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SD Department of Transportation
Office of Research

Supplementary Report - 4

Physical and Elastic Properties of Natural Pozzolan Blended (Type-IP) Cement Concretes

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Physical and Elastic Properties of Natural Pozzolan Blended (Type-IP) Cement Concretes

Development of a Type IP Cement

Study SD91-11
Final Report

Prepared by
South Dakota School of Mines and Technology
Department of Civil Engineering
Rapid City, SD 57701-3995

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DISCLAIMER

This work was performed under the supervision of the SD91-11 Technical Panel:

Sarah Chadima ..... SD Geological Survey
Dan Johnston .... Office of Research
Court Patterson .... SD Cement Plant
Howard Schill ..... Materials and Surfacing
David Wang ...... Materials and Surfacing

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V. Ramakrishnan and V. R. Sure

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16. Abstract

Alkali reactive sands or coarse aggregates, when used in concrete structures, produce severe deterioration because of expansion and cracking. The use of pozzolan blended cement is an attractive solution to mitigate this problem. This report presents the results of an experimental investigation to evaluate the characteristics of pozzolan blended cement concretes. A comparison of these properties with those of unblended cements is also given. The Type I/II cement was blended with three different amounts of 10%, 15%, 25% by weight of cement with five different types of natural pozzolans available in the western South Dakota near Rapid City. The tests carried out include: (1) Fresh concrete properties such as slump, unit weight, vebe time, air content, and concrete temperature and (2) Hardened concrete properties such as compressive strength, static modulus of elasticity, flexural and impact strengths.

All tests were done according to the ASTM recommendations and procedures. Good workability of concrete was achieved even though the water content was kept uniformly the same for all mixes, without adding any water reducing agent or superplasticizer. The test results indicated that there was no significant difference in the physical properties of pozzolan blended cement concretes in comparison with control concrete during mixing and placing. An increase in the pozzolan content slightly decreased the compressive strength and modulus of rupture. The static modulus results indicated that the values were almost the same for all the concretes.

From the results of the static flexure test, load deflection curves were plotted from which the toughness indexes were calculated according to the ASTM standard method. The toughness indexes (ASTM) decreased slightly with an increase in the amount of pozzolan.

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CHAPTER 1 INTRODUCTION

1.1 GENERAL

Alkali reactive sands or coarse aggregates, when used in concrete structures, produce severe deterioration. It is known that certain internal chemical reactions between the cement alkalies and aggregates cause harmful expansions. These alkali-aggregate reactions (AAR) normally occur between the cement alkalies such as sodium and potassium hydroxide and certain type of siliceous materials in the aggregate. Three types of alkali aggregate reactions have been recognized and are based on the type of mineral causing the expansion (1).

1. Alkali-Silica Reaction: The rocks and minerals involved in this type of AAR are the vitreous poorly crystalline and strained forms of silica which occur in sedimentary, igneous, and metamorphic rocks in the form of opal, chert, chalcedony and quartz. Expansion has also been found to result from the use of some volcanic rocks when silicate glasses or crypto-crystalline minerals are present. The expansions caused by these forms of silica have been found to be significantly slower than those caused by opal. The mechanism involved in the alkali-silica reaction is the formation of a siliceous gel formed by the reaction between the cement alkalies and the silica minerals which absorb water and exerts a swelling pressure leading to cracks in concrete.

2. Alkali-Carbonate Reaction: This was described in the 1960's when it was recognized. It is an expansive mechanism but is different from alkali-silica reaction. In this type of reaction, dolomite has been found to be the main rock causing the reaction. A detailed study of this phenomenon was carried out by Grattan-Bellew and Gillott (2) In this type of reaction the gel was absent and the volume increase was found to be causing the expansion.

3. Alkali-Silicate Reaction: Some silicate rocks like low grade metamorphic greywackes, phyllites, and argillites have been attributed to this type of reaction.

The main factor contributing to the alkali-silica reaction is the amount of alkali present in the cement. The alkali hydroxide formed with sodium or potassium ions which are present in the cement in the form of salts and double salts such as potassium sulfate. When these salts go into the solution,the sulfate or chloride ions react with certain components such as C_3A. The hydroxyl ion is available to rise the PH and render the solution aggressive to reactive silica. Another source of alkalies is from the de-icing salts (NaCl). Curing conditions leading to concentration of soluble alkalies at the surface contribute to the enhancement of AAR in concrete.

In order to prevent these deleterious expansions the following three options are available:

1. To use low-alkali cement,
2. To avoid reactive aggregates, and

3. To partially replace cement with fly ash or pozzolans.

Low-alkali cements had been used nationwide to mitigate alkali-aggregate reactions in concrete. However, it is known that low-alkali cements have also been associated with severe alkali-aggregate reactivity in pavements and further low-alkali cement may not always be available. The depletion of good quality aggregates near construction sites has created a need to develop methods that will permit the successful use of marginal aggregates.

Therefore the last option is more attractive. There is an abundant supply of fly ash and other pozzolans. A perusal of the proceedings of three International Conferences (3,4,5) on the use of pozzolans in concrete has shown that pozzolans have effectively controlled AAR with good success. The factors that influence the ability of pozzolan in controlling alkali-aggregate reactions are chemical composition of pozzolan, mixture proportions, type of reactive aggregates and amount of pozzolan used. Some investigators, using low levels of pozzolan replacement, have found that the available alkalies in pozzolan participate in alkali-aggregate reactions (6,7,8). However it was shown by Malhotra and his co-researchers (9,10,11) that when high volume pozzolan replacements are used, the harmful expansions are eliminated. Therefore, in this investigation, five selected pozzolans and one fly ash have been used to mitigate alkali-aggregate reactions.

1.2 PROBLEM STATEMENT

Some existing concrete pavements in South Dakota showed severe deterioration because they might have been constructed with alkali reactive sands. Screening some of the sands by South Dakota Department of Transportation using ASTM C289 test procedure (the dissolved silica test) had indicated that some of the sands currently used may be definitely or potentially deleterious. In South Dakota the majority of alkali aggregate reaction problems are associated with reactive sands, and the Sioux quartzite, which is extensively used in South Dakota pavement construction, is also alkali reactive although very slowly. The best solution to minimize or to eliminate the above mentioned problem will be to use pozzolan blended type IP cement.

A type IP cement is a blended hydraulic cement meeting the requirements of ASTM C595-89 "Standard specifications for Blended Hydraulic Cements" and is manufactured by intergrinding a pozzolan with portland cement clinker or by the intimate blending of the pozzolan with a finished cement. The greatest benefit in the reduction of potential AAR expansion would be gained by using intergrinding. There is also a need to establish the suitability of the pozzolan for blending or intergrinding with cements so that maximum benefit in terms of reducing alkali-aggregate reaction potential could be achieved without adversely affecting or altering other properties of concrete. In this study five pozzolans and one fly ash were selected and concretes were made with newly developed blended cements to test their properties and other desirable performance characteristics.

1.3 OBJECTIVES

The primary objective of this investigation is to determine the physical properties of the pozzolan blended cement concretes and compare them with those of unblended cement concrete, made with unblended Type I/II cement. This was achieved by carrying out tests to determine

1. The fresh concrete properties of pozzolan blended cement concretes.
2. The characteristics of hardened concrete such as compressive strength, static modulus, static flexure strength, unit weight and impact strength.
3. The toughness indexes according to the ASTM method with the help of load deflection curves.

1.4 DEFINITIONS OF THE TERMS USED IN THIS REPORT:

1. Compressive Strength - The compressive strength of a specimen is defined as the maximum load attained during the test divided by the cross-sectional area of the specimen.

2. Static Modulus - The value of Young's modulus of elasticity obtained from measuring stress-strain relationships derived from other than dynamic loading.

3. **First Crack** - The point on the load deflection curve when the curve becomes non linear.

4. **First Crack Deflection** - The deflection value on the load deflection curve at the first crack.

5. **First Crack Toughness** - The energy equivalent to the area of the load deflection curve upto the first crack.

6. **Toughness** - The energy equivalent to the area under the load deflection curve upto a specified deflection.

7. **Toughness Indexes** - The number obtained by dividing the area upto a specified deflection by the area upto the first crack of the load deflection curve.

8. **Toughness Index, I_5** - The number obtained by dividing the area upto 3.0 times the first crack deflection by the area upto the first crack of the load deflection curve.

9. **Toughness Index, I_{10}** - The number obtained by dividing the area upto 5.5 times the first crack deflection by the area upto the first crack of the load deflection curve.

10. **Toughness Index, I_{20}** - The number obtained by dividing the area upto 10.5 times the first crack deflection by the area upto the first crack of the load deflection curve.

CHAPTER 2 LITERATURE SURVEY

2.1 HISTORY OF ALKALI-AGGREGATE REACTION

"Alkali" and Portland cement have been associated in one sense or another almost from the inception of its use in the USA. First there was the effect of "Alkali" on cement, then later the effect of "Alkali" in cement. In the first case, the problem was the effect of the sulfate of the alkali metals (sodium and potassium) and alkali earth metals (magnesium and calcium) on the cement matrix of concrete. In the second case the problem concerned the effect of the hydration products of the sodium and potassium compounds of the cement on the aggregate in the concrete(12).

Despite positive evidence of a reaction between something in the cement with something in the stone (or vice versa), the problem was allowed to stand without any marked attempt at solving it until some years later when the stone producers provided funds for work at Purdue University. There, under Anderegg, it was shown that the alkali in the cement was quickly dissolved by mixing water and dissolved some organic products in the stone and dispersed others. With this information at hand, non-staining cements, low in total alkali, were marketed largely by producers of other than Portland cement(12).

Even with these facts no further study of the alkali or other minor constituents in cement were made. After the lapse of another span of time, a worker under Stanton in the

California Highway Department laboratory came up with the evidence that the alkali could and did react deleteriously with some minerals in aggregate and so at last there was definitely shown the need of study of all the constituents of Portland cement as well as a like study of aggregates(12).

2.2 MECHANISM OF EXPANSION

Expansion is produced when the alkali-silica complex imbibes in water. The initial, most damaging expansion may occur after the product becomes plastic or fluid, if initially formed cracks have no outlets. The force is that of swelling pressure or hydraulic pressure, the two being fundamentally alike(13).

2.3 AUSTRALIAN STUDY

Mortar containing high alkali cement and reactive aggregate is expanded by a reaction product that is present in the gel condition. The swelling aggregate particles produce cracks, which are not completely filled by the reaction product, unless unusually large quantities of water are available for absorption. Observation has shown that the reacting particles do not become soft and readily deformable until considerable time has elapsed after expansion begins. No evidence has been found to suggest that the reaction product is confined to its site of formation by a semi-permeable membrane. It is capable of flowing or is forced along cracks and when large voids are present at or near reacting particles the reaction product will move into them. It seems reasonable to assume that mortar is expanded by swelling gels, not by solutions(14).

The mobility of alkalies in hardened mortar suggests that the aggregate reaction process can occur over a long period. Thus even low alkali cement, if given sufficient time, may cause expansion and cracking(14).

2.4 TESTS AND OBSERVATIONS

In spite of the extensive laboratory investigations of alkali-aggregate reaction, the only reasonable hypothesis of the casual relationship between the alkali-aggregate reaction in concrete and the mechanical disruption which follows that reaction has been that of Hansen(15). His hypothesis proposed that mechanical disruption was caused by the formation of a semi-permeable gel following the reaction of the alkali-hydroxide solution with the reactive silicious aggregate(15).

It is the purpose of the investigation to report the results of some experiments which appear to substantiate and to provide some amplifications for Hansen's hypothesis. Test specimens composed of high alkali cement and reactive aggregate (opal) were exposed to conditions promoting the reaction resulting in cracking and expansion. Petrographic examination at frequent intervals during the course of exposure indicated that the chemical reaction results in liquefaction, swelling and migration of the reaction products. The liquefied gel produced by the reaction fills pores existing in the specimen. After the pore is filled, a reaction at the pore wall occurs to form a dense, semi-permeable membrane through which osmosis takes place, resulting in expansion & cracking(15).

In mortar bar expansion test it was observed that many types of aggregates were combined in varying amounts and sizes with high and low alkali cements and formed into 1"x1"x10" in mortar bars. The bars were stored either at 70 F or at 100 F and their expansions measured at ages ranging from one month to four years.

In combination with high alkali cements, opal, opaline chert and a siliceous dolomitic limestone were found to cause greatest expansion. Certain aggregates containing volcanic glasses and some natural sands and gravel also caused excessive expansion with one exception, these sands contained small amount of opal.

Greatly delayed expansion resulted with the very fine sizes of opal, particularly in combination with high sodium cement. Materials such as dehydrated kaolin, soda, feldspar, magnesium fluosilicate, acetic acid, and calcium hydroxide added in small amounts as a remedial measure were ineffective. However, diatomaceous earth in sufficient quantity as a cement replacement eliminated expansion(15).

2.5 USE OF POZZOLAN IN CEMENT

Portland-Pozzolan cements are being used in major structures to combat the deterioration of concrete due to alkali-aggregate reaction and to obtain other desired properties in concrete. In connection with alkali-aggregate reaction work extensive studies of pozzolanic materials have been made to achieve a better understanding of their characteristics. A pozzolan is considered as any siliceous material, natural or artificial, processed or unprocessed, which in the presence of lime and water develops cementitious properties(16).

The use of pozzolanic cements is not new. There was an old Roman aqueduct built along the Rhine river 2000 years ago. The cement used in that concrete aqueduct was a volcanic pozzolan and crudely burned lime. Until the recent discovery that pozzolans inhibit or reduce expansion due to alkali aggregate reaction the only remedial measure known was to limit, as low as practicable, the alkali content of the cement(16).

Pozzolan cements are also known to be effective in producing concrete resistant to the corrosive action of alkali soils and sea water. There is growing evidence that Portland-Pozzolan cement is the answer to many concrete durability problems, and consequently there is a definite trend toward greater and more widespread demand for pozzolanic type of cements. It was also indicated that if and when effective portland-pozzolan cements can be obtained

6) Ability of pozzolanic materials to reduce the rate at which soluble compounds are leached from concrete.
7) Greater impermeability.

CHAPTER 3 MATERIALS, MIXES AND TEST SPECIMEN

3.1 MATERIALS

Cement

Type I-II portland cement satisfying the requirements of ASTM C150 was used for all mixes. The cement was produced by the South Dakota Cement Plant in Rapid City, South Dakota

Pozzolan

Five selected pozzolans which were found to be effective in controlling the alkali aggregate reaction were used in this investigation. Selected pozzolans are given in Table 3A.

Fly Ash

The fly ash used was a low-calcium, ASTM class F and was obtained from a source in North Dakota, and was supplied by the South Dakota Department of Transportation.

Coarse Aggregate

The coarse aggregate used was crushed lime stone, obtained from a local source in Rapid City. The maximum size of the coarse aggregate was 3/4"(20 mm) with absorption coefficient of 0.45% and fineness modulus of 6.57. A sample sieve analysis of the aggregate is given in Table 1A.

Fine Aggregate

The fine aggregate used was natural sand with a water absorption coefficient of 1.60% and a fineness modulus of 2.56. The sieve analysis is shown in Table 1B.

Both the coarse and fine aggregates satisfied the grading requirements of ASTM C33.

Water

The water used was tap water from the Rapid City Municipal water supply system. The temperature of the water was maintained between 70°F and 72°F.

Air Entraining Agent

The Air entraining agent (Prokrete) of dosage 55.0 cc was used for all the mixes.

3.2 MIXTURE PROPORTIONS

The basic mix proportions are given in Tables 2A, 2B and 2C. The mix designations are shown in Table 3B. Twenty mixes were made by using five pozzolans and one fly ash with varying the percentage of pozzolan as 10%, 15%, 25% and 0.0%(control). Each mix was made in one batch of 2.80 cu.ft. All the mixing was done in a six cubic feet capacity drum mixer. The materials were added to the mixer according to ASTM C192 in the following sequence:

The coarse aggregate and fine aggregate were added in alternate layers. Then two thirds water was added and mixed for one minute to allow the aggregate to absorb water. Cement was then added and the remaining part of the water was added. This was followed by the addition of the Air Entraining agent . All the ingredients were mixed for three minutes which was followed by a three minute rest period and a final mixing period of two minutes.

3.3 TEST SPECIMENS

The following specimens were cast from each mix, nine 6" x 12" (150mm x 300mm) cylinders for compressive strength and static modulus tests. Three 4" x 4" x 14" (100mm x100mmx 350mm) beams for static flexure and toughness tests and three 6"x $2^1/2$"(150mm x63mm) specimens for Impact strength. The specimens were covered with plastic sheets for 24 hours at room temperature. They were then demolded and placed in a lime saturated water tank maintained at 74°F. They remained in water until they were tested at 3, 7 and 28 days.

CHAPTER 4 TESTS FOR CONCRETE

4.1 TESTS FOR FRESH CONCRETE

The freshly mixed concrete was tested for slump (ASTM C143), Air content (ASTM C231), Fresh Concrete unit weight (ASTM C138), Concrete temperature and Vebe time which is recommended by the ACI Committee 544. The results of these tests are given in Table No.4.

4.2 TESTS FOR HARDENED CONCRETE

4.2.1 Compressive Strength and Static Modulus

Cylinders were tested for Compressive Strength at 3, 7 and 28 days according to ASTM C39. They were also tested for the Static Modulus (ASTM C469).

4.2.2 Static Flexure Test

Beams were tested at 28 days for Static Flexural Strength (ASTM C1018). The span length was 12 inches. Deflection was measured at mid-span by using a dial gage accurate to 0.0001 2inch. This test is a deflection controlled test. The rate of deflection was kept in the range of 0.0002 to 0.0004 inches per minute as per ASTM C1018. The loads were recorded at every 0.0002 inch increment in deflection till the first crack appeared after which loads were recorded at regular intervals. The maximum load reached was noted for every beam and is called the first crack load. From the loads and deflections obtained from the tests, load deflection curves were drawn from which the toughness indexes by the ASTM method.

4.2.3 Impact Test

The specimen were tested for impact at 28 days by drop weight test method. In this method, the equipment consisted of a standard manually operated 10 lbs weight with an 18 inch drop, a 2.5 inch diameter hardened steel ball, a flat steel base plate with a positioning bracket and four positioning lugs. The specimen was placed on the base plate with its rough surface facing upwards. The hard steel ball was placed on the top of the specimen and within the four positioning brackets. The compactor was placed with its base on the steel ball. The test was performed on a flat rigid surface to minimize the energy losses. The hammer was dropped consecutively, and the number of blows required to cause the first visible crack on the specimens was recorded. The impact resistance of the specimen to ultimate failure was also recorded by the number of blows required to open the crack sufficiently so that the pieces of specimen were touching at least three sides of the four positioning lugs on the base plate.

CHAPTER 5 TEST RESULTS AND DISCUSSIONS

5.1 FRESH CONCRETE PROPERTIES

All pozzolans and fly ash used in this program performed well. The results of the tests for unit weight, concrete temperature, room temperature and humidity are given in Table 4A. The unit weight for all the twenty mixes was consistent implying that the different percentage of pozzolans did not have much influence on the unit weight of concrete. The pozzolan blended concrete specimens were placed with relative ease and compacted using a vibrating Table. The room temperature, humidity and the concrete temperature were noted to make sure that the mixing of the concrete for twenty mixes was done under similar conditions. It was observed that the mixing action caused intimate spreading of pozzolan uniformly throughout the concrete mix. The fresh concrete specimens with blended pozzolan cement were observed to have very little or no surface bleeding and no segregation. Slump and vebe time tests were conducted to determine the workability of the concrete mixes. Satisfactory air content was maintained by adding 55.0 cc of Air entraining agent for all the mixes. The finishability was good. The water cement ratio was maintained at 0.423.

5.1.1 Workability

The addition of higher percentage of pozzolan reduced the workability except in the case of fly ash where the workability was increased with an increase in the percentage of fly ash. Two tests were done to determine the workability of mixes, namely slump and vebe time. These test results indicated that satisfactory workability can be maintained by using pozzolan blended cement concrete mixes. Figures 1A, 1B, 1C, 2A, 2B, 2C, 3A, 3B, 3C show comparison of slump, vebe time and vebe slump for 10, 15 and 25 percentage mixes respectively. Figures 12A, 12B, 13A, 13B, 14A, 14B, 15A, 15B, 16A, 16B, 17A, 17B show comparison of slump and vebe time respectively for each pozzolan with variation in the percentage of pozzolan.

5.1.2 Air content

An air entraining agent of 55.0 cc was added for all the mixes uniformly. Satisfactory air content was obtained for the pozzolan blended cement concrete mixes. Figures 4A, 4B, 4C show comparison of air content for 10, 15, 25 percentage of pozzolan blended concrete mixes respectively. Figures 12C, 13C, 14C, 15C, 16C, 17C show comparison of air content for each pozzolan with the variation in the percentage of pozzolan.

5.1.3 Fresh concrete unit weight

The results of fresh concrete unit weight are given in Tables 5A(i), 5B(i) and 5C(i) for 10, 15, 25 percentage of pozzolan blended concrete mixes respectively. The results indicate that there is no significant change in the unit weight with the increase of the pozzolan content. Figures 5A, 5B, 5C show comparison of unit weight for 10, 15, 25 percentage of pozzolan blended concrete mixes respectively.

5.1.4 Finishability

Good finishability was achieved with pozzolan blended concrete mixes for all the three percentages of pozzolan additions.

5.2 HARDENED CONCRETE PROPERTIES

5.2.1 Compressive Strength

The compressive strength test results for 3, 7 and 28 days are given in Tables 5A, 5B and 5C for 10, 15 and 25 percentages of pozzolan blended concrete mixes respectively. There was a significant increase in strength from 3 to 7 and 7 to 28 days period. Figures 6A, 6B, 6C show comparison of compressive strength for 10, 15, 25 percentage mixes respectively. However, the increase of pozzolan content did not have much effect on the compressive strength of the blended pozzolan concrete as shown in figures 12D, 13D, 14D, 15D, 16D and 17D.

The following increases in the compressive strength for 10 percent pozzolan blended concrete mixes were observed in comparison with control mix. At 3 days 13 percent for LK2 pozzolan, 8 percent for PS1E pozzolan, 12 percent for CT1 pozzolan, 16 percent for SM2 pozzolan, 3 percent for MW1 pozzolan were observed. At 7 days 1 percent for fly ash, 9 percent for LK2 pozzolan, 12 percent for PS1E pozzolan, 4 percent for CT1 pozzolan, 6 percent for SM2 pozzolan were observed, where as 7 percent reduction for MW1 pozzolan was observed. At 28 days 6 percent for fly ash, 1 percent for PS1E pozzolan, 10 percent for SM2 pozzolan were observed, where as 7 percent reduction for LK2 pozzolan, 6 percent reduction for CT1 pozzolan and 8 percent reduction for MW1 pozzolan were observed.

The following increases in the compressive strength were observed for 15 percent pozzolan blended concrete mixes in comparison with control mix. At 3 days 3 Percent for LK2 pozzolan, 1 percent for PS1E pozzolan, 9 percent for CT1 pozzolan, 3 percent for SM2 pozzolan were observed, where as 14 percent reduction for fly ash, and 3 percent reduction for MW1 pozzolan were observed. At 7 days 4 percent increase for CT1 pozzolan was observed, where as 5 percent reduction for fly ash, 3 percent reduction for PS1E pozzolan, 2 percent reduction for SM2 pozzolan, and 10 percent reduction for MW1 pozzolan were observed. At 28 days 10 percent increase for SM2 pozzolan was observed where as 2 percent reduction for fly ash, 4 percent reduction for LK2 pozzolan, 5 percent reduction for PS1E pozzolan, 6 percent reduction for CT1 pozzolan, and 22 percent reduction for MW1 pozzolan were observed.

The following reductions in the compressive strength were observed for 25 percent pozzolan blended concrete mixes in comparison with control mix. At 3 days 52 percent for fly ash, 14 percent for LK2 pozzolan, 22 percent for PS1E pozzolan, 14 percent for CT1 pozzolan, 17 percent for SM2 pozzolan, and 35 percent for MW1 pozzolan were observed. At 7 days 40 percent for fly ash, 20 percent for LK2 pozzolan, 13 percent for PS1E pozzolan, 23 percent increase for CT1 pozzolan, 6 percent for SM2 pozzolan, and 36 percent for MW1 pozzolan were observed. At 28 days 49 percent for fly ash, 15 percent for LK2 pozzolan, 20 percent for CT1 pozzolan, 16 percent increase for SM2 pozzolan, and 40 percent for MW1 pozzolan were observed. The normalization factors 0.875, 0.842, and 0.949 were applied to calculate compressive strengths at 3, 7, and 28 days which were obtained by comparing the compressive strengths of two batches of control mixes since the concretes with 25 percent pozzolan were mixed in a separate batch.

5.2.2 Static Modulus

The results of the static modulus at 3, 7, 28 days are given in Tables 5A, 5B, 5C for 10, 15 and 25 percentage pozzolan blended concrete mixes respectively. The static modulus results indicated that the values were reasonably consistent for all the mixes as shown in Figures 7A, 7B and 7C. Figures 12E, 13E, 14E, 15E, 16E, 17E show comparison of static modulus for each pozzolan with the increase in the percentage of pozzolan.

5.2.3 Flexural Strength

The 28 day static flexural strength test results were shown in Tables 6A, 6B and 6C for 10, 15 and 25 percent blended pozzolan concrete mixes respectively. A slight decrease in the modulus of rupture was observed with an increase in the percentage of pozzolan as shown in figures 8A, 8B and 8C. Figures 12F, 13F, 14F, 15F, 16F, and 17F give the comparison of flexural strength for individual pozzolans with three different percentages of pozzolan.

The following increases in the flexural strength for 10 percent pozzolan blended concrete mixes were observed in comparison with control mix. 8 percent for PS1E pozzolan, 23 percent for CT1 pozzolan, 29 percent for SM2 pozzolan were observed, where as a reduction of 5 percent for fly ash, LK2 pozzolan and MW1 pozzolan were observed.

The following increases in the flexural strength for 15 percent pozzolan blended concrete mixes were observed in comparison with control mix; 5 percent for LK2 pozzolan, 7 percent for CT1 pozzolan, 18 percent for SM2 pozzolan were observed, where as 7 percent reduction for fly ash, 4 percent reduction for PS1E pozzolan and 15 percent reduction for MW1 pozzolan were observed.

The following reductions in the flexural strength for 25 percent blended pozzolan concrete mixes were observed in comparison with control mix; 36 percent for fly ash, 13 percent for LK2 pozzolan, 2 percent for PS1E pozzolan , 12 percent for CT1 pozzolan, 36 percent for MW1 pozzolan were observed, where as 6 percent increase was observed for SM2 pozzolan. A normalization factor 0.833 was applied to calculate flexural strength at 28 days for 25 percent blended pozzolan concrete mixes which was obtained by comparing the flexural strengths of two batches of control mixes. Concretes with 25 percent pozzolan were mixed in a separate batch.

5.2.4 Load Deflection Curve Behavior

Load deflection curves are a standardized method of showing the energy absorbed by beams during their load induced flexural deflections. The area under the load deflection curve gives the energy absorbed by the beam.

From the load deflection curves it was observed that there was not much difference in elasto-plastic behavior of control and blended pozzolan concretes. All the beams both control and blended pozzolan concrete beams failed immediately after the formation of first crack.

5.2.5 Toughness Indices (ASTM)

The calculated toughness indexes are given in Tables 7A, 7B, and 7C for 10, 15, and 25 percent blended pozzolan concrete mixes. The results indicate that there was no significant change in toughness with an increase in the percentage of pozzolan. The comparison of the toughness index I_5 for different pozzolans with three percentages of pozzolan is shown in figures 9A, 9B, and 9C respectively. The toughness indeces had decreased a little signifying that with an increase of percentage of pozzolan, a lower energy absorption capacity is achieved.

The following increases in the toughness index I_5 for 10 percent pozzolan blended mixes were observed in comparison with control mix; 6 percent for fly ash, 3 percent for LK2 pozzolan, 4 percent for PS1E pozzolan, 31 percent for SM2 pozzolan were observed, where as 2 percent reduction for CT1 pozzolan and 8 percent reduction for MW1 pozzolan were observed.

The following increases in the toughness index I_5 for 15 percent of pozzolan blended concrete mixes were observed in comparison with control mix; 6 percent for LK2 pozzolan, 4 percent for PS1E pozzolan were observed, where as 20 reduction for fly ash, 12 percent reduction for CT1 pozzolan, 28 percent reduction for SM2 pozzolan and 1 percent reduction for MW1 pozzolan were observed.

The following reductions in the toughness index I_5 for 25 percent of pozzolan blended concrete mixes were observed in comparison with control mix; 23 percent for fly ash, 24 percent for LK2 pozzolan, 10 percent for CT1 pozzolan, 5 percent reduction for SM2 pozzolan, and 22 percent reduction for MW1 pozzolan were observed where as no reduction was observed for PS1E pozzolan.

5.2.6 Impact Strength

The drop weight test (ACI Committee 544) was used in this investigation. The results for 10, 15 and 25 percentages of pozzolan blended concrete mixes are given in Tables 8A, 8B, 8C respectively. The comparison of impact strength shown in figures 11A, 11B, 11C for 10, 15 and 25 percentage mixes, indicate that the number of blows for first crack and the number of blows to failure had decreased with an increase in the percentage of pozzolan. The comparison of impact strength for individual pozzolans with increase of percentage of pozzolan is shown in Figures 12H, 13H, 14H, 15H, 16H, 17H.

CONCLUSIONS

1. The compressive strengths of natural pozzolan and fly ash blended cement concretes, for 10 and 15% pozzolans by weight of cement, were not affected due to the addition of pozzolans. When compared to control concretes, compressive strengths of pozzolan blended cement concretes were not significantly different at 3, 7, and 28 days, because the water to cementitious ratio was the same for all the concretes. However, there was some loss of workability due to the addition of pozzolans. When the pozzolans were blended at 25% by weight of cement, the compressive strengths of pozzolan blended cement concretes decreased slightly at 3, 7, and 28 days. The maximum decrease occured in the case of pozzolan MW1 and fly ash. The workability of natural pozzolan blended cement concrete decreased appreciably whereas the workability increased in the case of fly ash blended cement concrete.

2. The influence of blended cements on the static modulus of elasticity of concrete was similar to that of their effect on the compressive strength. For all concretes, there was a direct relationship between the elastic modulus and the compressive strength.

3. The toughness indexes (ASTM) decreased with an increase in the pozzolan content.

4. The flexural toughnesses and flexural strengths decreased with an increase in the pozzolan content.

5. The impact strengths decreased with an increase in the pozzolan content.

6. All the pozzolans performed reasonably well, with no problems with regard to workability, segregation, bleeding and placing.

7. Good finishability was achieved in all concretes.

8. No significant difference in performance characteristics was observed with an increase in the pozzolan content.

9. The Air content of concretes decreased slightly with an increase in the pozzolan content.

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TABLE 1A SIEVE ANALYSIS - COARSE AGGREGATE (3/4" maximum size)

Sieve size Passing through	Retained on	Percent Retained by weight
1.5 in	1.0 in	0.00
1.0 in	3/4 in	3.10
3/4 in	1/2 in	36.00
1/2 in	3/8 in	22.96
3/8 in	1/4 in	23.98
1/4 in	# 4	8.88
# 4	# 8	3.12
# 8	Pan	1.936

Fineness Modulus = 657.03/100 = 6.57

TABLE 1B SIEVE ANALYSIS FOR FINE AGGREGATE

Sieve size Passing through	Retained on	Percent Retained by weight
1/4 in	# 4	.36
# 4	# 8	3.70
# 8	# 16	22.00
# 16	# 30	28.90
# 30	# 50	21.90
# 50	# 100	17.00
#100	# 200	5.40
#200	Pan	.54

Fineness Modulus = 256.16/100 = 2.56

1 INCH= 2.54 CMS

TABLE 2 BASIC MIX PROPORTIONS FOR CONTROL AND POZZOLAN BLENDED CEMENT CONCRETES

MATERIAL	CONTROL MIX	10% MIX	15% MIX	25% MIX	UNITS
Coarse Aggregate	1753	1753	1753	1753	lb/cu yd
Fine Aggregate	1257	1257	1257	1257	lb/cu yd
Cement	600	540	510	450	lb/cu yd
Water	254	254	254	254	lb/cu yd
Pozzolan	NIL	60	90	150	lb/cu yd
Superplasticizer	NIL	NIL	NIL	NIL	
Air entraining agent	55	55	55	55	CC

1 LB= 0.4536 KGS
1 YARD= 0.9144 METER

TABLE 3A. DESIGNATION, LOCATION, DEPOSIT AND DESCRIPTION OF POZZOLANS

DESGN	LOCATION	DEPOSIT	DESCRIPTION
(1)LK2	SOUTH SIDE OF MAIN ST. IN THE GAP, RAPID CITY NE1/4,NE1/4, NW1/4,SEC. 2, TIN, R7E	EARLY CRET. LAKOTA FM.	SILICIFIED VOLCANIC TUFF
(2)PS1E	DAKOTA BLOCK PLANT, R.C. PIT LOCATED IN BOX ELDER AREA	UPPER CRETACEOUS	BROWN SHALE; EXPANDED PIERRE SHALE BY KILN HEATING
(3)CT1	S.H OF CUNY TABLE CENTER OF SEC 20; T41N;R45W	SHARPS FM 10-15 FT ABOVE ROCKY FORD ASH	LIGHT GRAY-MORE LIKE A SILTSTONE
(4)SM2	S.PART OF SHEEP MNT. TABLE SE1/4 NE1/4 SW1/4 SEC 28 T43N R44W	LOWER PART OF ROCKY FORD ASH	V.WHITE, HARD VOLCANIC TUFF
(5)MW1	HAINES AVE SAME AS MW1 BUT EAST OF HAINES AVE	MOWRY SHALE	WEATHERED SAMPLE

DESGN- Designation

TABLE 3B MIX DESIGNATION

MIX NUMBER	TYPE OF POZZOLAN	PERCENTAGE OF POZZOLAN
C	CONTROL	NIL
F-1	FLY ASH	10
F-2	FLY ASH	15
F-3	FLY ASH	25
LK2-1	LK2	10
LK2-2	LK2	15
LK2-3	LK2	25
PS1E-1	PS1E	10
PS1E-2	PS1E	15
PS1E-3	PS1E	25
CT1-1	CT1	10
CT1-2	CT1	15
CT1-3	CT1	25
SM2-1	SM2	10
SM2-2	SM2	15
SM2-3	SM2	25
MW1-1	MW1	10
MW1-2	MW1	15
MW1-3	MW1	25

TABLE 4A(i) PROPERTIES OF FRESH CONCRETES WITH 10% POZZOLAN BLENDED CEMENTS

MIX #	AEA DOSAGE (C.C)	ROOM TEMP. (F)	ROOM HUMIDITY (%)	CONCRETE TEMP. (F)	UNIT WEIGHT (LB/FT^3)
CONTROL	55.2	70	45	66	145.07
F-1	55.2	70	45	68	147.09
LK2-1	55.2	70	30	78	149.52
PS1E-1	55.2	80	35	78	147.50
CT1-1	55.2	75	35	66	151.54
SM2-1	55.2	74	34	72	149.11
MW1-1	55.2	80	45	79	148.71

AEA-AIR ENTRAINING AGENT

TABLE 4A(ii) PROPERTIES OF FRESH CONCRETES WITH 10% POZZOLAN BLENDED CEMENTS

MIX #	SLUMP(in) INITIAL SLUMP	VEBE SLUMP	AVERAGE SLUMP	AIR CONTENT (%)	VEBE TIME (sec)
CONTROL	1.75	1.75	1.75	5.4	1.6
F-1	2.75	2.75	2.75	5.8	1.7
LK2-1	1.75	1.25	1.50	4.3	2.2
PS1E-1	1.50	1.75	1.63	4.0	2.1
CT1-1	0.50	0.00	0.25	3.4	7.6
SM2-1	0.25	0.00	0.13	3.1	7.5
MW1-1	0.50	0.00	0.25	2.8	7.4

1 LB= 0.4536 KGS
1 FOOT= 0.3048 METER

TABLE 4B(i) PROPERTIES OF FRESH CONCRETES WITH 15% POZZOLAN BLENDED CEMENTS

MIX #	AEA DOSAGE (C.C)	ROOM TEMP. (F)	ROOM HUMIDITY (%)	CONCRETE TEMP. (F)	UNIT WEIGHT (LB/FT^3)
CONTROL	55.2	70	45	66	145.07
F-2	55.2	72	45	70	143.86
LK2-2	55.2	80	35	76	147.50
PS1E-2	55.2	80	35	76	147.90
CT1-2	55.2	74	35	70	149.92
SM2-2	55.2	74	40	72	150.32
MW1-2	55.2	80	45	79	150.73

AEA-AIR ENTRAINING AGENT

TABLE 4b(ii) PROPERTIES OF FRESH CONCRETES WITH 15% POZZOLAN BLENDED CEMENTS

MIX #	SLUMP(in) INITIAL SLUMP	VEBE SLUMP	AVERAGE SLUMP	AIR CONTENT (%)	VEBE TIME (sec)
CONTROL	1.75	1.75	1.75	5.4	1.6
F-2	3.50	3.50	3.50	6.8	1.0
LK2-2	1.50	1.00	1.25	4.0	2.5
PS1E-2	1.50	1.00	1.25	4.5	2.2
CT1-2	0.25	0.00	0.13	3.2	6.3
SM2-2	0.13	0.00	0.07	3.0	9.2
MW1-2	0.25	0.00	0.13	2.1	9.9

1 LB= 0.4536 KGS
1 FOOT= 0.3048 METER

TABLE 5A COMPRESSIVE STRENGTH AND ELASTIC MODULUS FOR CONCRETES WITH 10% POZZOLAN BLENDED CEMENTS

SP. #	AGE (days)	DIMENSIONS LENGTH (in)	DIA (in)	UNIT WT. (lb/ft^3)	STATIC MODULUS (10^6psi)	COMPRESSIVE STRENGTH (psi)
C-1	3	12.12	6.00	146.26	4.24	3465
C-2	3	12.15	5.99	146.85	4.26	2945
C-3	3	12.19	6.04	146.52	4.19	3405
MEAN					**4.23**	**3272**
S.D.					0.04	284.00
C.V.					0.01	0.09
C-4	7	12.09	5.98	146.99	4.27	4255
C-5	7	12.17	5.98	147.02	4.27	4005
C-6	7	12.08	5.99	147.48	5.33	4300
MEAN					**4.62**	**4187**
S.D.					0.61	158.90
C.V.					0.13	0.04
C-7	28	12.19	6.04	145.66	5.66	6220
C-8	28	12.07	5.95	149.49	5.04	5240
C-9	28	12.21	5.99	147.10	4.54	5035
MEAN					**5.08**	**5498**
S.D.					0.56	633.30
C.V.					0.11	0.12
F1-1	3	12.13	5.95	148.85	3.60	3335
F1-2	3	12.13	6.02	145.48	4.22	3345
F1-3	3	12.16	6.05	143.94	4.87	3200
MEAN					**4.23**	**3293**
S.D.					0.64	80.90
C.V.					0.15	0.02
F1-4	7	12.06	5.98	147.10	5.34	4030
F1-5	7	12.12	6.01	146.66	5.28	4525
F1-6	7	12.02	5.99	146.05	4.26	4175
MEAN					**4.96**	**4243**
S.D.					0.61	254.50
C.V.					0.12	0.06
F1-7	28	12.07	6.01	146.14	5.28	5950
F1-8	28	12.08	5.98	146.65	5.34	5535
F1-9	28	12.11	6.02	145.53	5.28	6050
MEAN					**5.30**	**5845**
S.D.					0.03	273.10
C.V.					0.01	0.05

C- Control mix

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.

Table 5A contd.

SP. #	AGE (days)	DIMENSIONS LENGTH (in)	DIA (in)	UNIT WT. (lb/ft^3)	STATIC MODULUS (10^6psi)	COMPRESSIVE STRENGTH (psi)
LK21-1	3	12.19	5.94	150.91	4.32	3695
LK21-2	3	12.21	6.07	143.70	4.15	3660
LK21-3	3	12.19	6.05	145.20	4.18	3765
MEAN					**4.22**	**3707**
S.D.					0.09	53.46
C.V.					0.02	0.01
LK21-4	7	12.31	5.91	140.79	4.37	4645
LK21-5	7	12.20	5.93	1423.38	4.34	4775
LK21-6	7	12.34	5.98	1452.31	5.35	4280
MEAN					**4.69**	**4566**
S.D.					0.57	256.60
C.V.					0.12	0.06
LK21-7	28	12.16	5.98	147.40	5.31	4810
LK21-8	28	12.20	5.99	147.27	5.32	5425
LK21-9	28	12.12	5.99	146.62	5.32	5160
MEAN					**5.32**	**5132**
S.D.					0.01	308.48
C.V.					0.00	0.06
PS1E1-1	3	12.20	6.02	141.67	4.22	3815
PS1E1-2	3	12.20	5.98	147.71	4.27	3540
PS1E1-3	3	12.15	6.02	146.39	4.08	3255
MEAN					**4.19**	**3537**
S.D.					0.10	280.01
C.V.					0.02	0.08
PS1E1-4	7	12.39	5.98	147.04	4.27	4630
PS1E1-5	7	12.15	5.99	146.03	5.30	4905
PS1E1-6	7	12.15	5.97	148.15	5.36	4490
MEAN					**4.98**	**4675**
S.D.					0.61	211.12
C.V.					0.12	0.05
PS1E1-7	28	12.14	5.99	147.17	5.25	5865
PS1E1-8	28	12.26	6.01	145.58	5.63	5745
PS1E1-9	28	12.28	5.97	147.66	5.00	5030
MEAN					**5.29**	**5547**
S.D.					0.32	451.45
C.V.					0.06	0.08

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.

Table 5A contd.

SP. #	AGE (days)	DIMENSIONS LENGTH (in)	DIA (in)	UNIT WT. (lb/ft^3)	STATIC MODULUS (10^6psi)	COMPRESSIVE STRENGTH (psi)
CT11-1	3	12.05	5.98	149.06	4.27	3630
CT11-2	3	11.98	5.98	149.31	4.27	3635
CT11-3	3	12.03	5.97	149.51	4.29	3720
MEAN					**4.28**	**3662**
S.D.					0.01	50.58
C.V.					0.00	0.01
CT11-4	7	11.99	6.02	150.11	5.08	4150
CT11-5	7	12.00	5.97	152.60	5.06	4525
CT11-6	7	12.04	5.99	150.14	5.26	4395
MEAN					**5.13**	**4357**
S.D.					0.11	190.42
C.V.					0.02	0.04
CT11-7	28	12.09	5.97	150.41	5.41	5030
CT11-8	28	12.16	5.98	149.72	5.71	5195
CT11-9	28	11.99	5.99	150.43	5.33	5325
MEAN					**5.48**	**5183**
S.D.					0.20	147.85
C.V.					0.04	0.029
SM21-1	3	12.11	5.96	149.36	4.30	3835
SM21-2	3	12.03	6.03	148.61	4.57	3715
SM21-3	3	12.17	5.98	149.21	4.27	3880
MEAN					**4.38**	**3810**
S.D.					0.17	85.29
C.V.					0.04	0.022
SM21-4	7	12.20	5.97	149.20	4.29	4355
SM21-5	7	12.19	5.99	148.14	5.33	4530
SM21-6	7	12.17	5.98	148.68	5.34	4485
MEAN					**4.99**	**4457**
S.D.					0.60	90.88
C.V.					0.12	0.02
SM21-7	28	12.16	5.98	148.21	5.34	6070
SM21-8	28	12.22	5.99	149.79	5.33	6005
SM21-9	28	12.18	6.02	149.75	5.27	6040
MEAN					**5.31**	**6038**
S.D.					0.04	32.53
C.V.					0.01	0.01

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.

Table 5A contd.

SP. #	AGE (days)	DIMENSIONS LENGTH (in)	DIA (in)	UNIT WT. (lb/ft^3)	STATIC MODULUS (10^6psi)	COMPRESSIVE STRENGTH (psi)
MW11-1	3	12.11	5.99	148.11	4.27	3340
MW11-2	3	12.03	5.98	149.37	3.56	3525
MW11-3	3	12.04	5.98	147.88	4.27	3245
MEAN					**4.03**	**3370**
S.D.					0.41	142.39
C.V.					0.10	0.042
MW11-4	7	12.08	6.00	147.71	5.31	3800
MW11-5	7	12.07	5.98	148.06	4.25	3910
MW11-6	7	12.16	5.96	151.21	4.30	3940
MEAN		**2**			**4.62**	**3883**
S.D.					0.60	73.71
C.V.					0.13	0.02
MW11-7	28	12.13	5.99	147.91	5.33	5225
MW11-8	28	12.07	6.02	148.41	5.27	5060
MW11-9	28	12.24	5.99	147.94	5.33	4940
MEAN					**5.31**	**5075**
S.D.					0.03	143.09
C.V.					0.01	0.03

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.

S.D.-Standard deviation
C.V.- Coefficient of variance

TABLE 5B COMPRESSIVE STRENGTH AND ELASTIC MODULUS FOR CONCRETES WITH 15% POZZOLAN BLENDED CEMENTS

SP. #	AGE (days)	DIMENSIONS LENGTH (in)	DIA (in)	UNIT WT. (lb/ft^3)	STATIC MODULUS (10^6psi)	COMPRESSIVE STRENGTH (psi)
F2-1	3	12.08	6.00	143.23	3.54	2705
F2-2	3	12.10	5.99	143.17	3.87	2950
F2-3	3	12.15	5.95	145.20	4.31	2825
MEAN					**3.91**	**2827**
S.D.					0.39	122.51
C.V.					0.10	0.04
F2-4	7	12.16	5.97	144.07	4.28	3930
F2-5	7	12.11	6.01	144.29	4.23	4070
F2-6	7	12.06	6.12	138.86	4.08	3960
MEAN					**4.20**	**3987**
S.D.					0.10	73.71
C.V.					0.02	0.02
F2-7	28	12.12	5.98	144.68	4.27	5265
F2-8	28	12.18	5.98	143.27	4.27	5475
F2-9	28	12.08	5.98	144.32	4.50	5455
MEAN					**4.35**	**5398**
S.D.					0.13	115.90
C.V.					0.03	0.02
LK22-1	3	12.21	5.98	147.16	4.08	3380
LK22-2	3	12.18	6.01	146.77	4.16	3390
LK22-3	3	12.12	6.02	147.03	4.17	3325
MEAN					**4.14**	**3365**
S.D.					0.05	35.00
C.V.					0.01	0.01
LK22-4	7	12.07	5.92	148.74	4.36	4215
LK22-5	7	12.17	5.98	138.40	4.27	4000
LK22-6	7	12.21	5.98	142.07	4.27	4340
MEAN					**4.30**	**4185**
S.D.					0.52	171.97
C.V.					0.01	0.04
LK22-7	28	12.19	5.98	147.34	5.34	5250
LK22-8	28	12.17	5.98	146.53	5.34	5285
LK22-9	28	12.21	5.98	147.42	5.33	5370
MEAN					**5.34**	**5302**
S.D.					0.01	61.71
C.V.					0.01	0.01

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.

Table 5B contd.

SP. #	AGE (days)	DIMENSIONS LENGTH (in)	DIA (in)	UNIT WT. (lb/ft^3)	STATIC MODULUS (10^6psi)	COMPRESSIVE STRENGTH (psi)
PS1E2-1	3	12.06	5.99	145.58	4.26	3340
PS1E2-2	3	12.07	6.01	146.15	4.22	3360
PS1E2-3	3	12.13	6.06	143.16	4.16	3185
MEAN					**4.21**	**3295**
S.D.					0.05	95.79
C.V.					0.01	0.03
PS1E2-4	7	12.06	5.97	148.20	4.29	4115
PS1E2-5	7	12.03	5.99	148.06	4.27	4035
PS1E2-6	7	12.04	5.98	147.29	4.27	4060
MEAN					**4.28**	**4070**
S.D.					0.01	40.93
C.V.					0.00	0.01
PS1E2-7	28	12.04	5.98	147.68	5.34	5110
PS1E2-8	28	12.09	5.98	147.32	5.35	5330
PS1E2-9	28	12.11	5.99	146.52	5.33	5205
MEAN					**5.34**	**5215**
S.D.					0.01	110.34
C.V.					0.00	0.02
CT12-1	3	12.06	6.02	147.61	4.22	3635
CT12-2	3	12.07	5.97	149.90	3.73	3485
CT12-3	3	12.04	5.97	149.66	3.57	3625
MEAN					**3.84**	**3582**
S.D.					0.34	83.86
C.V.					0.09	0.02
CT12-4	7	12.04	6.02	148.94	4.52	4390
CT12-5	7	11.97	6.01	148.57	4.23	4440
CT12-6	7	12.13	5.99	148.56	4.26	4255
MEAN					**4.33**	**4362**
S.D.					0.16	95.70
C.V.					0.04	0.02
CT12-7	28	12.05	5.99	148.52	5.32	5250
CT12-8	28	12.07	6.02	148.41	4.22	5095
CT12-9	28	12.03	5.98	149.52	5.35	5205
MEAN					**4.96**	**5183**
S.D.					0.64	79.74
C.V.					0.13	0.02

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.

Table 5B contd.

SP. #	AGE (days)	DIMENSIONS LENGTH (in)	DIA (in)	UNIT WT. (lb/ft^3)	STATIC MODULUS (10^6psi)	COMPRESSIVE STRENGTH (psi)
SM22-1	3	12.13	5.97	149.53	3.57	3425
SM22-2	3	12.17	6.05	146.95	4.18	3360
SM22-3	3	12.14	5.99	147.95	4.09	3355
MEAN					**3.95**	**3380**
S.D.					0.33	39.05
C.V.					0.08	0.01
SM22-4	7	12.11	5.97	150.61	5.05	4255
SM22-5	7	12.19	5.98	148.25	4.27	4145
SM22-6	7	12.16	5.99	149.04	5.33	3945
MEAN					**4.88**	**4115**
S.D.					0.55	157.16
C.V.					0.11	0.04
SM22-7	28	12.21	5.99	148.82	5.33	6200
SM22-8	28	12.15	6.03	148.08	5.30	5805
SM22-9	28	12.31	5.99	148.44	5.32	6100
MEAN					**5.32**	**6035**
S.D.					0.02	205.37
C.V.					0.00	0.034
MW12-1	3	12.22	5.99	146.23	3.41	3180
MW12-2	3	12.08	5.98	148.01	3.57	3385
MW12-3	3	12.09	6.01	146.87	3.53	3000
MEAN					**3.50**	**3188**
S.D.					0.08	192.64
C.V.					0.02	0.06
MW12-4	7	12.07	5.98	149.33	4.27	3735
MW12-5	7	12.11	6.01	148.98	4.23	3775
MW12-6	7	12.11	6.03	148.59	4.21	3855
MEAN					**4.24**	**3788**
S.D.					0.03	61.10
C.V.					0.01	0.02
MW12-7	28	12.09	5.98	149.13	5.34	4650
MW12-8	28	12.22	5.98	150.04	3.56	3170
MW12-9	28	12.04	5.29	149.20	4.29	4965
MEAN					**4.40**	**4262**
S.D.					0.89	958.44
C.V.					0.20	0.23

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.

S.D.-Standard deviation
C.V.- Coefficient of variance

TABLE 5C COMPRESSIVE STRENGTH AND ELASTIC MODULUS FOR CONCRETES WITH 25% POZZOLAN BLENDED CEMENTS

SP. #	AGE (days)	DIMENSIONS LENGTH (in)	DIA (in)	UNIT WT. (lb/ft^3)	STATIC MODULUS (10^6psi)	COMPRESSIVE STRENGTH (psi)
F3-1	3	12.07	6.00	137.53	3.54	1790
F3-2	3	12.12	5.99	137.93	3.04	1345
F3-3	3	12.10	5.99	138.76	3.55	1580
MEAN					3.37	**1572**
S.D.					0.29	222.62
C.V.					0.09	0.142
F3-4	7	12.14	5.99	137.92	4.26	2520
F3-5	7	12.09	6.01	138.78	4.24	2810
F3-6	7	12.12	5.98	138.04	3.56	2205
MEAN					**4.02**	**2512**
S.D.					0.40	302.59
C.V.					0.01	0.12
F3-7	28	12.21	5.97	138.03	4.29	3485
F3-8	28	12.14	5.98	137.83	4.27	3489
F3-9	28	12.11	5.97	138.40	4.29	3899
MEAN					**4.28**	**3624**
S.D.					0.01	238.46
C.V.					0.002	0.07
LK23-1	3	12.05	6.05	144.15	3.55	2587
LK23-2	3	12.09	5.91	149.55	3.57	3014
LK23-3	3	12.05	6.00	145.85	3.33	2805
MEAN					**3.48**	**2802**
S.D.					0.13	213.52
C.V.					0.04	0.076
LK23-4	7	12.16	5.99	146.90	3.87	3439
LK23-5	7	12.12	6.03	148.36	3.85	3298
LK23-6	7	12.09	6.01	144.85	3.75	3300
MEAN					**3.82**	**3346**
S.D.					0.06	80.84
C.V.					0.02	0.024
LK23-7	28	12.17	5.98	142.02	4.07	4475
LK23-8	28	12.14	6.02	146.71	4.03	4674
LK23-9	28	12.08	5.98	147.48	4.07	4792
MEAN					**4.06**	**4647**
S.D.					0.01	160.22
C.V.					0.002	0.03

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.

Table 5C contd.

SP. #	AGE (days)	DIMENSIONS LENGTH (in)	DIA (in)	UNIT WT. (lb/ft^3)	STATIC MODULUS (10^6psi)	COMPRESSIVE STRENGTH (psi)
PS1E3-1	3	12.11	5.99	145.39	3.51	2671
PS1E3-2	3	12.09	6.01	144.85	3.48	2163
PS1E3-3	3	12.11	5.96	146.02	3.64	2852
MEAN					**3.54**	**2562**
S.D.					0.09	357.20
C.V.					0.02	0.14
PS1E3-4	7	12.03	5.98	146.51	3.70	3633
PS1E3-5	7	12.06	5.97	147.48	3.64	3685
PS1E3-6	7	12.06	5.98	147.01	3.72	6586
MEAN					**3.69**	**3635**
S.D.					0.04	49.52
C.V.					0.01	0.01
PS1E3-7	28	12.00	5.98	147.68	4.08	6219
PS1E3-8	28	12.01	5.99	146.73	4.07	5935
PS1E3-9	28	12.03	5.97	147.19	4.09	5455
MEAN					**4.08**	**5870**
S.D.					0.01	386.17
C.V.					0.002	0.07
CT13-1	3	12.06	5.99	148.22	3.56	2783
CT13-2	3	12.14	5.97	148.23	3.58	2895
CT13-3	3	12.15	6.00	147.75	3.53	2720
MEAN					**3.56**	**2799**
S.D.					0.02	88.64
C.V.					0.006	0.03
CT13-4	7	12.13	5.98	147.47	3.81	3173
CT13-5	7	12.12	5.99	148.06	3.89	3188
CT13-6	7	12.07	5.98	148.52	3.64	3316
MEAN					**3.78**	**3226**
S.D.					0.13	78.59
C.V.					0.03	0.02
CT13-7	28	12.11	6.02	147.13	4.03	4157
CT13-8	28	12.08	6.01	148.91	4.04	4620
CT13-9	28	12.03	5.98	149.52	4.06	4390
MEAN					**4.04**	**4389**
S.D.					0.02	231.50
C.V.					0.004	0.053

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.

Table 5C contd.

SP. #	AGE (days)	DIMENSIONS LENGTH (in)	DIA (in)	UNIT WT. (lb/ft^3)	STATIC MODULUS ($10^6 psi$)	COMPRESSIVE STRENGTH (psi)
SM23-1	3	12.08	5.99	147.17	3.71	2632
SM23-2	3	12.06	5.99	147.65	3.55	2845
SM23-3	3	12.10	5.99	146.36	3.55	2638
MEAN					**3.61**	**2705**
S.D.					0.01	121.28
C.V.					0.03	0.045
SM23-4	7	12.06	5.98	147.13	3.81	3843
SM23-5	7	12.03	5.98	147.51	3.64	3813
SM23-6	7	12.02	5.98	149.02	3.81	4155
MEAN					**3.75**	**3937**
S.D.					0.10	189.39
C.V.					0.026	0.05
SM23-7	28	12.09	6.00	147.80	4.05	4638
SM23-8	28	12.09	5.98	149.29	4.08	4466
SM23-9	28	12.07	4.07	147.81	4.07	4798
MEAN					**4.07**	**4634**
S.D.					0.02	166.04
C.V.					0.004	0.04
MW13-1	3	12.18	5.98	145.30	3.33	2162
MW13-2	3	12.09	6.04	144.38	3.20	1728
MW13-3	3	12.10	5.98	147.42	3.16	2460
MEAN					**3.23**	**2117**
S.D.					0.08	368.10
C.V.					0.03	0.17
MW13-4	7	12.14	5.98	149.51	3.56	2758
MW13-5	7	12.16	6.02	148.00	3.52	2726
MW13-6	7	12.17	5.99	149.14	3.56	2533
MEAN					**3.55**	**2672**
S.D.					0.02	121.72
C.V.					0.007	0.046
MW13-7	28	12.24	6.01	147.95	4.00	2998
MW13-8	28	12.22	5.97	149.07	4.14	3526
MW13-9	28	12.22	5.97	149.07	4.29	3526
MEAN					**4.14**	**3182**
S.D.					0.15	340.54
C.V.					0.035	0.11

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.

S.D.-Standard deviation
C.V.- Coefficient of variance

TABLE 6A FIRST CRACK STRENGTH AND MAXIMUM FLEXURAL STRENGTH FOR CONCRETES WITH 10% POZZOLAN BLENDED CEMENTS

SP.#	AGE (DAYS)	FOR FIRST CRACK LOAD (lbs)	DEFLECTION (in)	STRESS (psi)	MAX. LOAD (lbs)	FLEXURAL STRENGTH (psi)
C-1	28	2700	0.0005	431	3520	562
C-2	28	3180	0.0002	574	3180	574
C-3	28	2420	0.0003	443	3340	611
MEAN				**483**	**3347**	**582**
S.D.				79.32	170.10	25.54
C.V.				0.16	0.05	0.04
F1-1	28	3280	-	540	3280	540
F1-2	28	3500	0.0009	585	3500	585
F1-3	28	3140	0.0013	536	3180	543
MEAN				**554**	**3320**	**556**
S.D.				27.21	163.71	25.16
C.V.				0.05	0.05	0.05
LK21-1	28	3240	0.0012	576	3240	576
LK21-2	28	3540	0.0014	605	3540	605
LK21-3	28	3120	0.0016	547	3120	545
MEAN				**576**	**3300**	**556**
S.D.				29	216.3	25.16
C.V.				0.05	0.07	0.05
PS1E-1	28	3760	0.0012	648	3760	648
PS1E-2	28	3360	0.0013	604	3380	608
PS1E-3	28	3580	0.0015	626	3580	626
MEAN				**626**	**3573**	**627**
S.D.				22	190.09	20.03
C.V.				0.04	0.05	0.03
CT11-1	28	4140	0.0015	762	4140	762
CT11-2	28	3800	0.0010	659	4040	700
CT11-3	28	3860	0.0012	685	3880	689
MEAN				**702**	**4020**	**717**
S.D.				53.60	131.15	39.36
C.V.				0.08	0.03	0.05

C- Control mix

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.
1 LB= 0.4536 KGS.

Table 6A contd.

SP.#	AGE (DAYS)	FOR FIRST CRACK LOAD (lbs)	DEFLECTION (in)	STRESS (psi)	MAX. LOAD (lbs)	FLEXURAL STRENGTH (psi)
SM21-1	28	3780	0.0012	656	3780	656
SM21-2	28	4420	0.0013	766	4560	790
SM21-3	28	4300	0.0013	754	4300	754
MEAN				**725**	**4213**	**753**
S.D.				60.34	397.16	69.35
C.V.				0.08	0.09	0.09
MW11-1	28	1980	0.0008	361	2900	528
MW11-2	28	3180	0.0012	579	3180	579
MW11-3	28	1620	0.0007	276	3220	548
MEAN				**405**	**3100**	**552**
S.D.				156.30	174.40	25.70
C.V.				0.39	0.06	0.05

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.
1 LB= 0.4536 KGS.

S.D.-Standard deviation
C.V.- Coefficient of variance

TABLE 6B FIRST CRACK STRENGTH AND MAXIMUM FLEXURAL STRENGTH FOR CONCRETES WITH 15% POZZOLAN BLENDED CEMENTS

SP.#	AGE (DAYS)	FOR FIRST CRACK LOAD (lbs)	DEFLECTION (in)	STRESS (psi)	MAX. LOAD (lbs)	FLEXURAL STRENGTH (psi)
F2-1	28	2500	0.0007	423	3120	528
F2-2	28	3440	-	604	3440	604
F2-3	28	2700	0.0010	485	2720	489
MEAN				**504**	**3093**	**540**
S.D.				91.98	360.74	58.48
C.V.				0.18	0.12	0.11
LK22-1	28	3640	0.0014	623	3640	623
LK22-2	28	3620	0.0014	627	3620	627
LK22-3	28	3420	0.0012	580	3420	580
MEAN				**610**	**3560**	**610**
S.D.				26.06	121.66	26.05
C.V.				0.04	0.03	0.04
PS1E2-1	28	3320	0.0011	592	3220	592
PS1E2-2	28	3080	0.0013	529	3080	529
PS1E2-3	28	3120	0.0014	552	3120	552
MEAN				**558**	**3140**	**558**
S.D.				31.88	72.11	31.88
C.V.				0.06	0.02	0.06
CT12-1	28	3280	0.0012	576	3280	576
CT12-2	28	3460	0.0013	605	3460	605
CT12-3	28	3560	0.0013	643	3780	682
MEAN				**608**	**3507**	**621**
S.D.				33.60	253.24	54.78
C.V.				0.06	0.07	0.09
SM22-1	28	4200	0.0100	716	4200	716
SM22-2	28	4340	0.0012	727	4400	737
SM22-3	28	3340	0.0012	607	3380	615
MEAN				**683**	**3993**	**689**
S.D.				66.34	540.49	65.22
C.V.				0.10	0.14	0.09
MW12-1	28	3320	0.0015	566	3320	566
MW12-2	28	2900	0.0014	502	2900	502
MW12-3	28	2460	0.0015	424	2460	424
MEAN				**497**	**2893**	**497**
S.D.				71.11	430.03	71.11
C.V.				0.14	0.15	0.14

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.
1 LB= 0.4536 KGS.

TABLE 6C FIRST CRACK STRENGTH AND MAXIMUM FLEXURAL STRENGTH FOR CONCRETES WITH 25 % POZZOLAN BLENDED CEMENTS

SP.#	AGE (DAYS)	FOR FIRST CRACK LOAD (lbs)	DEFLECTION (in)	STRESS (psi)	MAX. LOAD (lbs)	FLEXURAL STRENGTH (psi)
C -1	28	2700	0.0005	431	3520	562
C -2	28	3180	0.0002	574	3180	574
C -3	28	2420	0.0003	443	3340	611
MEAN				**483**	**3347**	**582**
S.D.				79.32	170.10	25.54
C.V.				0.16	0.05	0.04
F3-1	28	1860	0.0010	310	2300	383
F3-2	28	2120	0.0011	367	2180	378
F3-3	28	1860	0.0009	300	2220	358
MEAN				**326**	**2233**	**373**
S.D.				36.22	61.10	13.00
C.V.				0.11	0.03	0.04
LK23-1	28	2932	0.0006	534	2932	534
LK23-2	28	2866	0.0005	497	2882	500
LK23-3	28	2832	0.0005	485	2832	485
MEAN				**506**	**2882**	**507**
S.D.				25.41	50.00	24.98
C.V.				0.05	0.02	0.05
PS1E3-1	28	3282	0.0014	598	3282	598
PS1E3-2	28	2799	0.0006	528	2799	528
PS1E3-3	28	3149	0.0010	579	3149	579
MEAN				**568**	**3077**	**568**
S.D.				36.35	249049	36.35
C.V.				0.06	0.09	0.06
CT13-1	28	3115	0.0013	556	3132	558
CT13-2	28	2782	0.0006	474	2832	483
CT13-3	28	2832	0.0014	492	2849	495
MEAN				**507**	**2938**	**512**
S.D.				42.77	168.51	40.72
C.V.				0.08	0.06	0.08

C- Control mix

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.
1 LB= 0.4536 KGS.

Table 6C contd.

SP.#	AGE (DAYS)	FOR FIRST CRACK LOAD (lbs)	DEFLECTION (in)	STRESS (psi)	MAX. LOAD (lbs)	FLEXURAL STRENGTH (psi)
SM23-1	28	2932	0.0008	542	2932	542
SM23-2	28	3607	0.0009	613	4048	688
SM23-3	28	3432	0.0010	615	3432	615
MEAN				**590.00**	**3471**	**615**
S.D.				41.33	559.00	72.77
C.V.				0.07	0.16	0.11
MW13-1	28	2049	0.0014	367	2049	367
MW13-2	28	2266	0.0012	400	2282	403
MW13-3	28	1666	0.0005	285	2066	354
MEAN				**351**	**2132**	**374**
S.D.				58.77	129.89	25.20
C.V.				0.17	0.06	0.07

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.
1 LB= 0.4536 KGS.

S.D.-Standard deviation
C.V.- Coefficient of variance

TABLE 7A ASTM- TOUGHNESS INDEXES FOR CONCRETES WITH 10% POZZOLAN BLENDED CEMENTS

SP#	AGE (days)	FLEXURAL STRENGTH (psi)	FIRST CRACK TOUGHNESS (in-lbs)	I_5
C-1	28	562	1.792	4.000
C-2	28	574	2.240	3.800
C-3	28	611	-	-
MEAN		**582**	**2.016**	**3.900**
S.D.		25.54	0.317	0.141
C.V.		0.04	0.157	0.036
F1-1	28	540	-	-
F1-2	28	585	2.016	5.555
F1-3	28	543	4.032	2.722
MEAN		**556**	**3.024**	**4.139**
S.D.		25.16	1.425	2.000
C.V.		0.05	0.471	0.484
LK21-1	28	576	3.136	4.428
LK21-2	28	605	2.912	4.538
LK21-3	28	547	2.464	3.090
MEAN		**556**	**2.837**	**4.019**
S.D.		25.16	0.342	0.806
C.V.		0.05	0.121	0.201
PS1E1-1	28	648	3.360	5.067
PS1E1-2	28	608	3.136	3.929
PS1E1-3	28	626	3.136	3.143
MEAN		**627**	**3.211**	**4.046**
S.D.		20.03	0.129	0.967
C.V.		0.03	0.040	0.239

C- Control mix

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.
1 LB= 0.4536 KGS.

Table 7A contd.

SP#	AGE (days)	FLEXURAL STRENGTH (psi)	FIRST CRACK TOUGHNESS (in-lbs)	I_5
CT11-1	28	762	3.360	4.400
CT11-2	28	700	2.912	3.308
CT11-3	28	689	3.584	3.706
MEAN		**717**	**3.285**	**3.805**
S.D.		39.36	0.342	0.553
C.V.		0.05	0.104	0.145
SM21-1	28	656	3.584	4.500
SM21-2	28	790	3.808	4.471
SM21-3	28	754	2.912	6.385
MEAN		**733**	**3.435**	**5.119**
S.D.		69.35	0.466	1.097
C.V.		0.09	0.136	0.214
MW11-1	28	528	2.016	3.444
MW11-2	28	579	3.584	3.063
MW11-3	28	548	2.464	4.272
MEAN		**552**	**2.608**	**3.593**
S.D.		25.70	0.808	0.618
C.V.		0.05	0.300	0.172

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.
1 LB= 0.4536 KGS.

S.D.-Standard deviation
C.V.- Coefficient of variance

TABLE 7B ASTM- TOUGHNESS INDEXES FOR CONCRETES WITH 15% POZZOLAN BLENDED CEMENTS

SP#	AGE (days)	FLEXURAL STRENGTH (psi)	FIRST CRACK TOUGHNESS (in-lbs)	I_5
F2-1	28	528	3.136	2.571
F2-2	28	604	1.792	3.625
F2-3	28	489	-	-
MEAN		**540**	**2.464**	**3.098**
S.D.		58.48	0.950	0.745
C.V.		0.11	0.386	0.241
LK22-1	28	623	2.688	3.833
LK22-2	28	627	2.464	5.091
LK22-3	28	580	2.912	3.508
MEAN		**610**	**2.688**	**4.144**
S.D.		26.05	0.224	0.836
C.V.		0.04	0.083	0.202
PS1E2-1	28	592	3.136	3.785
PS1E2-2	28	529	2.016	4.333
PS1E2-3	28	552	3.360	4.067
MEAN		**557**	**2.837**	**4.062**
S.D.		31.88	0.720	0.274
C.V.		0.06	0.254	0.067
CT12-1	28	576	2.912	2.923
CT12-2	28	605	2.912	3.308
CT12-3	28	682	2.688	4.083
MEAN		**621**	**2.837**	**3.438**
S.D.		54.78	0.129	0.591
C.V.		0.09	0.046	0.172
SM22-1	28	716	3.136	4.071
SM22-2	28	737	3.360	2.133
SM22-3	28	615	2.912	2.236
MEAN		**689**	**3.136**	**2.813**
S.D.		65.72	0.224	1.090
C.V.		0.09	0.071	0.388
MW12-1	28	566	2.688	3.833
MW12-2	28	502	2.464	3.455
MW12-3	28	424	2.016	4.333
MEAN		**497**	**2.389**	**3.874**
S.D.		71.11	0.342	0.440
C.V.		0.140	0.143	0.113

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.
1 LB= 0.4536 KGS.

TABLE 7C ASTM- TOUGHNESS INDEXES FOR CONCRETES WITH 25% POZZOLAN BLENDED CEMENTS

SP#	AGE (days)	FLEXURAL STRENGTH (psi)	FIRST CRACK TOUGHNESS (in-lbs)	I_5
C -1	28	562	1.792	4.000
C -2	28	574	2.240	3.800
C -3	28	611	-	-
MEAN		**582**	**2.016**	**3.900**
S.D.		25.54	0.317	0.141
C.V.		0.04	0.157	0.036
F3-1	28	383	2.822	3.357
F3-2	28	378	2.822	2.786
F3-3	28	358	4.232*	2.810
MEAN		**373**	**2.822**	**2.984**
S.D.		13.00	0.000	0.323
C.V.		0.04	0.000	0.108
LK23-1	28	534	0.806*	4.500
LK23-2	28	500	1.814	2.330
LK23-3	28	485	1.814	2.110
MEAN		**507**	**1.814**	**2.980**
S.D.		24.98	0.000	1.321
C.V.		0.05	0.000	0.443
PS1E3-1	28	598	2.419	4.083
PS1E3-2	28	528	2.620	3.692
PS1E3-3	28	579	1.612	5.125*
MEAN		**568**	**2.217**	**3.889**
S.D.		36.35	0.533	0.276
C.V.		0.06	0.241	0.071

C- Control mix

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.
1 LB= 0.4536 KGS.

Table 7C contd.

SP#	AGE (days)	FLEXURAL STRENGTH (psi)	FIRST CRACK TOUGHNESS (in-lbs)	I_5
CT13-1	28	558	1.612	4.875*
CT13-2	28	483	2.419	3.000
CT13-3	28	495	1.814	4.000
MEAN		**512**	**1.948**	**3.500**
S.D.		40.72	0.420	0.707
C.V.		0.08	0.216	0.202
SM23-1	28	542	2.822	4.000
SM23-2	28	688	1.612	7.750*
SM23-3	28	615	1.007	3.400
MEAN		**615**	**1.813**	**3.700**
S.D.		72.66	0.924	0.424
C.V.		0.12	0.510	0.115
MW13-1	28	367	1.814	3.444
MW13-2	28	403	2.419	2.917
MW13-3	28	354	1.612	2.750
MEAN		**374**	**1.948**	**3.057**
S.D.		25.20	0.420	0.362
C.V.		0.07	0.216	0.119

1 PSI= 0.0068944 MPA.
1 INCH= 2.54 CMS.
1 LB= 0.4536 KGS.

S.D.-Standard deviation
C.V.- Coefficient of variance

TABLE 8A IMPACT TEST RESULTS FOR CONCRETES WITH 10 % POZZOLAN BLENDED CEMENTS

SP.#	AGE (days)	NUMBER OF BLOWS TO FIRST CRACK	NUMBER OF BLOWS TO FAILURE
C-1	28	78	80
C-2	28	133	135
MEAN		**106**	**108**
F1-1	28	58	63
F1-2	28	146	151
MEAN		**102**	**107**
LK21-1	28	63	68
LK21-2	28	115	119
LK21-3	28	245*	248*
MEAN		**89**	**94**
PS1E11-1	28	191	194
PS1E11-2	28	46	49
MEAN		**119**	**122**
CT11-1	28	26	30
CT11-2	28	235	238
CT11-3	28	199	203
MEAN		**153.33**	**157**
SM21-1	28	130	133
SM21-2	28	346*	349*
MEAN		**130**	**133**
MW11-1	28	149	153
MW11-2	28	240*	243*
MEAN		**149**	**153**

C- Control mix
* Outlayer neglected in calculations

TABLE 8B IMPACT TEST RESULTS FOR CONCRETES WITH 15 % POZZOLAN BLENDED CEMENTS

SP.#	AGE (days)	NUMBER OF BLOWS TO FIRST CRACK	NUMBER OF BLOWS TO FAILURE
F2-1	28	86	90
F2-2	28	71	75
MEAN		**79**	**83**
LK22-1	28	108	111
LK22-2	28	358*	361*
MEAN		**108**	**111**
PS1E12-1	28	20	23
PS1E12-2	28	23	26
MEAN		**22**	**25**
CT12-1	28	61	64
CT12-2	28	58	65
MEAN		**60**	**65**
SM22-1	28	77	80
SM22-2	28	113	117
MEAN		**95**	**99**
MW12-1	28	113	118
MW12-2	28	37	42
MEAN		**75**	**80**

* Outlayer neglected in calculations

TABLE 8C IMPACT TEST RESULTS FOR CONCRETES WITH 25 % POZZOLAN BLENDED CEMENTS

SP.#	AGE (days)	NUMBER OF BLOWS TO FIRST CRACK	NUMBER OF BLOWS TO FAILURE
F3-1	28	47	51
F3-2	28	42	46
MEAN		**45**	**49**
LK23-1	28	51	55
LK23-2	28	111	113
LK23-3	28	40	43
MEAN		**67**	**70**
PS1E3-1	28	13	16
PS1E3-2	28	84	89
PS1E3-3	28	117	121
MEAN		**71**	**75**
CT13-1	28	51	53
CT13-2	28	21	23
CT13-3	28	197*	201*
MEAN		**36**	**38**
SM23-1	28	97	100
SM23-2	28	277*	279*
SM23-3	28	121*	124*
MEAN		**97**	**100**
MW13-1	28	12	15
MW13-2	28	47	51
MW13-3	28	78	80
MEAN		**46**	**49**

* Outlayer neglected in calculations

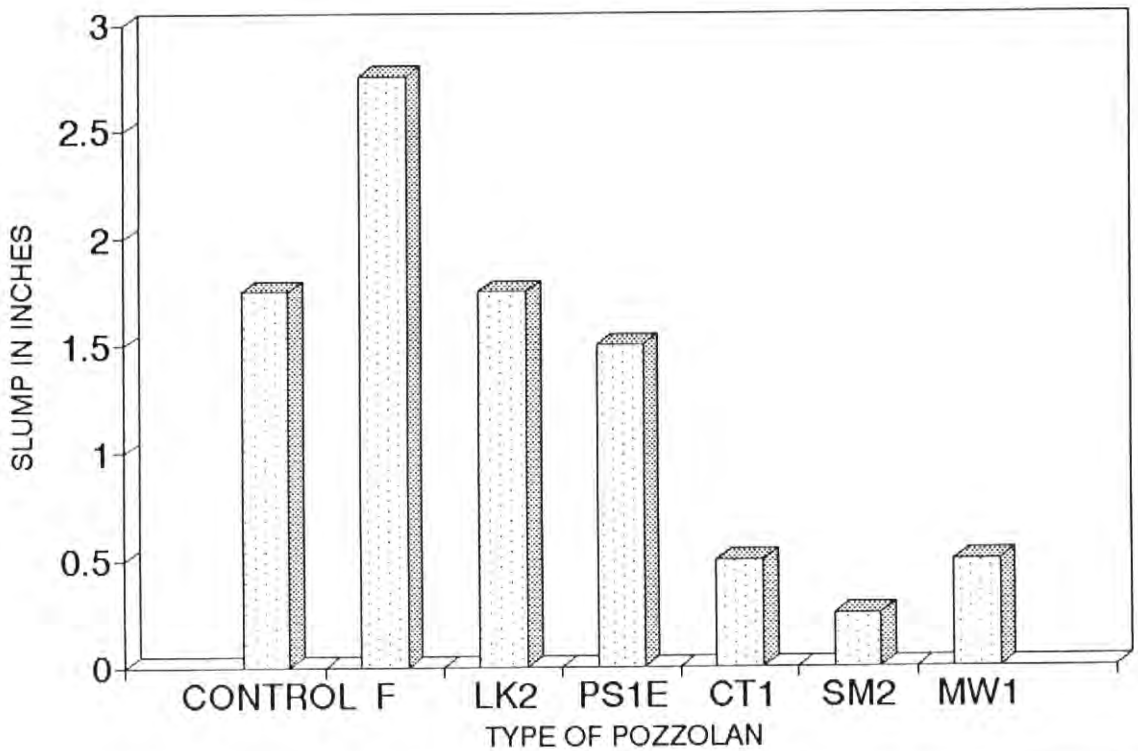


FIG1A: COMPARISON OF SLUMP FOR CONCRETES WITH

10% POZZOLAN BLENDED CEMENTS

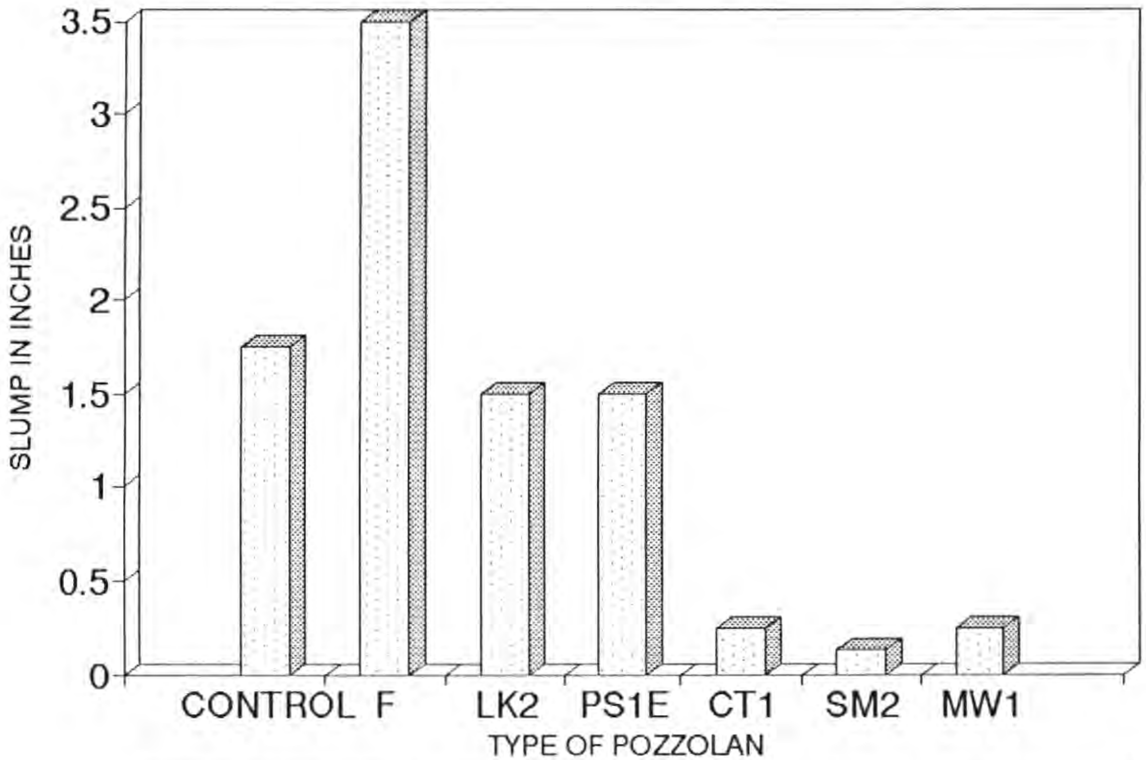


FIG 1B: COMPARISON OF SLUMP FOR CONCRETES WITH

15% POZZOLAN BLENDED CEMENTS

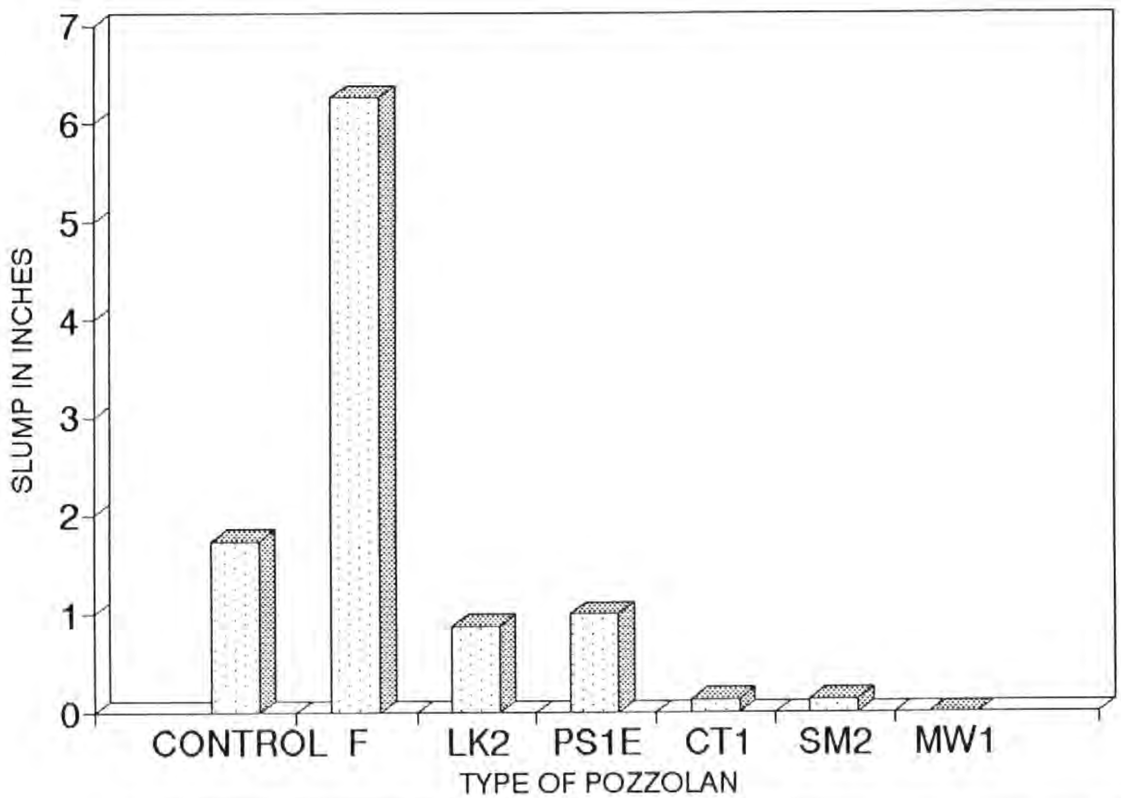


FIG 1C: COMPARISON OF SLUMP FOR CONCRETES WITH

25% POZZOLAN BLENDED CEMENTS

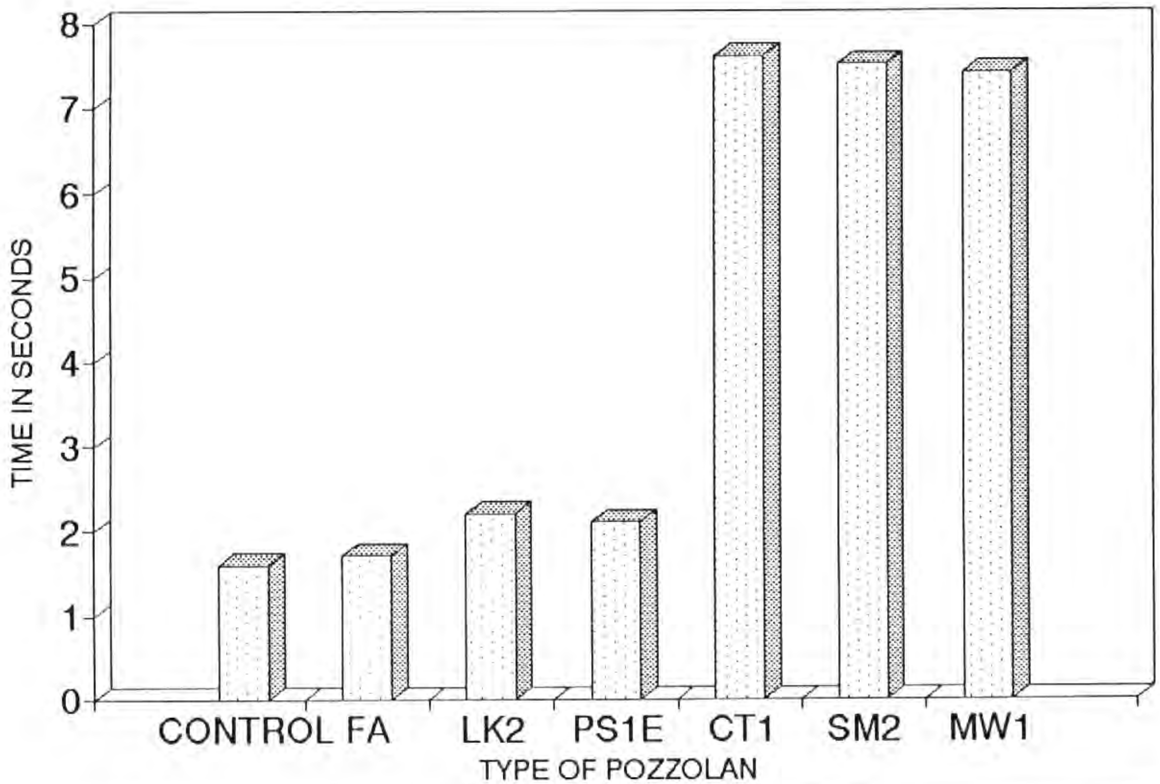


FIG2A: COMPARISON OF VEBE TIME FOR CONCRETES WITH

10% POZZOLAN BLENDED CEMENTS

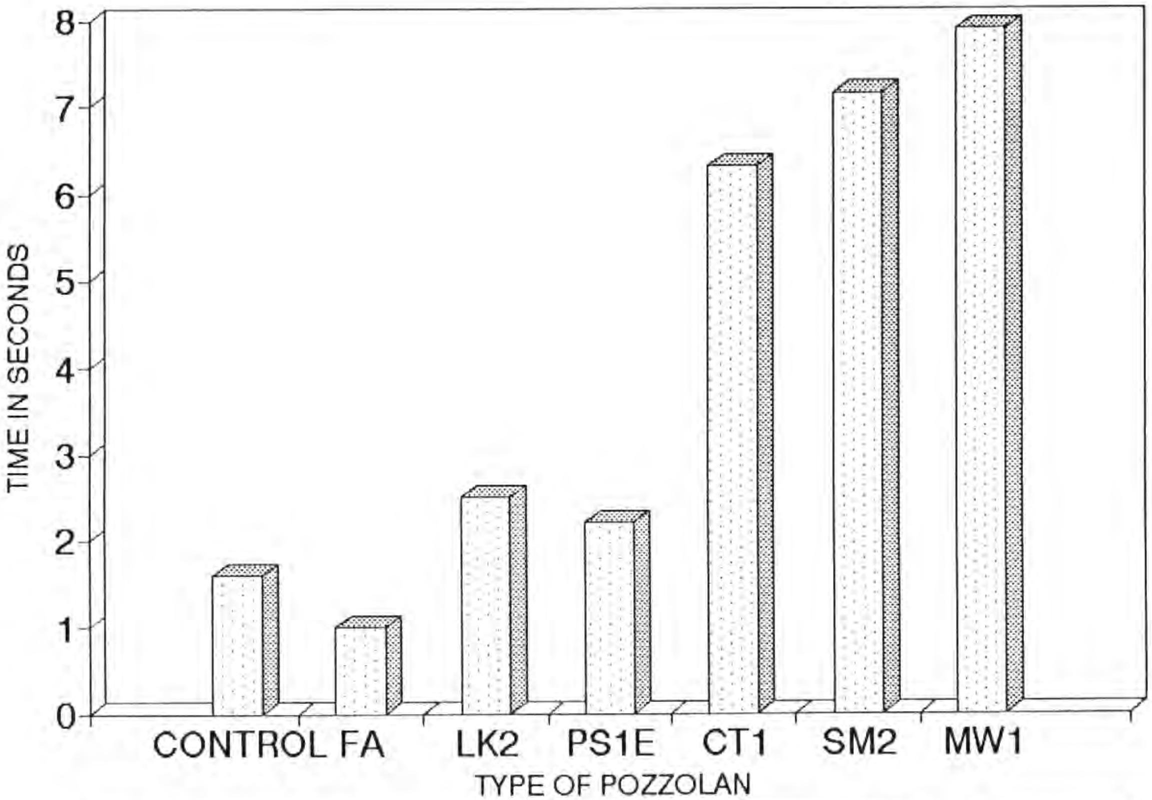


FIG2B: COMPARISON OF VEBE TIME FOR CONCRETES WITH

15% POZZOLAN BLENDED CEMENTS

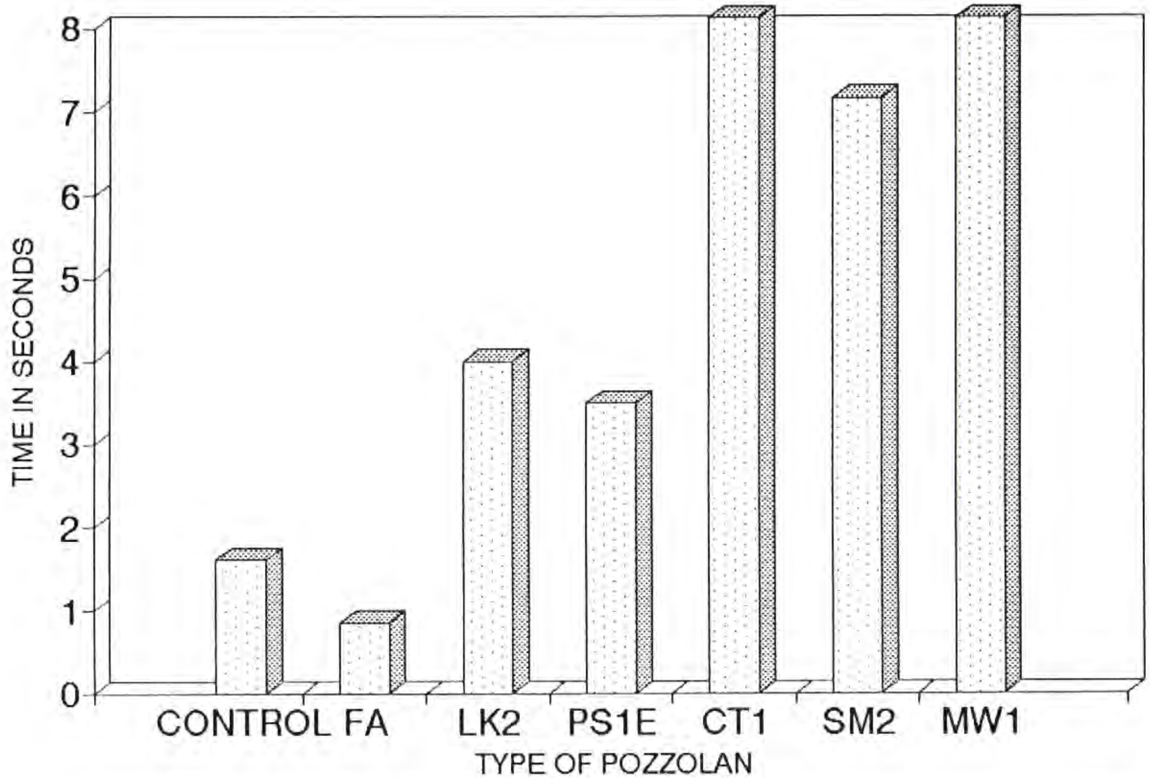


FIG2C: COMPARISON OF VEBE TIME FOR CONCRETES WITH

25% POZZOLAN BLENDED CEMENTS

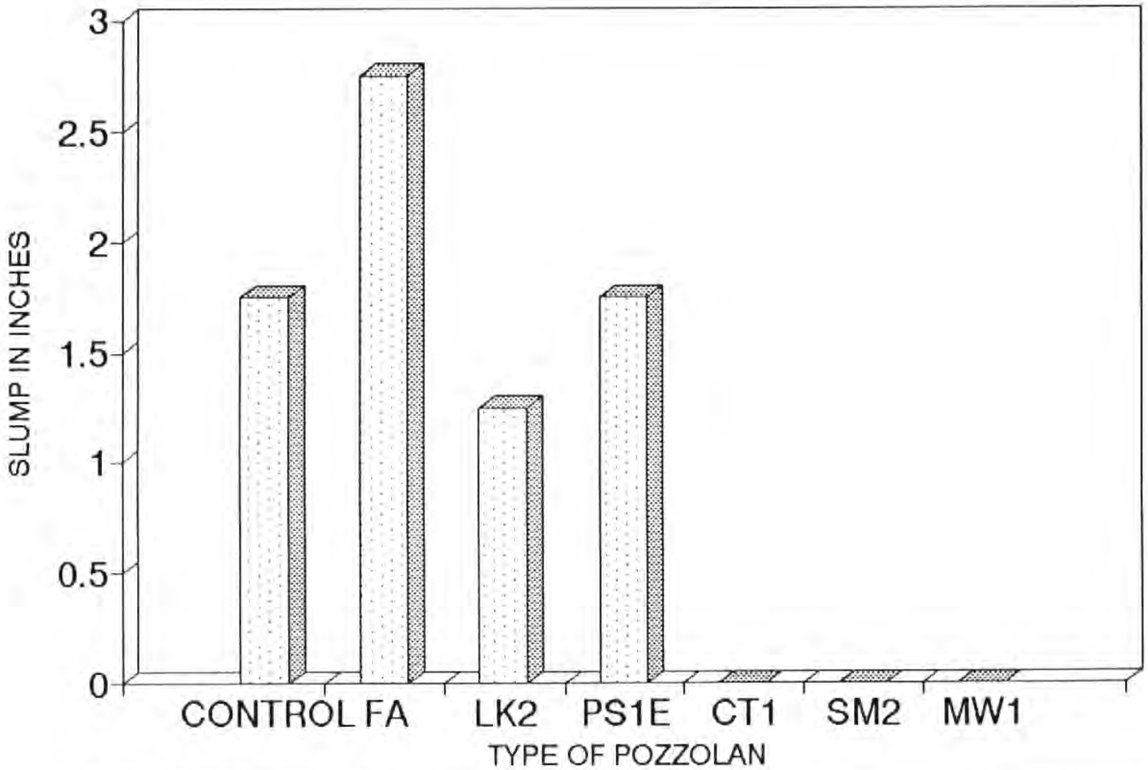


FIG3A: COMPARISON OF VEBE SLUMP FOR CONCRETES WITH

10% POZZOLAN BLENDED CEMENTS

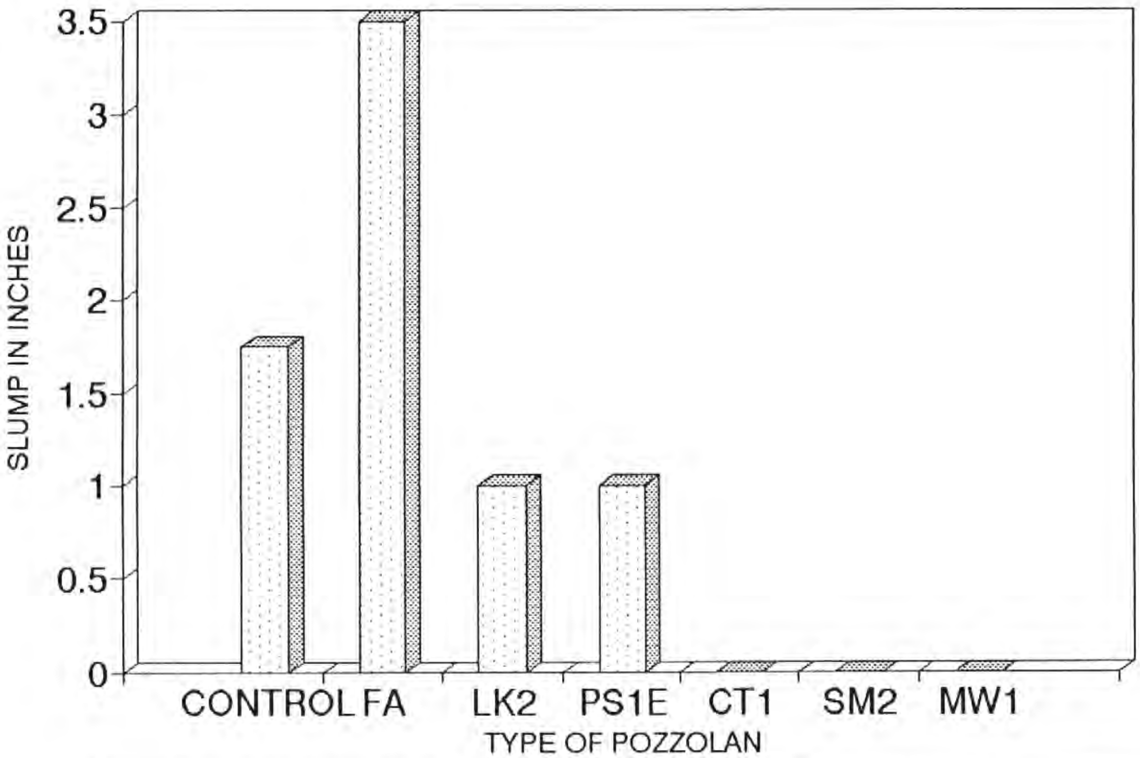


FIG3B: COMPARISON OF VEBE SLUMP FOR CONCRETES WITH

15% POZZOLAN BLENDED CEMENTS

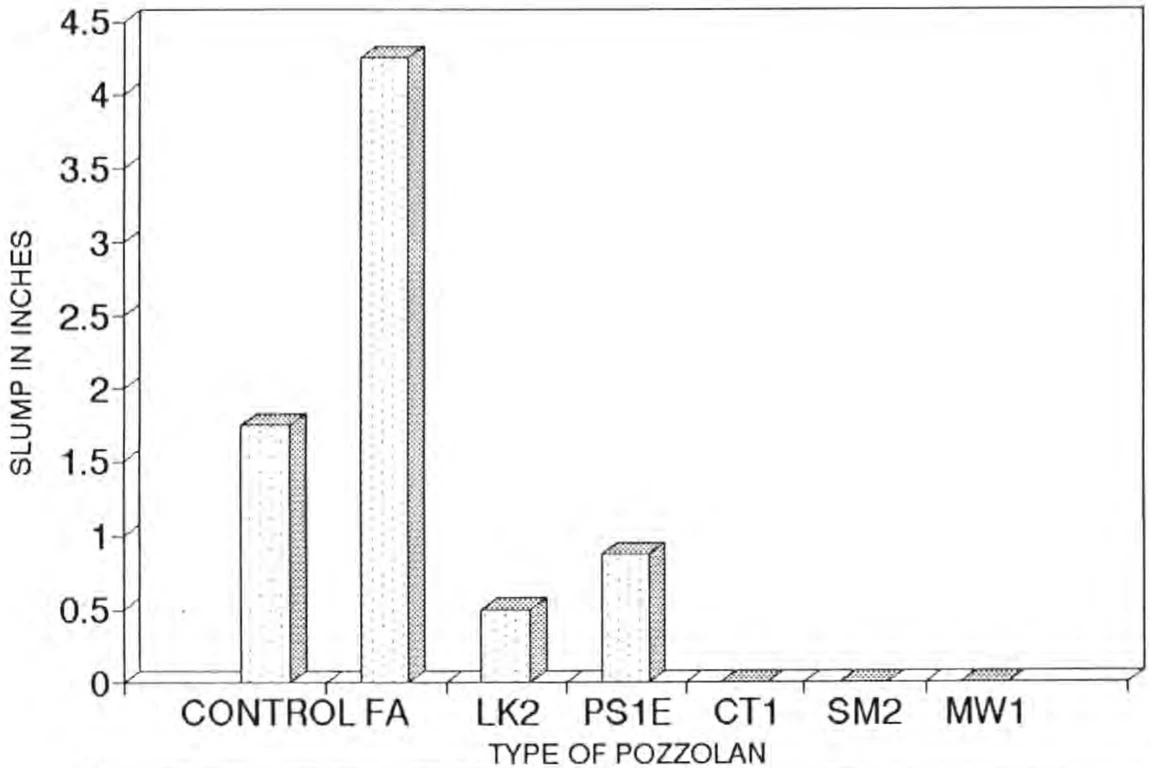


FIG3C: COMPARISON OF VEBE SLUMP FOR CONCRETES WITH

25% POZZOLAN BLENDED CEMENTS

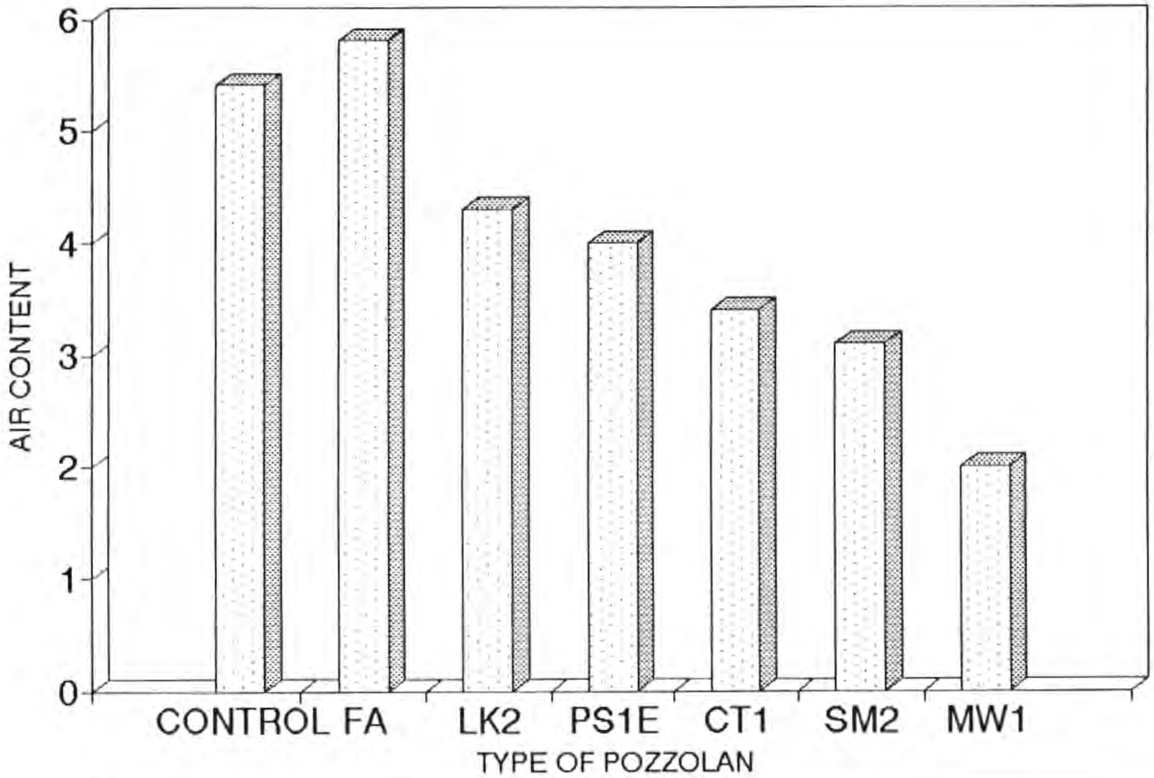


FIG4A: COMPARISON OF AIR CONTENT FOR CONCRETES WITH

10% POZZOLAN BLENDED CEMENTS

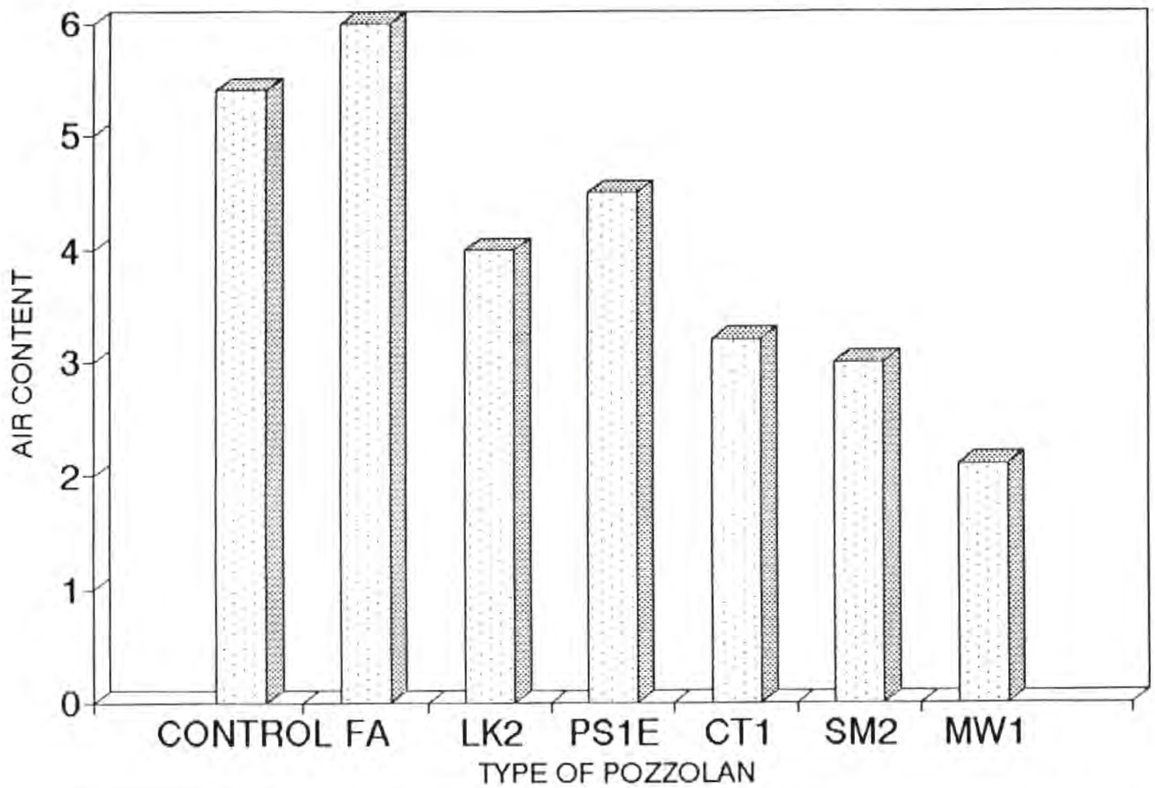


FIG4B: COMPARISON OF AIR CONTENT FOR CONCRETES WITH

15% POZZOLAN BLENDED CEMENTS

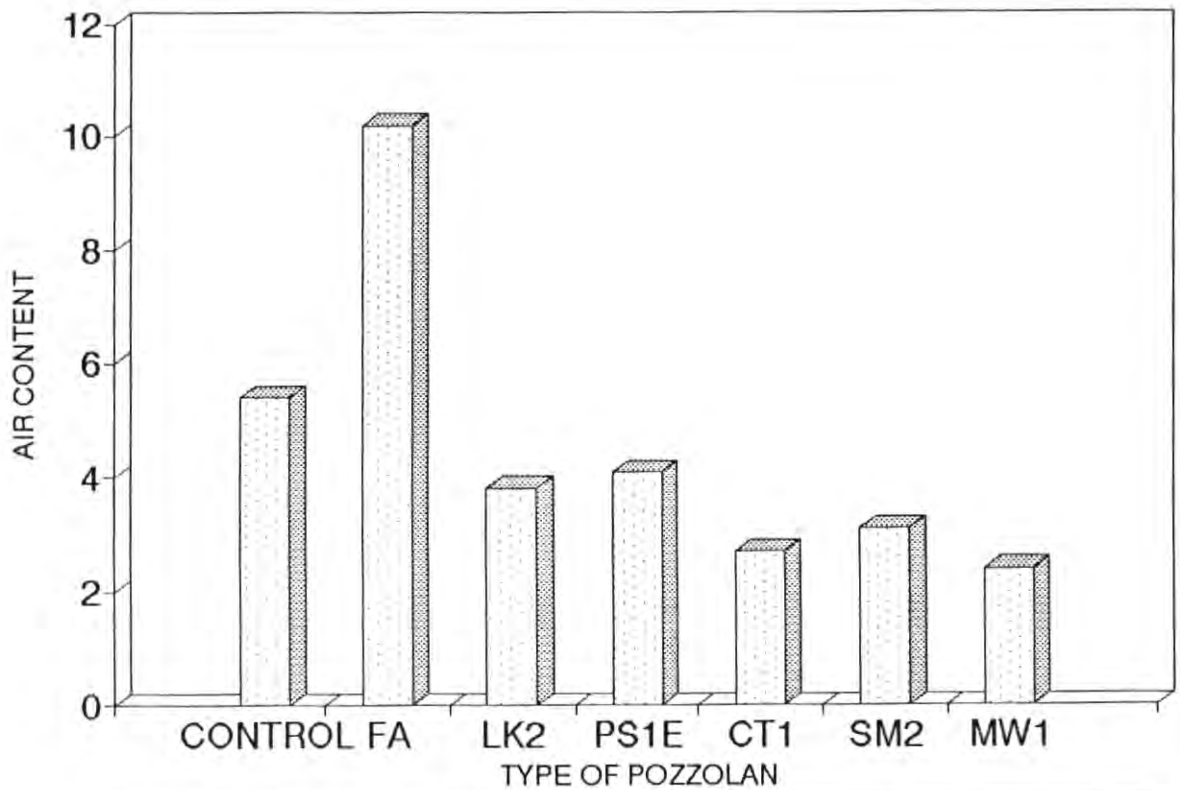


FIG4C: COMPARISON OF AIR CONTENT FOR CONCRETES WITH

25% POZZOLAN BLENDED CEMENTS

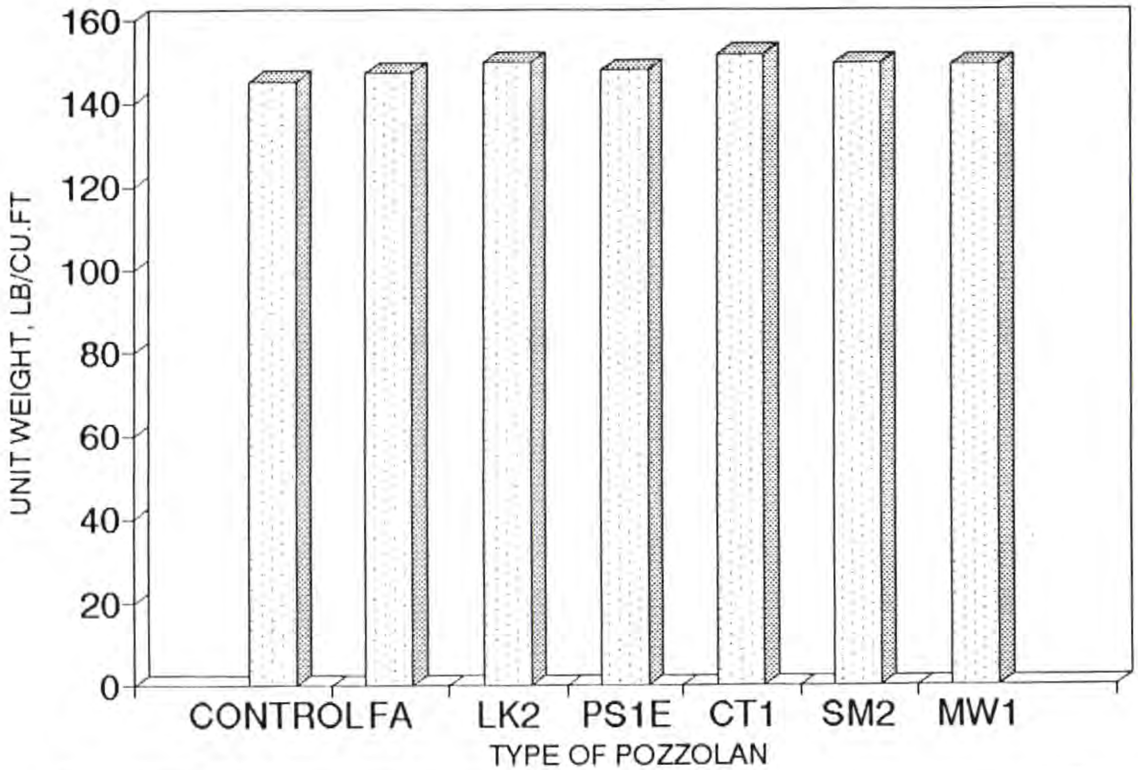


FIG 5A: COMPARISON OF UNIT WEIGHT FOR CONCRETES WITH

10% POZZOLAN BLENDED CEMENTS

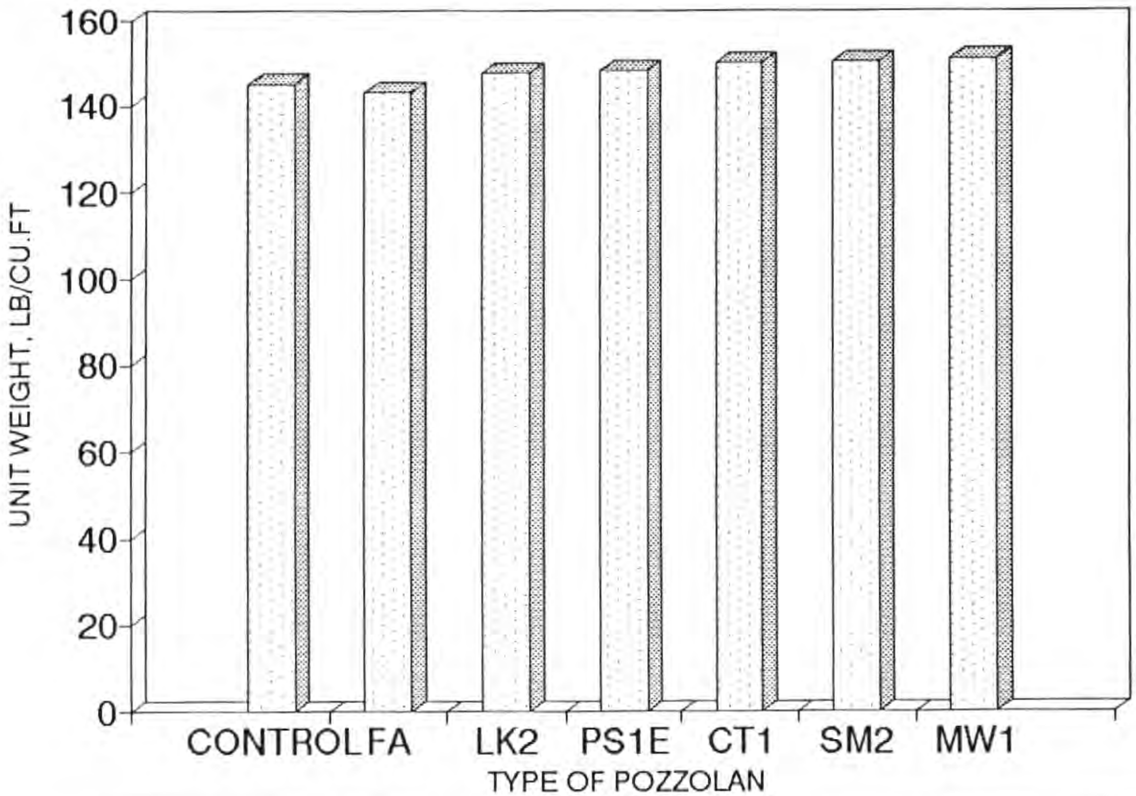


FIG 5B: COMPARISON OF UNIT WEIGHT FOR CONCRETES WITH

15% POZZOLAN BLENDED CEMENTS

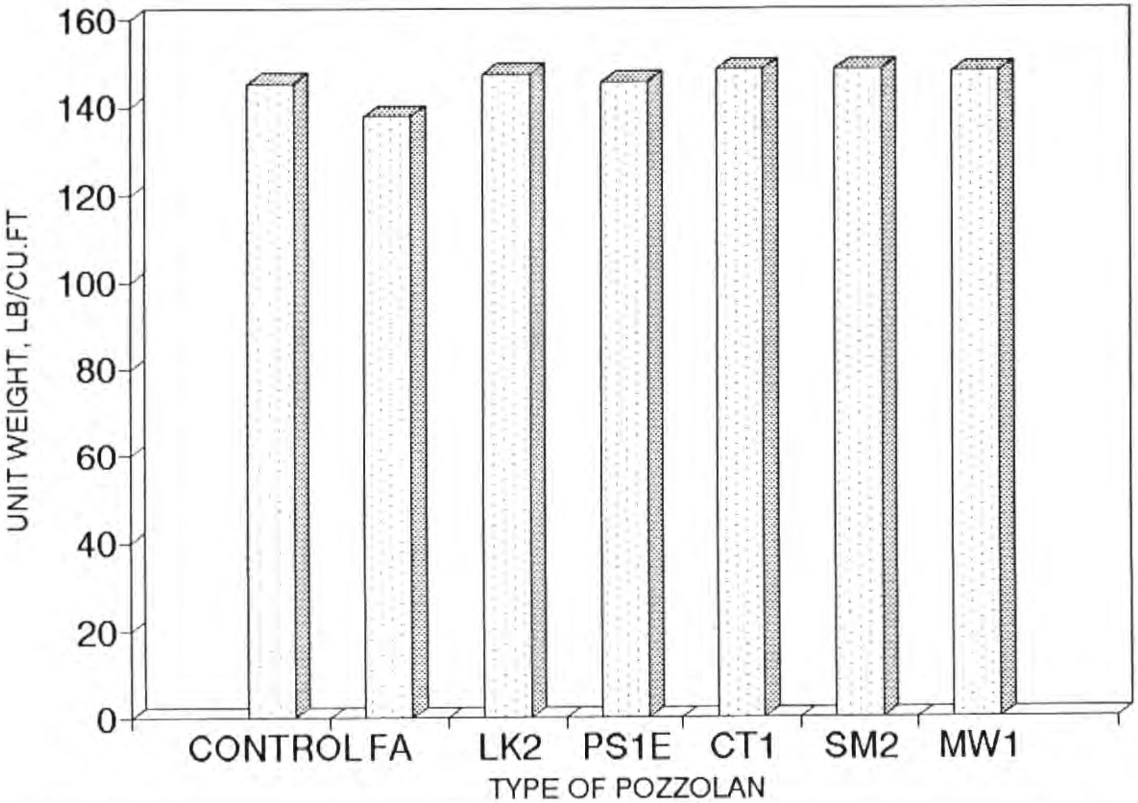


FIG 5C: COMPARISON OF UNIT WEIGHT FOR CONCRETES WITH

25% POZZOLAN BLENDED CEMENTS

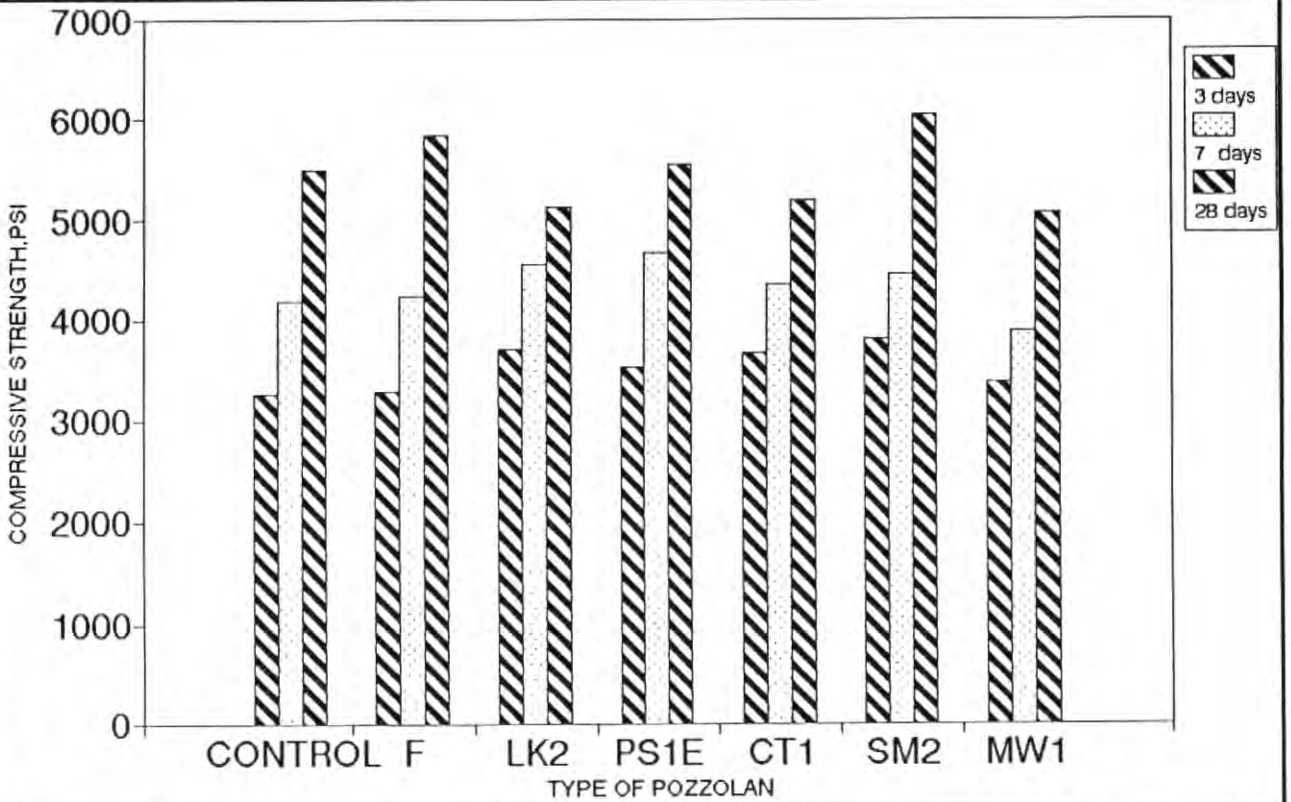


FIG 6A: COMPARISON OF COMPRESSIVE STRENGTH FOR CONCRETES

WITH 10% POZZOLAN BLENDED CEMENTS

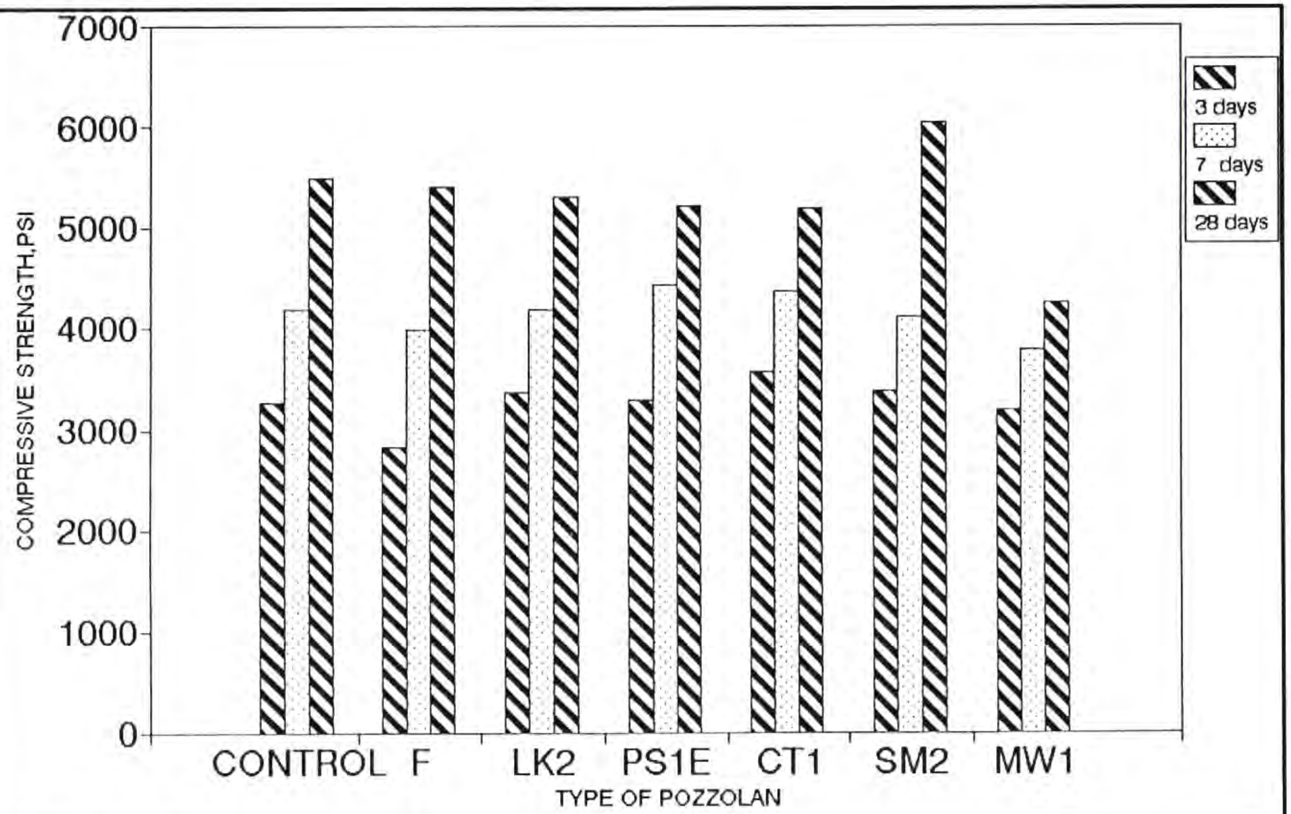


FiG 6B: COMPARISON OF COMPRESSIVE STRENGTH FOR CONCRETES WITH 15% POZZOLAN BLENDED CEMENTS

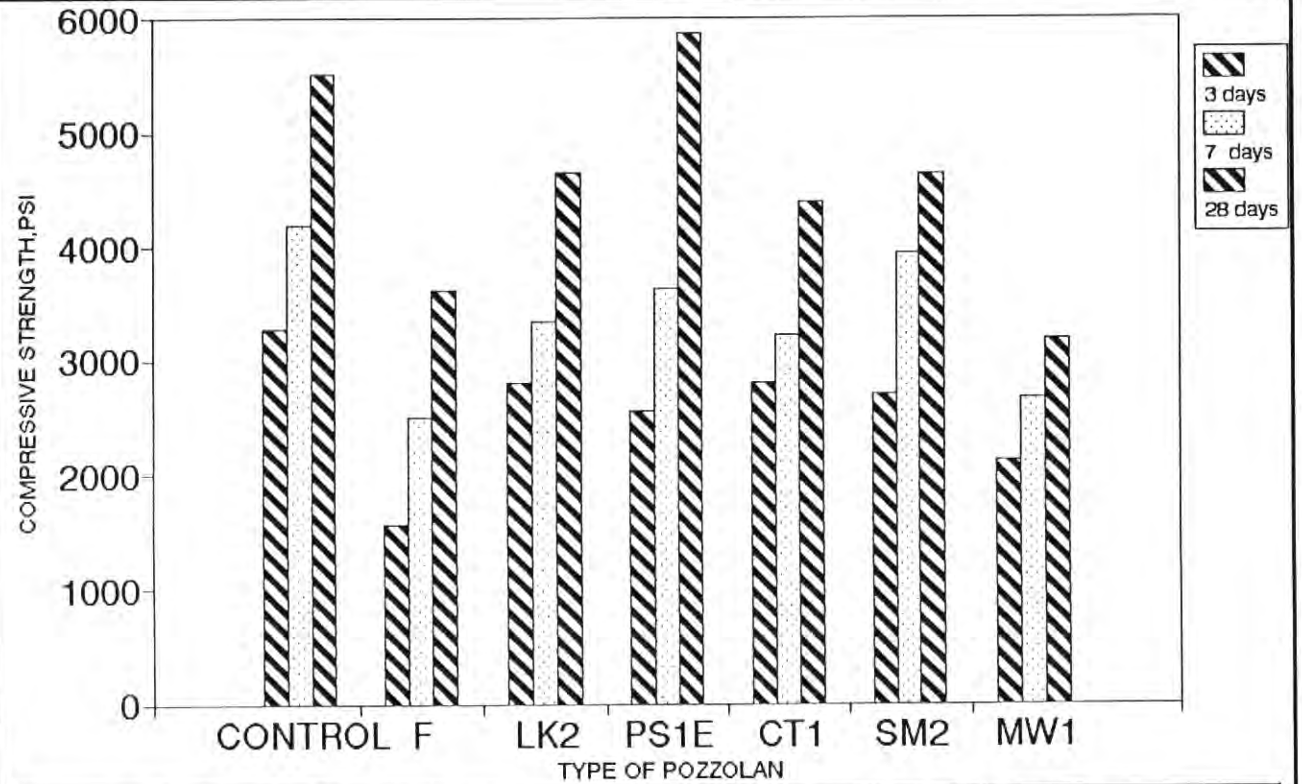


FIG 6C: COMPARISON OF COMPRESSIVE STRENGTH FOR CONCRETES

WITH 25% POZZOLAN BLENDED CEMENTS

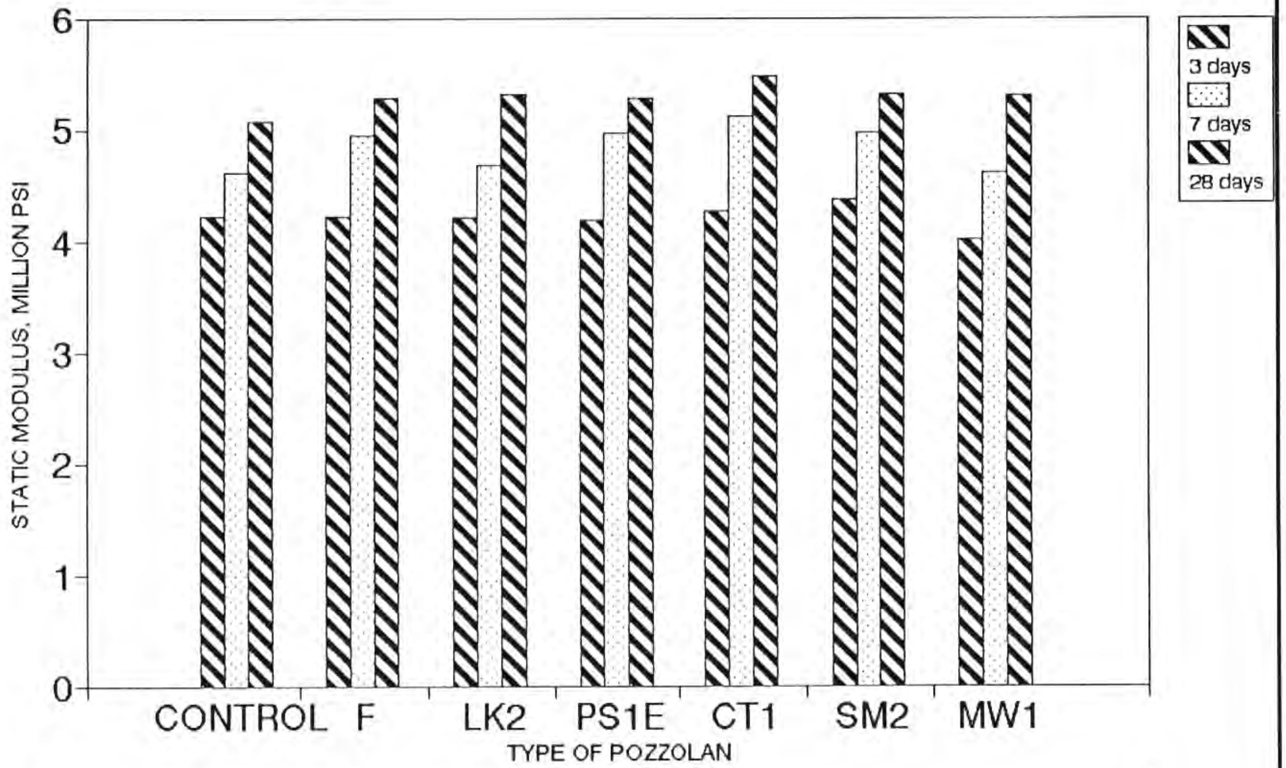


FIG 7A : COMPARISON OF STATIC MODULUS FOR CONCRETES

WITH 10% POZZOLAN BLENDED CEMENTS

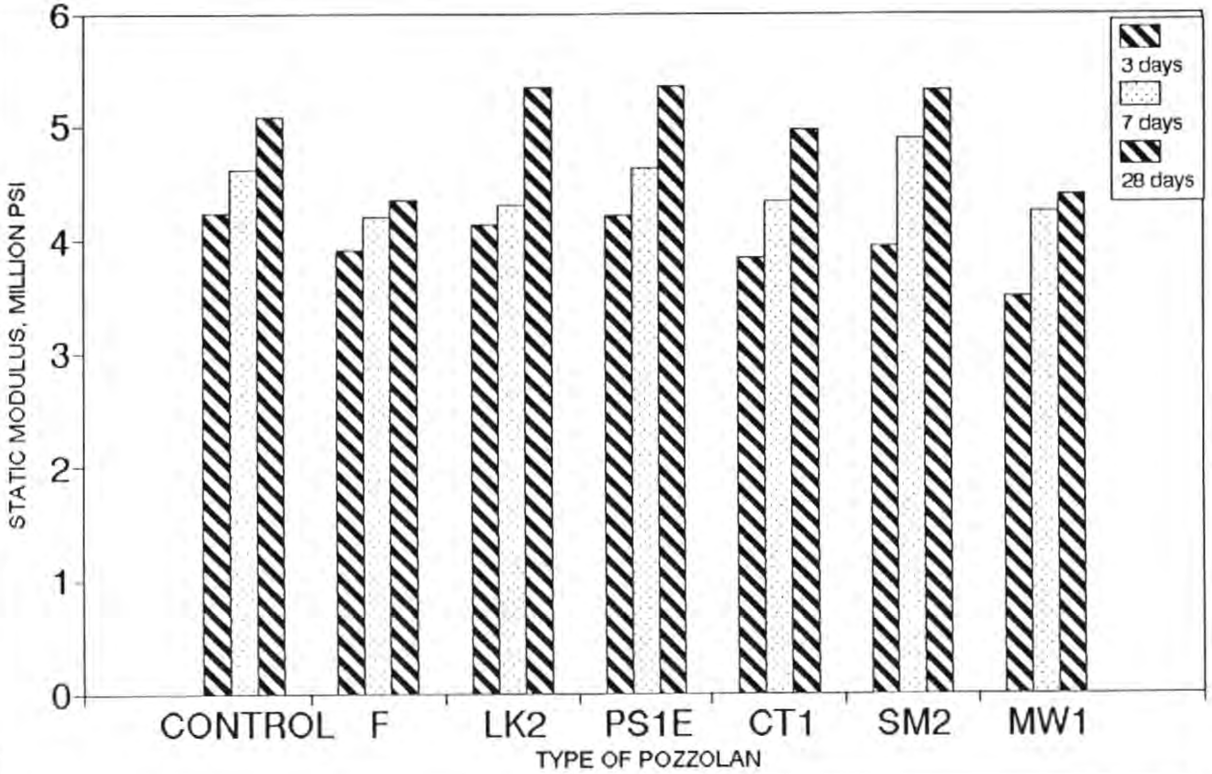


FIG 7B : COMPARISON OF STATIC MODULUS FOR CONCRETES

WITH 15% POZZOLAN BLENDED CEMENTS

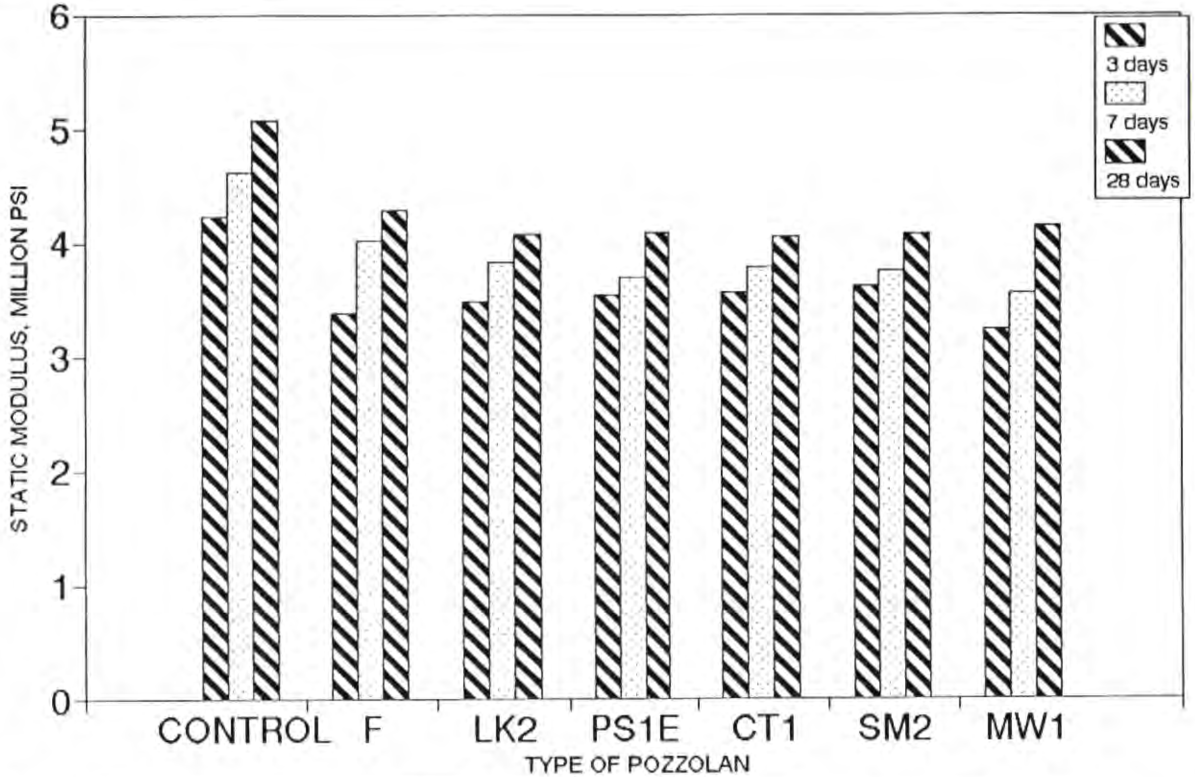


FIG 7C : COMPARISON OF STATIC MODULUS FOR CONCRETES

WITH 25% POZZOLAN BLENDED CEMENTS

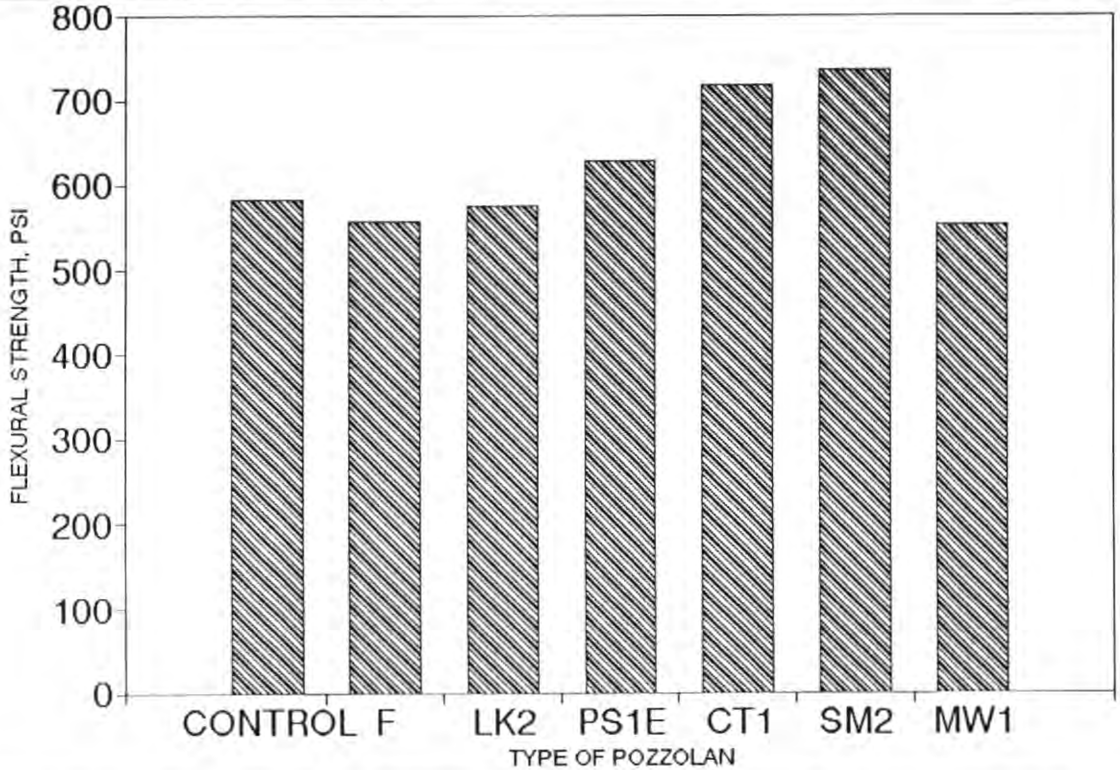


FIG 8A : COMPARISON OF FLEXURAL STRENGTH FOR CONCRETES WITH

10% POZZOLAN BLENDED CEMENTS

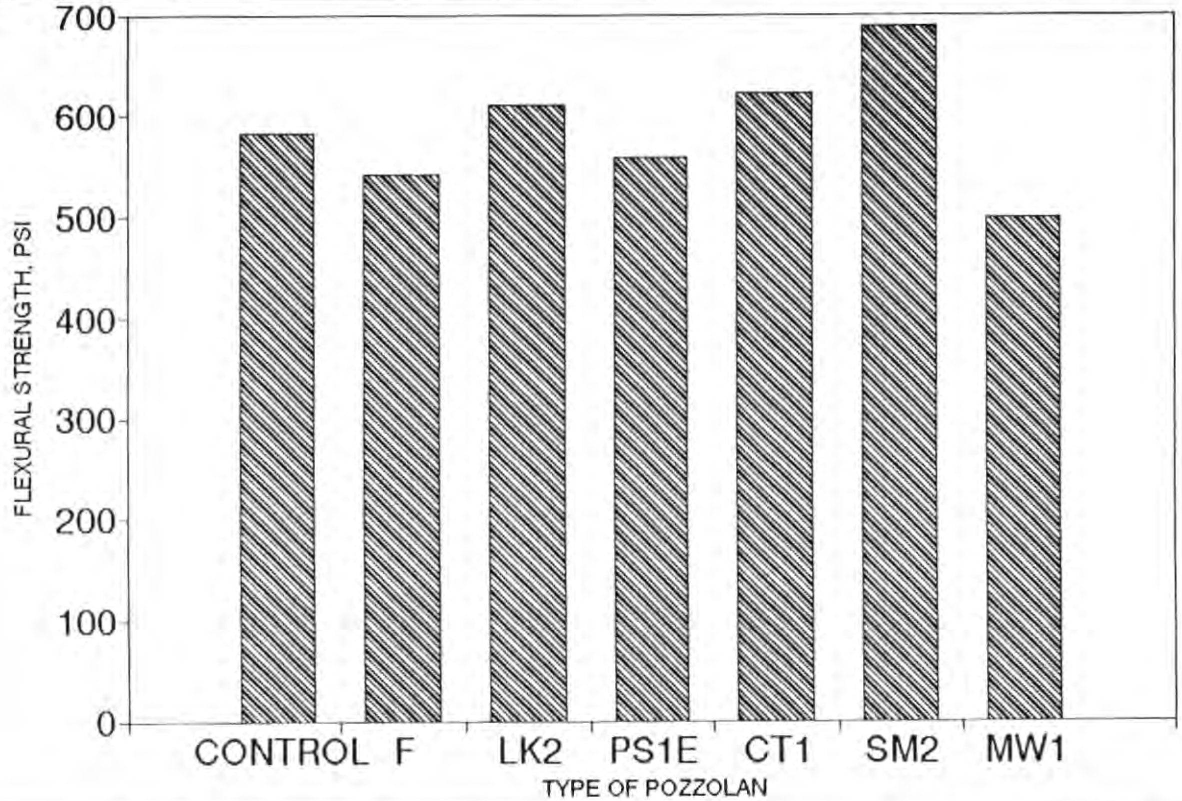


FIG 8B : COMPARISON OF FLEXURAL STRENGTH FOR CONCRETES WITH

15% POZZOLAN BLENDED CEMENTS

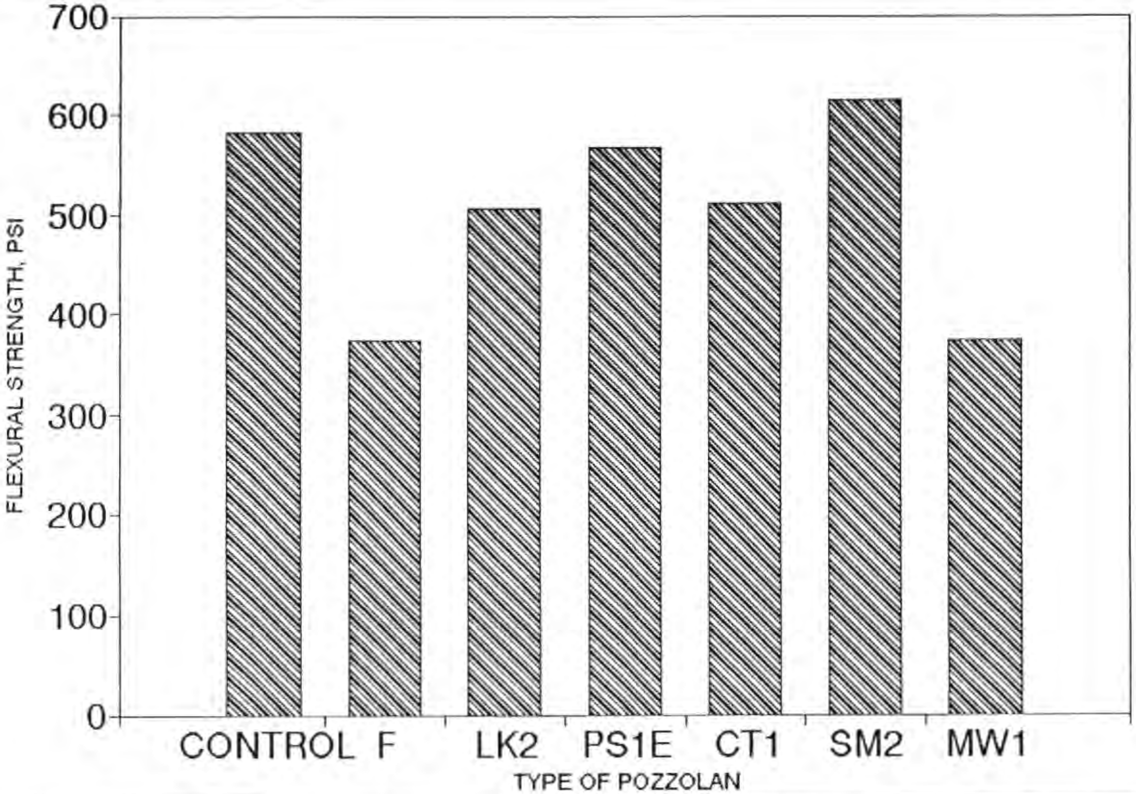


FIG 8C : COMPARISON OF FLEXURAL STRENGTH FOR CONCRETES WITH

25% POZZOLAN BLENDED CEMENTS

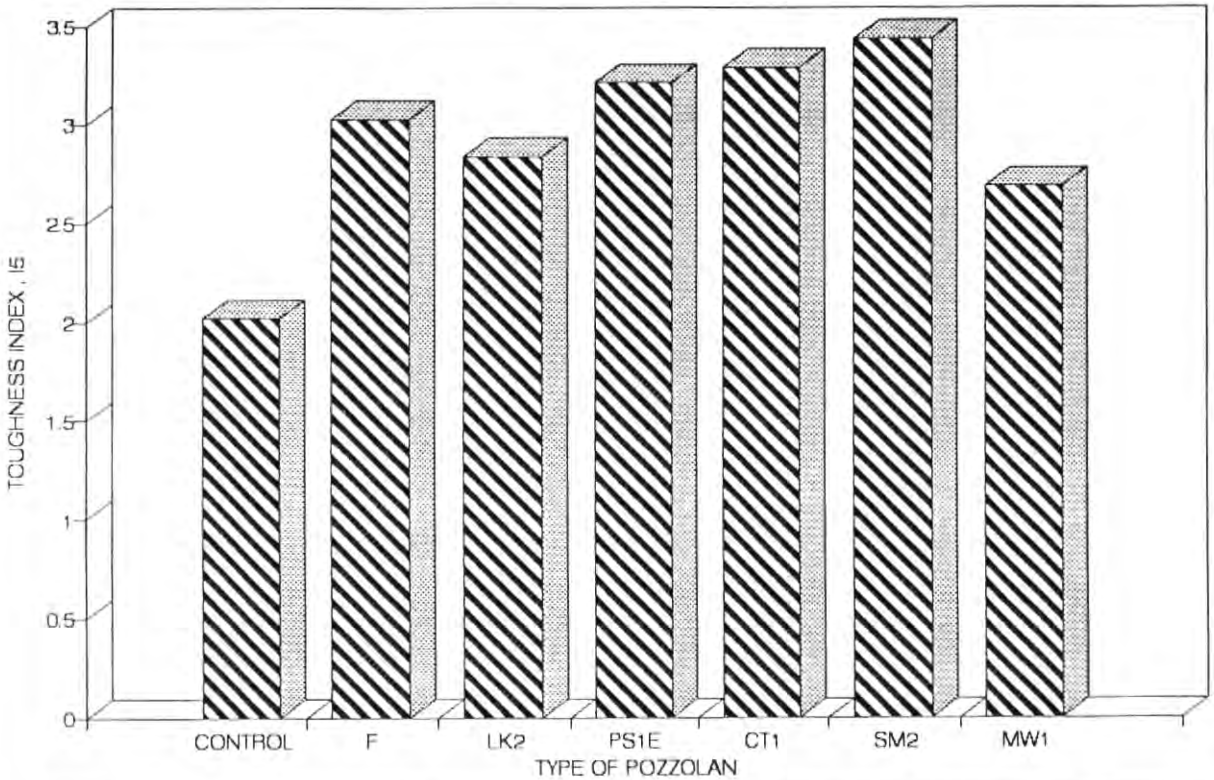


FIG 9A:COMPARISON OF FIRST CRACK TOUGHNESS FOR CONCRETES

WITH 10% POZZOLAN BLENDED CEMENTS

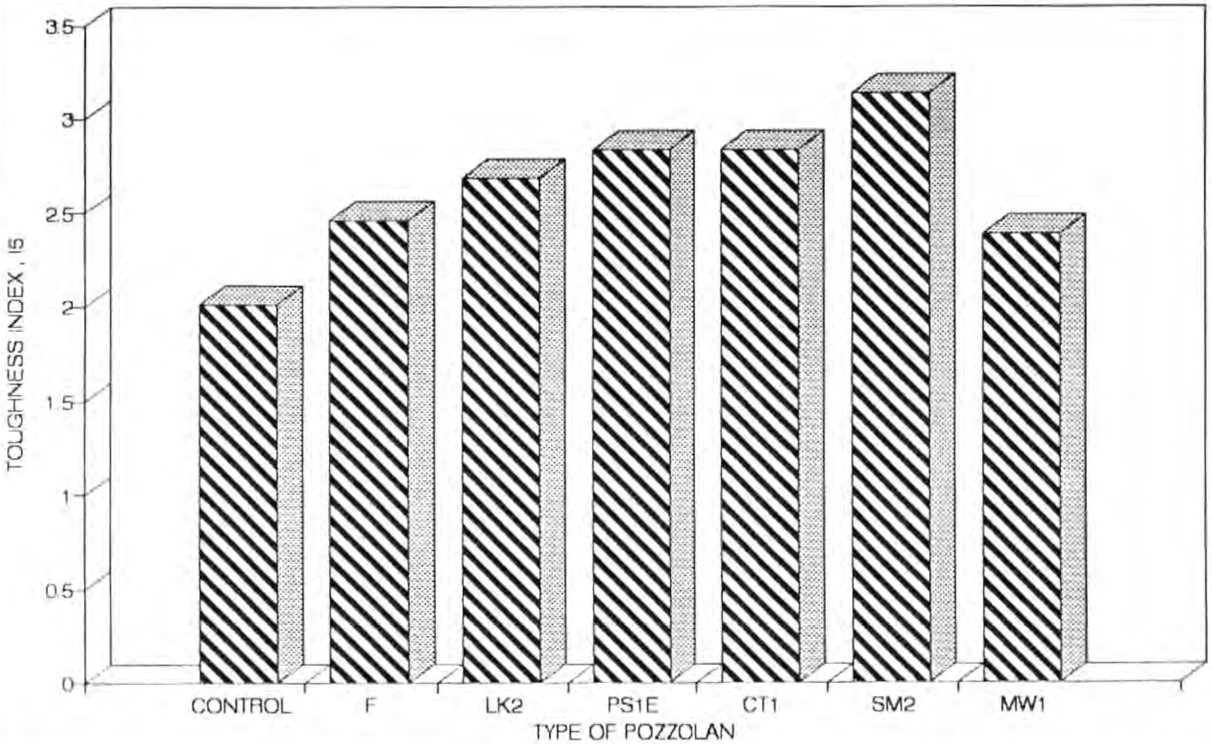


FIG 9B:COMPARISON OF FIRST CRACK TOUGHNESS FOR CONCRETES WITH

15% POZZOLAN BLENDED CEMENTS

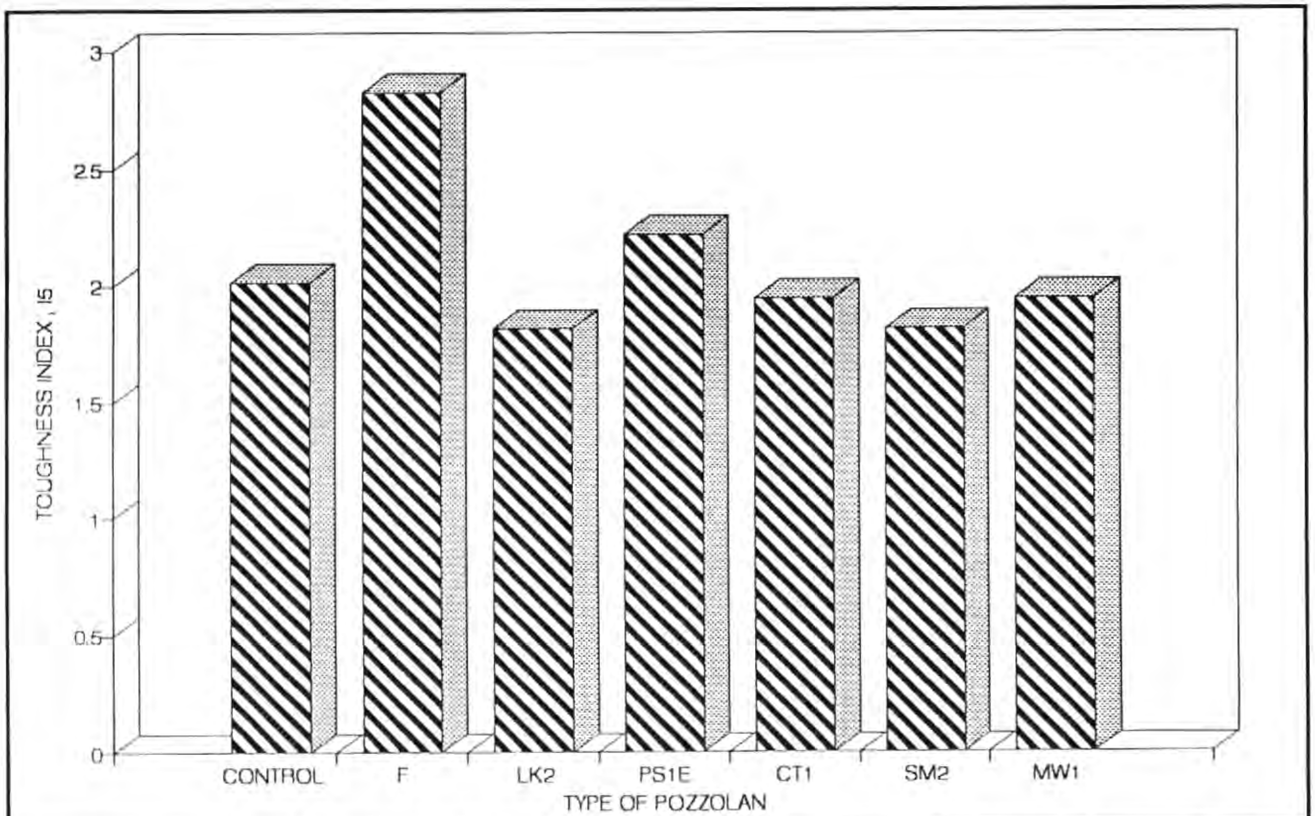


FIG 9C:COMPARISON OF FIRST CRACK TOUGHNESS FOR CONCRETES WITH

25% POZZOLAN BLENDED CEMENTS

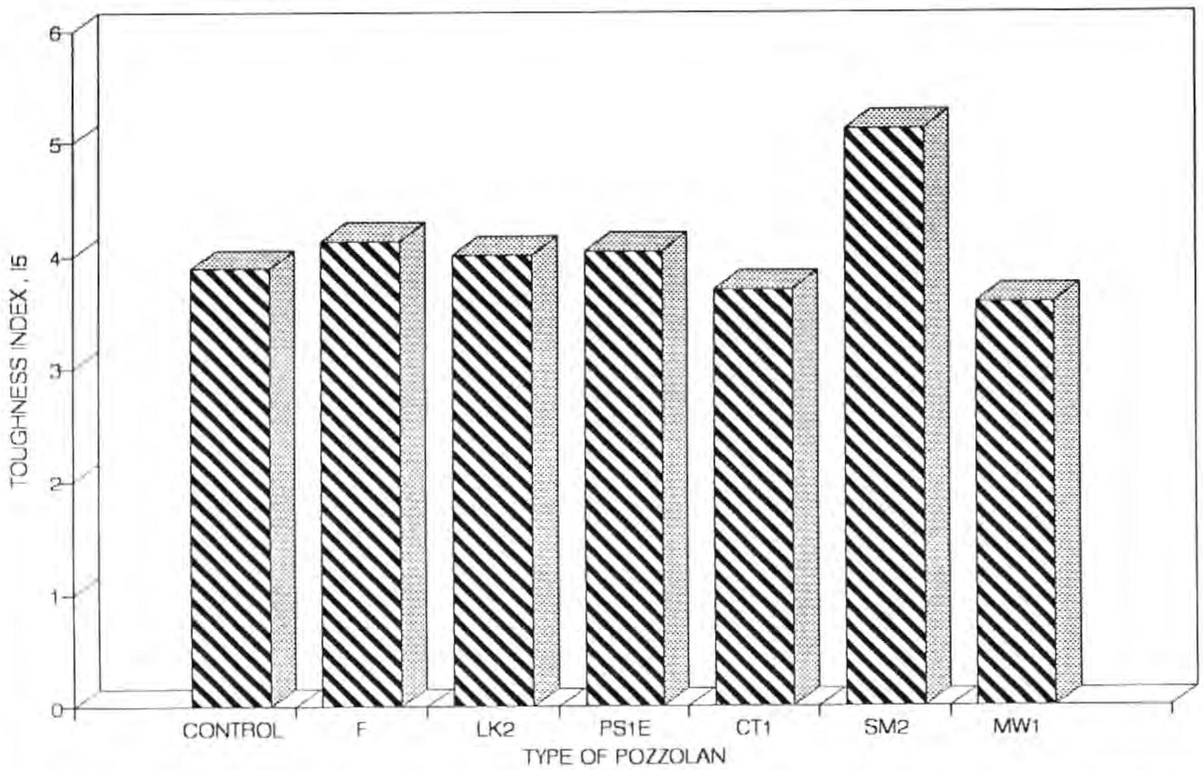


FIG 10A : COMPARISON OF TOUGHNESS INDEX , I5 FOR CONCRETES WITH

10% POZZOLAN BLENDED CEMENTS

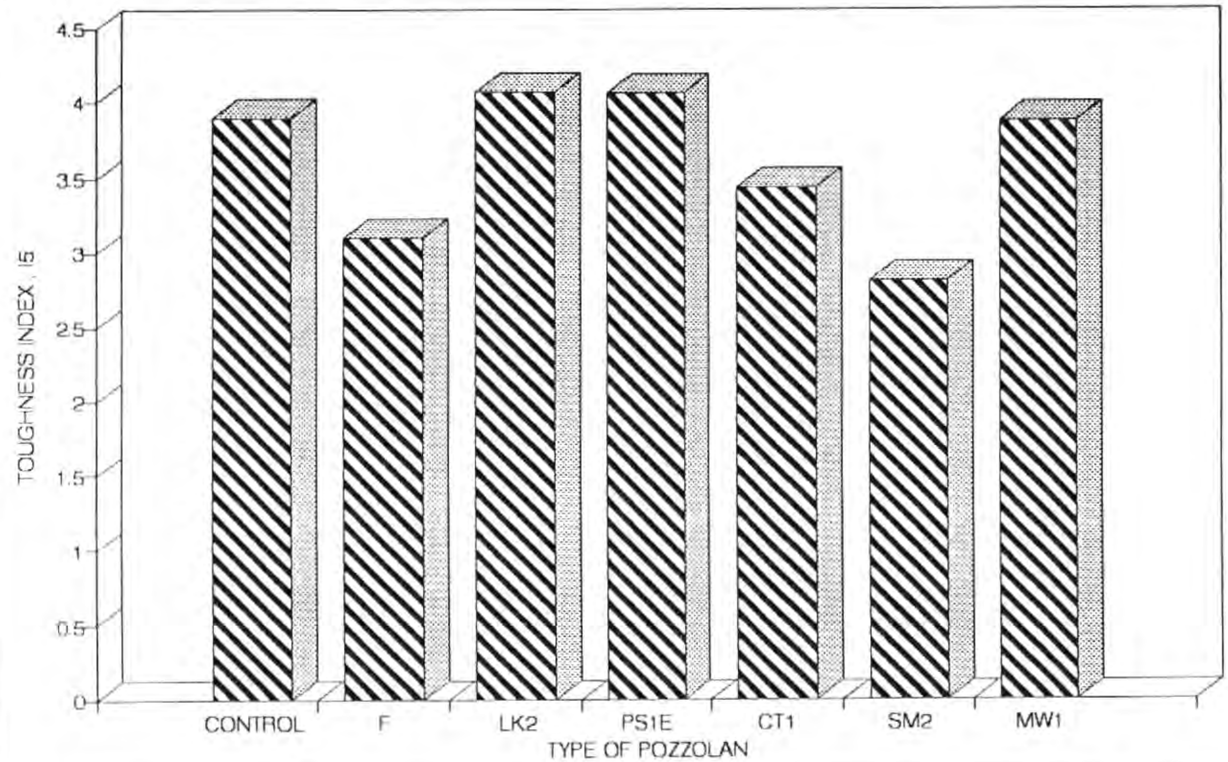


FIG 10B : COMPARISON OF TOUGHNESS INDEX , I5 FOR CONCRETES WITH

15% POZZOLAN BLENDED CEMENTS

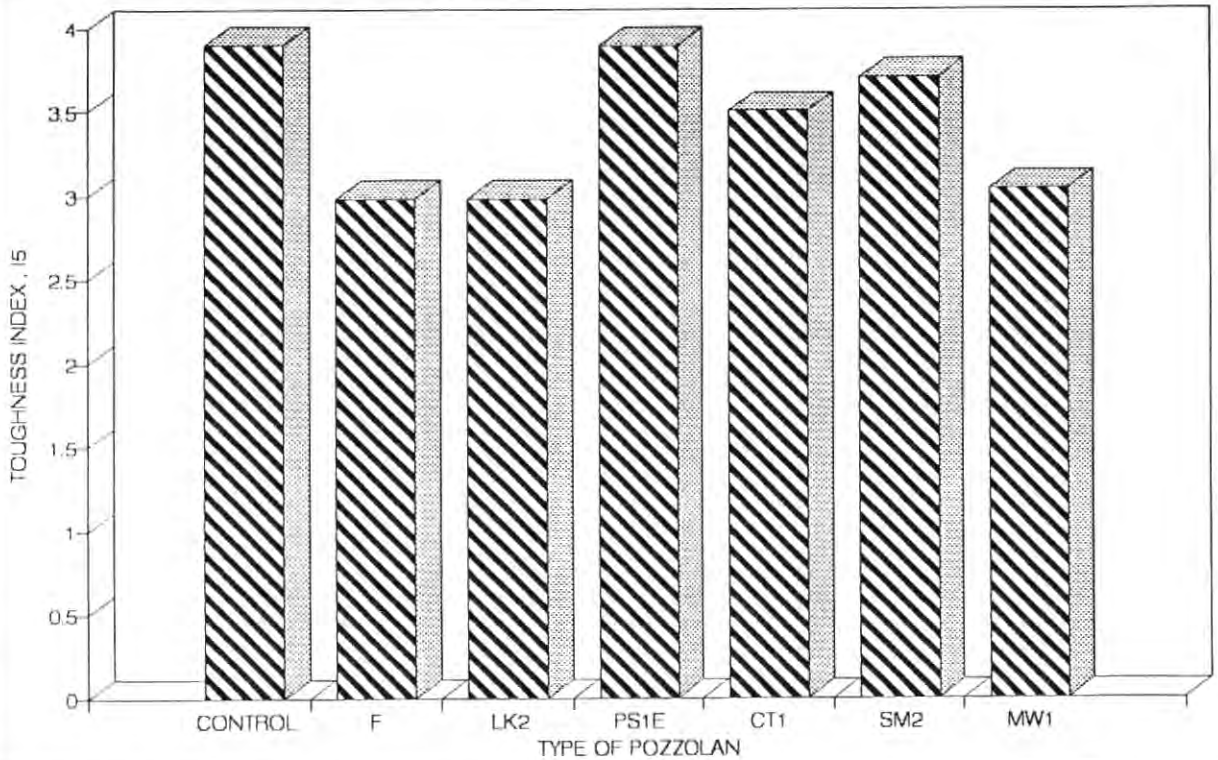


FIG 10C : COMPARISON OF TOUGHNESS INDEX , I5 FOR CONCRETES WITH

25% POZZOLAN BLENDED CEMENTS

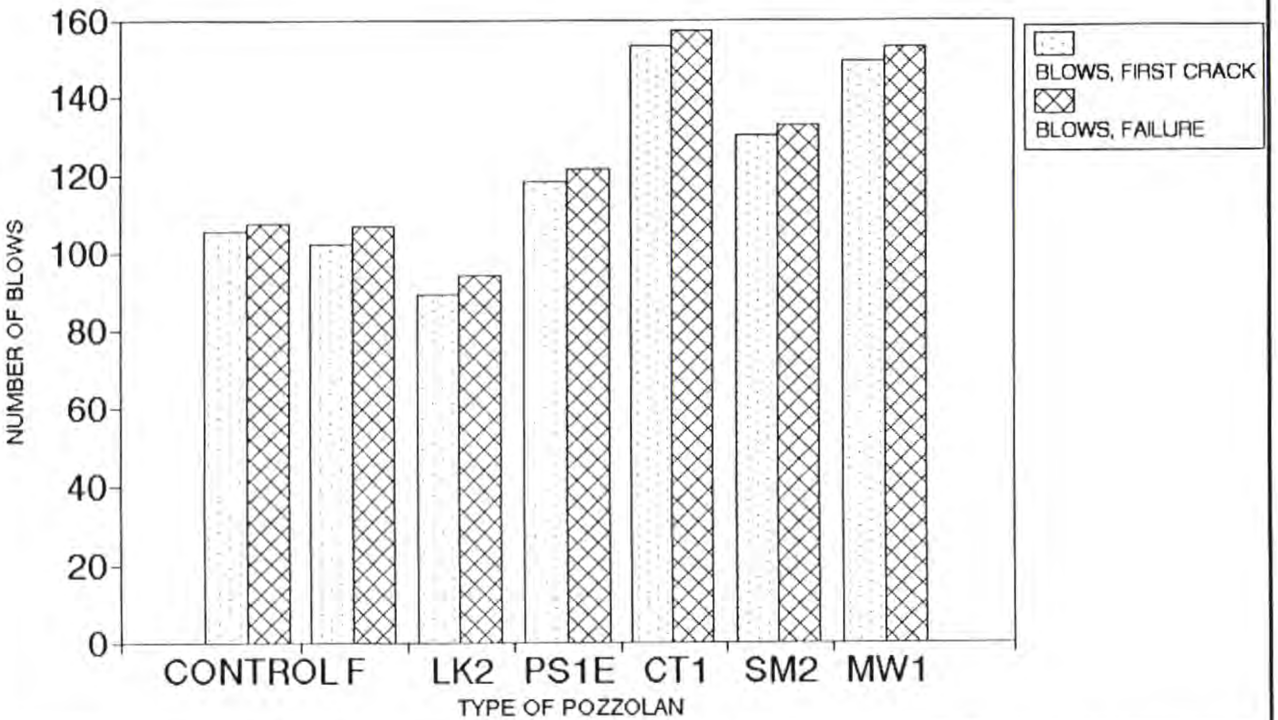


Fig. 11A: COMPARISON OF IMPACT STRENGTH FOR CONCRETES WITH

10% POZZOLAN BLENDED CEMETNS

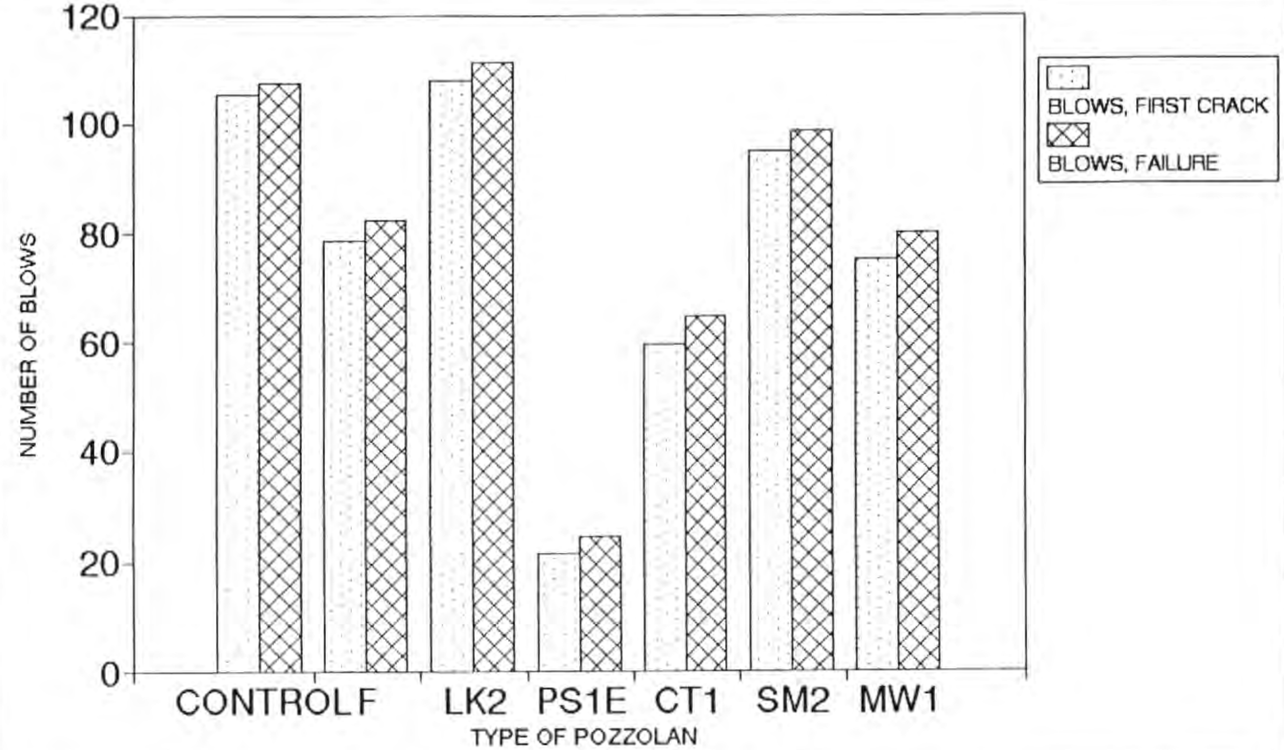


Fig. 11B: COMPARISON OF IMPACT STRENGTH FOR CONCRETES WITH

15% POZZOLAN BLENDED CEMENTS

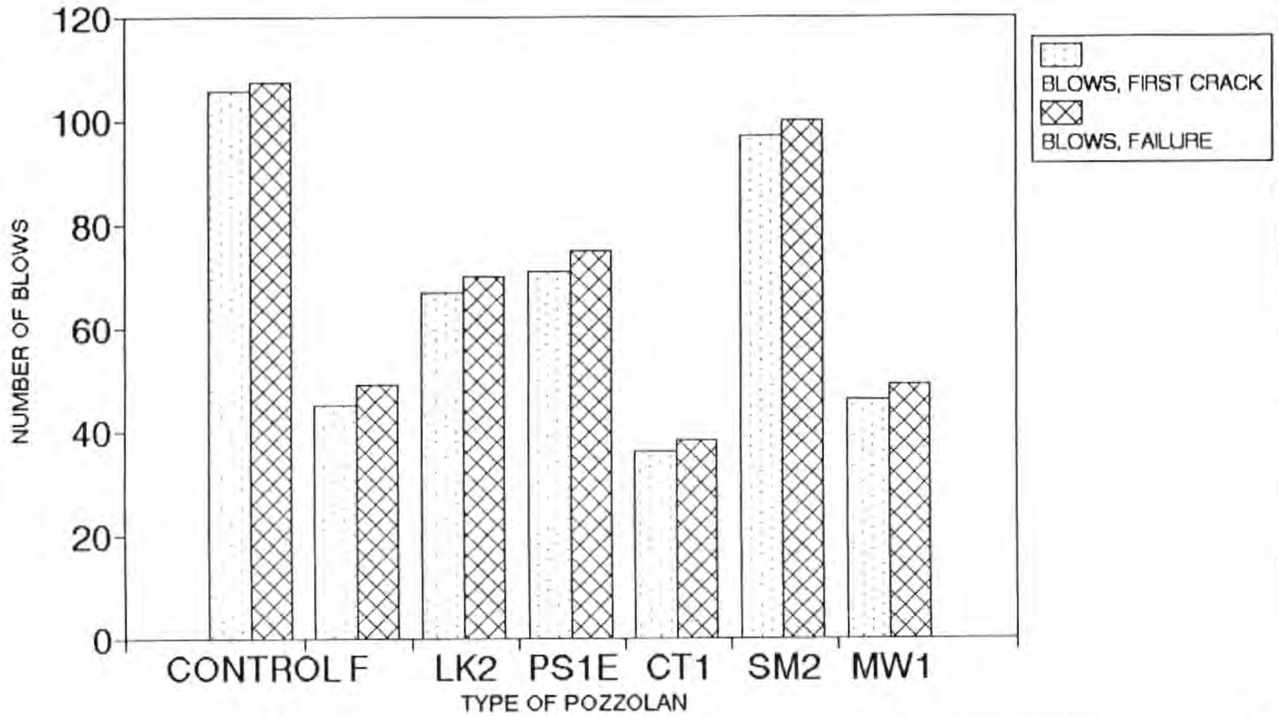


Fig. 11C: COMPARISON OF IMPACT STRENGTH FOR CONCRETES WITH

25% POZZOLAN BLENDED CEMENTS

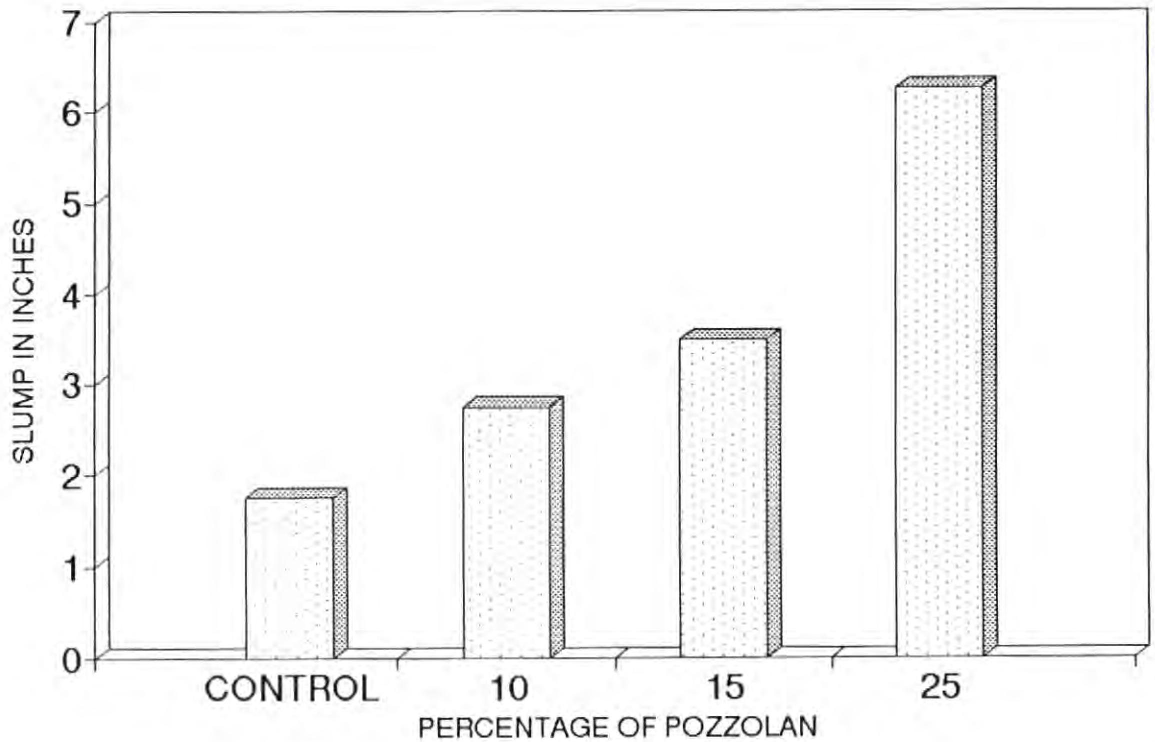
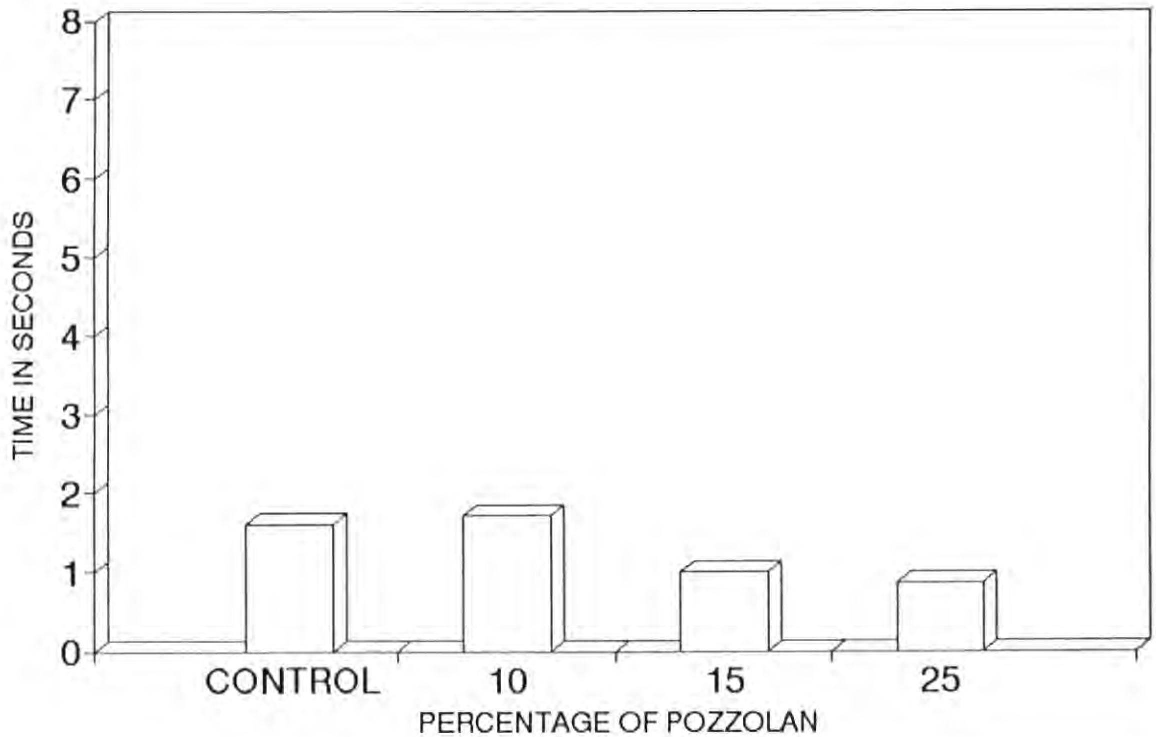


FIG 12A: COMPARISON OF SLUMP FOR CONCRETES WITH

FLY ASH BLENDED CEMENTS



12B: COMPARISON OF VEBE TIME FOR CONCRETES WITH

FLY ASH BLENDED CEMENTS

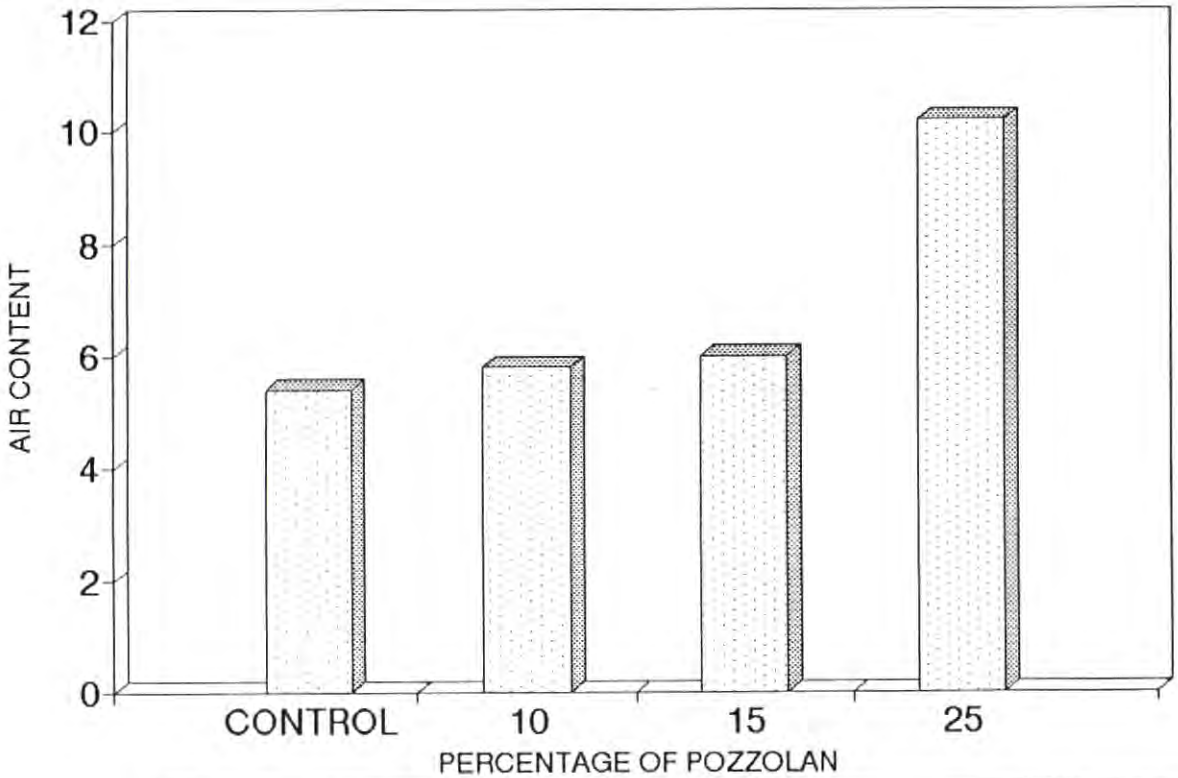


FIG 12C: COMPARISON OF AIR CONTENT FOR CONCRETES WITH

FLY ASH BLENDED CEMENTS

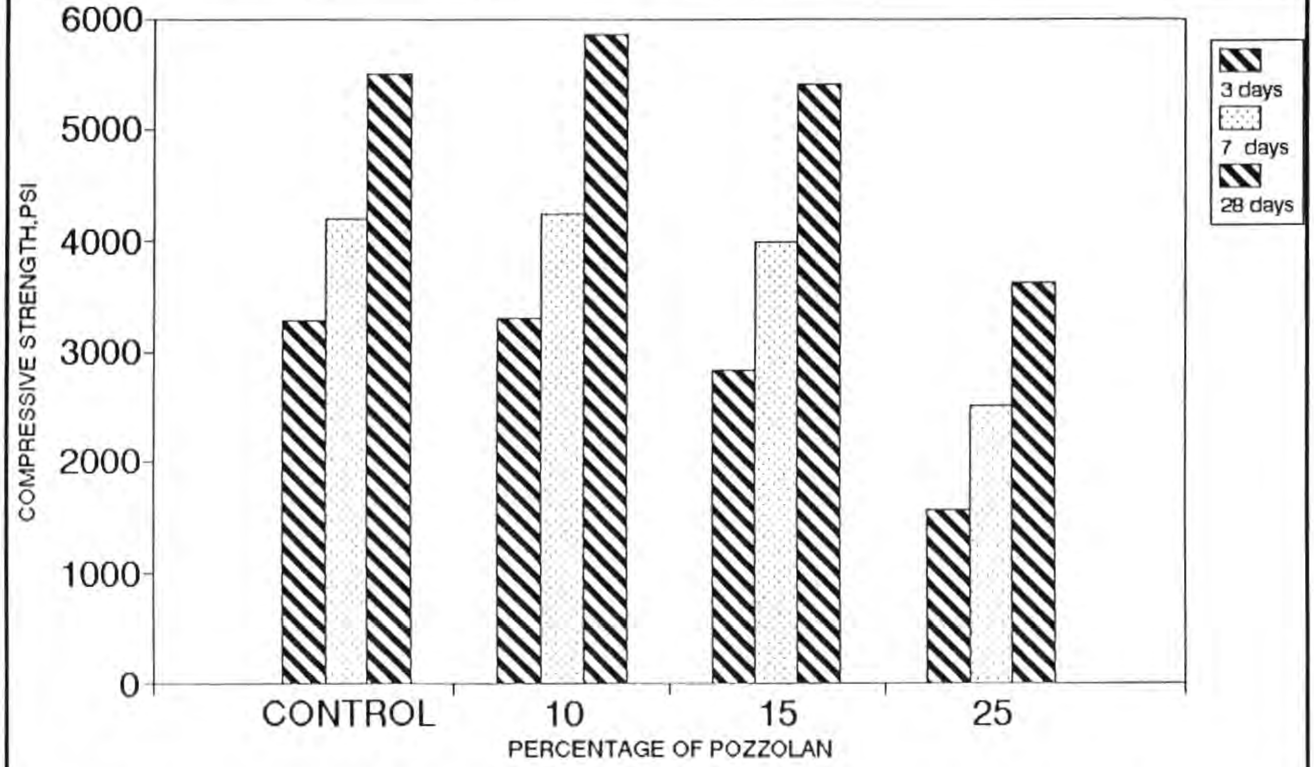


FiG 12D: COMPARISON OF COMPRESSIVE STRENGTH FOR CONCRETES

WITH FLY ASH BLENDED CEMENTS

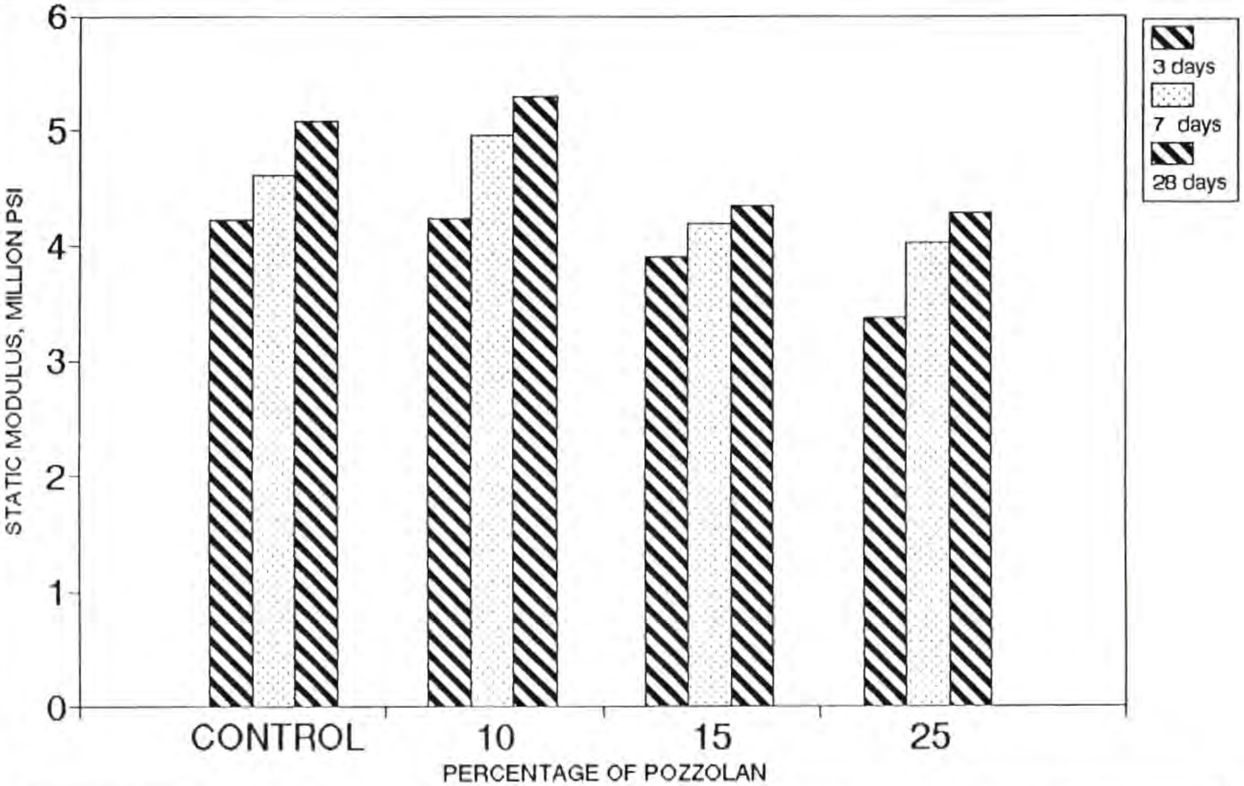


FIG 12E : COMPARISON OF STATIC MODULUS FOR CONCRETES WITH

FLY ASH BLENDED CEMENTS

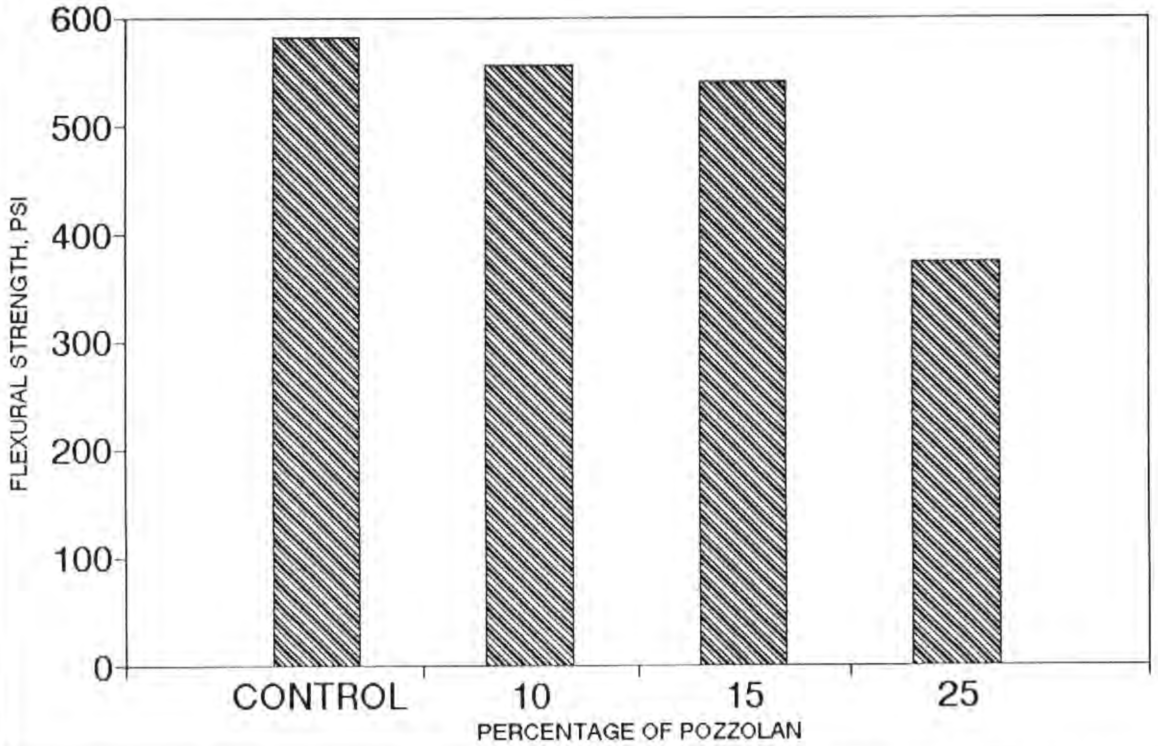


FIG 12F : COMPARISON OF FLEXURAL STRENGTH FOR CONCRETES WITH

FLY ASH BLENDED CEMENTS

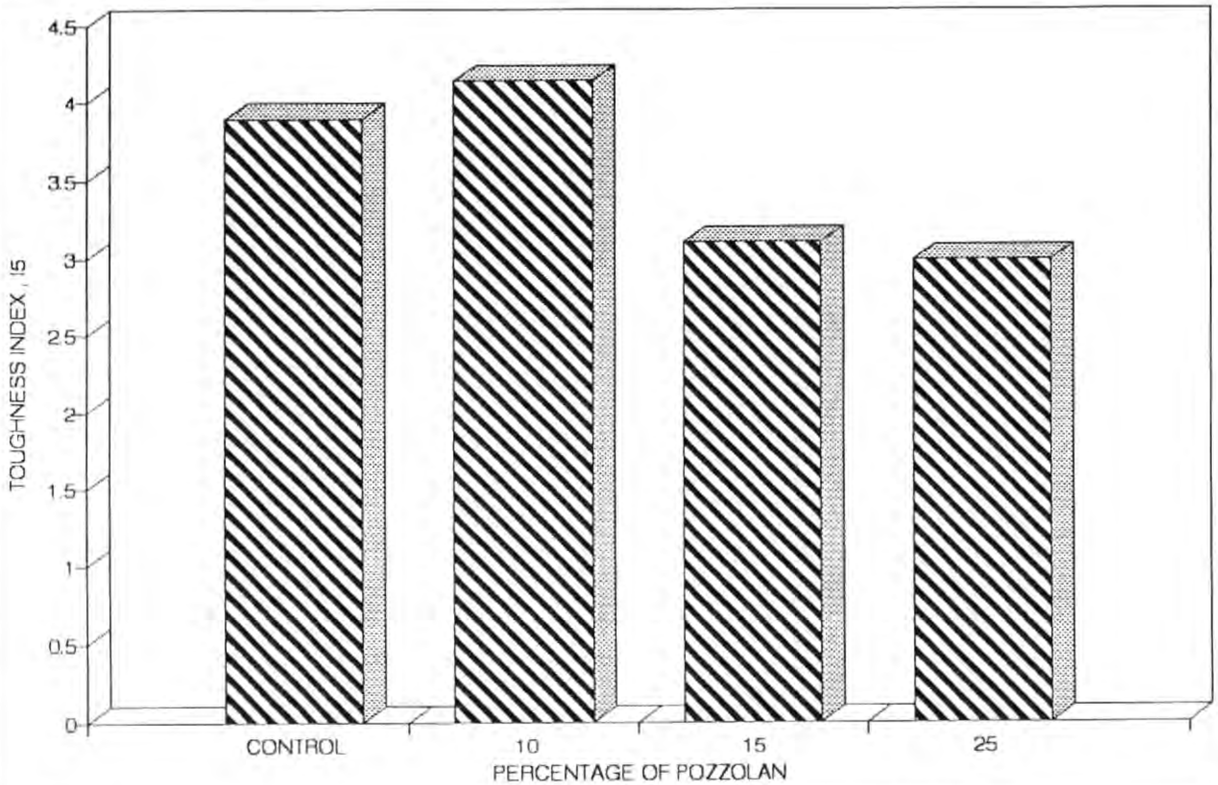


FIG 12G : COMPARISON OF TOUGHNESS INDEX , I5 FOR CONCRETES

WITH FLY ASH BLENDED CEMENTS

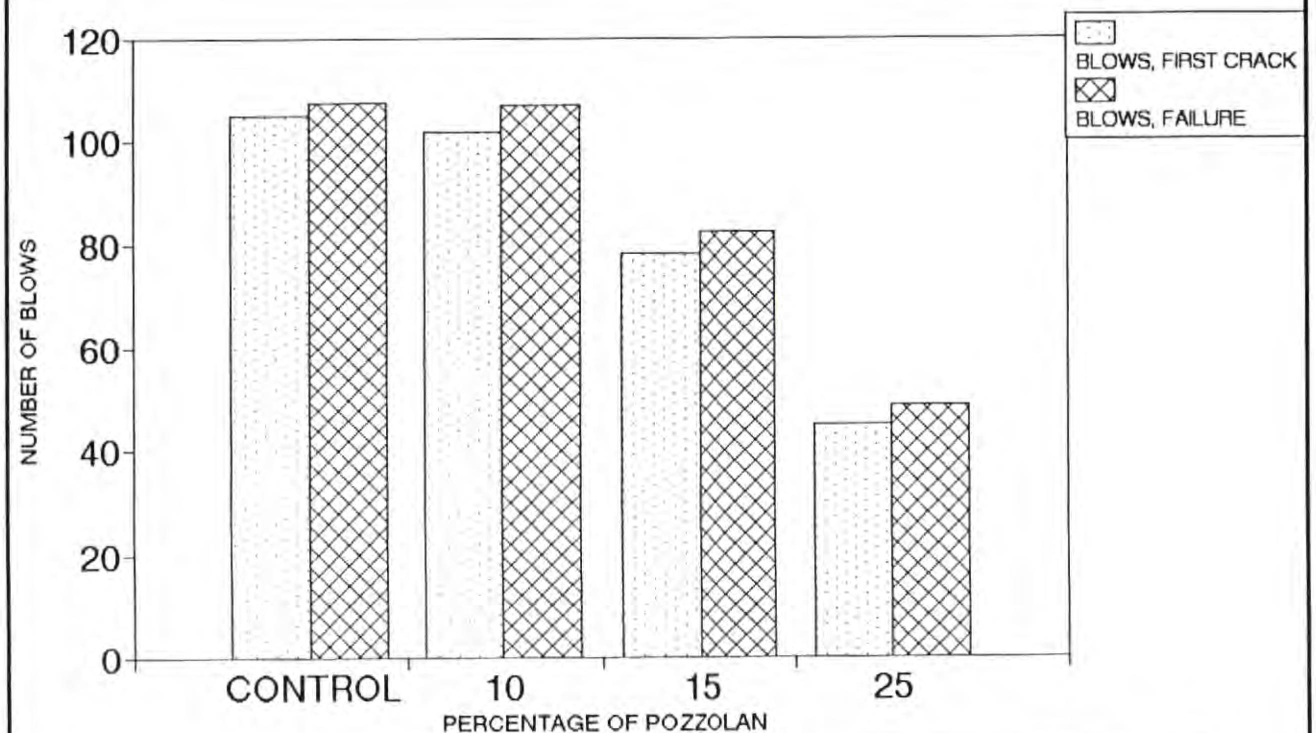


Fig. 12 H: COMPARISON OF IMPACT STRENGTH FOR CONCRETES WITH FLY ASH BLENDED CEMENTS

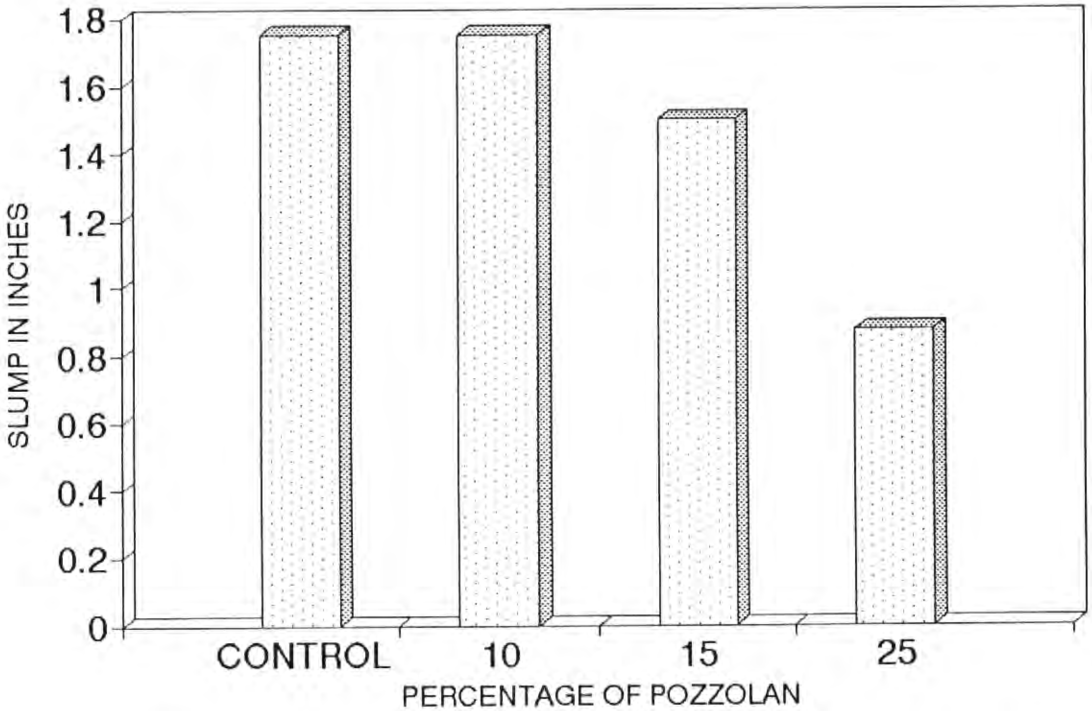
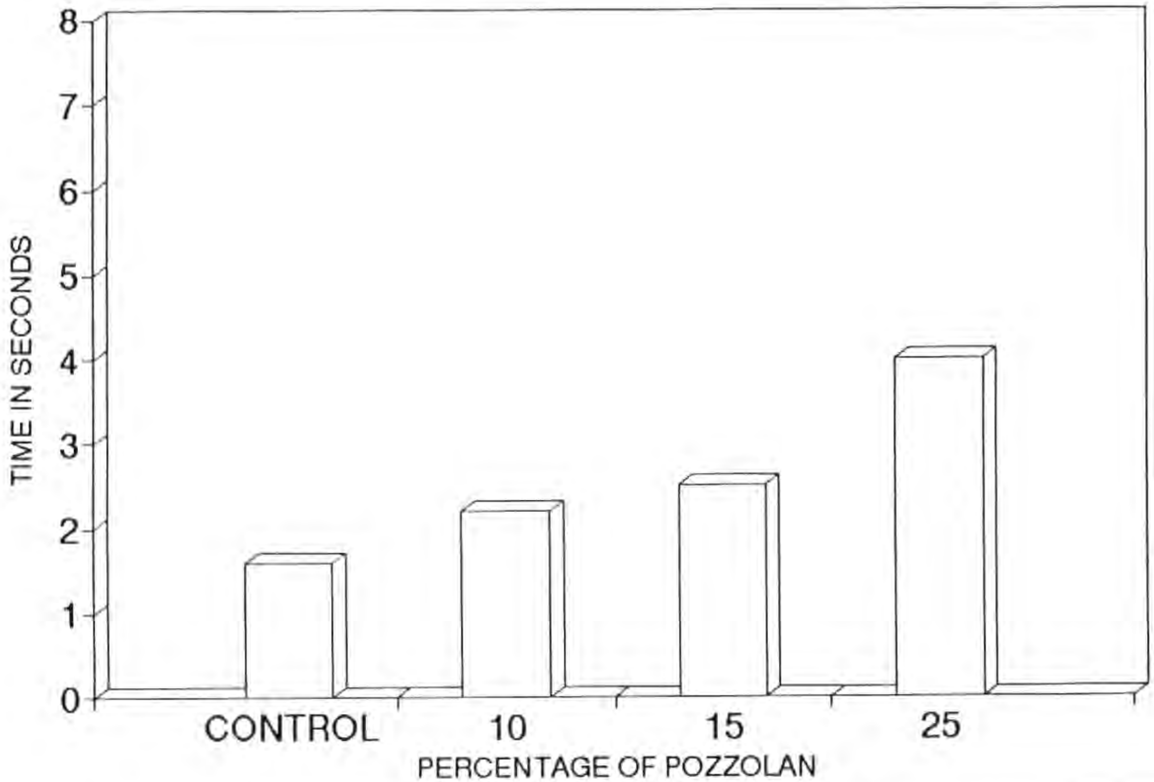


FIG 13A: COMPARISON OF SLUMP FOR CONCRETES WITH

LK2 POZZOLAN BLENDED CEMENTS



13B: COMPARISION OF VEBE TIME FOR CONCRETES WITH

LK2 POZZOLAN BLENDED CEMENTS

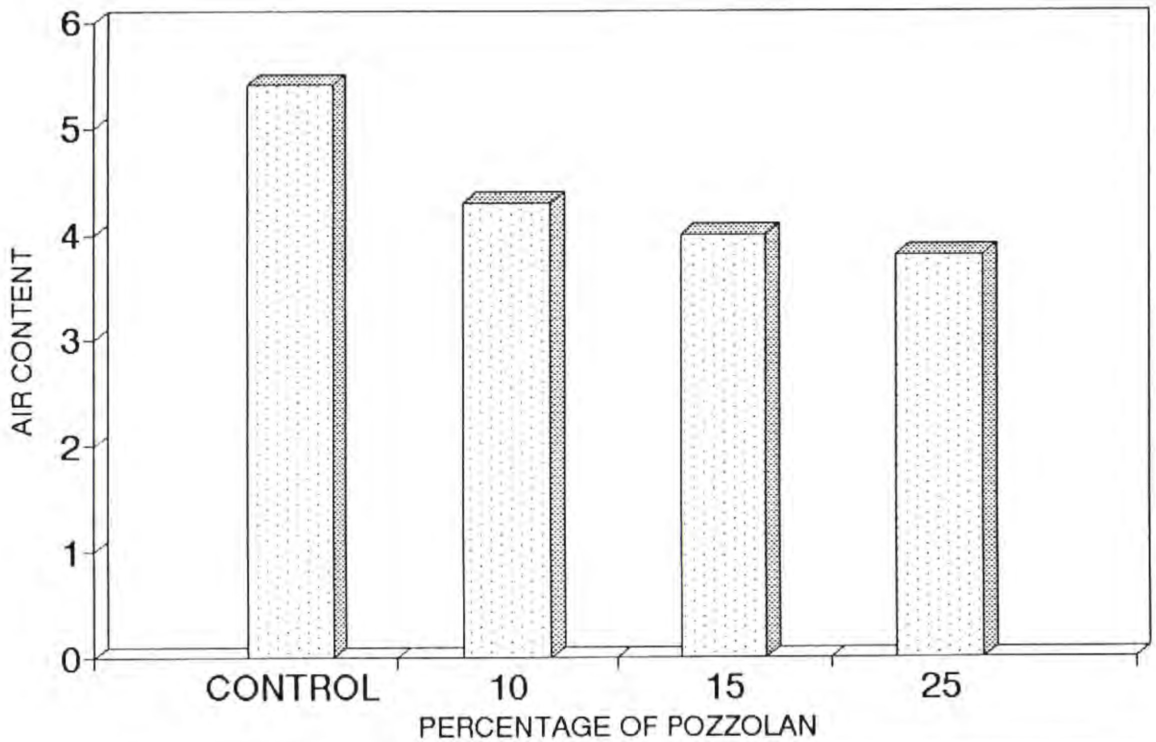


FIG 13C: COMPARISON OF AIR CONTENT FOR CONCRETES WITH

LK2 POZZOLAN BLENDED CEMENTS

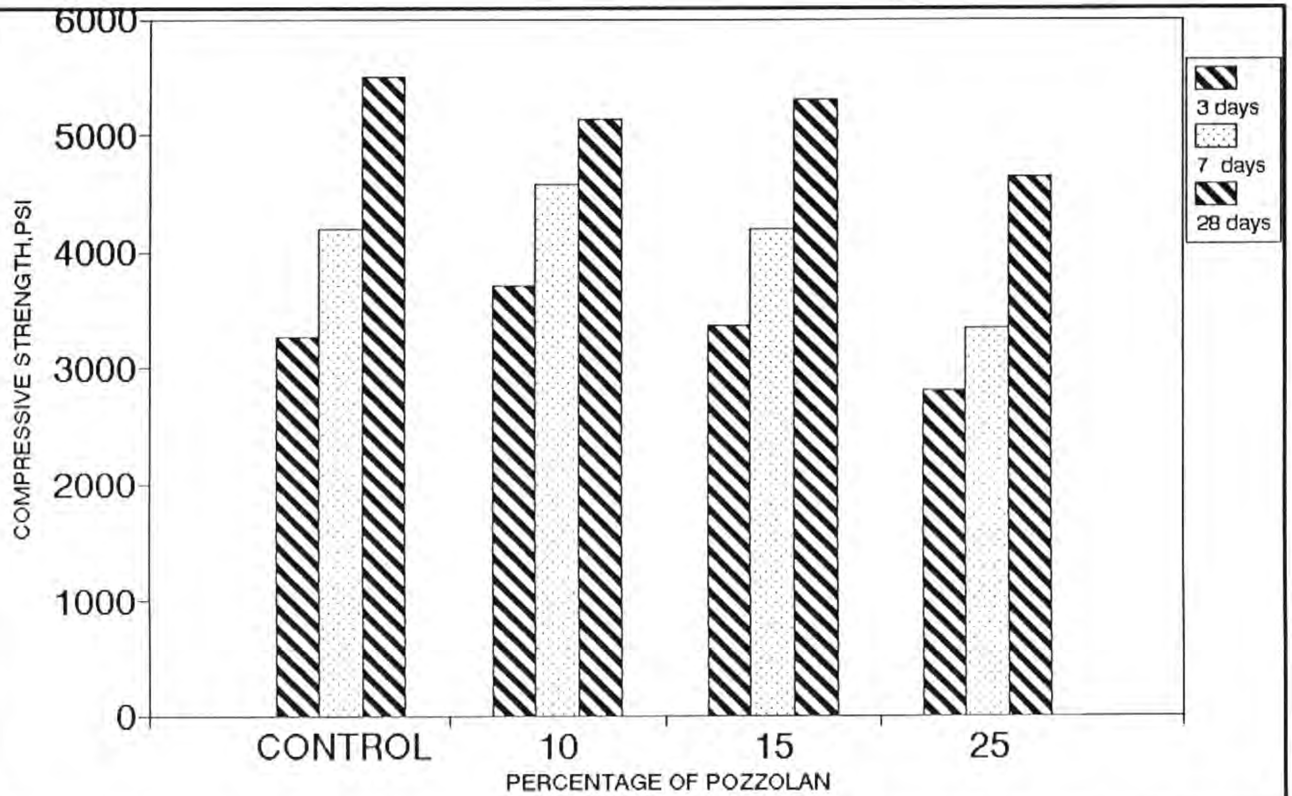


FiG 13D: COMPARISON OF COMPRESSIVE STRENGTH FOR CONCRETES

WITH LK2 POZZOLAN BLENDED CEMENTS

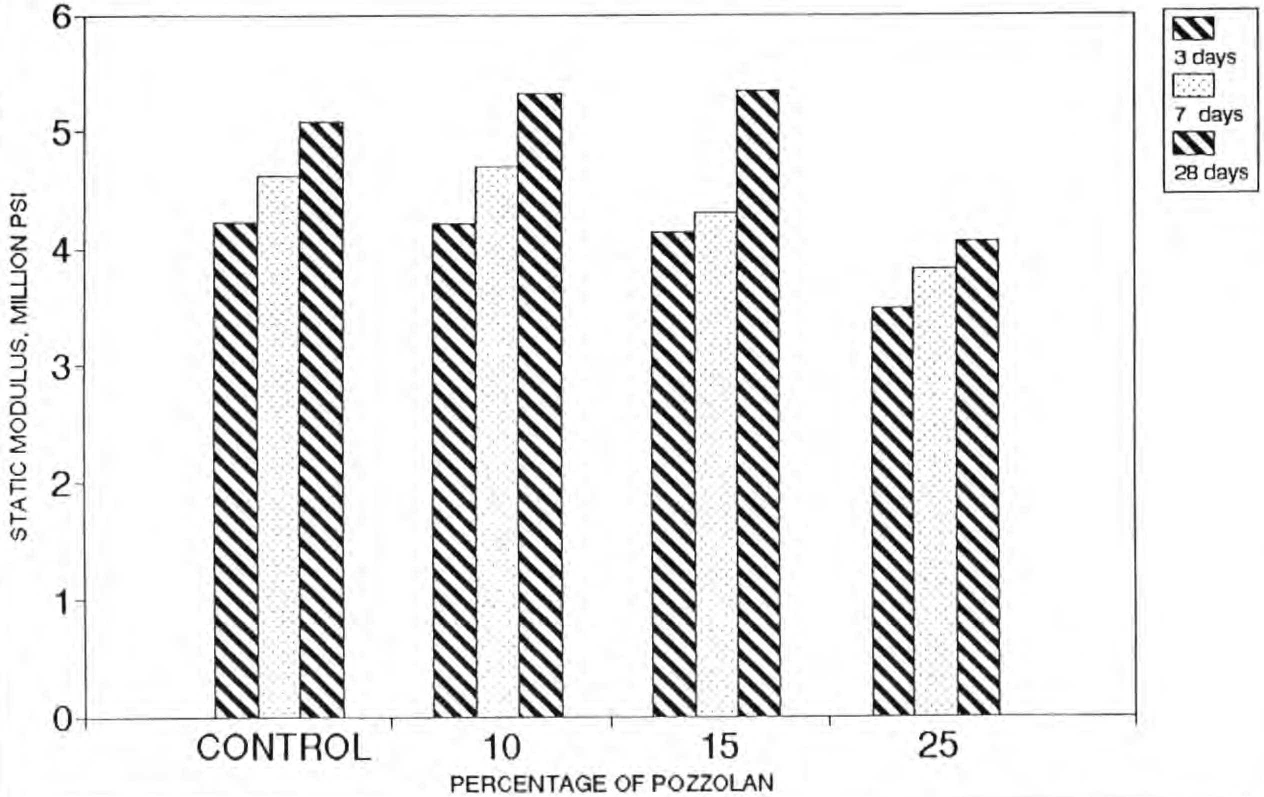


FIG 13E : COMPARISON OF STATIC MODULUS FOR CONCRETES WITH

LK2 POZZOLAN BLENDED CEMENTS

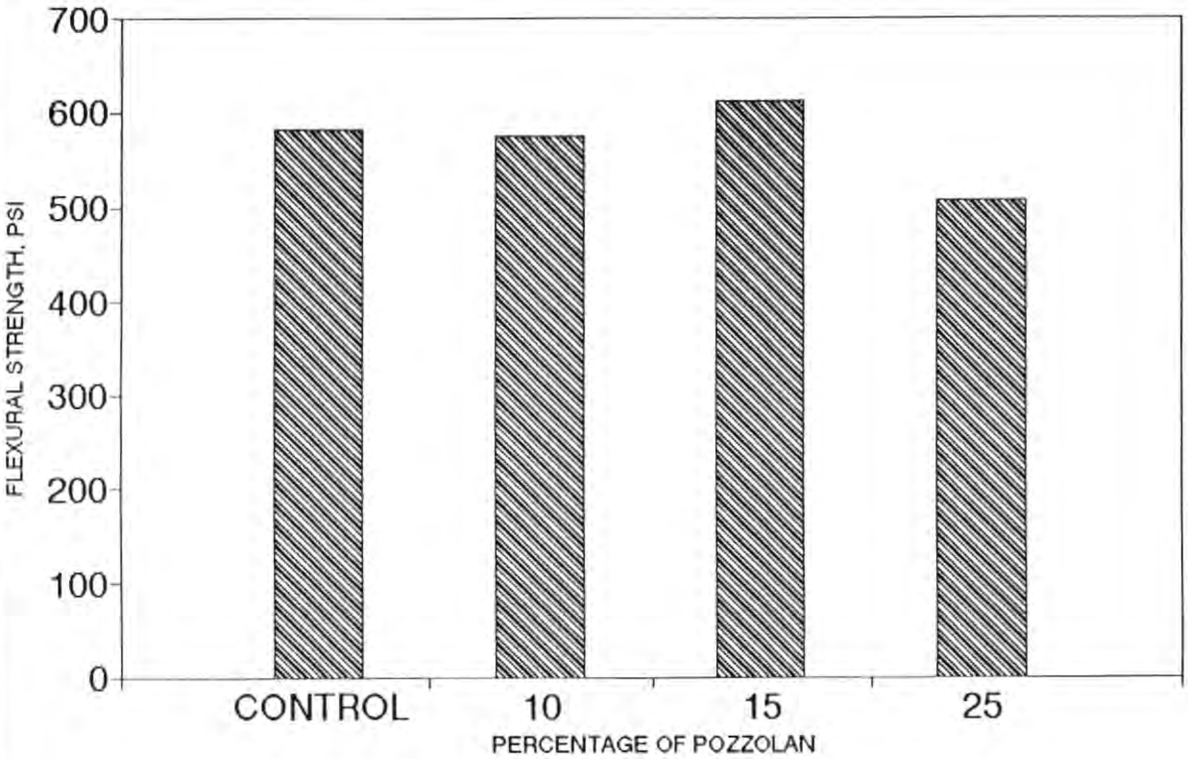


FIG 13F : COMPARISON OF FLEXURAL STRENGTH FOR CONCRETESS WITH

LK2 POZZOLAN BLENDED CEMENTS

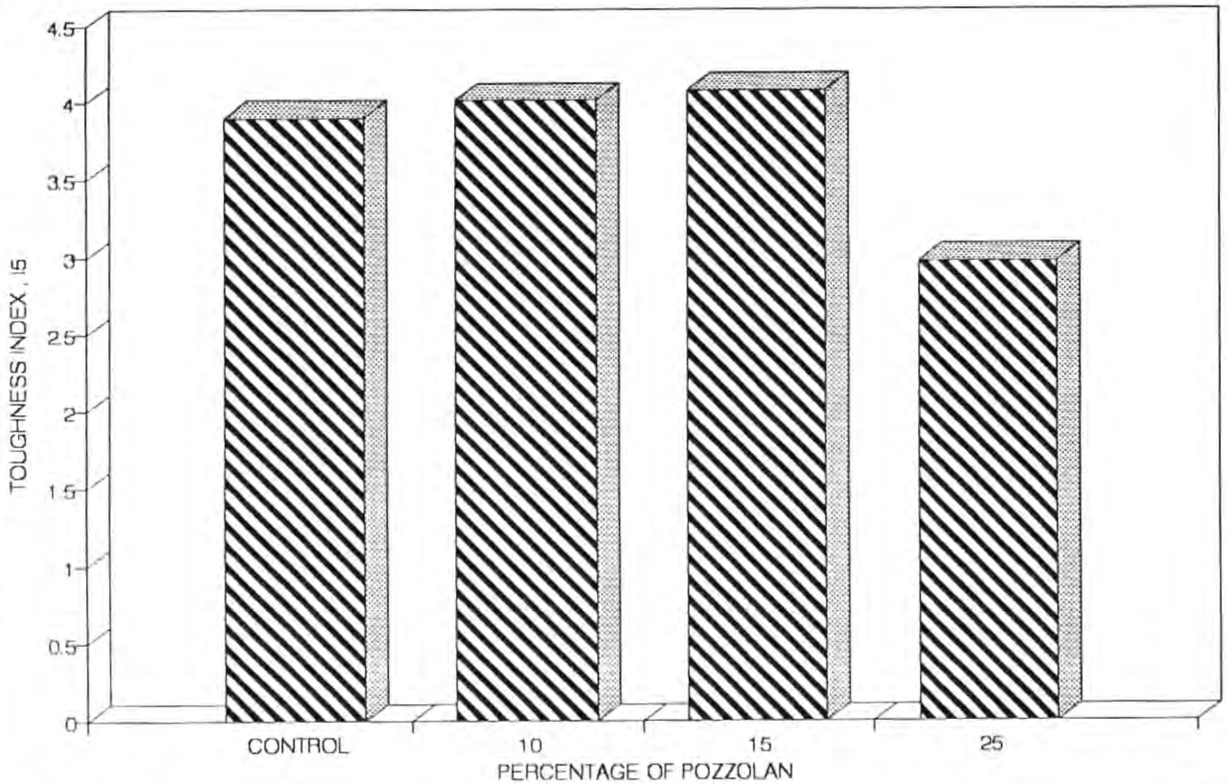


FIG 13G : COMPARISON OF TOUGHNESS INDEX , I5 FOR CONCRETES

WITH LK2 POZZOLAN BLENDED CEMENTS

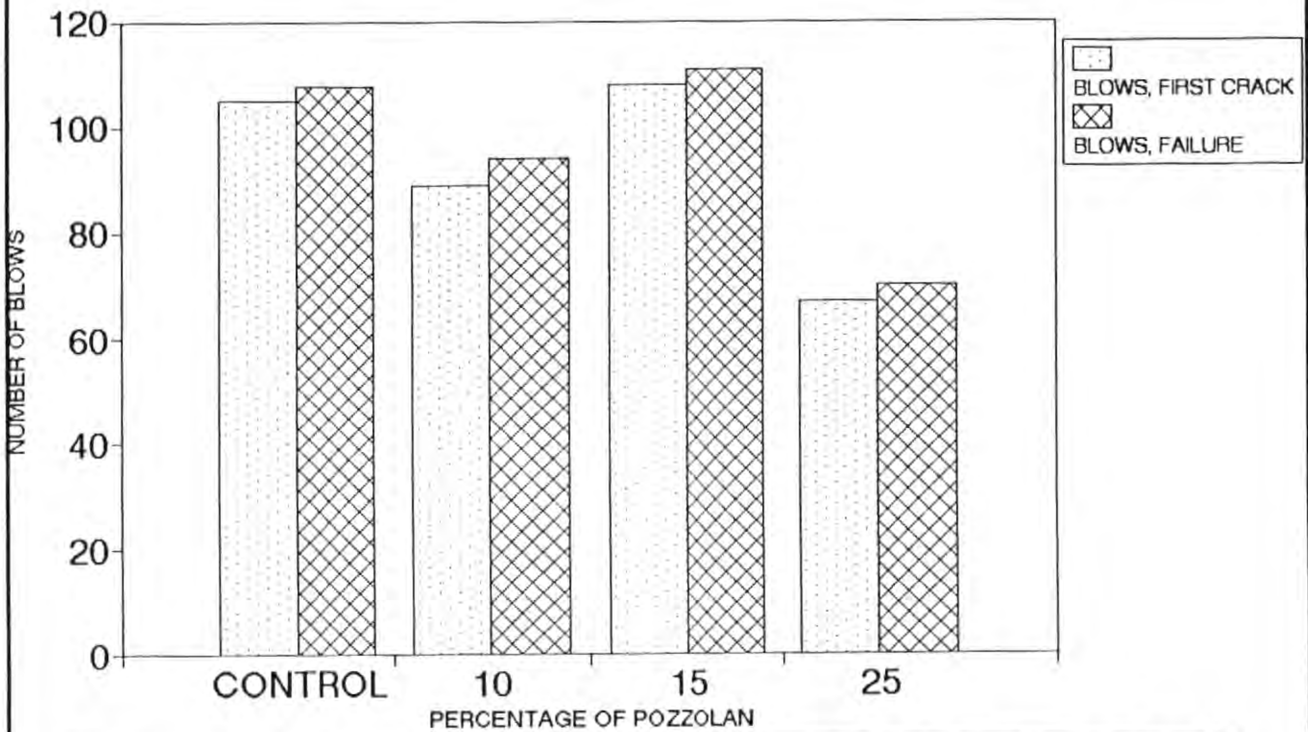


Fig. 13 H: COMPARISON OF IMPACT STRENGTH FOR CONCRETES

WITH LK2 POZZOLAN BLENDED CEMENTS

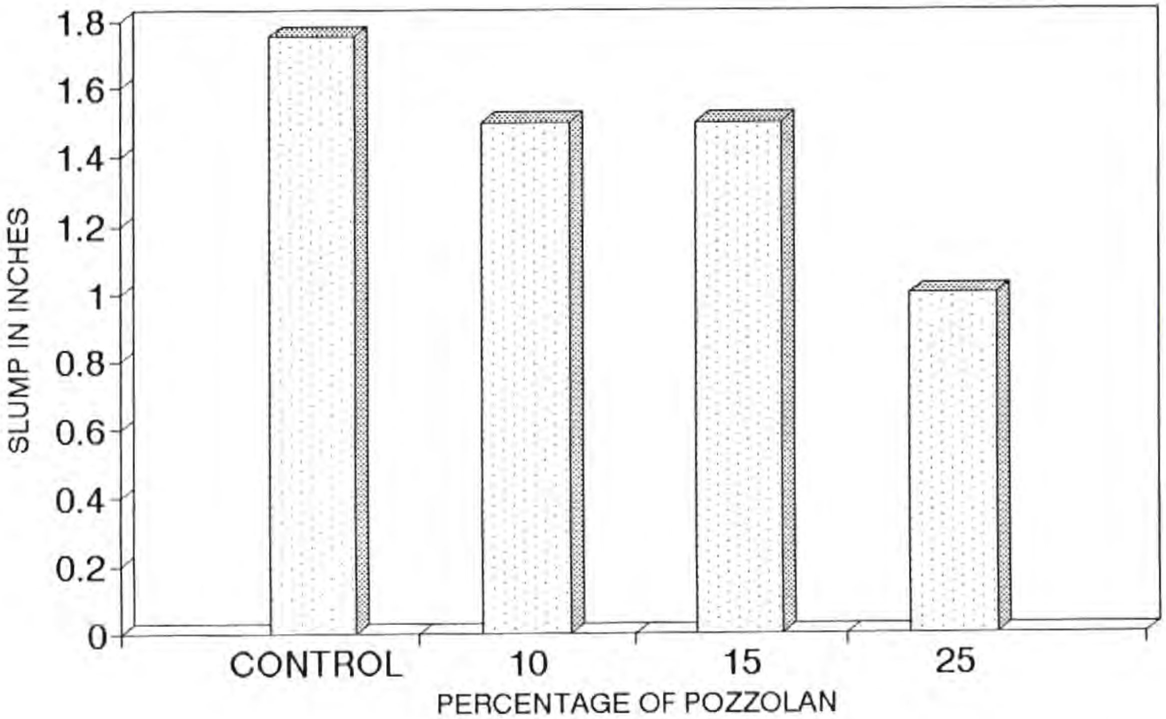
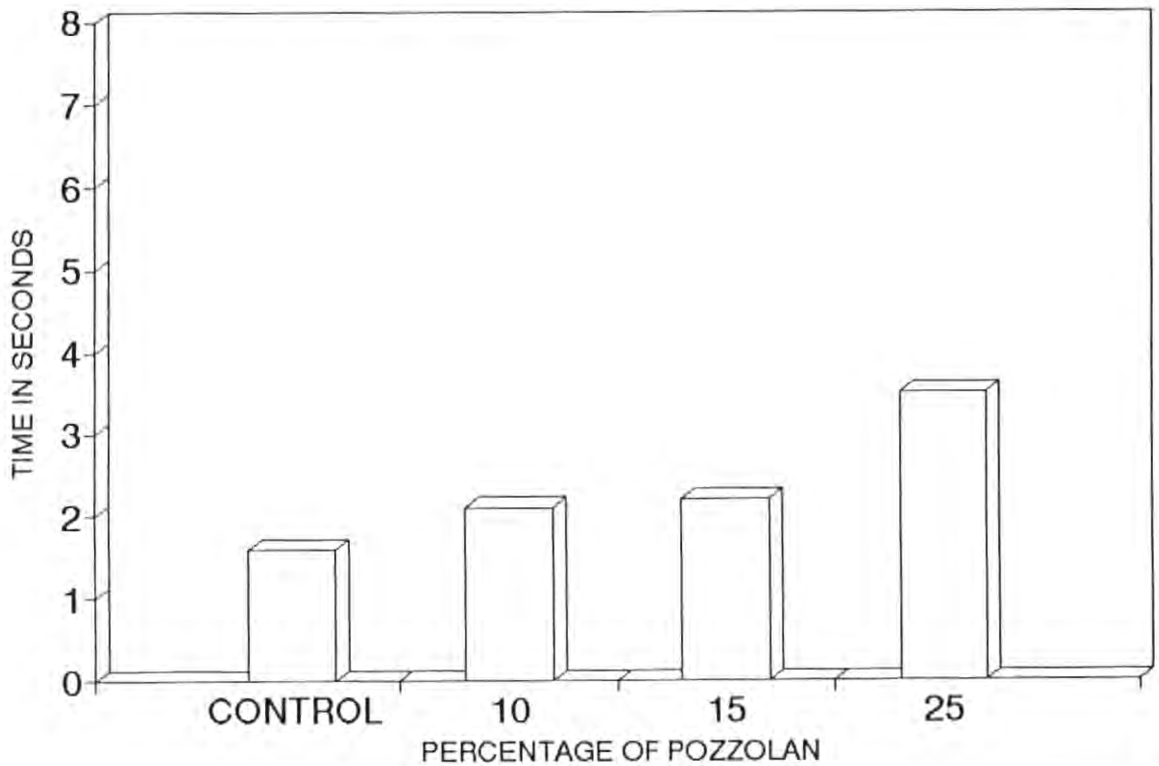


FIG14A: COMPARISON OF SLUMP FOR CONCRETES WITH

PS1E POZZOLAN BLENDED CEMENTS



14B: COMPARISON OF VEBE TIME FOR CONCRETES WITH PS1E POZZOLAN BLENDED CEMENTS

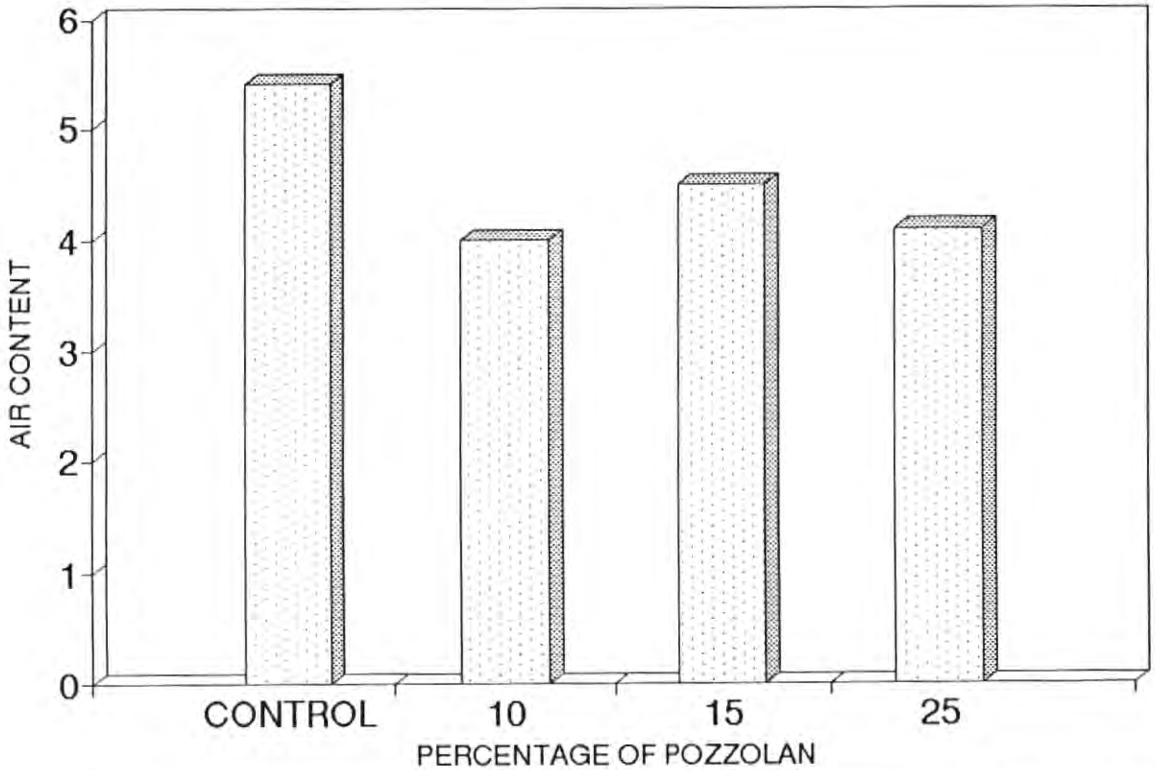


FIG 14C: COMPARISON OF AIR CONTENT FOR CONCRETES WITH

PS1E POZZOLAN BLENDED CEMENTS

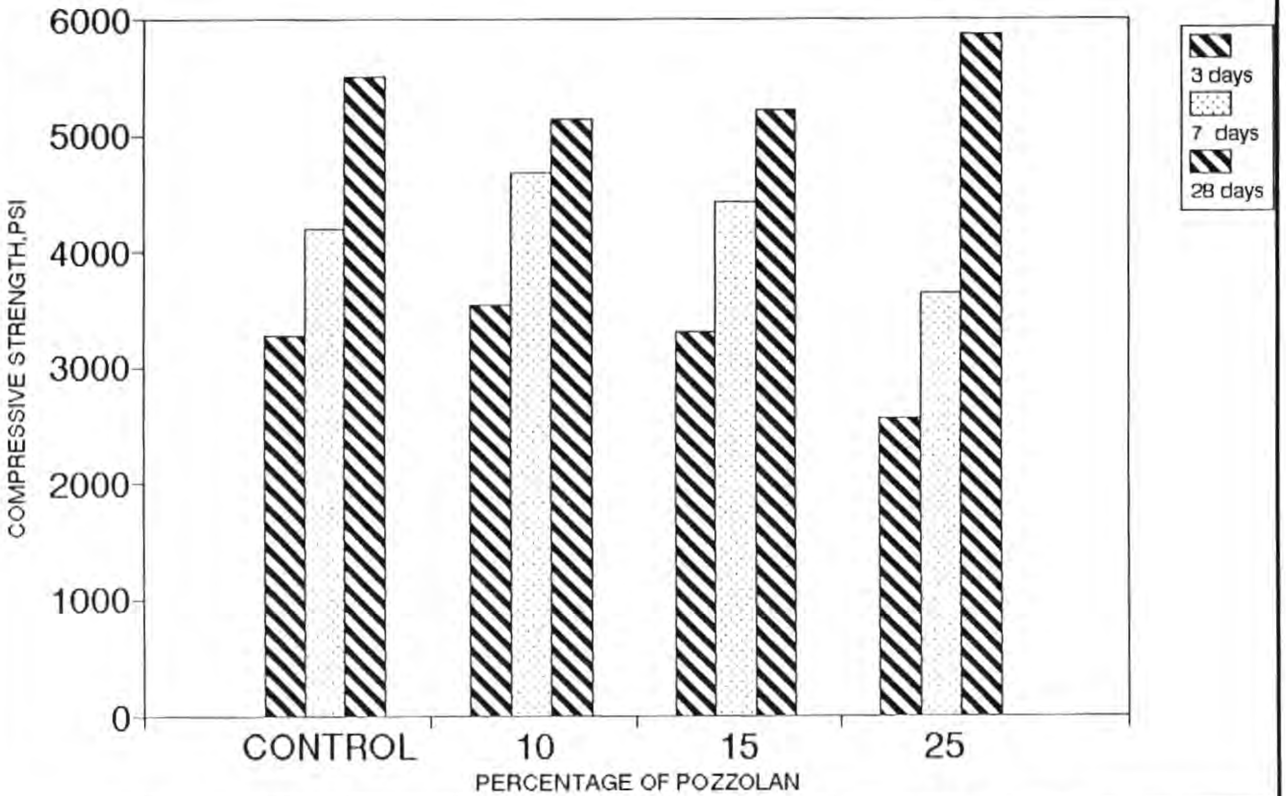


FIG 14D: COMPARISON OF COMPRESSIVE STRENGTH FOR CONCRETES

WITH PS1E POZZOLAN BLENDED CEMENTS

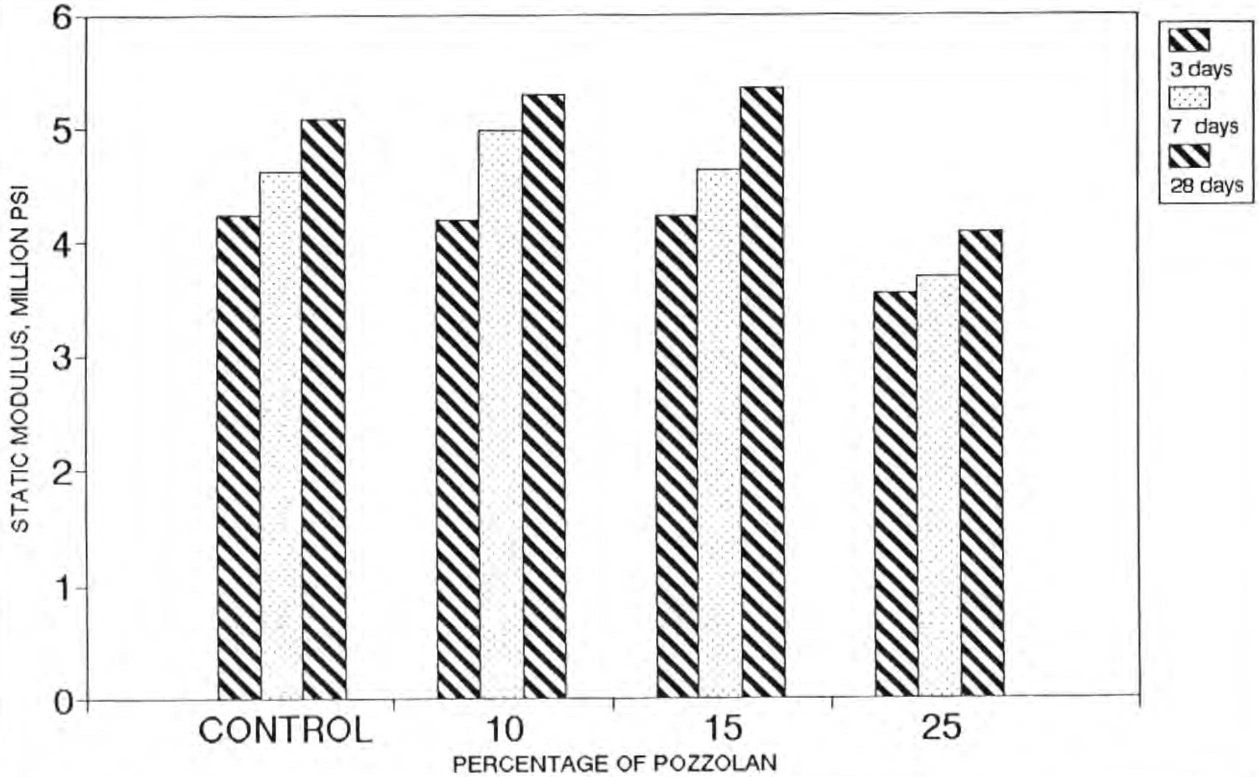


FIG 14E : COMPARISON OF STATIC MODULUS FOR CONCRETES WITH

PS1E POZZOLAN BLENDED CEMENTS

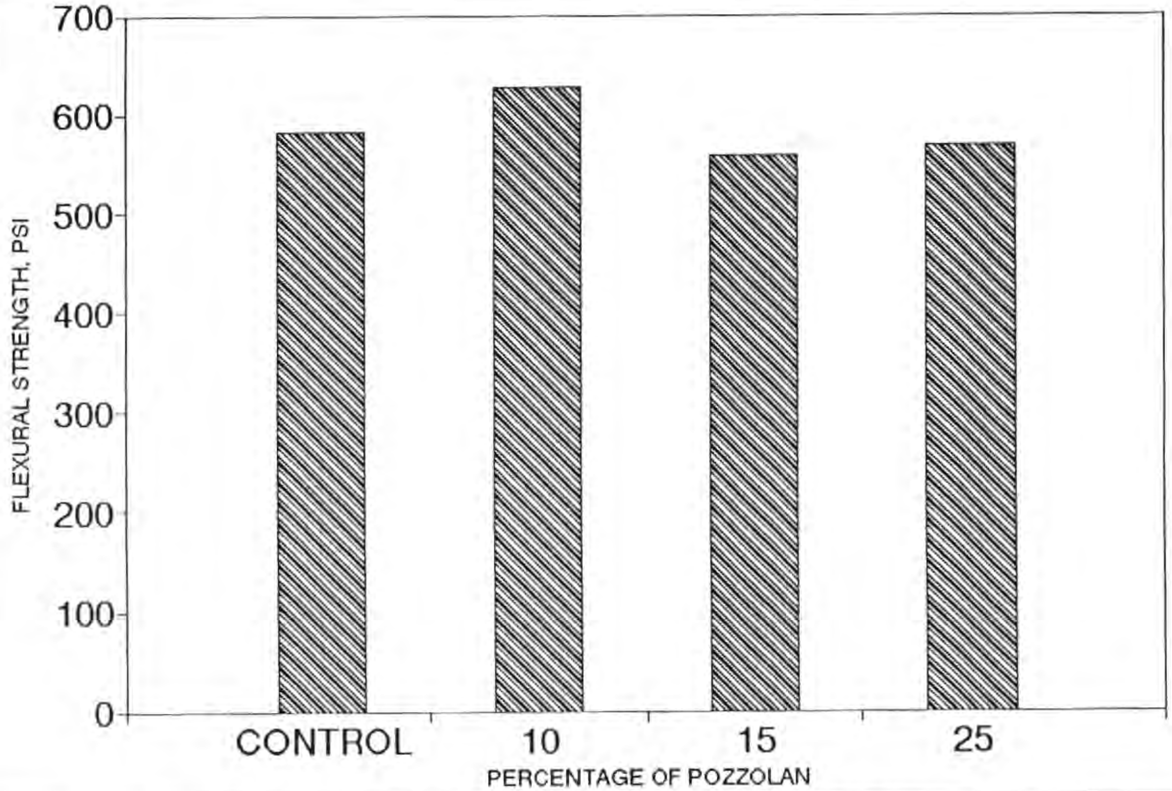


FIG 14F : COMPARISON OF FLEXURAL STRENGTH FOR CONCRETES WITH PS1E POZZOLAN BLENDED CEMENTS

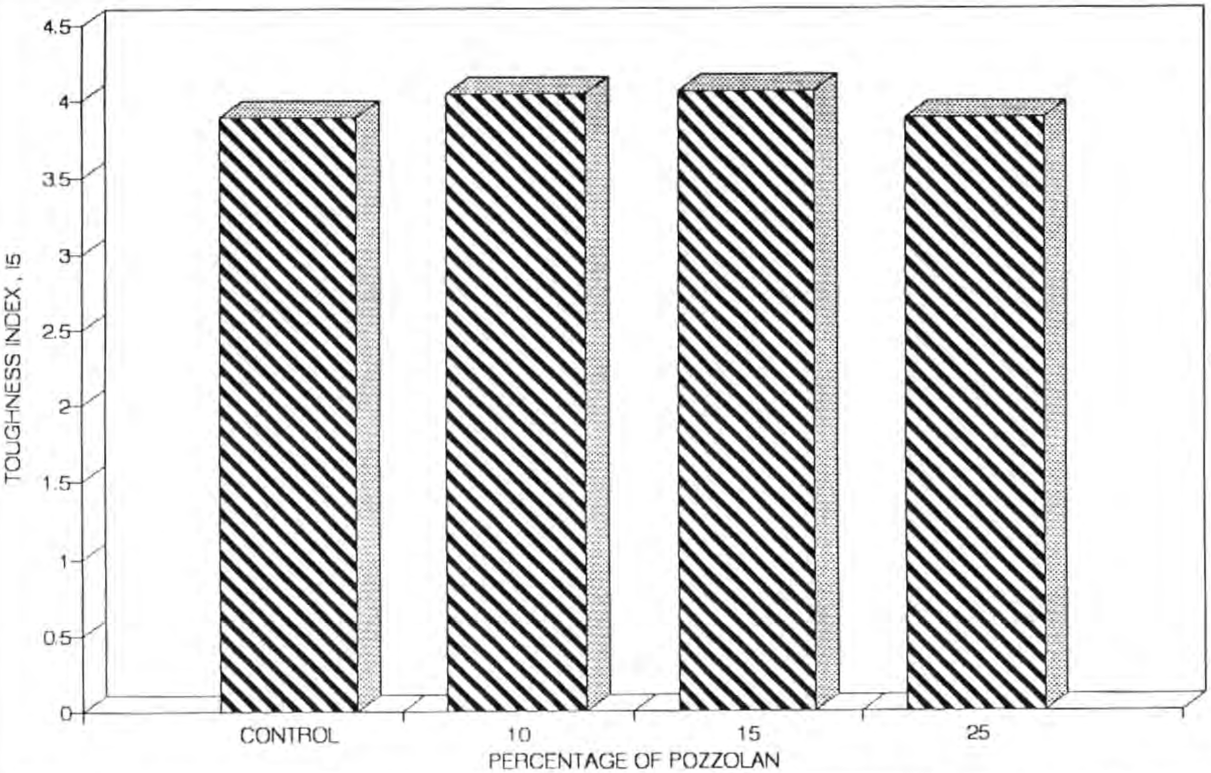


FIG 14G : COMPARISON OF TOUGHNESS INDEX , I5 FOR CONCRETES

WITH PS1E POZZOLAN BLENDED CEMENTS

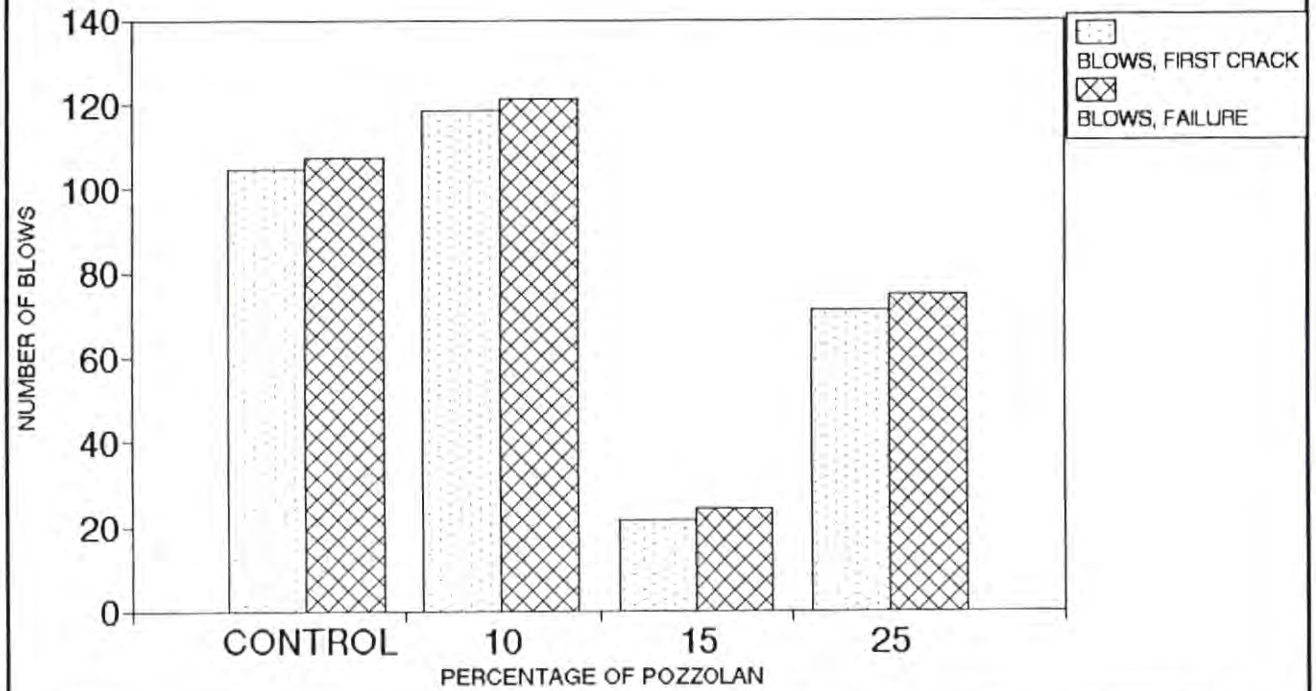


Fig. 14 H: COMPARISON OF IMPACT STRENGTH FOR CONCRETES

WITH PS1E POZZOLAN BLENDED CEMENTS

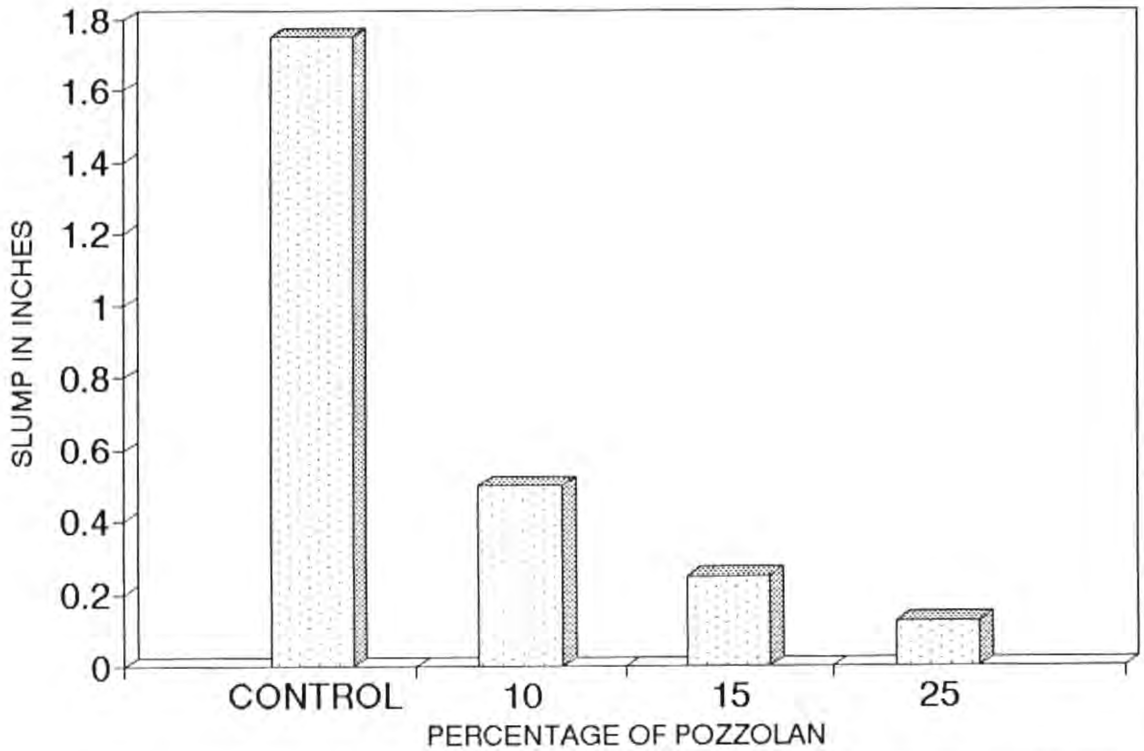
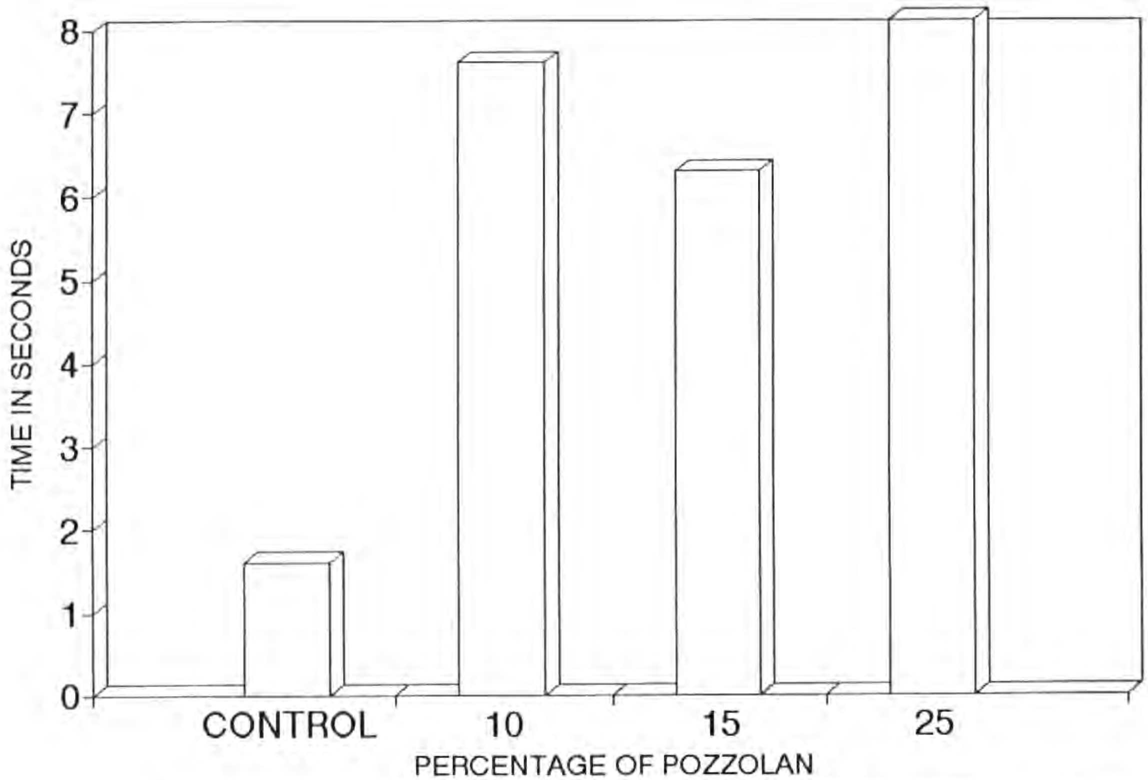


FIG 15A: COMPARISON OF SLUMP FOR CONCRETES WITH

WITH CT1 POZZOLAN BLENDED CEMENTS



15B: COMPARISON OF VEBE TIME FOR CONCRETES WITH

CT1 POZZOLAN BLENDED CEMENTS

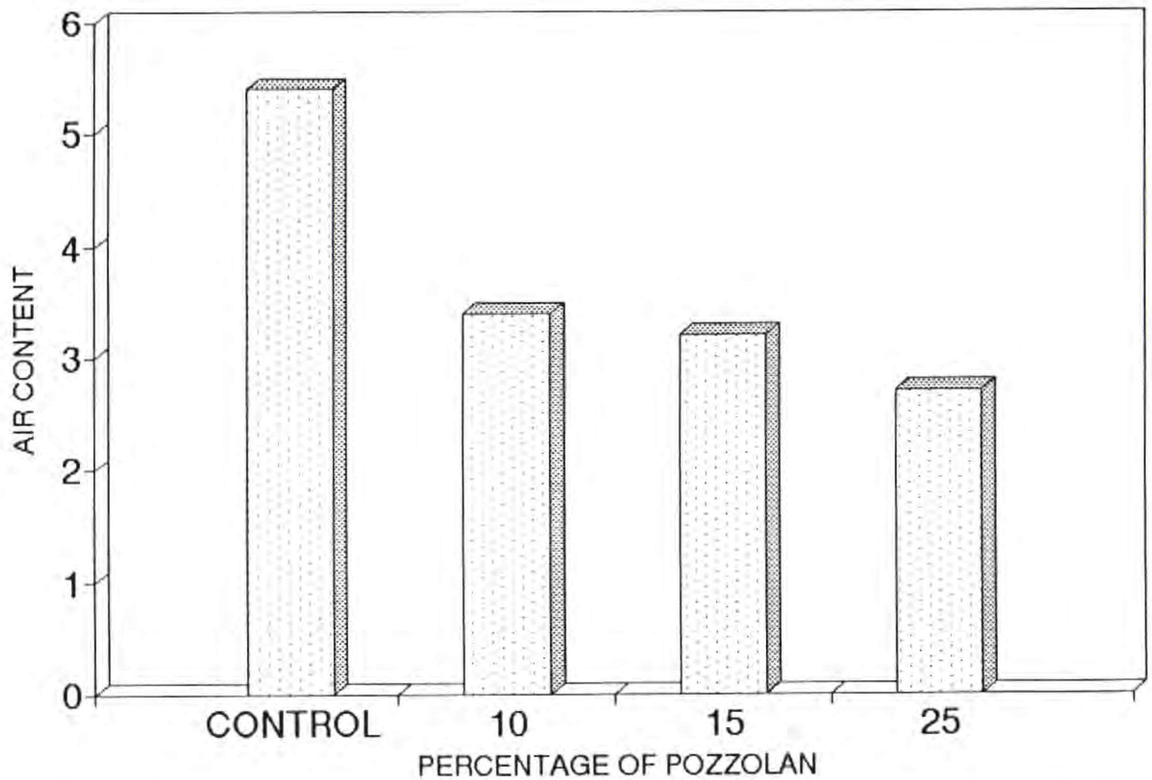


FIG 15C: COMPARISON OF AIR CONTENT FOR CONCRETES WITH

CT1 POZZOLAN BLENDED CEMENTS

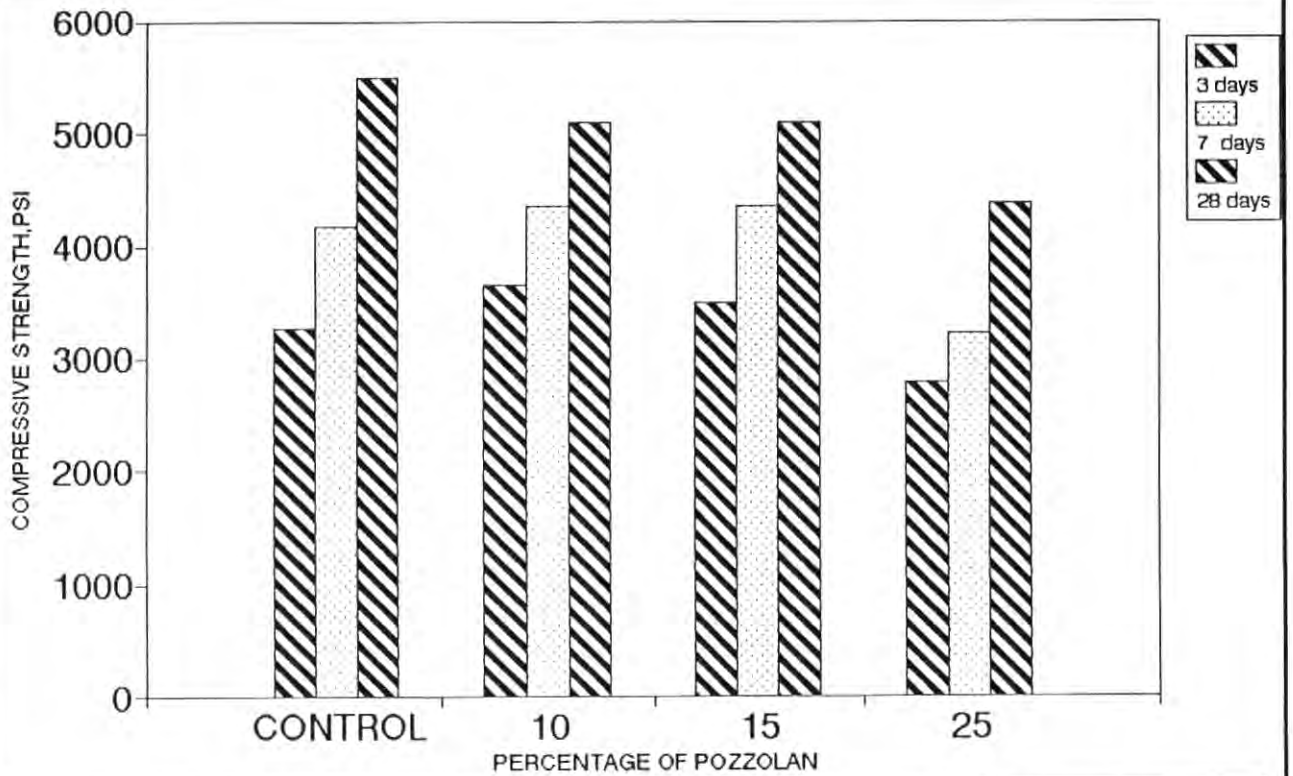


FiG 15D: COMPARISON OF COMPRESSIVE STRENGTH FOR CONCRETES

WITH CT1 POZZOLAN BLENDED CEMENTS

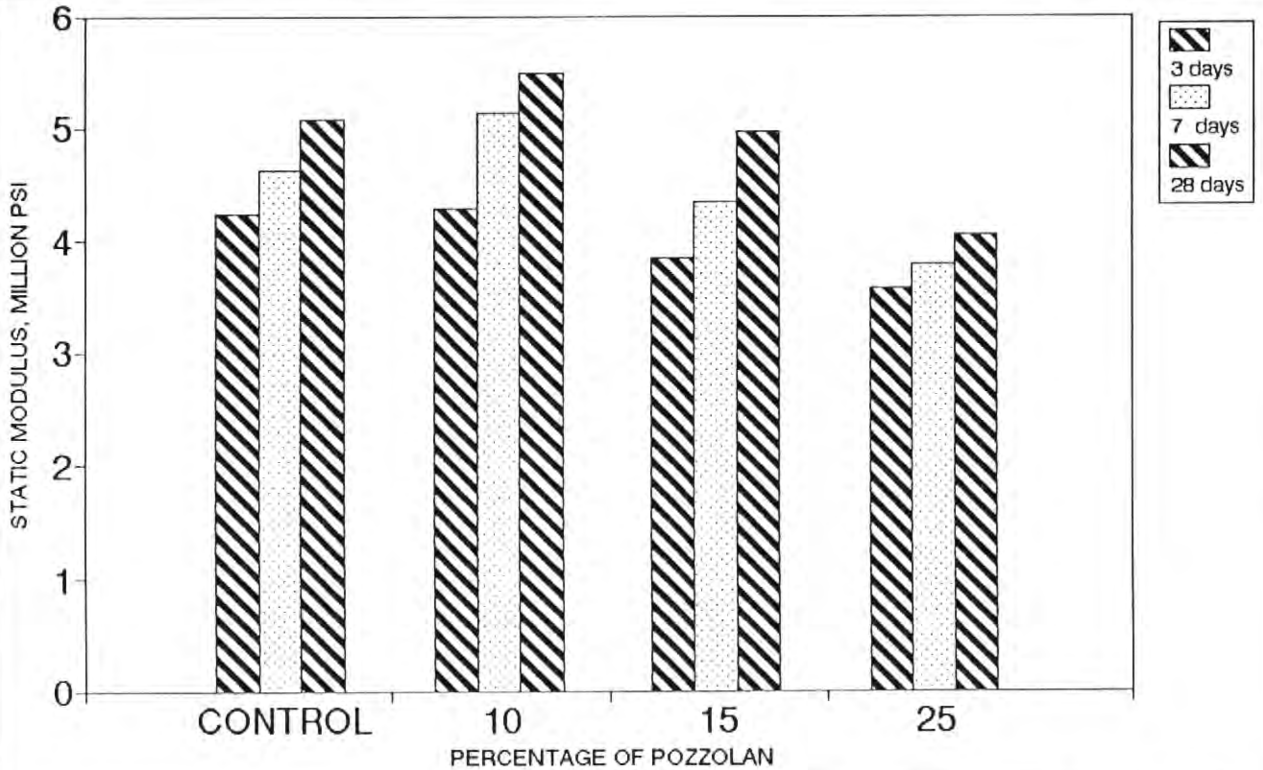


FIG 15E : COMPARISON OF STATIC MODULUS FOR CONCRETES WITH

CT1 POZZOLAN BLENDED CEMENTS

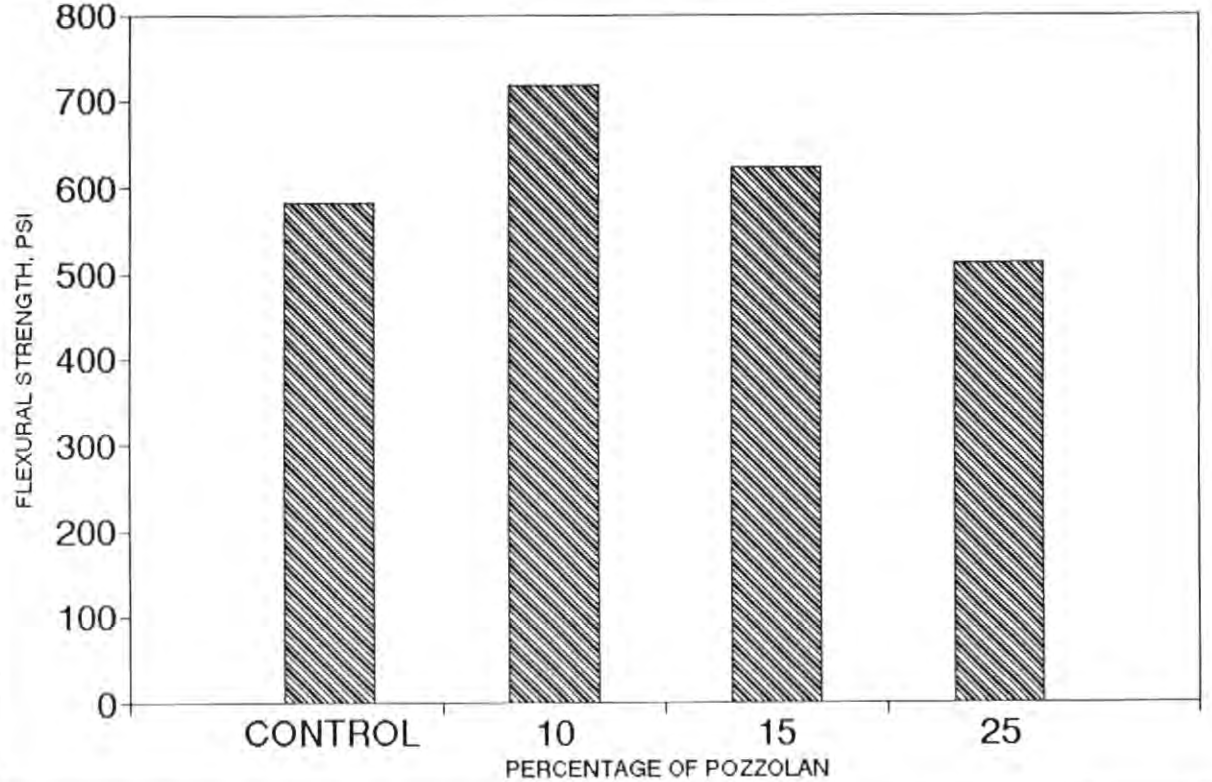


FIG 15F : COMPARISON OF FLEXURAL STRENGTH FOR CONCRETES WITH

CT1 POZZOLAN BLENDED CEMENTS

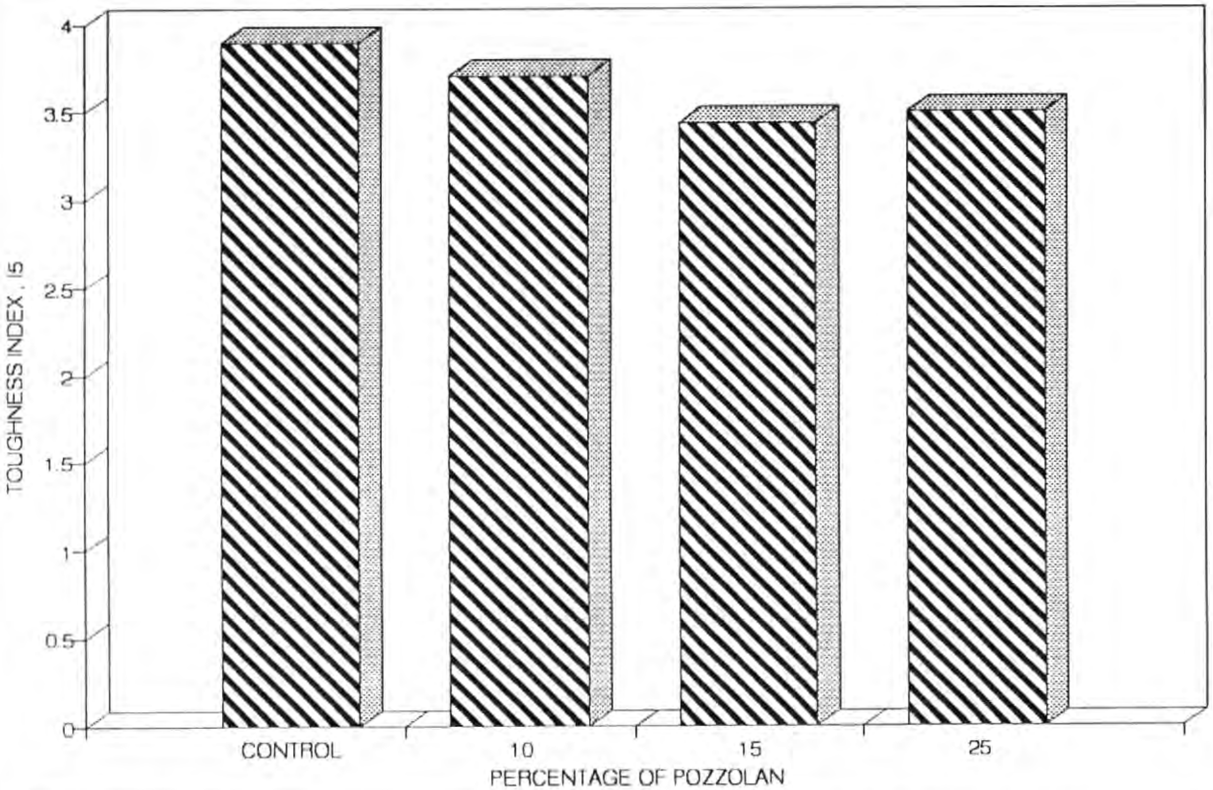


FIG 15G : COMPARISON OF TOUGHNESS INDEX , I5 FOR CONCRETES

WITH CT1 POZZOLAN BLENDED CEMENTS

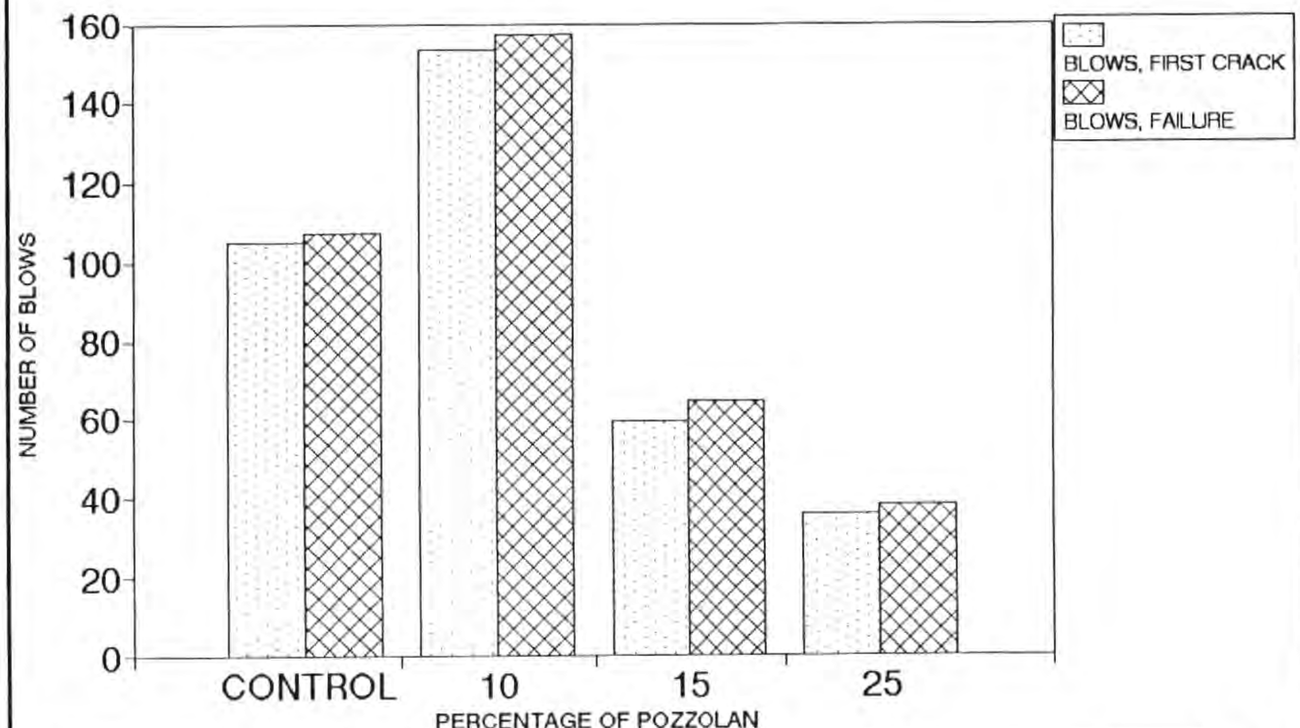


Fig. 15 H: COMPARISON OF IMPACT STRENGTH FOR CONCRETES WITH CT1 POZZOLAN BLENDED CEMENTS

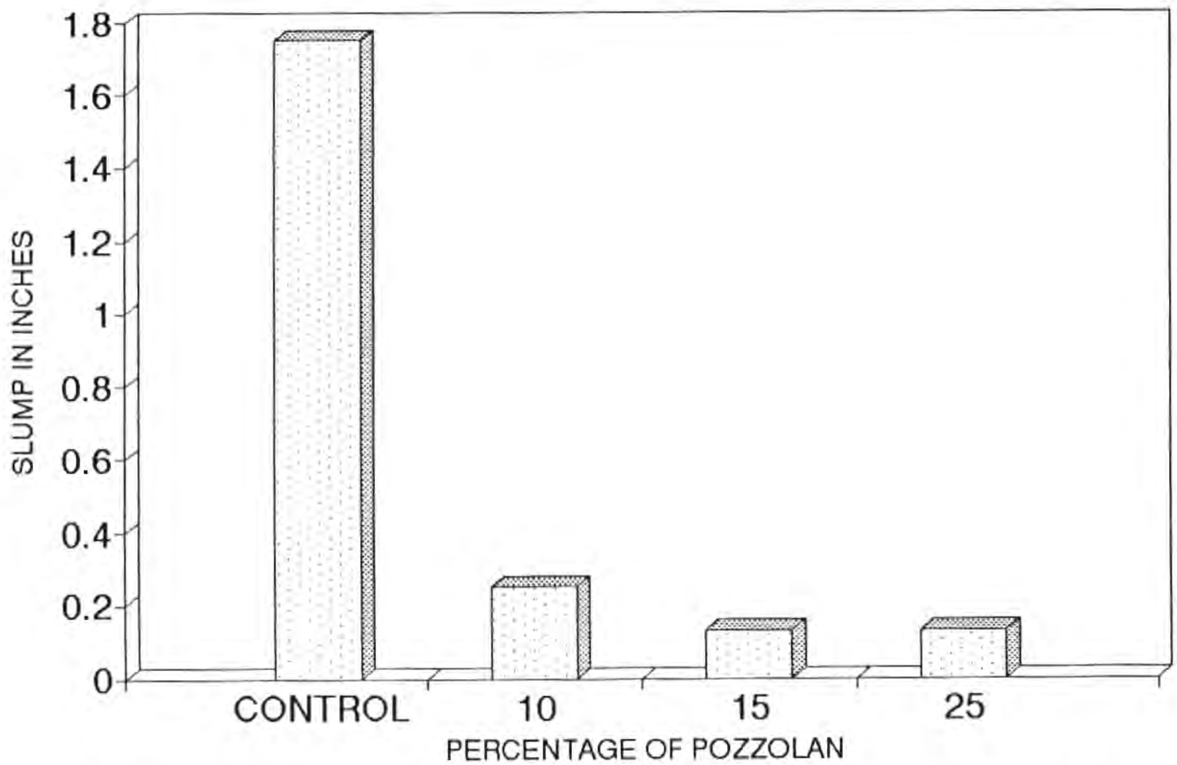
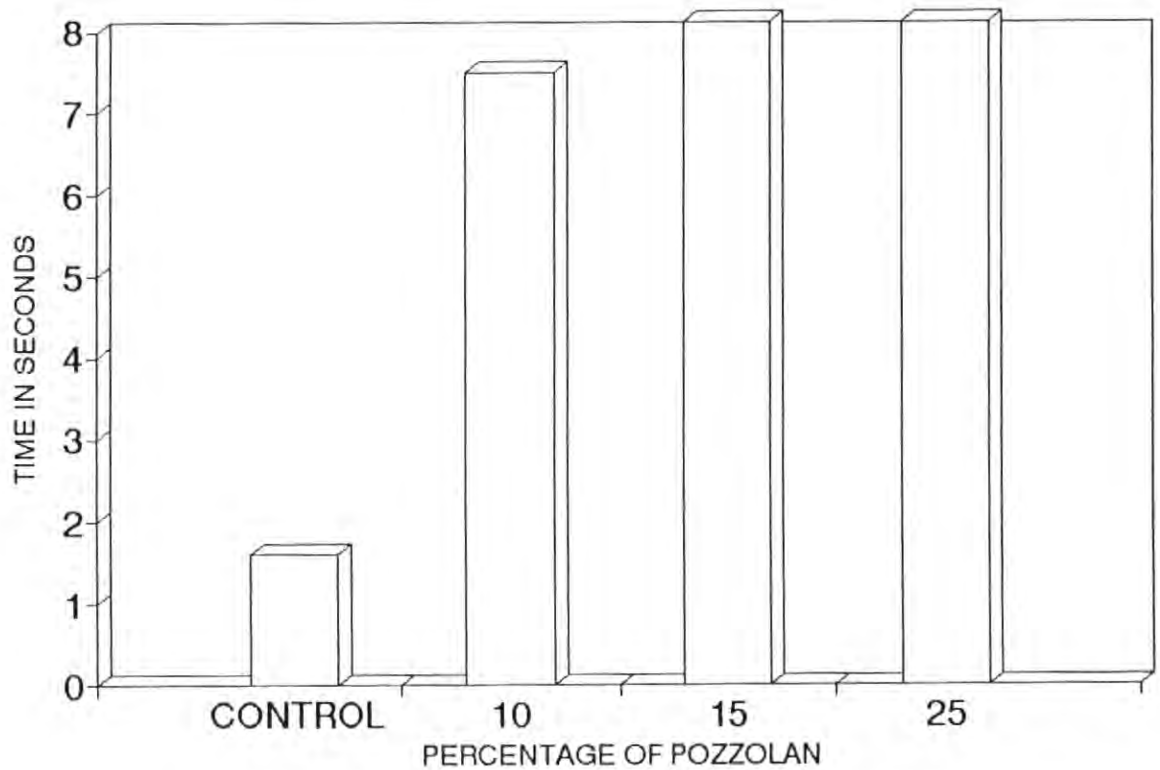


FIG16A: COMPARISON OF SLUMP FOR CONCRETES WITH

SM2 POZZOLAN BLENDED CEMENTS



16B: COMPARISON OF VEBE TIME FOR CONCRETES WITH

SM2 POZZOLAN BLENDED CEMENTS

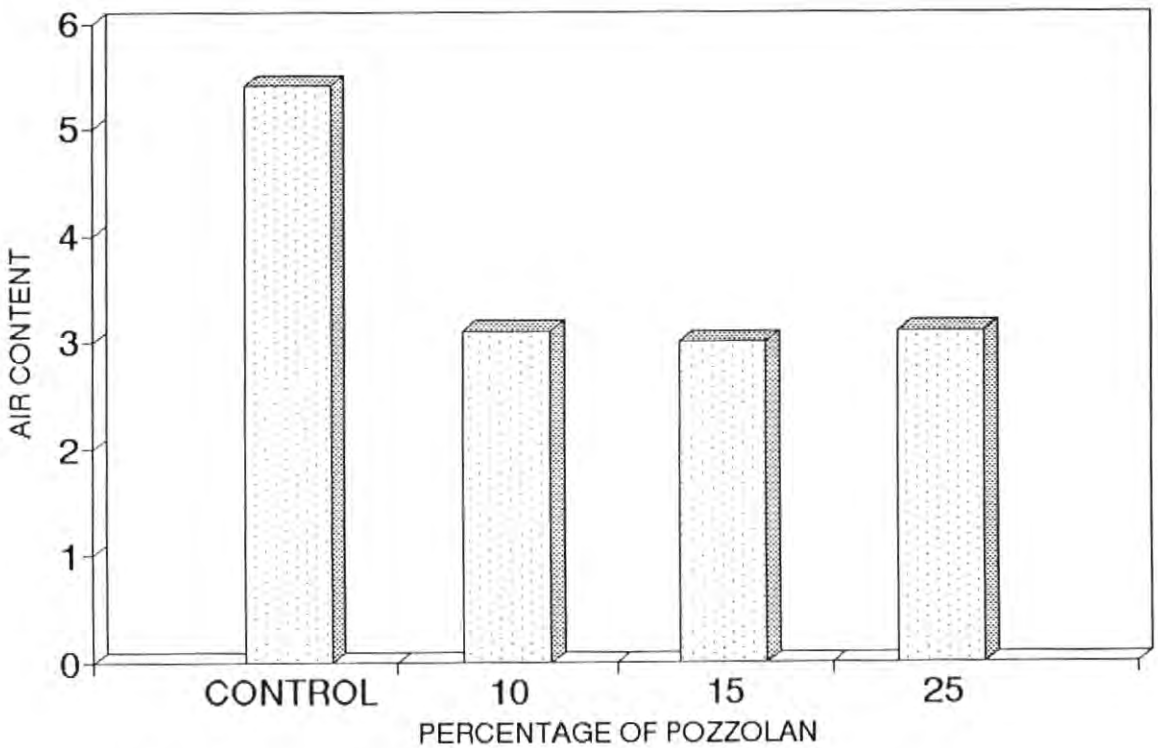


FIG 16C: COMPARISON OF AIR CONTENT FOR CONCRETES WITH

SM2 POZZOLAN BLENDED CEMENTS

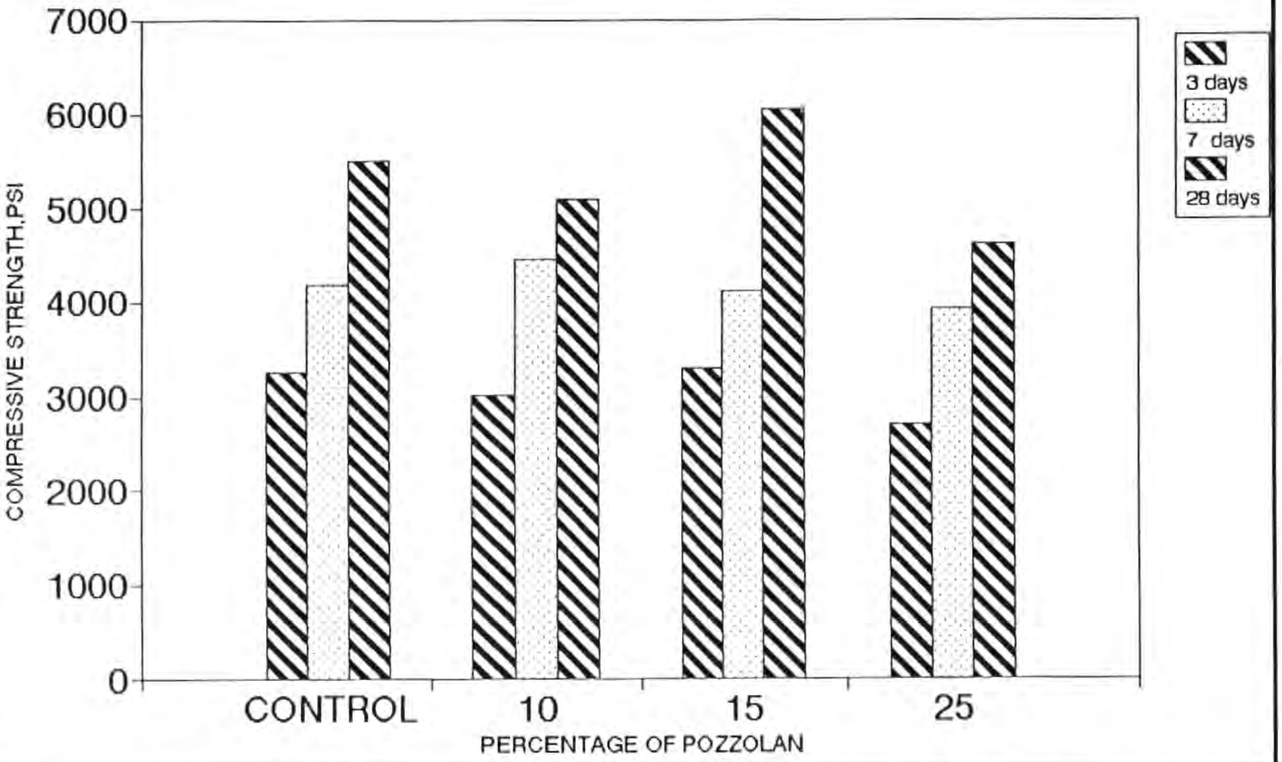


FiG 16D: COMPARISON OF COMPRESSIVE STRENGTH FOR CONCRETES

WITH SM2 POZZOLAN BLENDED CEMENTS

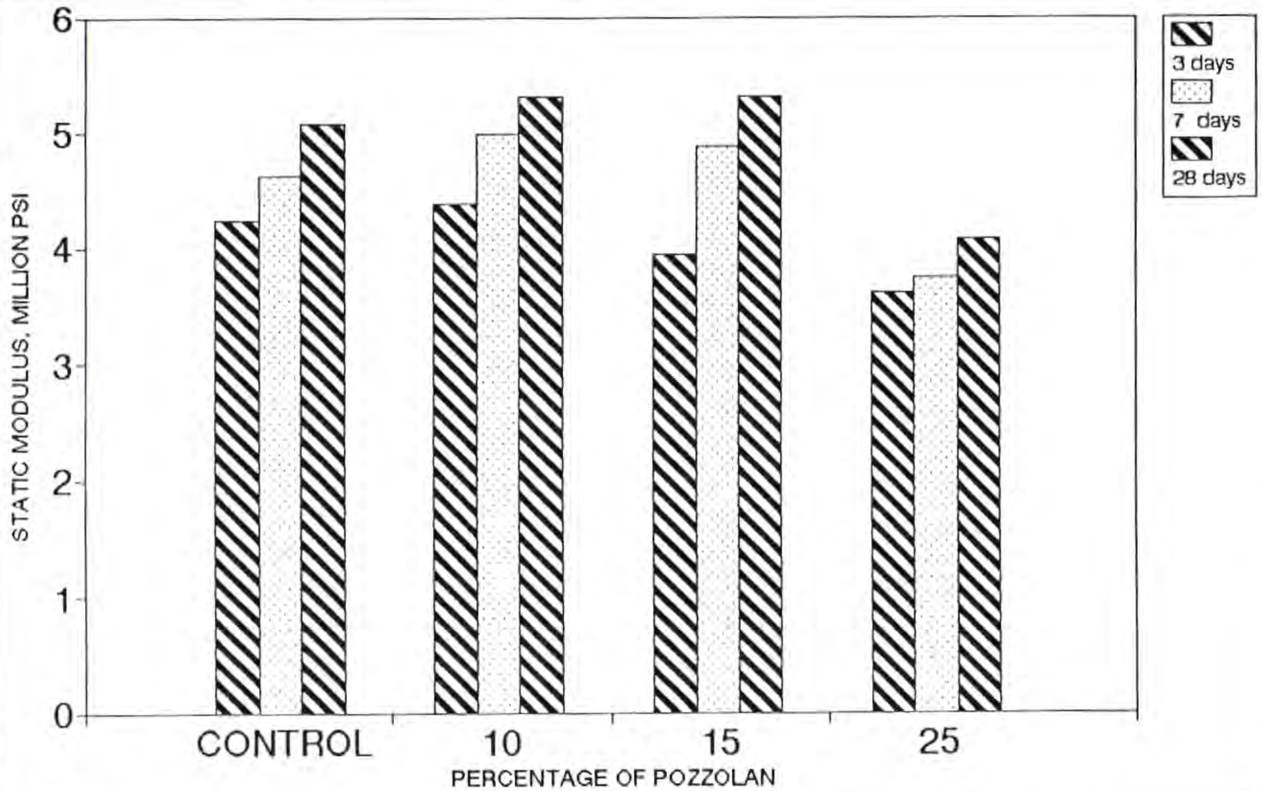


FIG 16E : COMPARISON OF STATIC MODULUS FOR CONCRETES WITH

SM2 POZZOLAN BLENDED CEMENTS

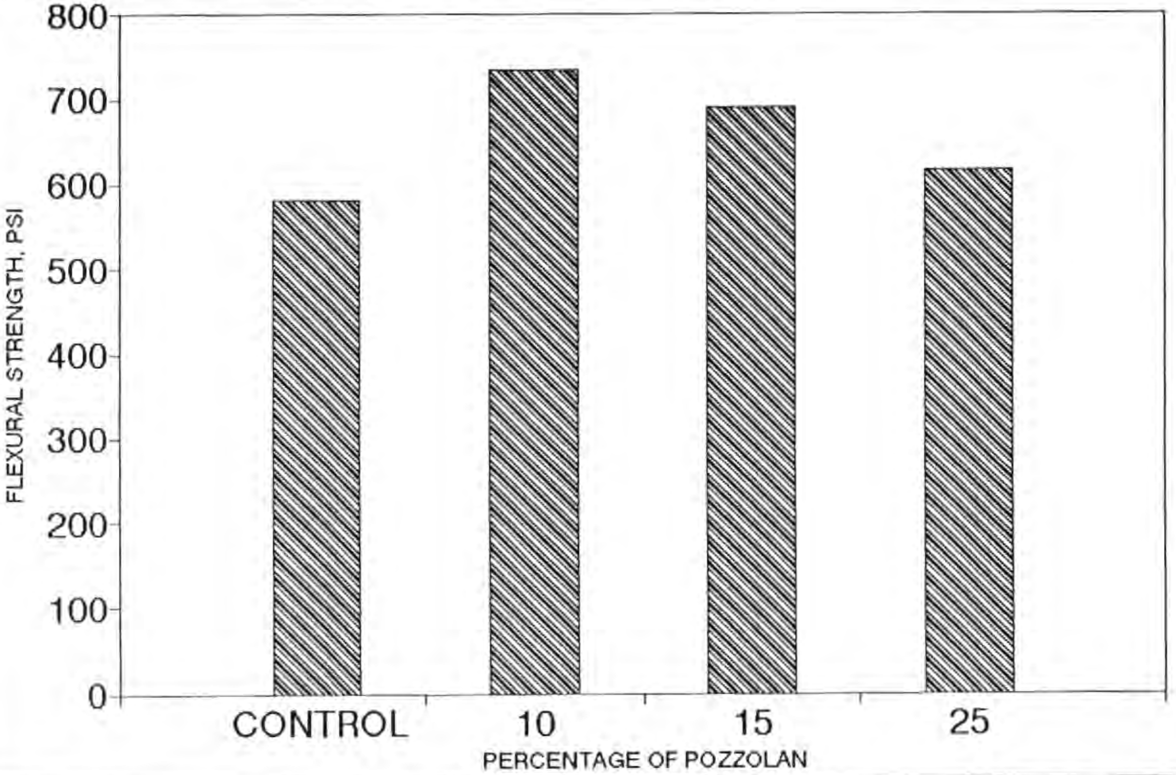


FIG 16F : COMPARISON OF FLEXURAL STRENGTH FOR CONCRETES WITH

SM2 POZZOLAN BLENDED CEMENTS

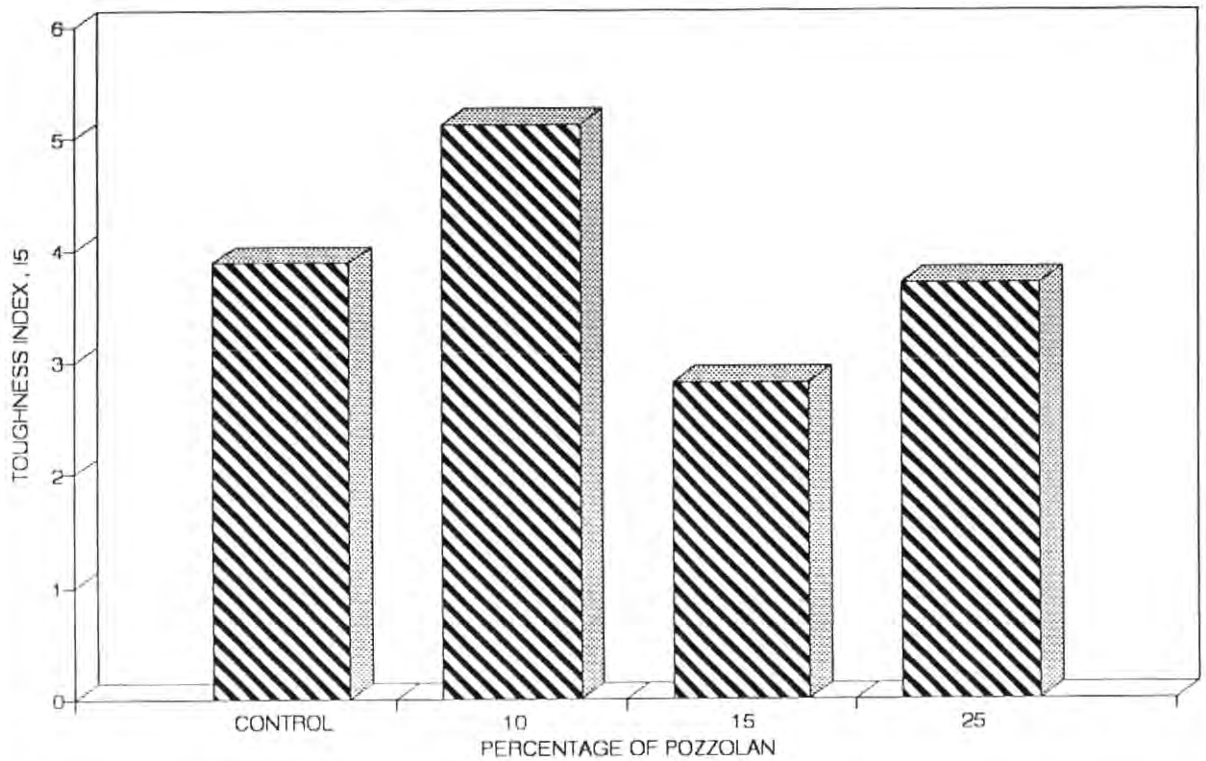


FIG 16G : COMPARISON OF TOUGHNESS INDEX , I5 FOR CONCRETES

WITH SM2 POZZOLAN BLENDED CEMENTS

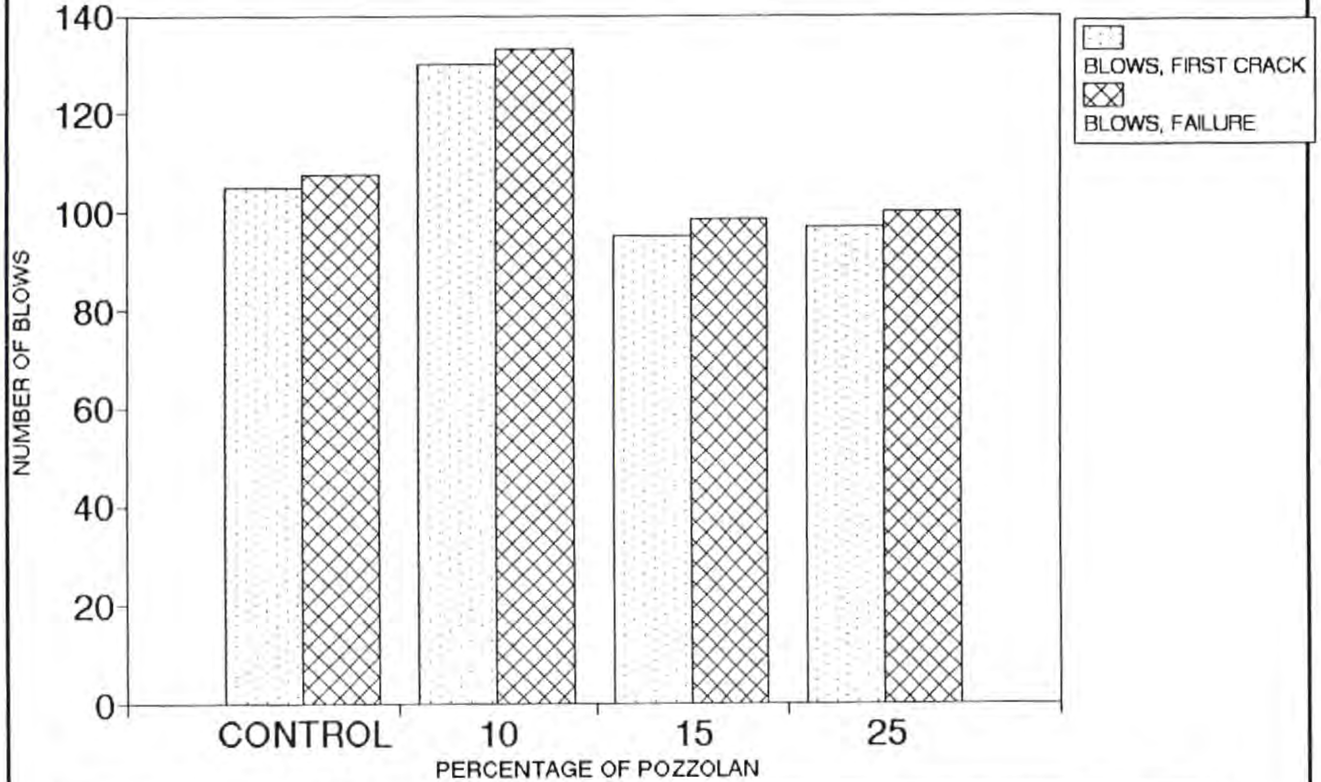


Fig. 16 H: COMPARISON OF IMPACT STRENGTH FOR CONCRETES WITH SM2 POZZOLAN BLENDED CEMENTS

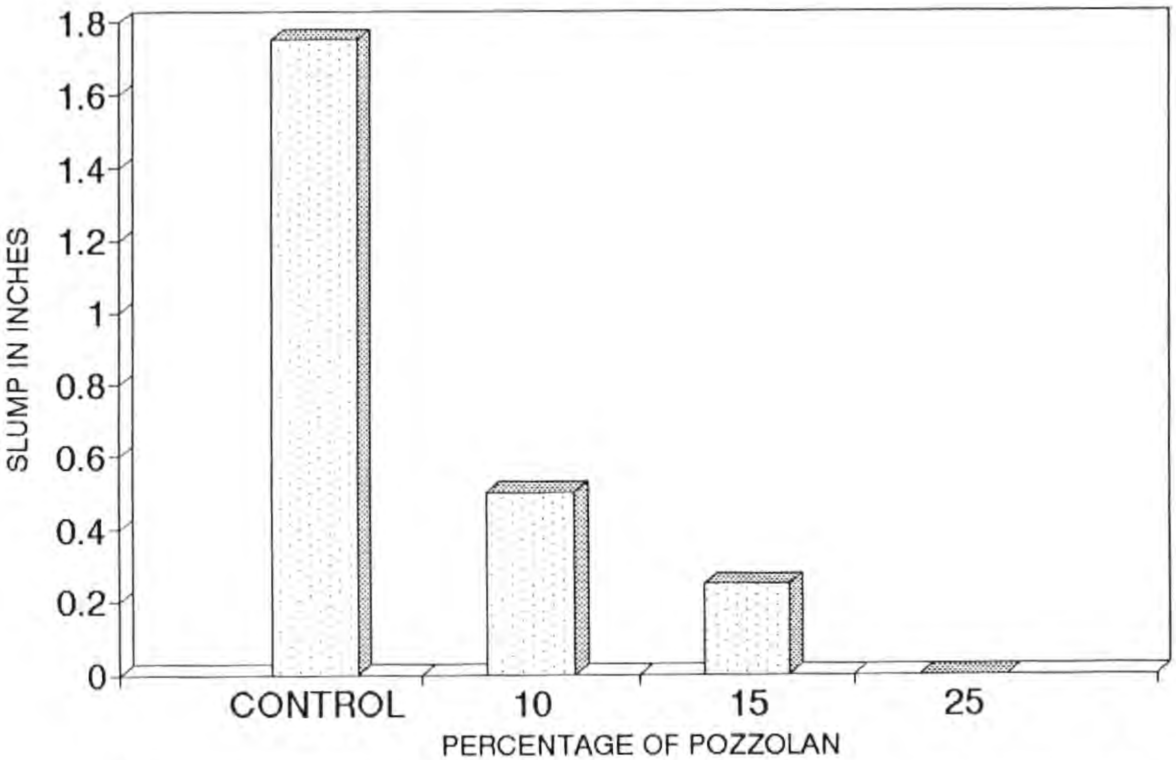
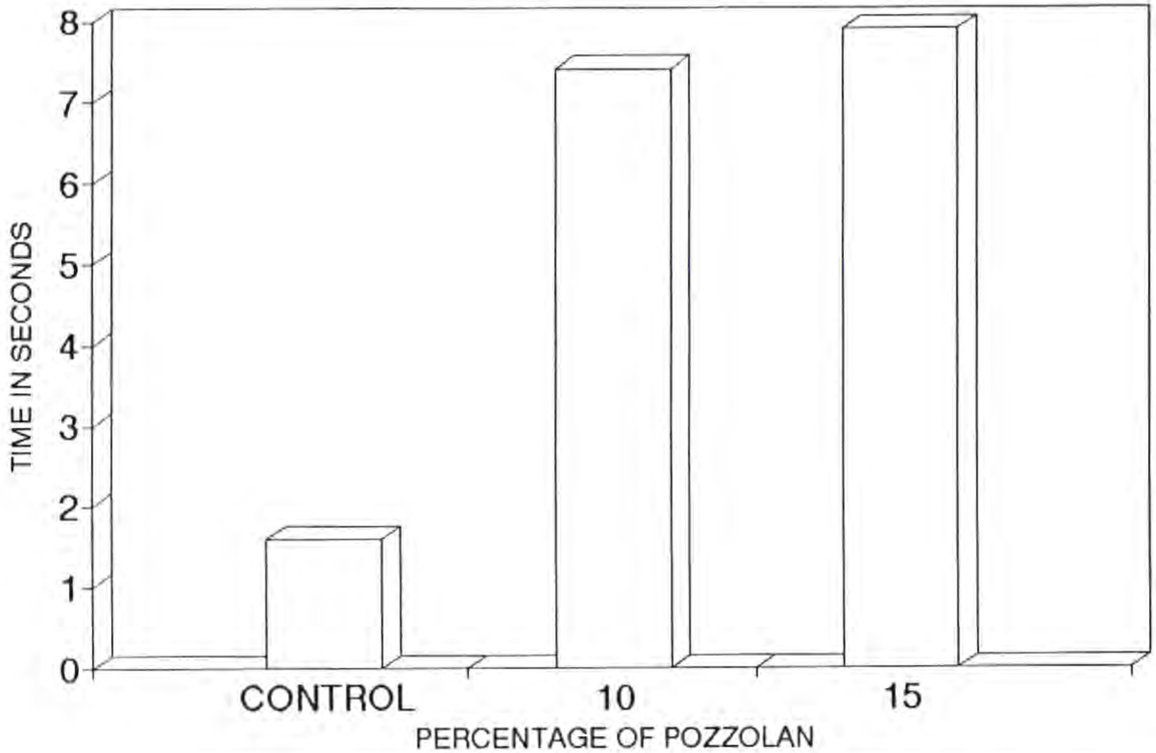


FIG 17A: COMPARISON OF SLUMP FOR CONCRETES WITH

MW1 POZZOLAN BLENDED CEMENTS



17B: COMPARISION OF VEBE TIME FOR CONCRETES WITH

MW1 POZZOLAN BLENDED CEMENTS

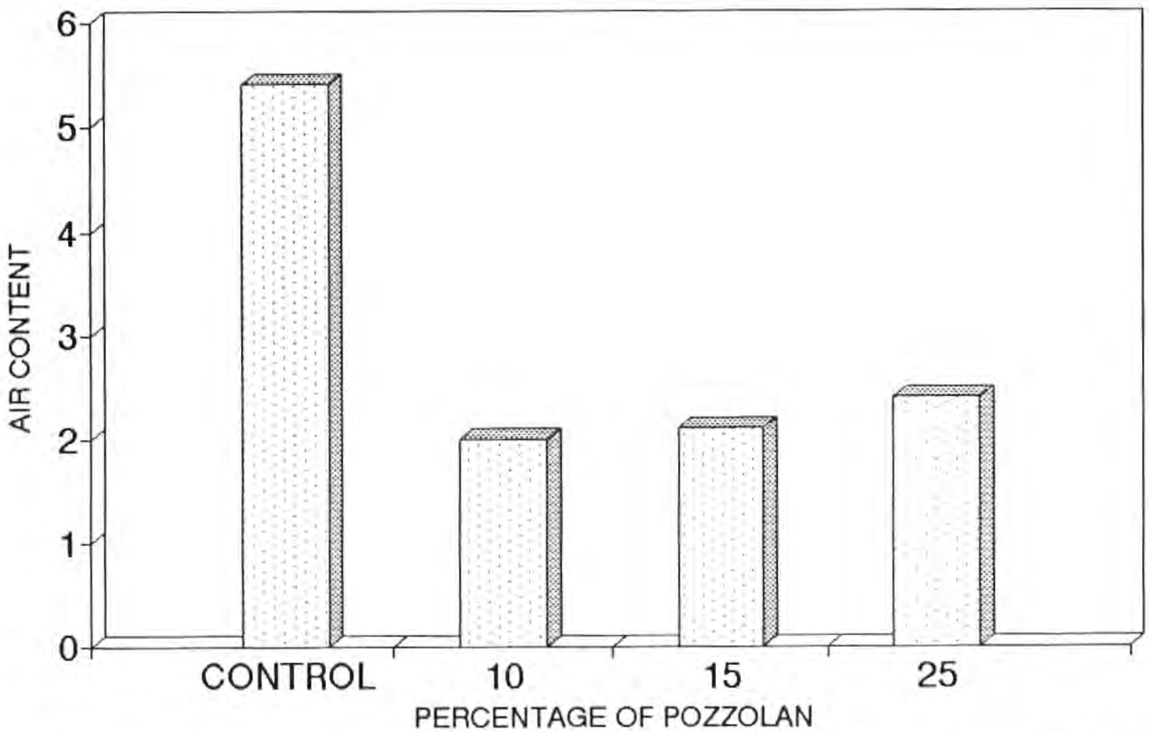


FIG 17C: COMPARISON OF AIR CONTENT FOR CONCRETES WITH

MW1 POZZOLAN BLENDED CEMENTS

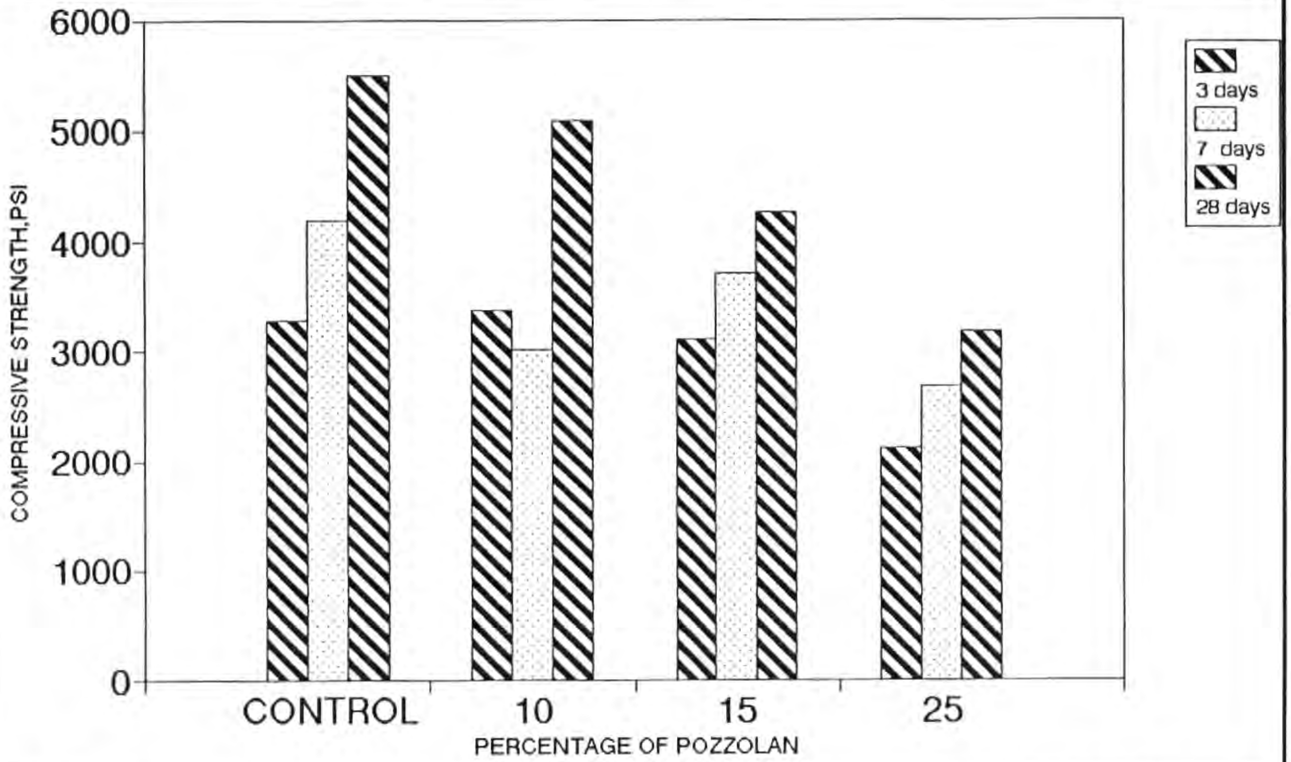


FiG 17D: COMPARISON OF COMPRESSIVE STRENGTH FOR CONCRETES

WITH MW1 POZZOLAN BLENDED CEMENTS

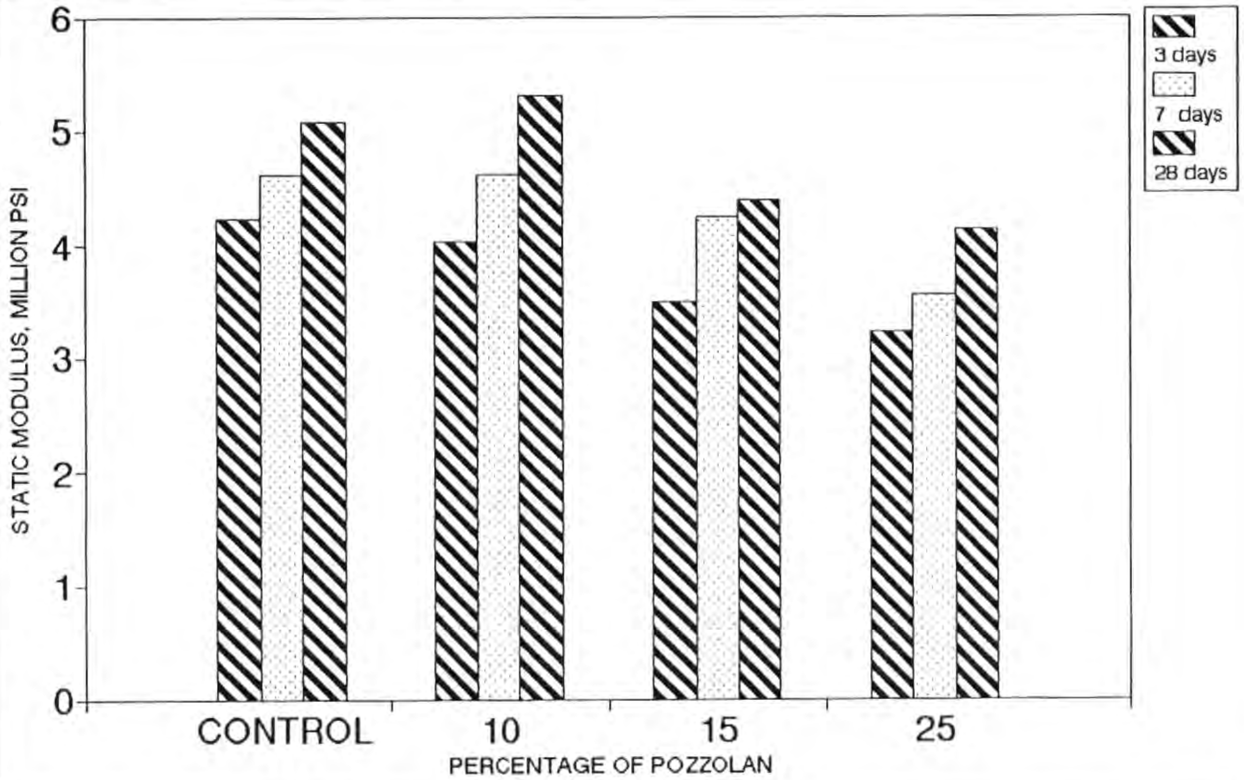


FIG 17E : COMPARISON OF STATIC MODULUS FOR CONCRETES WITH

MW1 POZZOLAN BLENDED CEMENTS

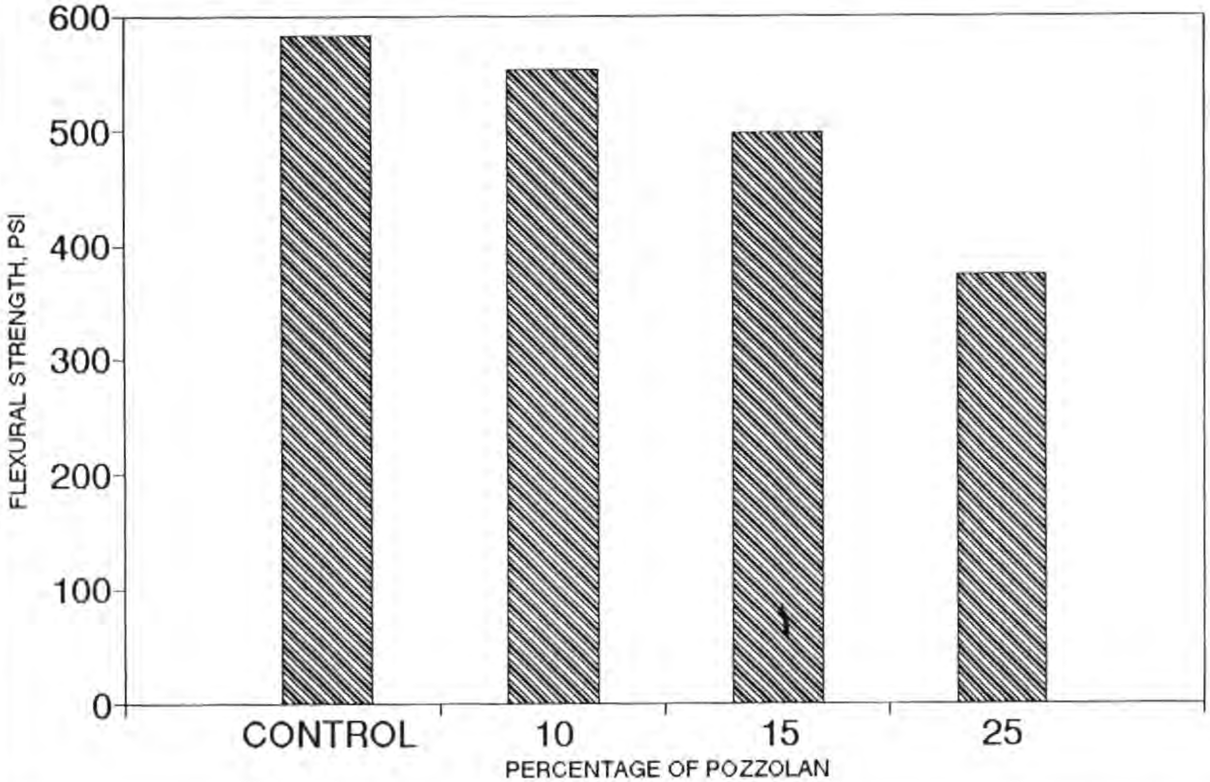


FIG 17F : COMPARISON OF FLEXURAL STRENGTH FORCONCRETES WITH

MW1 POZZOLAN BLENDED CEMENTS

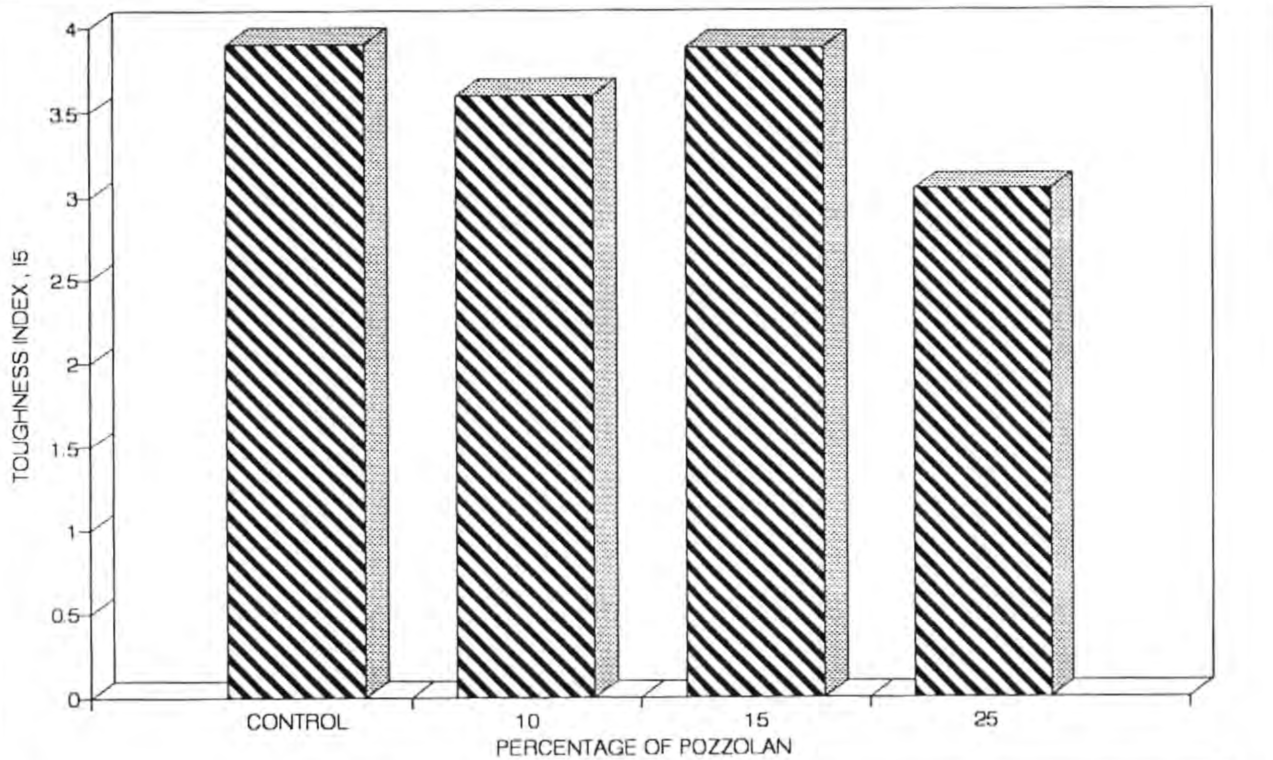


FIG 17G : COMPARISON OF TOUGHNESS INDEX , I5 FOR CONCRETES
WITH MW1 POZZOLAN BLENDED CEMENTS

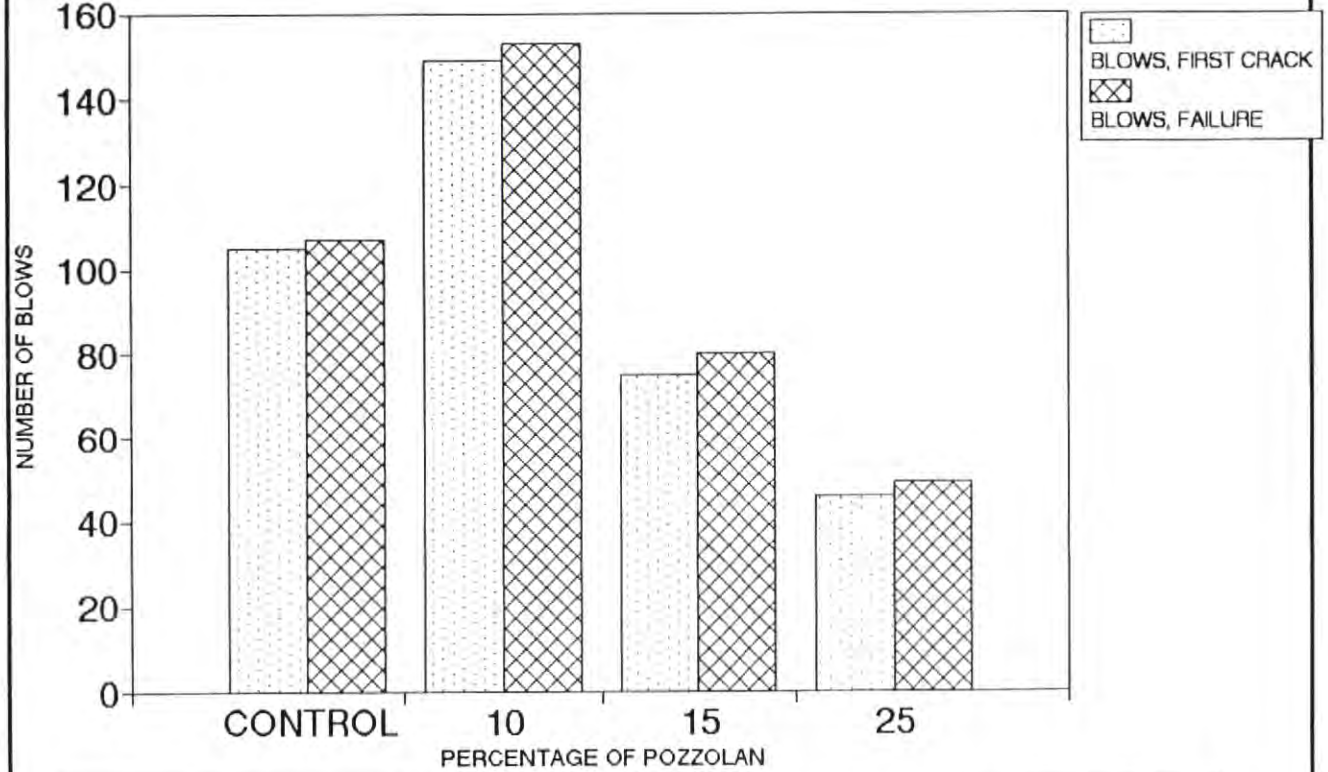


Fig. 17 H: COMPARISON OF IMPACT STRENGTH FOR CONCRETES

WITH MW1 POZZOLAN BLENDED CEMENTS