a slightly different water content. In such cases the flow test was made to verify the consistency and both consistencies were recorded as shown in Appendix C.

After mixing, the mortar bars were placed on a wooden platform. Then the molds were covered with a wet burlap so no water would evaporate from the bars, and the platform was covered with plastic which was tightly fitted around it. A small home humidifier was used to maintain 100% relative humidity of the air within the curing platform during the first 24 hours. Figure 11 shows this set up.

3.4.2 Mixing Procedure. The mixing process followed ASTM C 305, Standard Method for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency. The procedure is summarized as follows: The total amount of water was placed first in the mixer bowl. Then the cementitious materials were added and mixed at 140 ± 5 rpm for 30 seconds. After that, the total amount of aggregate was added slowly over a period of 30 seconds while the mixer continued to work. Afterwards, the mortar was mixed for another 30 seconds at 285 ± 10 rpm and then the bowl was covered with plastic and the mix was left to stand for 1-1/2 minutes. The process finished with one minute of mixing at 285 ± 10 rpm.

This process was kept constant so the 864 mortar bars were homogeneous and the results from the test were comparable.

Mixer bowl and paddle complied with the ASTM C 305 specification, and are shown in Fig. 12.

3.4.3 Mortar Bar Test Procedure and Instrumentation. The mortar bar method (ASTM C 227) of the American Society for Testing and Materials has been widely criticized and questioned as an indicator of the alkali reactivity of a type of aggregate. The method used,

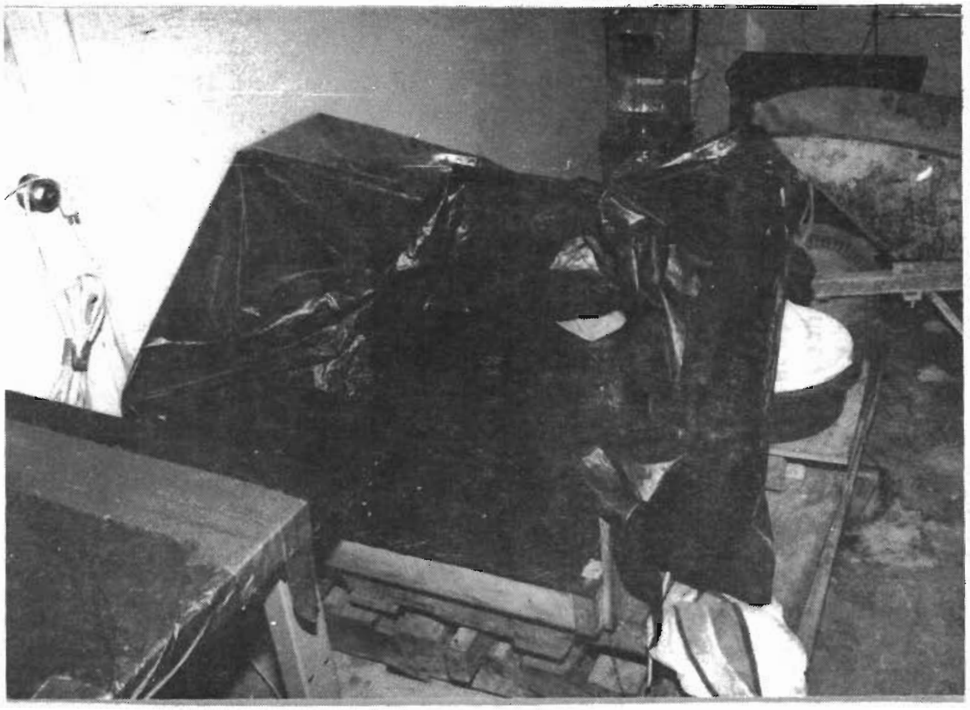


Fig. 11 Curing platform with humidifier

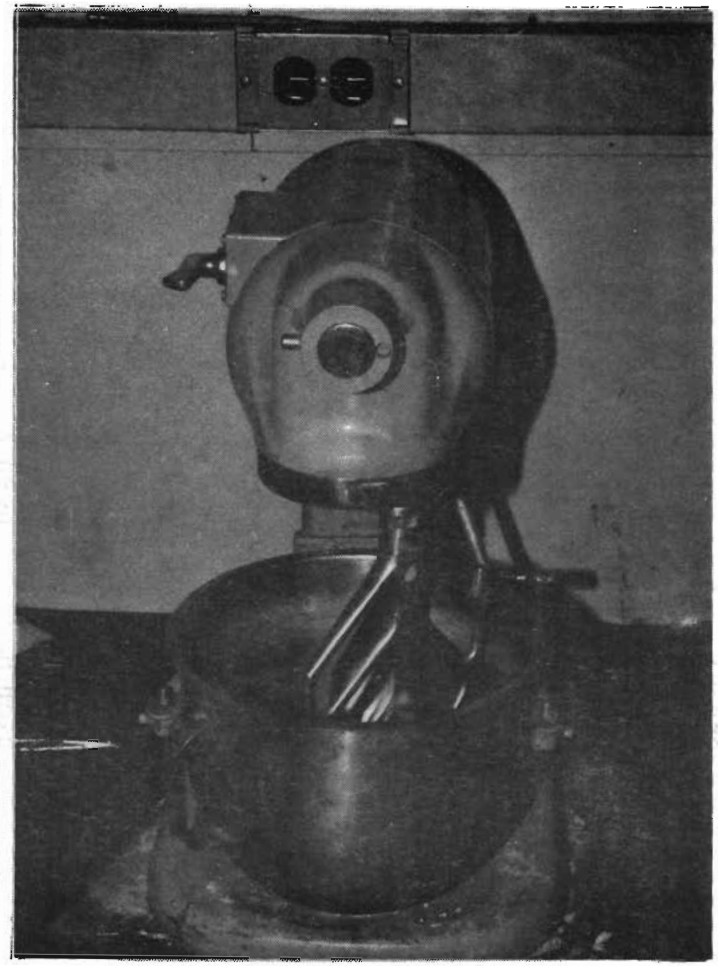


Fig. 12 Mixer, bowl, and paddle used in this investigation

according to the same organization, to indicate the effectiveness of mineral admixture in preventing expansion due to alkali-aggregate reaction (ASTM C 441) is based also on the Mortar Bar Method and therefore the doubts about the latter are applicable to the former.

However, two facts made these methods appropriate to be used in this study. The first being that the present program will make a comparative analysis of the relative behavior of the different combinations achieved using the materials depicted above. The second fact is that ASTM C 227 and C 441 are the specifications that have been in use in concrete practice in the United States for many years. Thus, if any correlation is to be done with previous work the mortar bar method had to be used. Furthermore, no other method has proved to be absolutely reliable nor has any other method shown better correlation with concrete in real structures. The prism method specified by the Canadian Standards Association uses concrete instead of mortar and it has been suggested that it could be a better indicator of the behavior of the materials tested in concrete in real structures. The use of this method will be considered only in later stages of this project. The requirements of ASTM C 227 are summarized below. The apparatus included sieves (ASTM E 11), mixer, paddles and mixing bowl (ASTM C 305), temper and trowel (ASTM C109), molds (ASTM C 490), and containers which have not been specified and which were a special design for this study, are described in Section 3.2.

The temperature for the molding room and for the materials was set within the range 68-81.5° F. The temperature for the moist cabinet, the mixing water and the measuring room was set at a stricter range of 73.4 ± 3° F, and the temperature of the storage room was set at 100 ± 3° F. The relative humidity of the molding room could not be less than 50%.

The mix proportioning corresponded to one part of cement to 2.25 parts of graded aggregate by weight for all mixes containing no fly ash. The aggregates were graded according to Table 5. For mixes with fly ash, 15%, 28% and 37% of the weight of the cement in the mixes containing no fly ash was replaced with the same weight of fly ash. Detailed information on the mix proportions is given in Appendix C. According to ASTM C227, the sequence of making batches of mortar had to be done randomly. For this project, all the mixes were listed by groups of aggregates and then numbered from 1 to 108. Using a programmable calculator with a random number generator built in, the list was renumbered randomly so the making of the batches did not follow any particular order.

Storage and measurements also followed this specification. The first measurement was done after stripping the molds. The specimens were stored in special containers which provided 100% relative humidity. The containers were stored in an environmental chamber

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

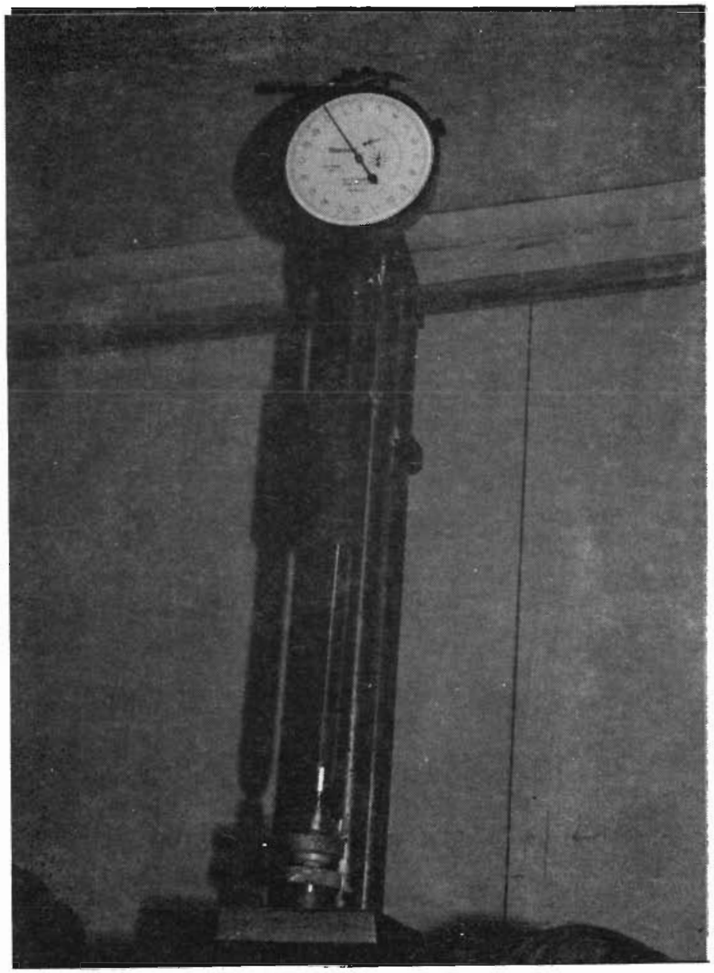


Fig. 13 Photograph of length comparator

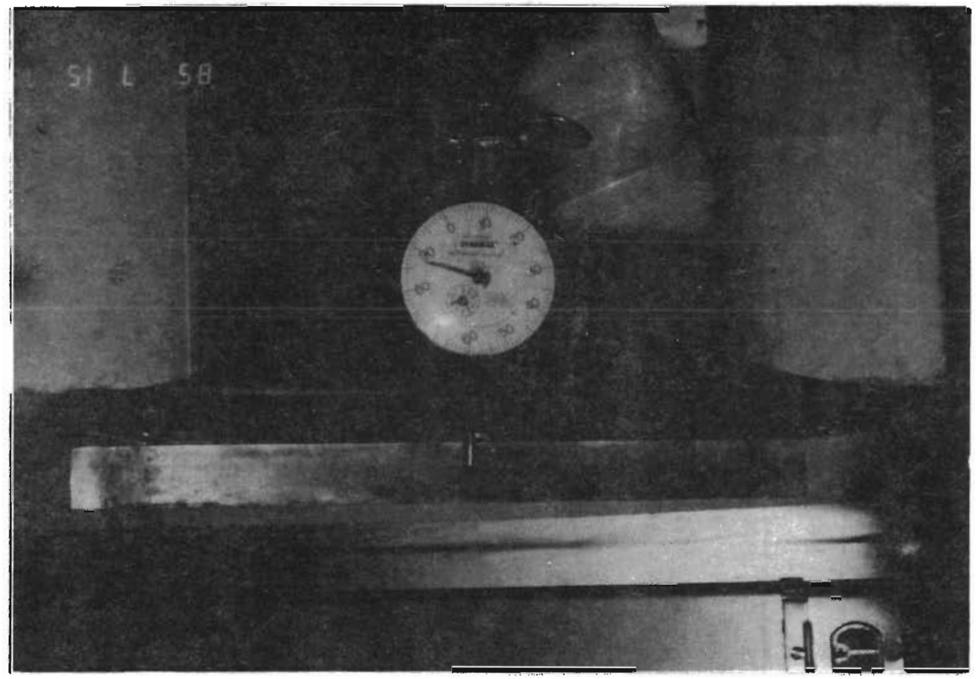


Fig. 14 Warp meter

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.

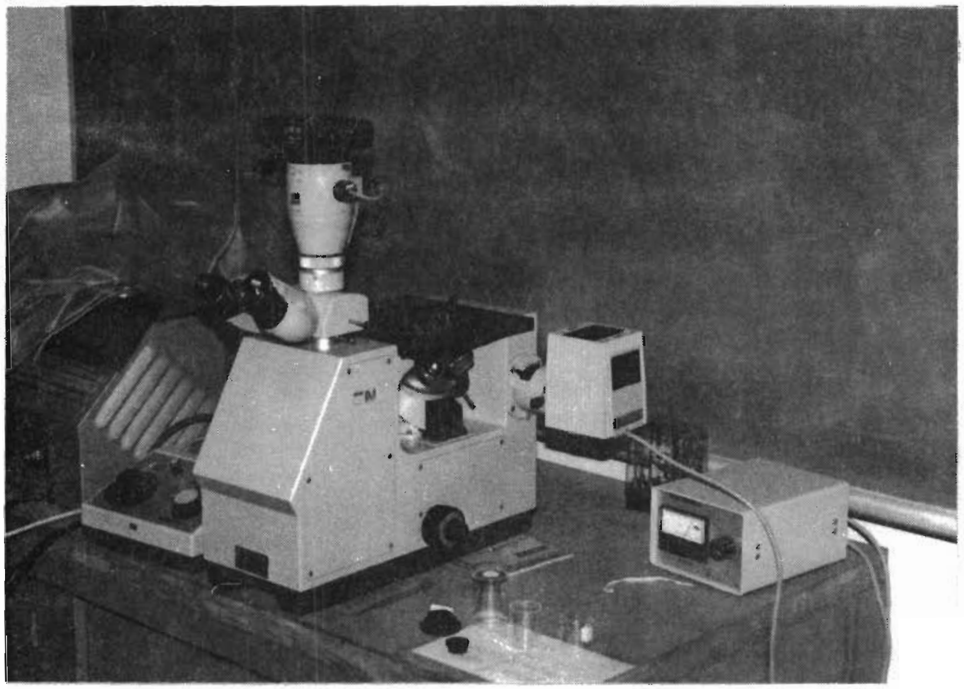


Fig. 15 Photograph of reflected light microscope

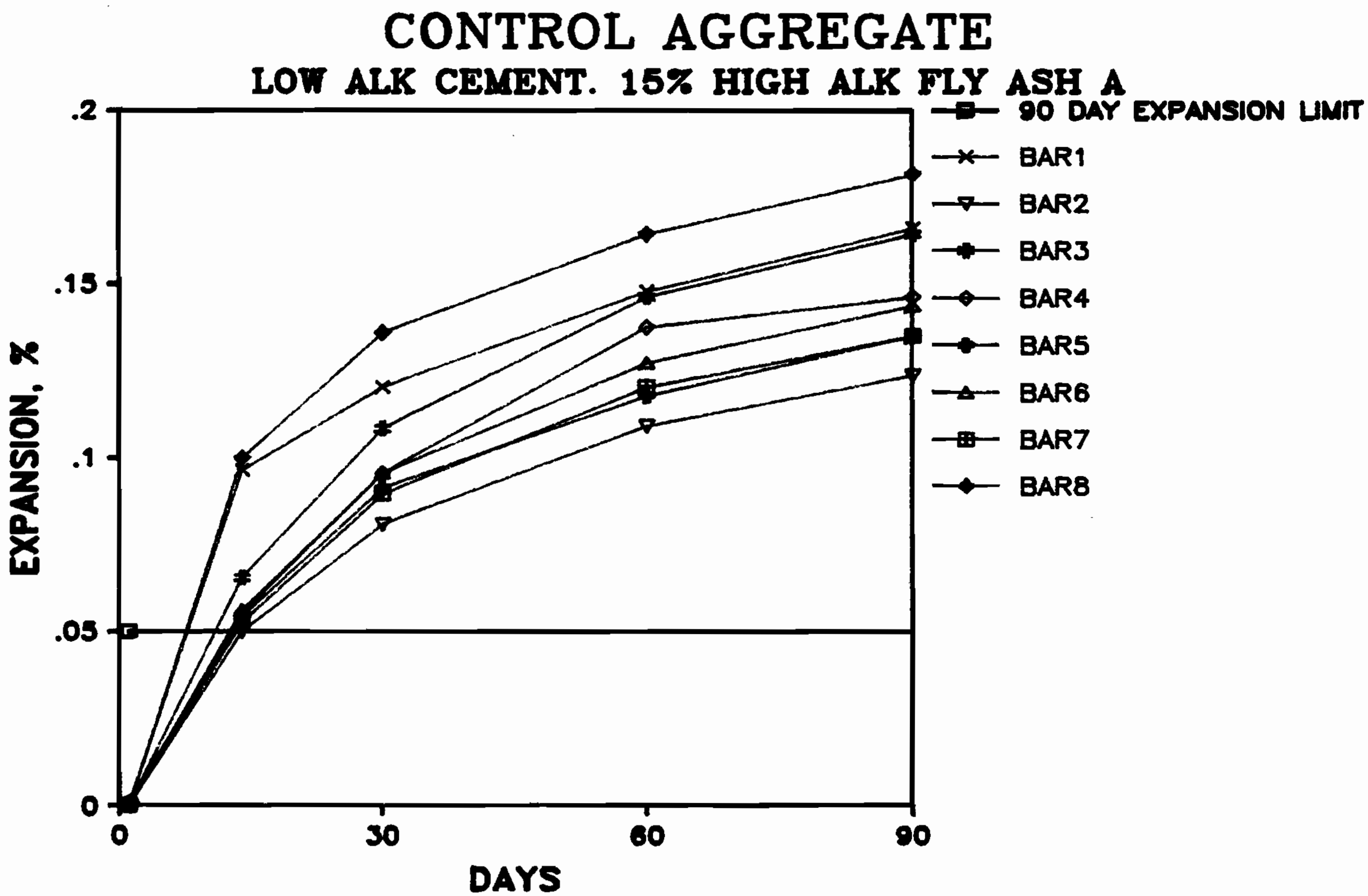


Fig. 16 Typical plot for a mix containing pyrex glass and low alkali cement.
No fly ash

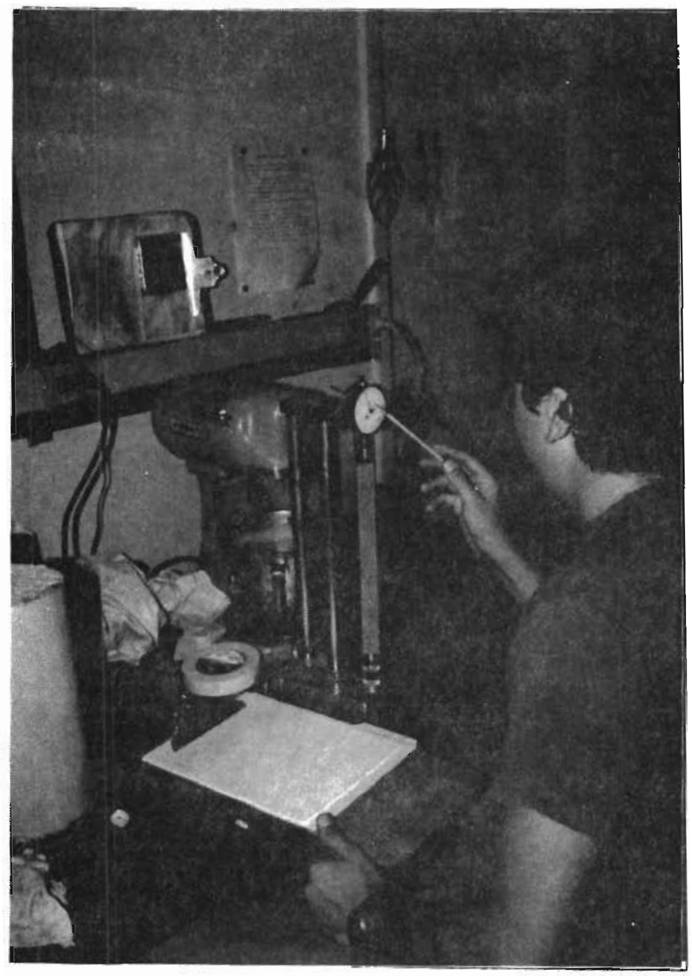


Fig. 17 Measurement of a specimen's length

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.

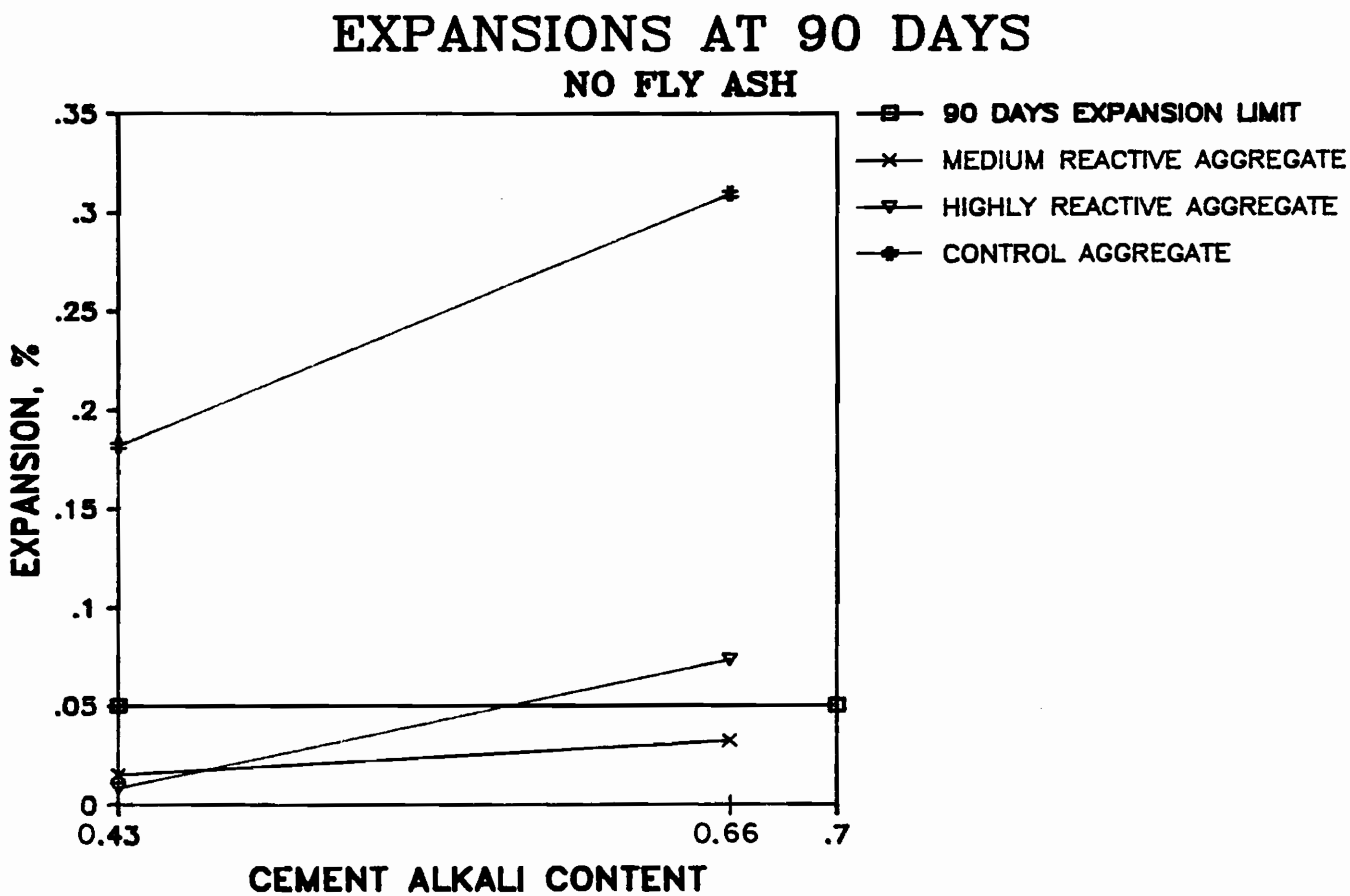


Fig. 18 Percentage of expansion vs alkali content of cement for all mixes made with reactive aggregates and without fly ash

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

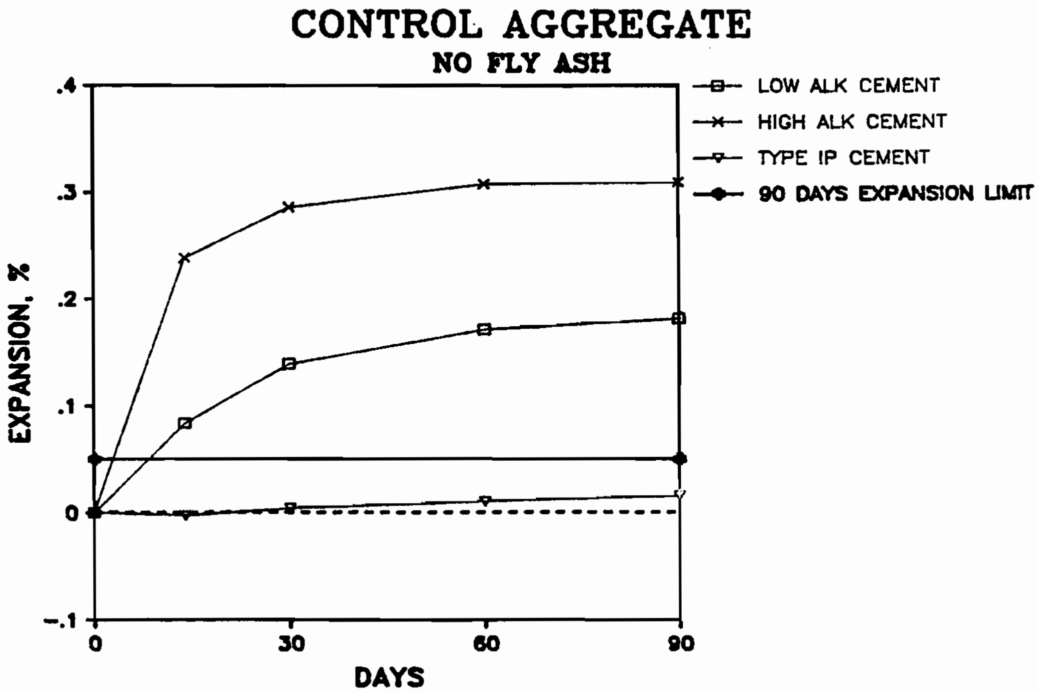


Fig. 19 Percentage of expansion vs time for all mixes made with control aggregate and without fly ash

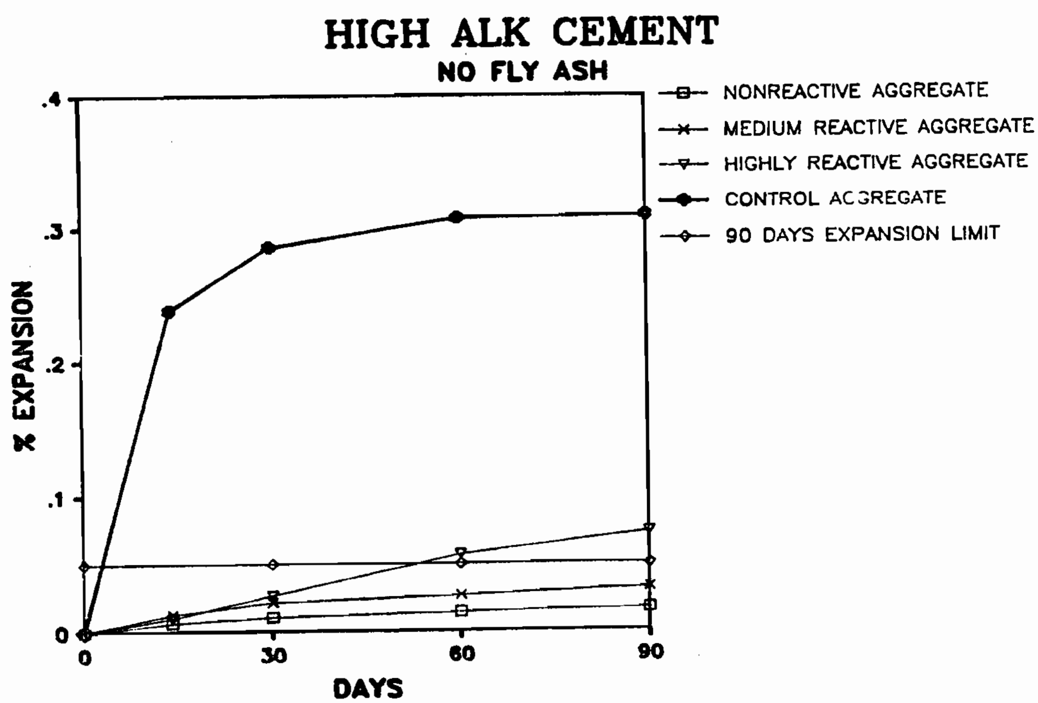


Fig. 20 Percentage of expansion vs time for all mixes made with high alkali cement and without fly ash

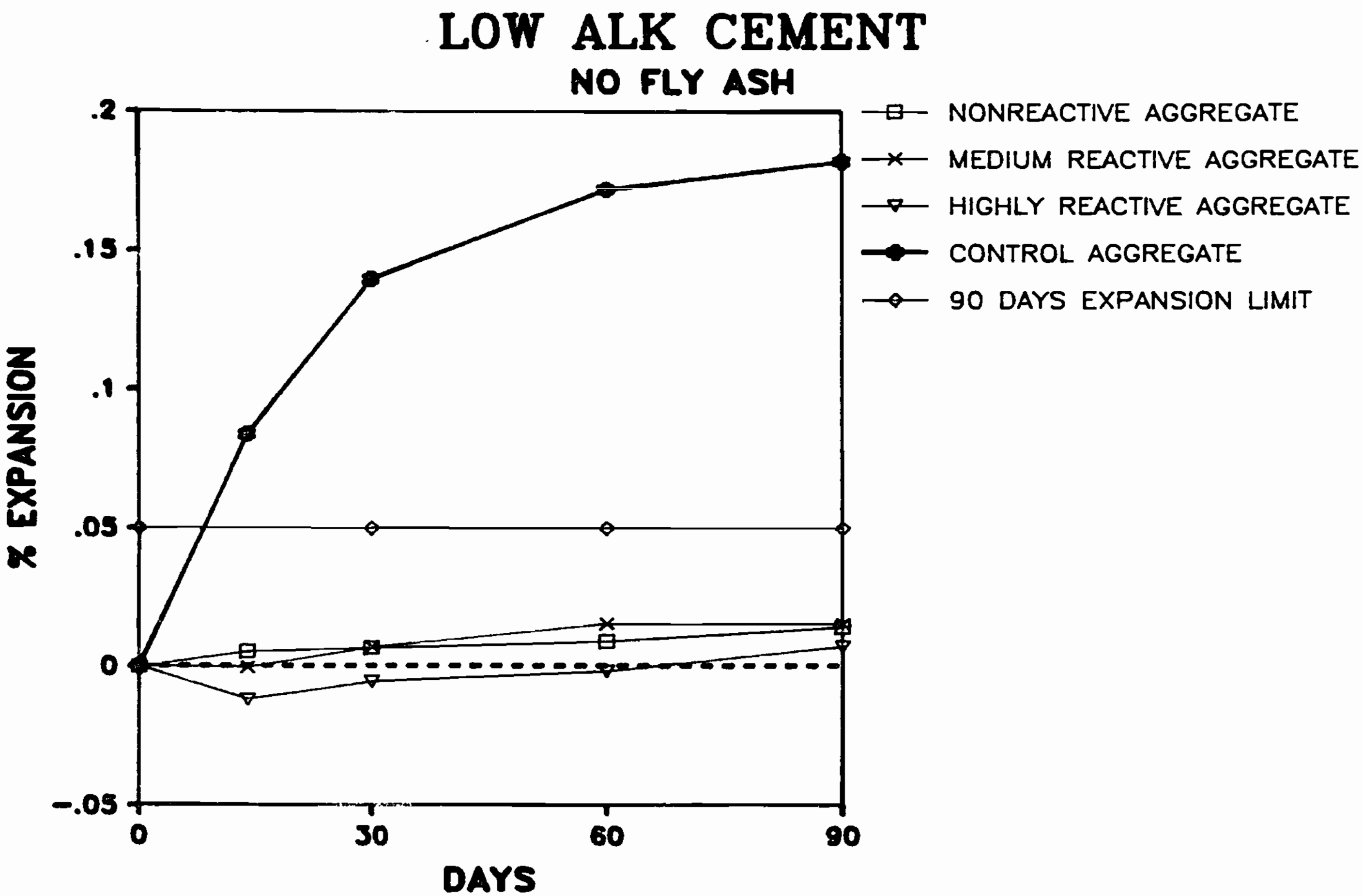


Fig. 21 Percentage of expansion vs time for all mixes made with low alkali cement and without fly ash

ashes were classified as high or low in alkalies for each type, according to their content of available alkalies, as follows:

1. Low alkali fly ash A having 0.57% available alkalies

2. High alkali fly ash A having 1.38% available alkalies

3. Low alkali fly ash B having 1.67% available alkalies

4. High alkali fly ash B having 4.35% available alkalies

For all aggregates, mortar bar expansion was larger for higher content of available alkalies in the fly ashes, especially when the expansions were close or above the expansion limit. A typical plot is shown in Fig. 22.

The test results for the different types of fly ash used were grouped into 12 graphs included in Appendix A, plotting percentage of expansion vs. time, one for each type of aggregate and each percentage of fly ash replacement. An example of such a graph is shown in Fig. 23.

4.4.2 Percentage of Cement Replaced. All fly ashes in this study were used as a cement replacement with percentages varying from 0% to 37% by weight.

In general, as exemplified in Fig. 24, mortar bar expansions were smaller for higher percentages of cement being replaced for all aggregates tested. However, for high available alkali content fly ashes, some percentages of replacement of cement with fly ash resulted in an expansion larger than the expansion of the mixes without fly ash. An example of this can be seen in Fig. 25.

The test results for the different percentages of cement replaced were grouped into 16 graphs included in Appendix A, plotting percentage of expansion vs. time, one for each source of aggregate and fly ash. An example of such a graph is shown in Fig. 26.

4.5 Petrographic Analysis

The progress of the alkali-aggregate reaction in two mixes was monitored with time using petrographic analysis. At each measurement time, a section from one bar was taken and polished to be looked at through a microscope using reflected light. The results of these observations were correlated qualitatively with the results from the mortar bar test. For mortar bars with large expansions at a given exposure age, the petrographic analysis showed wide spreading of mortar cracking and cracking of some aggregates in the sample stub.

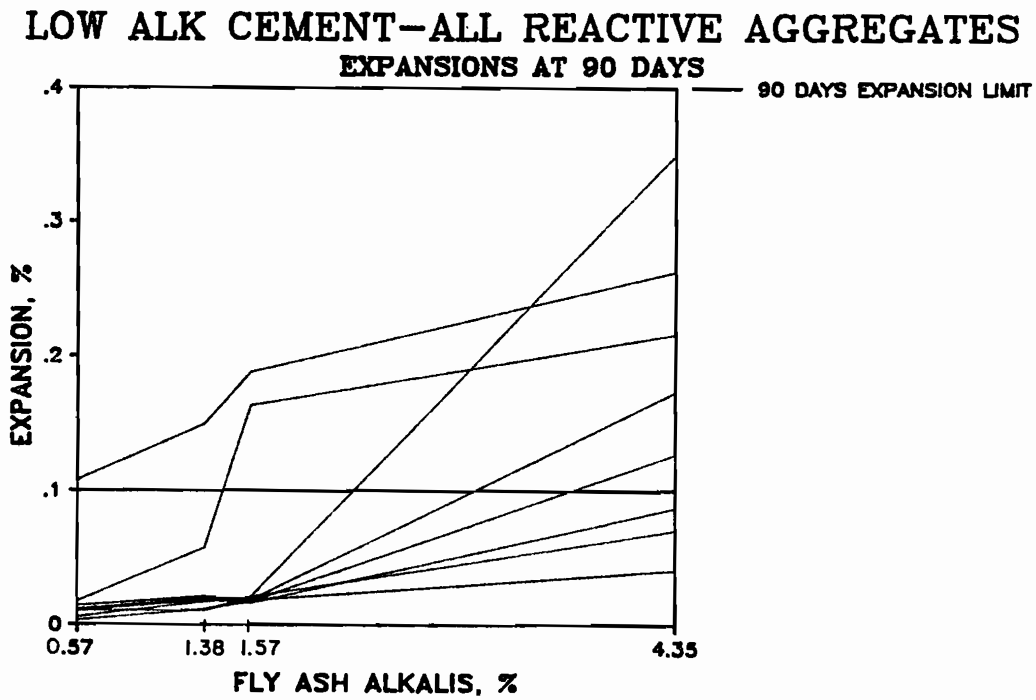


Fig. 22 Percentage of expansion at 90 days vs content of alkalis of fly ash for all mixes made with reactive aggregates and low alkali cement

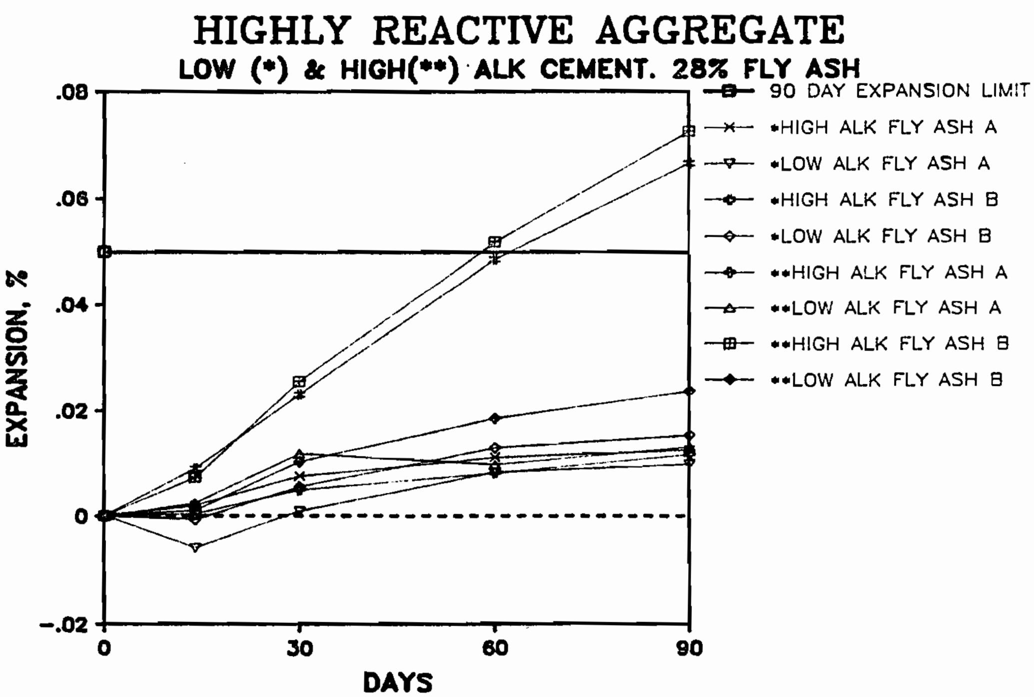


Fig. 23 Percentage of expansion vs time for all mixes made with highly reactive aggregate, containing 28% fly ash

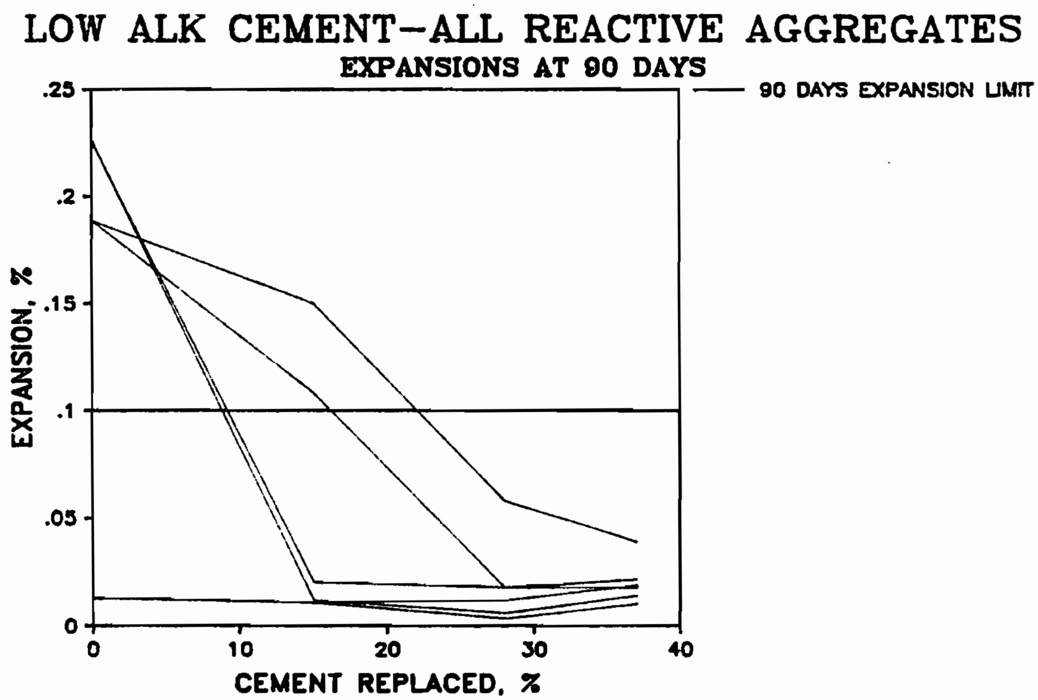


Fig. 24 Percentage of expansion at 90 days vs percentage of cement being replaced, for all mixes made with reactive aggregates and low alkali cement

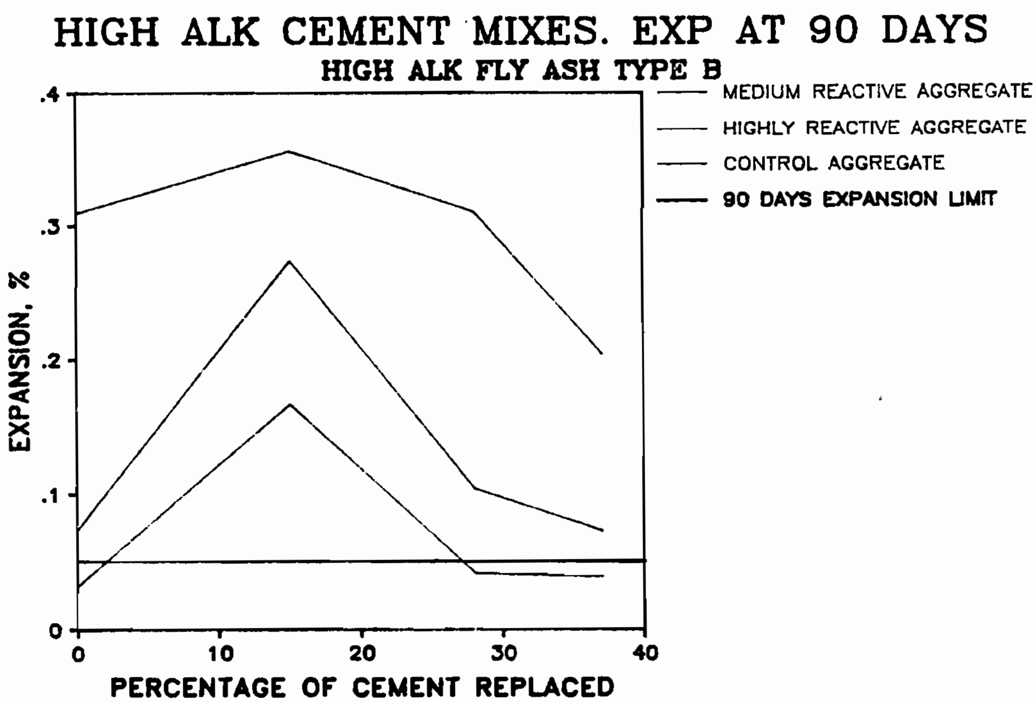


Fig. 25 Percentage of expansion at 90 days vs percentage of cement being replaced, for all mixes made with reactive aggregates, high alkali cement, and high alkali Type B fly ash

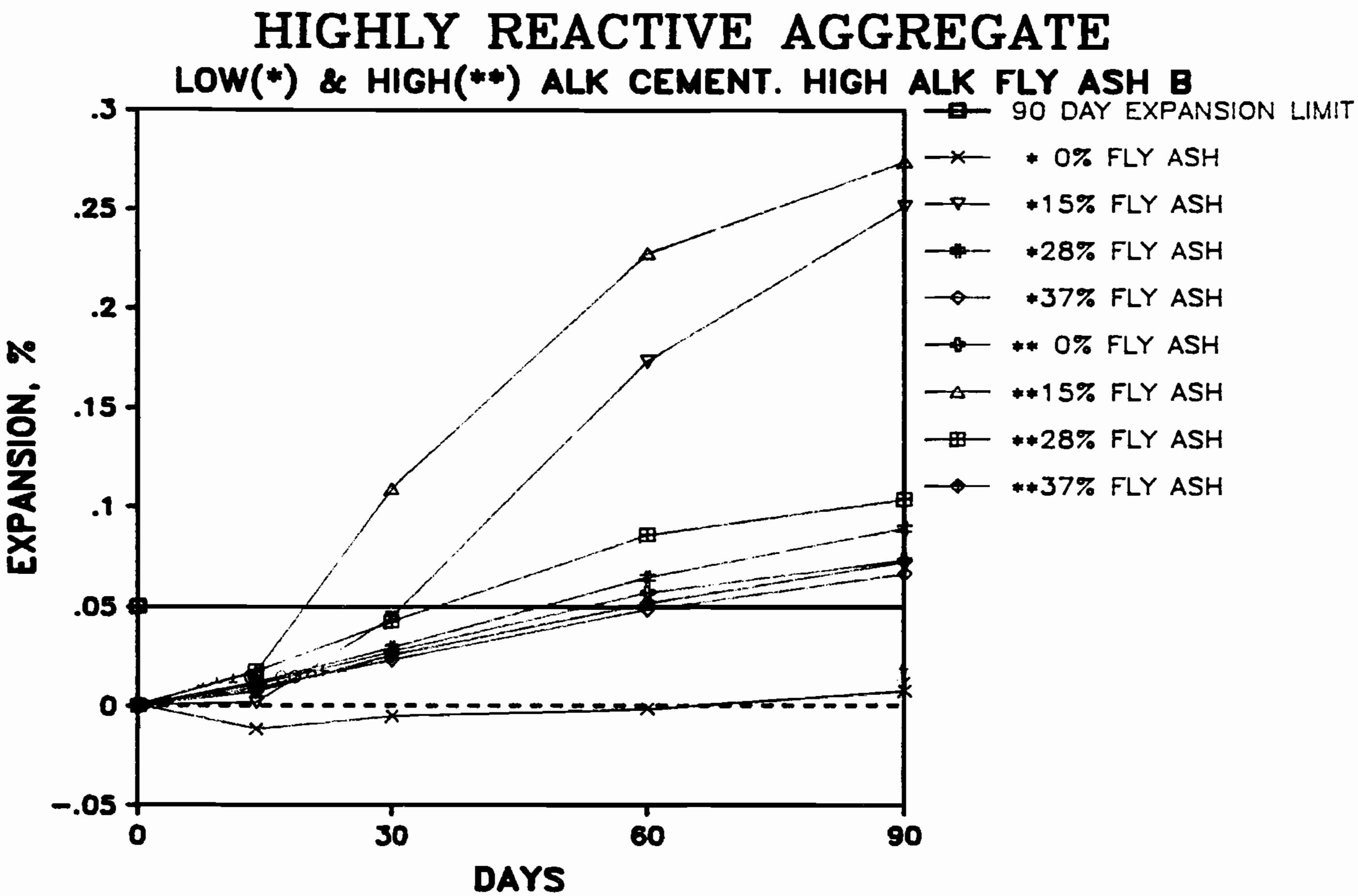


Fig. 26 Percentage of expansion vs time for all mixes made with highly reactive aggregate and high alkali Type B fly ash

White fluffy deposits where observed in bars with large expansions and some gel was observed in the sample stubs.

4.6 Chemical Analysis

X-ray diffractions were used to try to find a trend in chemical changes that could be related to the progress of alkali-aggregate reaction. These tests were done on sections of the same bars where the stubs for petrographic analysis were taken.

Also the tap water used was chemically analyzed to determine its chemical composition and to establish its pH. the water pH was reported to be 8.14. The water exhibited a sodium content of 42.3 ppm. X-ray diffraction results and complete water analysis are shown in Appendix A.

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

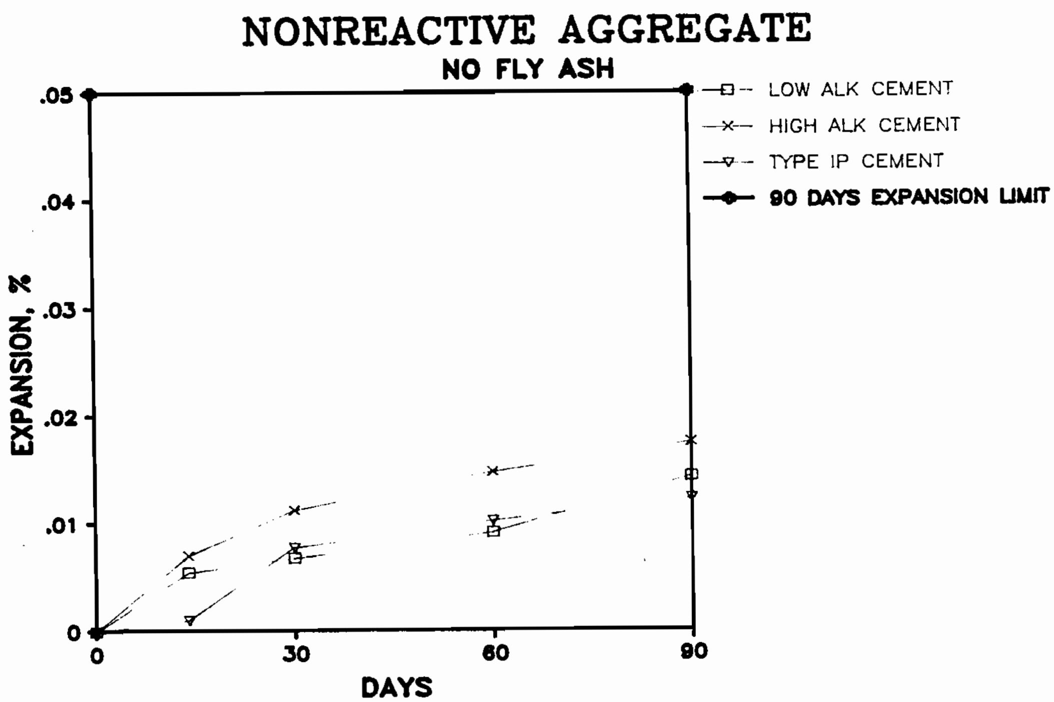


Fig. 27 Percentage of expansion vs time for all nonreactive aggregate mixes without fly ash added during mixing

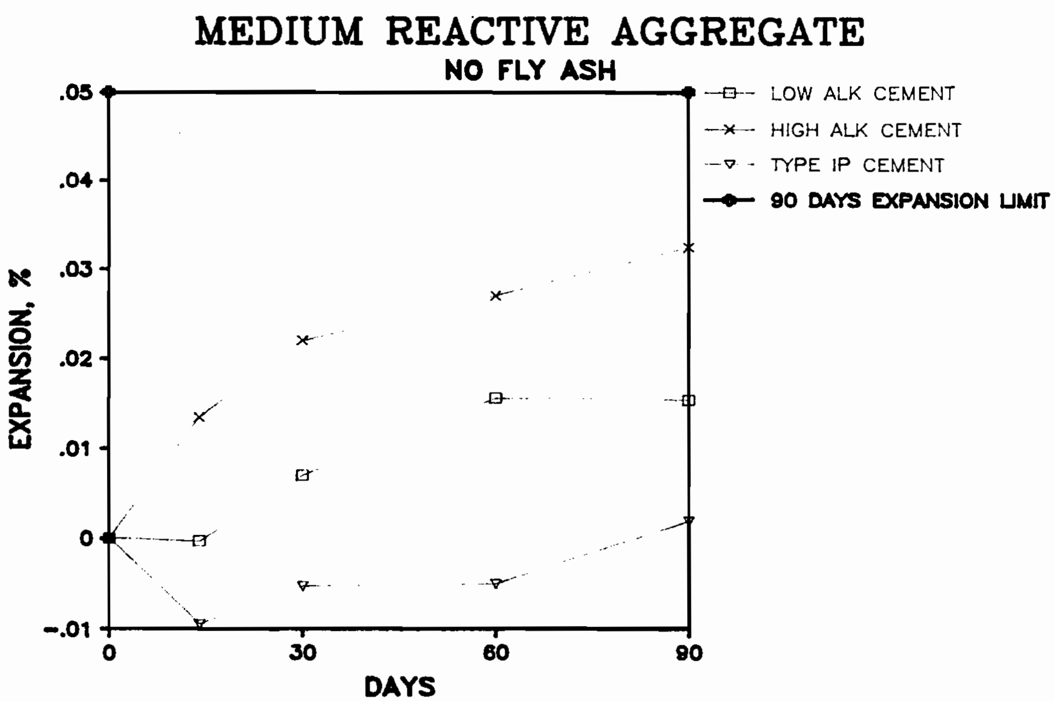


Fig. 28 Percentage of expansion vs time for all medium reactive aggregate mixes without fly ash added during mixing

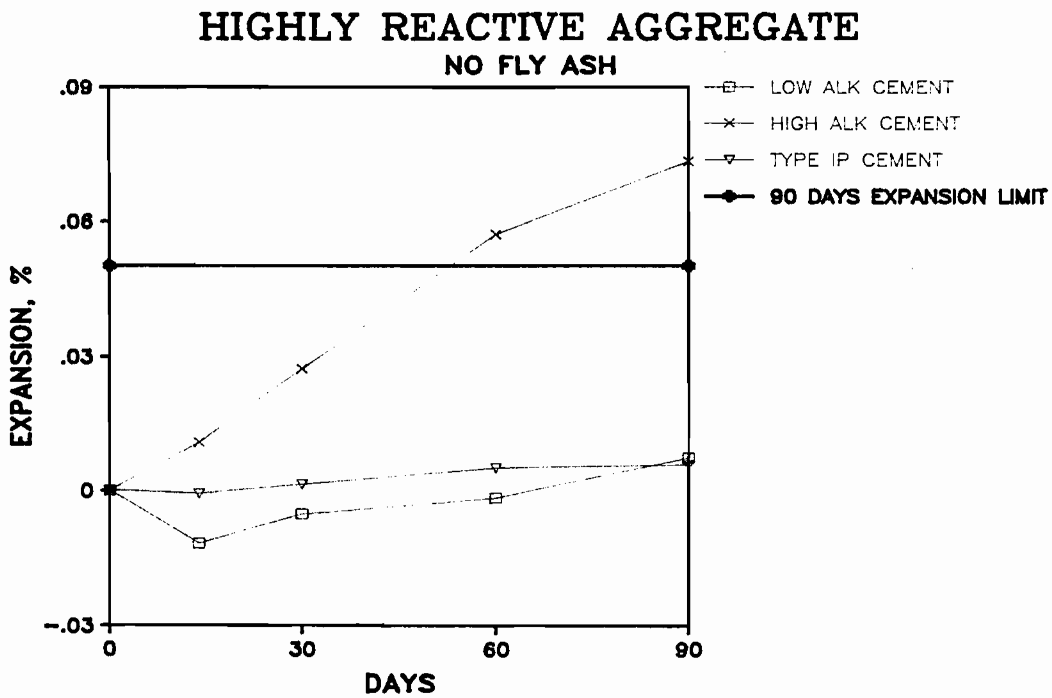


Fig. 29 Percentage of expansion vs time for all highly reactive aggregate mixes without fly ash added during mixing

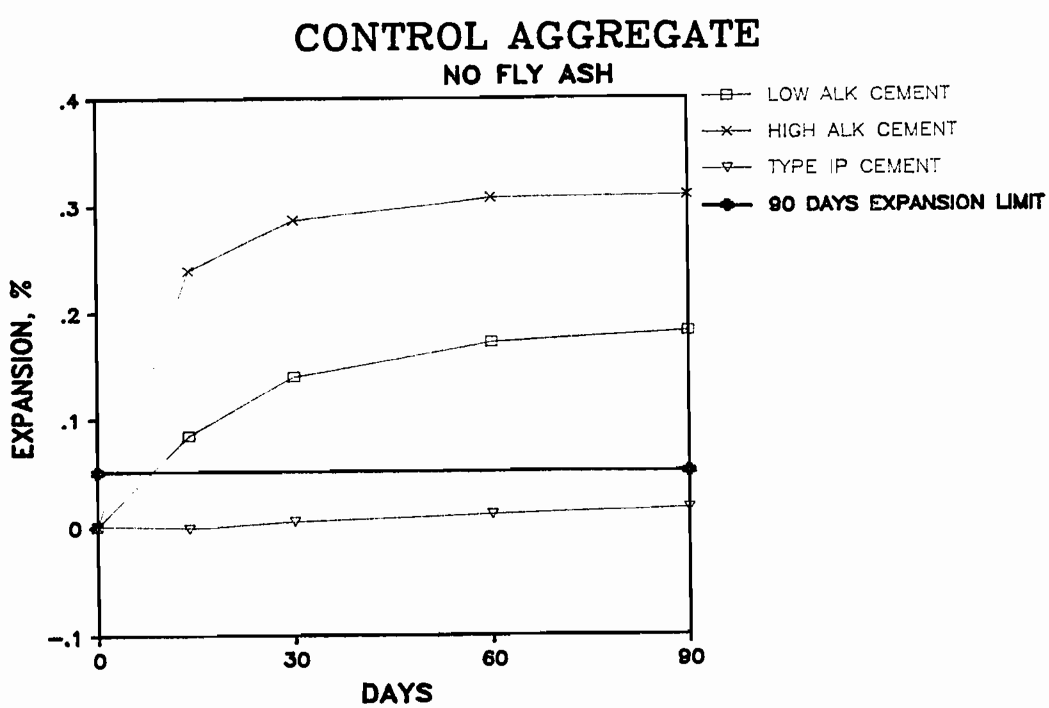


Fig. 30 Percentage of expansion vs time for all control aggregate mixes without fly ash added during mixing

cement mixes resulted in negligible expansion even with highly reactive aggregate, as shown in Fig. 29.

The test results from the mixes made with control aggregate (pyrex glass) and without fly ash, for each of the cements considered in the project, show perfectly that the only way to really diminish substantially the reaction between poorly crystallized silica in the aggregate and the alkalies in the cement is with the addition of fly ash. Figure 30 exemplifies this. Both high and low alkali cement mixes made in combination with pyrex glass, expanded well beyond the 0.05% limit for 90 days, and even at 14 days, while the mix containing Type IP cement in combination with pyrex glass did not exceed the expansion limit.

Although the total alkali content for the Type IP cement is 0.504%, which is higher than the 0.43% alkali content of the low alkali cement, the beneficial effect of the addition of fly ash in the blend, in reducing alkali-aggregate related expansion, is significant.

When expansions are significant, mixes containing higher alkali cements cause larger expansions in mortar bars than mixes containing lower alkali cements.

It has to be noted that the high alkali cement used in this test has 0.66% total alkalies: only 0.06% higher than the upper limit established by ASTM C150 for low alkali cements. Based on the test results, the 0.06% upper limit does not seem to provide an adequate guideline to differentiate between cements for use in concrete where alkali-aggregate reaction damage could occur. As shown in Fig. 30, mortar bars made of mixes made using low alkali cement having 0.42% alkali content exceeded the expansion limit at 90 days.

The 0.6% limit on total alkalies suggested by ASTM C150, is the result of tests made on mixes containing opal [5], a type of amorphous silica which is very reactive. Although these results were applicable for opal, they were not necessarily applicable for other types of reactive materials such as metastable forms of silica or certain types of glass.

5.3 Aggregate Type

Figure 31 shows that, when using low alkali cement in mixes without fly ash, except for the control aggregate, the mixes made with either nonreactive, medium reactive or highly reactive aggregate expanded at 90 days only up to approximately one-fifth of the 0.05% expansion limit for 90 days.

When using high alkali cement, the expansion at 90 days, for the mix containing highly reactive aggregate, was of the order of 1-1/2

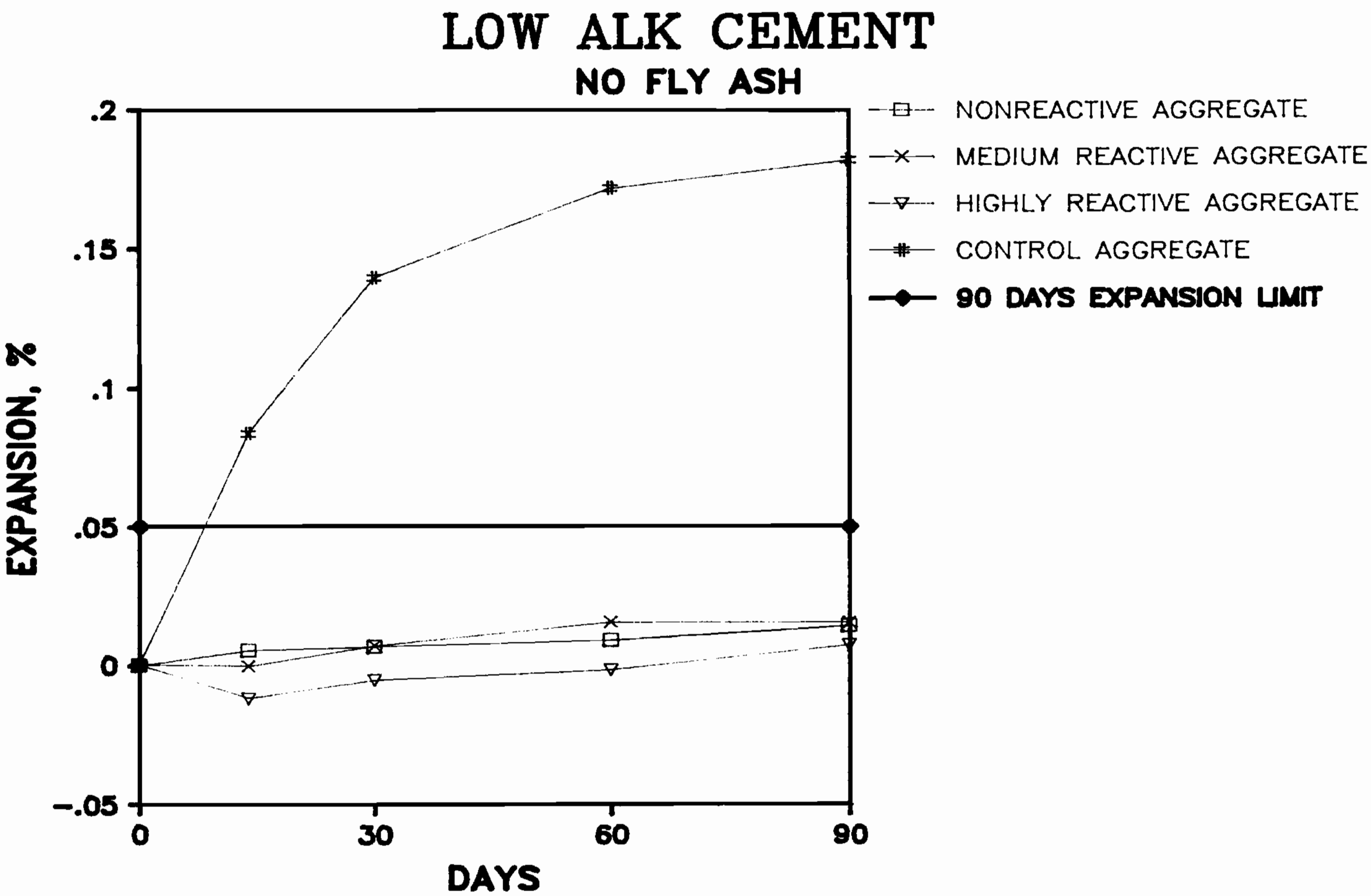


Fig. 31 Percentage of expansion vs time for all low alkali cement mixes without fly ash

times the expansion limit for 90 days. While the medium reactive aggregate showed an expansion of more than 75% of that limit, as can be seen in Fig. 32.

These differences can be explained in terms of the composition of the highly reactive material which contained five possible sources of reactive constituents, according to the petrographic data obtained using ASTM C295: Quartz, chert, volcanic rock fragments, volcanic glass and tuff, while the medium reactive aggregate contained only two possible sources of reactive constituents: rhyolite and chert.

Nevertheless, it cannot be said with accuracy that the medium reactive aggregate is safe to be used in combination with high alkali cement, especially when it is considered that the alkali content of the high alkali cement for this project is barely above the lower limit set by ASTM C150 for that classification.

When Type IP cement is used, even the pyrex glass represents a source of aggregate which results in an expansion below the expansion limit for 90 days, according to the test results shown in Fig. 33. Again, this cannot be attributed to anything else than to the beneficial effect of the presence of fly ash in the mix. The fly ash used in making Type IP cement had an available alkali content of only 0.34%. The blend has a total available alkali of 0.504%.

In conclusion, the use of mortar bar test results based on ASTM C227 seems to provide a procedure for recognizing sources of aggregate of potential alkali-reactivity.

5.4 Fly Ash

It is clear that the addition of fly ash to concrete can be beneficial with respect to the prevention of damage due to alkali-aggregate reaction. The question is, what types of fly ash are best suited for the job and in what quantity should the fly ash be added? The test results showed, among other things, that available alkalies in the fly ash do play an important role on the effectiveness of the preventive action of fly ash in alkali-aggregate reaction related damage, and that, in some instances, certain percentage replacements could have a worsening effect rather than a preventive action.

5.4.1 Type. For any combination of aggregate and cement used in this project, even if no expansion beyond the expansion limit was observed at 90 days, differences in reactivity between mixes using different fly ash types were observed.

In this report, a truly preventive effect, for a certain replacement of cement by fly ash, with respect to alkali-aggregate reaction, is defined as that which causes a reduction of expansions in

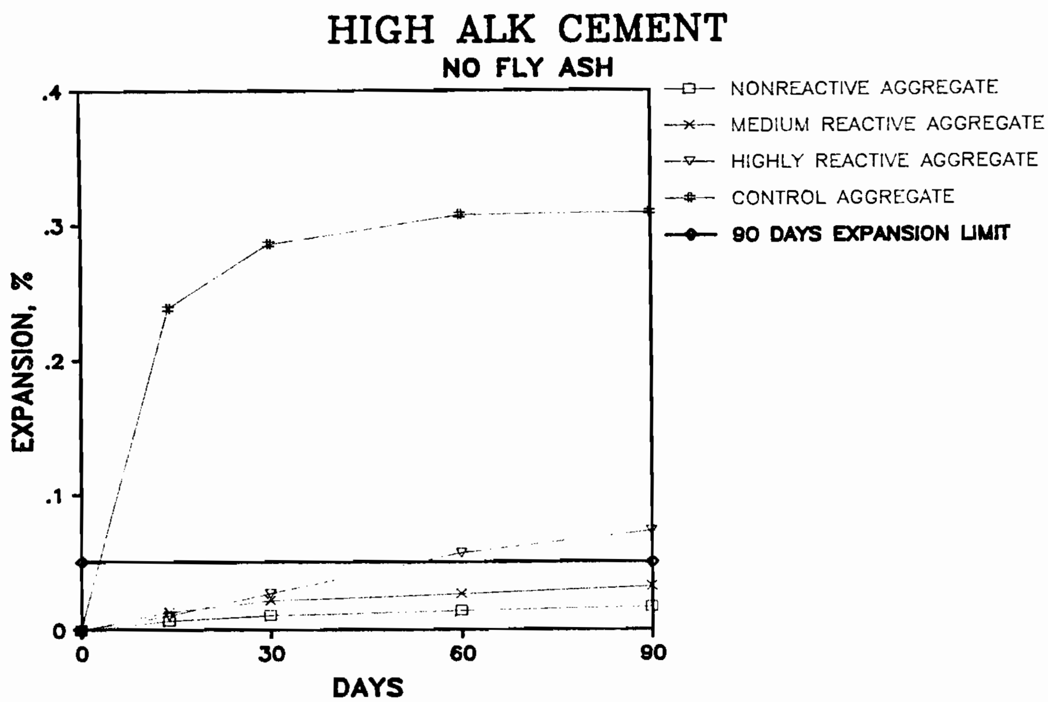


Fig. 32 Percentage of expansion vs time for all high alkali cement mixes without fly ash

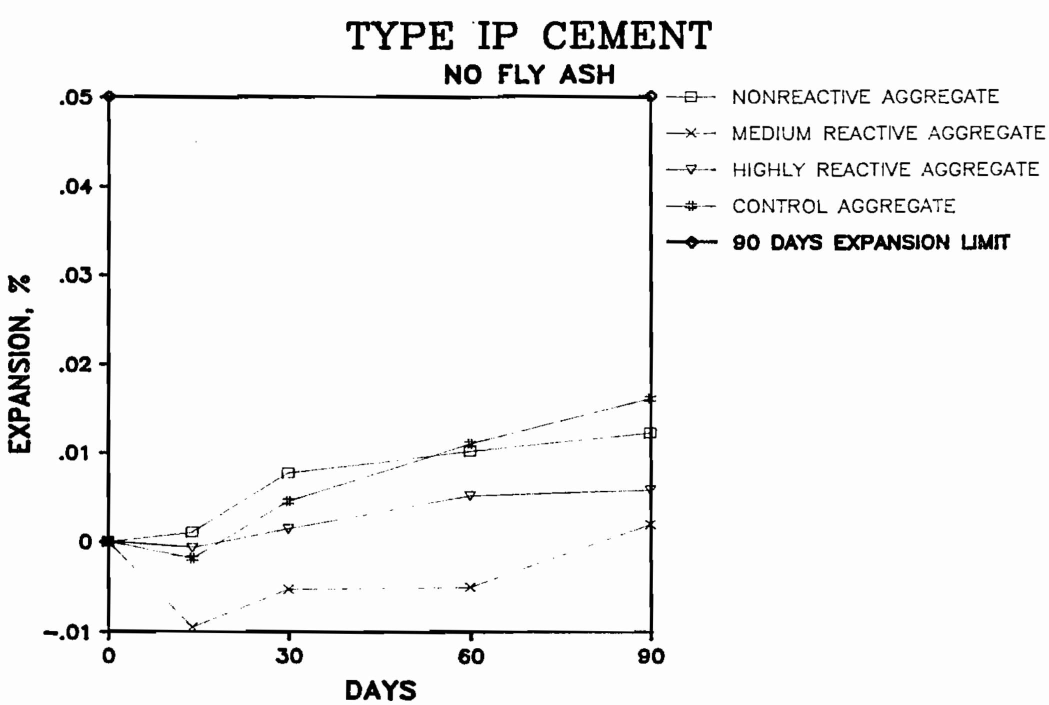


Fig. 33 Percentage of expansion vs time for all Type IP cement mixes

mortar bars made with control aggregate from values above the safe limit to values below that limit. For example, Figs. 34 and 35 show two groups of test results from mixes made with the control aggregate: one group with expansions at 14 days above the ASTM limit for 90 days and the other group with expansions at 90 days at or below the limit for 90 days. The more reactive group consists of mixes containing 37% Type B fly ashes, while the nonreactive group consists of mixes containing 37% Type A fly ashes.

Evidently, the first group is not as effective as the second group in the prevention of alkali-aggregate reaction. In general, the same trend can be seen for any mix which showed reaction, as the figures in Appendix A illustrate. These differences could be attributed mainly to the nature of the coal used.

Coal has been classified in different ways as its use and applications grew in number and complexity. The first classification attempt was done based on the color and texture of the coal - brown and gray coals, for example. Then, it was classified according to the amount of metamorphic change during the coal-forming process (coalification), which is called classification by rank and is known as the "industrial classification." Finally, the coal was classified according to its properties, or what is known as "scientific classification" [34].

Classification of the most broad use is the classification by rank. Coal deposits were formed from plant materials by the action of heat acting through long periods of time, supplemented by the effect of pressure. The stages of coalification involve first the formation of peat, then lignite, followed by subbituminous coal, bituminous coal and finally anthracite [35].

The content of alkalies in the plant matter is well known but the greater part of alkali metals present in coal is assumed to have come from the inorganic admixtures, particularly muscovite and clay minerals [36], introduced into the coal during coalification by waters bringing the elements from areas marginal to the coal deposits or from the consolidating enclosing sediments [37].

In this project, the Type A fly ashes come from the combustion of lignite while Type B fly ashes come from the combustion of subbituminous coal. Being subbituminous coal subjected to coalification for a longer period of time than lignite, it can be expected that the former contains more alkalies than the latter. Moreover, different coals have different mineral-matter content, which will be the noncombustible residue remaining after coal combustion, in other words, the ash.

Table 6 shows the available alkali content for each one of the fly ashes used in this part of the current project. As shown in the

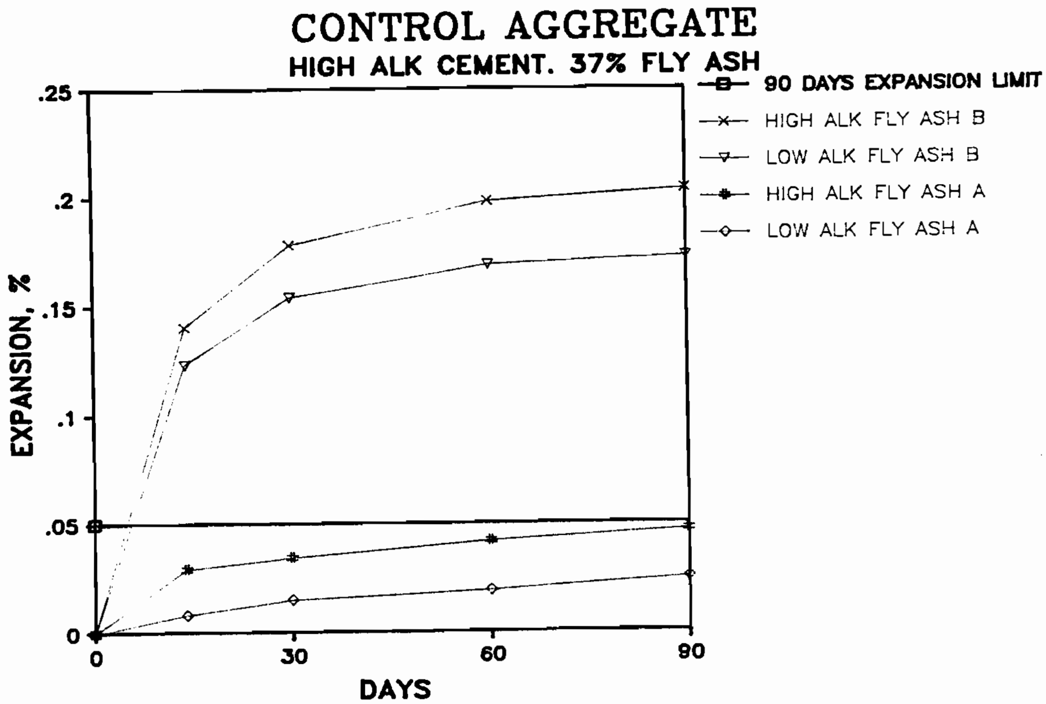


Fig. 34 Percentage of expansion vs time for all control aggregate mixes containing high alkali cement with 37% fly ash

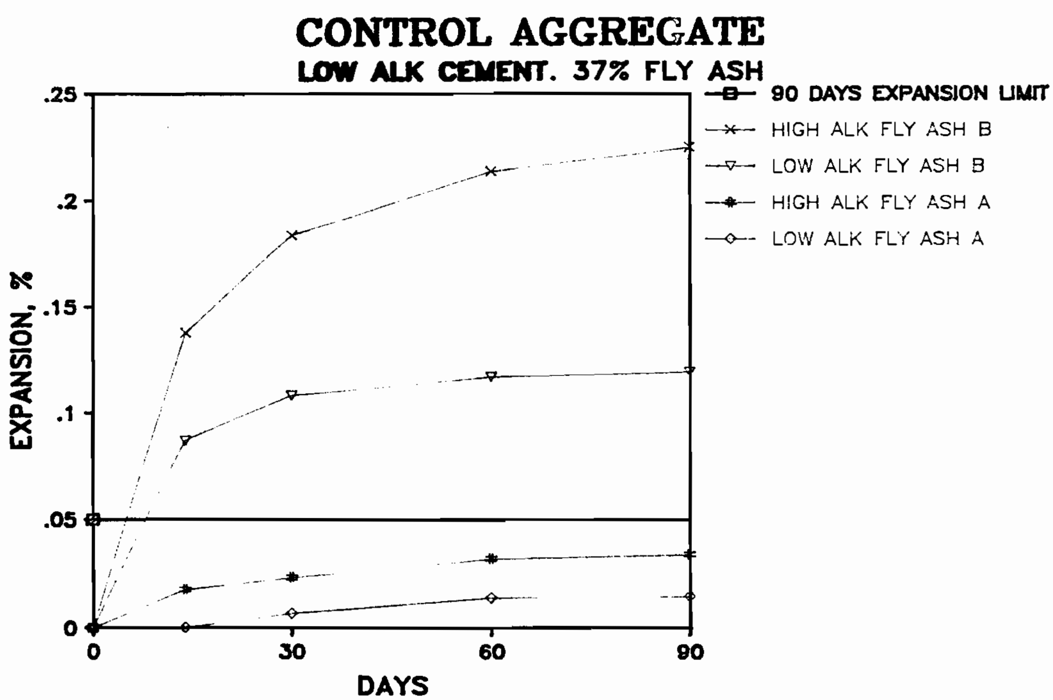


Fig. 35 Percentage of expansion vs time for all control aggregate mixes containing low alkali cement with 37% fly ash

table, Type B fly ashes have higher available alkali content than Type A fly ashes.

Table 7 shows that, on the average, the ash content, or mineral-matter content, of western subbituminous coals is 1.7 times greater than the ash content of a lignite coal.

Test results seem to confirm that, regardless of cement or aggregate type used, the main feature defining the difference in behavior between two fly ash types with respect to alkali-aggregate reactivity is the available alkali content. As an example, Fig. 36 shows the expansion history for all mixes containing reactive aggregates. Here, for both high and low alkali cement, the higher the content of alkalies in the fly ash, the higher the expansion.

Dunstan affirms that "the alkalies of the fly ash seem to have little effect on these [alkali-aggregate reaction] expansions." However, his reports are based on 14-day expansions, which could have been too early to reach adequate conclusions. Moreover, the cement he used had a very high alkali content, of about 1.19%, which could have offset the effect of the alkali in the fly ash for that 14-day period studied.

Figure 37 shows that for mixes using highly reactive aggregate and 37% fly ash replacement, two mixes experienced expansions at 90 days beyond the 0.05% limit and significantly greater than the expansions of the rest of the mixes using the other sources of fly ash. The difference between the two mixes reacting the most and the rest lies only in the type and composition of fly ash. The high alkali fly ash Type B has an available alkali content of 4.35%, which is a much greater value than the next highest alkali content which corresponds to 1.67% for the low alkali fly ash Type B. In fact, the test results of the current project show that, in general, the alkali content of fly ash is a very important factor affecting the beneficial effect of fly ash replacement in the prevention of alkali-aggregate related expansion.

These differences in effectiveness on the beneficial effect of fly ash replacement is seen for all aggregates used and all percentages of replacement as shown in Figs. 38 through 40. In the three figures the two differing mixes mentioned above can be clearly observed, even when the expansions are below the 0.05 expansion limit as in Figs. 39 and 40.

Both ASTM and TSDHPT suggest an upper limit of 1.5% for the alkali content of either of Class F or C or Type A or B fly ashes. This limit seems to be an arbitrary figure. A striking coincidence must be noted though. According to an investigation carried out by the Bureau of Mines [37] on 373 samples of commercial coal which were determined to be representative of the coal produced throughout the

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

	Ultimate analysis (dry) (wt %)						Proximate Analysis (as received)				Heating value as received (Btu/lb)
Coal Type	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

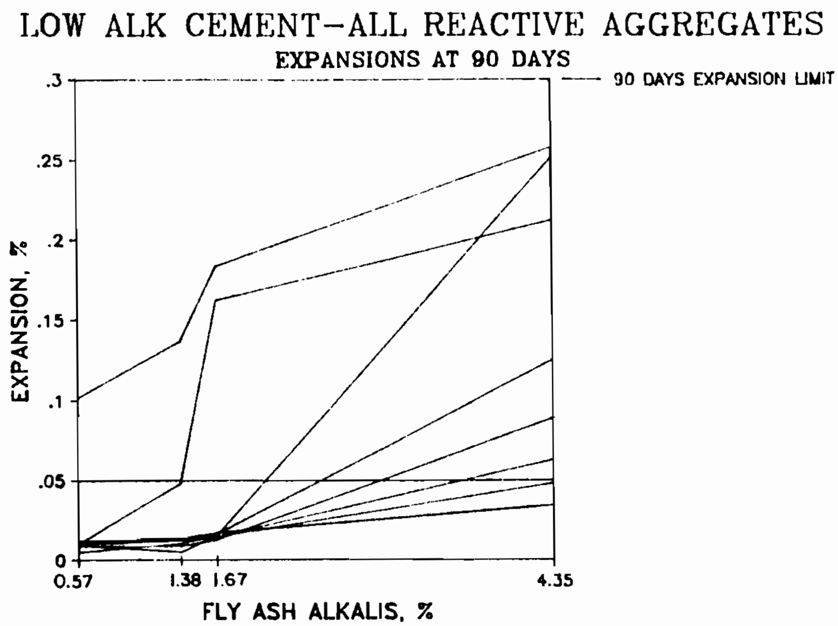


Fig. 36 (a) Percentage of expansion at 90 days vs content of alkalies of fly ash, for all mixes made with reactive aggregates and with low alkali cement

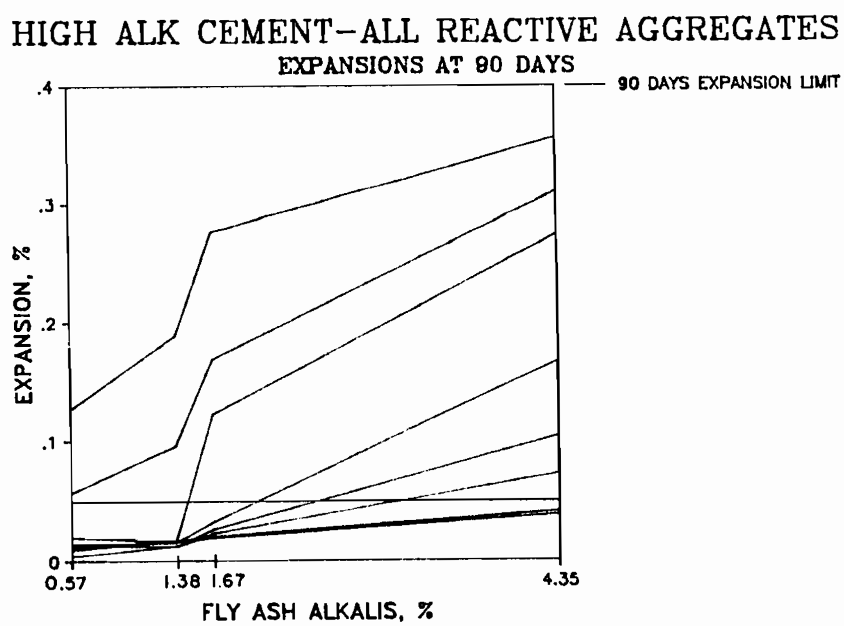


Fig. 36 (b) Percentage of expansion at 90 days vs content of alkalies of fly ash, for all mixes made with reactive aggregates and with high alkali cement

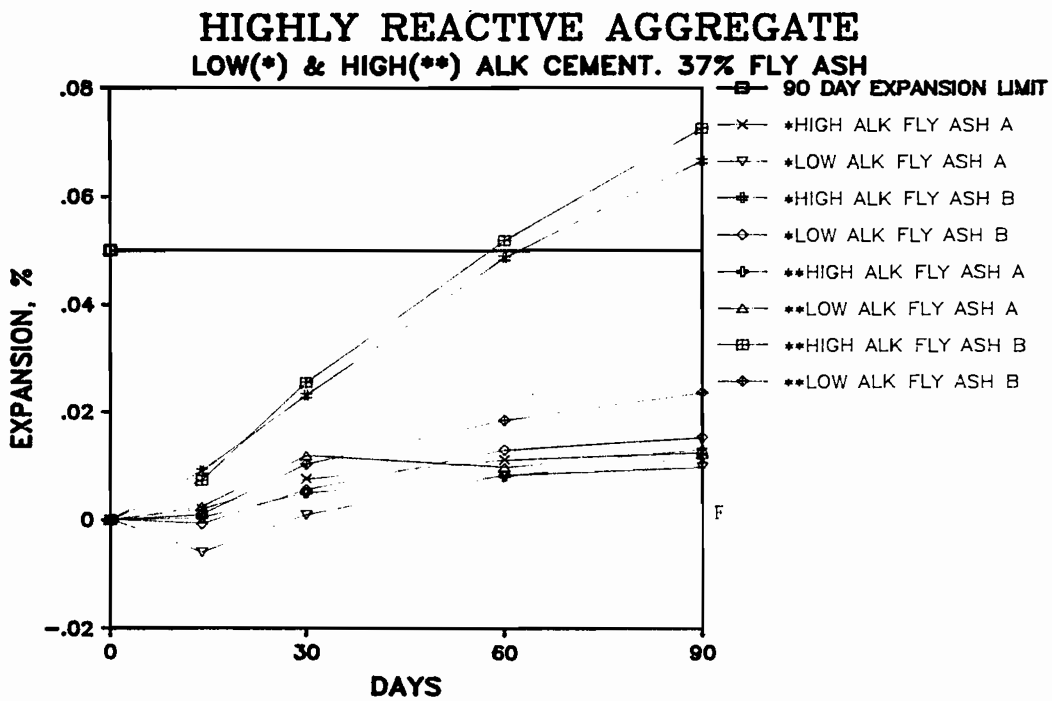


Fig. 37 Percentage of expansion vs time for all highly reactive aggregate mixes containing 37% fly ash

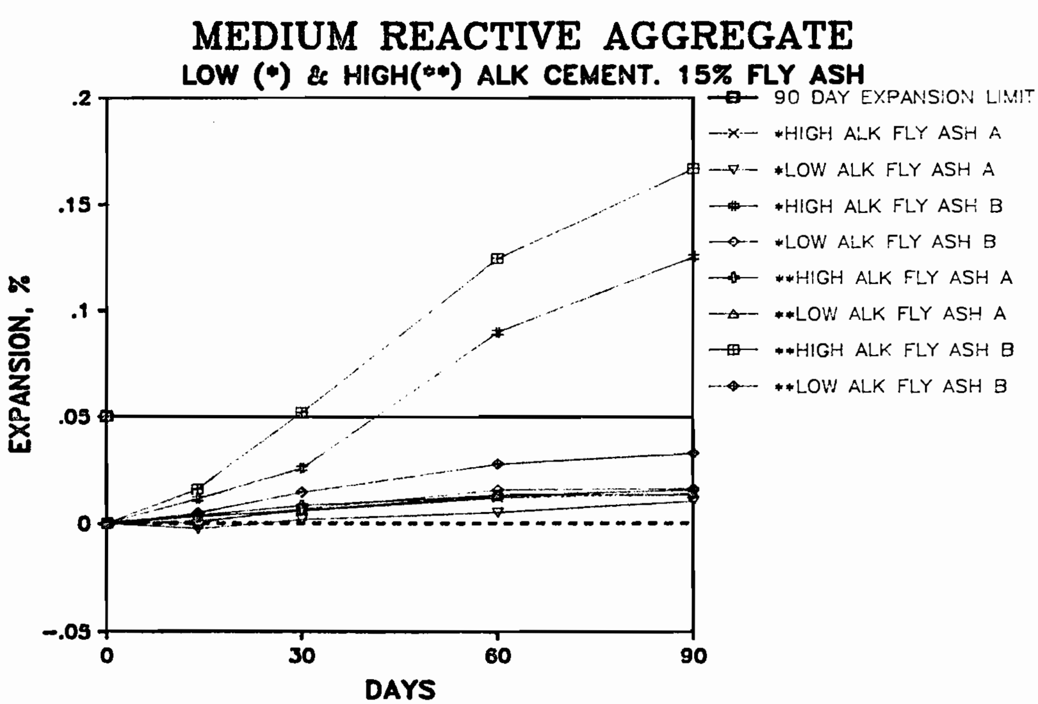


Fig. 38 Percentage of expansion vs time for all medium reactive aggregate mixes containing 15% fly ash

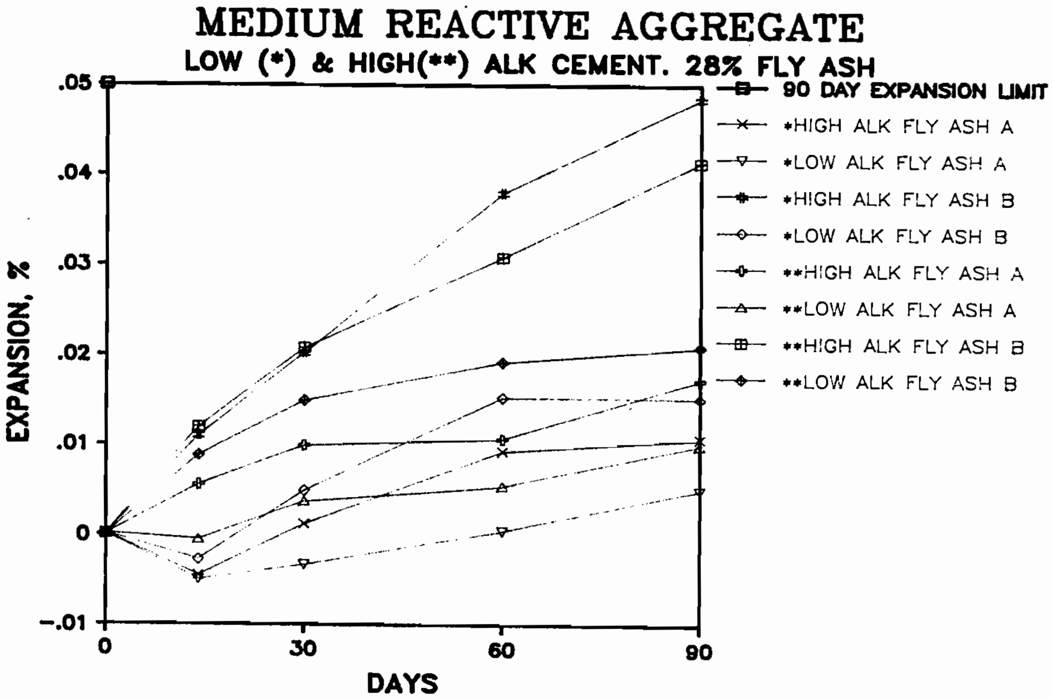


Fig. 39 Percentage of expansion vs time for all medium reactive aggregate mixes containing 28% fly ash

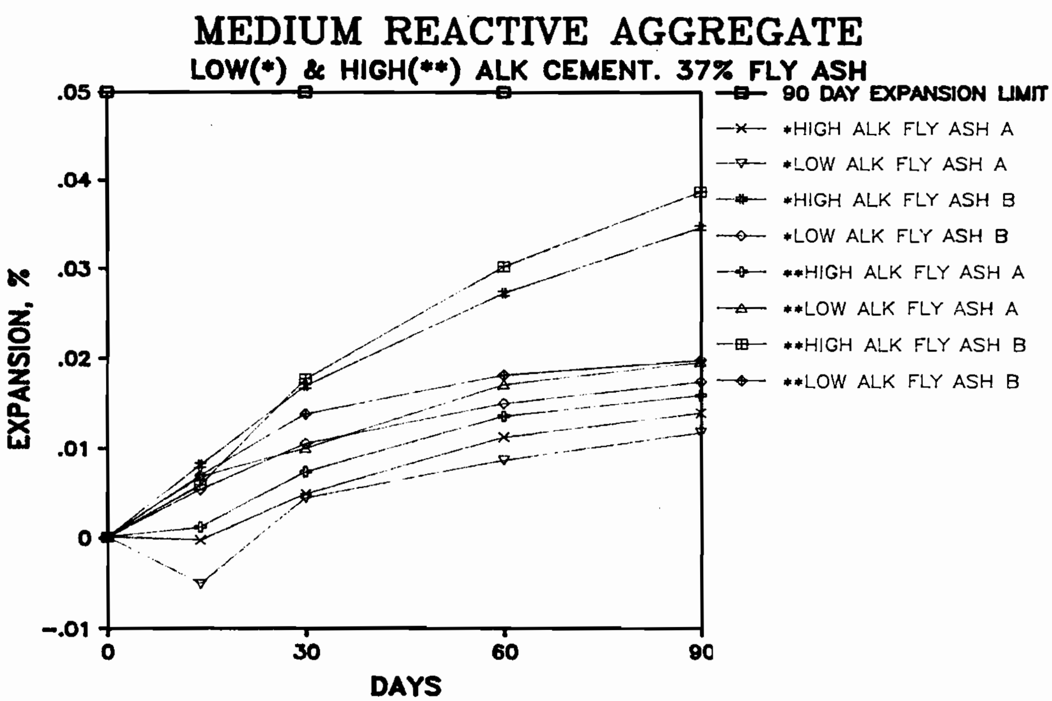


Fig. 40 Percentage of expansion vs time for all medium reactive aggregate mixes containing 37% fly ash

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

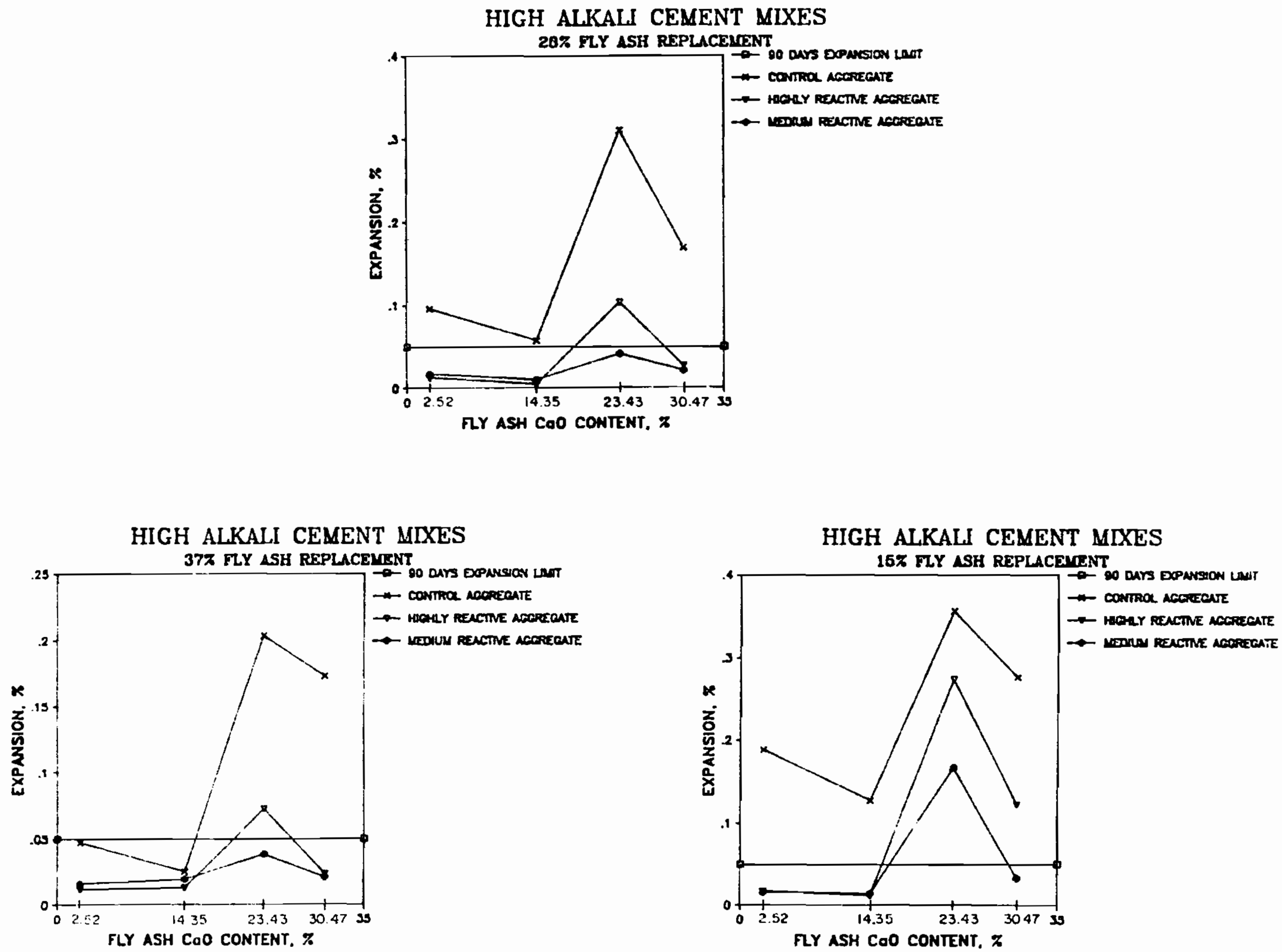


Fig. 41 Percentage of expansion at 90 days vs CaO content of fly ash for all mixes made with reactive aggregates and high alkali cement

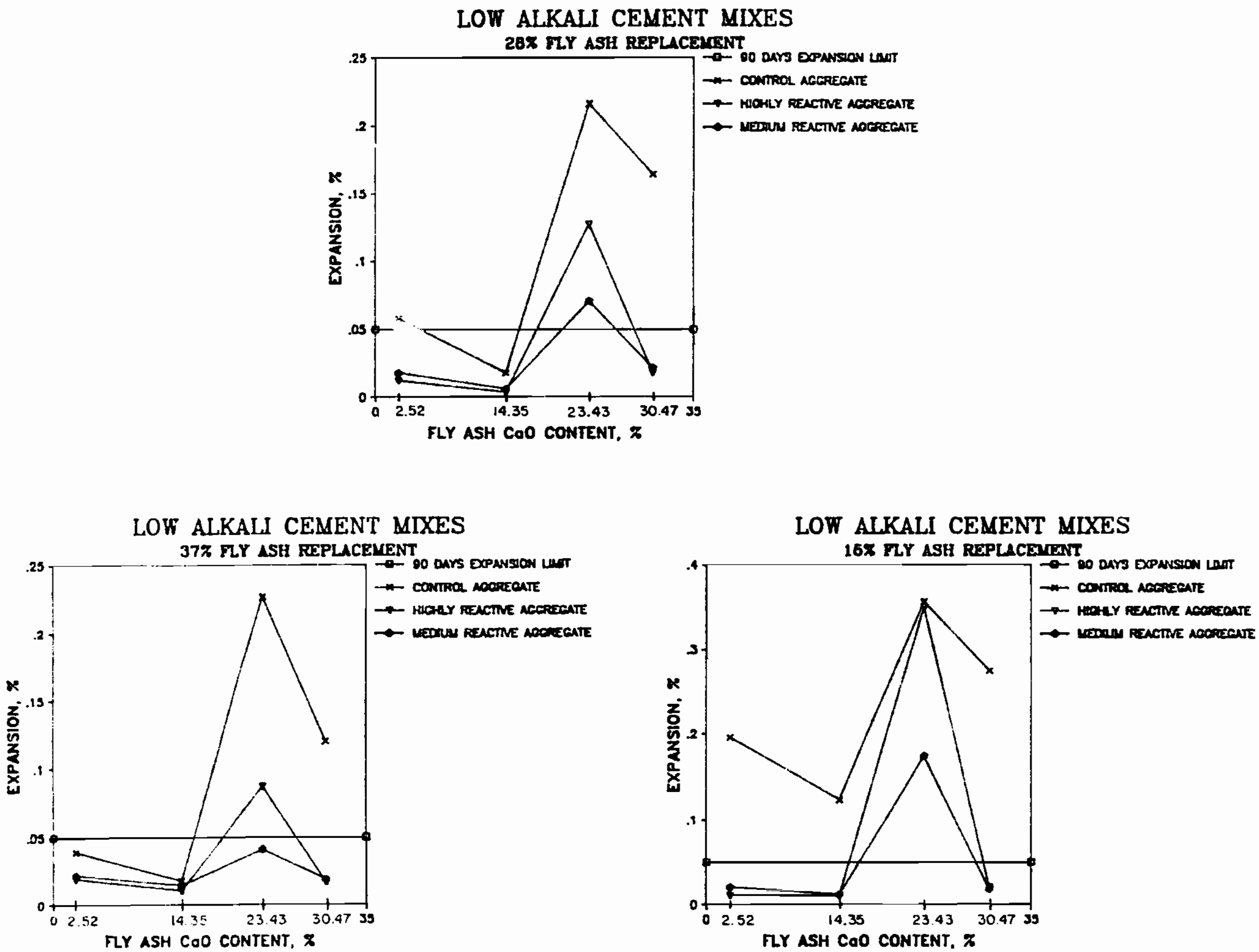


Fig. 42 Percentage of expansion at 90 days vs CaO content of fly ash for all mixes made with reactive aggregates and low alkali cement

the prevention of alkali-aggregate reaction related damage to concrete is the content of available alkalies of the fly ash. The content of calcium of the fly ash seems to have little effect on the effectiveness of the fly ash in preventing or controlling the alkali-aggregate reaction in concrete.

5.4.2 Percentage of Cement Replaced. In general, the test results of this study suggest that the effect of fly ash on the prevention of deleterious expansion due to alkali-aggregate reaction is affected by the amount of cement being replaced.

For all mixes containing fly ash with less than 1.5% content of alkalies, the effectiveness in the reduction of the expansions with respect to the mix containing no fly ash improves as the percent of cement replaced with fly ash increases. Figure 43 shows that for all mixes made with reactive aggregates and for both high and low alkali cement, it can be observed that 0% fly ash mixes reacted to cause a larger expansion than the mixes with 15, 28 and 37% in that order. However, in some instances, there seems to be a trend for a slight increase in expansions above 28% fly ash replacement. The relationship between the percentage of cement being replaced with fly ash and mortar bar expansion is not linear. For example, the results in Fig. 44 suggest a much greater effect of 28% replacement than that of 15% replacement than can be accounted for by the mere percentage difference.

This effect is amplified as the available alkali content of the fly ash increases.

In general, the test results show that as the available alkali content of the fly ash increases, the expansion reduction obtained from lower percentages of replacement tends to disappear and, sometimes, to turn into a deleterious action. Figure 45 shows that for low alkali cement mixes containing fly ash with 1.67% available alkalies there is an instance in which a 15% fly ash replacement of low alkali cement does not reduce the expansion when compared with the expansion of the mix containing no fly ash. Furthermore, as it can be seen in the same figure, a 15% fly ash replacement of high alkali cement results in an increase in the expansion of the mortar bar over that of the mortar bar without fly ash instead of resulting in a reduction of that expansion.

The peak in expansions is more obvious when the fly ash used in the mixes has a very high content of available alkalies. Figure 46 shows the expansions of mixes containing all reactive aggregates using fly ash with 4.35% available alkalies. Here, for both low and high alkali cement mixes, a 15% fly ash replacement results in larger expansions when compared with those of the mixes containing no fly ash.

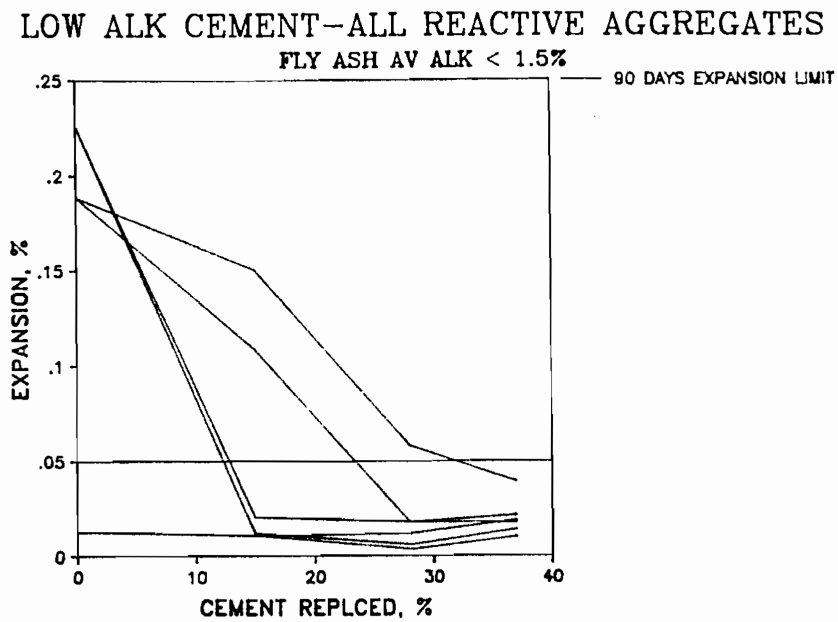


Fig. 43 (a) Percentage of expansion at 90 days vs percentage of cement being replaced, for all mixes made with low alkali cement and with fly ash containing less than 1.5% alkalies

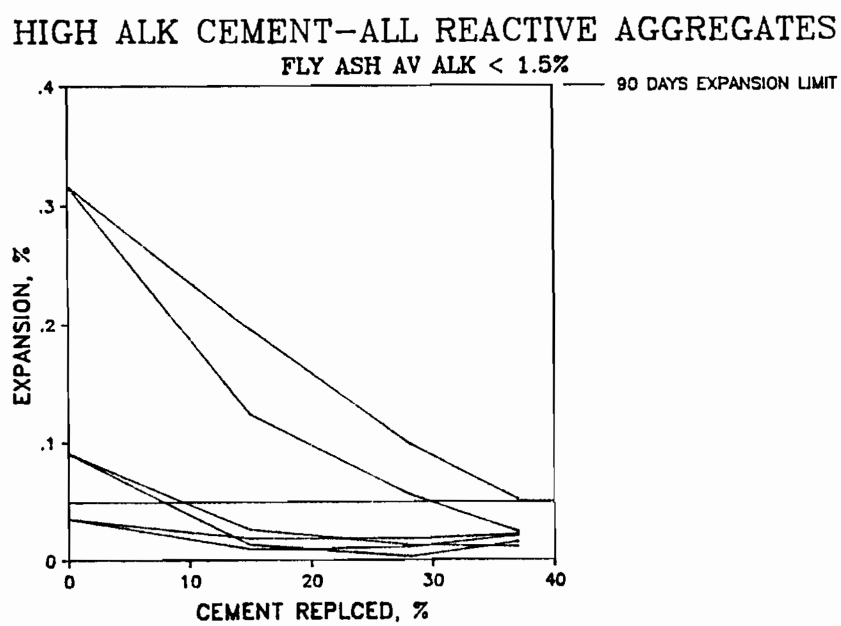


Fig. 43 (b) Percentage of expansion at 90 days vs percentage of cement being replaced, for all mixes made with high alkali cement and with fly ash containing less than 1.5% alkalies

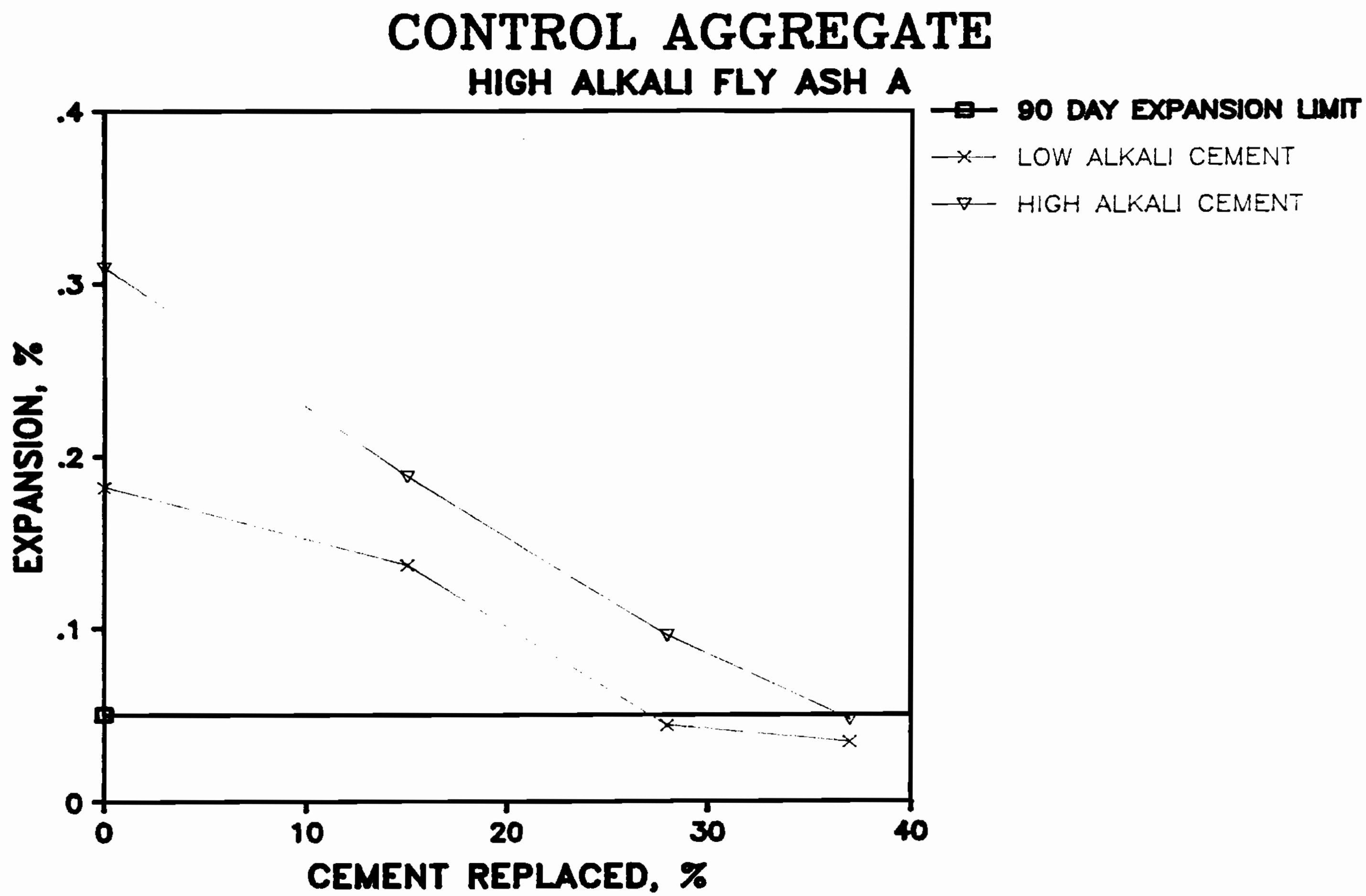


Fig. 44 Percentage of expansion vs time for all control aggregate mixes containing Type A fly ash with high content of alkalies. Expansions measured at 90 days

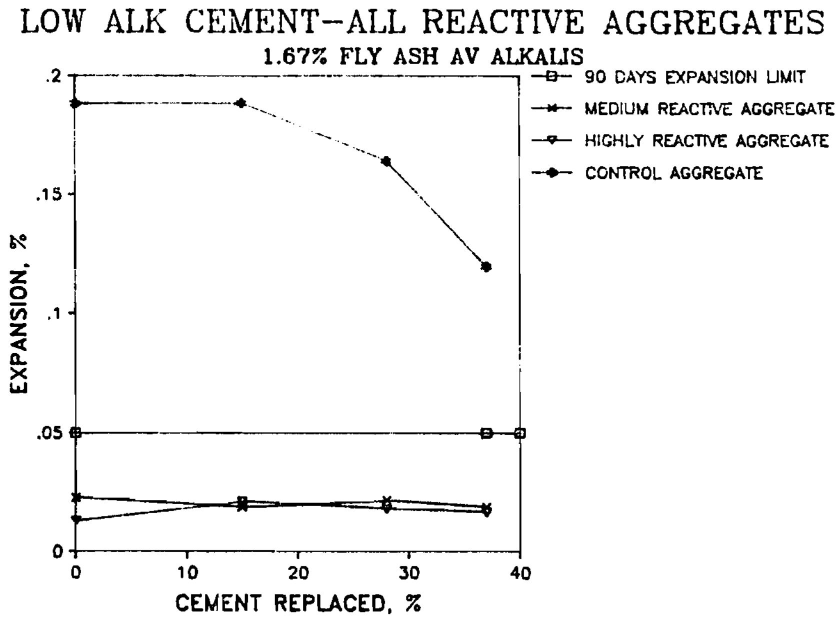


Fig. 45 (a) Percentage of expansion at 90 days vs percentage of cement being replaced, for all mixes made with low alkali cement, reactive aggregates, and fly ash containing 1.67% alkalies

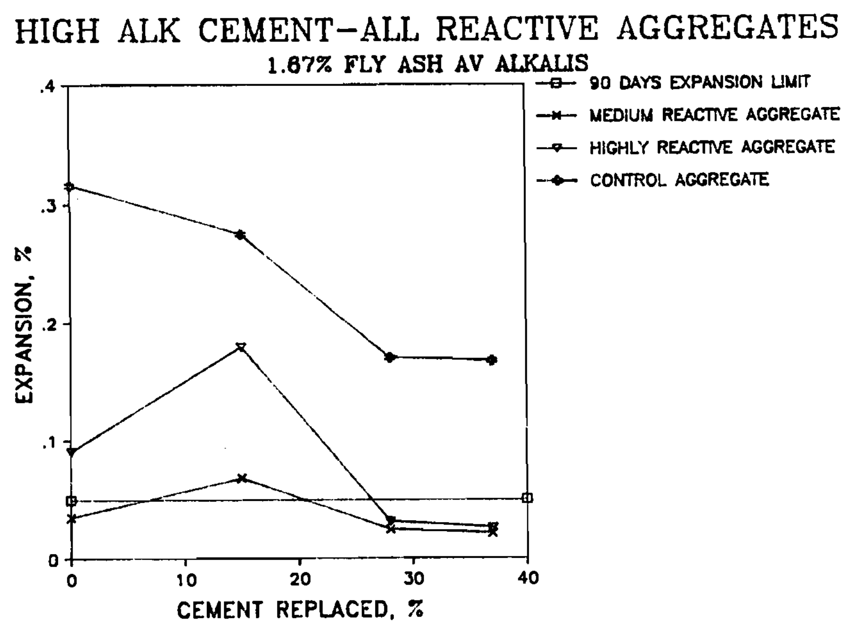


Fig. 45 (b) Percentage of expansion at 90 days vs percentage of cement being replaced, for all mixes made with high alkali cement, reactive aggregates, and fly ash containing 1.67% alkalies

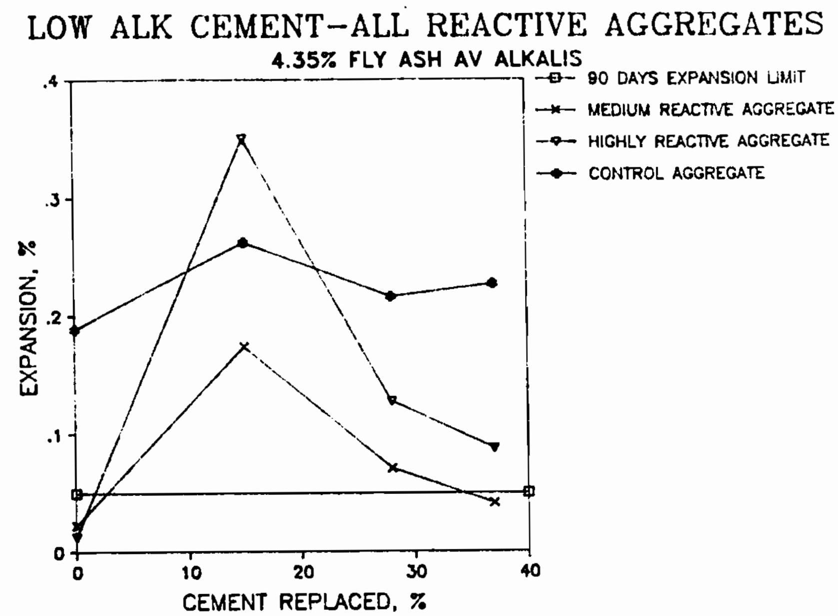


Fig. 46 (a) Percentage of expansion at 90 days vs percentage of cement being replaced, for all mixes made with low alkali cement, reactive aggregates, and fly ash containing 4.35% alkalies

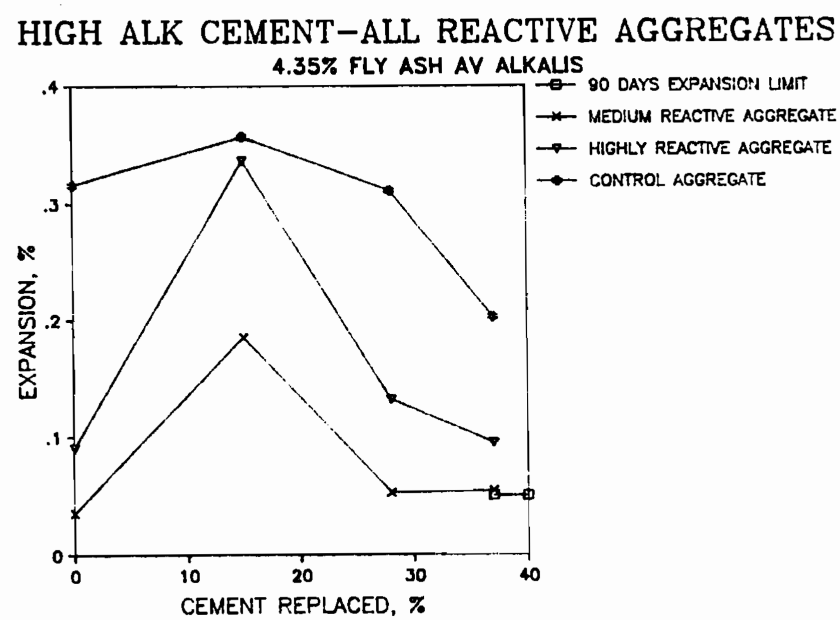


Fig. 46 (b) Percentage of expansion at 90 days vs percentage of cement being replaced, for all mixes made with high alkali cement, reactive aggregates, and fly ash containing 4.35% alkalies

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.

The theory just exposed is purely speculative and cannot be demonstrated with the test results from this part of the study, but rather it gives an explanation of the test results observed accounting for their soundness and accuracy, despite this unusual outcome.

In addition, there is one factor which has not been analyzed so far and that could play a role in the alkali-aggregate reaction. This factor is the blending of the fly ash with the cement prior to the mixing process as opposed to the addition of the fly ash to the mix during the mixing process at the mixing plant or at the job site.

The Type IP cement used in this project is a blend made with Type I portland cement containing 0.43% total alkalies. The low alkali content cement used in this project has the same 0.43% alkali content. A direct comparison cannot be made because the fly ash replacement used in the Type IP cement is 20%, a percentage which was not tested in this study. Furthermore, the fly ash used for the Type IP cement has an alkali content of 0.31% available alkalies which does not match with any of the fly ashes used in this study. However, mortar bars made with a low alkali cement mix containing 15% of the low alkali fly ash A, which has 0.57% of available alkalies could be expected to show slightly greater expansions than for mortar bars using a Type IP cement mix, provided both mixes use the same aggregate. In the same way, mortar bars using a low alkali cement mix containing 28% of the same low alkali fly ash and in combination with the same aggregate, can be expected to show slightly smaller expansions than the Type IP cement mix mortar bars.

Figure 47 points to the contrary. For highly reactive aggregate, expansions of Type IP cement mix mortar bars were not between the expansions for 15% and 28% fly ash replacement of the mortar bars made with the mixes described above, but they were even smaller than the 28% fly ash replacement mix mortar bar expansions. These results were also true for mixes using medium reactive and control aggregate. Therefore, it seems that the blending of the fly ash with the clinker prior to grinding gives to the resultant matrix a degree of homogeneity that improves the prevention of expansion due to alkali-aggregate reaction in the concrete.

The increased effectiveness of the fly ash in Type IP cement in reducing the expansion due to alkali-aggregate reaction in concrete can be attributed to the increased surface area of the fly ash due to the fly ash being interground with the cement clinker. Recent developments indicate that the intergrinding of the fly ash with the clinker does not result in a crushing of the fly ash particles, but in a breakage of the agglomerates of fly ash particles rendering the fly ash finer.

Finally, the replacement of 28% by weight of cement by fly ash gave satisfactory results for all mixes except for the highly reactive

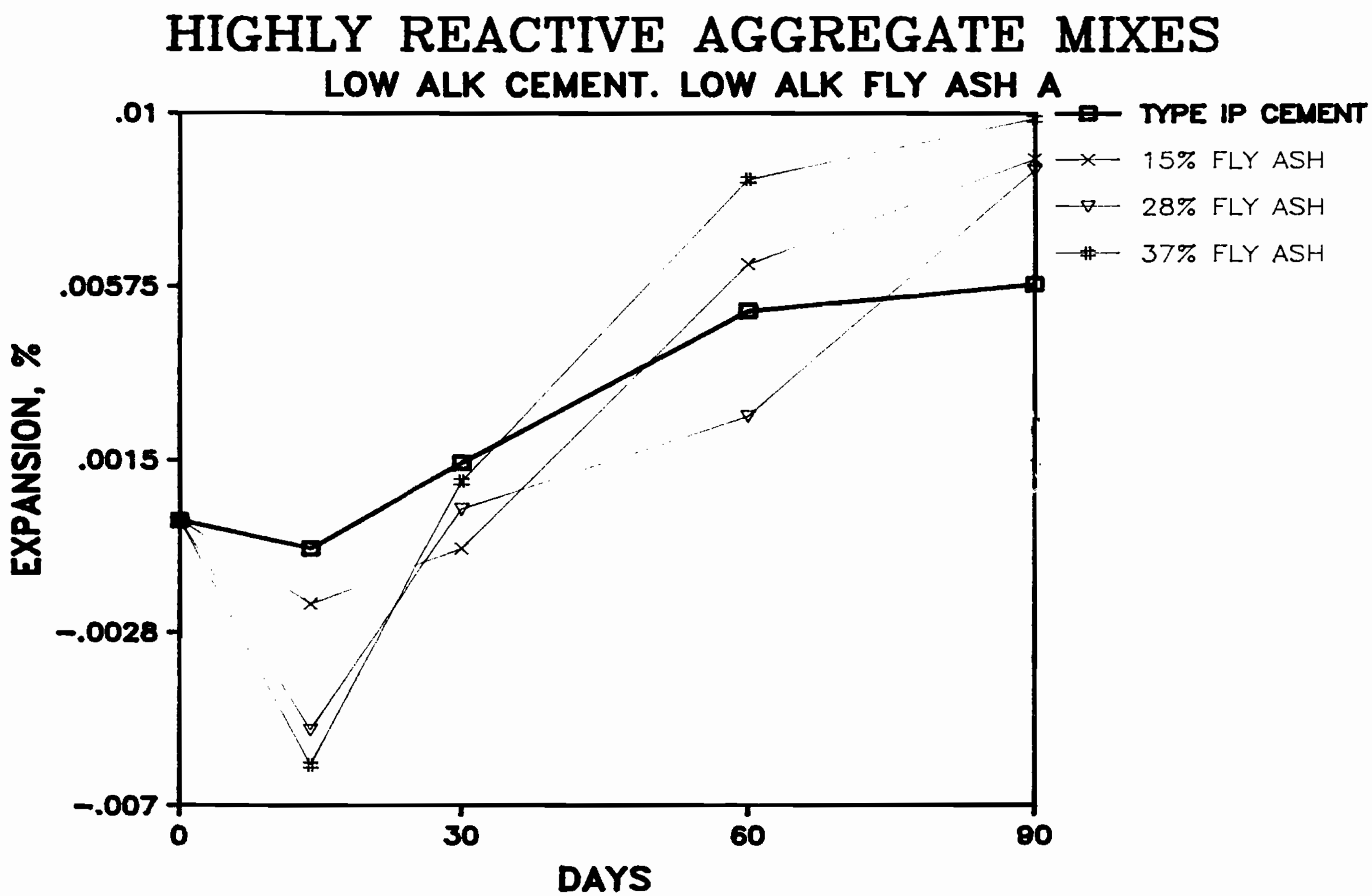


Fig. 47 Percentage of expansion vs time for all highly reactive aggregate mixes containing low alkali cement and Type A fly ash with low content of alkalies

aggregate mixes using high alkali fly ash Type B, for which a fly ash replacement of 37% produced reductions in the expansions at 90 days that were close but still above the safe expansion limit for 90 days.

5.5 Petrographic Analysis

The petrographic analysis is a diagnosis tool rather than an analytical tool. It was used in this study to support and corroborate the findings based on the mortar bar test expansions. Usually, the petrographic analysis in alkali-aggregate reaction related studies is made to differentiate between alkali-silica reaction and alkali-carbonate reaction. In the present case, the aggregate chosen for the experiment were selected in terms of their ability to produce alkali-silica reaction. No carbonate rock fragments were detected in the ASTM C295 test performed on all aggregates used herein.

In all cases, when a mix displayed excessive expansions a petrographic analysis showed one, some, or all of the next characteristics depending on the degree of reaction: rims around the aggregates, degradation of its borders, cracking in some aggregates, and cracking in the paste. Being that the alkali-aggregate reaction is an aggregate corrosion process, it is expected that the first evidences of the reaction occur on the aggregate. The test results seem to demonstrate so. Small excessive expansions showed mainly rims around the aggregates (Fig. 48) and, in some instances, degradation of their borders (Fig. 49). Larger expansions produced cracking in the aggregate (Fig. 50), and finally severe expansions cause cracking the paste (Fig. 51).

All mortar bars from mixes that reacted to cause expansion close or above the safe expansion limits, were covered by a white fluffy deposit to a greater or lesser extent depending on the degree of reaction (see Fig. 52). Some gel was observed when polished stubs were prepared for petrographic analysis.

5.6 Chemical Analysis

Since in the present part of this project no tests using different water pH or sodium content was conducted, the chemical analysis of the water was performed only for information purposes and no conclusion can be deducted from the water analysis results. However, it must be pointed out that the particular water used in this test had a pH of 8.14 which is considered typical for tap water in Austin, Texas.

The chemical analysis in the form of x-ray diffractions conducted on several key mortar bar samples did not provide useful information regarding the mechanism by which the reaction occurs and by which fly

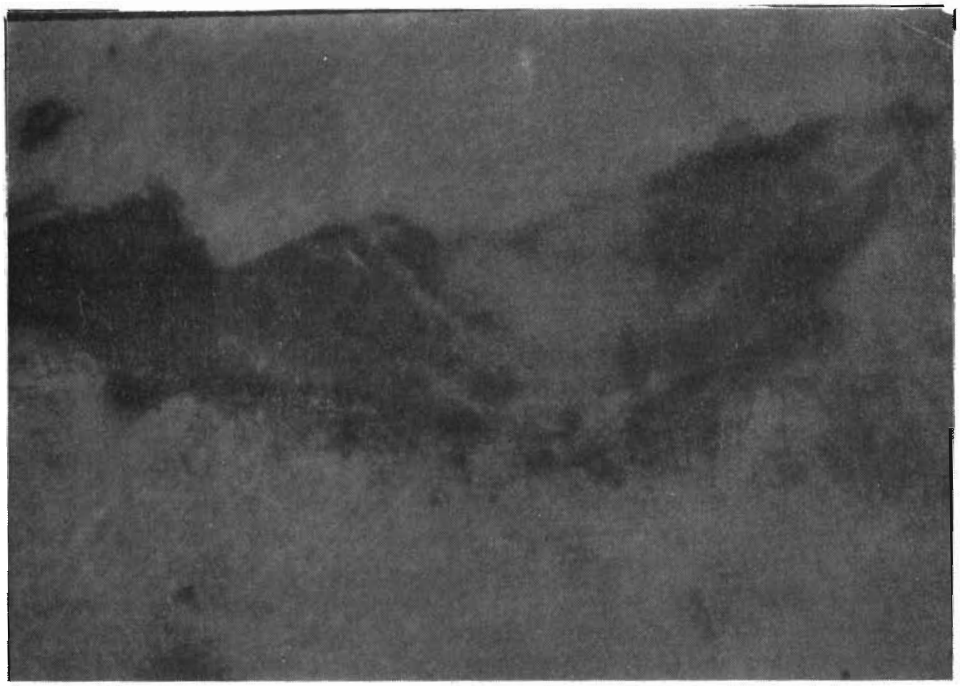


Fig. 48 Aggregate particle surrounded by a reaction rim

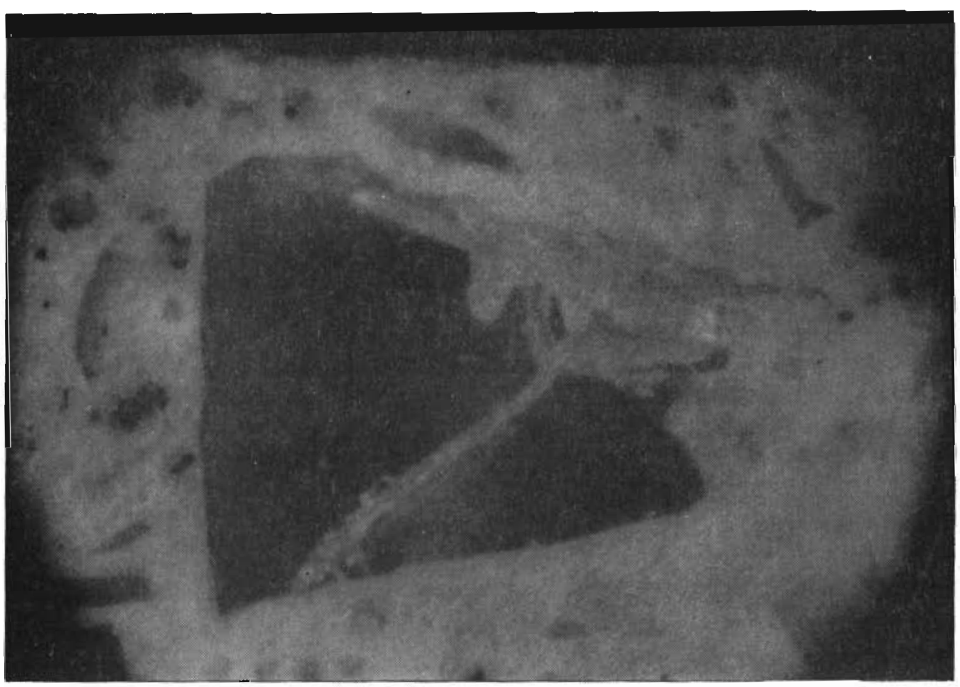


Fig. 49 Aggregate particle with degraded edges

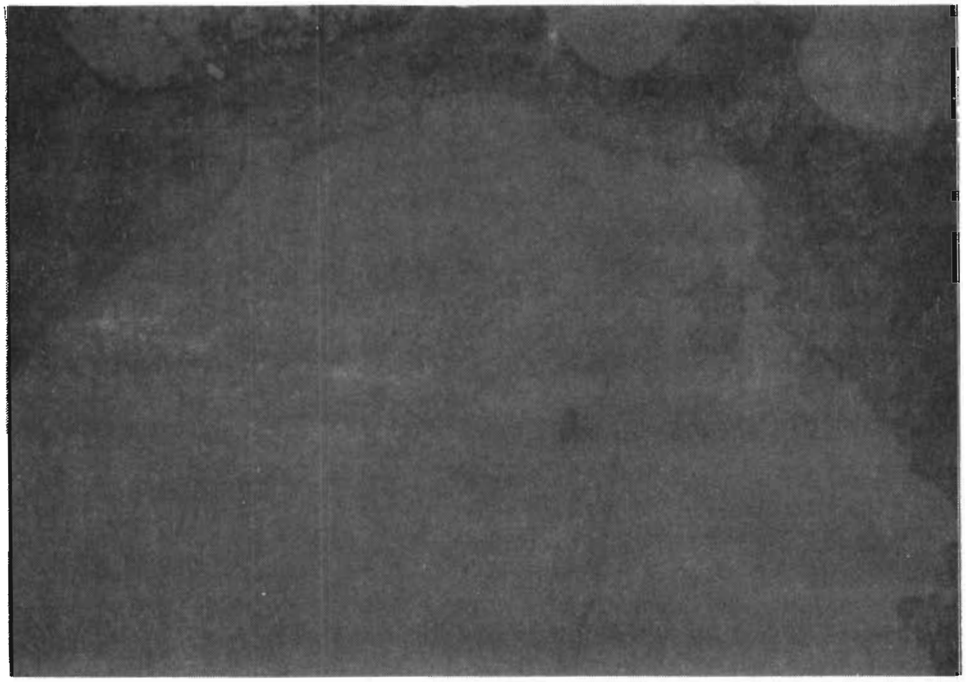


Fig. 50 Cracked aggregate particle

Fig. 51 Both aggregate particle and paste cracked

Fig. 52 Cracked mortar bar surface covered with white deposit

ash reduces the expansion. No trends were observed when the reaction was monitored with time on samples from the same mortar bar. This was the most probable result, though, since an x-ray diffraction analysis shows mainly qualitative content of minerals. In other words, it will show the change with time of the total amount of alkalies present in the sample. Thus, a differentiation between the changes due to a normal hydration process and changes produced by the alkali-aggregate reaction or by the action of fly ash upon alkali-agregate reaction would be unlikely to be observed. Other methods as the EDAX technique using SEM, scanning electron microscope, were not considered. Chemical analyses were suspended as soon as enough evidence showed that no useful information was being provided by the analysis results.

5.7 Specimen Age

Some researchers have conducted the Mortar Bar Test, ASTM C227, using a 14-day exposure period. For this purpose a limit of expansion at 14 days of 0.02% has been suggested.

For a high alkali cement mix using different percentages of the highest alkali fly ash, the reaction at 14 days would have been called innocuous, as can be observed in Fig. 53. In that figure it can be noticed that it was not until 30 days of testing that the behavior of the different fly ash replacements could be differentiated. None of them could have been compared with the safe expansion limit at 90 days based on results at previous time periods. In other words, the mortar bar expansion is not linear with time.

The same is true for predicting the effect of using different types of fly ash as Fig. 54 illustrates.

For low alkali cement the specimen age is even more critical because expansions at early ages are very small. For example, a mortar bar made with medium reactive aggregate and low alkali cement with 28% high alkali fly ash B replacement, expanded only 0.01% at 14 days, but at 90 days the expansion was of the order of 0.048%, almost the 0.05% expansion limit for 90 days.

The same is observed for all types of aggregates and can only be related to the fact that the alkali-aggregate reaction is a very slow reaction. Although ASTM C227 was conceived to give accelerated results, its correlation with the reaction in real structures under non-controlled environment has created doubts on its validity among concrete researchers.

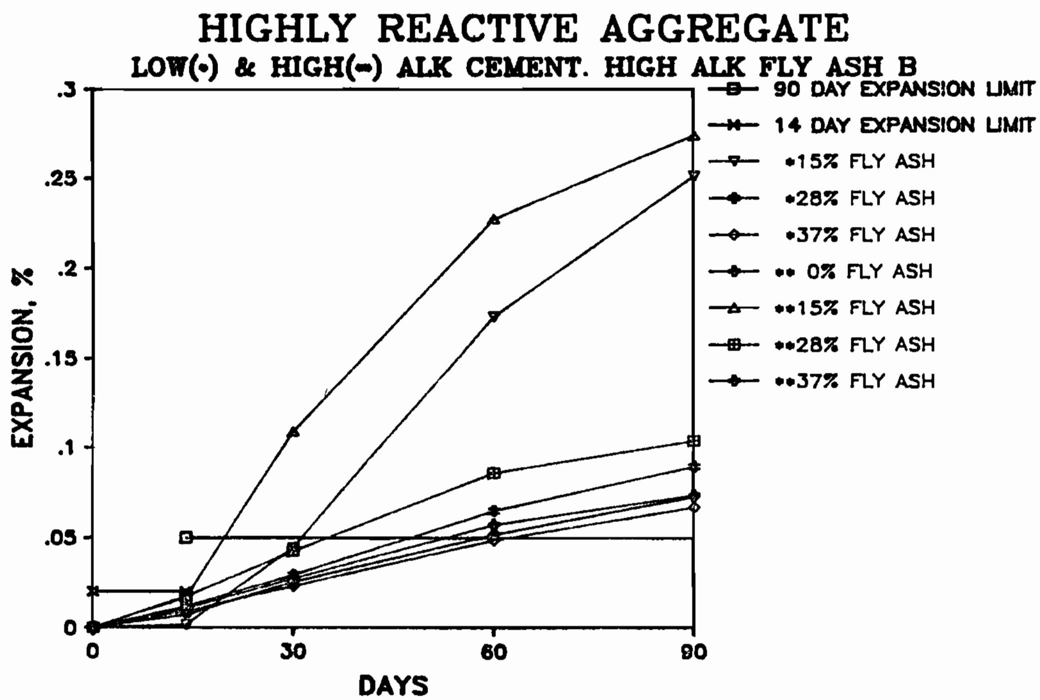


Fig. 53 Percentage of expansion vs time for all mixes made with highly reactive aggregate and high alkali Type B fly ash

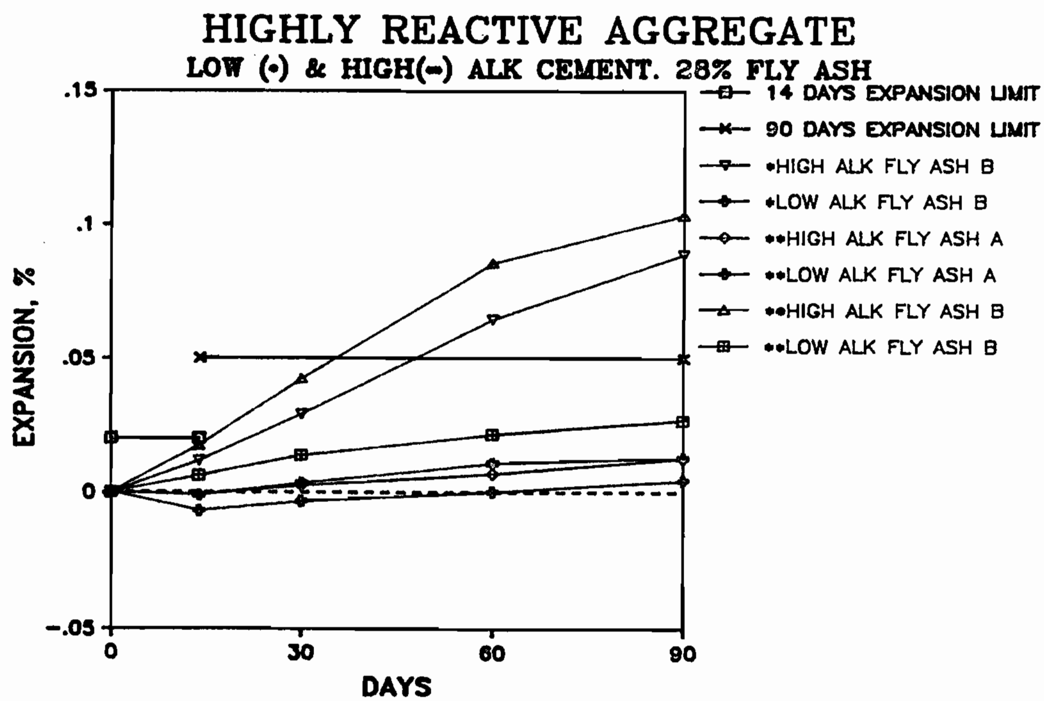


Fig. 54 Percentage of expansion vs time for all mixes made with highly reactive aggregate containing 28% fly ash

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

5. The available alkalies contained in the fly ash do participate in the alkali-aggregate reaction in concrete, regardless of fly ash type

6. Calcium content of the fly ash seems to have a negligible effect on alkali-aggregate reaction in concrete

7. When the available alkali content of fly ash is less than 1.7% its beneficial effect in preventing expansion due to alkali-aggregate reaction increases as the percentage of cement replaced increases, regardless of fly ash type

8. As the available alkali content of fly ash increases, there is a minimum percentage of cement replaced below which the fly ash causes expansions larger than those of a mix without fly ash, and above which the fly ash causes smaller expansions. This minimum is known as the pessimum limit

9. For fly ash mixes which exhibit a pessimum limit, the lower the available alkali content of the cement the higher the pessimum limit, and vice-versa

10. Minimum percentage of replacement, rather than the 1.5% maximum available alkali content specified by both ASTM and TSDHPT, is the factor defining the effectiveness of fly ash replacement to prevent deleterious expansions in concrete due to alkali-aggregate reaction

11. The minimum period of time to conduct the ASTM C227 to provide accurate information is 90 days

6.3 Recommendations.

Based on the test results of this project, the following recommendations can be suggested to practicing engineers:

1. Unless an aggregate has been proven to be non-alkali-reactive, always use fly ash replacement of the cement, regardless of the cement alkali content

2. When using an aggregate classified as alkali-reactive, or when using aggregate of unknown reactivity, replace a minimum 28% of the weight of cement by fly ash with less than 1.7% available alkali content

3. If the available fly ash contains considerably more than 1.7% available alkalies, a percentage of cement replaced of more than 50% is suggested

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.

13. Diamond, Sidney. "Effects of Two Danish Flyashes on Alkali Contents of Pore Solutions of Cement-Flyash Pastes," Cement and Concrete Research, Vol. 11, No. 3, 1981, pp. 383-394.

14. Dent Glasser, L.S. and Kataoka, N. "The Chemistry of Alkali-Aggregate Reaction," Cement and Concrete Research, Vol. 11, No. 1, 1981, pp. 1-9.

15. Samuel, George et al. "Alkali-Silica Reaction in Concrete," Proceedings of the Sixth International Conference on Cement Microscopy, March 26-29, 1984, Albuquerque, NM, pp. 277-291.

16. Pettifer, K. and Nixon, P.J. "Alkali-Metal Sulphate-A Factor Common to Both Alkali-Aggregate Reaction and Sulphate Attack on Concrete," Cement and Concrete Research, Vol. 10, No. 2, 1980, pp. 173-181.

17. Cain, Craig J. "Fly Ash - A New Resource Material," Concrete, November 1983, pp. 28-32.

18. Albinger, John M. "Fly Ash for Strength and Economy," Concrete International, April 1984, pp. 32-34.

19. Popovics, Sandor. "Strength Relationships for Fly Ash Concrete," ACI Journal, January-February 1982, pp. 43-49.

20. Malhotra, V.M. "Use of Mineral Admixtures for specialized Concretes," Concrete International, April 1984, pp. 19-24.

21. Dunstan, Jr., E.R. "The Effect of Fly Ash on Concrete Alkali-Aggregate Reaction," Cement, Concrete and Aggregates, CCAGDP, Vol. 3, No. 2, Winter 1981, pp. 101-104.

22. Tang, Ming-shu, Ye, Yu-Feng, Yuan, Mei-qi and Zhen, Shi-hua. "The Preventive Effect of Mineral Admixtures on Alkali-Silica rection and Its Mechanisms," Cement and Concrete Research, Vol. 13, No. 2, 1983, pp. 171-176.

23. Hobbs, D.W. "Possible Influence of Small Additions of PFA, GBFS and Limestone Flour Upon Expansion Caused by the Alkali-Silica Reaction," Magazine of Concrete Research, Vol. 35, No. 122, March 1983, pp. 55-58.

24. Gaze, M.E. and Nixon, P.J. "The Effect of PFA Upon Alkali-Aggregate Reaction," Magazine of Concrete Research, Vol. 35, No. 123, June 1983, pp. 107-110.

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.

36. "ASTM Symposium on Field Description of Coal," Ottawa, 22-23 September, 1976.

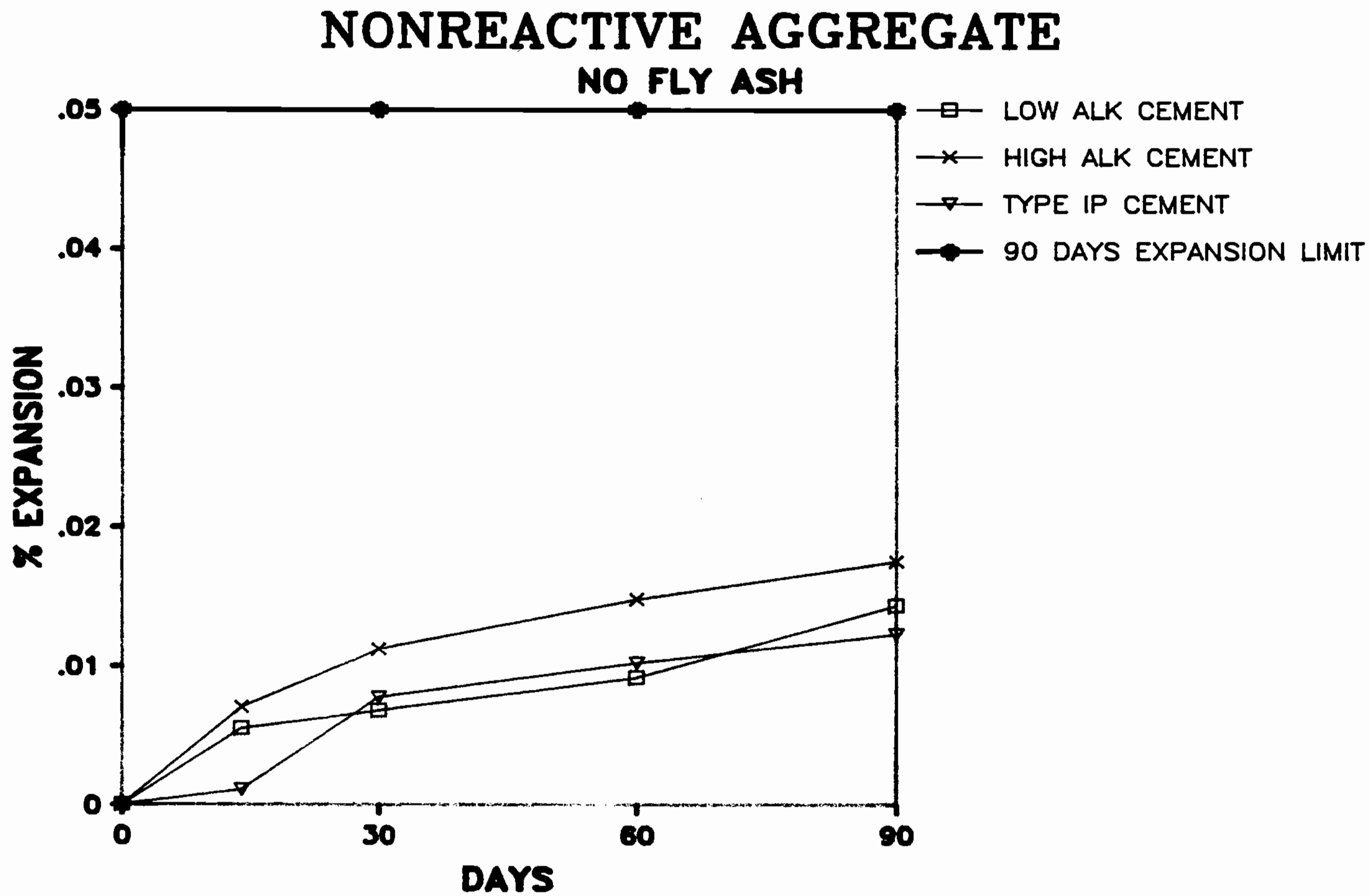
37. Torrey, S. "Coal Ash Utilization," Noyes Data Corporation, New Jersey, 1978.

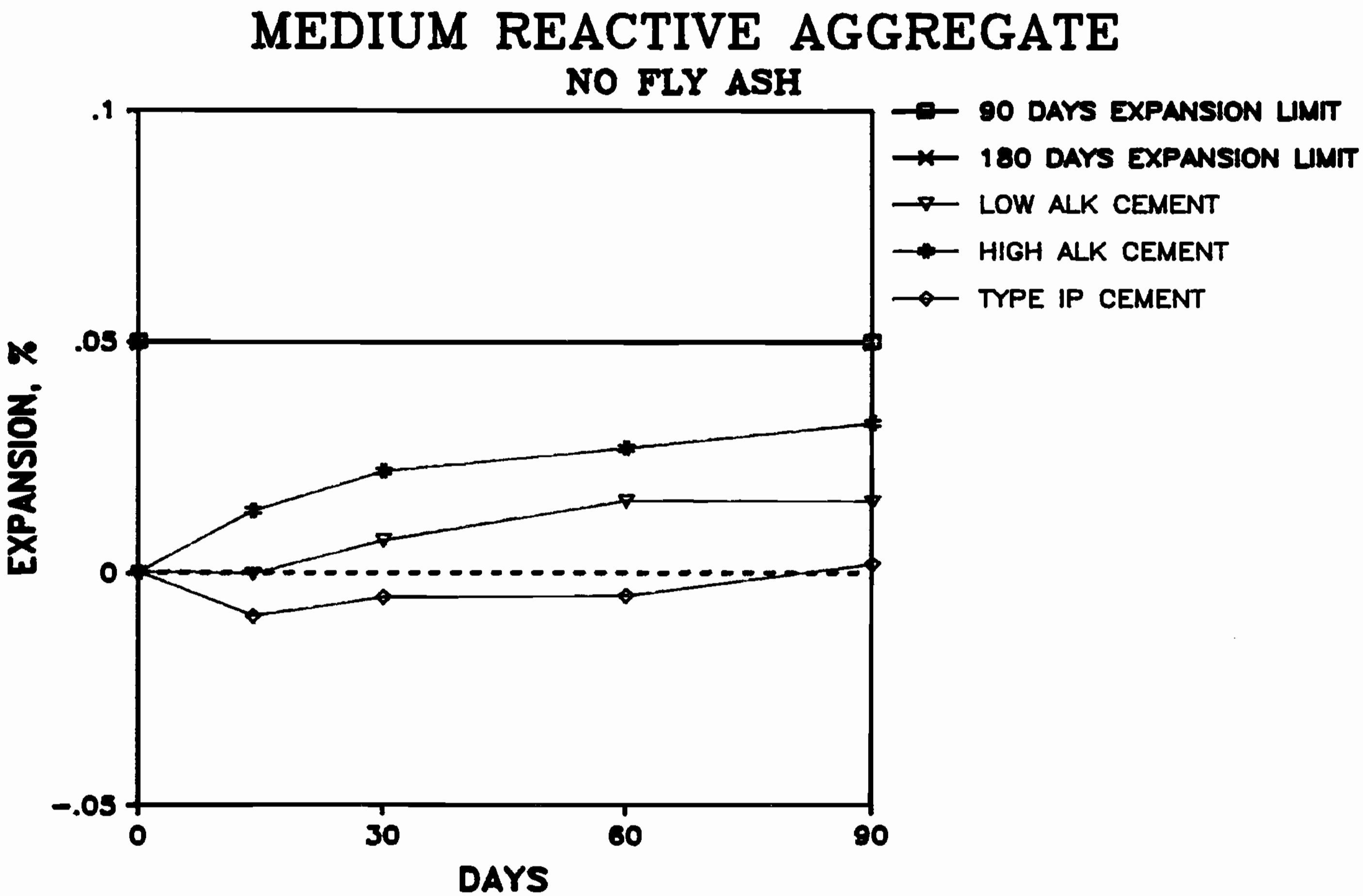
APPENDIX A

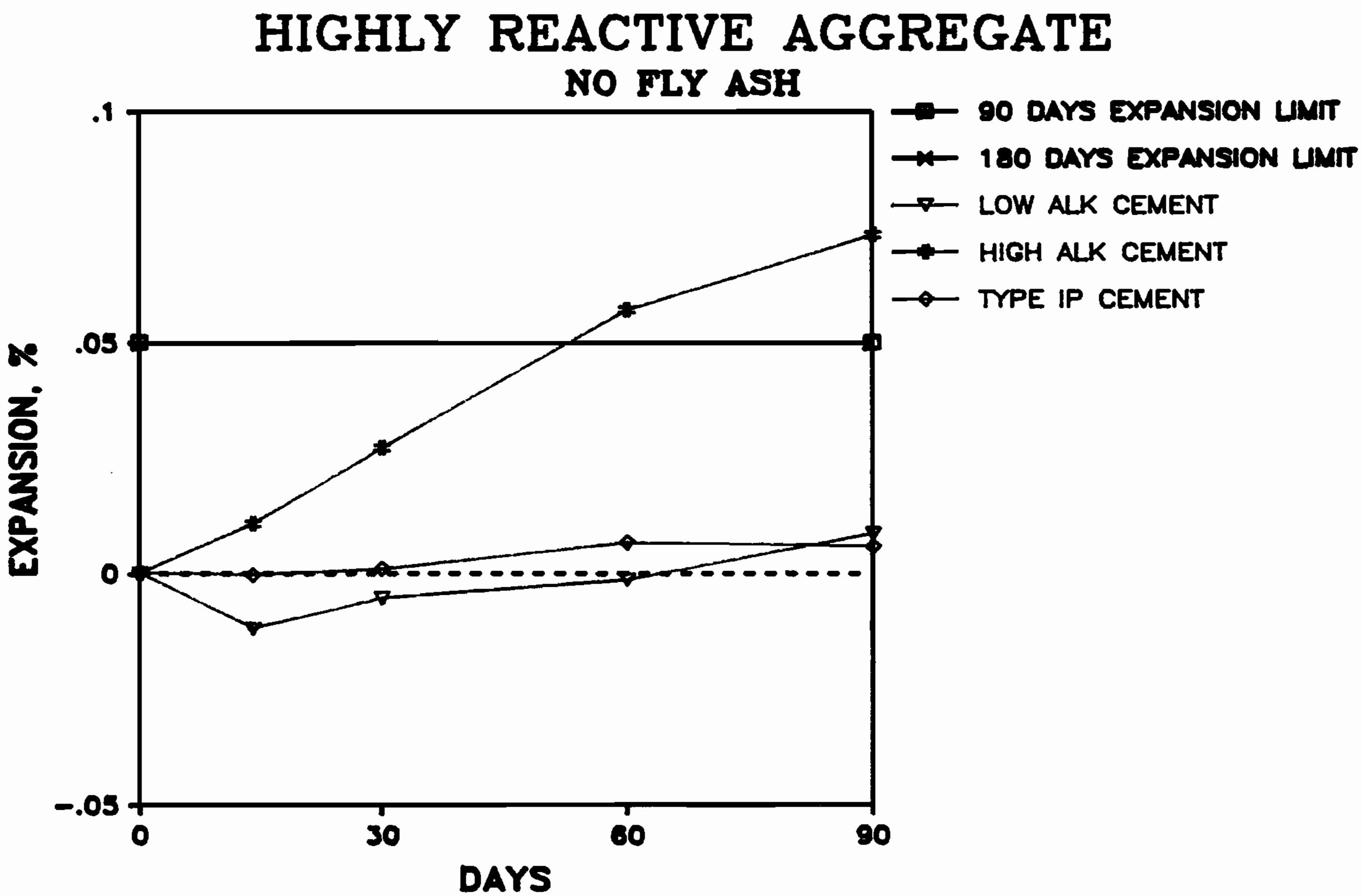
GRAPHS AND TEST RESULT DATA

MIXES WITHOUT FLY ASH

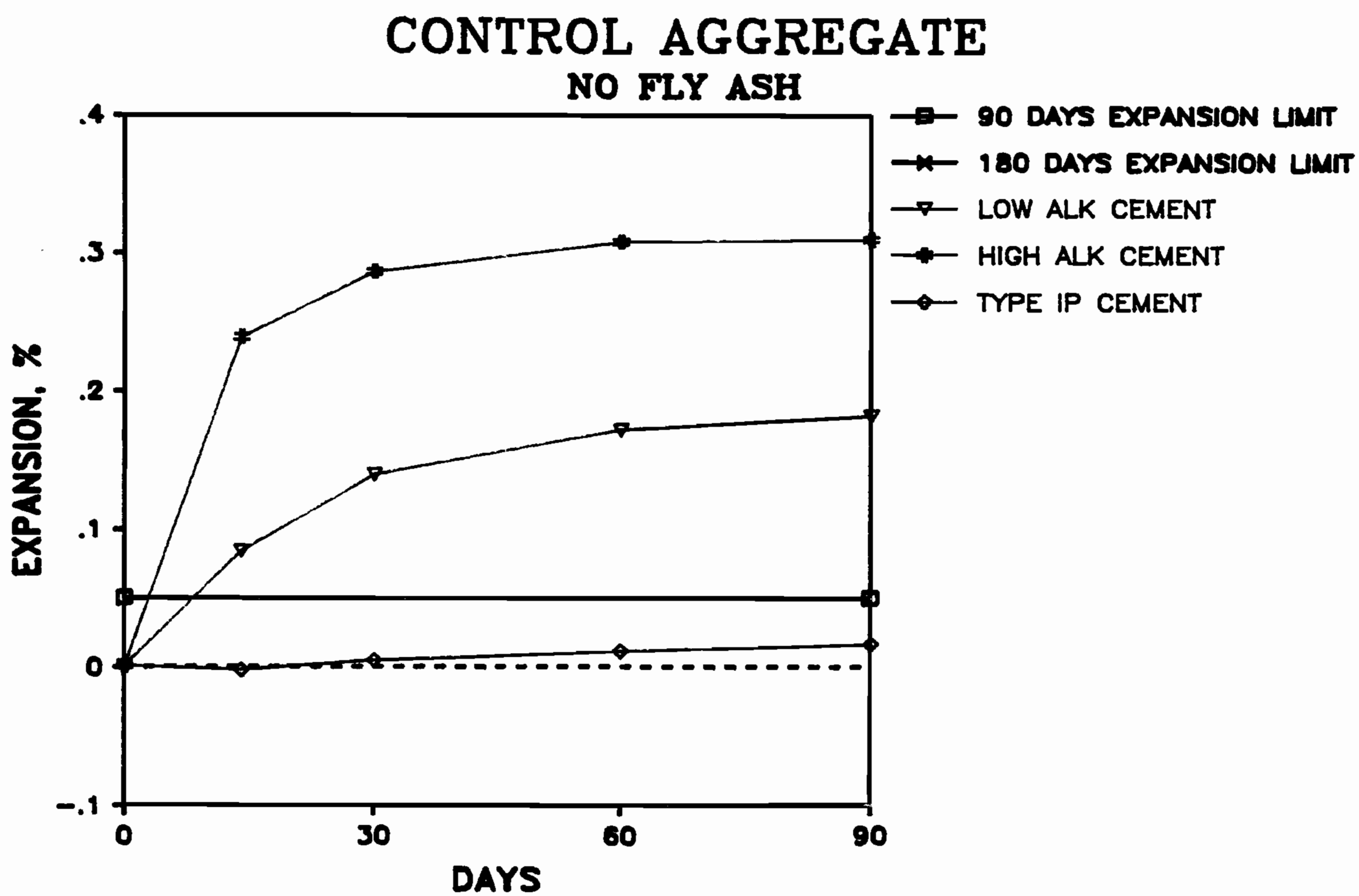
CURVES FOR THE AGGREGATES


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


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

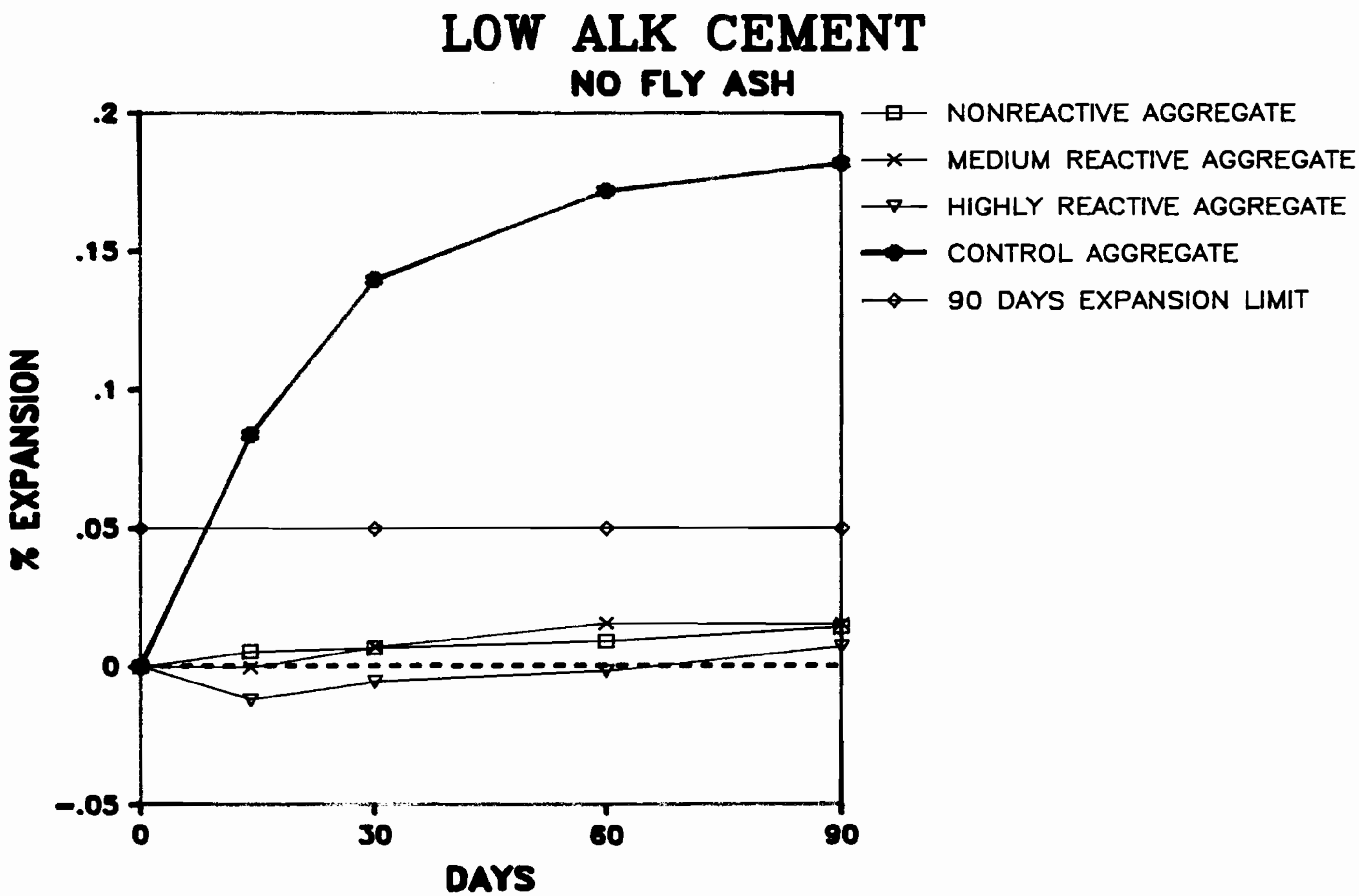


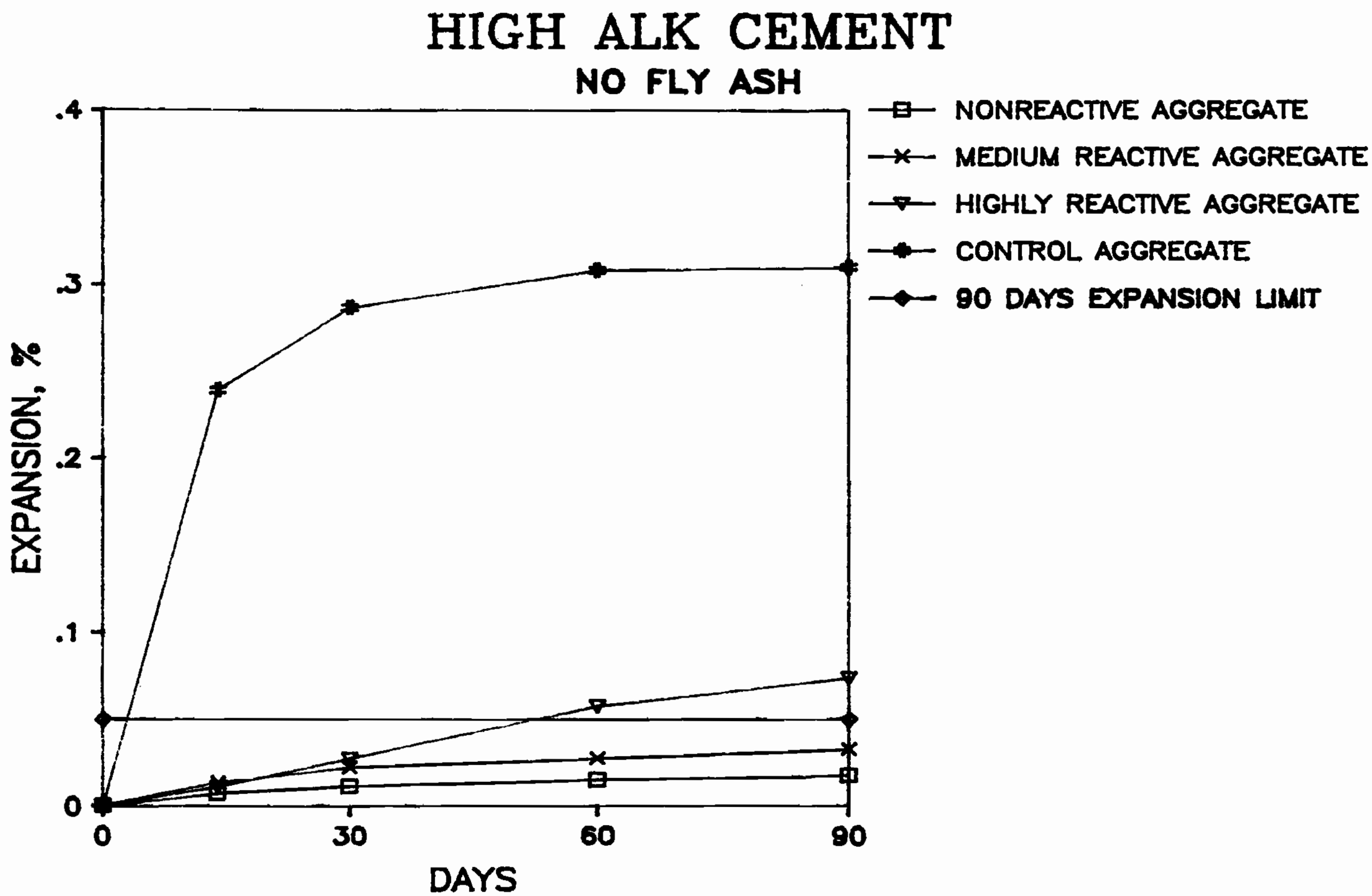
HIGHLY REACTIVE AGGREGATE
NO FLY ASH
90 DAYS EXPANSION LIMIT
180 DAYS EXPANSION LIMIT
LOW ALK CEMENT
HIGH ALK CEMENT
TYPE IP CEMENT
EXPANSION, %
.1
.05
0
-.05
0
30
60
90
DAYS

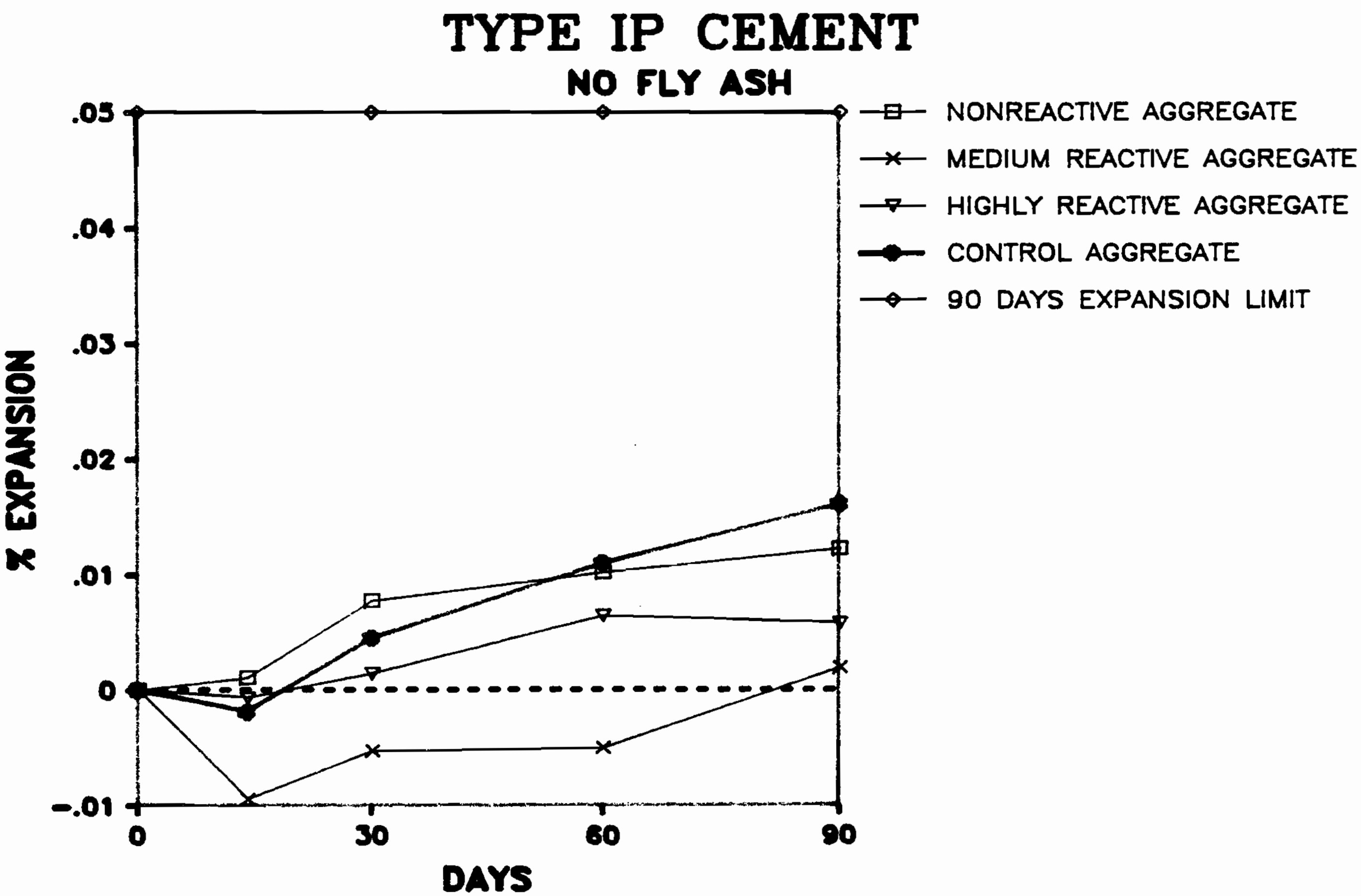

CONTROL AGGREGATE
NO FLY ASH
.4
.3
.2
.1
0
-.1
EXPANSION, %
0
30
60
90
DAYS
90 DAYS EXPANSION LIMIT
180 DAYS EXPANSION LIMIT
LOW ALK CEMENT
HIGH ALK CEMENT
TYPE IP CEMENT

MIXES WITHOUT FLY ASH

CURVES FOR THE CEMENTS


LOW ALK CEMENT
NO FLY ASH
NONREACTIVE AGGREGATE
MEDIUM REACTIVE AGGREGATE
HIGHLY REACTIVE AGGREGATE
CONTROL AGGREGATE
90 DAYS EXPANSION LIMIT
% EXPANSION
.2
.15
.1
.05
0
-.05
0
30
60
90
DAYS


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


TYPE IP CEMENT
NO FLY ASH
.05
.04
.03
.02
.01
0
-.01
% EXPANSION
0
30
60
90
DAYS
NONREACTIVE AGGREGATE
MEDIUM REACTIVE AGGREGATE
HIGHLY REACTIVE AGGREGATE
CONTROL AGGREGATE
90 DAYS EXPANSION LIMIT

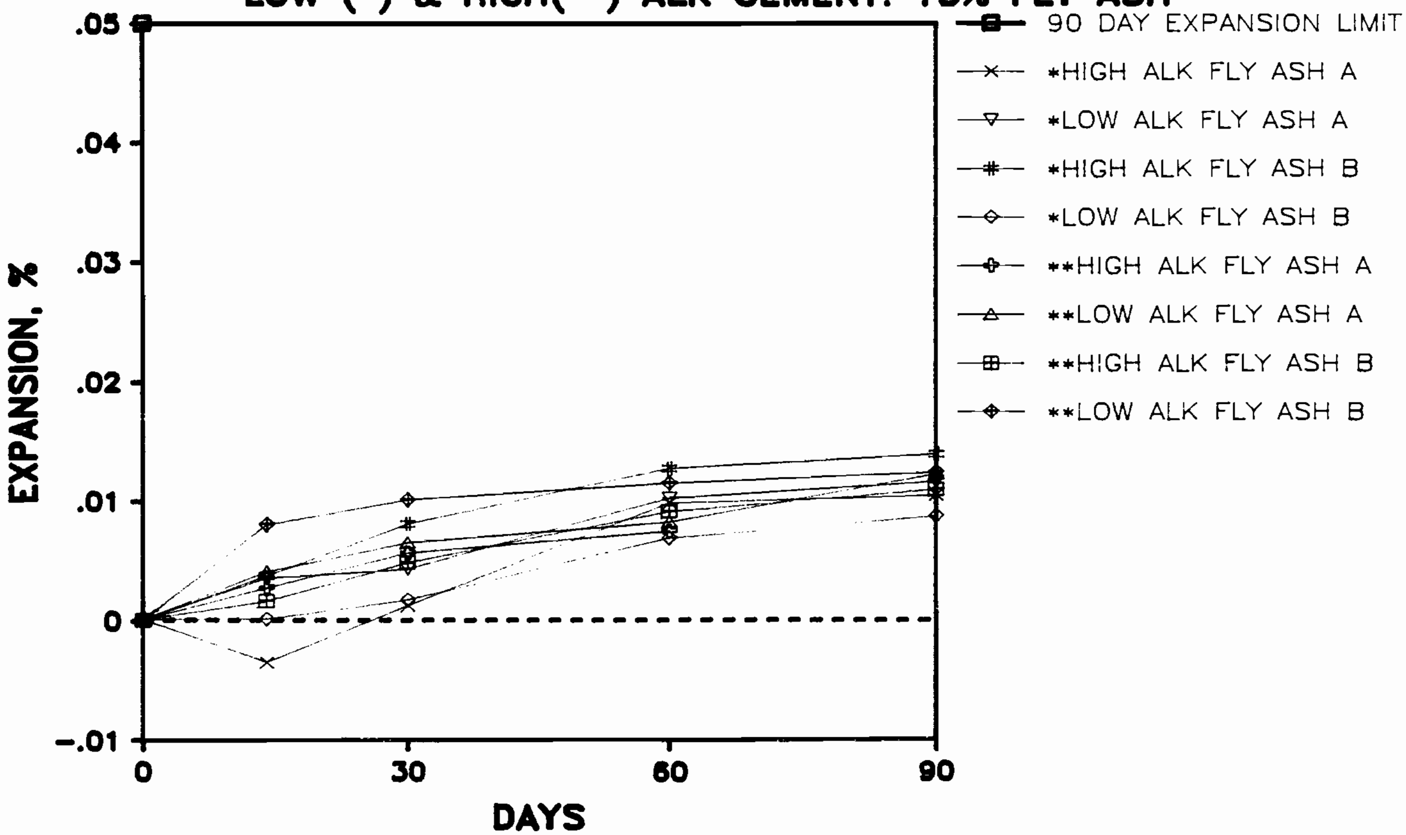
MIXES CONTAINING FLY ASH

ALL TYPES OF FLY ASH FOR EACH AGGREGATE

AND EACH FLY ASH REPLACEMENT

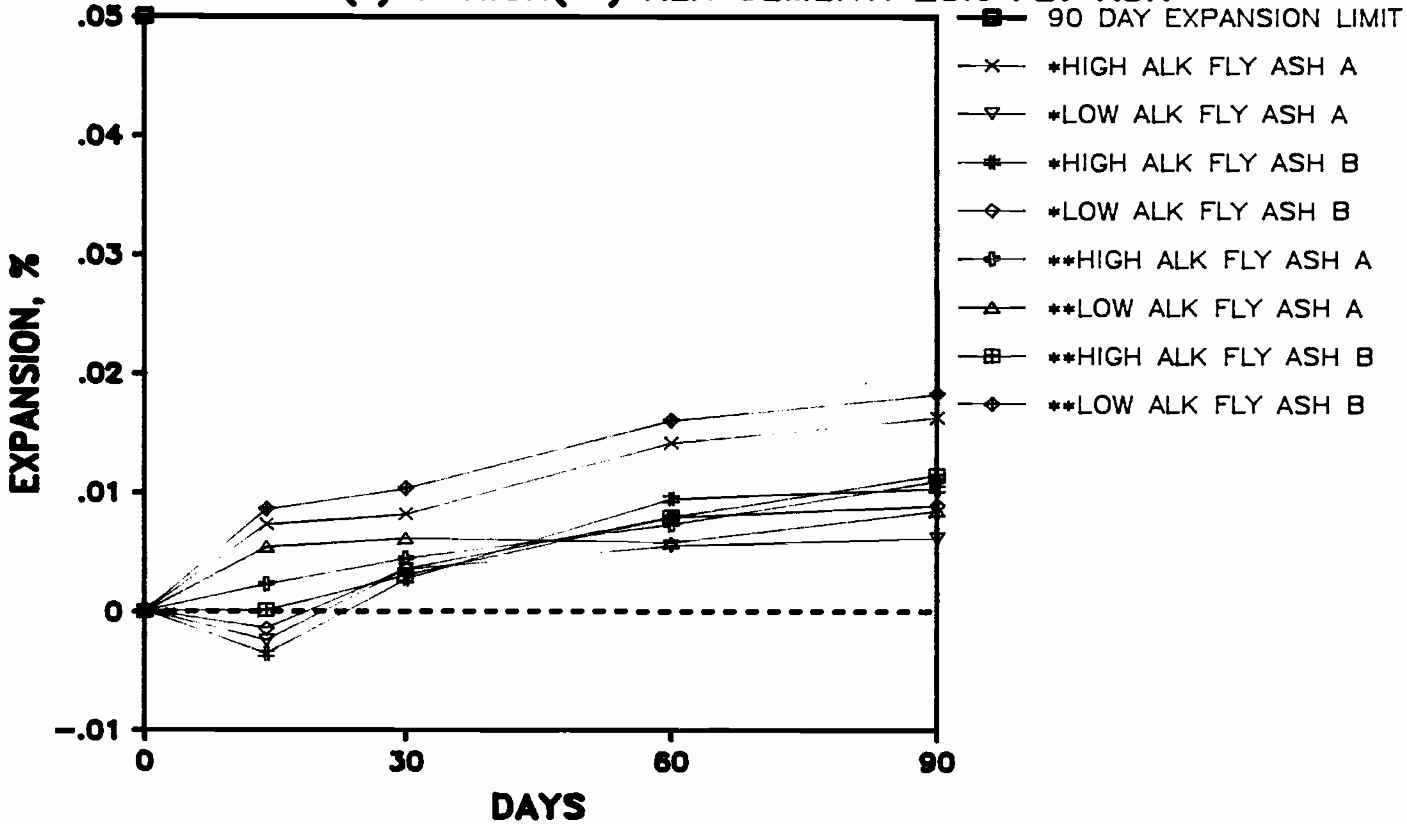
NONREACTIVE AGGREGATE

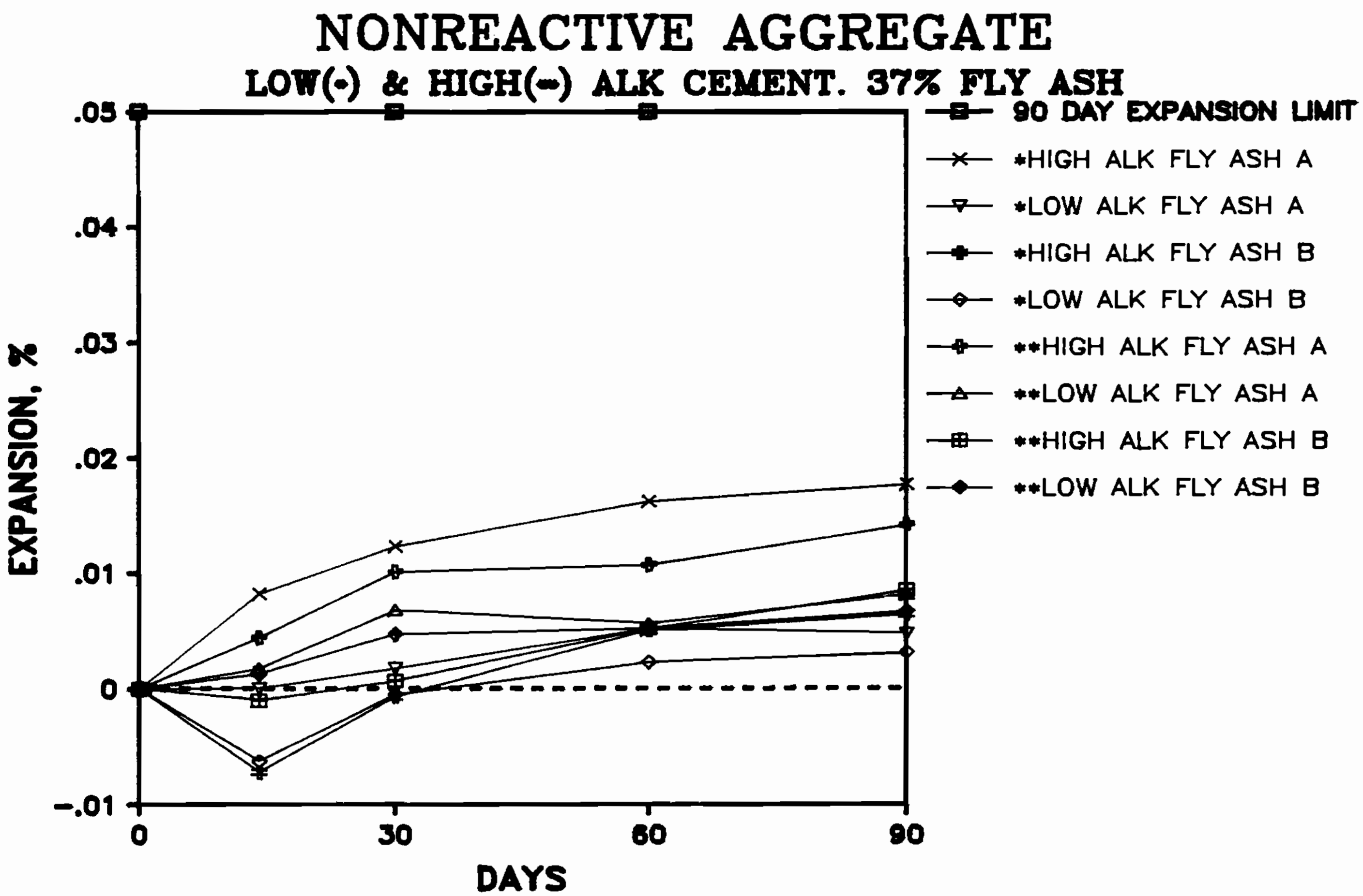
LOW (*) & HIGH(**) ALK CEMENT. 15% FLY ASH



NONREACTIVE AGGREGATE

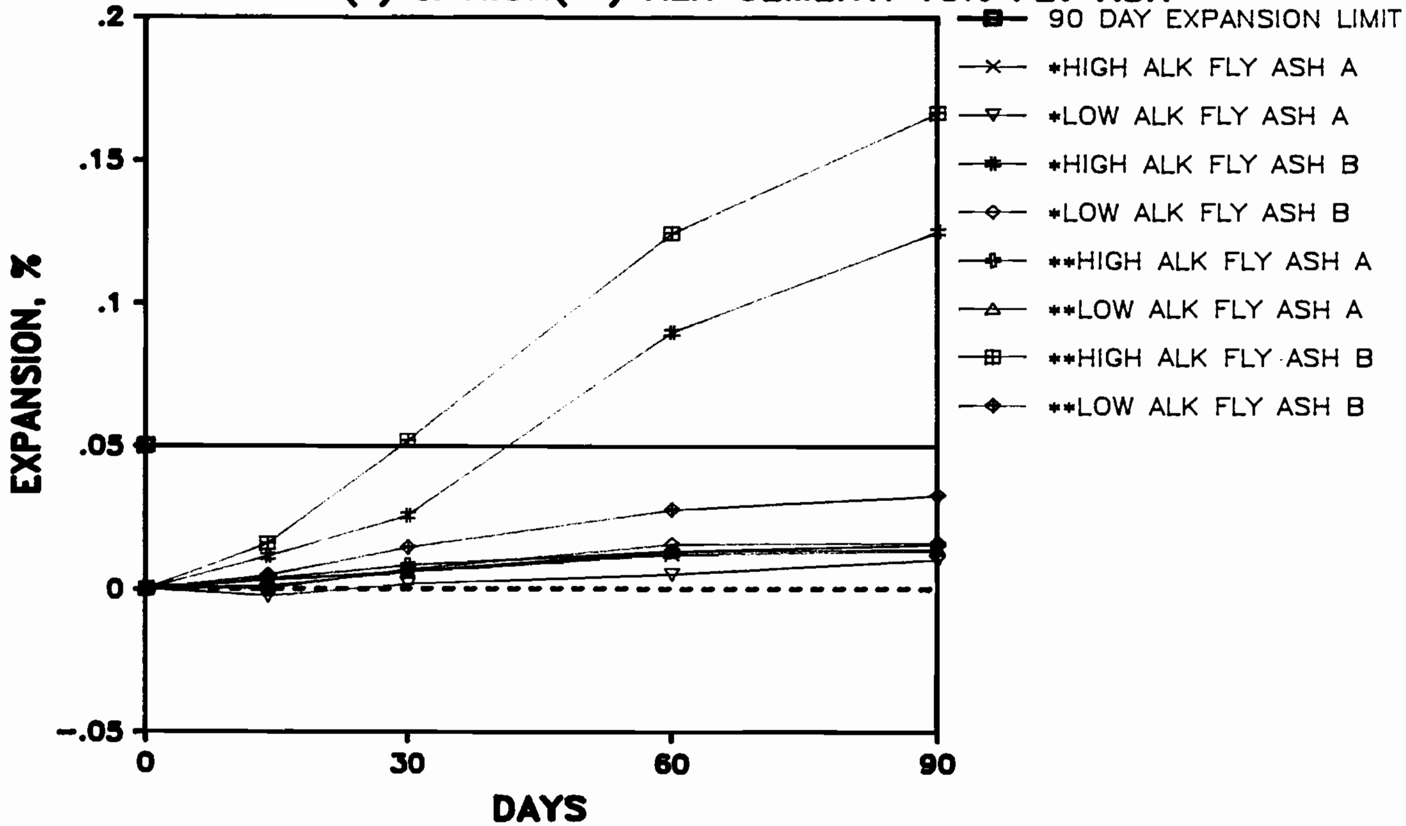
LOW (*) & HIGH(**) ALK CEMENT. 28% FLY ASH




NONREACTIVE AGGREGATE
LOW(*) & HIGH(**) ALK CEMENT. 37% FLY ASH
EXPANSION, %
.05
.04
.03
.02
.01
0
-.01
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

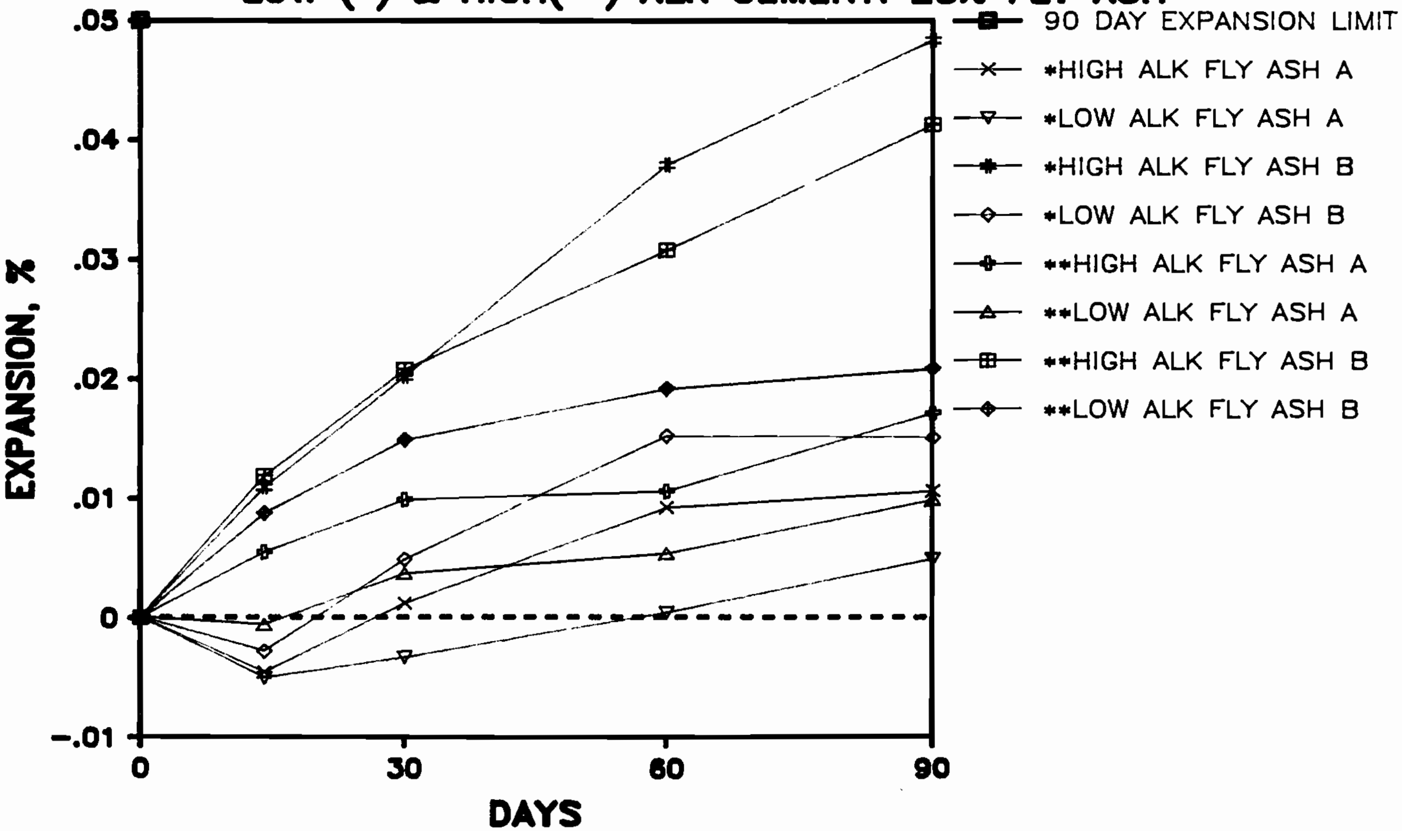
MEDIUM REACTIVE AGGREGATE

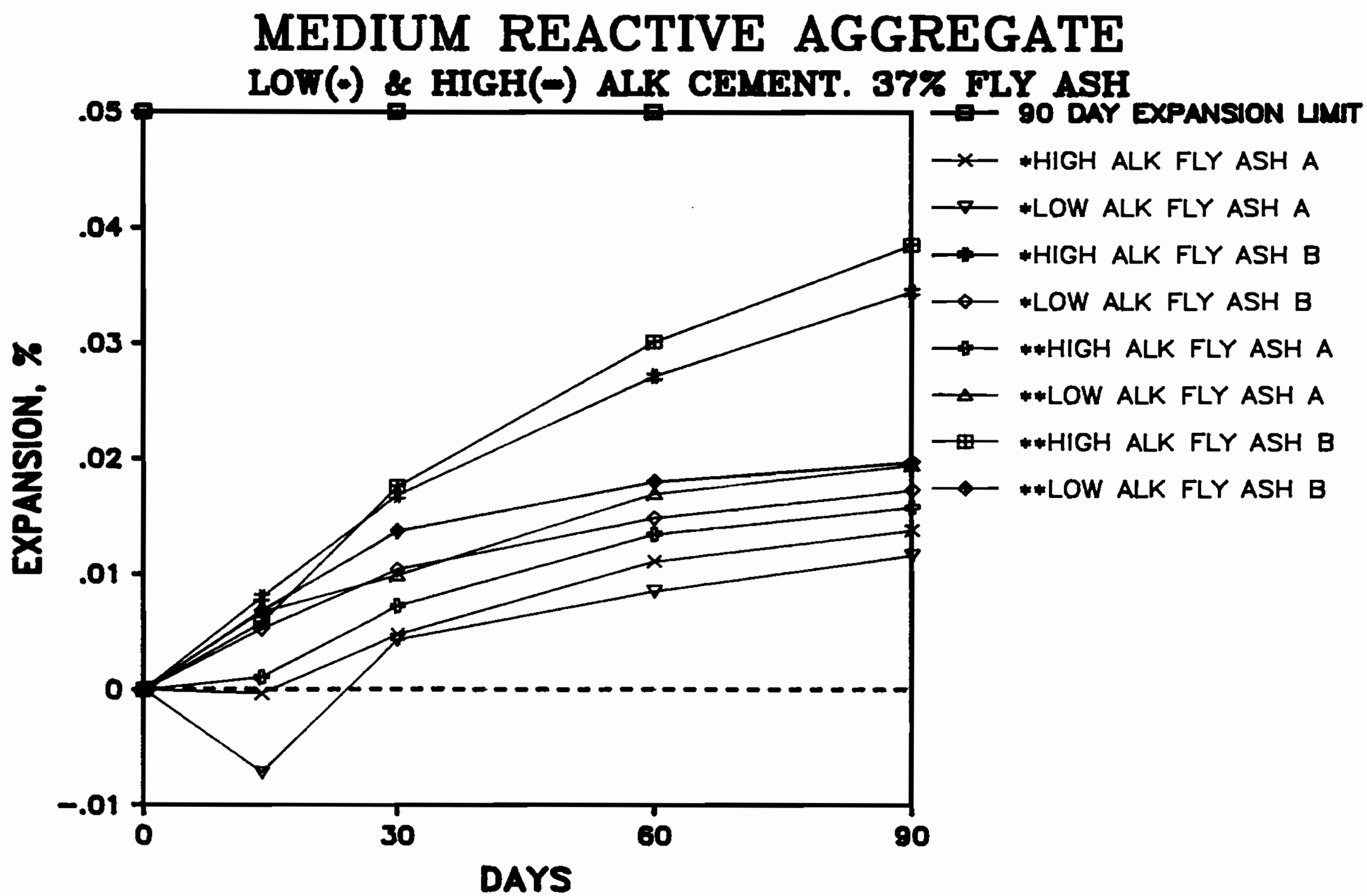
LOW (*) & HIGH(**) ALK CEMENT. 15% FLY ASH



MEDIUM REACTIVE AGGREGATE

LOW (*) & HIGH(**) ALK CEMENT. 28% FLY ASH

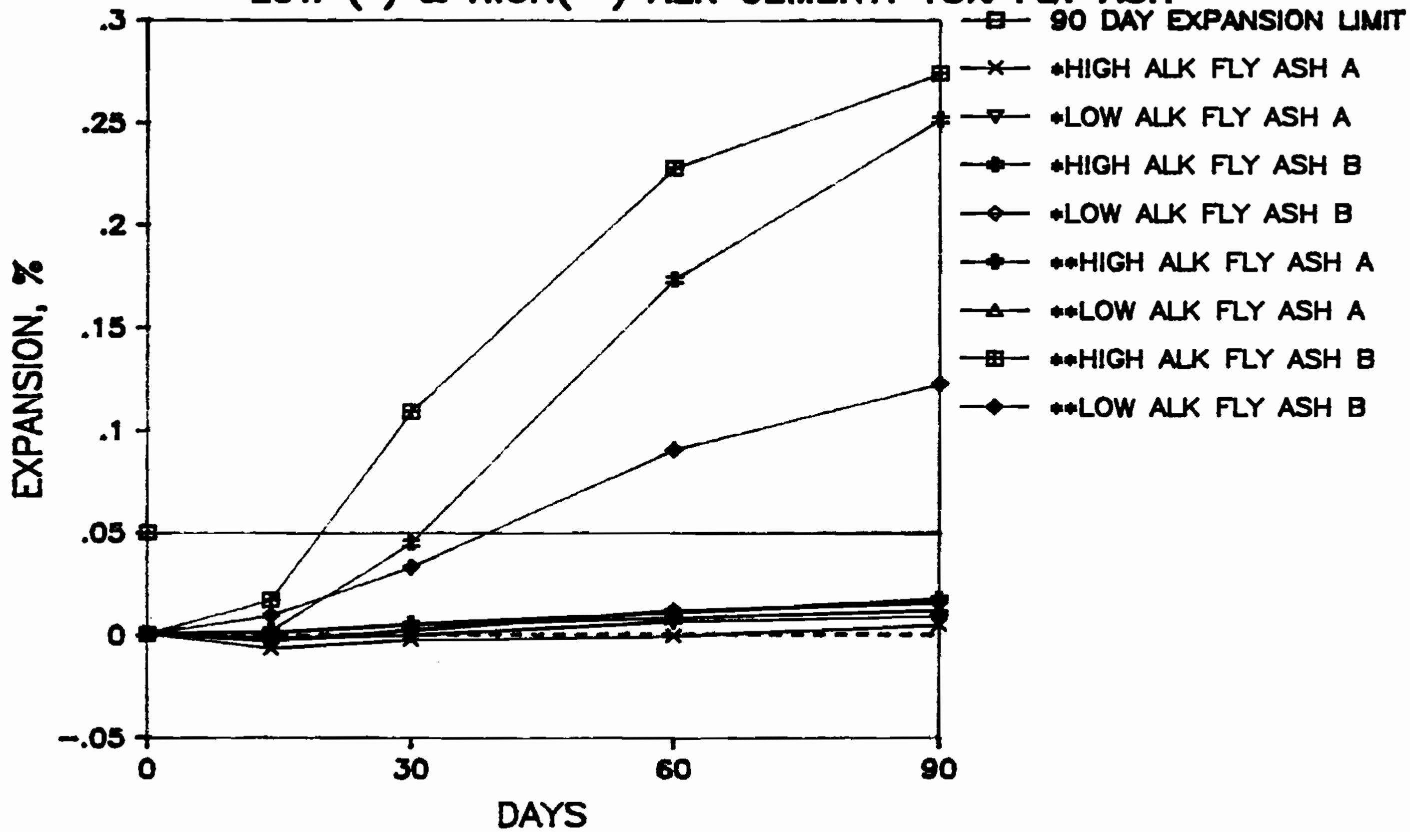


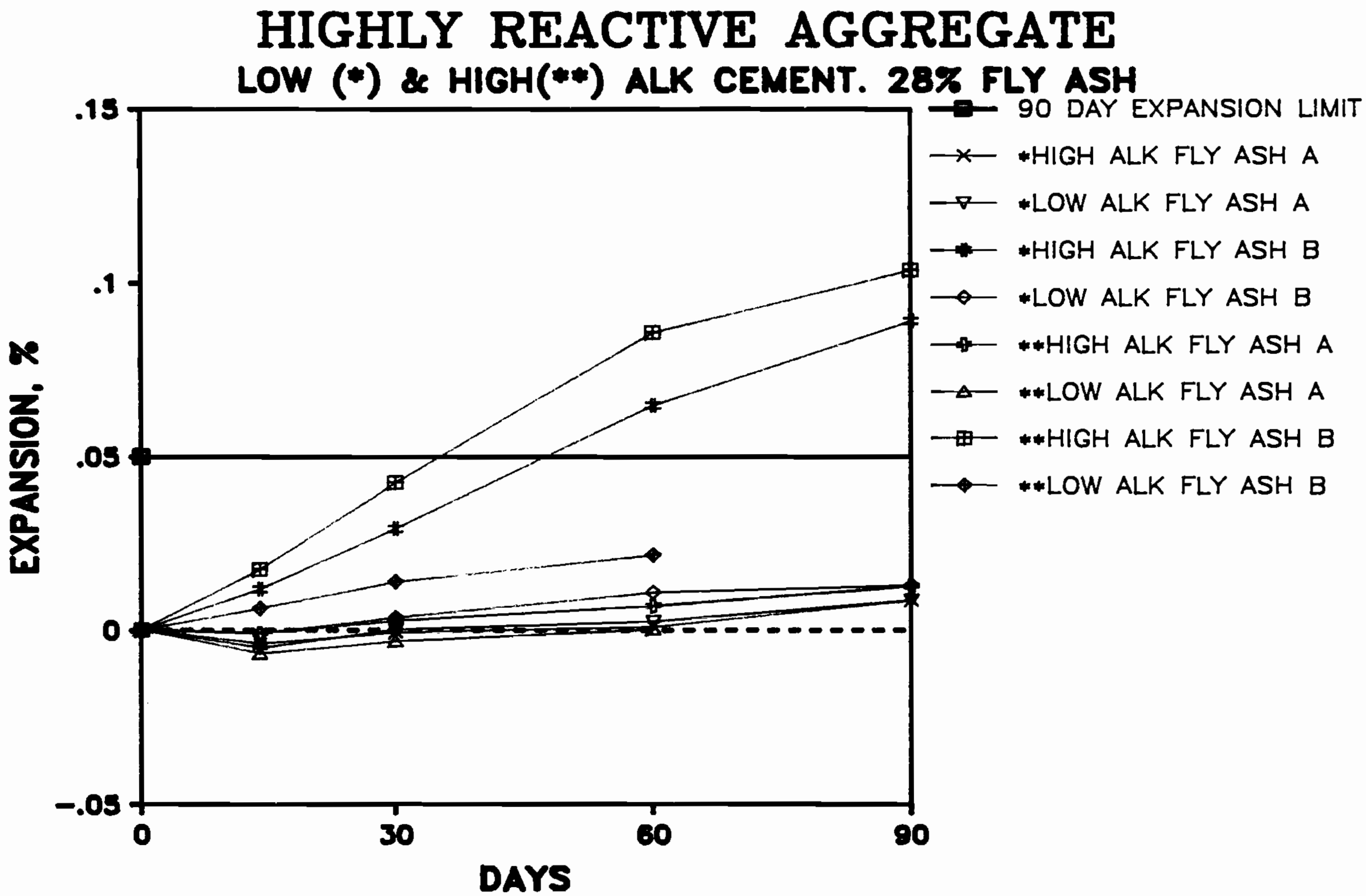


MEDIUM REACTIVE AGGREGATE
LOW(-) & HIGH(=) ALK CEMENT. 37% FLY ASH
EXPANSION, %
.05
.04
.03
.02
.01
0
-.01
0
30
60
90
DAYS
90 DAY EXPANSION LIMIT
*HIGH ALK FLY ASH A
*LOW ALK FLY ASH A
*HIGH ALK FLY ASH B
*LOW ALK FLY ASH B
**HIGH ALK FLY ASH A
**LOW ALK FLY ASH A
**HIGH ALK FLY ASH B
**LOW ALK FLY ASH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

HIGHLY REACTIVE AGGREGATE

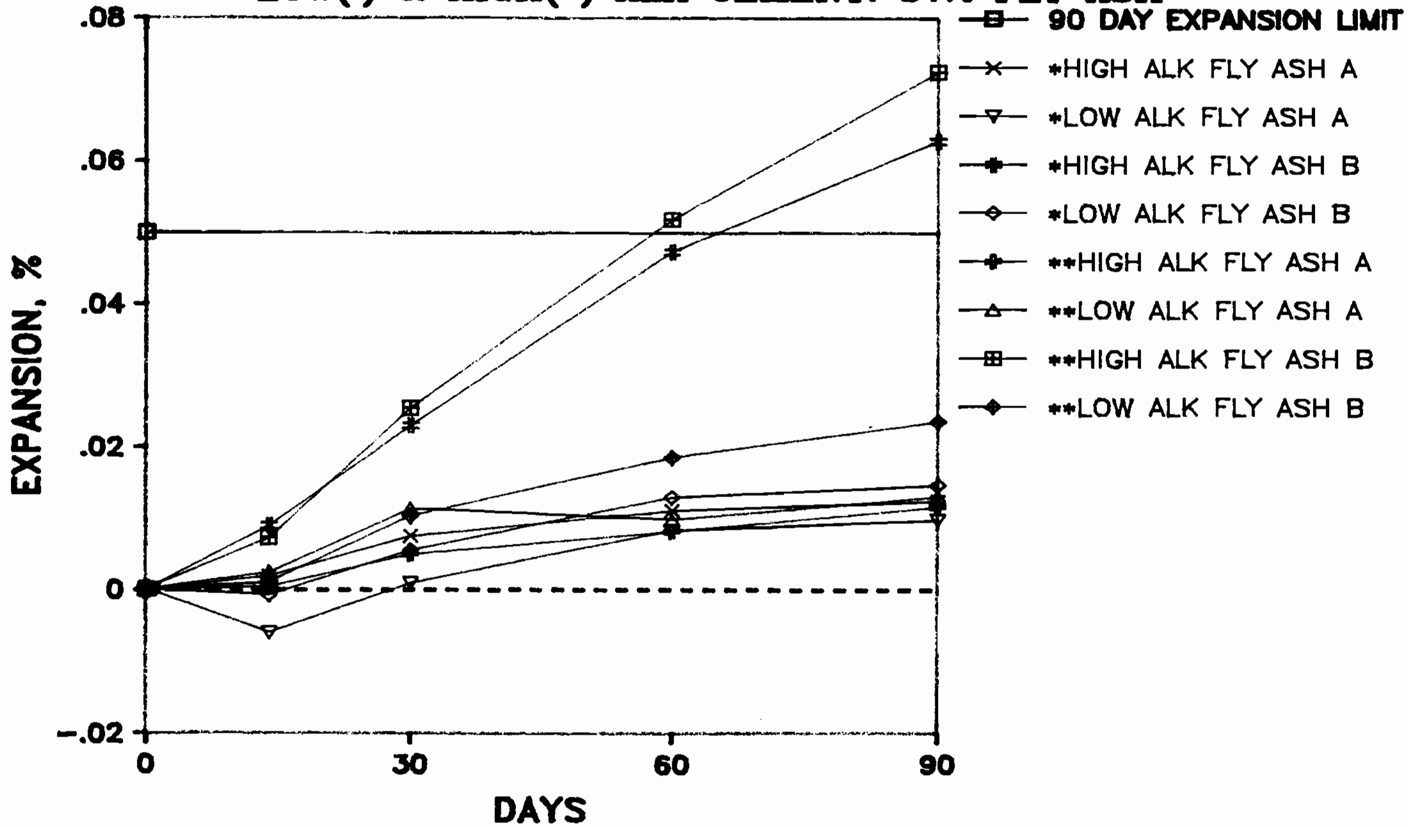
LOW (*) & HIGH(**) ALK CEMENT. 15% FLY ASH

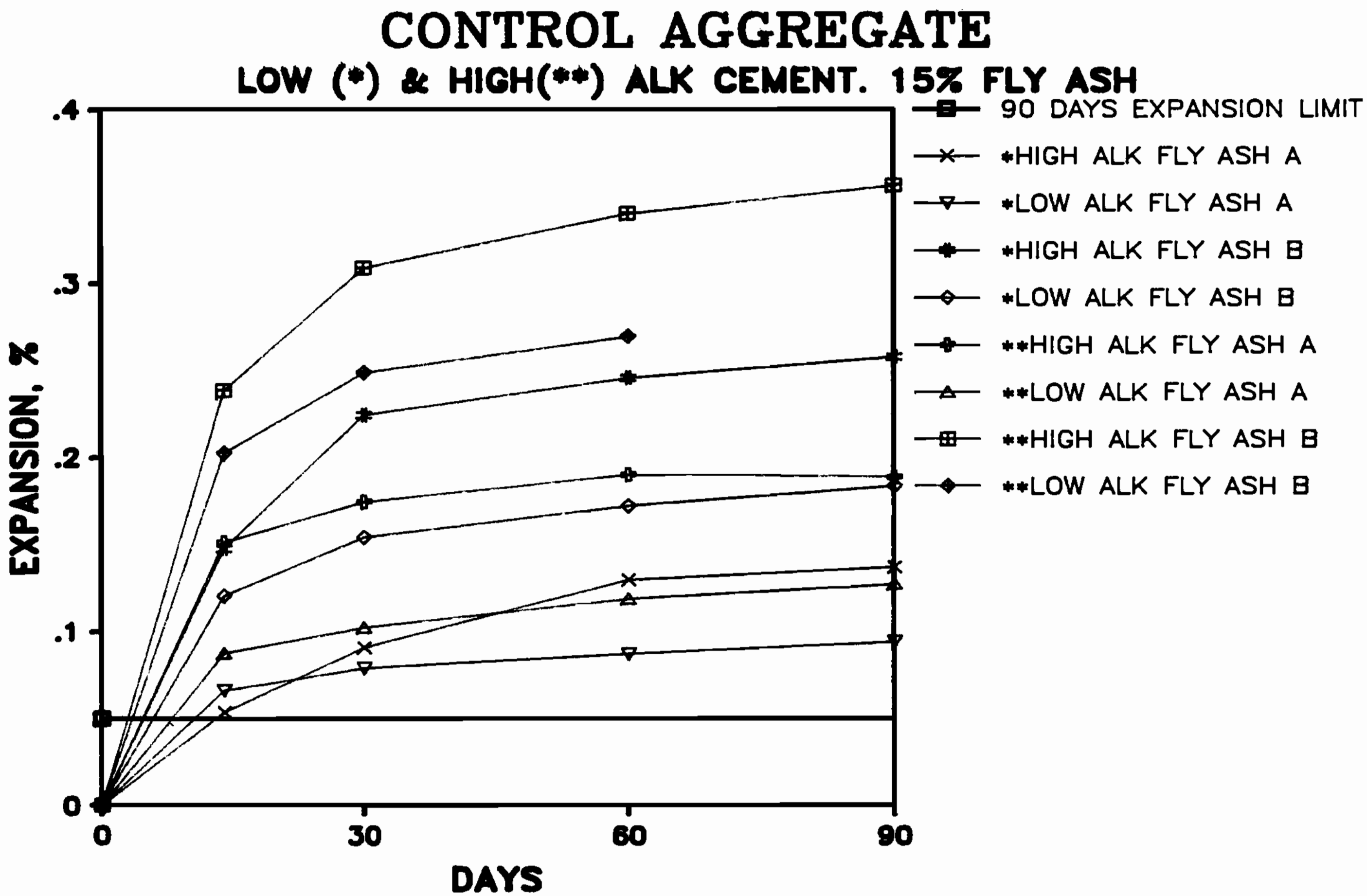



HIGHLY REACTIVE AGGREGATE
LOW (*) & HIGH(**) ALK CEMENT. 28% FLY ASH
.15
.1
.05
0
-.05
EXPANSION, %
0
30
60
90
DAYS
90 DAY EXPANSION LIMIT
*HIGH ALK FLY ASH A
*LOW ALK FLY ASH A
*HIGH ALK FLY ASH B
*LOW ALK FLY ASH B
**HIGH ALK FLY ASH A
**LOW ALK FLY ASH A
**HIGH ALK FLY ASH B
**LOW ALK FLY ASH B

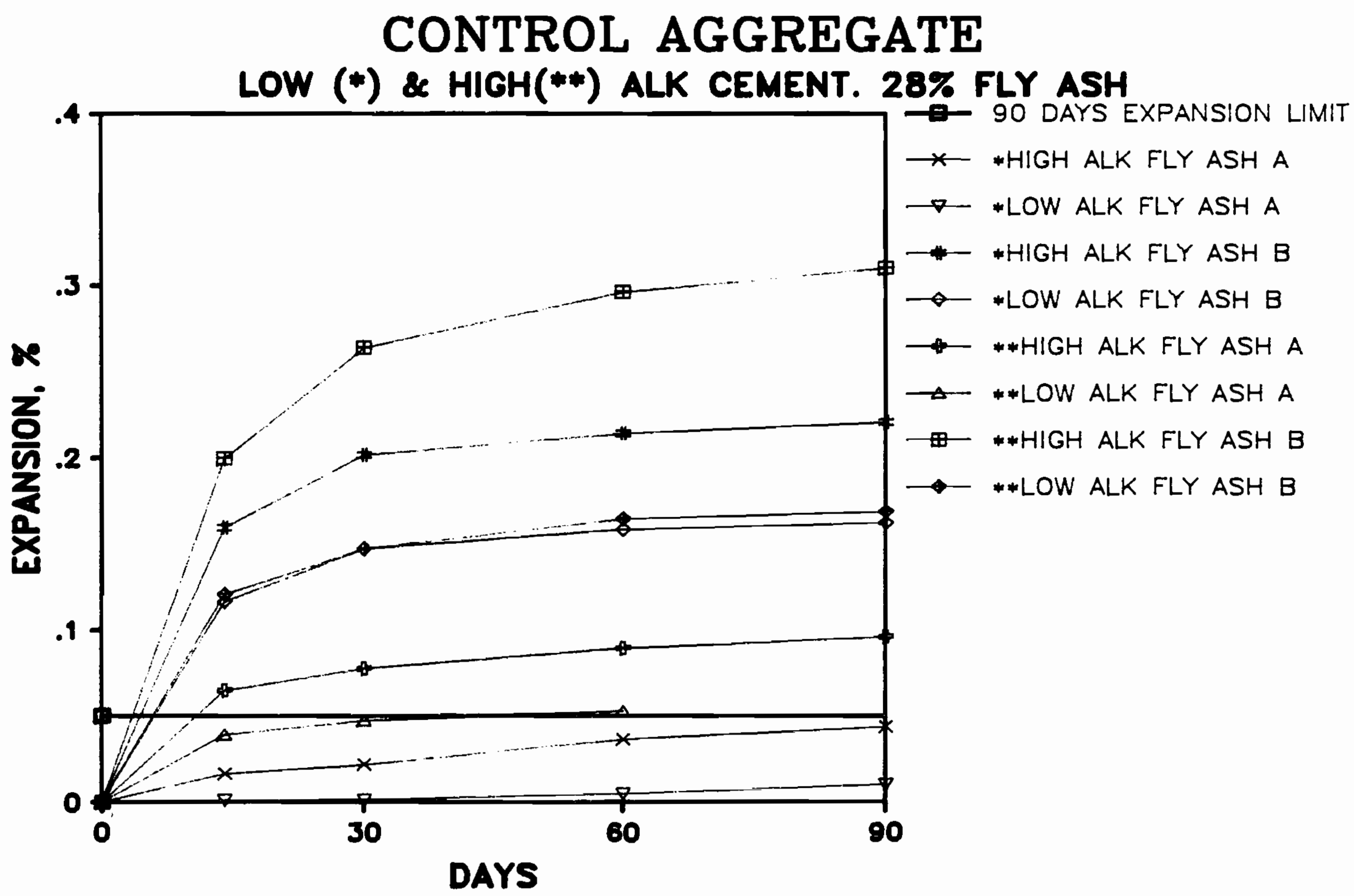
HIGHLY REACTIVE AGGREGATE

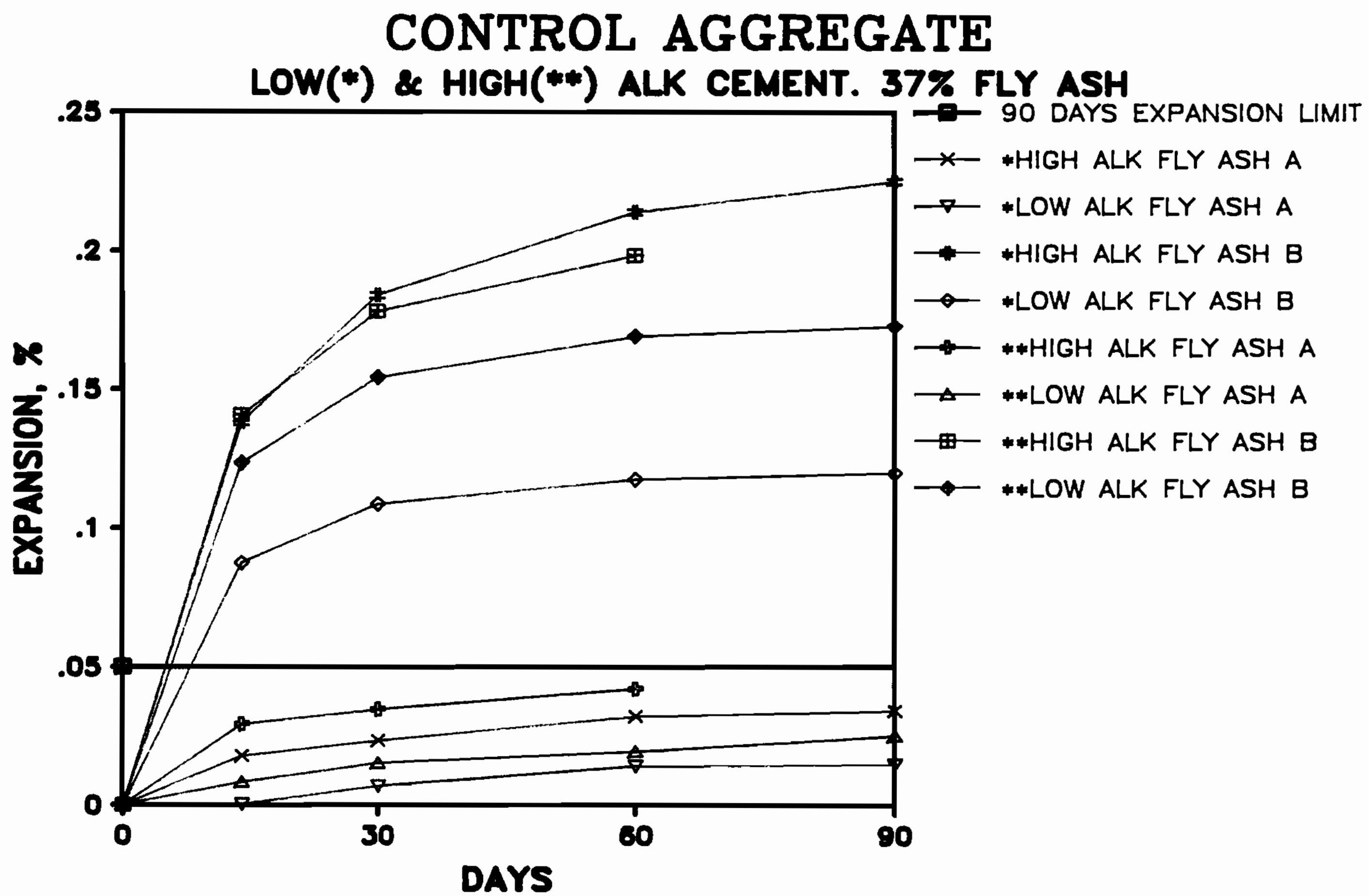
LOW(*) & HIGH(**) ALK CEMENT. 37% FLY ASH





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

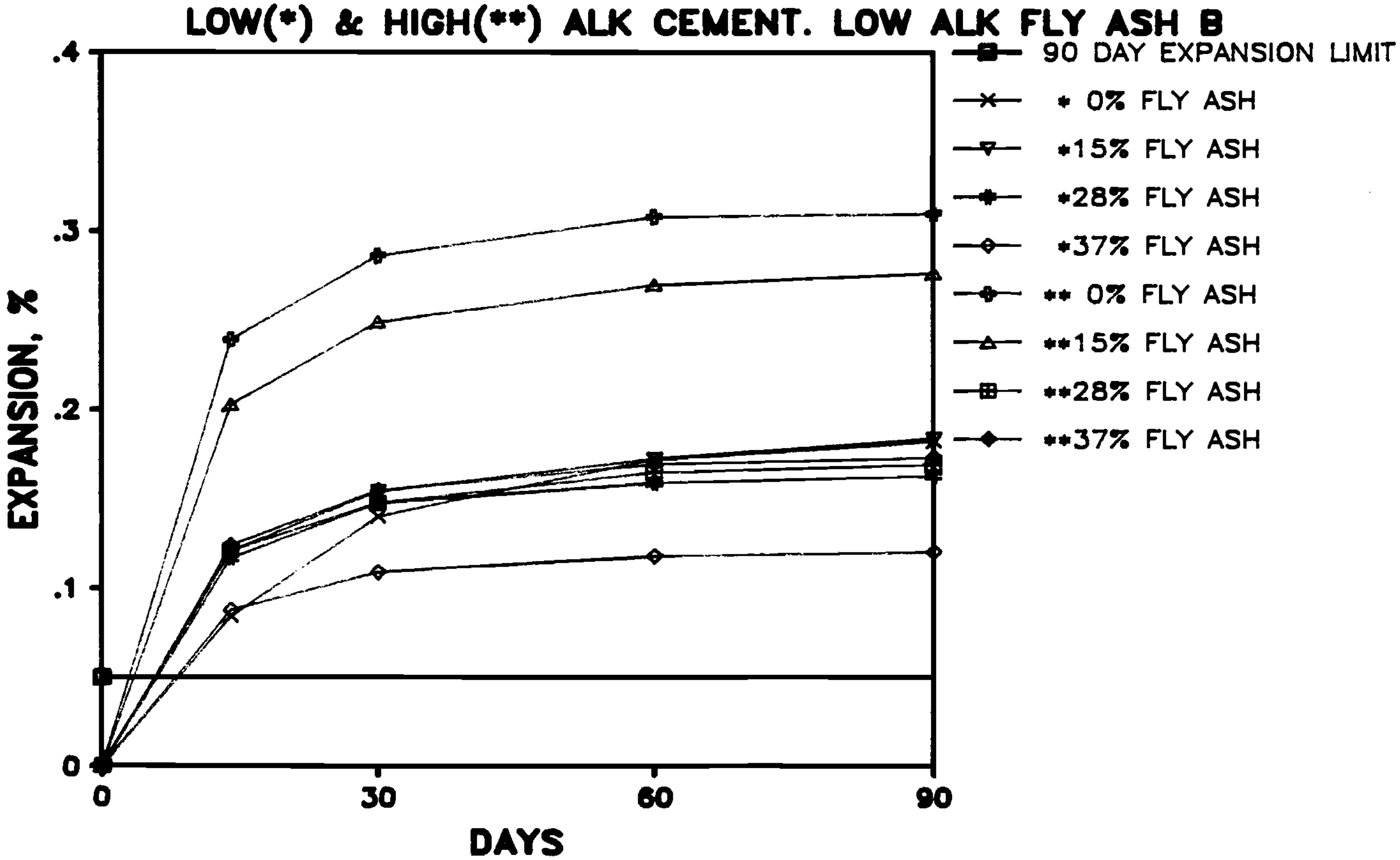

CONTROL AGGREGATE
LOW(*) & HIGH(**) ALK CEMENT. 37% FLY ASH
EXPANSION, %
.25
.2
.15
.1
.05
0
0
30
60
90
DAYS
90 DAYS EXPANSION LIMIT
*HIGH ALK FLY ASH A
*LOW ALK FLY ASH A
*HIGH ALK FLY ASH B
*LOW ALK FLY ASH B
**HIGH ALK FLY ASH A
**LOW ALK FLY ASH A
**HIGH ALK FLY ASH B
**LOW ALK FLY ASH B

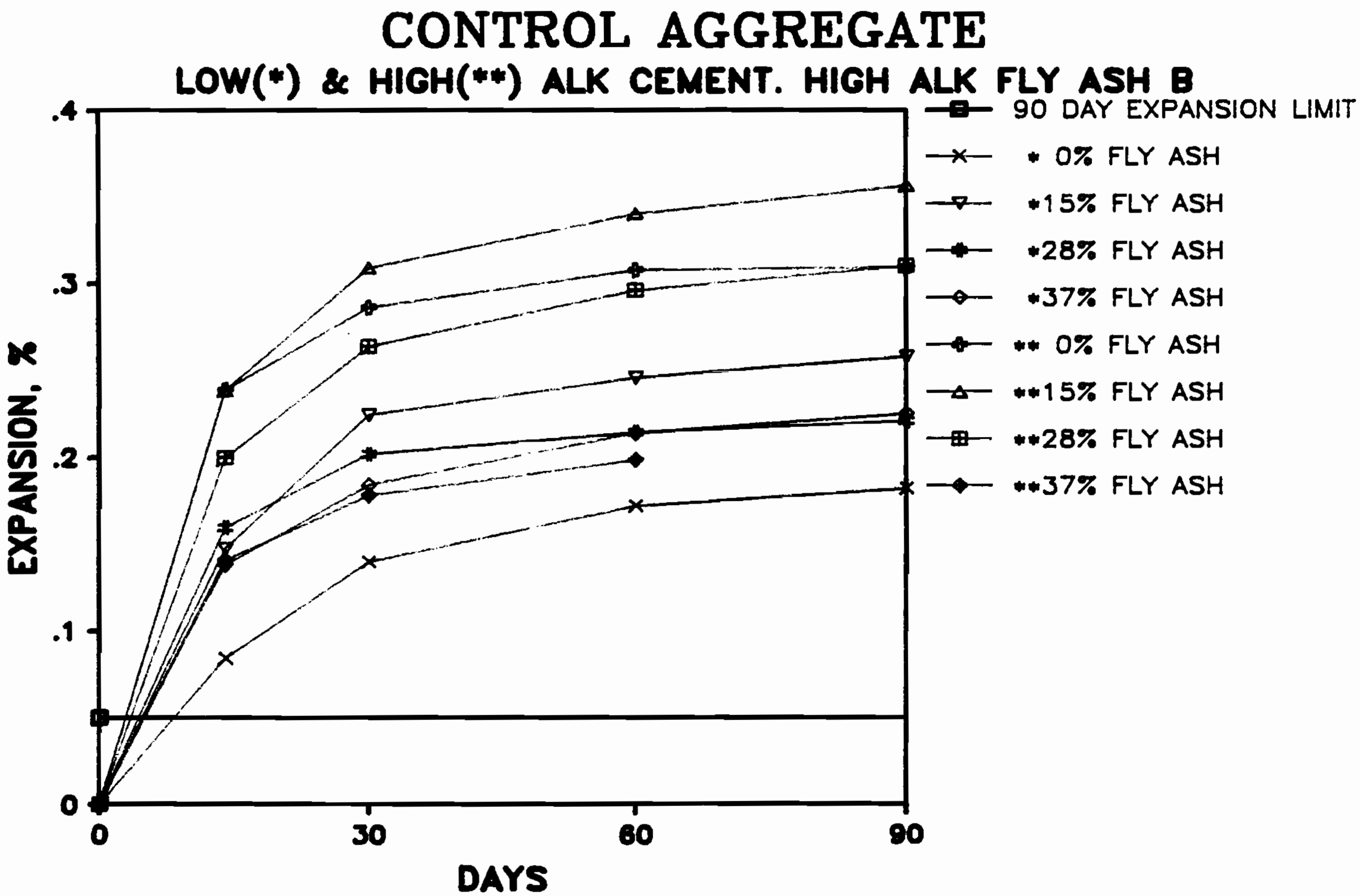
MIXES CONTAINING FLY ASH

ALL PERCENTAGES OF FLY ASH REPLACEMENTS

FOR EACH AGGREGATE TYPE AND EACH FLY ASH TYPE

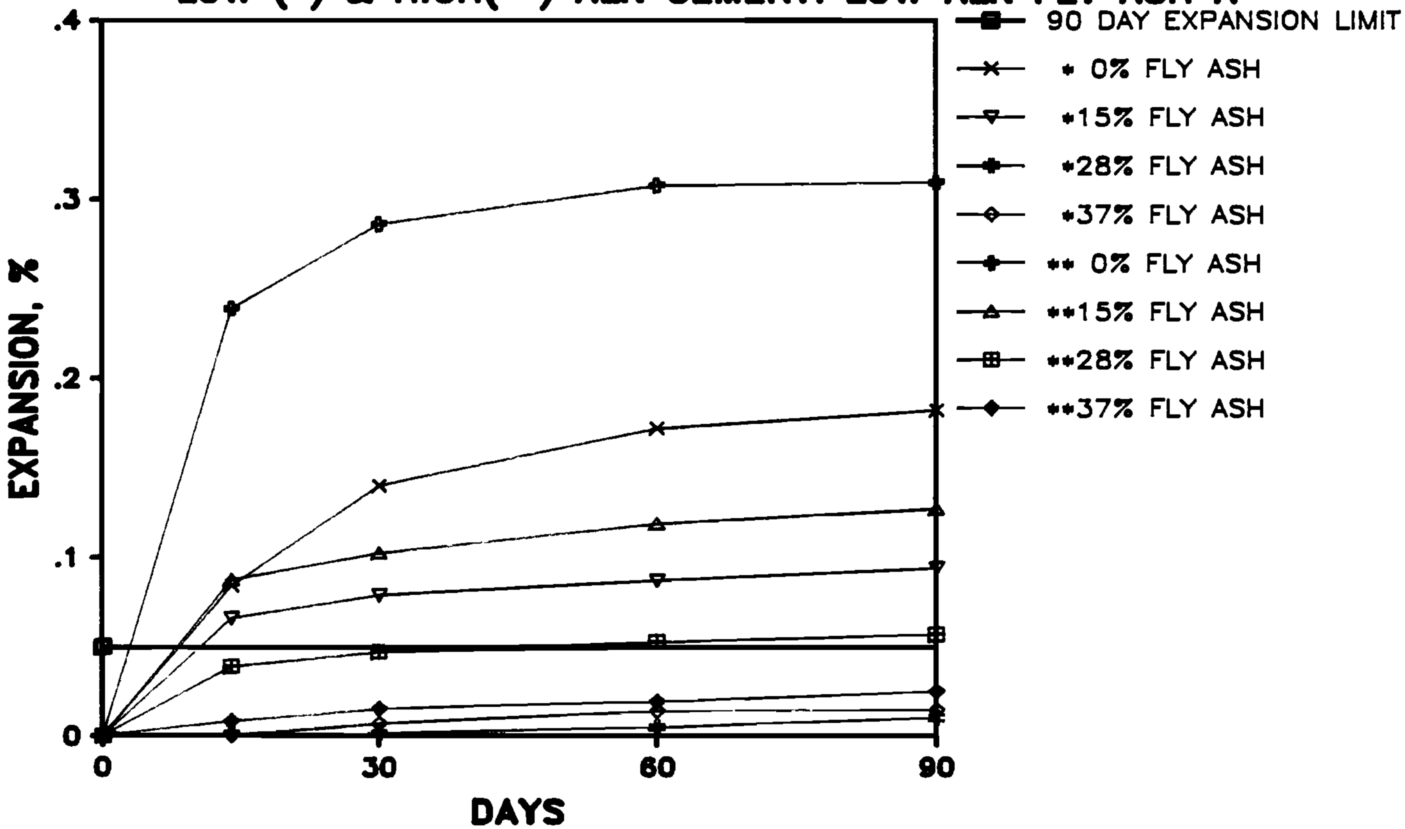
CONTROL AGGREGATE




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

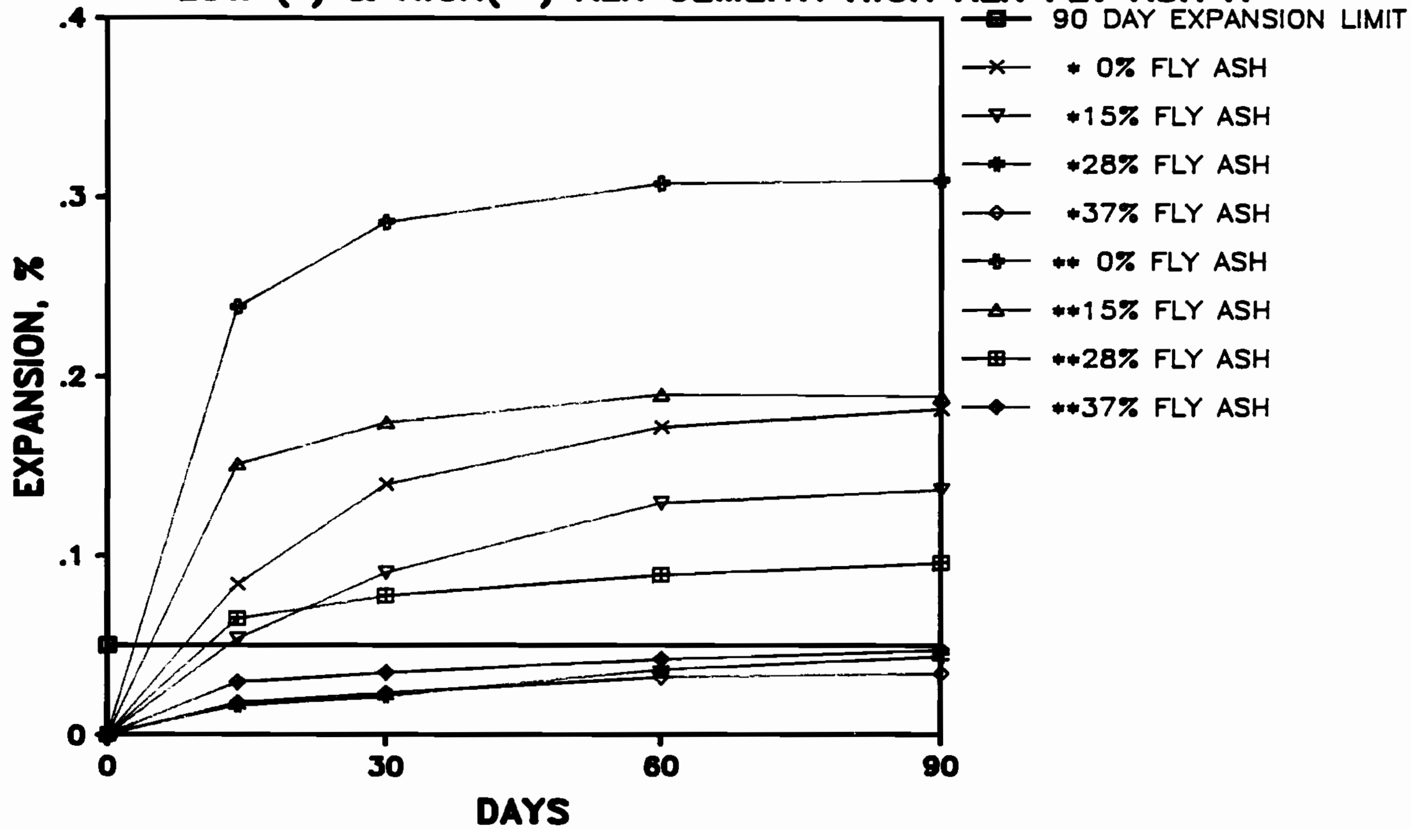
CONTROL AGGREGATE

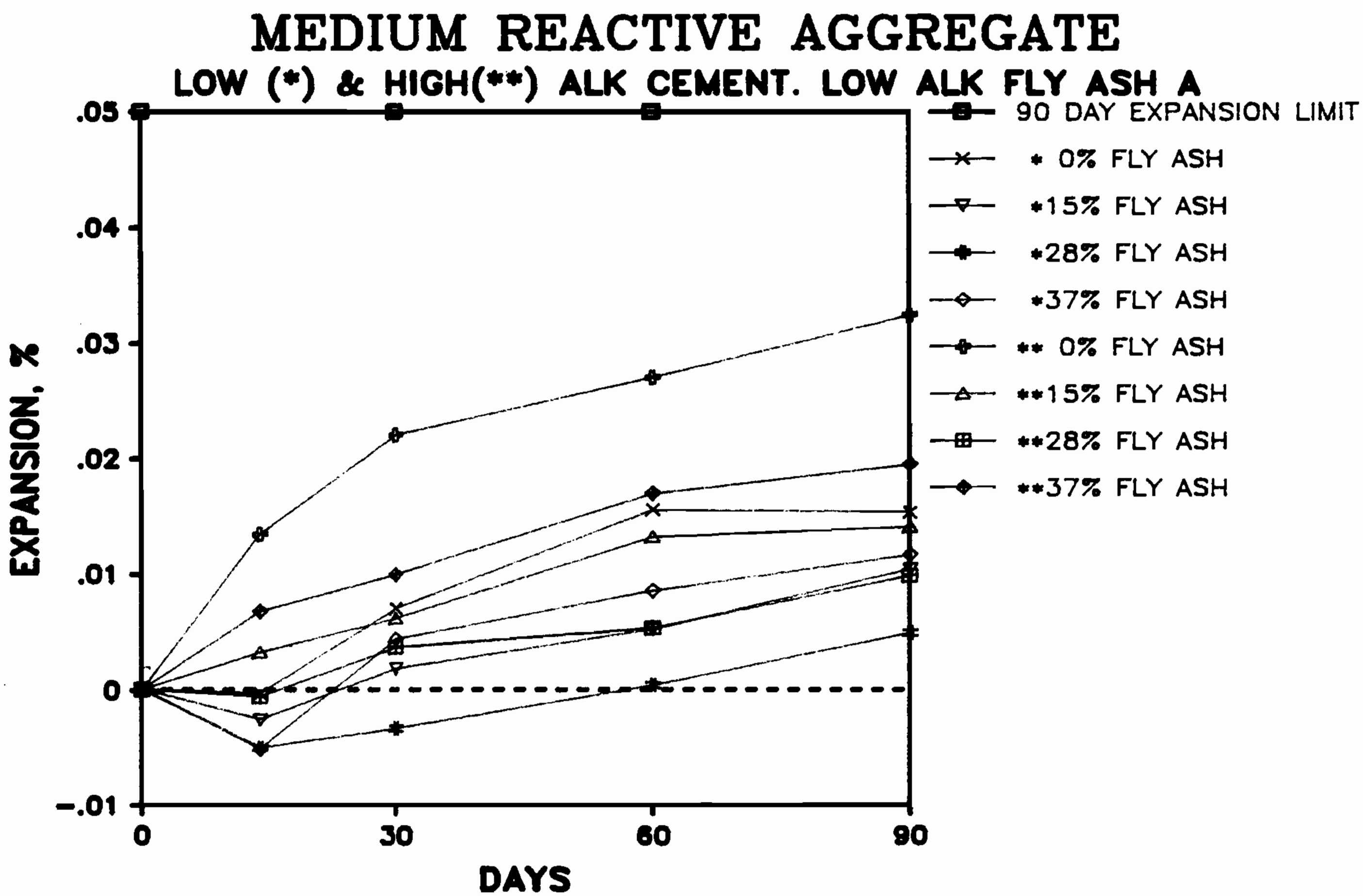
LOW (*) & HIGH(**) ALK CEMENT. LOW ALK FLY ASH A



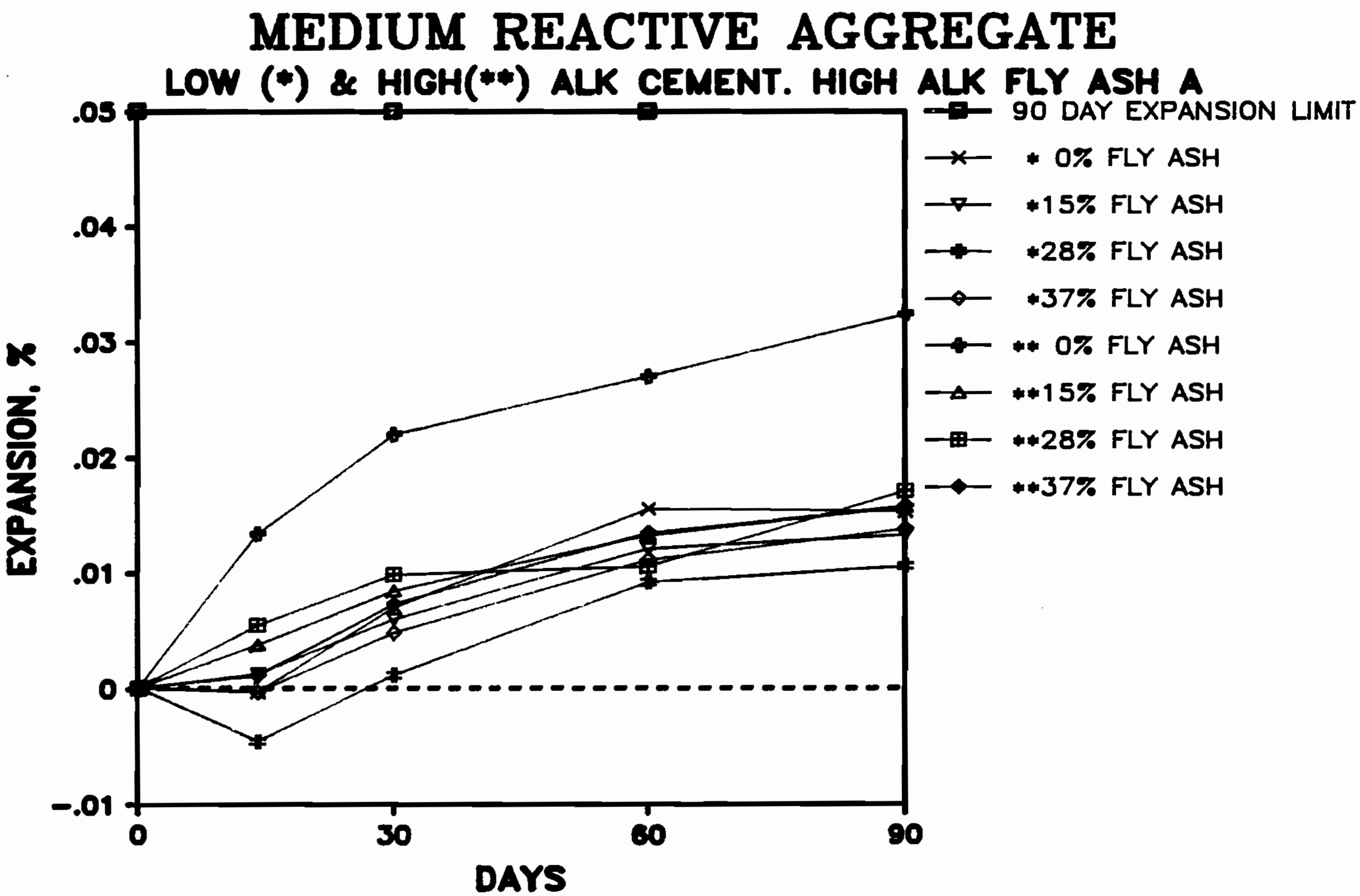
CONTROL AGGREGATE

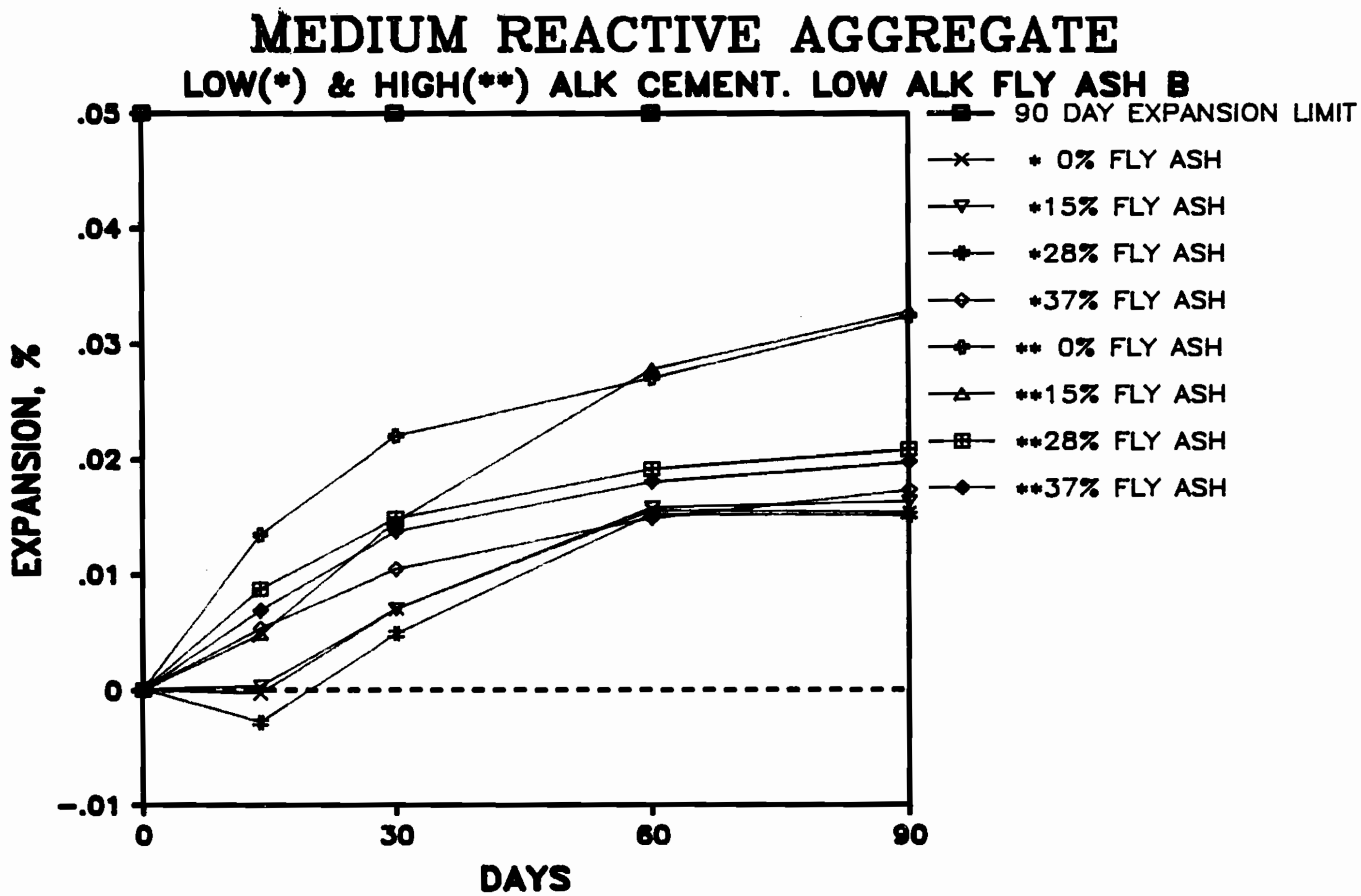
LOW (*) & HIGH(**) ALK CEMENT. HIGH ALK FLY ASH A





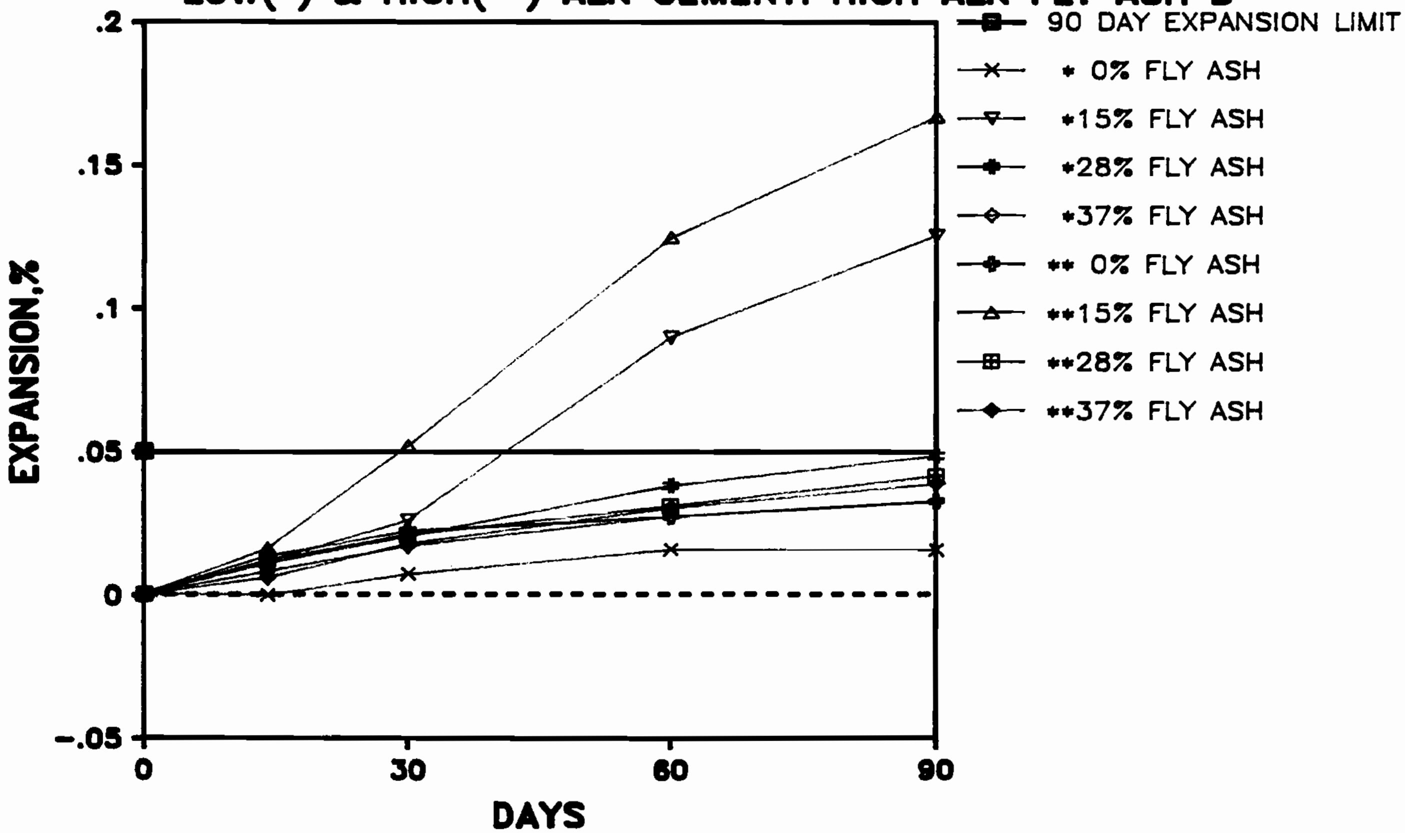
MEDIUM REACTIVE AGGREGATE
LOW (*) & HIGH(**) ALK CEMENT. LOW ALK FLY ASH A
.05
.04
.03
.02
.01
0
-.01
EXPANSION, %
0
30
60
90
DAYS
90 DAY EXPANSION LIMIT
* 0% FLY ASH
*15% FLY ASH
*28% FLY ASH
*37% FLY ASH
** 0% FLY ASH
**15% FLY ASH
**28% FLY ASH
**37% FLY ASH


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

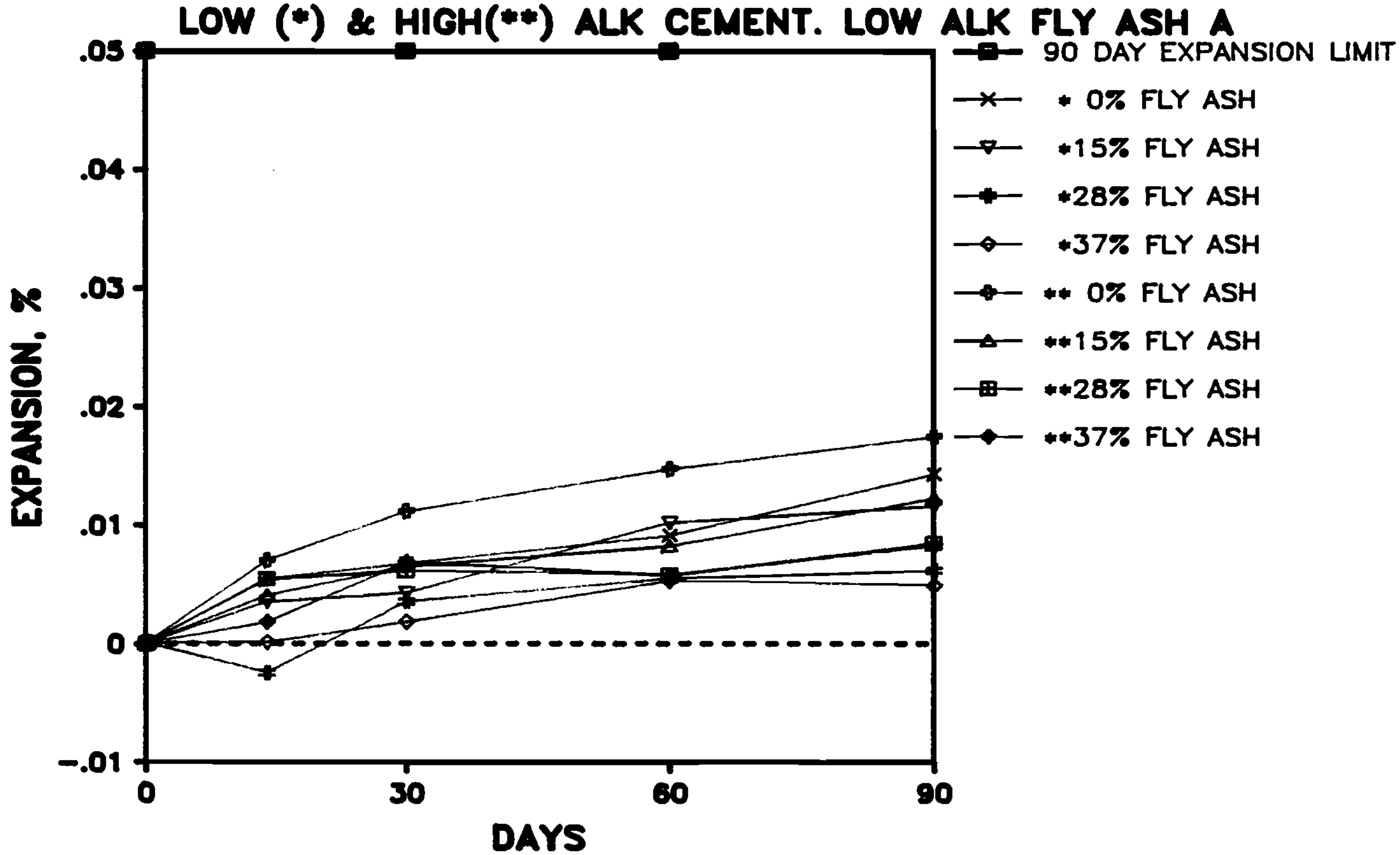

MEDIUM REACTIVE AGGREGATE
LOW(*) & HIGH(**) ALK CEMENT. LOW ALK FLY ASH B
EXPANSION, %
.05
.04
.03
.02
.01
0
-.01
0
30
60
90
DAYS
90 DAY EXPANSION LIMIT
* 0% FLY ASH
*15% FLY ASH
*28% FLY ASH
*37% FLY ASH
** 0% FLY ASH
**15% FLY ASH
**28% FLY ASH
**37% FLY ASH

MEDIUM REACTIVE AGGREGATE

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

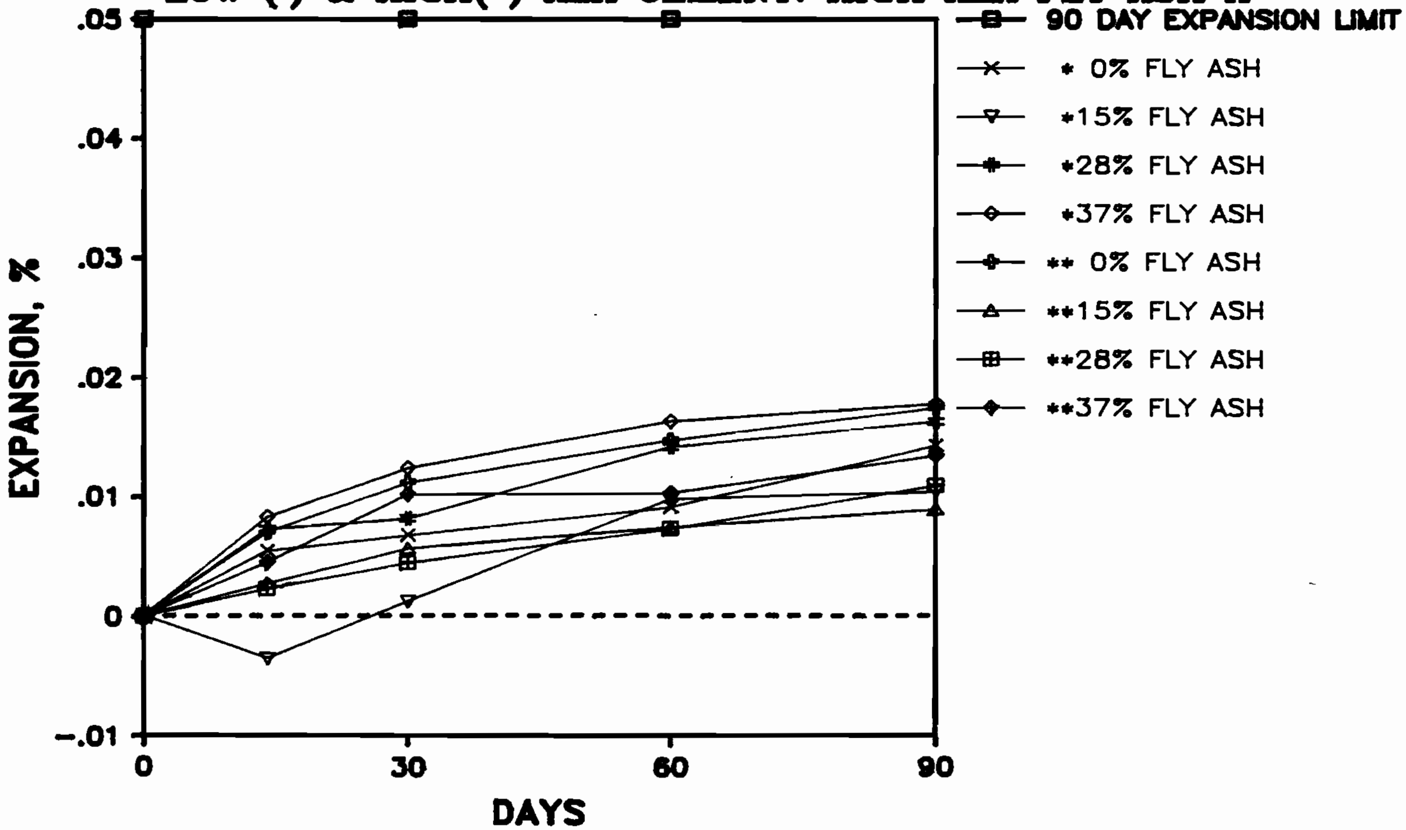


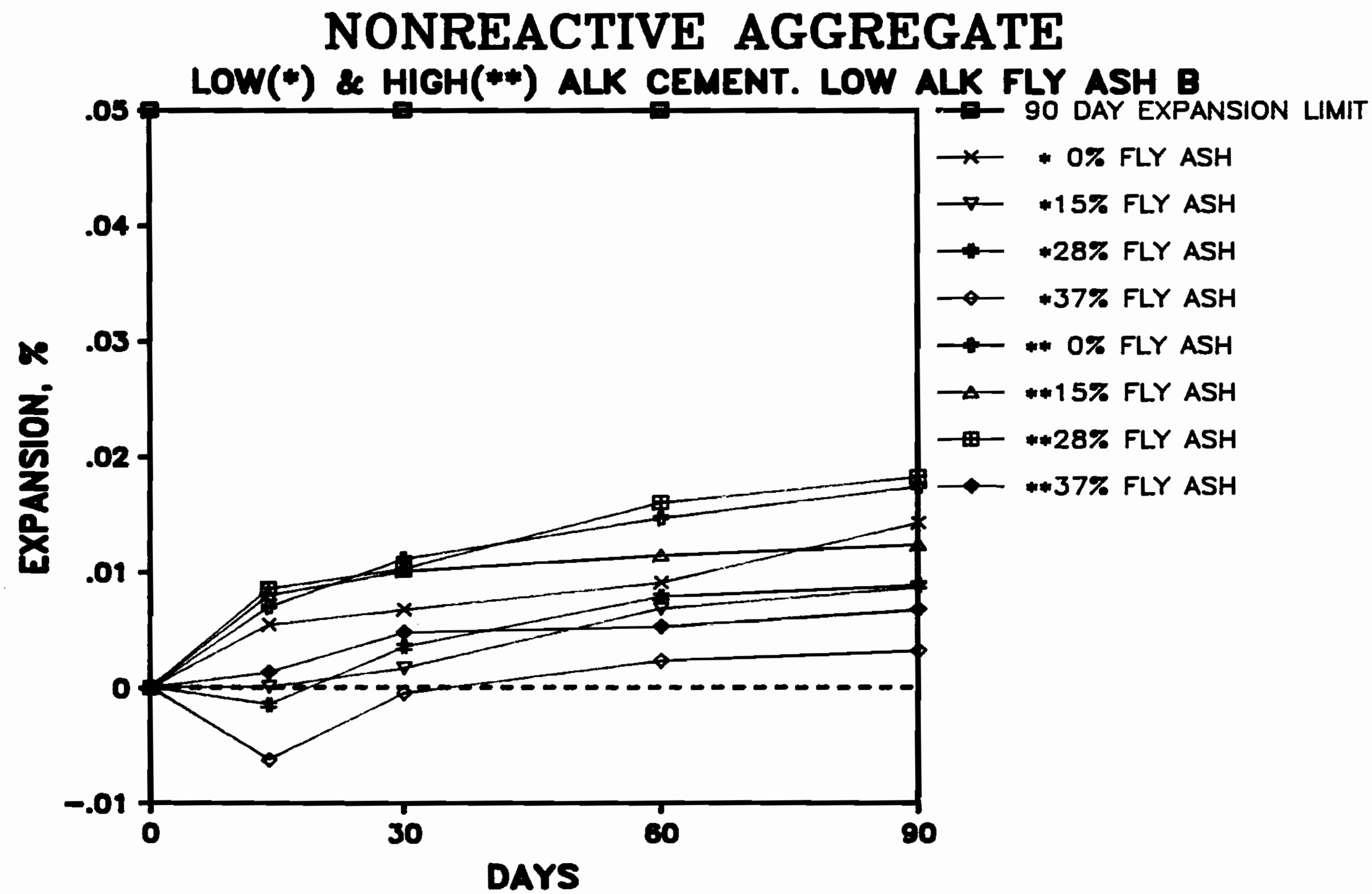
NONREACTIVE AGGREGATE



NONREACTIVE AGGREGATE

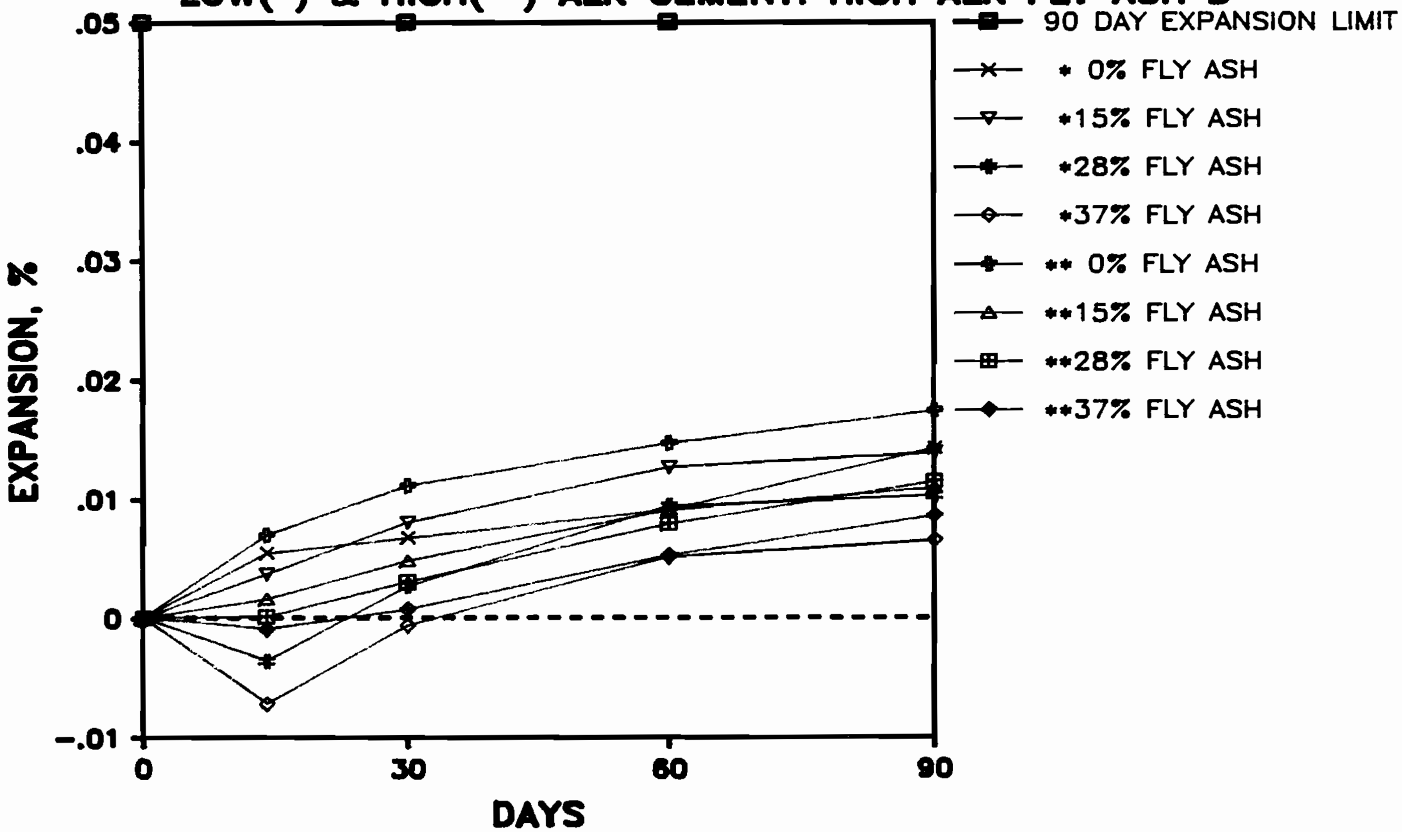
LOW (*) & HIGH(**) ALK CEMENT. HIGH ALK FLY ASH A

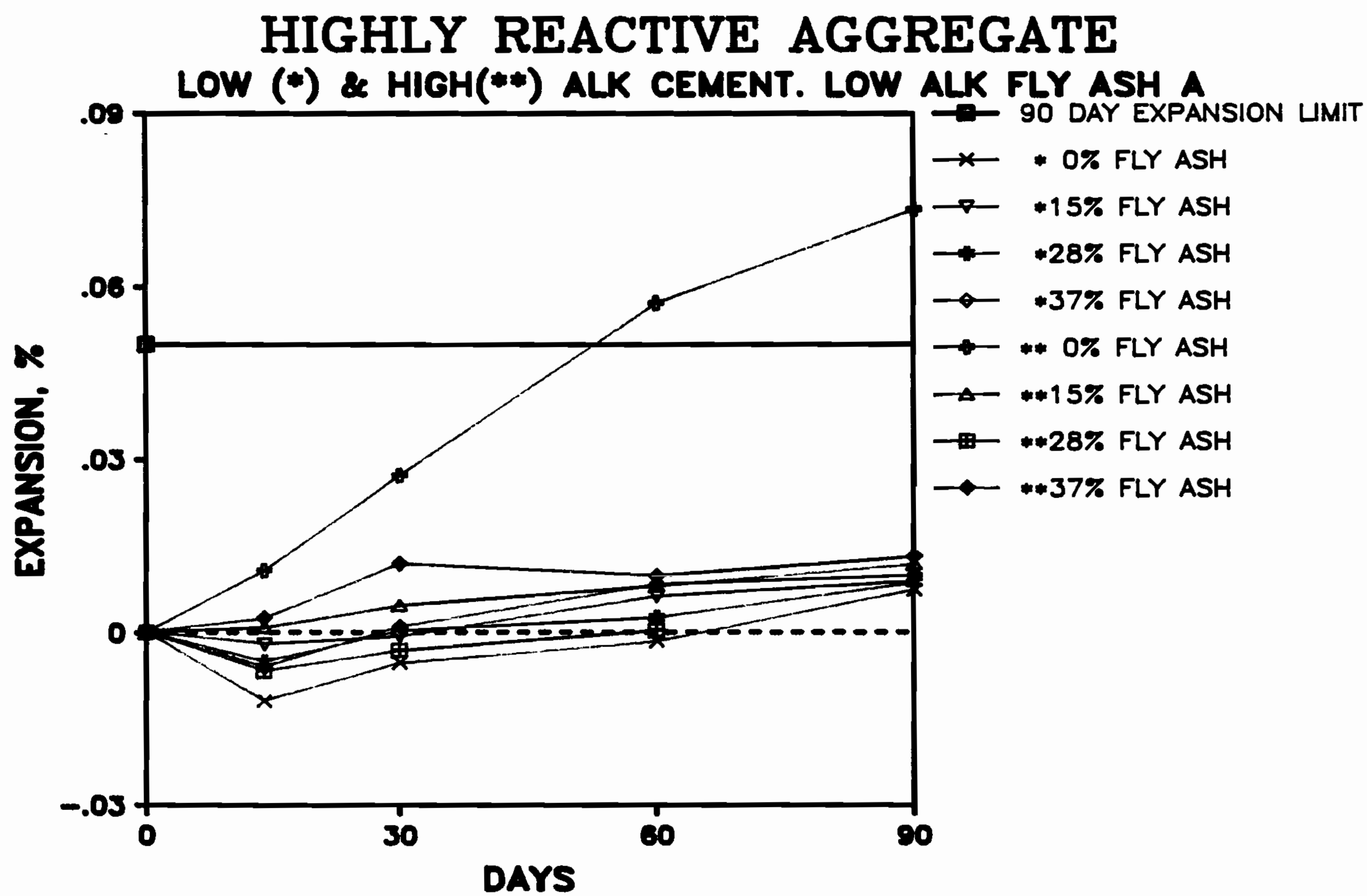



NONREACTIVE AGGREGATE
LOW(*) & HIGH(**) ALK CEMENT. LOW ALK FLY ASH B
.05
.04
.03
.02
.01
0
-.01
EXPANSION, %
0
30
60
90
DAYS
90 DAY EXPANSION LIMIT
* 0% FLY ASH
*15% FLY ASH
*28% FLY ASH
*37% FLY ASH
** 0% FLY ASH
**15% FLY ASH
**28% FLY ASH
**37% FLY ASH

NONREACTIVE AGGREGATE

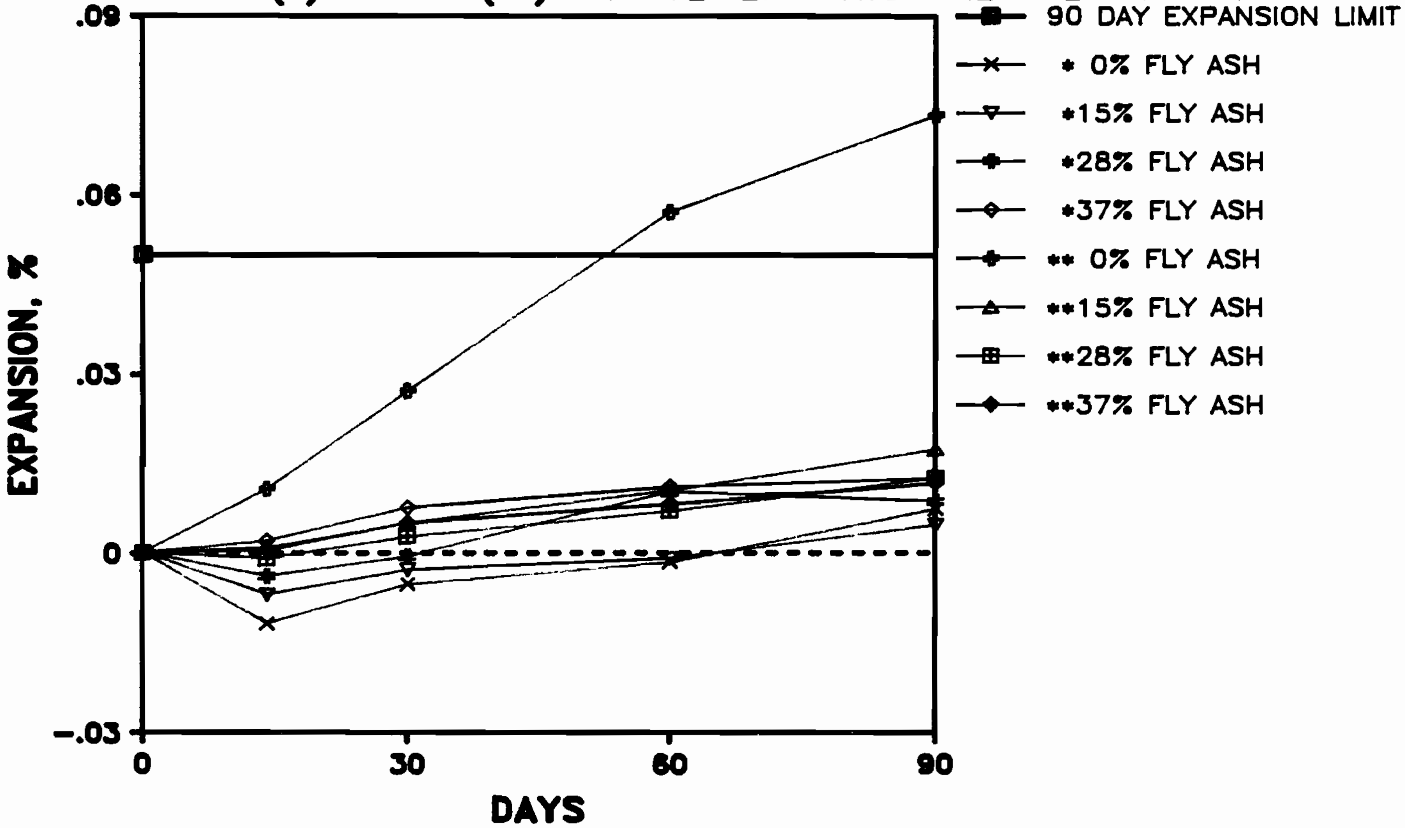
LOW(*) & HIGH(**) ALK CEMENT. HIGH ALK FLY ASH B

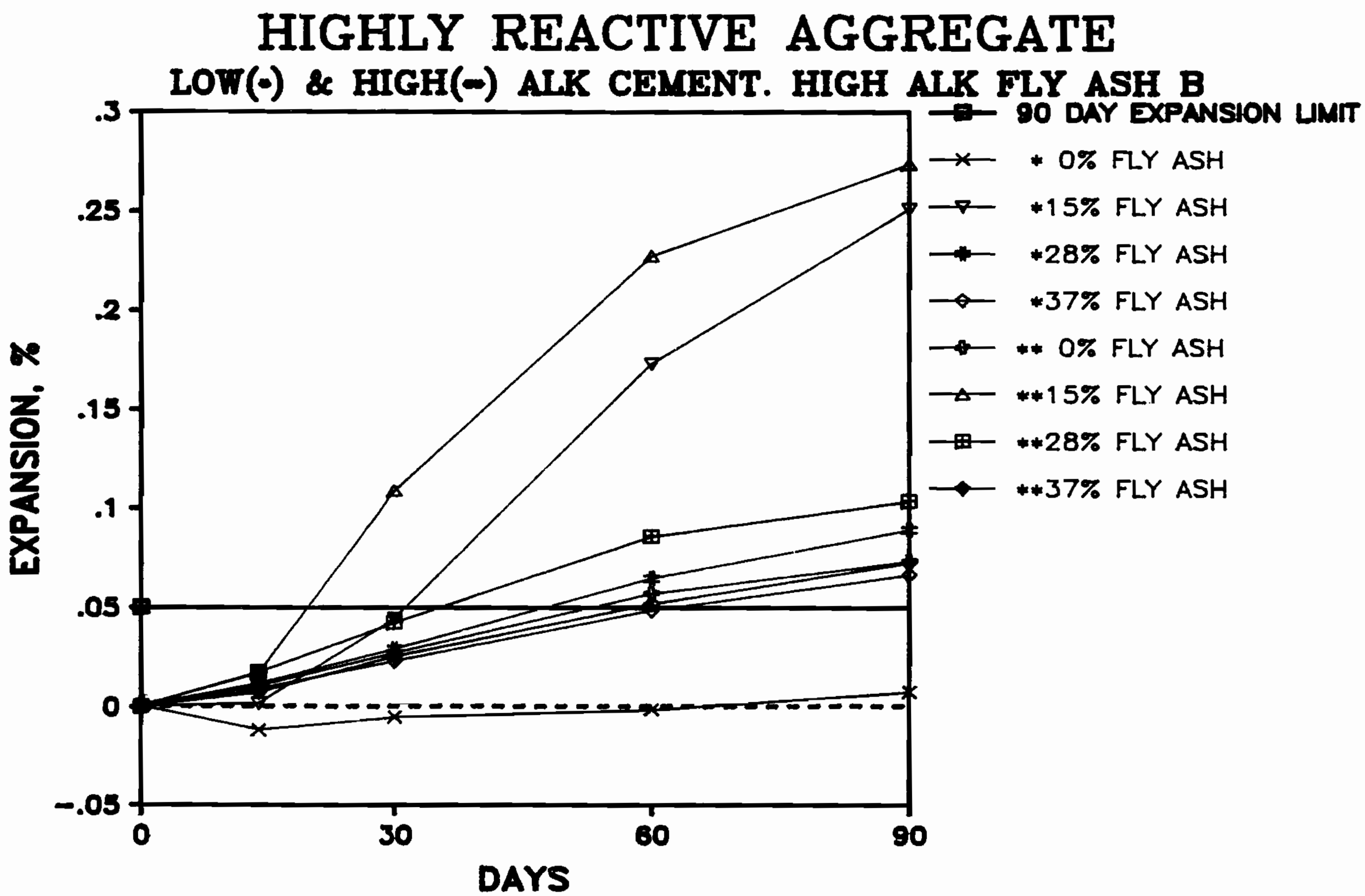



HIGHLY REACTIVE AGGREGATE
LOW (*) & HIGH(**) ALK CEMENT. LOW ALK FLY ASH A
.09
.06
.03
0
-.03
0
30
60
90
DAYS
EXPANSION, %
90 DAY EXPANSION LIMIT
* 0% FLY ASH
*15% FLY ASH
*28% FLY ASH
*37% FLY ASH
** 0% FLY ASH
**15% FLY ASH
**28% FLY ASH
**37% FLY ASH

HIGHLY REACTIVE AGGREGATE

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



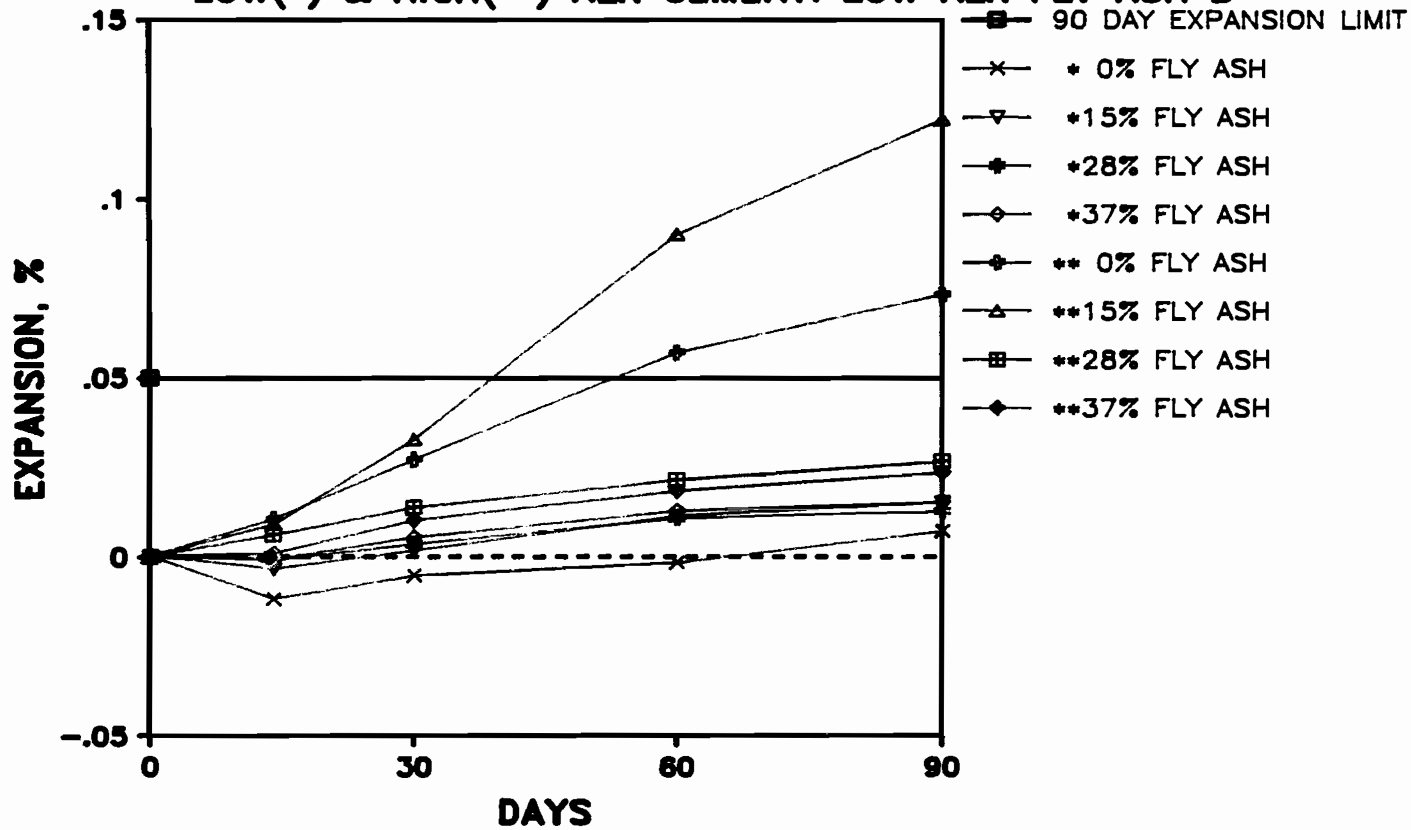


HIGHLY REACTIVE AGGREGATE
LOW(*) & HIGH(**) ALK CEMENT. HIGH ALK FLY ASH B
.3
.25
.2
.15
.1
.05
0
-.05
EXPANSION, %
0
30
60
90
DAYS
90 DAY EXPANSION LIMIT
* 0% FLY ASH
*15% FLY ASH
*28% FLY ASH
*37% FLY ASH
** 0% FLY ASH
**15% FLY ASH
**28% FLY ASH
**37% FLY ASH

133

HIGHLY REACTIVE AGGREGATE

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



-MIX 1-

NONREACTIVE AGGREGATE, LOW ALKALI CEMENT, NO FLY ASH

DAYS: READINGS:

DAYS	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

DAYS	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:

DAYS	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

DAYS	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:

DAYS	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

DAYS	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 4-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	601	SAMPLE	182	173	221	62	183	280
14	604	SAMPLE	188	178	223	67	188	290
30	609	SAMPLE	SAMPLE	183	229	73	193	295
60	613	SAMPLE	SAMPLE	186	235	79	201	303
90	615	SAMPLE	SAMPLE	190	236	79	201	303

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.002567	0	.005153	.004295	.001717	.004299	.004294	.008581
30	.006846	0	0	.008589	.006869	.009457	.008589	.012872
60	.010269	0	0	.011166	.012020	.014616	.015460	.019737
90	.011981	0	0	.014602	.012879	.014616	.015460	.019737

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.003721	.008070	.012706	.013907

-MIX 5-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	148	275	259	227	189	BROKEN	277	202
14	151	276	258	225	189	BROKEN	275	204
30	152	277	257	227	193	BROKEN	278	207
60	159	285	266	231	198	BROKEN	282	212
90	161	287	270	236	198	BROKEN	283	213

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.002577	.000858	-.00086	-.00172	0	0	-.00172	.001717
30	.003436	.001716	-.00172	0	.003435	0	.000858	.004294
60	.009450	.008582	.006008	.003434	.007729	0	.004291	.008587
90	.011169	.010298	.009441	.007727	.007729	0	.005149	.009446

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.000123	.001718	.006869	.008708

-MIX 6-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	302	301	328	390	230	274	299	237
14	319	311	336	396	238	284	313	246
30	321	311	338	399	240	283	314	246
60	326	320	348	405	244	292	321	250
90	335	321	354	410	249	292	323	255

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.014586	.008580	.006862	.005144	.006868	.008582	.012012	.007726
30	.016302	.008580	.008578	.007716	.008585	.007724	.012870	.007726
60	.020592	.016302	.017156	.012860	.012019	.015447	.018876	.011160
90	.028314	.017160	.022303	.017147	.016312	.015447	.020592	.015452

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.007294	.008152	.014157	.016304

-MIX 7-

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

DAYS:	READINGS:							
	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							
	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:							
	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							
	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:							
	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							
	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 10-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	308	276	171	112	292	241	195	122
14	317	281	179	120	304	254	200	130
30	322	280	185	129	308	257	206	135
60	326	290	189	131	314	263	211	140
90	328	291	191	132	315	265	213	142

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.007721	.004291	.006872	.006875	.010297	.011160	.004294	.006875
30	.012011	.003433	.012025	.014610	.013729	.013735	.009447	.011171
60	.015443	.012014	.015461	.016328	.018877	.018886	.013740	.015468
90	.017159	.012873	.017179	.017188	.019735	.020602	.015458	.017186

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.008300	.012390	.016315	.017787

-MIX 11-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	245	238	205	365	295	253	92	202
14	238	240	210	363	294	250	96	203
30	238	240	208	366	296	250	96	204
60	242	245	210	371	302	255	99	207
90	244	245	216	371	300	255	98	210

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	-.00601	.001717	.004294	-.00172	-.00086	-.00258	.003438	.000859
30	-.00601	.001717	.002576	.000858	.000858	-.00258	.003438	.001717
60	-.00258	.006009	.004294	.005145	.006006	.001717	.006017	.004294
90	-.00086	.006009	.009446	.005145	.004290	.001717	.005157	.006870

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.000144	.001861	.005294	.004865

-MIX 12-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	312	276	241	224	268	263	302	359
14	305	274	233	216	258	251	292	357
30	312	280	240	224	267	260	300	361
60	318	287	249	230	274	268	307	365
90	321	287	247	231	275	269	307	369

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	-.00601	-.00172	-.00687	-.00687	-.00858	-.01030	-.00858	-.00172
30	0	.003433	-.00086	0	-.00086	-.00257	-.00172	.001715
60	.005147	.009440	.006867	.005151	.005149	.004291	.004290	.005145
90	.007721	.009440	.005151	.006010	.006008	.005150	.004290	.008576

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00715	-.00061	.005149	.006543

-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 16-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	329	260	302	387	264	230	196	313
14	332	265	310	390	267	233	202	320
30	336	268	314	393	271	236	205	323
60	338	270	317	395	273	239	207	324
90	344	275	318	400	276	241	211	330

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.002573	.004291	.006864	.002572	.002575	.002576	.005153	.006005
30	.006005	.006866	.010296	.005144	.006008	.005151	.007729	.008579
60	.007720	.008583	.012870	.006859	.007724	.007727	.009446	.009437
90	.012867	.012874	.013728	.011146	.010299	.009444	.012882	.014584

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.004076	.006497	.008214	.012228

-MIX 17-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	431	393	377	308	232	181	317	453
14	431	398	377	307	233	186	317	458
30	434	400	380	312	238	189	322	462
60	437	402	383	314	242	193	326	466
90	440	406	387	319	246	196	331	469

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	0	.004287	0	-.00086	.000859	.004294	0	.004284
30	.002571	.006001	.002572	.003432	.005151	.006871	.004289	.007712
60	.005142	.007716	.005145	.005148	.008585	.010307	.007721	.011139
90	.007713	.011145	.008574	.009437	.012019	.012883	.012010	.013710

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.001608	.004825	.009094	.010937

-MIX 18-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	146	303	434	-6	336	141	286	531
14	157	303	458	4	346	150	294	539
30	159	315	443	7	350	152	297	542
60	160	317	447	9	348	155	299	543
90	162	322	451	7	350	156	299	544

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.009450	0	.020568	.008603	.008577	.007733	.006865	.006850
30	.011169	.010296	.007713	.011183	.012008	.009451	.009439	.009419
60	.012028	.012012	.011141	.012904	.010293	.012028	.011155	.010276
90	.013746	.016302	.014569	.011183	.012008	.012888	.011155	.011132

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.008013	.010085	.011480	.012383

-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 22-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	240	198	238	284	270	114	242	311
14	252	209	246	297	280	122	251	320
30	254	212	251	301	283	124	251	322
60	260	217	255	305	289	132	255	328
90	262	220	258	308	290	135	258	331

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.010301	.009446	.006868	.011156	.008582	.006875	.007726	.007721
30	.012018	.012023	.011160	.014588	.011157	.008594	.007726	.009437
60	.017169	.016316	.014594	.018020	.016306	.015469	.011160	.014585
90	.018886	.018893	.017169	.020595	.017164	.018047	.013735	.017158

AVERAGES:

DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
0	.008584	.010302	.016066	.018273

-MIX 23-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	302	367	185	255	458	338	332	350
14	308	373	189	258	464	343	336	358
30	315	378	195	268	470	350	344	366
60	315	379	198	266	474	350	343	367
90	318	383	200	270	477	354	348	370

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.005148	.005145	.003435	.002575	.005141	.004289	.003431	.006861
30	.011154	.009433	.008588	.011158	.010282	.010293	.010293	.013722
60	.011154	.010290	.011165	.009442	.013709	.010293	.009435	.014580
90	.013728	.013720	.012883	.012875	.016280	.013724	.013724	.017153

AVERAGES:

DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
0	.004503	.010172	.010296	.013442

-MIX 24-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	273	346	326	325	223	386	262	273
14	275	347	328	326	226	389	263	277
30	282	353	335	333	231	393	269	282
60	281	352	332	332	230	393	268	279
90	282	354	335	335	232	396	273	284

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.001716	.000858	.001716	.000858	.002576	.002572	.000858	.003433
30	.007724	.006004	.007720	.006863	.006869	.006002	.006008	.007724
60	.006866	.005146	.005147	.006005	.006010	.006002	.005150	.005149
90	.007724	.006861	.007720	.008578	.007727	.008574	.009441	.009440

AVERAGES:

DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
0	.001823	.006864	.005684	.008258

-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 28-

MEDIUM REACTIVE AGGREGATE, LOW ALKALI CEMENT, NO FLY ASH

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	258	258	290	293	224	163	290	248
14	263	258	285	291	224	160	285	251
30	271	269	298	301	230	165	295	259
60	278	278	307	309	241	176	306	269
90	279	277	307	311	243	178	306	271

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.004292	0	-.00429	-.00172	0	-.00258	-.00429	.002575
30	.011158	.009441	.006865	.006864	.005151	.001718	.004290	.009442
60	.017166	.017166	.014587	.013729	.014596	.011167	.013729	.018026
90	.018025	.016308	.014587	.015445	.016313	.012885	.013729	.019743

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00034	.007009	.015571	.015327

-MIX 29-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	192	166	333	245	208	251	304	228
14	194	171	337	244	205	254	304	230
30	198	177	342	250	213	258	310	235
60	206	182	350	257	219	267	316	243
90	208	186	351	258	220	268	319	246

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.001718	.004295	.003431	-.00086	-.00258	.002575	0	.001717
30	.005153	.009449	.007720	.004292	.004293	.006009	.005148	.006010
60	.012023	.013744	.014582	.010301	.009445	.013734	.010296	.012878
90	.013741	.017180	.015440	.011159	.010304	.014592	.012870	.015454

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.001288	.006009	.012125	.013366

-MIX 30-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	322	241	258	167	287	290	231	466
14	325	244	260	164	283	288	228	469
30	327	246	261	164	286	292	230	473
60	331	251	266	170	290	296	235	478
90	336	258	270	179	296	305	242	483

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.002574	.002575	.001717	-.00258	-.00343	-.00172	-.00258	.002570
30	.004289	.004292	.002575	-.00258	-.00086	.001716	-.00086	.005997
60	.007721	.008584	.006866	.002577	.002574	.005148	.003434	.010281
90	.012010	.014593	.010300	.010308	.007723	.012871	.009444	.014565

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00258	.001859	.005272	.010442

-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 34-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	268	197	315	326	287	224	288	236
14	268	193	308	321	279	218	282	231
30	269	192	310	322	281	220	286	235
60	271	198	313	325	285	226	289	238
90	276	203	321	331	291	229	294	242

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	0	-.00344	-.00601	-.00429	-.00686	-.00515	-.00515	-.00429
30	.000858	-.00429	-.00429	-.00343	-.00515	-.00343	-.00172	-.00086
60	.002575	.000859	-.00172	-.00086	-.00172	.001717	.000858	.001717
90	.006866	.005153	.005147	.004289	.003432	.004293	.005149	.005151

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00503	-.00331	.000429	.004935

-MIX 35-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	366	334	234	198	226	293	235	249
14	381	345	246	210	234	304	248	264
30	389	356	257	220	246	317	262	276
60	403	374	284	243	268	334	298	296
90	413	386	297	258	278	346	306	307

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.012863	.009435	.010302	.010305	.006868	.009439	.011160	.012876
30	.019723	.018871	.019745	.018893	.017171	.020593	.023179	.023176
60	.031728	.034310	.042924	.038644	.036059	.035180	.045499	.040344
90	.040303	.044603	.054085	.051525	.044644	.045477	.060952	.049786

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.010911	.020169	.037910	.048353

-MIX 36-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	267	343	292	238	351	309	281	
14	274	340	288	236	345	303	279	
30	279	349	300	246	353	312	288	
60	286	360	310	255	364	322	297	
90	286	362	310	256	368	323	299	

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.006008	-.00257	-.00343	-.00172	-.00515	-.00515	-.00172	0
30	.010299	.005146	.006864	.006868	.001715	.002574	.006007	0
60	.016307	.014581	.015445	.014594	.011149	.011153	.013730	0
90	.016307	.016296	.015445	.015452	.014580	.012011	.015447	0

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00282	.004862	.015232	.015077

-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 40-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	102	118	185	252	142	185	181	193
14	114	127	191	260	146	189	195	211
30	117	132	196	264	153	195	200	215
60	122	136	202	270	157	201	206	220
90	124	140	205	273	161	202	208	222

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.010314	.007734	.005153	.006867	.003437	.003435	.012024	.015458
30	.012892	.012031	.009447	.010300	.009451	.008588	.016319	.018893
60	.017189	.015468	.014600	.015450	.012887	.013742	.021472	.023187
90	.018908	.018906	.017177	.018025	.016324	.014600	.023190	.024905

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.005325	.010452	.014890	.017323

-MIX 41-

MEDIUM REACTIVE AGGREGATE, HIGH ALKALI CEMENT, NO FLY ASH

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	300	SAMPLE	151	245	450	555	253	217
14	319	SAMPLE	SAMPLE	258	466	572	267	232
30	327	SAMPLE	SAMPLE	270	475	584	278	240
60	333	SAMPLE	SAMPLE	277	479	590	284	246
90	337	SAMPLE	SAMPLE	282	488	596	289	248

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.016302	0	0	.011159	.013710	.014554	.012017	.012879
30	.023166	0	0	.021460	.021422	.024828	.021459	.019748
60	.028314	0	0	.027469	.024850	.029964	.026609	.024900
90	.031746	0	0	.031761	.032562	.035101	.030900	.026617

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.013437	.022014	.027018	.032414

-MIX 42-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	376	139	233	286	318	618	380	458
14	386	141	237	291	324	622	384	464
30	387	146	241	296	330	628	391	468
60	392	151	246	303	336	634	397	473
90	395	155	250	305	338	636	400	476

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.008574	.001718	.003434	.004291	.005147	.003423	.003430	.005141
30	.009432	.006014	.006868	.008581	.010294	.008557	.009432	.008568
60	.013719	.010310	.011160	.014588	.015442	.013691	.014576	.012853
90	.016291	.013747	.014594	.016304	.017157	.015402	.017148	.015423

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.003798	.008468	.013292	.015758

-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 46-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	534	530	152	304	408	389	520	396
14	547	536	153	310	414	395	528	407
30	553	541	159	315	417	400	533	410
60	552	542	162	317	421	401	534	413
90	560	545	164	324	425	409	542	417

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.011132	.005138	.000859	.005148	.005143	.005144	.006851	.009430
30	.016269	.009419	.006014	.009438	.007715	.009431	.011133	.012002
60	.015413	.010276	.008591	.011154	.011144	.010288	.011989	.014574
90	.022263	.012845	.010309	.017159	.014573	.017147	.018840	.018003

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.005485	.009856	.010574	.017145

-MIX 47-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	238	154	336	398	363	326	180	357
14	240	152	333	397	360	327	181	361
30	244	159	338	403	365	332	184	366
60	246	159	340	404	368	333	186	366
90	250	169	345	411	371	338	190	370

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.001717	-.00172	-.00257	-.00086	-.00257	.000858	.000859	.003430
30	.005151	.004295	.001715	.004286	.001715	.005147	.003436	.007718
60	.006868	.004295	.003431	.005144	.004288	.006005	.005153	.007718
90	.010301	.012886	.007720	.011145	.006860	.010294	.008589	.011149

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00061	.003678	.005363	.009868

-MIX 48-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	246	258	250	236	375	417	376	365
14	261	273	265	248	384	429	389	380
30	271	282	275	261	394	437	398	389
60	279	294	284	274	407	464	413	406
90	291	308	298	286	420	464	426	415

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.012876	.012875	.012876	.010302	.007717	.010286	.011147	.012863
30	.021460	.020599	.021459	.021462	.016292	.017143	.018864	.020581
60	.028327	.030899	.029185	.032622	.027438	.040286	.031725	.035158
90	.038628	.042916	.041202	.042924	.038585	.040286	.042872	.042876

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.011889	.020737	.030765	.041286

-MIX 49-

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

DAYS: READINGS:

DAYS	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

DAYS	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:

DAYS	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

DAYS	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:

DAYS	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

DAYS	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 52-

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

DAYS: READINGS:

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	287	276	644	461	418	478	330	233
14	312	288	661	469	425	482	338	240
30	324	300	674	481	437	496	352	253
60	337	314	690	494	454	511	368	266
90	346	323	701	503	462	525	377	276

DAYS: % EXPANSION

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.021452	.010298	.014543	.006855	.006000	.003427	.006862	.006009
30	.031750	.020596	.025664	.017136	.016286	.015420	.018871	.017170
60	.042905	.032611	.039352	.028275	.030857	.028271	.032596	.028330
90	.050628	.040334	.048762	.035986	.037714	.040265	.040316	.036915

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.005831	.017580	.030157	.038588

-MIX 53-

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

DAYS: READINGS:

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	293	BROKEN	172	246	195	216	351	273
14	306	BROKEN	180	255	201	225	364	289
30	312	BROKEN	188	262	209	230	368	295
60	315	BROKEN	192	267	213	236	373	297
90	316	BROKEN	193	267	218	239	376	298

DAYS: % EXPANSION

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.011155	0	.006872	.007726	.005153	.007728	.011149	.013731
30	.016303	0	.013743	.013734	.012023	.012021	.014580	.018880
60	.018877	0	.017179	.018026	.015458	.017172	.018869	.020597
90	.019735	0	.018038	.018026	.019752	.019748	.021441	.021455

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.006869	.013734	.018025	.019742

-MIX 54-

MEDIUM REACTIVE AGGREGATE, CEMENT TYPE IP, NO FLY ASH

DAYS: READINGS:

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	162	225	226	158	162	190	261	141
14	158	218	218	146	147	187	248	138
30	159	220	222	149	155	181	252	138
60	161	222	222	150	154	184	255	141
90	166	229	229	159	163	191	260	146

DAYS: % EXPANSION

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	-.00344	-.00601	-.00687	-.01031	-.01289	-.00258	-.01116	-.00258
30	-.00258	-.00429	-.00343	-.00773	-.00601	-.00773	-.00772	-.00258
60	-.00086	-.00258	-.00343	-.00687	-.00687	-.00515	-.00515	0
90	.003436	.003434	.002576	.000859	.000859	.000859	-.00086	.004296

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00945	-.00526	-.00501	.001933

-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 58-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	154	SAMPLE	208	299	264	252	213	225
14	169	SAMPLE	213	300	266	252	215	236
30	210	SAMPLE	SAMPLE	346	320	303	265	274
60	348	SAMPLE	SAMPLE	492	486	461	453	415
90	394	SAMPLE	SAMPLE	574	579	540	547	476

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.012886	0	.004293	.000858	.001717	0	.001717	.009444
30	.048108	0	0	.040326	.048063	.043776	.044649	.042069
60	.166661	0	0	.165596	.190535	.179396	.206074	.163125
90	.206178	0	0	.235952	.270354	.247206	.286786	.215497

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
.043161	0	.001717	.044499	.173063	.251159

-MIX 59-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	290	197	427	407	272	243	216	252
14	293	194	422	399	260	236	215	252
30	299	200	429	407	267	244	217	258
60	308	212	440	420	277	253	230	268
90	309	214	445	423	287	261	236	273

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.002574	-.00258	-.00429	-.00686	-.01030	-.00601	-.00086	0
30	.007723	.002576	.001714	0	-.00429	.000858	.000859	.005150
60	.015445	.012881	.011142	.011144	.004291	.008584	.012021	.013734
90	.016303	.014599	.015427	.013715	.012873	.015452	.017172	.018025

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00343	.001860	.011584	.015446

-MIX 60-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	293	190	149	-160	143	171	223	218
14	288	183	145	-167	138	164	219	215
30	291	189	149	-162	144	172	225	222
60	301	193	156	-155	148	177	229	226
90	303	199	161	-149	152	181	233	229

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	-.00429	-.00601	-.00344	-.00603	-.00430	-.00601	-.00343	-.00258
30	-.00172	-.00086	0	-.00172	.000859	.000859	.001717	.003434
60	.006864	.002576	.006014	.004307	.004296	.005154	.005151	.006869
90	.008581	.007729	.010309	.009475	.007732	.008590	.008586	.009445

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00395	-.00057	.010305	.008585

-MIX 61-

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

DAYS: READINGS:

	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

	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:

	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

	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:

	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

	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 64-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	192	288	273	270	317	299	319	236
14	191	293	273	273	319	301	322	241
30	199	300	297	279	325	307	327	246
60	203	303	284	284	328	312	333	251
90	205	303	287	285	331	314	335	251

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	-.00086	.004290	0	.002575	.001716	.001716	.002574	.004292
30	.006012	.010297	.020597	.007724	.006863	.006864	.006863	.008585
60	.009447	.012871	.009440	.012015	.009437	.011154	.012010	.012877
90	.011164	.012871	.012015	.012873	.012010	.012870	.013726	.012877

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.002038	.007601	.011156	.012551

-MIX 65-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	416	374	270	118	229	280	377	366
14	411	365	264	109	222	272	372	364
30	420	376	270	118	229	278	378	370
60	428	383	282	127	235	291	385	377
90	430	385	283	128	237	292	387	380

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	-.00429	-.00772	-.00515	-.00773	-.00601	-.00687	-.00429	-.00172
30	.003429	.001715	0	0	0	-.00172	.000857	.003430
60	.010286	.007717	.010299	.007734	.005151	.009440	.006859	.009433
90	.012000	.009432	.011157	.008593	.006868	.010298	.008574	.012005

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	-.00601	.000964	.008365	.009866

-MIX 66-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	309	302	302	275	221	186	289	335
14	322	314	311	282	228	195	303	348
30	335	328	329	302	248	213	322	363
60	358	356	361	325	283	251	357	392
90	370	368	377	344	297	265	369	403

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.011153	.010296	.007722	.006007	.006010	.007730	.012013	.011151
30	.022306	.022308	.023166	.023171	.023182	.023189	.028317	.024017
60	.042039	.046331	.050621	.042909	.053232	.055825	.058350	.048891
90	.052334	.056627	.064349	.059215	.065252	.067848	.068647	.058327

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.009010	.023048	.048615	.066524

-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 70-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	238	299	302	354	439	283	338	376
14	244	299	303	356	438	285	340	380
30	249	303	306	361	443	289	344	383
60	250	307	308	364	447	293	348	387
90	253	309	317	369	452	299	353	387

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.005151	0	.000858	.001715	-.00086	.001716	.001715	.003430
30	.009443	.003432	.003432	.006003	.003428	.005149	.005146	.006002
60	.010301	.006864	.005148	.008576	.006856	.008581	.008577	.009432
90	.012877	.008580	.012870	.012864	.011141	.013730	.012866	.009432

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.000858	.004656	.008042	.011795

-MIX 71-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	368	54	301	334	308	342	289	193
14	410	84	322	356	327	362	305	224
30	521	211	431	456	438	469	413	354
60	SAMPLE	355	555	584	565	612	533	471
90	SAMPLE	384	618	638	636	681	579	517

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.036015	.025794	.018018	.018871	.016301	.017154	.013729	.026622
30	.131198	.134991	.111539	.104646	.111532	.108927	.106402	.138265
60	0	.258805	.217930	.214438	.220491	.231577	.209372	.238743
90	0	.283739	.271984	.260756	.281405	.290758	.248844	.278248

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.016814	.108609	.227337	.273676

-MIX 72-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	248	356	173	185	330	406	325	224
14	262	365	185	194	341	416	336	234
30	297	403	233	220	370	447	364	260
60	330	472	324	279	430	516	403	284
90	347	518	SAMPLE	310	460	559	434	298

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.012017	.007718	.010307	.007730	.009436	.008572	.009436	.008586
30	.042061	.040307	.051536	.030060	.034311	.035146	.033455	.030908
60	.070387	.099480	.129699	.080732	.085778	.094294	.066910	.051514
.22	.084980	.138929	0	.107356	.111511	.131155	.093502	.063533

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.009225	.032776	.090071	.122238

-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 76-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	403	318	387	282	270	277	285	160
14	412	325	391	291	277	283	293	168
30	420	336	400	301	286	291	301	170
60	429	344	410	310	298	299	308	180
90	433	352	417	319	309	309	315	185

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.007715	.006005	.003429	.007723	.006008	.005149	.006865	.006872
30	.014573	.015442	.011146	.016305	.013732	.012014	.013730	.008590
60	.022288	.022305	.019719	.024028	.024030	.018880	.019737	.017181
90	.025717	.029168	.025721	.031751	.033471	.027461	.025743	.021476

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.006221	.013849	.021569	.026762

-MIX 77-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	139	323	218	273	327	158	473	400
14	146	325	219	272	326	157	476	406
30	150	330	224	278	332	163	480	411
60	153	333	227	281	336	167	484	411
90	155	335	232	285	342	171	487	413

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.006014	.001716	.000859	-.00086	-.00086	-.00086	.002570	.005144
30	.009451	.006005	.005152	.004291	.004289	.004295	.005997	.009430
60	.012029	.008578	.007727	.006866	.007720	.007731	.009424	.009430
90	.013747	010294	.012020	.010298	.012867	.011168	.011994	.011144

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.000428	.005005	.008211	.011692

-MIX 78-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	274	338	313	344	245	130	303	296
14	278	341	313	348	250	132	305	303
30	288	351	323	358	259	138	316	311
60	286	351	323	355	257	138	313	311
90	290	354	326	357	262	140	317	314

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.003433	.002573	0	.003431	.004292	.001719	.001716	.006006
30	.012015	.011150	.008579	.012007	.012018	.006874	.011154	.012870
60	.010298	.011150	.008579	.009434	.010301	.006874	.008580	.012870
90	.013731	.013724	.011153	.011150	.014593	.008593	.012012	.015445

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.002452	.011869	.009724	.013115

-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 82-

CONTROL AGGREGATE, LOW ALKALI CEMENT. NO FLY ASH

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	145	145	5	10	198	226	265	260
14	280	248	118	210	270	330	323	470
30	315	300	214	303	347	402	518	566
60	348	344	245	334	383	439	555	597
90	360	358	261	346	394	449	562	603

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.115984	.088492	.097200	.172028	.061830	.089289	.049779	.180242
30	.146054	.133167	.179777	.252021	.127954	.151104	.217139	.262638
60	.174406	.170970	.206443	.278686	.158869	.182870	.248895	.289246
90	.184716	.182998	.220206	.289007	.168315	.191456	.254903	.294395

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.083762	.139570	.171779	.181871

-MIX 83-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	193	206	139	149	134	140	159	134
14	305	264	215	213	197	205	220	250
30	333	300	265	260	240	251	263	292
60	365	333	309	309	271	288	299	325
90	386	350	330	319	291	307	316	345

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.096184	.049804	.065298	.054983	.054131	.055847	.052401	.099670
30	.120230	.080717	.108258	.095362	.091078	.095369	.089340	.135757
60	.147712	.109054	.146062	.137458	.117714	.127159	.120266	.164112
90	.165746	123652	.164105	.146049	.134898	.143483	.134869	.181296

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.053433	.090373	.129346	.136590

-MIX 84-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	188	219	139	157	163	235	226	74
14	318	314	219	234	223	290	302	169
30	334	328	236	255	236	299	318	183
60	344	338	249	268	245	307	324	191
90	351	347	259	278	255	315	331	193

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.111647	.081567	.068735	.066147	.051541	.047216	.065249	.081668
30	.125389	.093587	.083341	.084187	.062708	.054943	.078986	.093704
60	.133977	.102173	.094511	.095355	.070439	.061811	.084138	.100581
90	.139989	.109900	.103103	.103946	.079029	.068678	.090147	.102300

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.066018	.078779	.087001	.093872

-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 88-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	204	187	282	272	168	184	203	144
14	220	192	280	273	166	185	208	159
30	223	195	281	273	171	188	211	163
60	227	200	286	278	173	192	215	167
90	232	205	292	284	180	198	220	171

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.013739	.004294	-.00172	.000858	-.00172	.000859	.004294	.012887
30	.016315	.006871	-.00086	.000858	.002577	.003435	.006870	.016324
60	.019750	.011165	.003433	.005149	.004295	.006871	.010305	.019760
90	.024044	.015459	.008581	.010298	.010308	.012024	.014598	.023197

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.001145	.001503	.004937	.010303

-MIX 89-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	248	-180	154	188	205	258	100	175
14	422	-40	270	294	449	412	262	391
30	469	11	315	318	509	473	331	447
60	487	31	331	341	542	505	362	473
90	491	35	335	344	550	514	372	482

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.149359	.120617	.099653	.091036	.209523	.132180	.139235	.185527
30	.189703	.164556	.138311	.111647	.261045	.184537	.198539	.233627
60	.205154	.181787	.152057	.131400	.289382	.212003	.225183	.255959
90	.208587	.185233	.155493	.133977	.296252	.219727	.233777	.263689

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.159441	.201601	.214113	.220697

-MIX 90-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	BROKEN	216	179	143	BROKEN	137	136	226
14	BROKEN	354	288	284	BROKEN	258	278	449
30	BROKEN	386	322	323	BROKEN	296	312	466
60	BROKEN	407	341	342	BROKEN	312	331	484
90	BROKEN	411	344	348	BROKEN	317	335	489

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	0	.118490	.093619	.121141	0	.103964	.122008	.191456
30	0	.145965	.122822	.154648	0	.136613	.151221	.206051
60	0	.163996	.139141	.170972	0	.150360	.167546	.221505
90	0	.167431	.141717	.176127	0	.154656	.170983	.225798

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.116401	.147112	.158403	.162183

-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 94-

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

DAYS: READINGS:

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	285	213	452	440	293	BROKEN	331	453
14	439	319	551	535	393	BROKEN	440	612
30	459	338	577	563	419	BROKEN	465	633
60	469	349	588	571	431	BROKEN	475	647
90	473	353	589	572	436	BROKEN	477	653

DAYS: % EXPANSION

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.132149	.091016	.084831	.081412	.085805	0	.093497	.136243
30	.149311	.107330	.107110	.105407	.108115	0	.114942	.154238
60	.157892	.116775	.116536	.112263	.118411	0	.123519	.166234
90	.161325	.120210	.117393	.113120	.122701	0	.125235	.171375

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.087312	.108581	.117501	.119732

-MIX 95-

CONTROL AGGREGATE, HIGH ALKALI CEMENT, NO FLY ASH

DAYS: READINGS:

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	226	SAMPLE	277	315	157	223	-143	181
14	563	SAMPLE	SAMPLE	565	454	507	120	476
30	593	SAMPLE	SAMPLE	604	504	568	173	514
60	620	SAMPLE	SAMPLE	626	533	593	195	540
90	621	SAMPLE	SAMPLE	631	532	595	198	542

DAYS: % EXPANSION

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.289330	0	0	.214473	.255139	.243833	.226515	.253369
30	.315086	0	0	.247930	.298092	.296206	.272163	.286006
60	.338267	0	0	.266804	.323005	.317670	.291111	.308337
90	.339126	0	0	.271093	.322146	.319387	.293695	.310055

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.238666	.285914	.307532	.309250

-MIX 96-

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

DAYS: READINGS:

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	514	522	744	361	180	165	20	284
14	710	711	897	499	340	339	183	481
30	731	735	923	526	372	368	212	510
60	745	757	938	544	392	388	229	530
90	751	763	945	550	400	398	236	538

DAYS: % EXPANSION

	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.167860	.161854	.130776	.118342	.137422	.149465	.140191	.169049
30	.185845	.182407	.152999	.141496	.164906	.174376	.165133	.193935
60	.197835	.201247	.165820	.156932	.182084	.191556	.179754	.211097
90	.202974	.206385	.171804	.162077	.188955	.200146	.185774	.217962

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.150945	.174229	.189913	.188302

-MIX 97-

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

DAYS: READINGS:

	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

	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:

	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

	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:

	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

	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 100-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	331	281	259	289	271	307	315	295
14	442	353	339	363	340	379	400	398
30	453	367	356	376	354	393	417	412
60	466	381	370	390	368	408	429	424
90	470	388	378	398	375	416	437	430

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.095213	.061786	.068664	.063498	.059217	.061772	.072921	.088378
30	.104648	.073800	.083255	.074653	.071232	.073784	.087505	.100390
60	.115799	.085814	.095272	.086666	.083247	.086653	.097800	.110687
90	.119230	.091821	.102138	.093531	.089254	.093516	.104663	.115835

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.064643	.077371	.089242	.095821

-MIX 101-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	234	287	375	378	370	415	166	208
14	303	339	422	420	411	447	212	285
30	307	345	434	429	420	456	223	292
60	315	355	440	438	429	467	231	298
90	318	358	443	440	433	468	234	301

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.059236	.044621	.040300	.036012	.035157	.027429	.039513	.066118
30	.062670	.049770	.050589	.043729	.042874	.035143	.048962	.072129
60	.069537	.058351	.055734	.051446	.050592	.044572	.055834	.077281
90	.072113	.060925	.058307	.053160	.054022	.045429	.058411	.079857

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.039121	.047185	.052755	.056965

-MIX 102-

CONTROL AGGREGATE, HIGH ALKALI CEMENT, 27% HIGH ALKALI FLY ASH B

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	500	263	216	234	186	260	407	420
14	760	510	442	467	401	474	627	665
30	826	580	515	550	474	559	703	736
60	860	621	555	591	513	599	735	771
90	873	635	570	609	532	SAMPLE	750	785

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.222698	.211994	.194048	.200027	.184651	.183675	.188587	.209994
30	.279229	.272073	.256727	.271282	.247346	.256630	.253735	.270849
60	.308351	.307262	.291072	.306480	.280841	.290962	.281166	.300849
90	.319486	.319278	.303951	.321933	.297159	0	.294024	.312848

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.199459	.263484	.295873	.309811

-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

-MIX 103-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	239	387	327	306	344	268	276	290
14	436	548	459	441	472	411	420	498
30	465	584	485	468	506	444	450	535
60	481	606	506	489	530	459	468	551
90	487	611	507	489	535	470	475	564

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.169115	.138035	.113230	.115824	.109783	.122728	.123578	.178479
30	.194010	.168900	.135533	.138989	.138944	.151050	.149323	.210228
60	.207745	.187762	.153547	.157006	.159528	.163923	.164770	.223957
90	.212896	.192049	.154404	.157006	.163816	.173364	.170777	.235112

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.120530	.147123	.164423	.168569

-MIX 104-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	230	205	263	218	243	183	243	254
14	294	241	295	249	280	214	281	323
30	299	242	302	256	289	220	288	329
60	305	250	310	263	297	232	297	335
90	311	256	317	269	304	235	303	340

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.054945	.030913	.027465	.026617	.031762	.026625	.032620	.059225
30	.059238	.031772	.033473	.032627	.039487	.031778	.038629	.064375
60	.064389	.038642	.040339	.038637	.046355	.042084	.046355	.069526
90	.069540	.043794	.046347	.043789	.052364	.044661	.051505	.073817

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.029334	.034628	.042069	.047077

-MIX 105-

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

DAYS: READINGS:

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	171	156	-254	181	87	266	274	566
14	196	168	-246	186	96	275	285	622
30	203	177	-237	197	106	282	292	627
60	206	183	-230	201	109	288	299	629
90	213	188	-225	208	115	294	305	638

DAYS: % EXPANSION

DAYS	BAR1	BAR2	BAR3	BAR4	BAR5	BAR6	BAR7	BAR8
1	0	0	0	0	0	0	0	0
14	.021474	.010309	.006897	.004294	.007736	.007724	.009440	.047939
30	.027486	.018040	.014656	.013742	.016332	.013732	.015447	.052219
60	.030063	.023195	.020690	.017178	.018911	.018882	.021455	.053931
90	.036076	.027490	.025001	.023190	.024068	.024031	.026604	.061635

AVERAGES:	DAY 1	DAY 14	DAY 30	DAY 60	DAY 90
	0	.008421	.015325	.019423	.025064

APPENDIX B

MATERIAL PROPERTIES

MATERIAL: Cement Type I
PRODUCER: Texas Cement Company, Buda, Texas

PHYSICAL PROPERTIES

COMPRESSIVE STRENGTH:	3 Day: 3843 psi 7 Day: 4515 psi 28 Day: 5422 psi
SPECIFIC SURFACE AREA:	1750 cm^2/gr
SOUNDNESS (Autoclave Expansion):	0.03%
TIME OF SETTING (Gillmore):	Initial: 3.25 hrs Final: 6.92 hrs
AIR CONTENT:	10.2%
NORMAL CONSISTENCY:	26.5%

CHEMICAL PROPERTIES

METAL OXIDES:	CaO: 63.54% Al_2O_3: 5.92% Fe_2O_3: 2.56% SiO_2: 19.73% SO_3: 2.97% MgO: 1.25%
ALKALI OXIDES:	Na_2: 0.07% K_2O: 0.90%
TOTAL ALKALIS (Na_2O + 0.6K_2O):	0.66%
PHASE ANALYSIS:	C_3S: 56.86% C_2S: 13.68% C_3A: 11.35% C_4AF: 7.78%
TOTAL OXIDES:	89.67%
TOTAL PHASES:	95.97%
LOSS ON IGNITION:	1.31%
INSOLUBLE RESIDUE:	0.27%

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: Cement Type IP (20% Fly Ash)
PRODUCER: Texas Industries, Inc., Midlothian, Texas

PHYSICAL PROPERTIES

COMPRESSIVE STRENGTH:	3 Day: 3415 psi 7 Day: 4140 psi 28 Day: 5330 psi
SPECIFIC SURFACE AREA:	3690 cm^2/gr
TIME OF SETTING (Gillmore):	Initial: 3.00 hrs Final: 5.00 hrs
SOUNDNESS (Autoclave Expansion):	-0.05%
AIR CONTENT:	10.2%
NORMAL CONSISTENCY:	24.0%

CHEMICAL PROPERTIES

METAL OXIDES:	CaO: 53.58% Al_2O_3: 8.46% Fe_2O_3: 2.73% SiO_2: 28.84% SO_3: 3.06% MgO: 1.10%
ALKALI OXIDES:	Na_2O: 0.24% K_2O: 0.40%
TOTAL ALKALIS ($Na_2O + 0.6K_2O$):	0.504%
LOSS ON IGNITION:	0.56%

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 A
PRODUCER: Big Brown Plant, Texas

PHYSICAL PROPERTIES

WATER REQUIREMENT:	88.00%
FINENESS:	9.00%
SOUNDNESS (Autoclave Expansion):	-0.02%
SPECIFIC GRAVITY:	2.46
INCREASE OF DRYING SHRINKAGE:	-0.02%

CHEMICAL PROPERTIES

SUM OF SiO_2, Al_2O_3, AND Fe_2O_3:	74.18%
CaO:	14.35%
SO_3:	1.00%
MgO:	2.56%
MOISTURE CONTENT:	0.01%
LOSS ON IGNITION:	0.35%
AVAILABLE ALKALIS ($Na_2O + 0.6K_2O$):	0.57%

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%

MATERIAL: Fly Ash Type B
PRODUCER: Harrington Plant, Unit 3, Texas

PHYSICAL PROPERTIES

WATER REQUIREMENT:	89.60%
FINENESS:	18.00%
SOUNDNESS (Autoclave Expansion):	0.01%
SPECIFIC GRAVITY:	2.63%
INCREASE OF DRYING SHRINKAGE:	-0.01%

CHEMICAL PROPERTIES

SUM OF SiO_2, Al_2O_3, AND Fe_2O_3:	62.90%
CaO:	30.47%
SO_3:	1.89%
MgO:	4.61%
MOISTURE CONTENT:	0.00%
LOSS ON IGNITION:	0.25%
AVAILABLE ALKALIS ($Na_2O + 0.6K_2O$):	1.67%

APPENDIX C

MIX DATA

MIX PROPORTIONS[a]

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
1	35.88	0.00	80.93	20 01	0.58	0	0	0.182	0.497	0.321
2	29.38	5.17	79.79	19.73	0.57	15	22	0.194	0.490	0.316
3	23.16	9.85	78.93	19.52	0.59	28	41	0.203	0.484	0.313
4	19.52	13.01	78.93	18.97	0.58	37	52	0.211	0.485	0.304
5	29.70	5.23	80.67	19.94	0.57	15	18	0.185	0.495	0.320
6	23.65	10.06	80.60	19.93	0.59	28	35	0.186	0.495	0.319
7	19.89	13.26	80.43	19.89	0.60	37	48	0.188	0.494	0.318
8	29.80	5.24	80.92	20.01	0.57	15	17	0.183	0.497	0.320
9	23.80	10.12	81.09	20 05	0.59	28	33	0.181	0.498	.0321
10	20.05	13.36	81.08	20.05	0.60	37	44	0.181	0.498	0.321
11	30.04	5.29	81.57	20.17	0.57	15	17	0.185	0.501	0.314
12	23.97	10.19	81.67	20.19	0.59	28	34	0.184	0.501	0.315
13	20.26	13.51	81.98	19.42	0.57	37	44	0.185	0.503	0.312
14	35.56	0.00	80.22	20.38	0.57	0	0	0.181	0.493	0.326
15	29.64	5.22	80.50	19.35	0.55	15	22	0.196	0.494	0.310
16	23.45	10.08	79903	18.93	0.56	28	41	0.206	0.491	0.303
17	19.81	13.06	79.28	18.78	0.57	37	52	0.212	0.487	0.301
18	29.84	5.25	81.03	19.76	0.58	15	18	0.186	0.497	0.318
19	23.84	10.16	80.54	19 91	0.59	28	35	0.186	0.495	0.319
20	20.25	13.49	81.88	19.12	0.57	37	46	0.191	0.503	0.306
21	30.07	5.29	81.65	19.63	0.55	15	17	0.184	0.501	0.314
22	23.78	10.22	81.04	20.04	0.59	28	33	0.181	0.498	0.321
23	20.51	13.67	82.93	19.08	0.56	37	44	0.185	0.509	0.306
24	29.77	5.24	80.85	19.99	0.57	15	17	0.183	0.498	0.321

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	80.69	20.00	0.59	28	34	.0183	0.497	0.320
26	20.19	13.45	81.81	19.82	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	0.528	0.278
28	32.04	5.84	87.02	18.73	0.44	15	22	0.212	0.520	0.288
29	26.21	10.84	85.91	18.52	0.48	28	41	0.221	0.514	0.285
30	21.17	14.10	85.59	18.18	0.48	37	52	0.229	0.512	0.259
31-Batch1	32.27	5.88	87.84	18.55	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	18.90	0.48	28	35	0.203	0.528	0.271
33	21.71	14.47	87.78	18.88	0.47	37	48	0.205	0.525	0.270
34	32.38	5.70	87.94	17.21	0.45	15	17	0.198	0.526	0.278
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	18.75	0.44	15	17	0.201	0.530	0.289
38	25.92	11.14	88.32	16.98	0.48	28	34	0.200	0.528	0.272
39	21.85	14.55	88.32	18.98	0.47	37	44	0.200	0.528	0.272
40	36.79	0.00	87.52	17.43	0.45	0	0	0.197	0.523	0.280
41	31.74	5.58	58.19	17.17	0.48	15	22	0.210	0.515	0.275
42	25.21	10.84	85.91	18 52	0.48	28	41	0.221	0.514	0.285
43	21.07	14.04	85.19	18.38	0.47	37	52	0.228	0.509	0.263
44	32.11	5.85	87.22	17.37	0.48	15	18	0.200	0.521	0.279
45	25.60	11.09	87.91	18.91	0.46	15	18	0.203	0.528	0.271
46	21.71	14.47	87.78	18.88	0.47	28	35	0.205	0.525	0.270
47	32.22	5.67	87.51	17.43	0.48	37	48	0.198	0.523	0.279
48	25.97	11.17	88.50	17.02	0.48	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
49	21.90	14.59	88.55	17.03	0.47	28	33	0.198	0.529	0.273
50	32.19	5.66	87.42	17.41	0.46	37	44	0.198	0.523	0.279
51	25.92	11.14	88.32	18.98	0.48	15	17	0.200	0.528	0.272
52	21.85	14.55	88.32	16.98	0.47	28	34	0.200	0.528	0.272
53	38.60	0.00	87.08	17.04	0.44	37	44	0.198	0.530	0.274
54	31.58	5.58	85.78	18.79	0.45	15	22	0.208	0.522	0.270
55	25.84	11.11	88.04	14.75	0.40	28	41	0.227	0.536	0.237
56	21.67	14.44	87.83	14.44	0.40	37	52	0.235	0.534	0.231
57	33.22	5.85	90.22	15.18	0.39	15	18	0.207	0.550	0.243
58-Batch1	28.45	11.37	90.15	15.11	0.40	28	35	0.209	0.549	0.242
58-Batch2	28.72	11.49	91.05	14.83	0.38	28	35	0.211	0.555	0.234
59-Batch1	22.13	14.75	89.48	15.38	0.42	37	48	0.209	0.545	0.246
59-Batch2	22.35	14.89	90.37	14.90	0.40	37	48	0.211	0.551	0.238
60	33.34	5.87	90.54	15.23	0.39	15	17	0.204	0.552	0.244
61	28.81	11.44	90.68	15.26	0.40	28	33	0.203	0.553	0.244
62	22.55	15.03	91.18	15.03	0.40	37	44	0.204	0.558	0.240
63	33.30	5.88	90.44	15.22	0.39	15	17	0.205	0.551	0.244
64-Batch1	25.66	11.03	87.45	18.82	0.48	28	34	0.198	0.533	0.269
64-Batch2	25.91	11.14	88.30	18.37	0.44	28	34	0.200	0.538	0.262
65	22.49	14.99	90.94	14.99	0.40	37	44	0.208	0.554	0.240
66	39.74	0.00	89.85	15.70	0.39	0	0	0.202	0.546	0.252
67	32.82	5.77	89.12	15.00	0.39	15	22	0.217	0.543	0.240
68	28.19	11.28	89.26	14.10	0.38	28	41	0.230	0.544	0.228
69	21.88	14.58	88.48	13.98	0.38	37	52	0.379	0.539	0.224
70	33.06	5.82	89.77	14.41	0.40	15	18	0.208	0.547	0.247

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	28.69	11.48	90.96	14.68	0.38	28	35	0.211	0.554	0.235
72	22.58	15.04	91.26	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	11.81	92.06	14.54	0.38	28	33	0.208	0.581	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	28.82	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	0.208	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	18.15	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	18.52	0.49	15	18	0.184	0.551	0.285
84	23.70	10.19	80.75	18.08	0.47	28	35	0.187	0.555	0.258
85	20.04	13.35	81.00	15.88	0.47	37	46	0.189	0.557	0.254
86	29.74	5.23	80.78	18.37	0.47	15	17	0.182	0.556	0.262
87	24.06	10.34	81.98	15.77	0.48	28	33	0.184	0.564	0.252
88	20.20	13.46	81.88	15.98	0.47	37	44	0.182	0.562	0.258
89	29.85	5.25	81.08	18.15	0.48	15	17	0.184	0.557	0.259
90	24.01	10.32	81.83	15.74	0.48	28	34	0.185	0.583	0.252
91	20.15	13.42	81.48	15.94	0.47	37	44	0.184	0.560	0.258
92	35.85	0.00	80.43	18.57	0.48	0	0	0.181	0.553	0.288
93	29.33	5.16	79.85	18.14	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	0.258

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
95	19.57	13.04	79.13	15.22	0.47	37	52	0.212	0.544	0.244
96	29.52	5.19	80.17	18.52	0.48	15	18	0.184	0.551	0.265
97	23.59	10.14	80.40	16.29	0.48	28	35	0.186	0.553	0.261
98	20.13	13.41	81.36	15.65	0.47	37	48	0.182	0.558	0.262
99	29.74	5.23	80.78	16.37	0.47	15	17	0.182	0.558	0.262
100	23.72	10.20	80.82	18.43	0.48	28	33	0.181	0.558	0.263
101	20.29	13.52	82.03	15.77	0.47	37	44	0.183	0.564	0.253
102	29.58	5.21	80.34	18.55	0.48	15	17	0.182	0.553	0.265
103	23.80	10.23	81.10	18.15	0.47	28	34	0.183	0.558	0.259
104	20.24	13.48	81.83	15.74	0.47	37	44	0.185	0.563	0.252
105	35.88	0.00	80.93	20.01	0.58	0	0	0.182	0.497	0.321
106	38.99	0.00	87.95	17.21	0.44	0	0	0.198	0.528	0.278
107	40.14	0.00	90.55	15.24	0.38	0	0	0.204	0.552	0.244
108	36.48	0.00	82.25	15.53	0.43	0	0	0.165	0.588	0.249

a. Original batch weight determined as per ASTM C 227 specification.
b. Refers to oven-dry weights per ft^3.
c. Refers to mixing water per ft^3 to produce the required consistency as per ASTM C 227 specification.
d. Cement + Fly Ash.
e. Refers to fly ash content expressed as a percent of the total weight and volume of the portland cement in the mixes without fly ash.