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SD Department of Transportation
Office of Research

Supplementary Report 2

A Comparative Study of the Physical Properties of Six Natural Pozzolan Blended Type-IP Cements

DISCLAIMER

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

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Supplementary Report 2

A Comparative Study of the Physical Properties of Six Natural Pozzolan Blended Type-IP Cements

Development of a Type IP Cement

Study SD91-11
Final Report

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16. Abstract

Cement contains many ingredients of which alkalies are minor compounds. Alkali reactive sands or coarse aggregates when used in concrete structures cause a major problem due to cracks formed by the expansive reaction between alkalies in cement and reactive forms of silica in aggregates. Use of natural pozzolans as a cement replacement is effective in inhibiting expansive alkali-silica reactivity. This investigation presents the experimental results to evaluate the physical properties of six natural pozzolans blended Type-IP cement specimens with 10, 15, and 25 percentages of pozzolans. The tests carried out include:

1. Physical properties of cement mortar such as compressive strength by ASTM C109 and air content by ASTM C185.
2. Physical properties of cement paste such as normal consistency by ASTM C187, time of setting by ASTM C191 and ASTM C266, and early stiffening of cement paste by ASTM C451.
3. Physical properties of cement such as fineness by ASTM C430 and ASTM C204, and density by ASTM C188.

From the test results it can be stated that there is no significant difference in the physical properties of cement mortar, cement paste, and cement, blended with 10 percent of LK2 natural pozzolan, when compared to respective properties of plain Portland cement mortar, cement paste, and cement.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

GLOSSARY

Pozzolan:
A siliceous or alumino-siliceous material that in itself possesses little or no cementetious value but in finely devided form and in the presence of moisture will chemically react with Alkali and Alkaline earth hydroxides at ordinary temperatures to form or assist in forming compounds possessing cementetious properties.

Natural Pozzolans:
These are the naturally occuring materials that exhibit pozzolanic properties such as some volcanic ash and lava deposits.

Portland-Pozzolan Cement Type IP:
It is a hydraulic cement consisting of an intimate and uniform blend of Portland cement and fine pozzolan produced either by intergrinding Portland cement clinker and pozzolan or by blending Portland cement and finely devided pozzolan.

Fly Ash:
It is a finely devided residue that results from the combustion of ground or powdered coal and is transported from the boiler by flue gases.

Class F Fly Ash:
It is a Fly Ash normally produced from burning anthracite or bituminous coal that meets the applicable requirements given in ASTM C618.

Alkali Silica Reaction:
It is the expansive reaction between alkalies in cement and reactive forms of silica in aggregate.

S.D:
Standard Deviation

C.V:
Coefficient of Variance

CHAPTER 1

INTRODUCTION

1.1 General

Most aggregates are chemically stable in hydraulic cement concrete, without deleterious interaction with other concrete ingredients. However, this is not the case for aggregates containing certain minerals that react with soluble alkalies in concrete. It is known that certain internal chemical reactions between the sodium and potassium alkalies in cement and reactive forms of silica in aggregates cause harmful expansions. Three types of alkali silica reactions (ASR) have been recognized and are based on the type of mineral causing the expansion (7).

1. Alkali-Silica Reactivity: The rocks and minerals involved in this type of ASR 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 expansion caused by these forms of silica has been found to be significantly slower than that 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 alkalis and the silica minerals that absorb water and exerts a swelling pressure leading to cracks in concrete.

2. Alkali-Carbonate Reactivity: This involves an expansive reaction between alkalis and certain fine grained dolomitic limestone, usually in the coarse aggregate sizes. A detailed study of this effect was done by Grattan-Bellew and Gillott (7). It is found that in this type of reaction the gel was absent but volume increase was found to be causing the expansion.

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

It is found that the main factor contributing to the alkali-silica reaction is the amount of alkali present in the cement. The alkali pertains to the 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 and the sulfate or chloride ions react with certain components such as C_3A (tri-calcium aluminate), the hydroxyl ion is available to increase the P^H and render the solution aggressive to react with silica. External sources of alkali from soils, deicers, and industrial processes can also contribute to reactivity. Curing conditions leading to concentration of soluble alkalis at the surface contribute to the enhancement of ASR in concrete.

The basic options for avoiding reactivity problems are relatively simple in concept:

1. Avoid reactive aggregates.
2. Use low alkali cement.
3. Partially replace or add to cement a mineral admixture or pozzolan.

Avoiding potentially reactive aggregates is the most effective approach to solving reactivity problems. Unfortunately, with a diminishing supply of proven non-reactive aggregate sources, concrete producers may have no alternative but to use potentially reactive aggregate.

Low alkali cements had been used nationwide to mitigate ASR in concrete. However, it is known that low-alkali cements have also been associated with severe alkali-aggregate reactivity in pavements because of the use of salts for highway deicing which increases the total available alkali in concrete. Also current environmental concerns are causing cement plants to produce cements with higher alkaline content. Further, for a number of reasons low-alkali cements are not always readily available, nor is reliance on a simple alkali cement specification always effective. The depletion of good quality aggregate near construction sites has created a need to develop methods that will permit the successful use of marginal aggregates.

Therefore the last option is a more preferable approach to controlling ASR. A perusal of the proceedings of three International Conferences (14 to 16) on the use of pozzolans in concrete has shown that pozzolans have effectively controlled ASR with good success. The factors that influence the ability of pozzolan in controlling alkali-silica 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 alkalis in pozzolan participate in alkali-aggregate reactions (13). However it was shown by Malhotra and his co-researchers (15 and 16) that when high volume pozzolan replacements are used, the harmful expansions are eliminated. Therefore, in this investigation, five selected natural pozzolans and a class F Fly Ash have been used to evaluate their effect on physical properties of cement when blended with these pozzolans.

1.2 Problem Statement

Some existing concrete pavements in South Dakota show 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) has indicated that some of the sands currently used may be definitely or potentially deleterious. In South Dakota the majority of alkali-silica 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. There are adequate supplies of natural pozzolans near Rapid City, South Dakota and the State-owned South Dakota Cement Plant located in Rapid City could manufacture the type-IP Cement. Therefore the feasibility of obtaining such a natural pozzolan needs to be investigated.

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 inter grinding 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 ASR expansion has been gained using a type-IP cement made by inter grinding. There is also a need to establish the suitability of the pozzolan for blending or inter grinding with cement so that maximum benefit in terms of reducing alkali-silica reaction potential could be achieved without adversely affecting or altering other properties of cement. In this study five natural pozzolans and a class F Fly Ash were selected and cement mortar, cement paste, and cement are made with newly developed blended cements to test for desirable physical properties.

1.3. Objectives

The primary objective of this investigation is to determine the physical properties of the pozzolan blended cement mortar, cement paste, and cement specimens and analyze to compare them with Portland cement specimens to evaluate the effect of the pozzolans. This was achieved by carrying out tests to determine:

1. The physical properties of cement mortar such as compressive strength and air content.
2. The physical properties of cement paste such as normal consistency, time of setting, and early stiffening.
3. The physical properties of cement such as density, fineness by No.325 sieve, and Blaine fineness.

CHAPTER 2

LITERATURE SURVEY

2.1 History of Alkali-Silica Reaction

The 20th century has been truly described as the concrete age since all over the world, concrete-either plain, reinforced or prestressed-has advanced with tremendous strides, surpassing all other time-honored construction materials. We are concerned with Portland cement concrete and, in the United States, that amounted to practically nothing before 1900. The demand in the United States for a hydraulic binding medium led to the cement industry. The early producers had to sell concrete. They taught the public what concrete was, what it was intended for, how to make it, and how to design the early structures in which it might be used.

The matter of "Alkali" in cement furnishes an example of a series of advances and hesitancies made at great expenditure and time. "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.

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 Dr. 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.

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 Thomas E. Stanton in 1940 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 (6).

2.2 Mechanism of Expansion

Expansion is produced when the alkali-silica complex imbibes 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 (7).

2.3 Australian Theory

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 cause 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 (8).

The mobility of alkalis 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.

2.4 Tests and Observations

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

It is the purpose of the present test 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.

In mortar bar expansion test it is observed that many types of aggregates were combined in varying amounts and sizes with high and low alkali cements and formed into 1x1x10 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 soda cement. Materials such as dehydrated kaolin, soda, feldspar, magnesium flurosilicate, acetic acid, and calcium hydroxide added in small amounts as correctiveness were ineffective. However, diatomaceous earth in sufficient quantity as a cement replacement eliminated expansion (10).

2.5 Use of Pozzolanic Cement

Portland-Pozzolan cements are being used in major structures to combat the deterioration of concrete due to alkali-silica reaction and to obtain other desired properties in concrete. In connection with this 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.

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. Perhaps engineers have ignored its advantages, when combined with Portland cement, long ago. Until the recent discovery that pozzolans inhibit or reduce expansion due to alkali-silica reaction the only remedial measure known was to limit, as low as practicable, the alkali content of the cement. This practical limit has been 0.6 % for sufficient protection against excessive expansion where highly reactive aggregates must be used (11).

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 towards greater and more widespread demand for pozzolanic type of cements. It is also indicated that if and when effective Portland-pozzolan cements can be obtained generally, a single type of cement will meet the requirements for all uses.

Some of the recognized types of Pozzolanic materials are:

1. Clays and Shales (must be calcined to activate)

a) Kaolinite type b) Montmorillonite type

2. Opaline materials (calcination may or may not be required)

a) Diatomaceous earth b) Opaline cherts and shales

3. Volcanic tuffs and pumicities

a) Rhyolithic types b) Andesitic types c) Phonolitic types

4. Industrial byproducts

a) Blast furnace slag b) Fly Ash c) Silica fume

2.6 Useful Properties of Portland - Pozzolan Cement in Mass Concrete

1. Lower heat of hydration and volume changes.
2. Greater tensile strength than Portland cement.
3. Marginal increase in compressive strength than Portland cement at later ages.
4. Provides resistance to sulfate attack.
5. Inherently resist cracking, apparently because of increased plastic flow and extendibility.
6. Greater ability of pozzolanic materials to reduce the rate at which soluble compounds are leached from concrete.
7. Greater impermeability.

2.7 Use of Fly Ash in Cement

Fly Ash from coal burning power plants is used in concrete primarily because of its pozzolanic and cementitious properties. These properties contribute to long term strength gain and improved durability when used with Portland cement. Other principal reasons for using Fly Ash include economy and beneficial modification of certain properties of fresh and hardened Portland cement concrete.

Fly Ash normally allows a reduction in the quantity of mixing water in a concrete mixture necessary to produce a target slump. Because of the fineness and rounded shape of the fly ash particles, its use generally improves the cohesion and workability of the concrete at a given slump. Segregation and bleeding are often reduced. As the concrete hardens, the fly ash makes use of developed heat from Portland cement hydration to accelerate Pozzolanic reactions and, thereby, promotes the reaction of the Fly Ash with available calcium and alkali hydroxides. Using Fly Ash in concrete generally allows a reduction in the required cement content, and therefore reduces the peak temperature developed in concrete during curing.

The effect of Fly Ash in hardened concrete increases long-term strength through continued pozzolanic reaction achieved with most Fly Ashes in concrete if the concrete is maintained in a moist environment at moderate temperatures. Continued long-term reaction of Fly Ash reduces the size of the pore spaces in the cement paste phase of the concrete. Permeability and the rate of diffusion of moisture and aggressive chemicals into the concrete is reduced, thereby, reducing the danger of damage due to sulfate attack, steel corrosion and alkali-silica reaction. The shape, fineness, particle size distribution, density, and composition of Fly Ash particles influence the properties of freshly mixed, unhardened concrete and the strength development of hardened concrete as previously indicated.

Individual particles in fly ash vary in size depending on the source of Fly Ash. Specific gravity of solid Fly Ash particles range from 1.97 to 3.02, but is normally in the range of 2.2 to 2.8. Some Fly Ash particles are capable of floating on water, indicating a specific gravity less than one. High specific gravity is often an indication of fine particles. The modulus of elasticity of Fly Ash concrete, as well as its compressive strength is some what lower at early ages and a little higher at later ages than similar concretes without Fly Ash, according to the Tennessee Valley Authority (1981) in a report on the properties of Class F Fly Ash (12).

CHAPTER 3

Materials, Mixture Designations, Proportions, 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.

Pozzolan: Five selected pozzolans, passing ASTM sieve No.325, which were found to be effective in controlling the alkali-silica reaction are being used in this investigation. Their source is given in Table 1. The raw pozzolan materials were crushed, using different sizes of crushing machines and finally ground in a ball mill to obtain the pozzolan in a fine powder form. The fine powder so obtained was sieved through ASTM sieve No.325 by a mechanical sieve shaker. The list of selected pozzolans is provided in Table 2.

Fly Ash: The Fly Ash, passing ASTM sieve No.325, 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.

Fine Aggregate:

1. Graded standard sand meeting the requirements of ASTM C778 was used for finding the compressive strength.

2. Standard sand (20-30 sand) meeting the requirements of ASTM C778 was used for finding the air content of cement mortar.

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.

3.2 Mixture Designations

The pozzolan blended cement mixture designations used for determining the cube compressive strength, air content, normal consistency, early stiffening, Vicat and Gillmore setting times, density, and fineness with various percentage replacements of selected pozzolans are given in the Table 3.

3.3 Mixture Proportions

3.3.1 Cube Compressive Strength

Mixture proportions were one part of pozzolan blended cement and 2.75 parts of graded standard sand proportioned by weighing. The water to pozzolan blended cement ratio was maintained at 0.485 for all the mixes. The cement was replaced with pozzolan by 10 %, 15 %, and 25 % by weight.

3.3.2 Air Content of Cement Mortar

According to ASTM C185, 350 grams of pozzolan blended cement and 1400 grams of standard 20-30 sand were used uniformly for all the mixes.

3.3.3 Normal Consistency and Time of Setting of Cement Paste

According to ASTM C187, 191 and 266, 650 grams of pozzolan blended cement was uniformly used for all the mixes to determine normal consistency and time of setting of cement paste.

3.3.4 Early Stiffening of Cement Paste

According to ASTM C451, 500 grams of pozzolan blended cement was uniformly used for all the mixes to determine the early stiffening of the cement paste.

3.3.5 Density of Cement

According to ASTM C188, 64 grams of pozzolan blended cement was used uniformly for all the mixes for determination of density.

3.3.6 Fineness of Cement

One gram of pozzolan blended cement for ASTM C430 test method and 50 grams of pozzolan blended cement for ASTM C184 test were uniformly used for all the mixes.

3.4 Test Specimen

For cube compressive strength with pozzolan replacement, 15 cubes of size two inches were cast for each mixture to test five cubes each at ages three, seven, 28 days for every 10 %, 15 % and 25 % pozzolan replacement.

CHAPTER 4

Test Procedures for Cement Mortar, Cement Paste, and Cement

4.1 Procedure for Cement Mortar Tests

4.1.1 Cube Compressive Strength

ASTM C109 test method for compressive strength of hydraulic cement mortar was basically adopted for the procedure. This test method covers the determination of the compressive strength of cement mortars, using two inch cubes. Mixing was done according to ASTM C305. The specimens were removed from the molds after 24 hours and placed in lime saturated water in the curing tank until the test age. The cubes were tested at three, seven, and 28 days. The results of these tests are given in Table 4.

4.1.2 Air Content of Cement Mortar

Mortar was prepared with standard 20-30 sand and the blended pozzolan cement, using water content sufficient to give 80 % flow. This mortar was compacted into a measure of known volume of 400 ml and weighed. The air content was from the measured density of mortar and the known densities of constituents. The mixture proportions were according to ASTM C185 test method. The results of these tests are given in Table 5.

4.2 Procedure for Tests on Cement Paste

4.2.1 Normal Consistency

ASTM C187 test method was used to determine the amount of water required to prepare hydraulic cement pastes for testing. The paste shall be of normal consistency when the plunger of Vicat apparatus settles to a point 10 mm below the original surface at 30 seconds after being released. Trail pastes were made with varying percentages of water until the normal consistency was obtained. The results of these tests are given in Table 6.

4.2.2 Early Stiffening of Cement by Paste Method

ASTM C451 test method was adopted to find the early stiffening of cement paste. Cement paste was prepared by using sufficient water to give a required initial penetration of 32 mm as measured by Vicat plunger at a stipulated time of 20 seconds after completion of mixing. Several trials were made to arrive at the target penetration. A second penetration, termed as the final penetration, is measured at a later stipulated time of five minutes after completion of mixing. The ratio of final to initial penetration is calculated as a percentage. The results of these tests are given in Table 7.

4.2.3 Time of Setting by Vicat Needle

ASTM C191 test method was adopted to find the setting times. This test method was used to determine the initial setting time and the final setting time of cement paste by using Vicat needle. Initial setting time is the time taken by the cement paste for a penetration of 25 mm with one mm needle. Final setting time is the time when one mm needle does not sink visibly into the paste. The penetration of the needle for every 15 minutes was determined and the time of setting was noted when the required level of penetration was obtained. The results of these tests are given in Table 8.

4.2.4 Time of Setting by Gillmore Needles

ASTM C266 test method was adopted to find the setting times. This test method was used to determine initial setting time and final setting time of cement paste by using Gillmore needles. In determining the time of setting the Gillmore needle is held in a vertical position and released gradually on the surface of cement paste. The initial setting time is the difference of time, in minutes, between the time of contact of cement and mixing water and the time the cement paste acquires its initial set without appreciable indentation with initial Gillmore needle. The difference in time, in minutes, between the time of contact of cement and mixing water and the time the cement paste acquires its final set without appreciable indentation with final Gillmore needle is the final setting time. The results of these tests are given in Table 9.

4.3 Procedure for Tests on Cement

4.3.1 Density

According to the specifications of ASTM C311, 64 grams of pozzolan blended cement was used for determining its density and 50 grams of natural pozzolan was used in place of 64 grams of cement for determining the density of pozzolan. The density was determined according to the test procedure specified in ASTM C188. Le-Chatelier flask was filled with kerosene up to a point on the stem between the zero and the one ml mark, and the reading was noted as the first reading. Sixty four grams of pozzolan blended cement or 50 grams of the pozzolan was added and the level of the kerosene was noted as the final reading. The difference between the first reading and the final reading was calculated as the volume of liquid displaced by the 64 or 50 grams as the case may be of the pozzolan blended cement or pozzolan used. The mass of test sample was divided by the volume of the liquid displaced and the value was recorded as the density of the test sample expressed as gm/cm^3. The flask has been immersed in a constant-temperature water bath for sufficient periods of time in order to avoid flask-temperature variations greater than 0.2^oC between the initial and final readings. The results of these tests are given in Table 10.

4.3.2 Fineness by No. 325 Sieve

The raw pozzolan materials were crushed, using different sizes of crushing machines and ground in a ball mill to obtain the pozzolan in a fine powder form. The powder so obtained was sieved through ASTM sieve No. 325 by a mechanical sieve shaker. The pozzolan passing ASTM sieve No.325 was used to produce the pozzolan blended cement at the required percentage level. The fineness of each of the blended pozzolan cement mixture was determined by finding the weight of mixture retained using electronic balance when wet sieved on No. 325 sieve in accordance with ASTM C430 test method. One gram of test cement was placed on No.325 sieve and wetted with a gentle stream of water. The sieve was removed from the nozzle and the pressure of the nozzle was adjusted to 10±0.5 psi. The sieve was returned to its position under the nozzle and washed for one minute, giving a circular motion to the sieve in a horizontal plane at the rate of one motion for second in the spray. The sieve and residue were dried and the fineness was calculated as percentage of material passing through the sieve. The results of these tests are given in Table 11.

4.3.3 Blaine Fineness

Air permeability apparatus was used for the determination of the Blaine fineness of the blended pozzolan cements. The Blaine fineness for the blended pozzolan cements was determined according ASTM C204 test method. The weight of the test sample used for the test was calculated depending on the desired porosity of bed of cement. To prepare the bed of cement, one filter paper disk was placed on the perforated disk and the calculated quantity of cement was placed in the permeability cell. Second filter paper disk was placed on the top of the cement and the cement was compressed with the plunger until the plunger collar is in contact with the top of the cell. The permeability cell is attached to the manometer tube, making certain that an airtight connection is obtained and taking care not to disturb the prepared bed of cement. The time interval was recorded to pass bottom meniscus of manometer liquid from second mark to the third mark. Temperature of the test was recorded and Blaine fineness is calculated using appropriate formula according to the ASTM C204 test method. The results of these tests are given in Table 12.

CHAPTER 5

TEST RESULTS AND DISCUSSION

5.1 Cement Mortar Properties

5.1.1 Cube Compressive Strength

The cube compressive strength results are given in the Table 4. The following variations in the mean compressive strength for 10 % pozzolan blended cement mortar mixes were observed in comparison with control test mixture specimens. At three days, a minimum decrease of 10.79 % for CT1 and a maximum decrease of 23.05 % for class F Fly Ash were observed. At seven days, the compressive strength with LK2 pozzolan was increased by 4.38 % and the maximum decrease in compressive strength by 31.75 % was observed with PS1E pozzolan. At 28 days, a minimum decrease in compressive strength by 5.43 % was observed for LK2 pozzolan and a maximum decrease in compressive strength by 23.54 % was observed with class F Fly Ash.

The following variations in the mean compressive strength for 15 % pozzolan blended cement mortar mixes were observed in comparison with control test mixture specimens. At three days, a minimum decrease of 12.06 % for LK2 and a maximum decrease of 40.71 % for class F Fly Ash were observed. At seven days, a maximum decrease of 40 % in compressive strength with PS1E and MW1 pozzolans was observed and the minimum decrease in compressive strength by 4.73 % with LK2 pozzolan was observed. At 28 days, a minimum decrease in compressive strength by 20.81 % was observed for CT1 pozzolan and a maximum decrease in compressive strength by 50.18 % was observed with MW1 pozzolan.

The following variations in the mean compressive strength for 25 % pozzolan blended cement mortar mixes were observed in comparison with control test mixture specimens. At three days, a minimum decrease of 13.80 % for LK2 and a maximum decrease of 45.43 % for class F Fly Ash was observed. At seven days, a maximum decrease of 43.12 % in compressive strength with MW1 pozzolan was observed and the minimum decrease in compressive strength by 5.33 % with LK2 pozzolan was observed. At 28 days, a minimum decrease in compressive strength by 25.72 % was observed for LK2 pozzolan and a maximum decrease in compressive strength by 54.61 % was observed with MW1 pozzolan.

Of all the natural pozzolans, the adverse effect of LK2 pozzolan was observed to be the least on the physical properties of cement and at 10 % replacement level, the decrease in compressive strength is insignificant.

5.1.2 Air Content

The air content, volume percentage, of the pozzolan blended cement mortars are given in Table 5. The air content of the pozzolan blended cement mortars was decreased with increase in the percentage replacement of cement by pozzolan. But the air content was increased with increase in percentage replacement of cement by class F Fly Ash.

The following variations in the air content for 10 % pozzolan blended cement mortar was observed in comparison with control test mortar. A maximum air content of 5.26 % was observed for PS1E pozzolan and a minimum air content of 3.86 % was observed for the CT1 pozzolan.

The following variations in the air content for 15 % pozzolan blended cement mortar was observed in comparison with control test mortar. A maximum air content of 5.05 % was observed for SM2 pozzolan and a minimum air content of 3.33 % was observed for the CT1 pozzolan.

The following variations in the air content for 25 % pozzolan blended cement mortar was observed in comparison with control test mortar. A maximum air content of 5.02 % was observed for class F Fly Ash and a minimum air content of 2.65 % was observed for the CT1 pozzolan.

5.2 Cement Paste Properties

5.2.1 Normal Consistency

The normal consistency, W/C %, of pozzolan blended cements is given table 6. The test results of the normal consistency indicated that there was an increase in the water demand with an increase in the percentage of pozzolan content in the pozzolan blended cement mixes as shown in Table 6. But the normal consistency was decreased with increase in the percentage replacement of cement in case of class F Fly Ash.

The following variations in the normal consistency values for 10 % pozzolan blended cements was observed in comparison with control test cement. A maximum normal consistency of 28.85 % was observed for SM2 pozzolan and a minimum normal consistency of 23.85% was observed for class F Fly Ash.

The following variations in the normal consistency values for 15% pozzolan blended cements was observed in comparison with control test cement. A maximum normal consistency of 31 % was observed for SM2 pozzolan and a minimum normal consistency of 23.54 % was observed for class F Fly Ash.

The following variations in the normal consistency values for 25 % pozzolan blended cements was observed in comparison with control test cement. A maximum normal consistency of 34.69 % was observed for MW1 pozzolan and a minimum normal consistency of 22.62 % was observed for class F Fly Ash.

5.2.2 Early Stiffening

The early stiffening, percentage final penetration of the plunger of Vicat apparatus, of the pozzolan blended cement paste is given Table 7. The early stiffening of the pozzolan blended cement pastes was decreased with increase in the percentage replacement of cement by all the pozzolans and class F Fly Ash. But the air content was increased with increase in percentage replacement of cement by class F Fly Ash.

The following variations in the early stiffening for 10 % pozzolan blended cements were observed in comparison with control test cement. A maximum of 64.5 % was observed with CT1 pozzolan and a minimum of 35.71 % was observed with PS1E pozzolan.

The following variations in the early stiffening for 15% pozzolan blended cements were observed in comparison with control test cement. A maximum of 61.76 % was observed with CT1 pozzolan and a minimum of 33.92 % was observed with PS1E pozzolan.

The following variations in the early stiffening for 25 % pozzolan blended cements were observed in comparison with control test cement. A maximum of 60.60 % was observed with class F Fly Ash pozzolan and a minimum of 29.82 % was observed with SM2 pozzolan.

5.2.3 Time of Setting by Vicat Apparatus

The Vicat initial and final setting time of the pozzolan blended cement pastes were given in Table 8. The Vicat initial and final setting time of the pozzolan blended cement pastes were increased with increase in the percentage replacement of cement by pozzolans and class F Fly Ash.

The following variations in initial and final setting times for 10 % pozzolan blended cements were observed in comparison with control test cement. A maximum initial setting time of 235 minutes MW1 pozzolan and a minimum initial setting time of 150 minutes with SM2 pozzolan were observed. A maximum final setting time of 345 minutes with MW1 and a minimum final setting time of 367 minutes for SM2 pozzolan were observed.

The following variations in initial and final setting times for 15 % pozzolan blended cements were observed in comparison with control test cement. A maximum initial setting time of 250 minutes MW1 pozzolan and a minimum initial setting time of 170 minutes with SM2 pozzolan were observed. A maximum final setting time of 360 minutes with MW1 and a minimum final setting time of 305 minutes for SM2 pozzolan were observed.

The following variations in initial and final setting times for 25 % pozzolan blended cements were observed in comparison with control test cement. A maximum initial setting time of 265 minutes MW1 pozzolan and a minimum initial setting time of 182 minutes with PS1E pozzolan were observed. A maximum final setting time of 460 minutes with MW1 and a minimum final setting time of 318 minutes for LK2 pozzolan were observed.

5.2.4 Time of Setting by Gillmore Needles

The Gillmore initial and final setting time of the pozzolan blended cement pastes were given in Table 9. The Gillmore initial and final setting time of the pozzolan blended cement pastes were increased with increase in the percentage replacement of cement by pozzolans and class F Fly Ash.

The following variations in initial and final setting times for 10 % pozzolan blended cements were observed in comparison with control test cement. A maximum initial setting time of 285 minutes MW1 pozzolan and a minimum initial setting time of 185 minutes with PS1E pozzolan were observed. A maximum final setting time of 420 minutes with MW1 and a minimum final setting time of 335 minutes for PS1E pozzolan were observed.

The following variations in initial and final setting times for 15 % pozzolan blended cements were observed in comparison with control test cement. A maximum initial setting time of 297 minutes MW1 pozzolan and a minimum initial setting time of 190 minutes with P1SE pozzolan were observed. A maximum final setting time of 480 minutes with MW1 and a minimum final setting time of 350 minutes for PS1E pozzolan were observed.

The following variations in initial and final setting times for 25 % pozzolan blended cements were observed in comparison with control test cement. A maximum initial setting time of 345 minutes MW1 pozzolan and a minimum initial setting time of 198 minutes with PS1E pozzolan were observed. A maximum final setting time of 520 minutes with MW1 and a minimum final setting time of 385 minutes for LK2 pozzolan were observed.

However, the results of setting time were within the allowable limits of ASTM specified limits (according to ASTM C595, the final setting time should not be more than 7 hours and the initial setting time should not be less than 45 minutes) except the Gillmore final setting time of MW12 and MW13.

5.3 Cement Properties

5.3.1 Density

The densities of pozzolan blended cement mixes are given in Table 10. The density for all the pozzolan blended cements were less than that of the cement. The densities of the pozzolan blended cements are varied between 2.895 gm/cm^3 and 3.077 gm/cm^3. The density of the pozzolan blended cements was decreased with increase in the percentage replacement of cement by all the pozzolans and class F Fly Ash.

The following variations in the density for 10 % pozzolan blended cements were observed in comparison with control test cement. A maximum density of 3.080 gm/cm^3 was observed with PS1E pozzolan and a minimum density of 3.033 gm/cm^3 was observed with SM2 pozzolan.

The following variations in the density for 15 % pozzolan blended cements were observed in comparison with control test cement. A maximum density of 3.048 gm/cm^3 was observed with LK2 and MW1 pozzolans, and class F Fly Ash and a minimum density of 2.950 gm/cm^3 was observed with CT1 pozzolan.

The following variations in the density for 25 % pozzolan blended cements were observed in comparison with control test cement. A maximum density of 3.005 gm/cm^3 was observed with PS1E pozzolan and a minimum density of 2.895 gm/cm^3 was observed with SM2 pozzolan.

5.3.2 Fineness by Sieve No.325

The fineness of the pozzolan blended cements was increased with increase in the percentage replacement of cement by all the pozzolans and class F Fly Ash. The fineness obtained by wet sieving through ASTM No.325 sieve for all pozzolan blended cements was above 90 % passing. This was achieved by initially running the raw material through different sizes of crushing machines. The crushed material was powdered to a fine form by using a ball mill. The fine powder so obtained was sieved through No.325 sieve using a mechanical sieve shaker. The pozzolans so sieved were blended with the cement at required percentages to produce the blended cements. The objective of obtaining a pozzolan blended cement, finer than 90 % passing was therefore achieved. The fineness of the pozzolan blended cements are given in Table 11.

The following variations in the fineness for 10 % pozzolan blended cements were observed in comparison with control test cement. A maximum fineness of 93.43 % with LK2 pozzolan and a minimum fineness of 92.98 % with CT1 pozzolan were observed.

The following variations in the fineness for 15 % pozzolan blended cements were observed in comparison with control test cement. A maximum fineness of 93.54 % with class F Fly Ash and a minimum fineness of 93.29 % with PS1E pozzolan were observed.

The following variations in the fineness for 25 % pozzolan blended cements were observed in comparison with control test cement. A maximum fineness of 94.36 % with CT1 pozzolan and a minimum fineness of 93.97 % with class F Fly Ash were observed.

5.3.3 Fineness by Blaine Air Permeability Apparatus

The Blaine fineness of the pozzolan blended cements was increased with increase in the percentage replacement of cement by all the pozzolans except class F Fly Ash. The Blaine fineness for the pozzolan blended cements are given in Table 12. From the Blaine fineness results it can be stated that the procedure used for obtaining the pozzolan blended cements in a fine form was adequate.

The following variations in the fineness for 10 % pozzolan blended cements were observed in comparison with control test cement. A maximum fineness of 481.23 m^2/kg with CT1 pozzolan and a minimum of 385.39 m^2/kg with class F Fly Ash were observed.

The following variations in the fineness for 15 % pozzolan blended cements were observed in comparison with control test cement. A maximum fineness of 524.26 m^2/kg with LK2 pozzolan and a minimum of 361.55 m^2/kg with class F Fly Ash were observed.

The following variations in the fineness for 25 % pozzolan blended cements were observed in comparison with control test cement. A maximum fineness of 634.19 m^2/kg with LK2 pozzolan and a minimum of 340.19 m^2/kg with class F Fly Ash were observed.

CHAPTER 6

DEVELOPMENT OF A MODEL FOR PREDICTING COMPRESSIVE STRENGTH

Statistical analysis has been used to relate the compressive strength of natural pozzolan blended cement to the percentage natural pozzolan added and its physical properties. The effect of addition of different natural pozzolans to the Dakota cement type I/II for all the five natural pozzolans and class F Fly Ash has been investigated.

A computer software " Microsoft Excel 4.0 " was used for this analysis. The parameters, percentage pozzolan, age in number of days, air content, normal consistency, density, and fineness were taken as the six independent variables. The compressive strength up to 28 days was taken as the dependent variable. The water/pozzolan blended cement ratio was kept the same throughout the investigation, and therefore it was eliminated as a parameter.

Observations made for all the pozzolans and class F Fly Ash were used for the regression analysis. Multiple-Linear-Regression analysis was used to develop a model of the form,

$$Y = X_0 + X_1 A + X_2 B + X_3 C + X_4 D + X_5 E + X_6 F$$

Where, Y = Compressive strength in psi

A = Age in number of days

B = Percentage addition of pozzolan

C = Air content, percentage volume

D = Normal consistency

E = Density gm/cc

F = Fineness Percentage

6.1 Model for Fitting the Results

The following equations were obtained from the regression analysis:

Model I:

$$Y = X_o+X_1 A+X_2 B+X_3 C+X_4 D+X_5 E+X_6 F$$

From Excel 4.0, the equation is

$$Y = -41079.90 + 53.10 A - 95.34 B + 51.17 C - 36.78 D - 2769.67 E +579.64 F$$

Model II:

$$Y = X_o+ X_1 A + X_2 B + X_3 C + X_4 D + X_5 E + X_6 F + X_7 CD + X_8 DE + X_9 EF + X_{10} FC$$

From Excel, the equation is

$$Y = -2291813+ 53.10 A - 148.40B - 35052.80 C -2641.34 D + 763007.40 E + 25361.64 F + 116 CD + 694.02 DE - 8371.38 EF +340.56 FC$$

Model III:

$$Y = X_o + X_1 A + X_2 B + X_3 C + X_4 D + X_5 E + X_6 F + X_7 CD + X_8 DE + X_9 EF + X_{10} FC + X_{11} C^2 + X_{12} D^2 + X_{13} E^2 + X_{14} F^2$$

From Excel, the equation is

$$Y = -8.2E+07+ 53.10 A -600.76 B - 158804 C +21840.05D + 135988833 E + 1304557 F - 871.32 CD-3551.36 DE - 1167810 EF + 2171.79 FC -2266.02 C^2 -131.36 D^2 - 438364 E^2 - 5113.97 F^2$$

Model III has high correlation coefficient of 0.89, therefore it is assumed as the full model and the hypothesis testing was done for the acceptance of the reduced model in comparison with the assumed full model.

6.2 Correlation Coefficient

The correlation coefficient describes the strength and direction of the relationship between the values of deferent variables. The correlation coefficient assumes values between -1 and +1 inclusive (31). A value of -1 indicates that there is a perfect negative linear relationship and a value of +1 indicates that there is a perfect positive linear relationship (31). If the correlation coefficient is close to zero there is a little or no relationship between the dependent and independent variables and it indicates a nonlinear relationship (30). The following range of values are useful in determining the significance of a variable in the relationship (32).

Correlation Coefficient	**Remarks**
0.0 to 0.2	very weak, negligible
0.2 to 0.4	weak, low
0.4 to 0.7	moderate
0.7 to 0.9	strong, marked, high
0.9 to 1.0	very strong, very high

The values of correlation coefficient for the models are as follows:

Model	Correlation coefficient	Standard Error	Significance Level
I	0.81	548	4.53 E-10
II	0.84	523	1.95 E-09
III	0.89	471	6.80 E-10

6.3 Standard Error and Significance Level

In statistical approach, it is considered that the samples are drawn from the population. It is likely that the estimates made from the samples are inaccurate if the samples are not indicative of the population from where they are drawn. Standard error is a parameter used to judge whether the sample represents the population from where it was taken. If the standard error is zero, the sample mean is the same as the population mean and it is evident that the population itself is the sample. The smaller the standard error, the more is the chance that the sample mean is close to the population mean. The standard error is related to three factors: (1) the standard deviation within the sample, (2) the size of the sample, and (3) the proportion of the population covered by the sample. The standard error is calculated by deviding sample standard deviation by the square root of number of observations.

Null Hypothesis denoted by "H_O" is defined as the possibility of a coefficient of variable in regression equation is zero. Significance level "n" of a variable means that Null Hypothesis is rejected ((1-n) x 100)% of the time. The lower is the significance level the lower is the chance that the Null Hypothesis is rejected and the coefficient is not equal to zero.

6.4 Tests on Reduced Models

In order to determine which of the six independent variables has a significant effect on the compressive strength, regression was carried out on reduced models. Among all of the reduced models, the model for which the correlation coefficient is the highest was chosen as the full model. The hypothesis testing was done for the reduced models in comparison to the full model. Hypothesis tests were done with -

H_O : as reduced model

H_1 : as full model

From the F-statistics tests, reduced models were accepted at very low levels of 0.006198 for model I and 0.011995 for model II when compared to the model III as a full model.

A comparison of the observed and predicted values of compressive strength at three, seven, and 28 days for all the natural pozzolans and class F Fly Ash were shown in Table 13. The difference of the predicted value of compressive strength with respect to the observed value of compressive strength is also shown in Table 13.

CHAPTER 7

CONCLUSIONS

1. The compressive strength, at seven and 28 days age, of mortar cubes made with one pozzolan, a gray, highly siliceous "fireclay" (LK2) from the Lakota formation was not affected when 10 % by weight of the cement replaced. The decrease in compressive strength of LK2 blended cement mortar cubes was the lowest at 15% and 25% replacement levels when compared to other pozzolans and class F Fly Ash.
2. The air content of pozzolan blended cement mortar decreased with an increase in the percentage of pozzolan for all the test pozzolans and class F Fly Ash.
3. Normal consistency increased with an increase in the percentage of all the pozzolans except class F Fly Ash.
4. It can be concluded from the results of the early stiffening by paste method that the decrease in the percentage final penetration with increase in the percentage of LK2 pozzolan was insignificant. A false set was observed in case of SM2 and PS1E pozzolans.
5. Initial and final setting times by Vicat apparatus were within the allowable limits for all the test pozzolans and class F Fly Ash.
6. Initial and final setting times by Gillmore needles were within the allowable limits for all the test pozzolans and class F Fly Ash except MW12 and MW13.
7. Density of pozzolan blended cements decreased with increase in the percentage of pozzolan and the decrease was insignificant in case of all the pozzolans and class F Fly Ash
8. The fineness of pozzolan blended cements was increased with the increase in percentage of pozzolan. The fineness results indicated that the procedure used for obtaining the required fineness was good.

REFERENCES

1. Steele, B. W., "Cracks in Concrete", American Concrete Institute Journal, Vol. 18, No. 6, Feb. 1947, pp. 629-633.
2. McConnell, D. Mielenz, R. C., Holland, Y. W., and Greene, T., "Cement-Aggregate Reaction in Concrete", American Concrete Institute Journal, Vol. 19, No. 2, Oct. 1947, pp.93-128.
3. Mielenz, R. C., Greene, K. T., and Benton, E. J., "Chemical Test for Reactivity of Aggregates with Cement Alkalies", American Concrete Institute Journal, Vol. 19, No. 3, 1947, pp. 193-221.
4. Parsons, W. H., and Insley, H., "Aggregate Reaction with Cement Alkalies", American Concrete Institute Journal, Vol. 19, No. 8, April 1948, pp. 625-632.
5. Stark, D., and DePuy, G., "Alkali-Silica Reaction in Five Dams in Southwestern United States", Concrete Durability, Katharine and Bryant Mather, International Conference, ACI, SP-100, Vol. 2, 1987, pp. 1759-1786.
6. Alasali, M. M., Malhotra, V. M., and Soles, J. A.", Performance of Various Test Methods for Assessing the Potential Alkali Reactivity of Some Canadian Aggregates", International Workshop on Alkali-Aggregate Reactions in Concrete; Occurrence, Testing and Control", Halifax, Canada, May 1990.
7. Grattan-Bellew, P., and Gillott, J., "Three Decades of Studying the Alkali Reactivity of Canadian Aggregates", Concrete Durability, Katharine and Bryant Mather, International Conference, ACI, SP-100, Vol. 2, 1987, pp. 1365-1384.
8. Farbiarz, J., and Carrasquillo, R., "Alkali-Aggregate Reaction in Concrete Containing Fly Ash", Concrete Durability, Katharine and Bryant Mather, International Conference, ACI, SP-100, Vol. 2, 1987, pp. 1787-1808.
9. Ramachandran, S., "Alkali Reactivity of Concrete Aggregates", M. S. Thesis, South Dakota School of Mines and Technology, Rapid City, South Dakota, 1991.

10. Xu, H. Y., and Chen, M., "AAR in Chinese Engineering Practices", Concrete Alkali Aggregate Reactions, Proceeding of the 7th International Conference, Ottawa, Canada, Edited by Patrick E. Grattan-Bellew, 1986, pp. 253-257.

11. Powers, T. C., "Use of Admixtures to Counteract Alkali-Aggregate Reaction", American Concrete Institute Journal, Vol. 22, No. 1, Sept. 1950, pp. 43-46.

12. American Concrete Institute Committee 226, "Use of Fly Ash in Concrete", ACI Materials Journal, Vol. 84, No. 5, Sept.- Oct. 1987, pp. 381-409

13. Alasali, M.M., "Alkali-Aggregate Reaction in Concrete: Investigations of Concrete Expansions from Alkali Contributed by Pozzolans or Slag", Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete-Proceedings. Third International Conference, Trondheim, Norway 1989, SP-114, V.1, ACI, Detroit, pp. 431-451.

14. Carrasquillo, R.L., and Snow, P.G., "Effects of Fly Ash on Alkali-Aggregate Reaction in Concrete", Proceedings of the Second International Conference on the use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, April 1986.

15. Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Proceedings, Third International Conference, Trondheim, Norway, 1989, ACI Special Publication SP-114, Two Volumes, Editor: V.M. Malhotra.

16. Second International Conference, Madrid, Spain, 1986, ACI Special Publication, SP-91, Editor: V.M. Malhotra.

17. Blight, G. E., Alexander, M. G., Ralph, T. K., and Lewis, B. A., "Effect of Alkali-Aggregate Reaction on the Performance of Reinforced Concrete Structure over a Six-year Period", American Concrete Institute Journal, Vol. 41, No. 147, June 1989, pp. 69-78.

18. Diamond, S., and Mukherjee, P. K., "Influence of Fly Ash in Alkali-Aggregate Reaction", Concrete Alkali-Aggregate Reactions, Proceedings of the 7th International Conference, Ottawa, Canada, Edited by Patrick E. Grattan-Bellew,

1986, pp. 44-48.

19. Farbiarz, J., Carrasquillo, R. L., and Snow, P. C., "Alkali-Aggregate Reaction in Concrete Containing Fly Ash", Concrete Alkali-Aggregate Reactions, Proceedings of the 7th International Conference, Ottawa, Canada, Edited by Patrick E. Grattan-Bellew, 1986, pp. 55-59.

20. Farbiarz, J., and Carrasquillo, R. L., "Effectiveness of Fly Ash Replacement in the Reduction of Damage Due to Alkali-Aggregate Reaction in Concrete", Research Report 450-1, Project 3-9-85-450, Center for Transportation Research, Bureau of Engineering Research, The University of Texas at Austin, May, 1992.

21. Larbi, J. A., and Bijen, J. M., "Effect of Mineral Admixtures on the Cement Paste Aggregate Interface", Proceedings, Fourth CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete, Editor V. M. Malhotra, American Concrete Institute SP-132, Vol. 1, Istanbul, Turkey, May 1992, pp. 655-669.

22. Soles, J. A., Malhotra, V. M., and Suderman, R. W., "The Role of Supplementary Cementing Materials in Reducing the Effects of Alkali-Aggregate Reactivity; CANMET Investigations", Concrete Alkali-Aggregate Reactions, Proceedings of the 7th International Conference, Ottawa, Canada, Edited by Patrick E. Grattan-Bellew, 1986, pp. 79-82.

23. Samuel, S., and Tyson P. E., "Control of Alkali-Silica Reactivity in Recycled Concrete Using Fly Ash", Proceedings, Fourth CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete, Supplementary Papers, Istanbul, Turkey, May 1992, pp. 15-20.

24. Ramachandran, S., Ramakrishnan, V., and Johnston, D., "The Role of High Volume Fly Ash in Controlling Alkali-Aggregate Reactivity", Proceedings, Fourth CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete, Editor V. M. Malhotra, American Concrete

TABLE 1 DESIGNATION, LOCATION, DEPOSIT, AND DESCRIPTION OF NATURAL POZZOLANS

DESIGNATION	LOCATION	DEPOSIT	DESCRIPTION
LK2	SOUTH SIDE OF MAIN ST. IN THE GAP, RAPID CITY NE1/4, NE1/4 NW1/4, SEC. 2, TIN, R7E, BHM	EARLY CRET. LAKOTA FM.	SILICIFIED VOLCANIC TUFF
PS1E	DAKOTA BLOCK PLANT, R.C. PIT LOCATED IN BOX ELDER AREA	UPPER CRETACEOUS	BROWN SHALE; EXPANDED PIERRE SHALE BY KILN HEATING
SM2	S.PART OF SHEEP MNT. TABLE SE1/4 NE1/4, SW1/4 SEC 28 T43N R44W, BHM	LOWER PART OF ROCKY FORD ASH	V.WHITE, HARD VOLCANIC TUFF
MW1	HAINES AVE 1.5 MIN OF RCMALL SE1/4 NW1/4 NW1/4 SEC 13 T2N; R8E BHM	MOWRY SHALE	WEATHERED SAMPLE
CT1	S.H. OF CUNY TABLE CENTER OF SEC 20; T41N; R45W, BHM	SHARPS FM 10-15 FT ABOVE ROCKY FORD ASH	WEATHERED SAMPLE

TABLE 2 LIST OF SELECTED NATURAL POZZOLANS

POZZOLAN TYPE	ABBREVIATION
NATURAL POZZOLAN	LK2
NATURAL POZZOLAN	PS1E
NATURAL POZZOLAN	SM2
NATURAL POZZOLAN	MW1
NATURAL POZZOLAN	CT1
CLASS F FLYASH	F

TABLE 3 MIXTURE DESIGNATIONS AND PROPORTIONS FOR TEST POZZOLANS

DESIGNATION	TEST POZZOLAN	% POZZOLAN BY WT.
C	CONTROL	NIL
LK21	LK2	10
LK22	LK2	15
LK23	LK2	25
PS1E1	PS1E	10
PS1E2	PS1E	15
PS1E3	PS1E	25
SM21	SM2	10
SM22	SM2	15
SM23	SM2	25
MW11	MW1	10
MW12	MW1	15
MW13	MW1	25
CT11	CT1	10
CT12	CT1	15
CT13	CT1	25
F1	CLASS F FLY ASH	10
F2	CLASS F FLYASH	15
F3	CLASS F FLYASH	25

TABLE 4 COMPRESSIVE STRENGTH OF POZZOLAN BLENDED CEMENT MORTAR CUBES ACCORDING TO ASTM C109 TEST METHOD

DESIGNATION	COMPRESSIVE STRENGTH IN PSI		
	3DAYS	7 DAYS	28 DAYS
C-1	2925	4325	5225
C-2	3075	3950	5650
C-3	3025	4325	5750
C-4	3350	4125	5475
C-5	3375	4375	5500
MEAN	**3150**	**4220**	**5520**
S.D.	2022	179	200
C.V.	0.064	0.042	0.036
LK21-1	2975	4825	5375
LK21-2	2625	4100	5325
LK21-3	2475	4350	5375
LK21-4	3050	4500	5125
LK21-5	2675	4250	4900
MEAN	**2760**	**4405**	**5220**
S.D.	243	276	207
C.V.	0.088	0.027	0.040
LK22-1	2500	4025	4475
LK22-2	2950	4200	3925
LK22-3	2650	4125	3950
LK22-4	2825	3800	4225
LK22-5	2925	3950	4675
MEAN	**2770**	**4020**	**4250**
S.D.	192	156	327
C.V.	0.069	0.039	0.077
LK23-1	2850	4225	3950
LK23-2	2850	3850	4375
LK23-3	2575	4200	3975
LK23-4	2700	3850	4050
LK23-5	2600	3850	4150
MEAN	**2715**	**3995**	**4100**
S.D.	132	199	172
C.V	0.049	0.050	0.042

TABLE 4 (CONTD..)

DESIGNATION	COMPRESSIVE STRENGTH IN PSI		
	3DAYS	7 DAYS	28 DAYS
PS1E1-1	2375	3000	4350
PS1E1-2	2500	2975	4200
PS1E1-3	2425	2875	3900
PS1E1-4	2450	3000	4625
PS1E1-5	2375	2550	4150
MEAN	**2425**	**2880**	**4245**
S.D.	53	192	267
C.V.	0.022	0.067	0.063
PS1E2-1	2500	2825	3600
PS1E2-2	2325	2725	4100
PS1E2-3	2500	2300	4275
PS1E2-4	2275	2350	3875
PS1E2-5	2375	2375	3950
MEAN	**2395**	**2515**	**3960**
S.D.	102	242	253
C.V.	0.043	0.096	0.064
PS1E3-1	2250	2450	4100
PS1E3-2	2500	2550	3300
PS1E3-3	2350	2600	3700
PS1E3-4	2350	2475	3050
PS1E3-5	2250	2500	3100
MEAN	**2340**	**2515**	**3450**
S.D.	103	60	444
C.V.	0.044	0.024	0.129
SM21-1	2550	3300	4500
SM21-2	2500	3825	4650
SM21-3	2450	3700	5025
SM21-4	2650	2575	5100
SM21-5	2750	2625	4925
MEAN	**2580**	**3205**	**4840**
S.D.	120	586	255
C.V.	0.047	0.183	0.053

TABLE 4 (CONTD..)

DESIGNATION	COMPRESSIVE STRENGTH IN PSI		
	3DAYS	7 DAYS	28 DAYS
SM22-1	2400	3425	4525
SM22-2	2425	3175	3675
SM22-3	2500	3125	3800
SM22-4	2475	2500	3250
SM22-5	2525	2850	3575
MEAN	**2465**	**3015**	**3765**
S.D.	52	353	471
C.V.	0.021	0.117	0.125
SM23-1	2350	2700	3375
SM23-2	2225	2750	3050
SM23-3	2375	3075	3250
SM23-4	2300	3000	3425
SM23-5	2250	2950	2800
MEAN	**2300**	**2895**	**3180**
S.D.	64	162	257
C.V.	0.028	0.056	0.081
MW11-1	2950	3925	4400
MW11-2	2975	4200	4250
MW11-3	2600	3850	4200
MW11-4	2775	3825	4300
MW11-5	2700	3700	4250
MEAN	**2800**	**3900**	**4280**
S.D.	161	186	76
C.V.	0.058	0.048	0.018
MW12-1	2575	2650	2550
MW12-2	2325	2600	2800
MW12-3	2275	2450	2725
MW12-4	2250	2475	2975
MW12-5	2400	2450	2700
MEAN	**2365**	**2525**	**2750**
S.D.	131	94	155
C.V.	0.055	0.037	0.056

TABLE 4 (CONTD..)

DESIGNATION	COMPRESSIVE STRENGTH IN PSI		
	3DAYS	7 DAYS	28 DAYS
MW13-1	2050	2250	2425
MW13-2	1850	2425	2500
MW13-3	1675	2425	2450
MW13-4	1675	2400	2550
MW13-5	1800	2500	2600
MEAN	**1810**	**2400**	**2505**
S.D.	155	92	72
C.V.	0.085	0.038	0.029
CT11-1	2725	2950	3600
CT11-2	2800	3100	4725
CT11-3	2900	3100	4675
CT11-4	2675	2875	5000
CT11-5	2950	3200	4200
MEAN	**2810**	**3045**	**4440**
S.D.	115	130	551
C.V.	0.041	0.043	0.124
CT12-1	2725	2800	4175
CT12-2	2575	2625	3850
CT12-3	2950	3000	5000
CT12-4	2650	2675	4825
CT12-5	2925	2950	4000
MEAN	**2765**	**2810**	**4370**
S.D.	166	165	512
C.V.	0.060	0.059	0.117
CT13-1	2300	2575	2600
CT13-2	2375	2350	2700
CT13-3	2150	2450	2875
CT13-4	2425	2500	3500
CT13-5	2350	2650	3375
MEAN	**2320**	**2505**	**3010**
S.D.	105	115	405
C.V.	0.045	0.046	0.135

TABLE 4 (CONTD..)

DESIGNATION	**COMPRESSIVE STRENGTH IN PSI**		
	3DAYS	**7 DAYS**	**28 DAYS**
C-1	2750	4250	5125
C-2	2920	3900	5475
C-3	2650	4150	4950
C-4	3050	3850	5250
C-5	2925	3720	5425
MEAN	**2859**	**3974**	**5245**
S.D.	158	219	216
C.V.	0.055	0.055	0.041
F1-1	2250	3125	4100
F1-2	1925	3200	4025
F1-3	2400	2925	3950
F1-4	2125	3150	3800
F1-5	2300	2850	4175
MEAN	**2200**	**3050**	**4010**
S.D.	183	153	144
C.V.	0.083	0.050	0.036
F2-1	1750	3400	3900
F2-2	1875	3500	3925
F2-3	1675	3325	4025
F2-4	1725	3100	3825
F2-5	1450	2950	3700
MEAN	**1695**	**3255**	**3875**
S.D.	156	225	121
C.V.	0.092	0.069	0.031
F3-1	1425	2950	3200
F3-2	1700	3025	3400
F3-3	1575	2750	3275
F3-4	1475	2925	3525
F3-5	1625	2800	3075
MEAN	**1560**	**2890**	**3295**
S.D.	111	113	175
C.V.	0.071	0.039	0.053

TABLE 5 AIR CONTENT OF POZZOLAN BLENDED CEMENT MORTAR ACCORDING TO ASTM C185 TEST METHOD

DESIGNATION	AIR CONTENT, VOLUME %
CONTROL	5.67
LK21	4.99
LK22	4.80
LK23	4.26
PS1E1	5.26
PS1E2	5.04
PS1E3	4.85
SM21	5.23
SM22	5.05
SM23	4.89
MW11	3.94
MW12	3.80
MW13	3.70
CT11	3.86
CT12	3.33
CT13	2.65
F1	4.84
F2	4.89
F3	5.02

TABLE 6 NORMAL CONSISTENCY OF POZZOLAN BLENDED CEMENT ACCORDING TO ASTM C187 TEST METHOD

DESIGNATION	NORMAL CONSISTENCY W/C %
CONTROL	24.15
LK21	25.00
LK22	25.62
LK23	26.39
PS1E1	24.46
PS1E2	24.77
PS1E3	25.39
SM21	28.85
SM22	31.00
SM23	34.54
MW11	28.39
MW12	30.54
MW13	34.69
CT11	26.54
CT12	27.85
CT13	29.31
F1	23.85
F2	23.54
F3	22.62

TABLE 7 EARLY STIFFENING OF POZZOLAN BLENDED CEMENT ACCORDING TO ASTM C451 (PASTE METHOD)

DESIGNATION	% FINAL PENETRATION
CONTROL	65.51
LK21	51.50
LK22	51.27
LK23	50.22
PS1E1	35.71
PS1E2	33.92
PS1E3	30.35
SM21	45.16
SM22	41.17
SM23	29.82
MW11	61.11
MW12	59.65
MW13	57.58
CT11	64.51
CT12	61.76
CT13	56.67
F1	62.50
F2	61.29
F3	60.60

TABLE 8 TIME OF SETTING OF POZZOLAN BLENDED CEMENT BY VICAT APPARATUS ACCORDING TO ASTM C191 TEST METHOD

DESIGNATION	TIME OF SETTING IN MINUTES	
	INITIAL	FINAL
CONTROL	122	233
LK21	170	290
LK22	203	308
LK23	248	318
PS1E1	175	315
PS1E2	178	325
PS1E3	182	337
SM21	150	267
SM22	170	305
SM23	200	370
MW11	235	345
MW12	250	360
MW13	265	460
CT11	203	333
CT12	208	350
CT13	213	373
F1	174	325
F2	177	340
F3	216	360

TABLE 9 TIME OF SETTING OF POZZOLAN BLENDED CEMENT BY GILLMORE NEEDLES ACCORDING TO ASTM C266 TEST METHOD

DESIGNATION	TIME OF SETTING IN MINUTES	
	INITIAL	FINAL
CONTROL	155	297
LK21	200	365
LK22	230	370
LK23	270	385
PS1E1	185	335
PS1E2	190	350
PS1E3	198	392
SM21	213	335
SM22	235	385
SM23	280	440
MW11	285	420
MW12	297	480
MW13	345	520
CT11	265	380
CT12	285	400
CT13	295	423
F1	215	355
F2	229	375
F3	260	395

TABLE 10 DENSITY OF POZZOLAN BLENDED CEMENT ACCORDING TO ASTM C188 TEST METHOD

DESIGNATION	DENSITY IN GRAMS/CM^3
CONTROL	3.122
LK21	3.077
LK22	3.048
LK23	2.991
PS1E1	3.080
PS1E2	3.033
PS1E3	3.005
SM21	3.033
SM22	2.962
SM23	2.895
MW11	3.062
MW12	3.048
MW13	2.980
CT11	3.048
CT12	2.950
CT13	2.936
F1	3.077
F2	3.048
F3	2.990

TABLE 11 FINENESS OF POZZOLAN BLENDED CEMENT BY No.325 SIEVE ACCORDING TO ASTM C430 TEST METHOD

DESIGNATION	% FINENESS
CONTROL	92.87
LK21	93.43
LK22	93.50
LK23	94.14
PS1E1	93.23
PS1E2	93.29
PS1E3	94.14
SM21	93.27
SM22	93.44
SM23	94.00
MW11	93.04
MW12	93.44
MW13	94.22
CT11	92.98
CT12	93.37
CT13	94.36
F1	93.35
F2	93.54
F3	93.97

TABLE 12 FINENESS OF POZZOLAN BLENDED CEMENT BY BLAINE AIR PERMEABILITY APPARATUS ACCORDING TO ASTM C204 TEST METHOD

DESIGNATION	BLAINE FINENESS
CONTROL	386
LK21	413
LK22	524
LK23	634
PS1E1	437
PS1E2	467
PS1E3	547
SM21	462
SM22	486
SM23	578
MW11	458
MW12	491
MW13	511
CT11	481
CT12	492
CT13	564

TABLE 13 COMPARISON OF OBSERVED AND PREDICTED VALUES OF COMPRESSIVE STRENGTH

DESIGNATION	AGE IN DAYS	OBSERVED COMPRESSIVE STRENGTH	PREDICTED COMPRESSIVE STRENGTH	% DIFFERENCE
C-1	3	3150	3772	-19.74
C-2	7	4220	3884	5.59
C-3	28	5520	5100	7.62
LK11	3	2760	3355	-21.57
LK11	7	4405	3568	19.01
LK11	28	5220	4683	10.29
LK12	3	2770	2965	-7.05
LK12	7	4020	3178	20.96
LK12	28	4250	4293	-1.01
LK13	3	2715	2964	-9.16
LK13	7	3995	3176	20.50
LK13	28	4100	4291	-4.66
PS1E1	3	2425	2540	-4.75
PS1E1	7	2880	2753	4.42
PS1E1	28	4245	3868	8.89
PS1E2	3	2395	2563	-7.01
PS1E2	7	2515	2775	-10.35
PS1E2	28	3960	3890	1.76
PS1E3	3	2340	2463	-5.27
PS1E3	7	2515	2676	-6.39
PS1E3	28	3450	3791	-9.88
SM21	3	2580	3040	-17.82
SM21	7	3205	3252	-1.47
SM21	28	4840	4367	9.77
SM22	3	2465	2622	-6.38
SM22	7	3015	2835	5.99
SM22	28	3765	3950	-4.91
SM23	3	2300	2269	1.34
SM23	7	2895	2482	14.28
SM23	28	3180	3597	-13.11
MW11	3	2800	3368	-20.28
MW11	7	3900	3580	8.20
MW11	28	4280	4696	-9.71
MW12	3	2365	2065	12.69
MW12	7	2525	2277	9.81
MW12	28	2750	3393	-23.36
MW13	3	1810	1675	7.44
MW13	7	2400	1888	21.34
MW13	28	2505	3003	-19.88

TABLE 13 (CONTD..)

DESIGNATION	AGE IN DAYS	OBSERVED COMPRESSIVE STRENGTH	PREDICTED COMPRESSIVE STRENGTH	% DIFERENCE
CT11	3	2810	2685	4.44
CT11	7	3045	2898	4.84
CT11	28	4440	4013	9.62
CT12	3	2765	2787	-0.81
CT12	7	2810	3000	-6.75
CT12	28	4370	4115	5.84
CT13	3	2320	2136	7.93
CT13	7	2505	2349	6.25
CT13	28	3010	3464	-15.07
F1	3	2200	2967	-34.86
F1	7	3050	3179	-4.24
F1	28	4010	4295	-7.10
F2	3	1695	2462	-45.26
F2	7	3255	2675	17.83
F2	28	3875	3790	2.20
F3	3	1560	1992	-27.70
F3	7	2890	2205	23.72
F3	28	3295	3320	-0.75

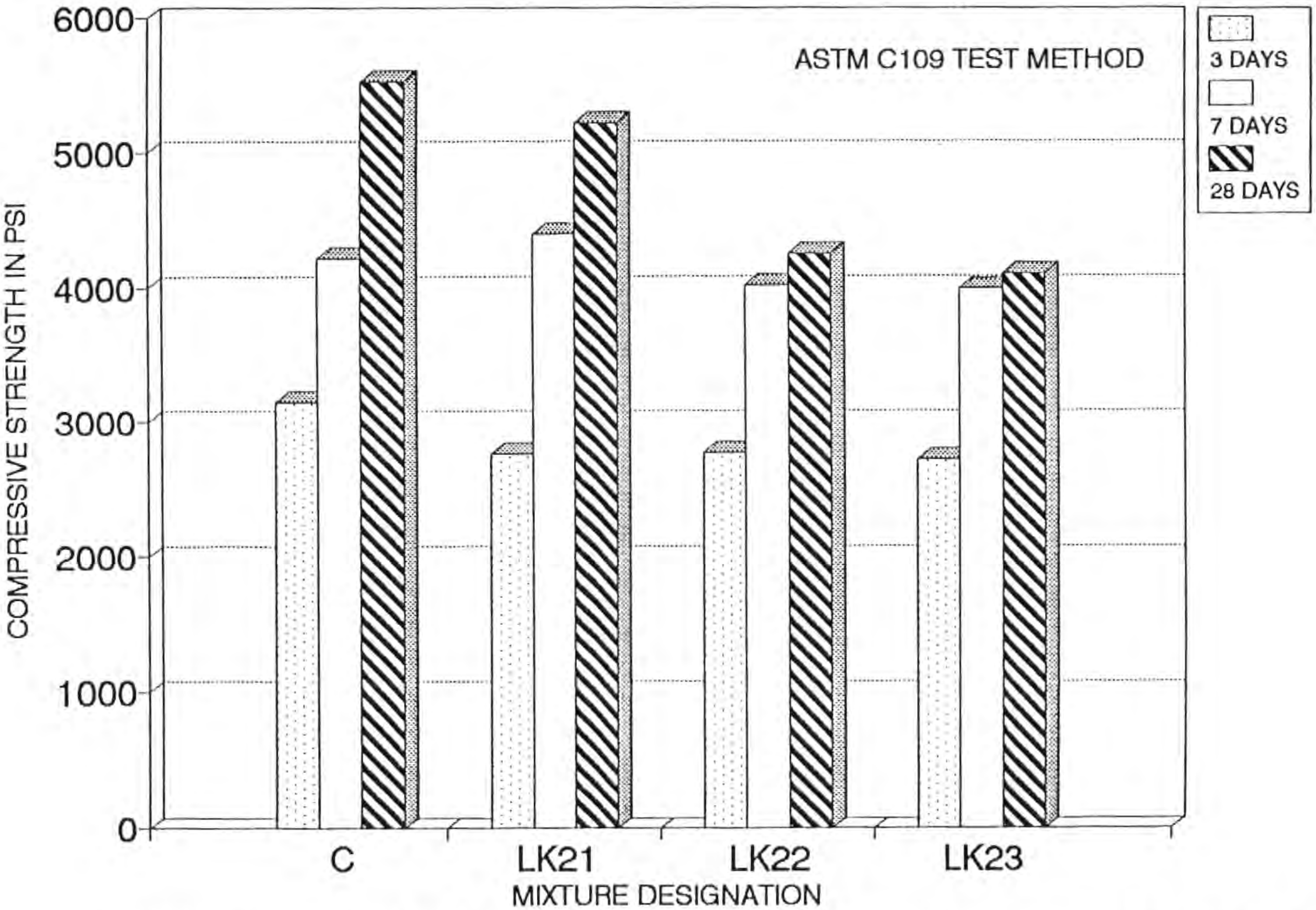

Figure 1 Comparison of compressive strength of cement mortar blended with LK2

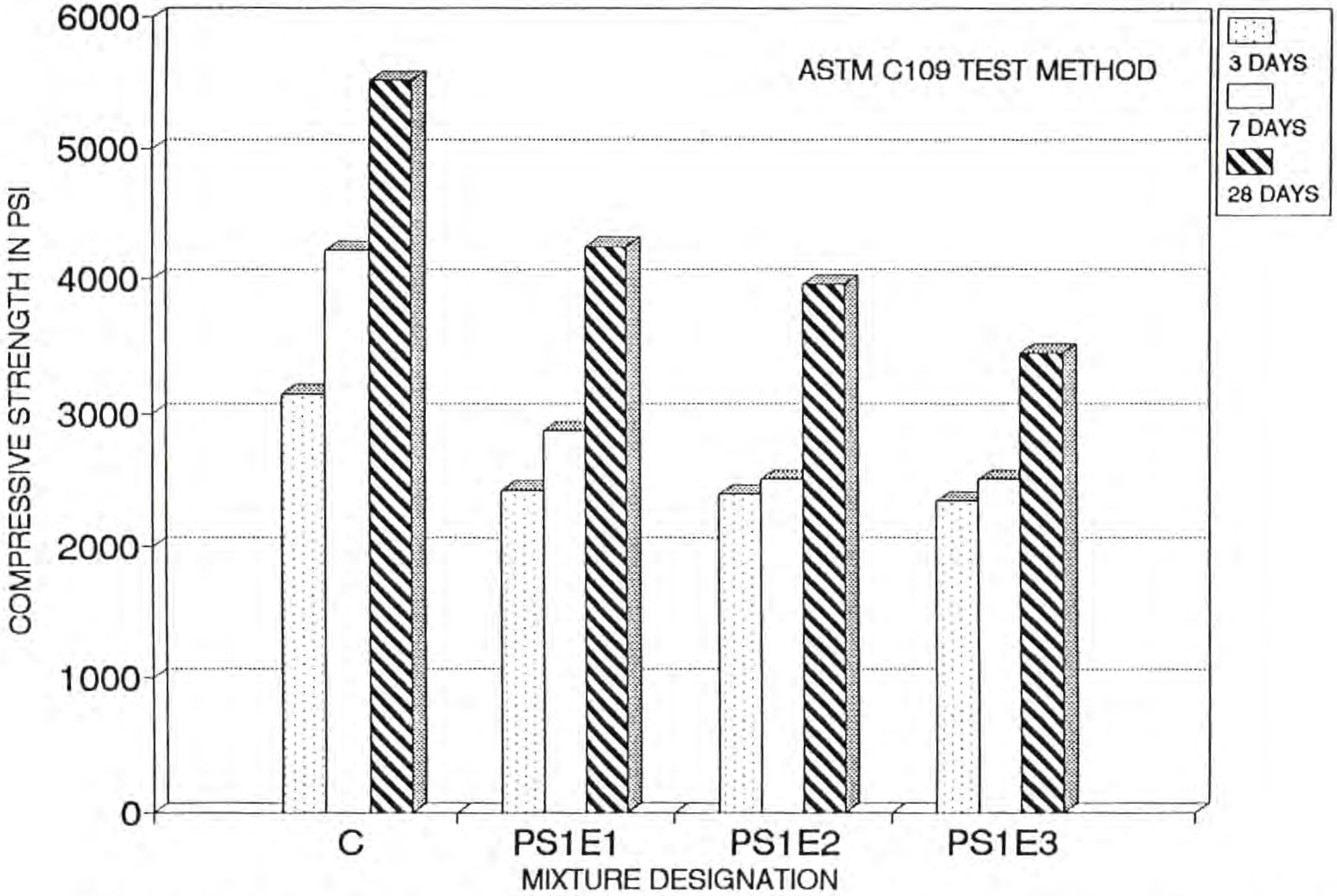

Figure 2 Comparison of compressive strength of cement mortar blended with PS1E

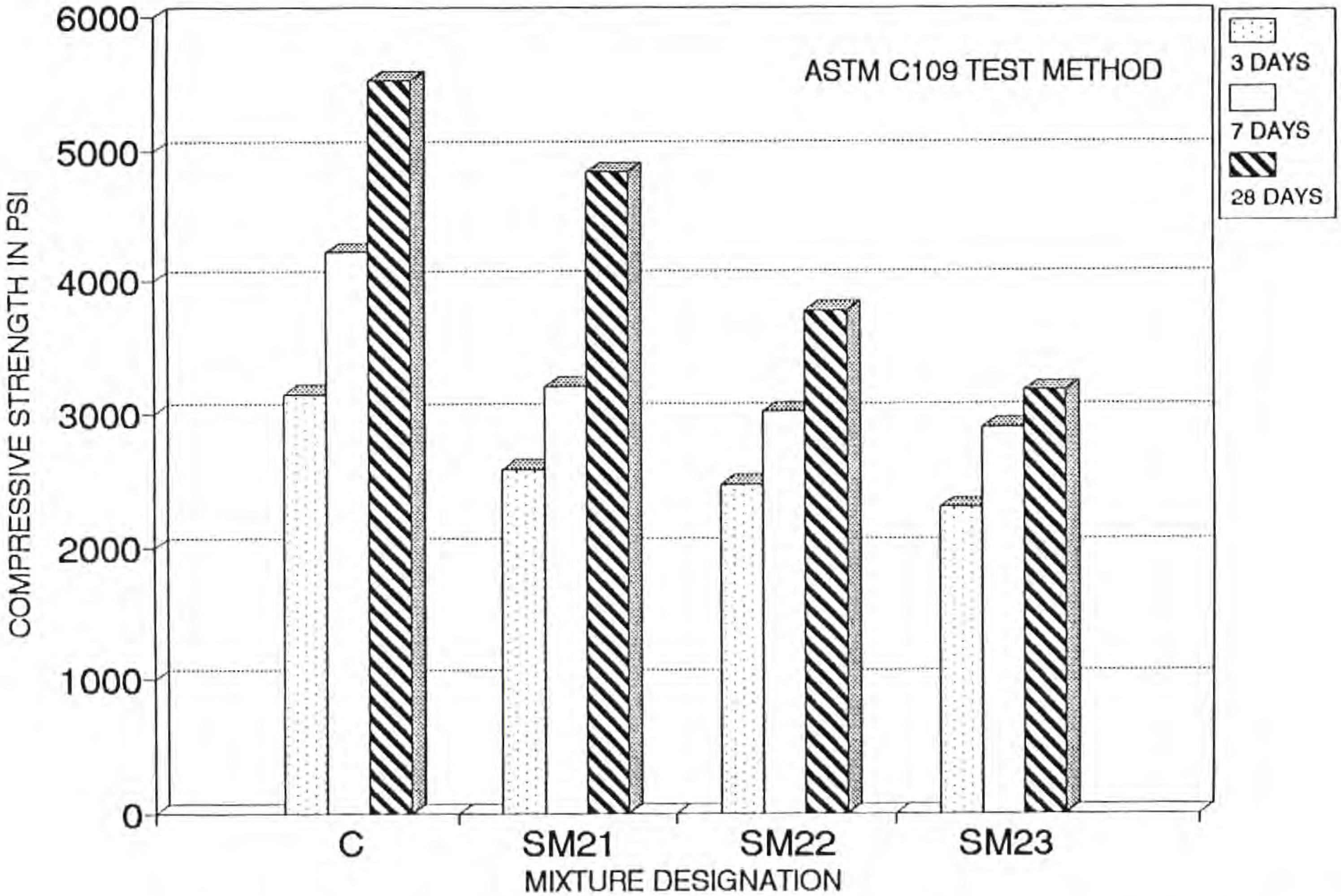

Figure 3 Comparison of cmpressive strength of cement mortar blended with SM2

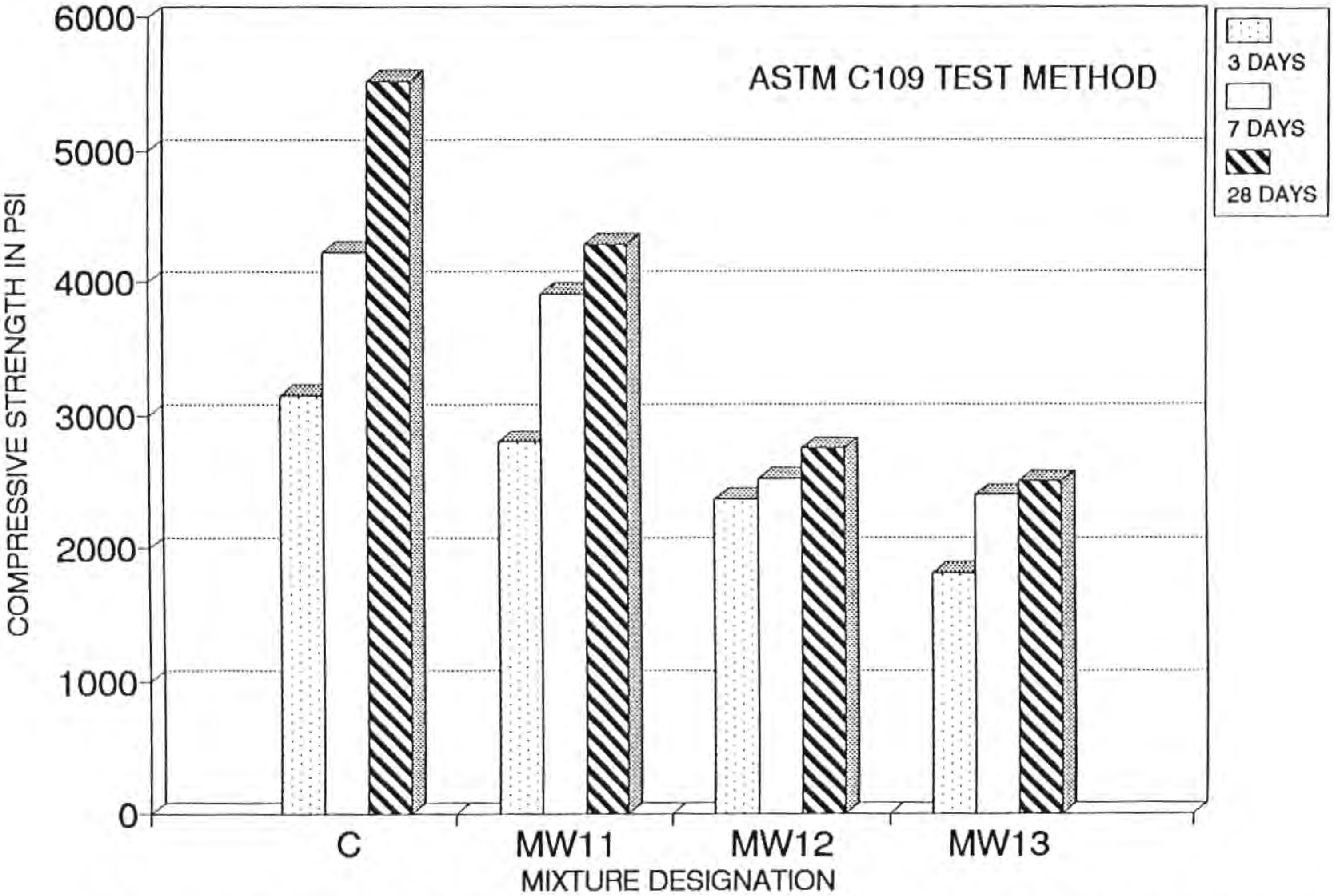

Figure 4 Comparison of compressive strength of cement mortar blended with MW1

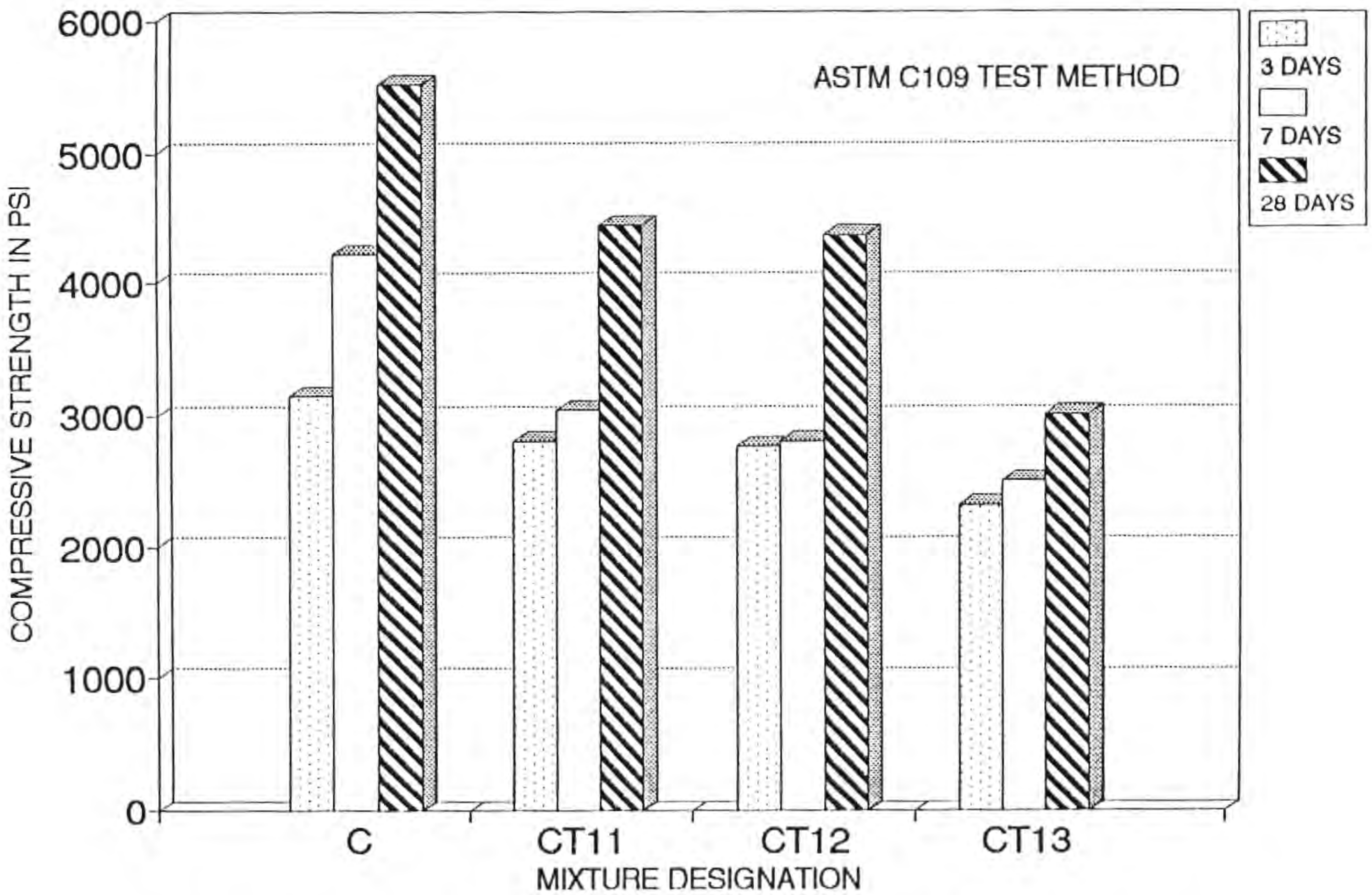

Figure 5 Comparison of compressive strength of cement mortar blended with CT1

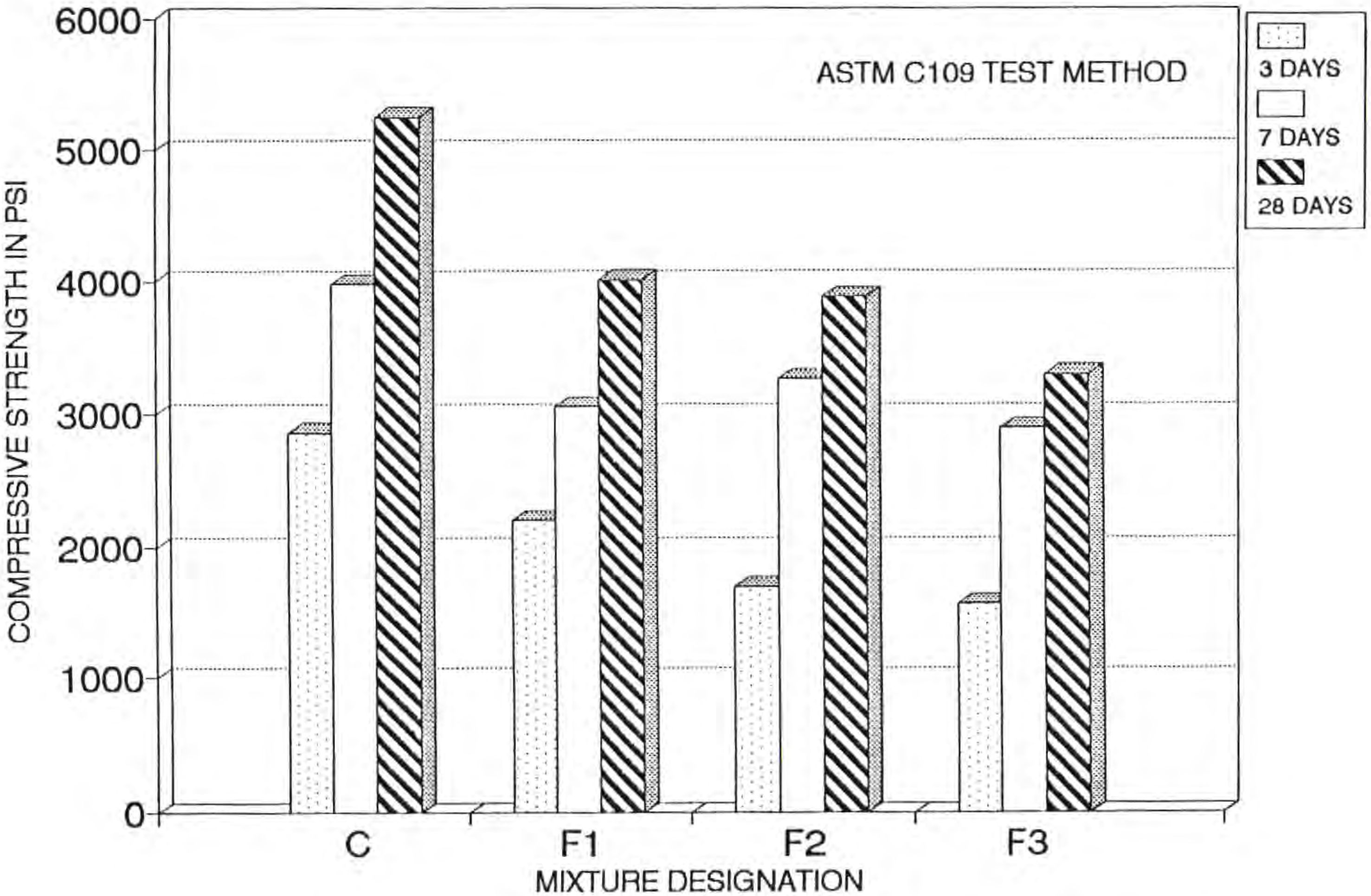

Figure 6 Comparison of Compressive strength of cement mortar blended with cllass F FlyAsh

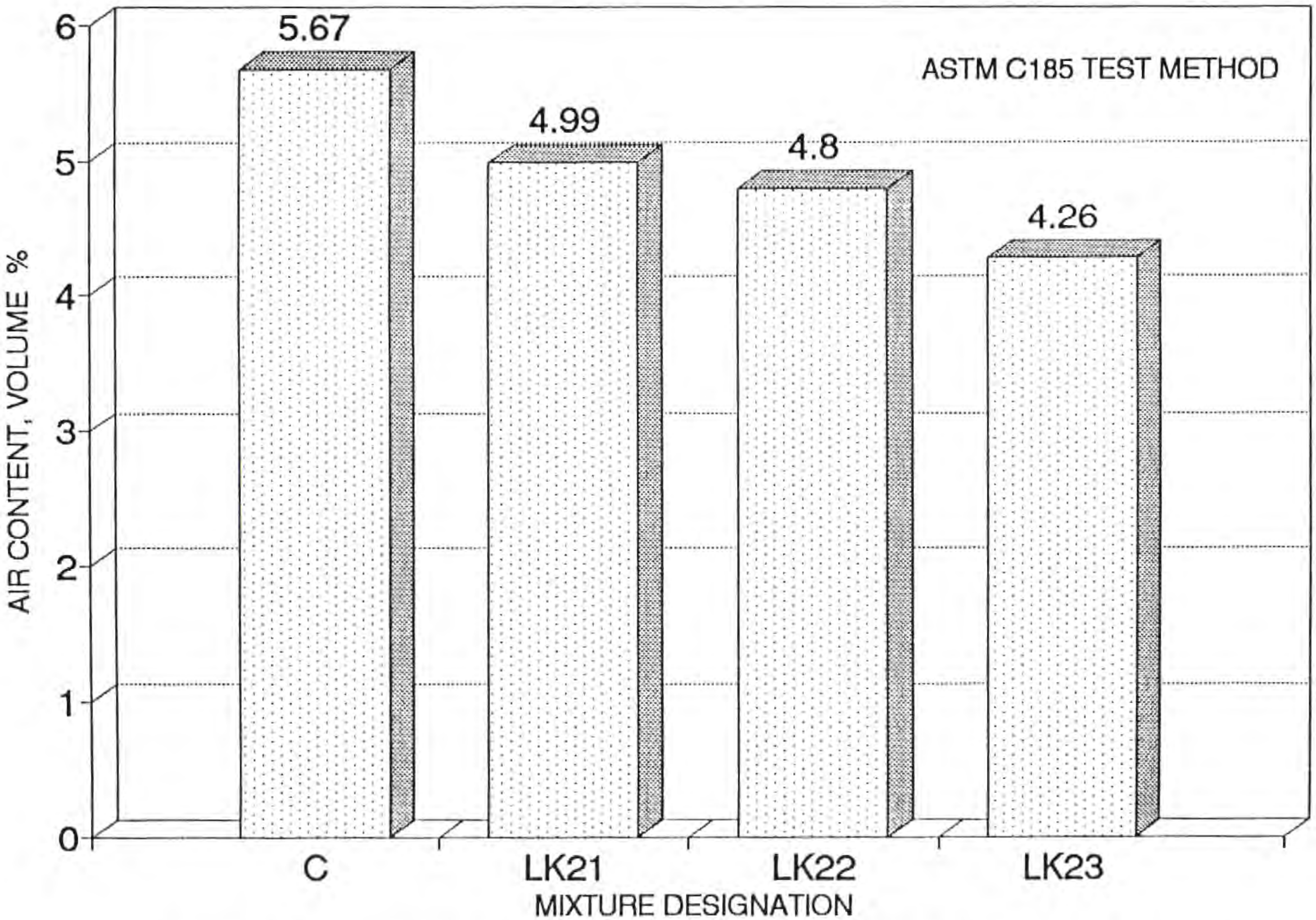

Figure 7 Comparison of air content of cement mortar blended with LK2

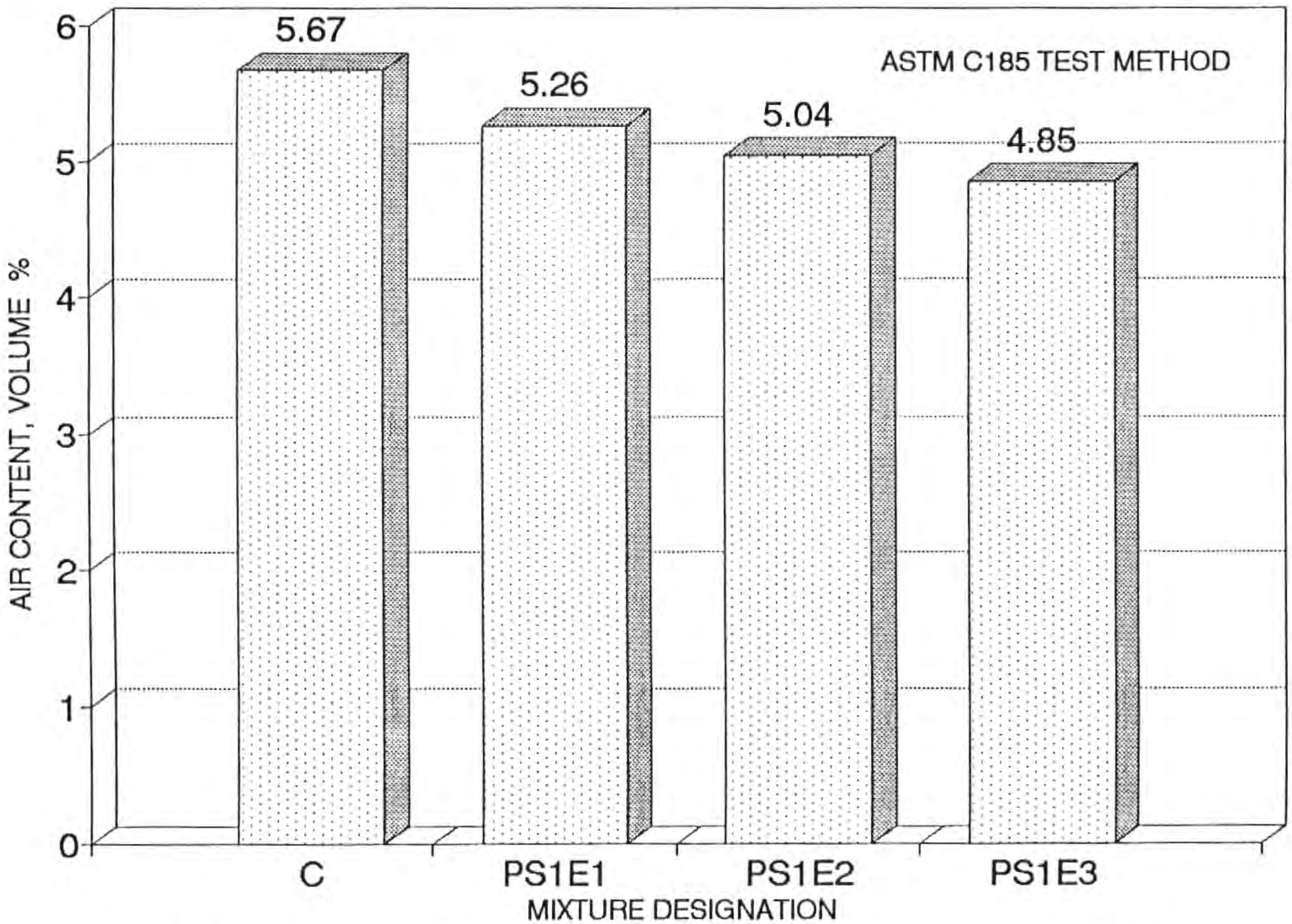

Figure 8 Comparison of air content of cement mortar blended with PS1E

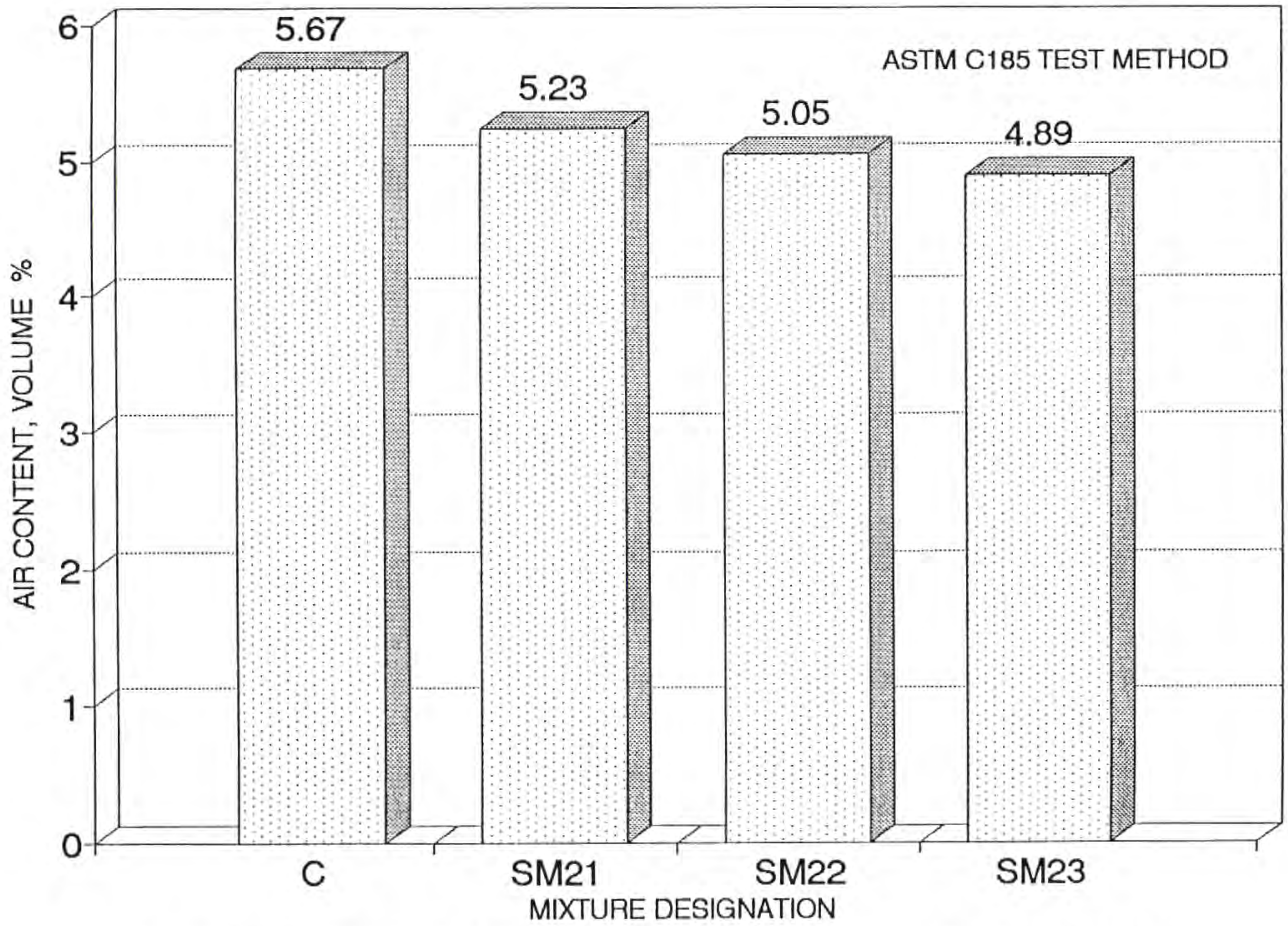

Figure 9 Comparison of air content of cement mortar blended with SM2

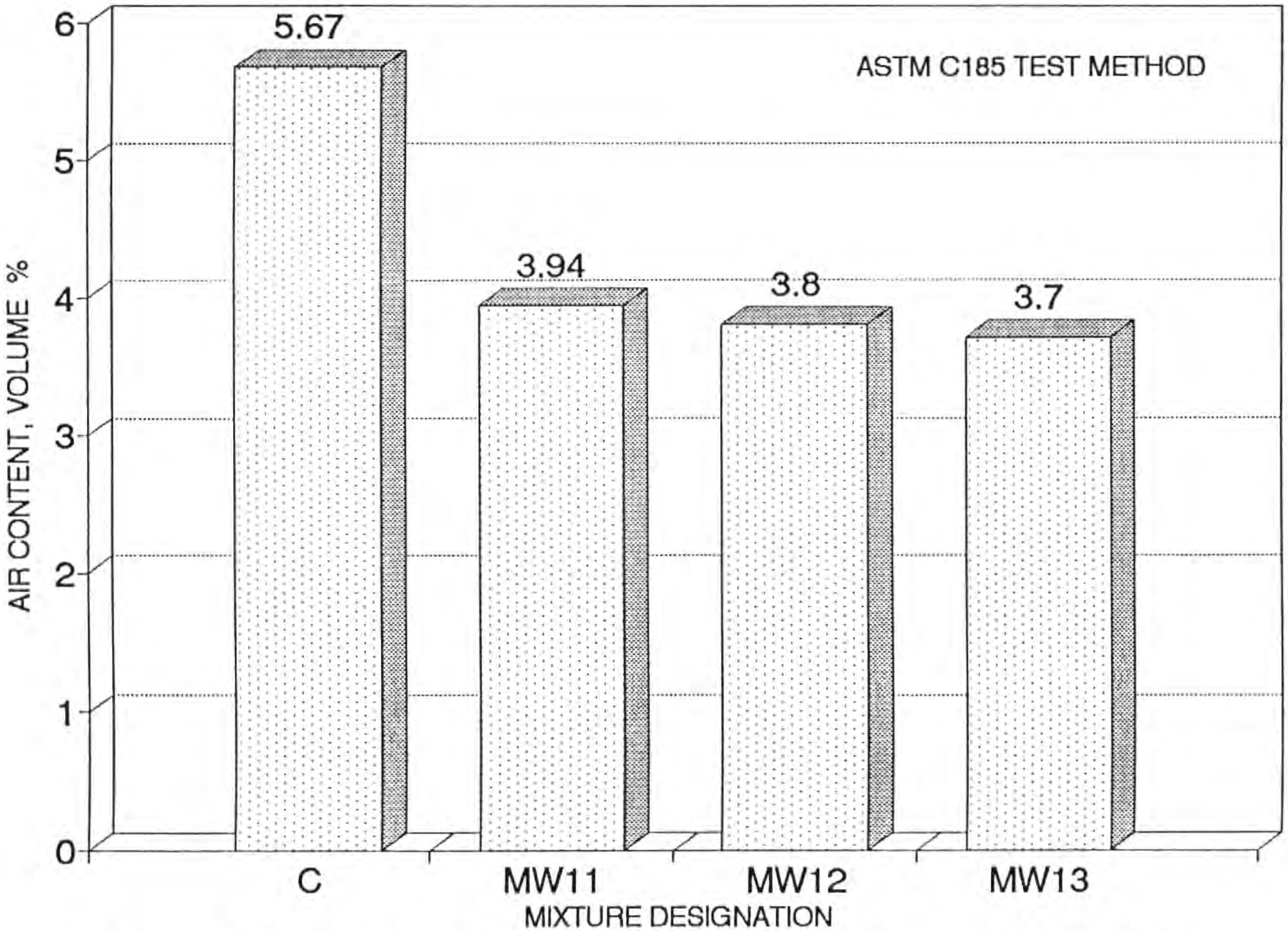

Figure 10 Comparison of air content of cement mortar blended with MW1

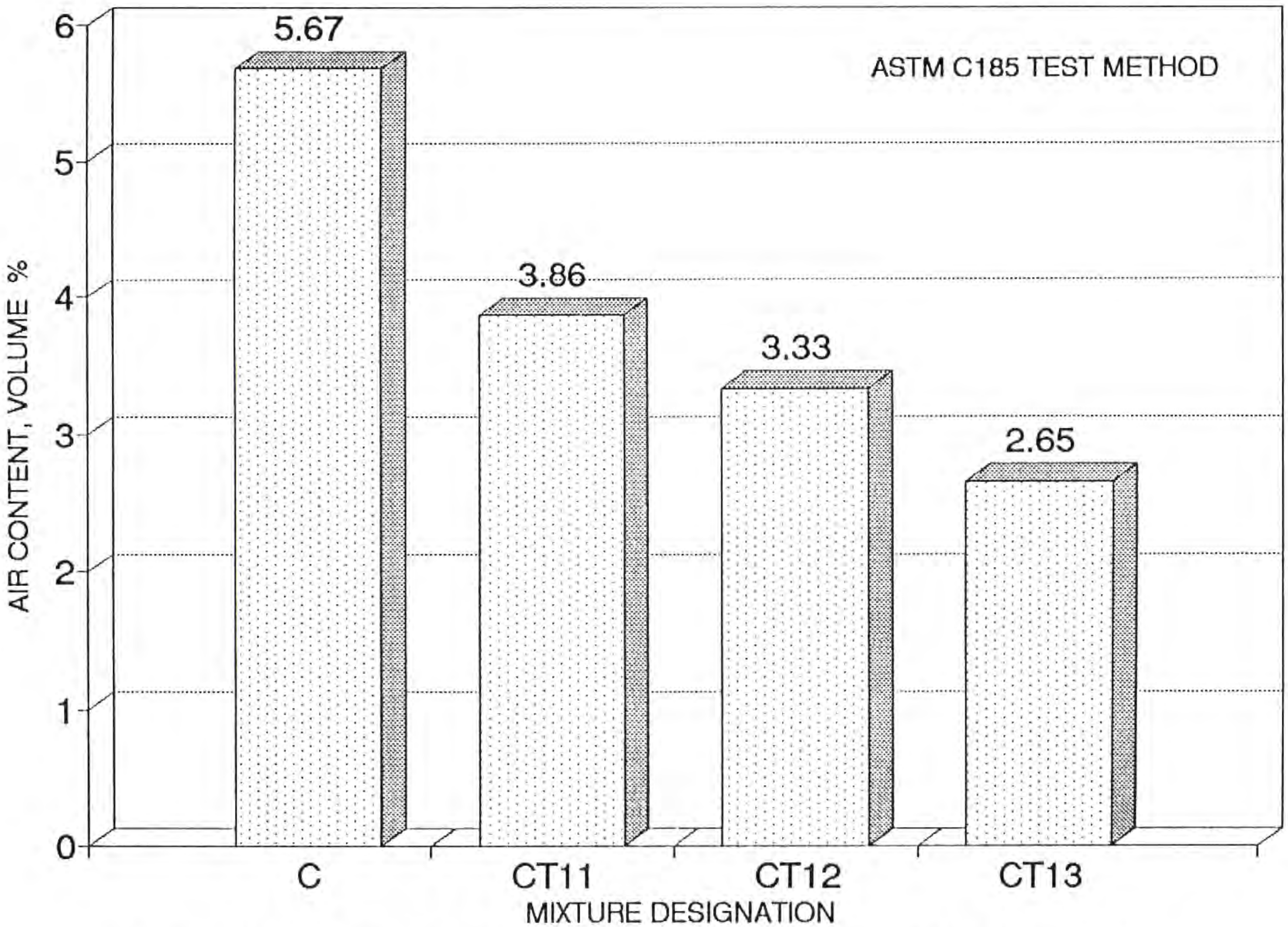

Figure 11 Comparison of air content of cement mortar blended with CT1

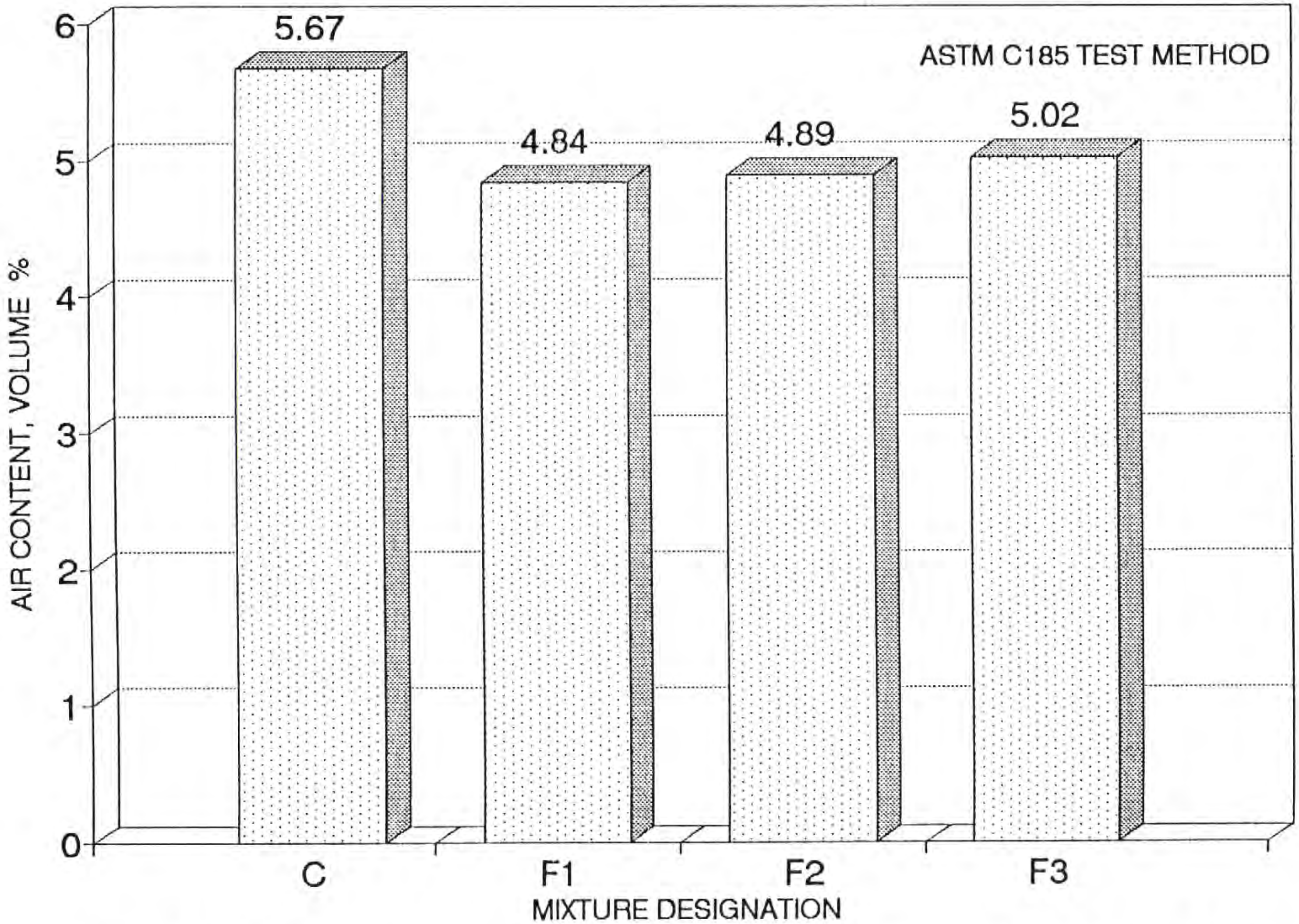

Figure 12 Comparison of air content of cement mortar blended with class F flyash

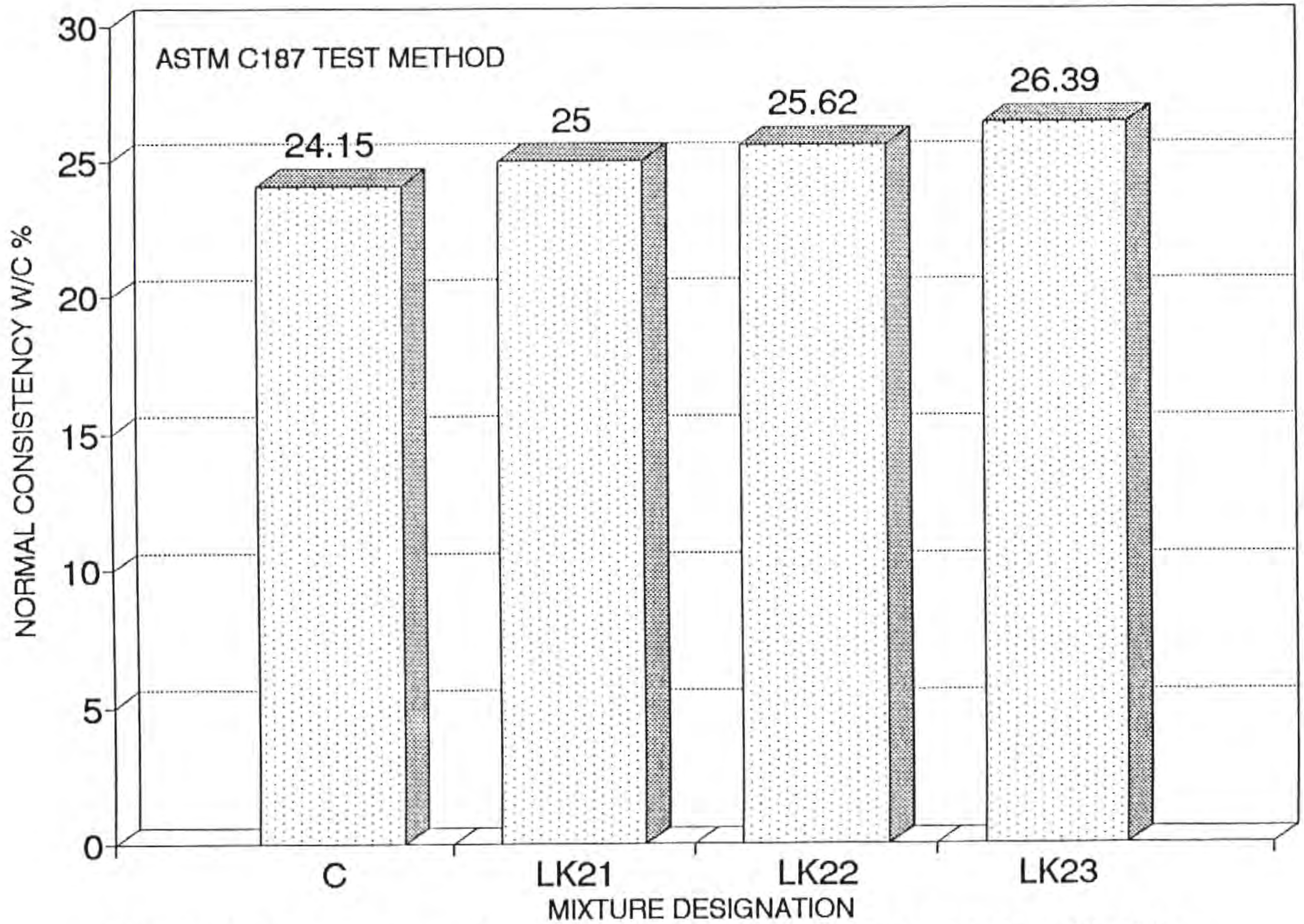

Figure 13 Comparison of normal consistency of cement blended with LK2

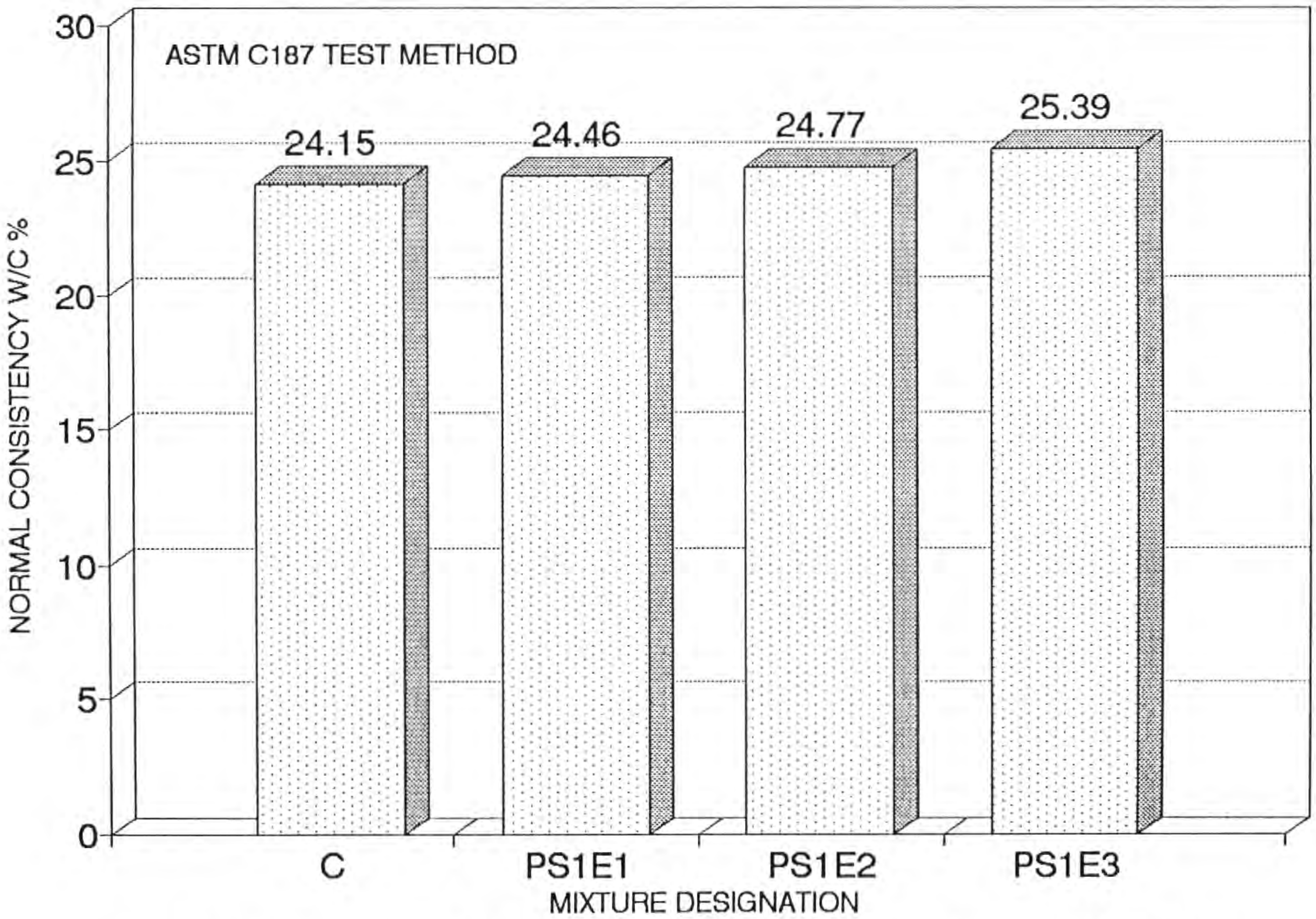

_Figure 14 Comparison of normal consistency of cement blended with PS1E

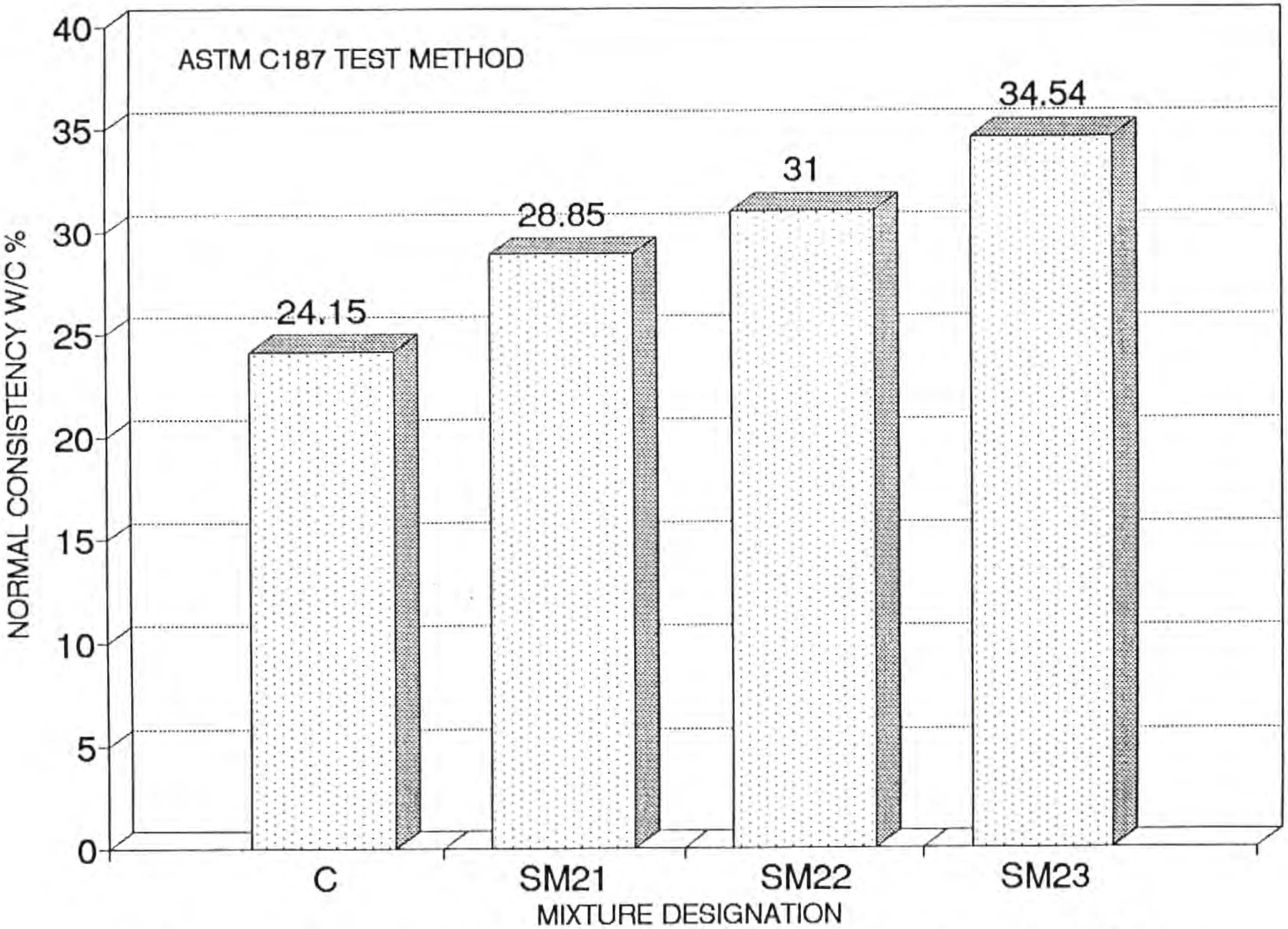

Figure 15 Comparison of normal consistency of cement blended with SM2

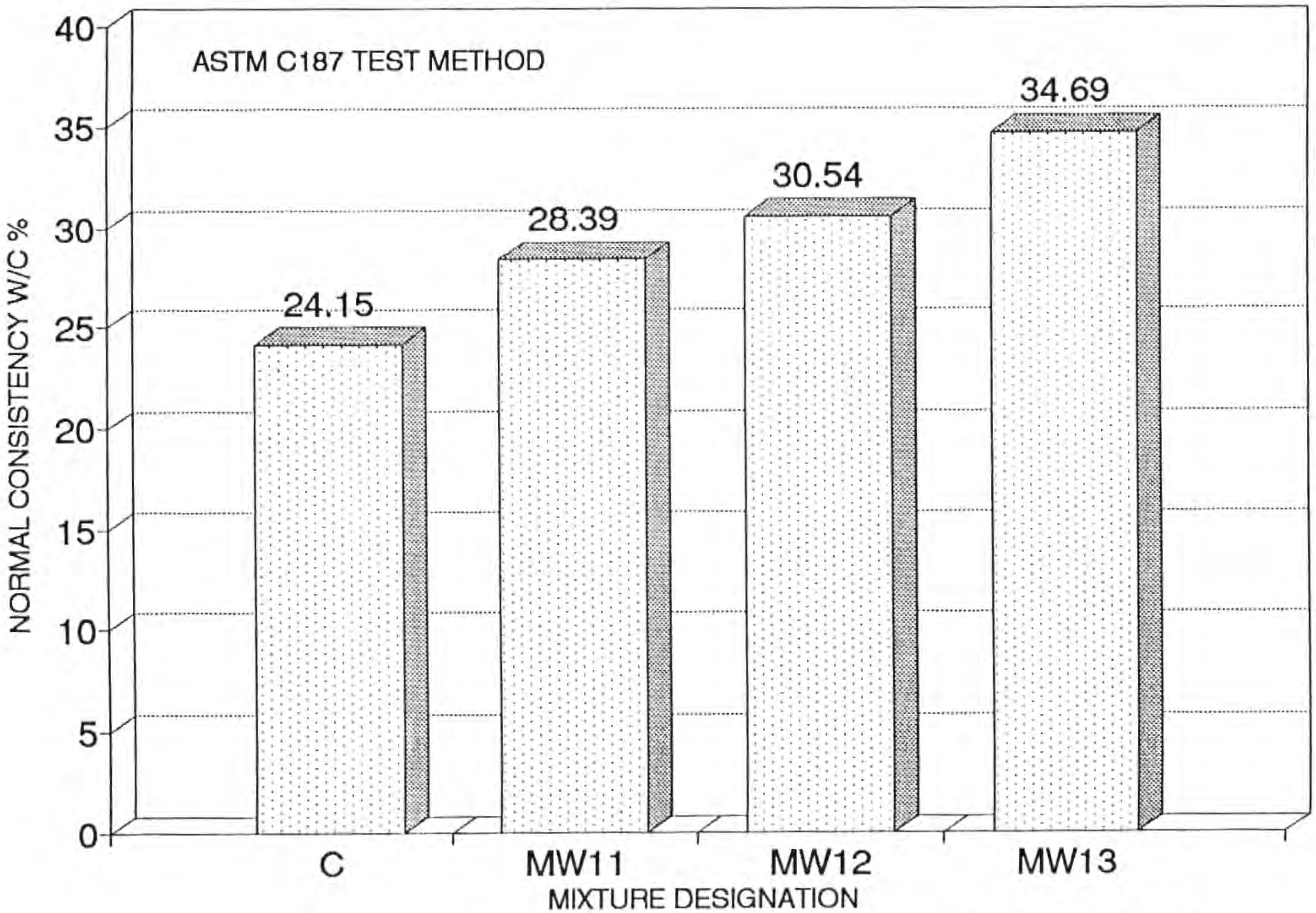

Figure 16 Comparison of normal consistency of cement blended with MW1

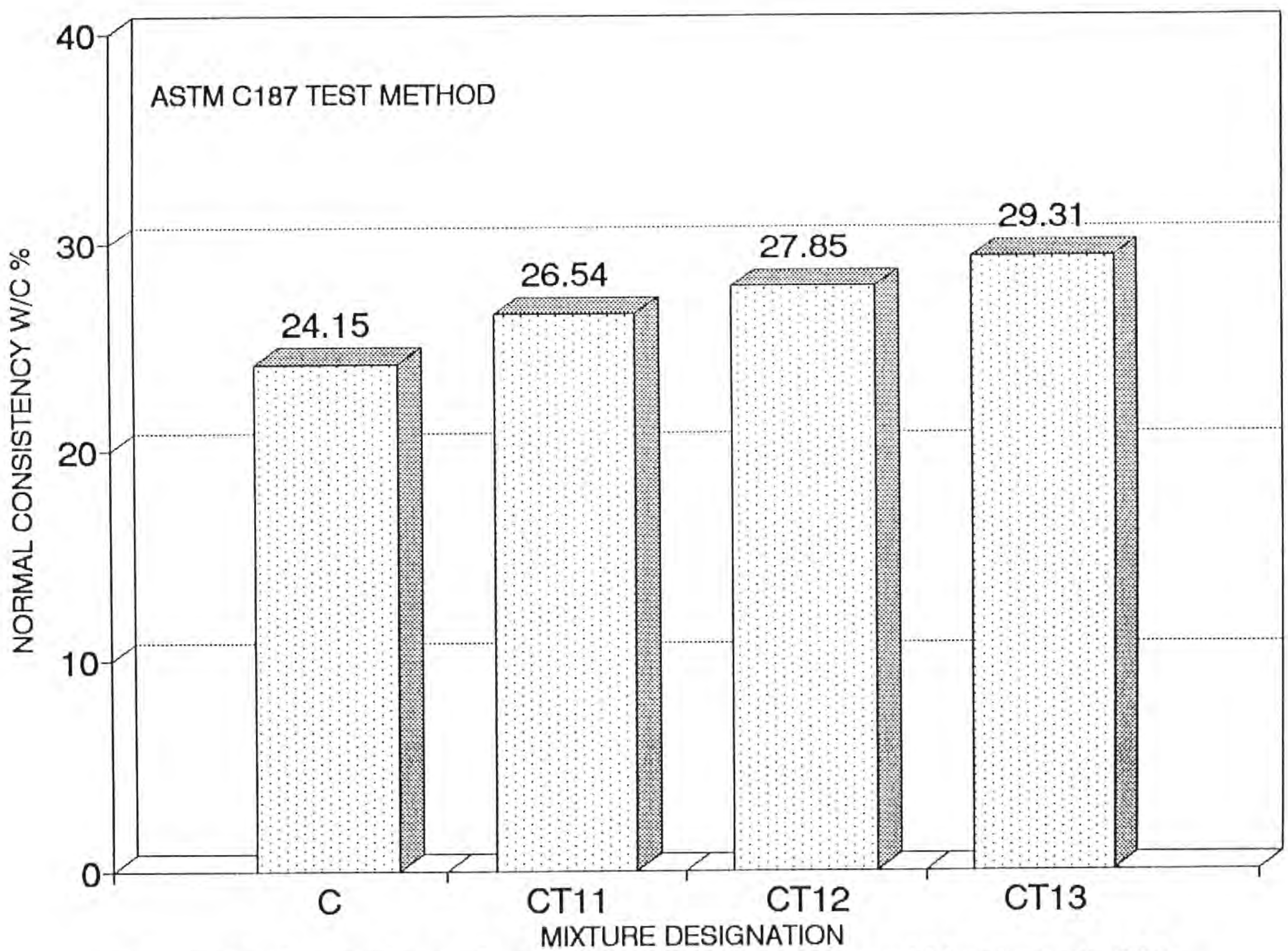

Figure 17 Comparison of normal consistency of cement blended with CT1

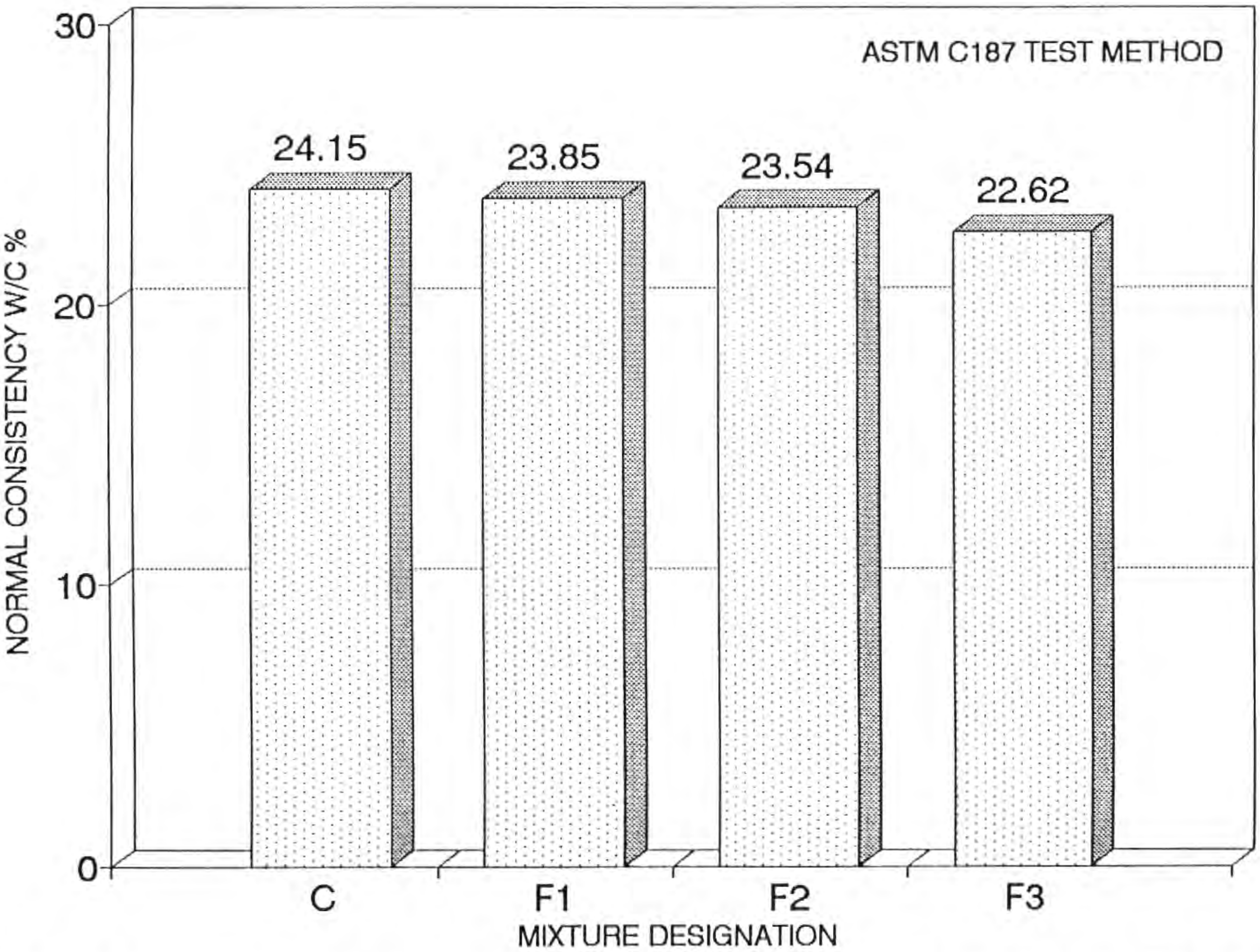

Figure 18 Comparison of normal consistency of cement blended with class F Fly Asl

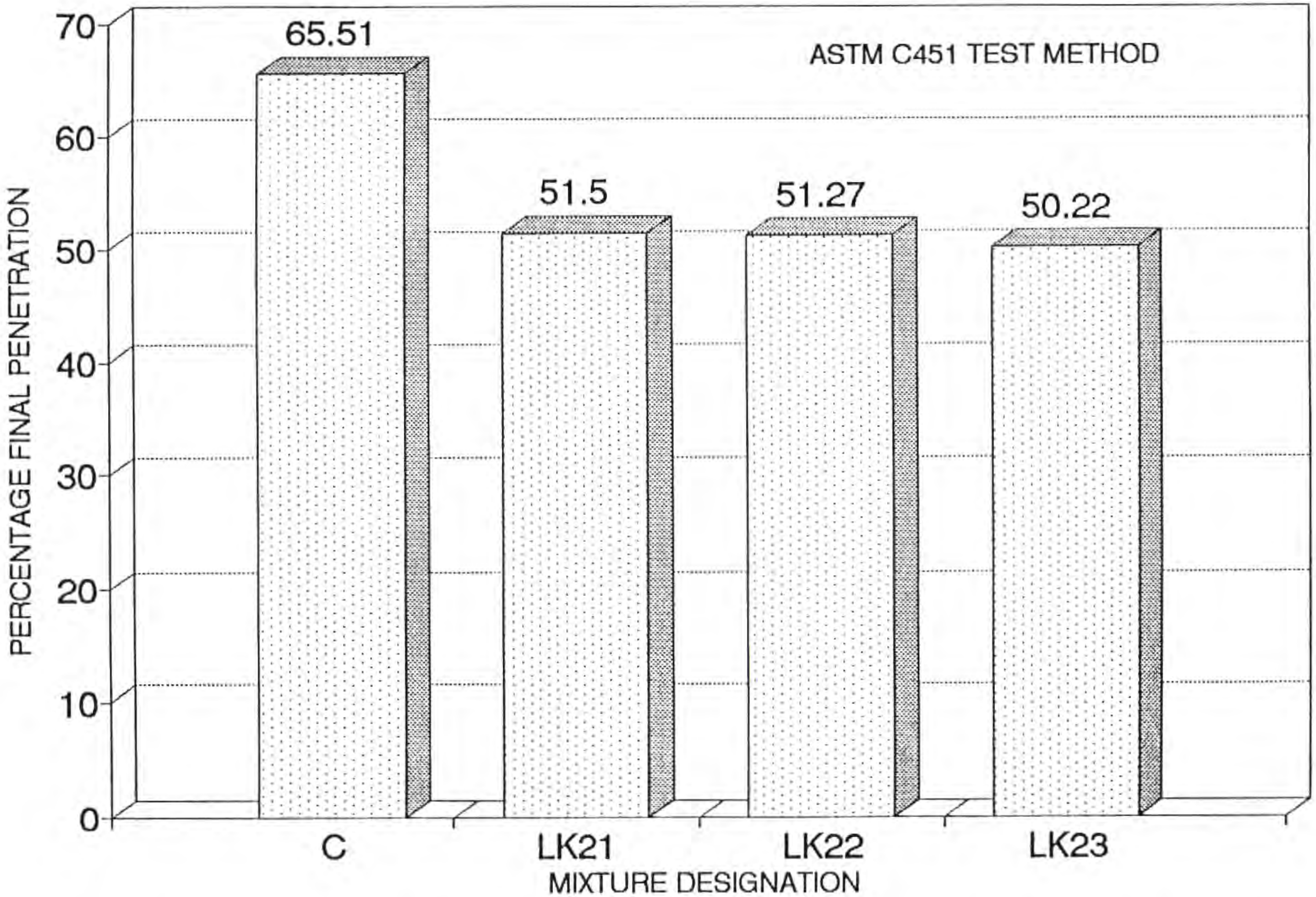

Figure 19 Comparison of early stiffening of cement blended with LK2 by Paste method

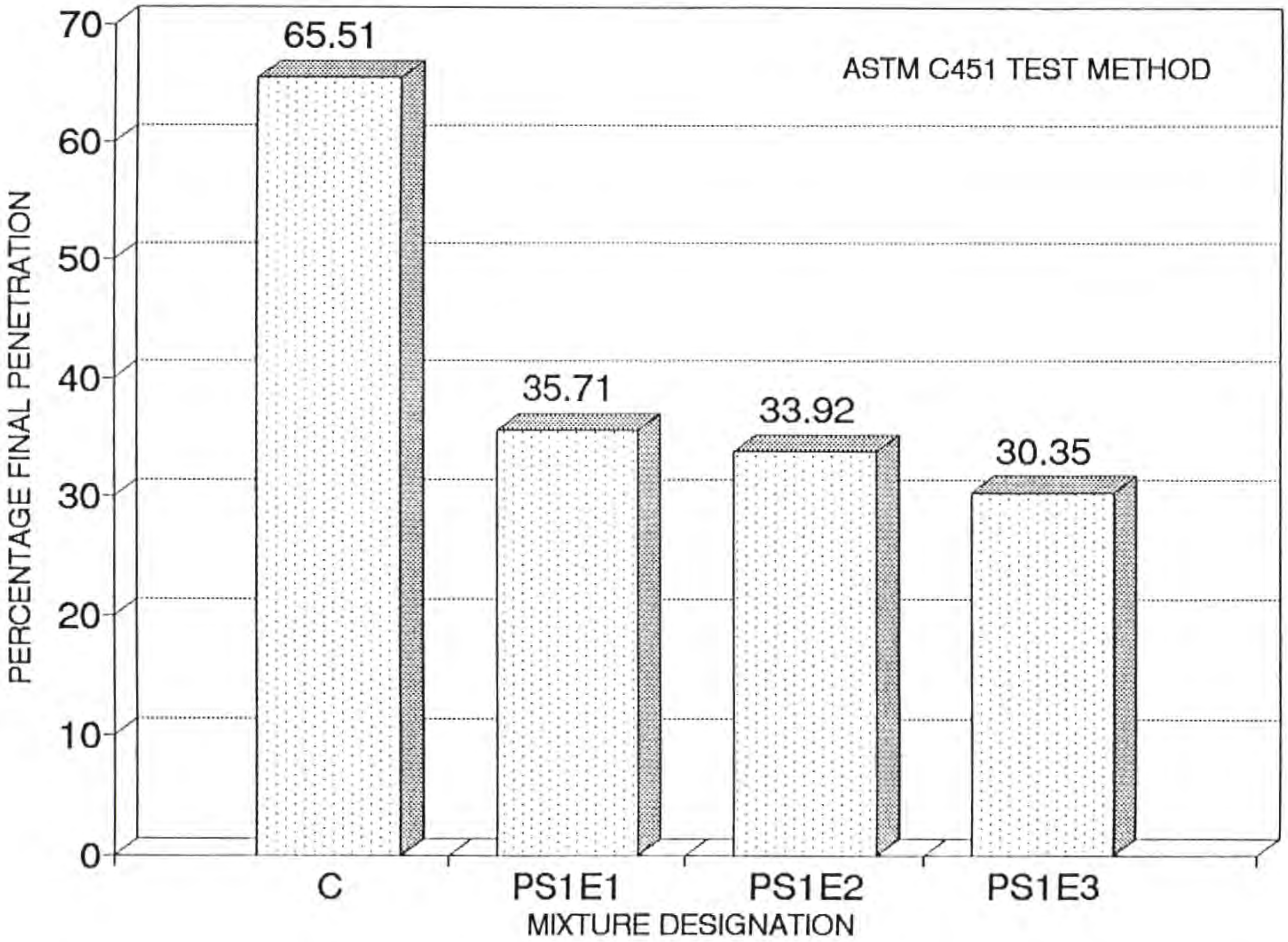

Figure 20 Comparison of early stiffening of cement blended with PS1E by Paste method

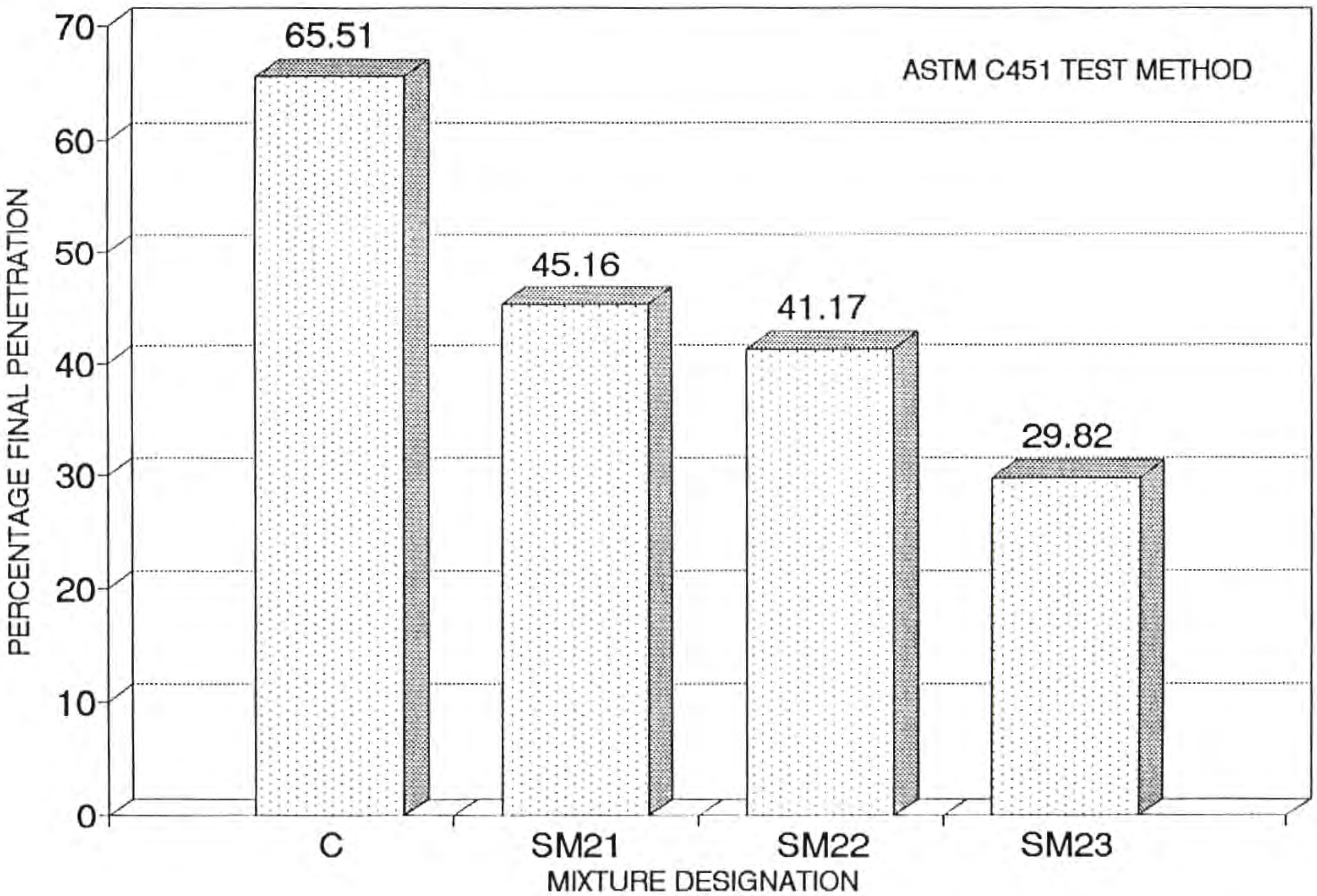

Figure 21 Comparison of early stiffening of cement blended with SM2 by Paste method

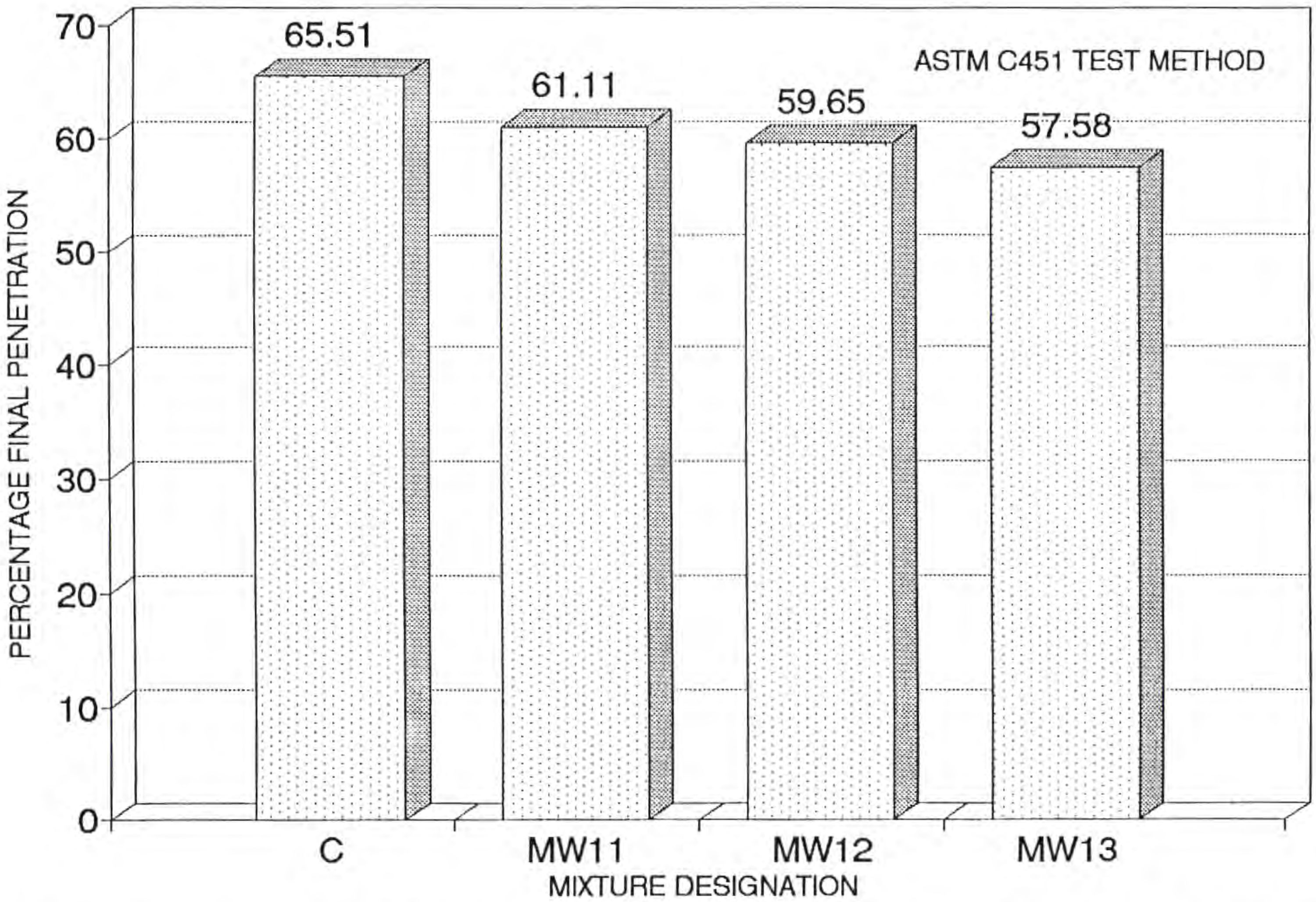

Figure 22 Comparison of early stiffening of cement blended with MW1 by Paste method

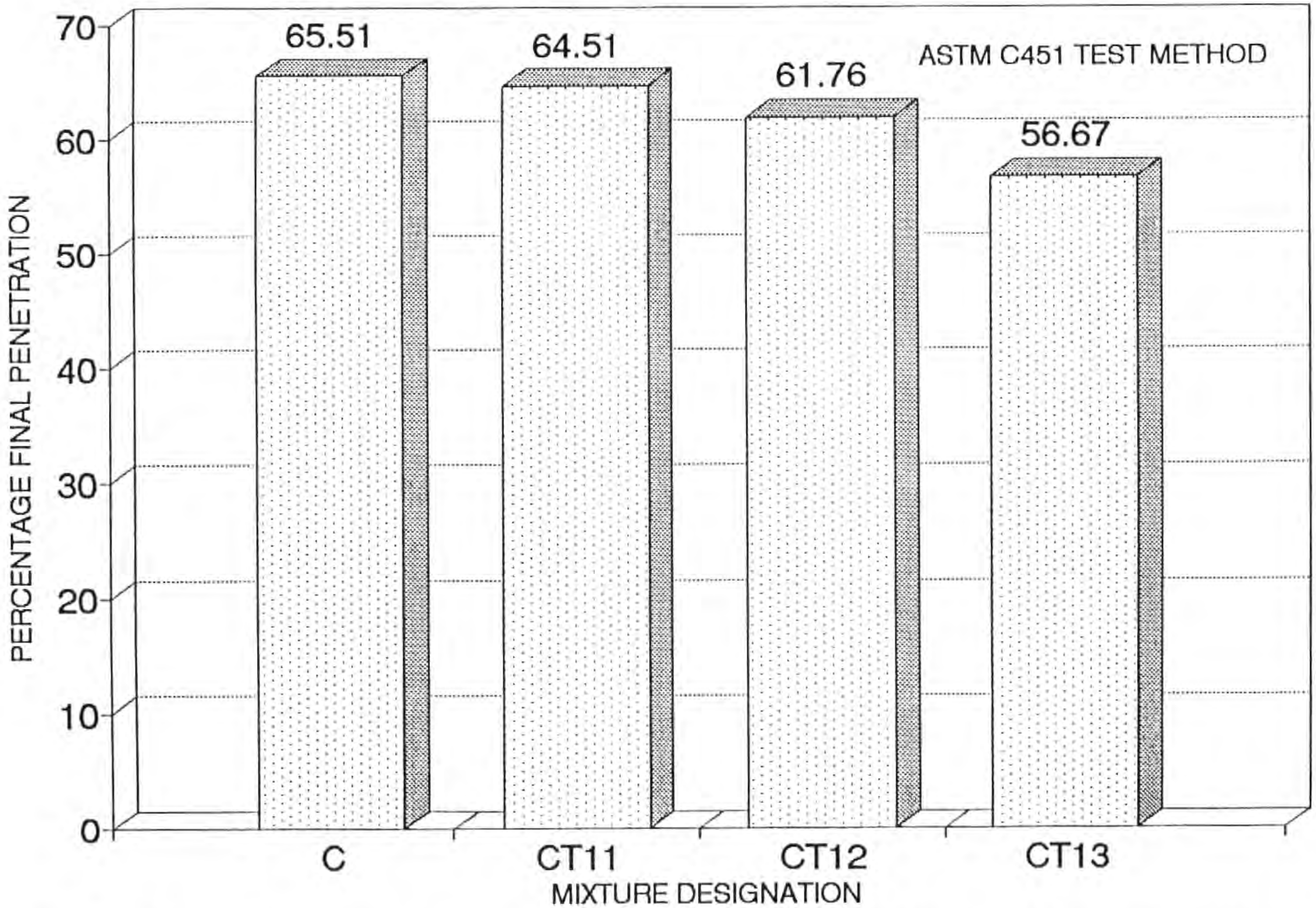

Figure 23 Comparison of early stiffening of cement blended with CT1 by Paste method

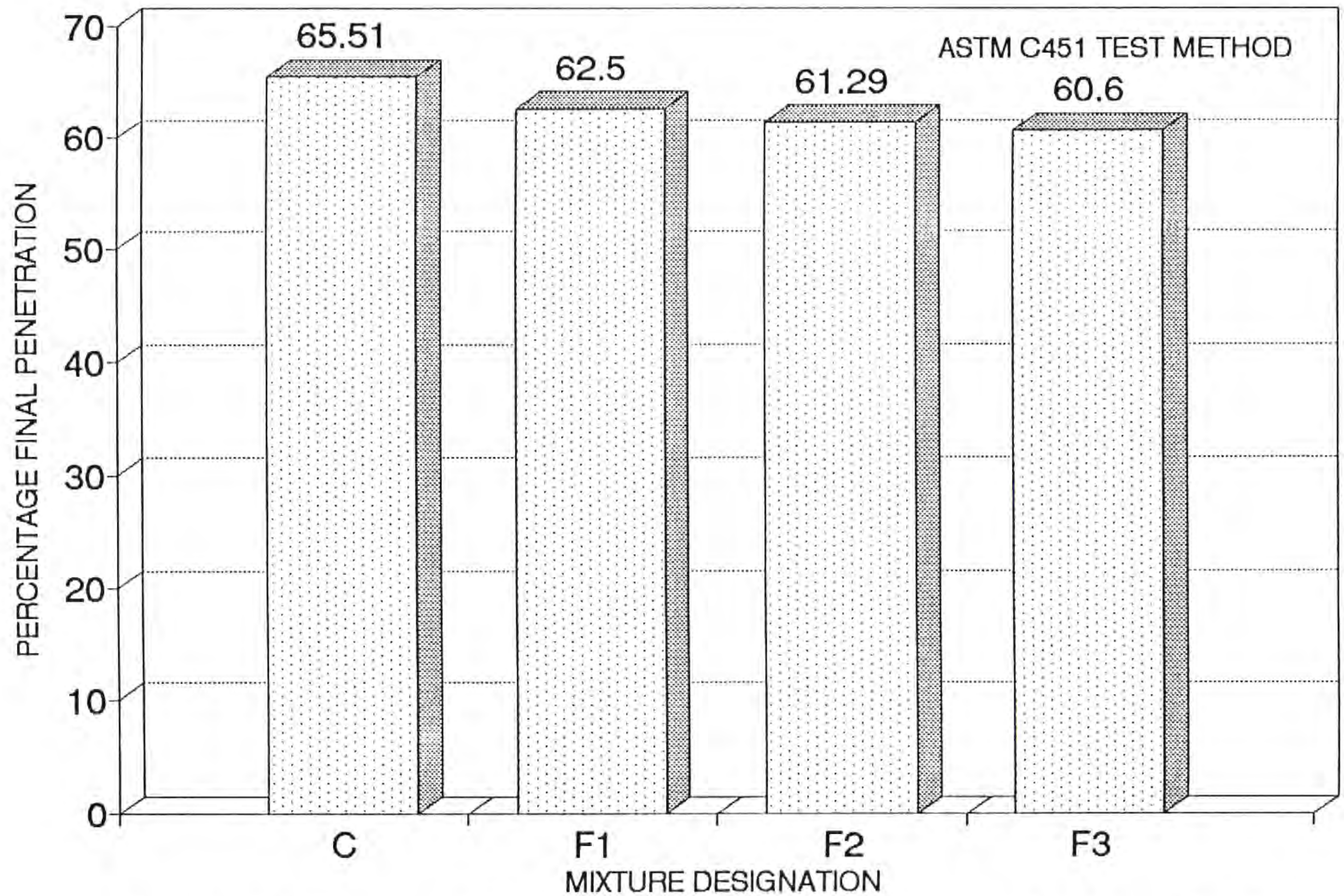

Figure 24 Comparison of early stiffening of cement blended with class F flyash by Paste method

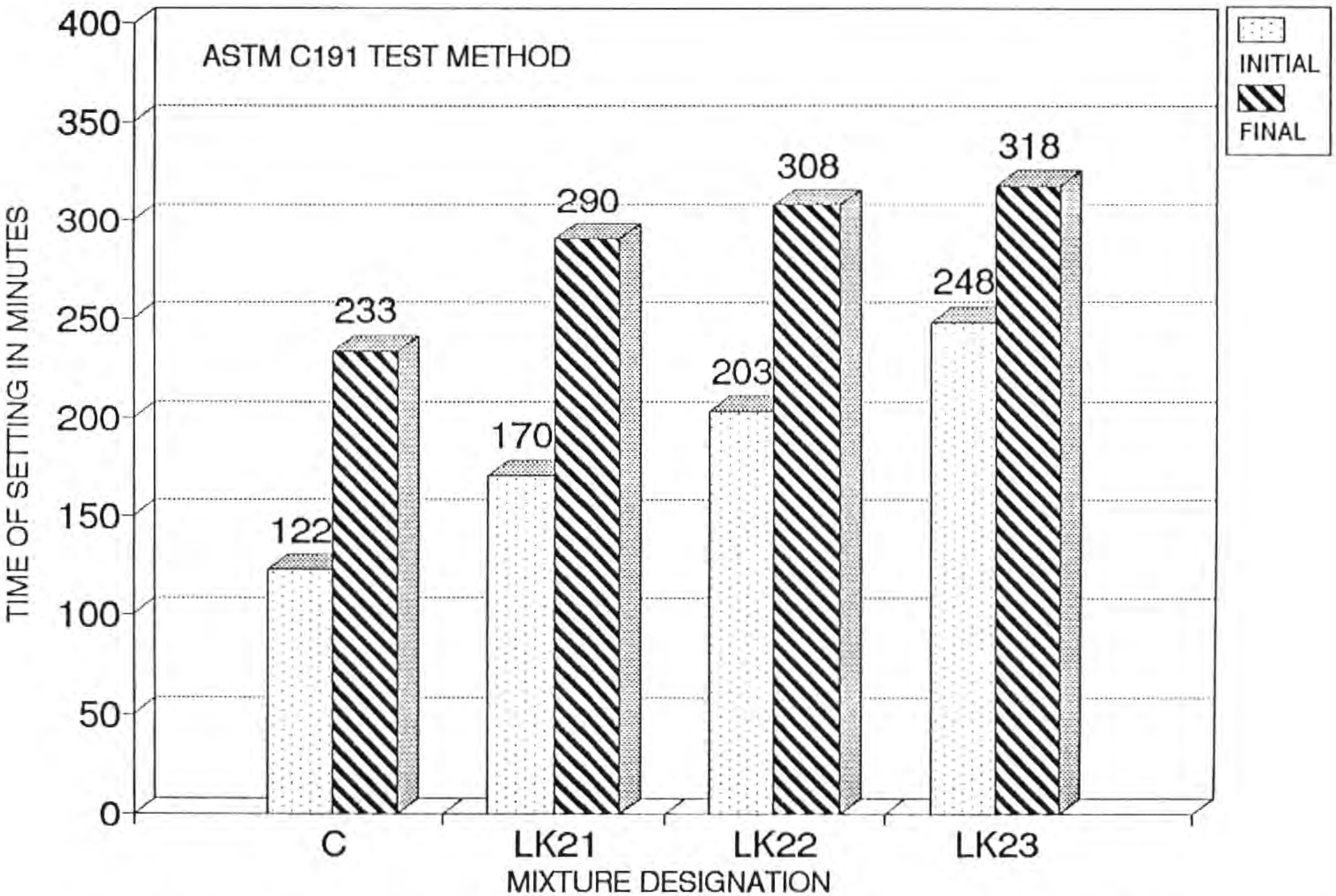

Figure 25 Comparison of time of setting of cement blended with LK2 by Vicat needle

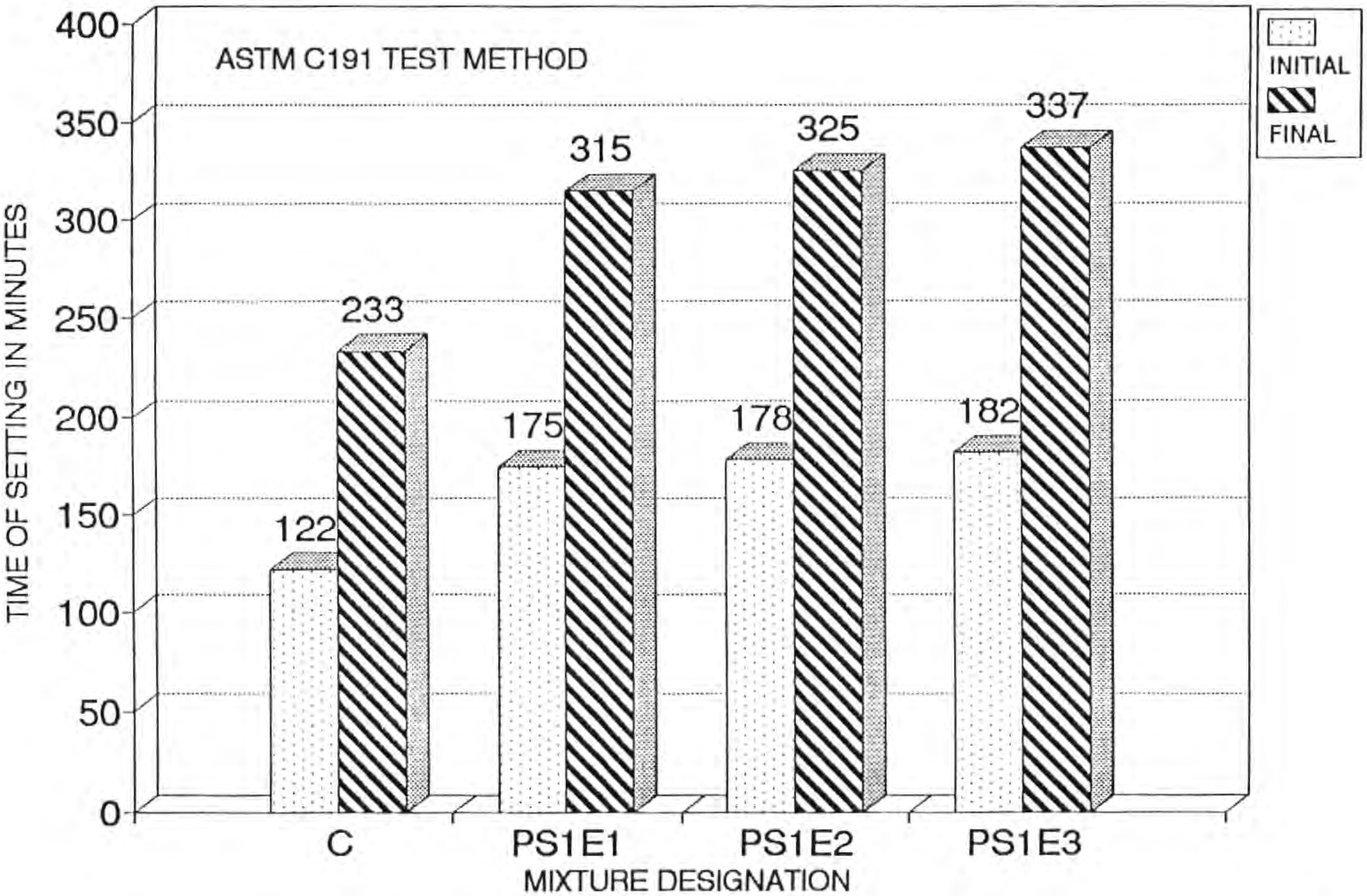

Figure 26 Comparison of time of setting of cement blended with PS1E by Vicat needle

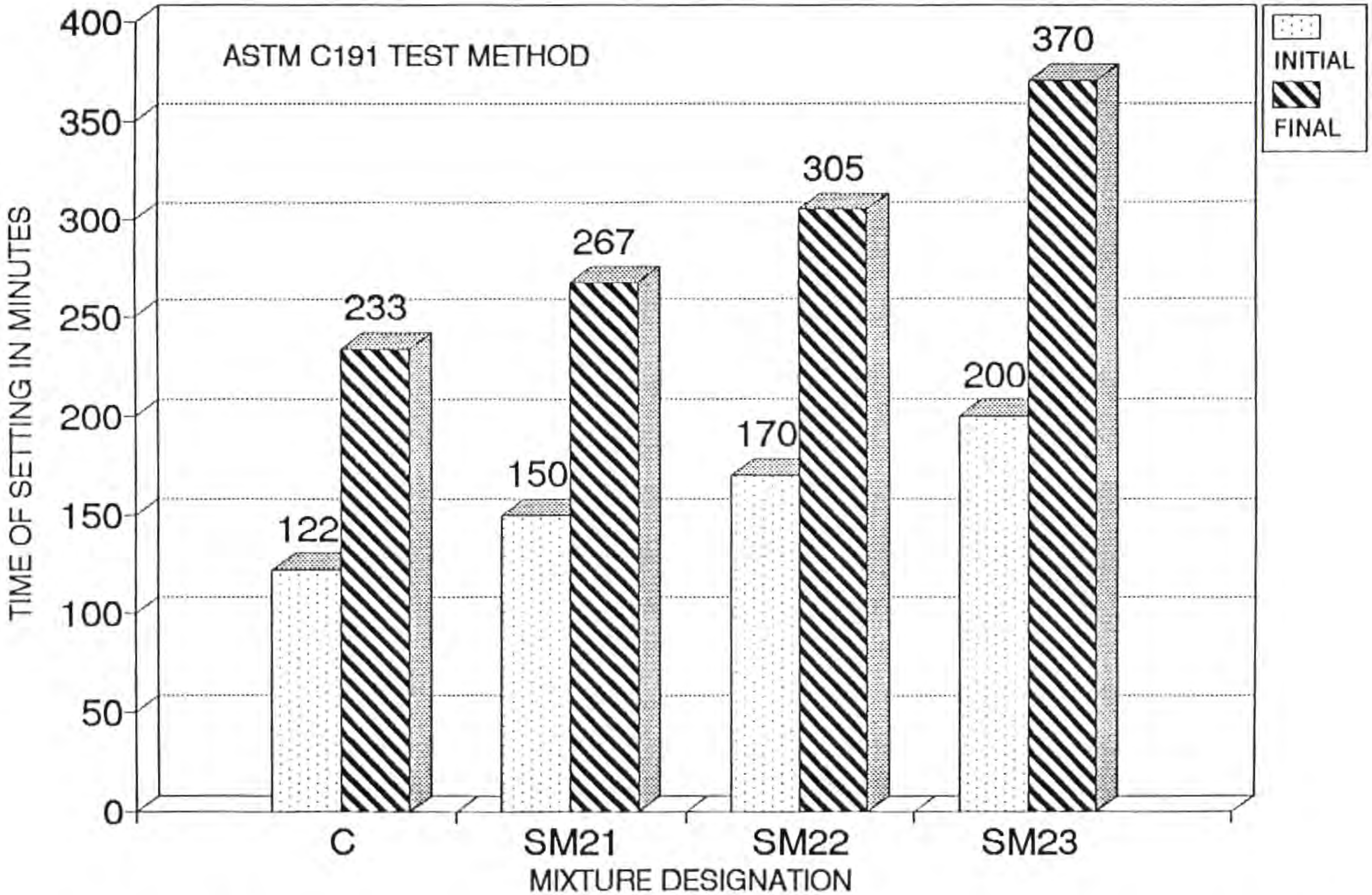

Figure 27 Comparison of time of setting of cement blended with SM2 by Vicat needle

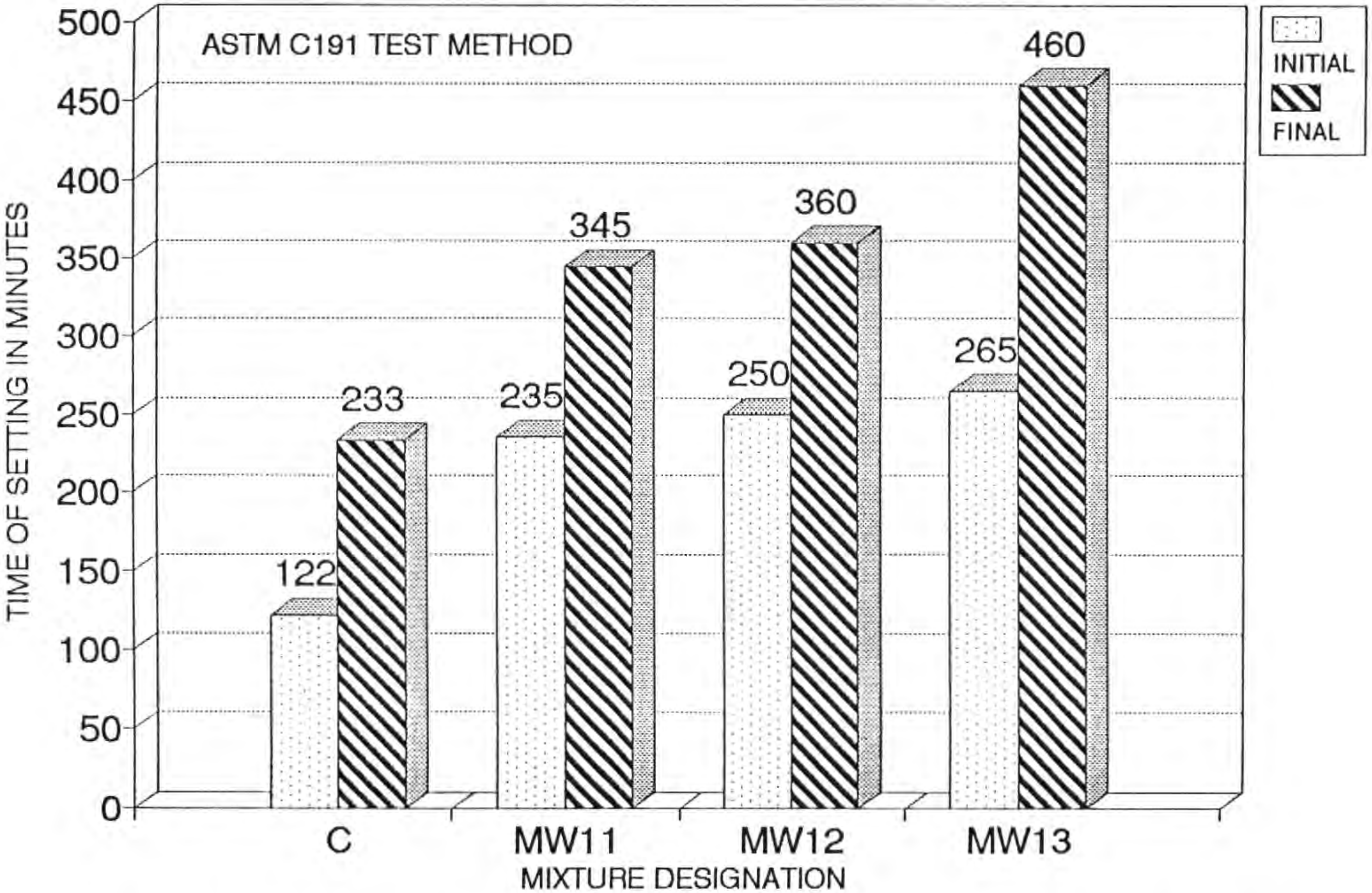

Figure 28 Comparison of time of setting of cement blended with MW1 by Vicat needle

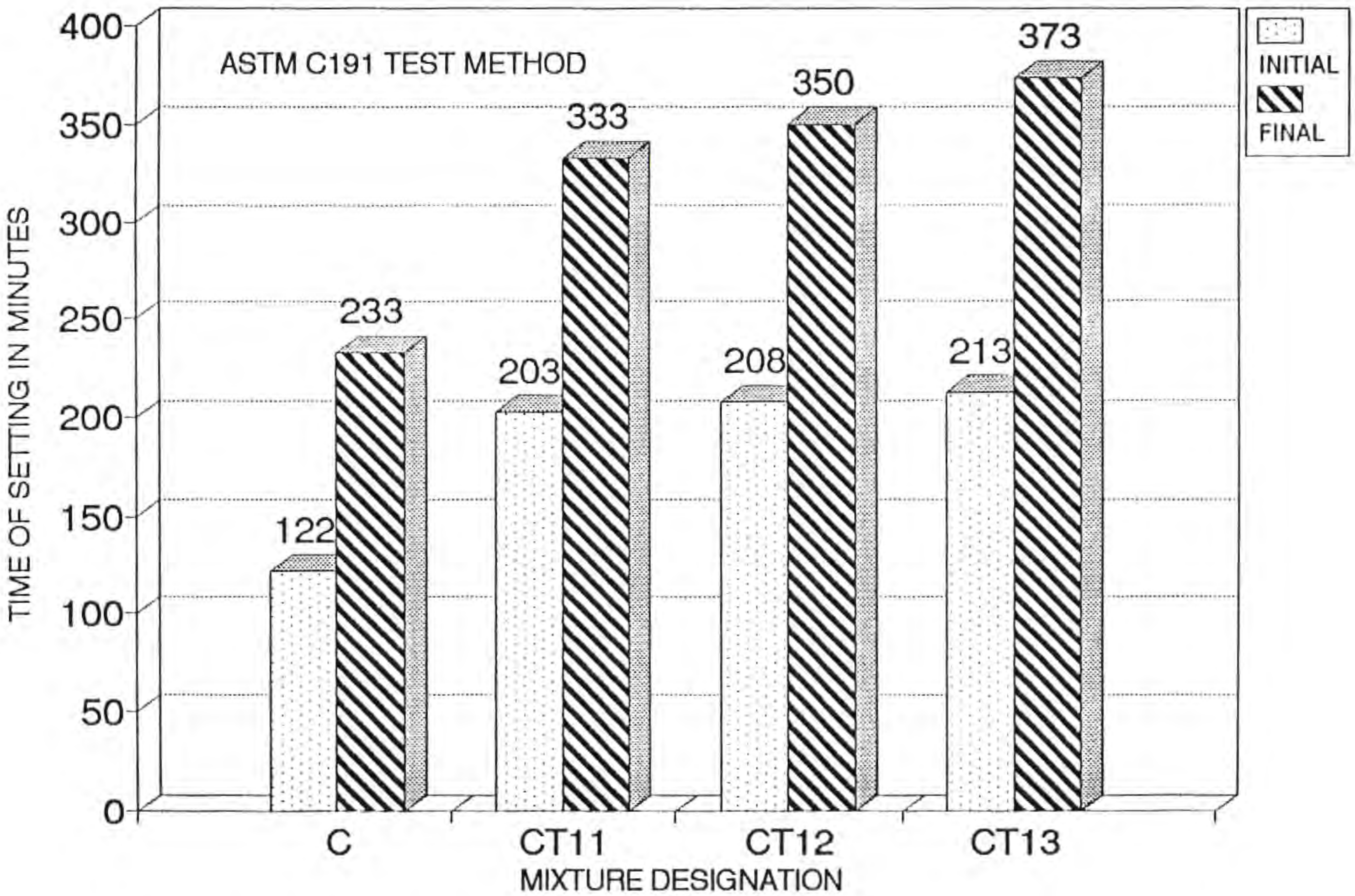

Figure 29 Comparison of time of setting of cement blended with CT1 by Vicat needle

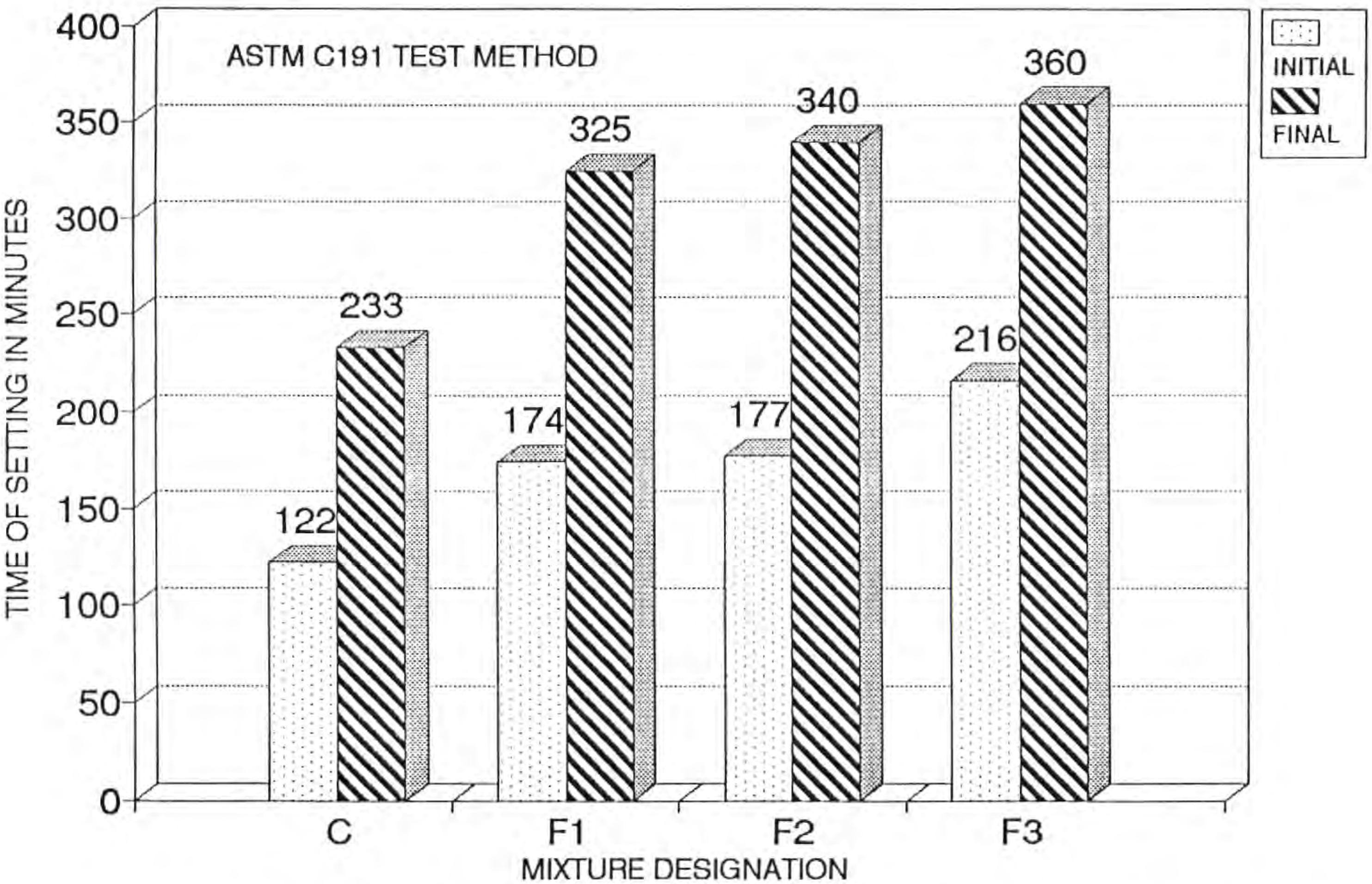

Figure 30 Comparison of time of setting of cement blended with class F flyash by Vicat needle

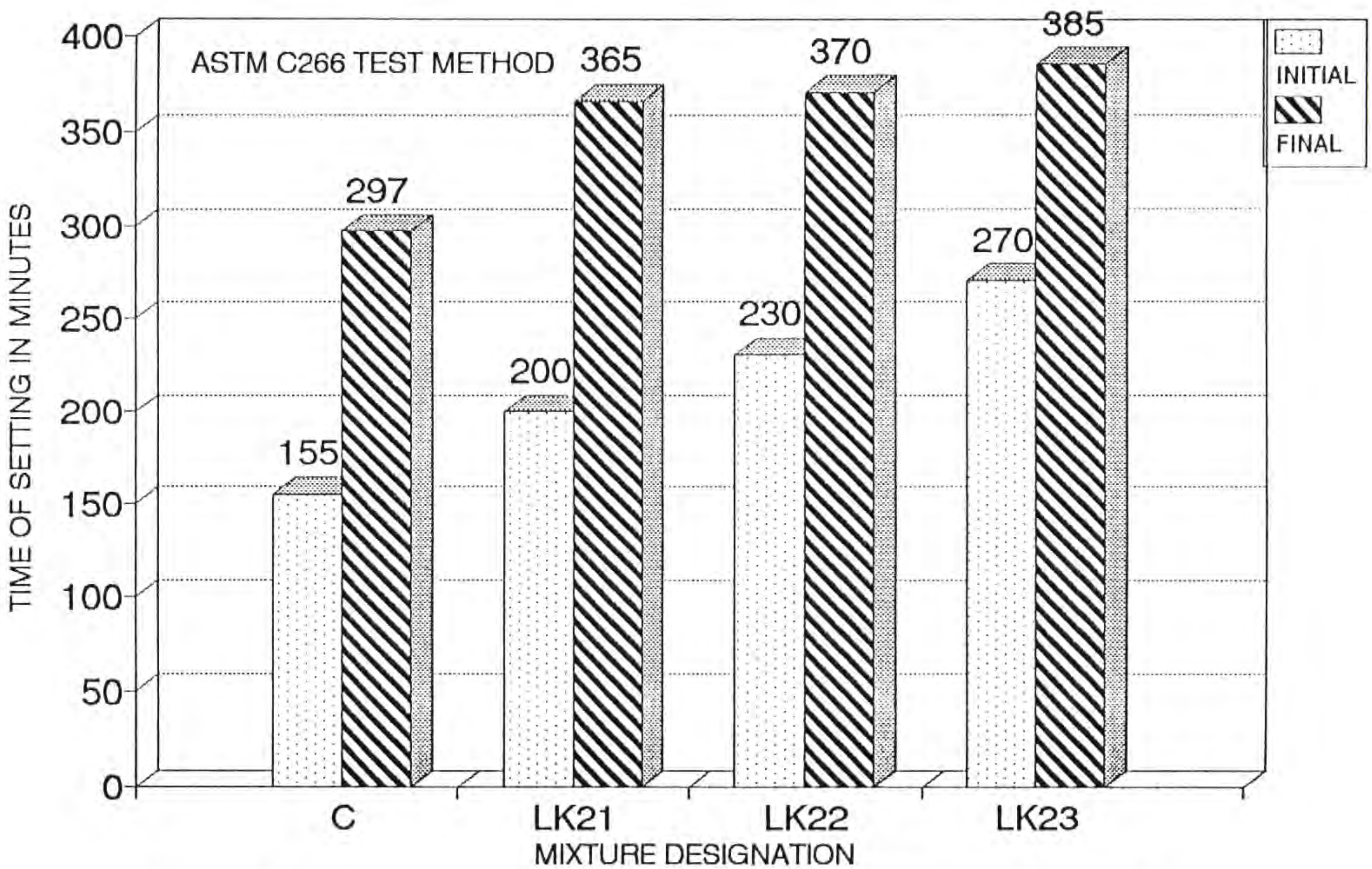

Figure 31 Comparison of time of setting of cement blended with LK2 by Gillmore needles

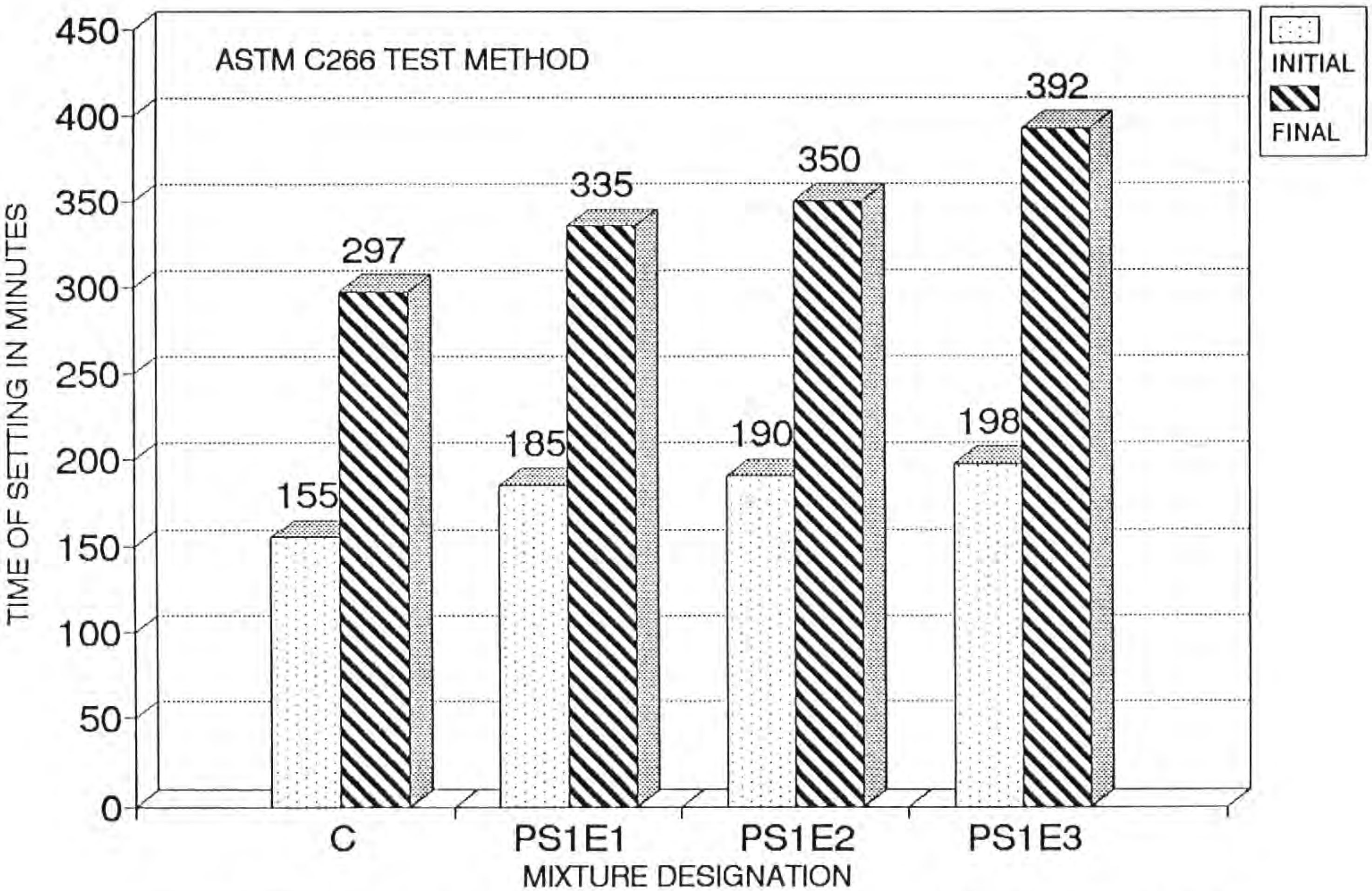

Figure 32 Comparison of time of setting of cement blended with PS1E by Gillmore needles

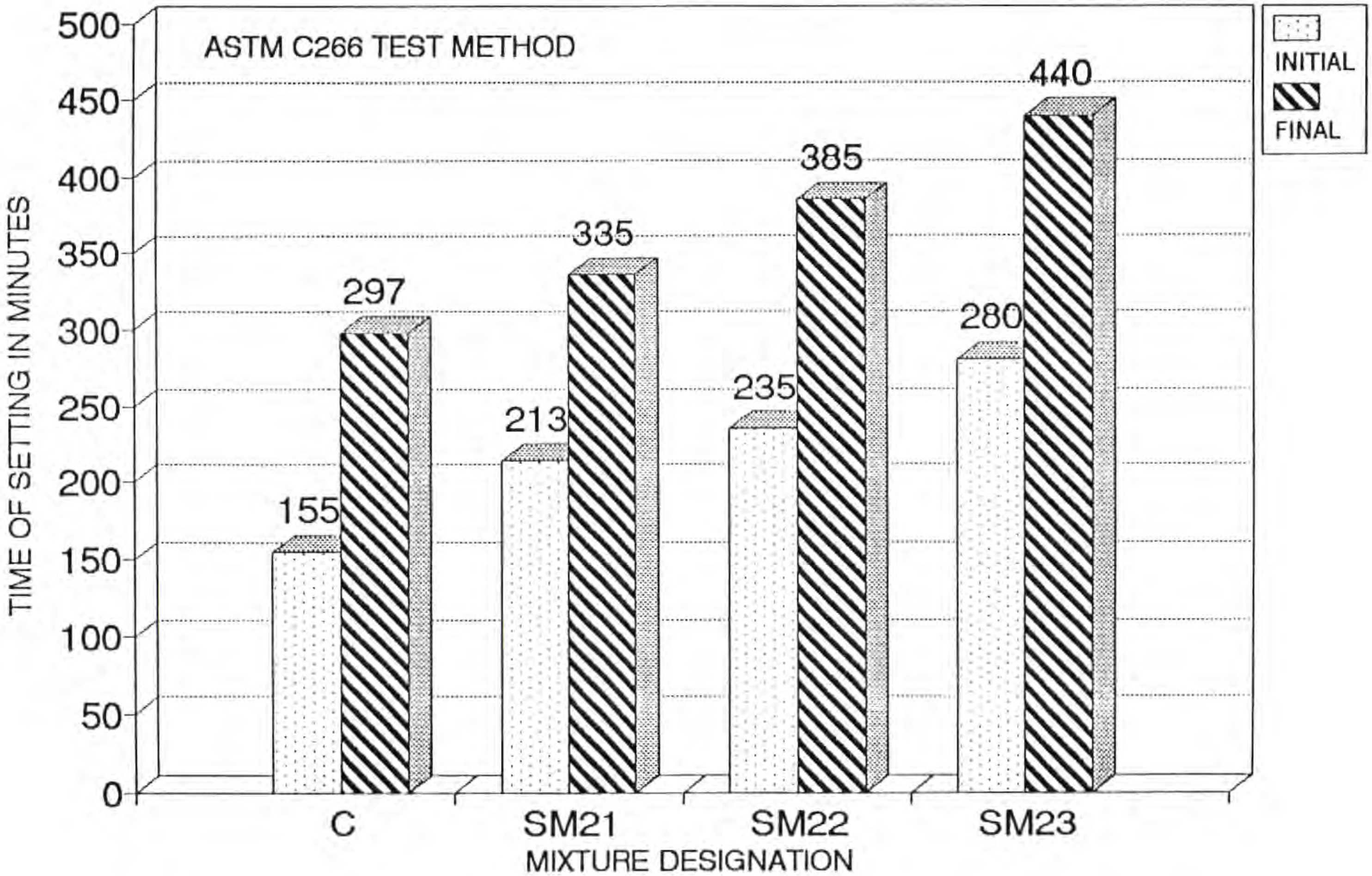

Figure 33 Comparison of time of setting of cement blended with SM2 by Gillmore needles

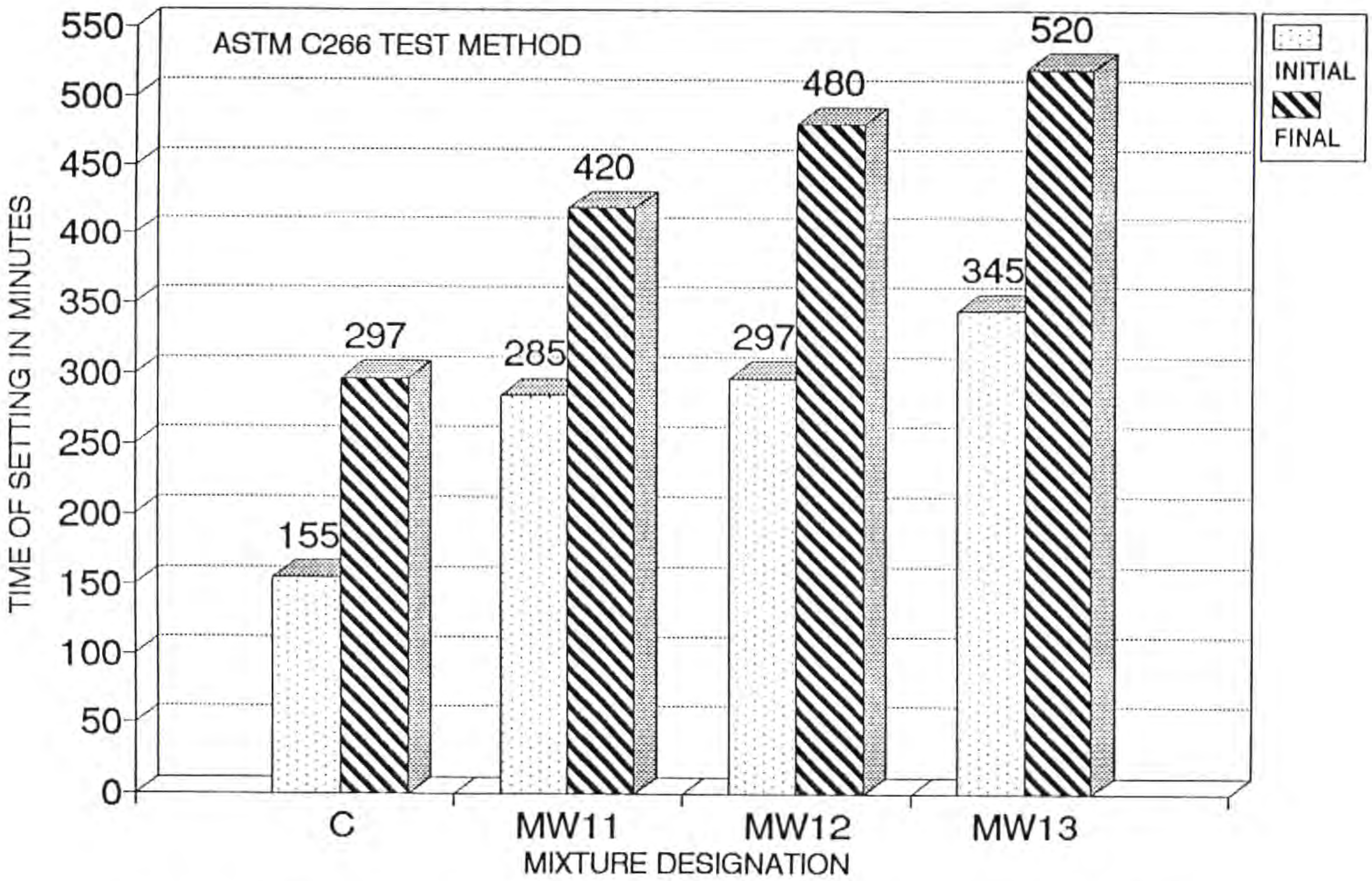

Figure 34 Comparison of time of setting of cement blended with MW1 by Gillmore needles

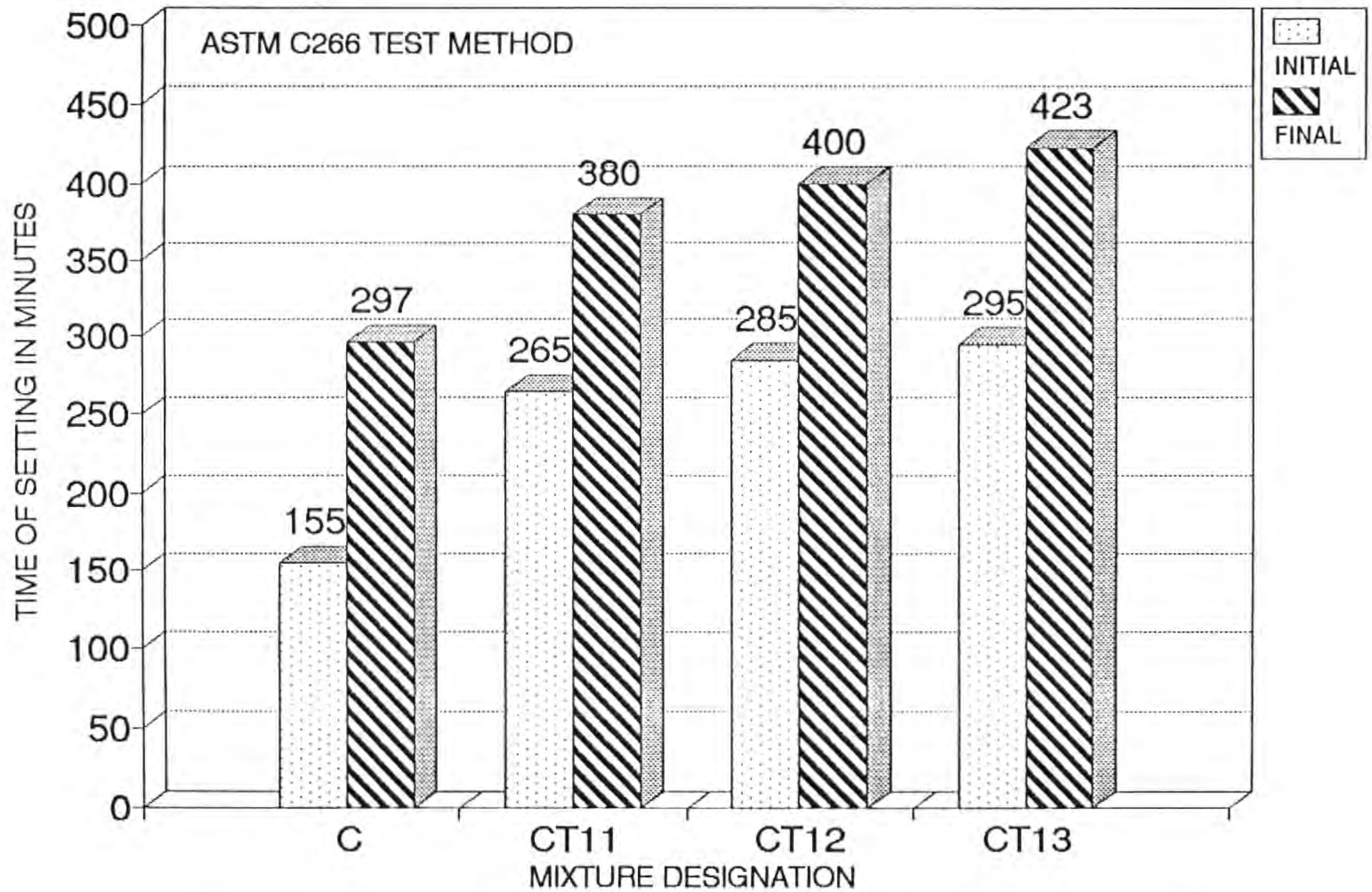

Figure 35 Comparison of time of setting of cement blended with CT1 by Gillmore needles

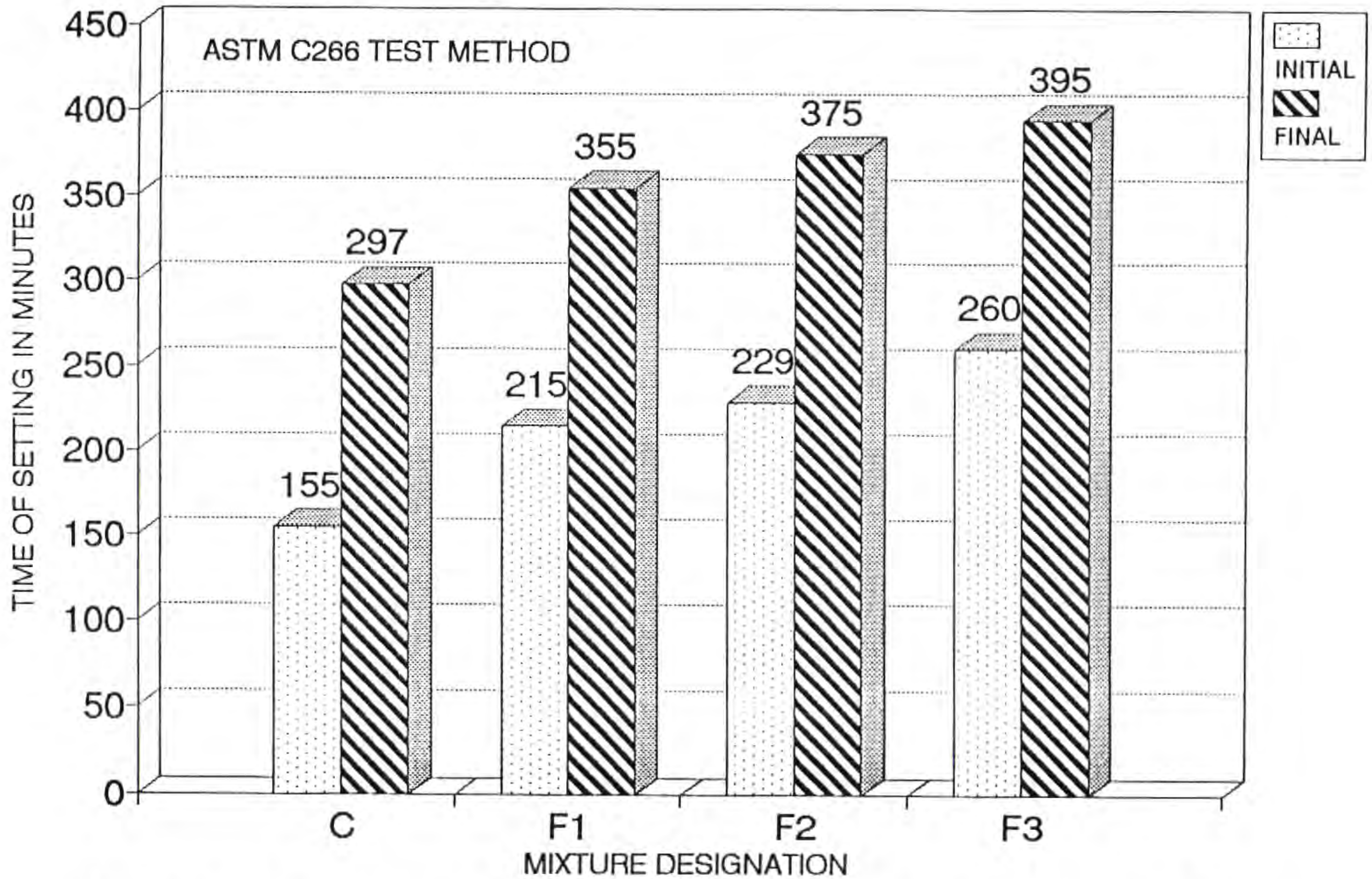

Figure 36 Comparision of time of setting of cement blended with class F flyash by Gillmore needles

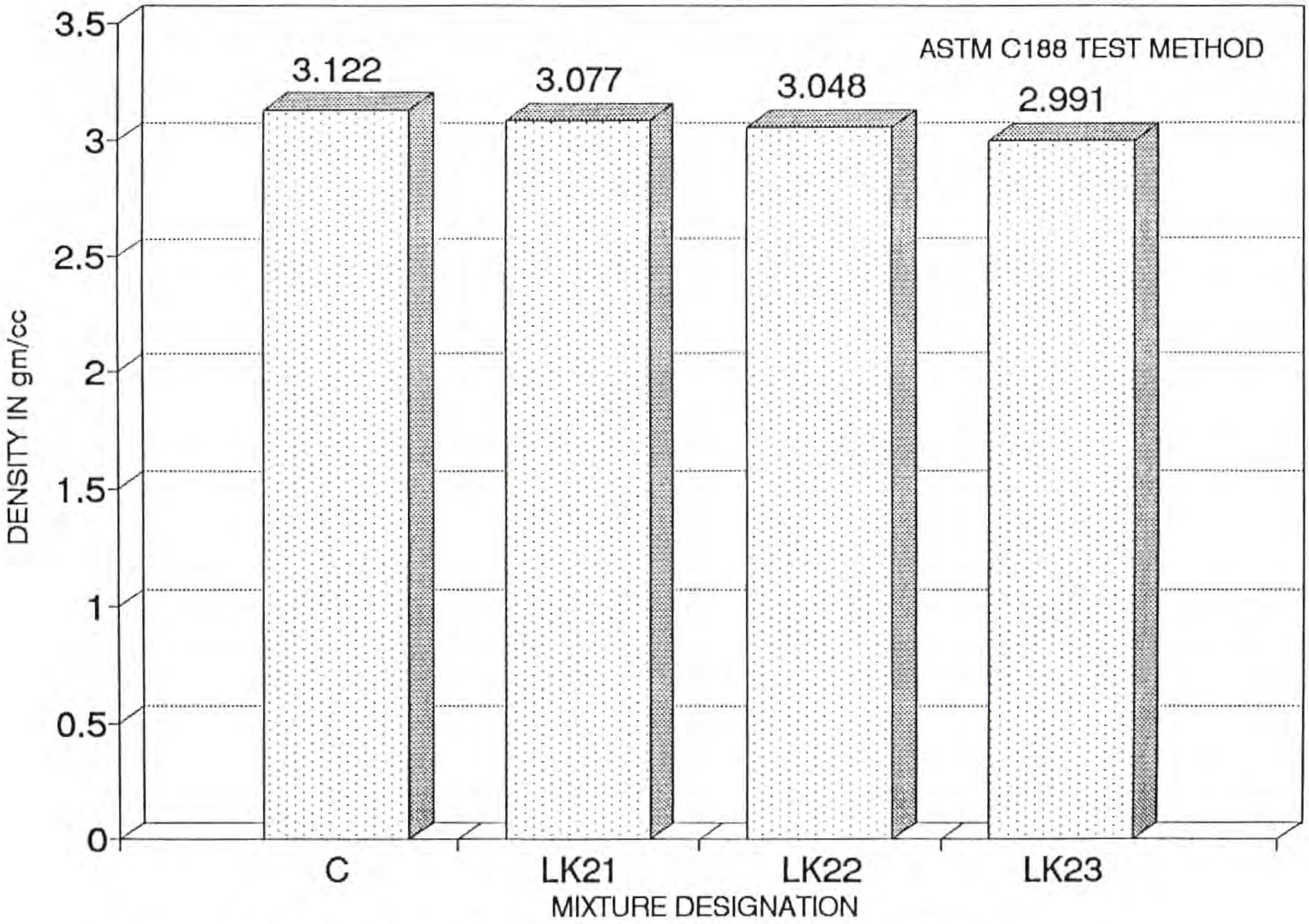

Figure 37 Comparison of density of cement blended with LK2

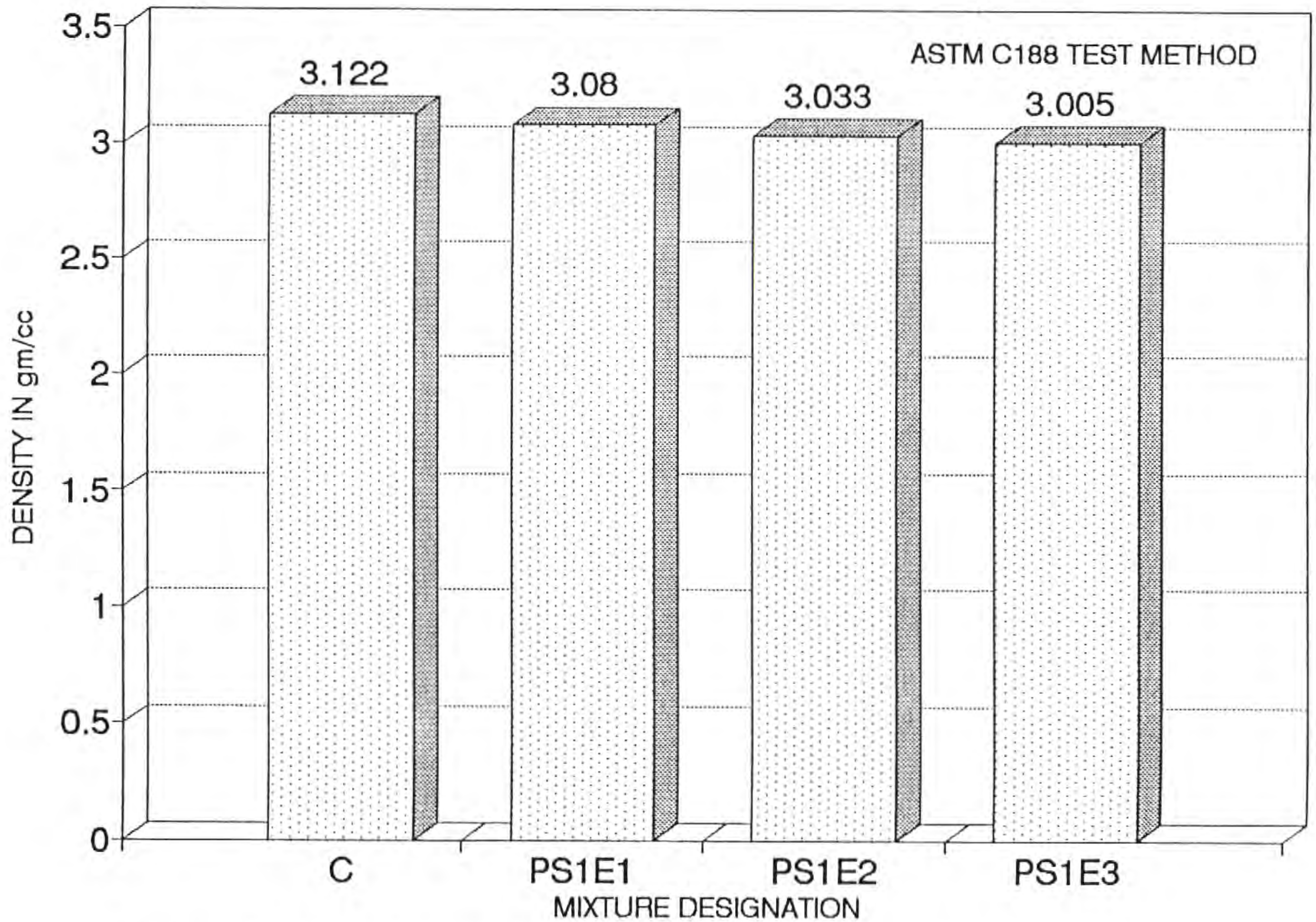

Figure 38 Comparison of density of cement blended with PS1E

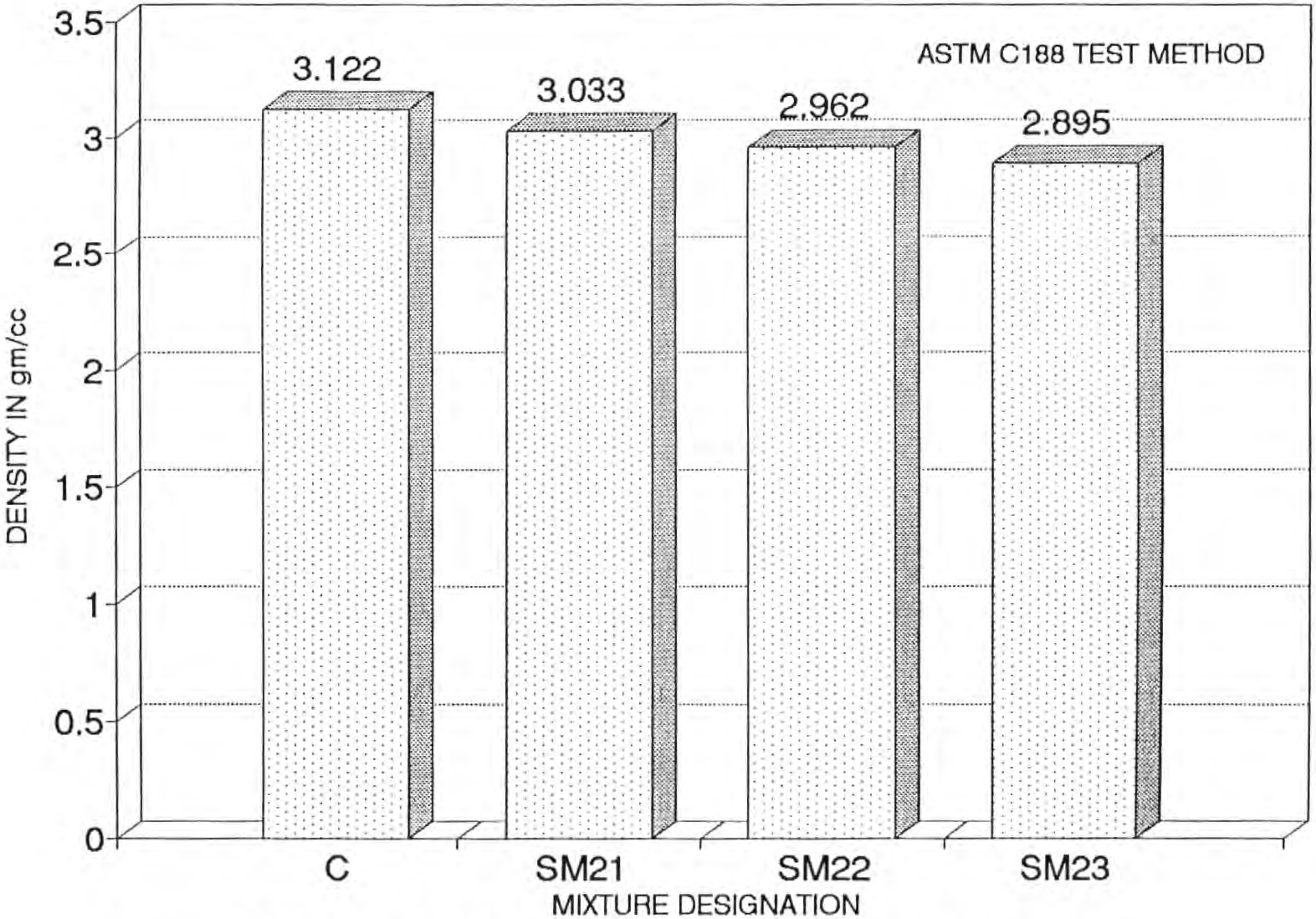

Figure 39 Comparison of density of cement blended with SM2

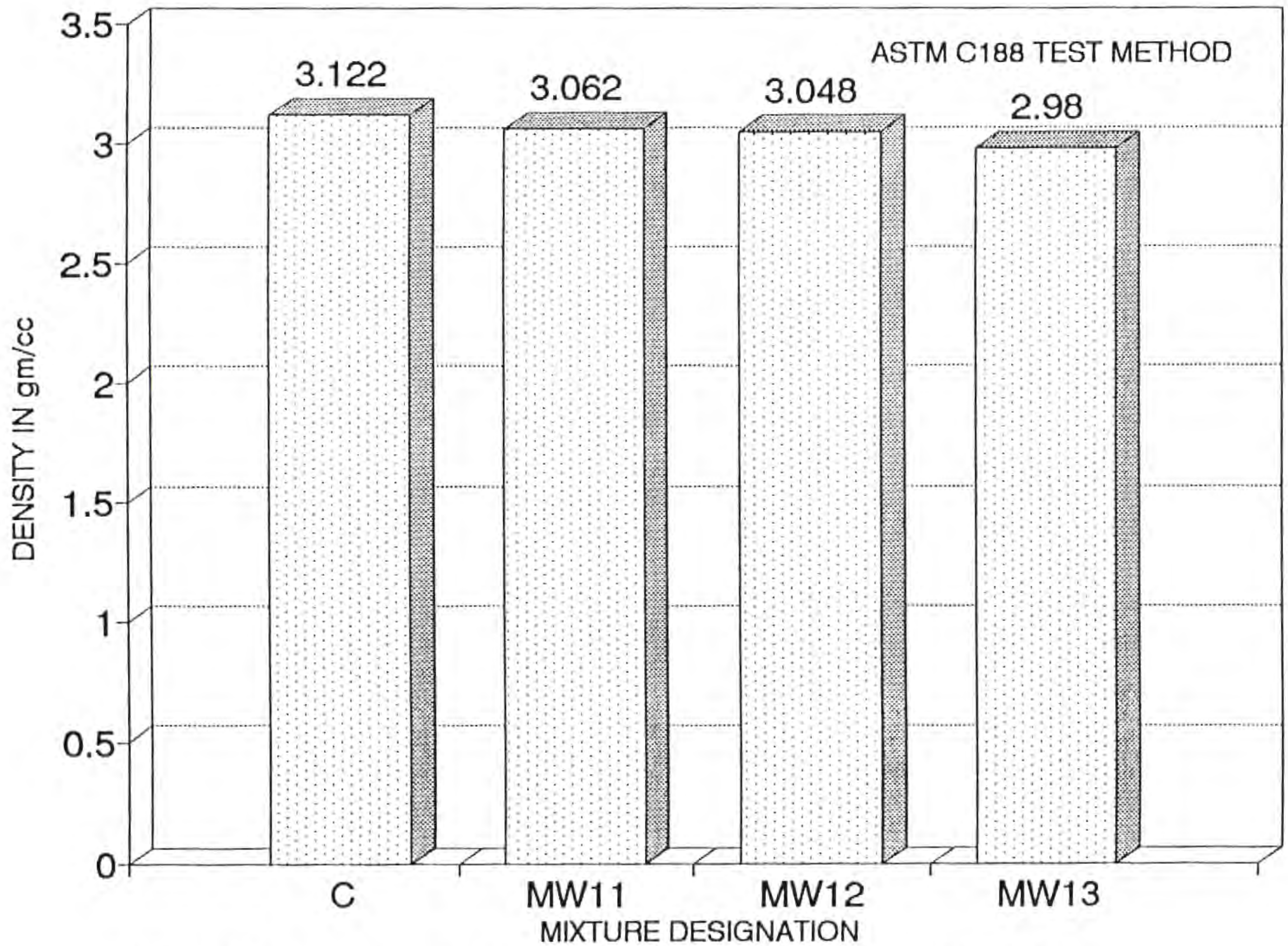

Figure 40 Comparison of density of cement blended with MW1

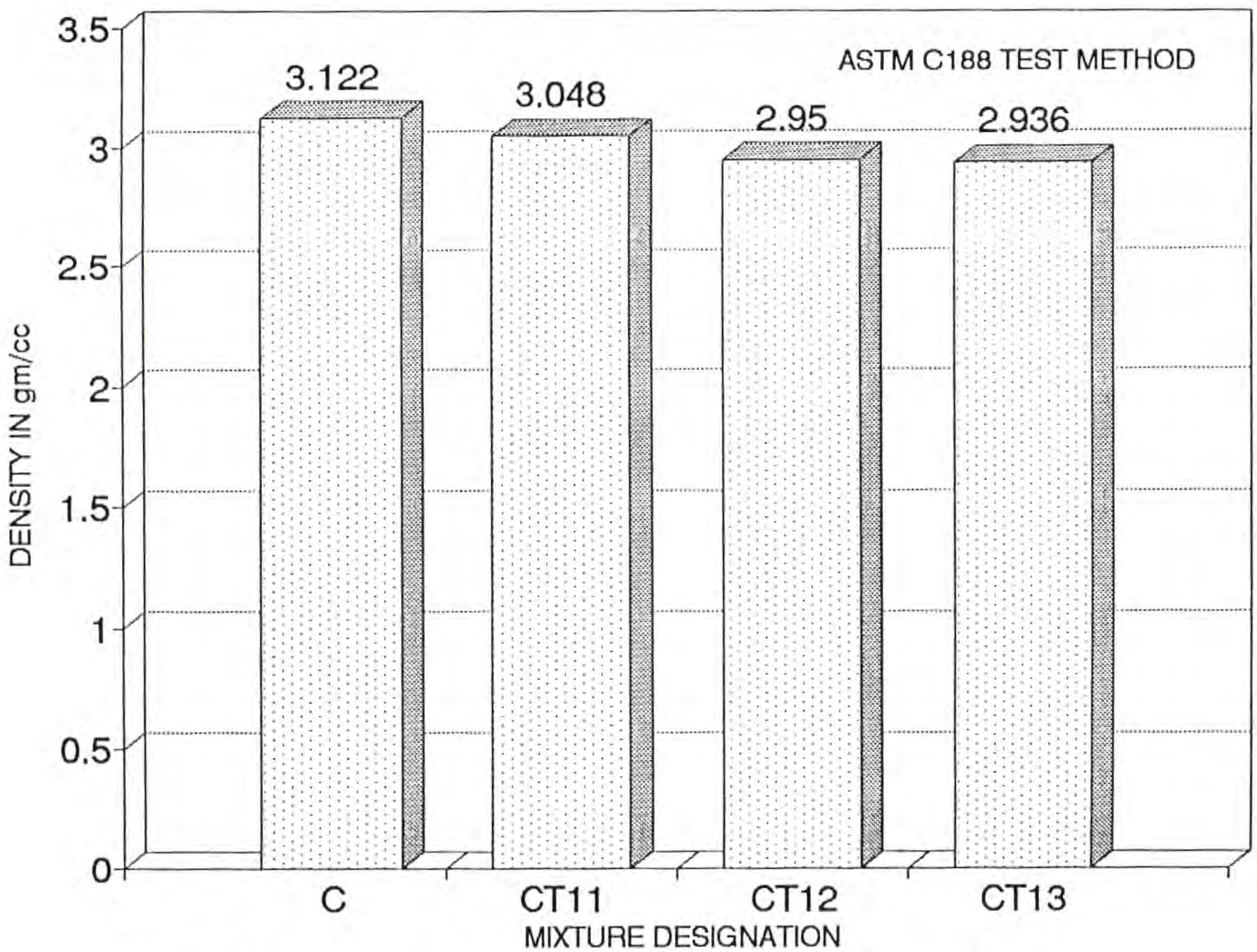

Figure 41 Comparison of density of cement blended with CT1

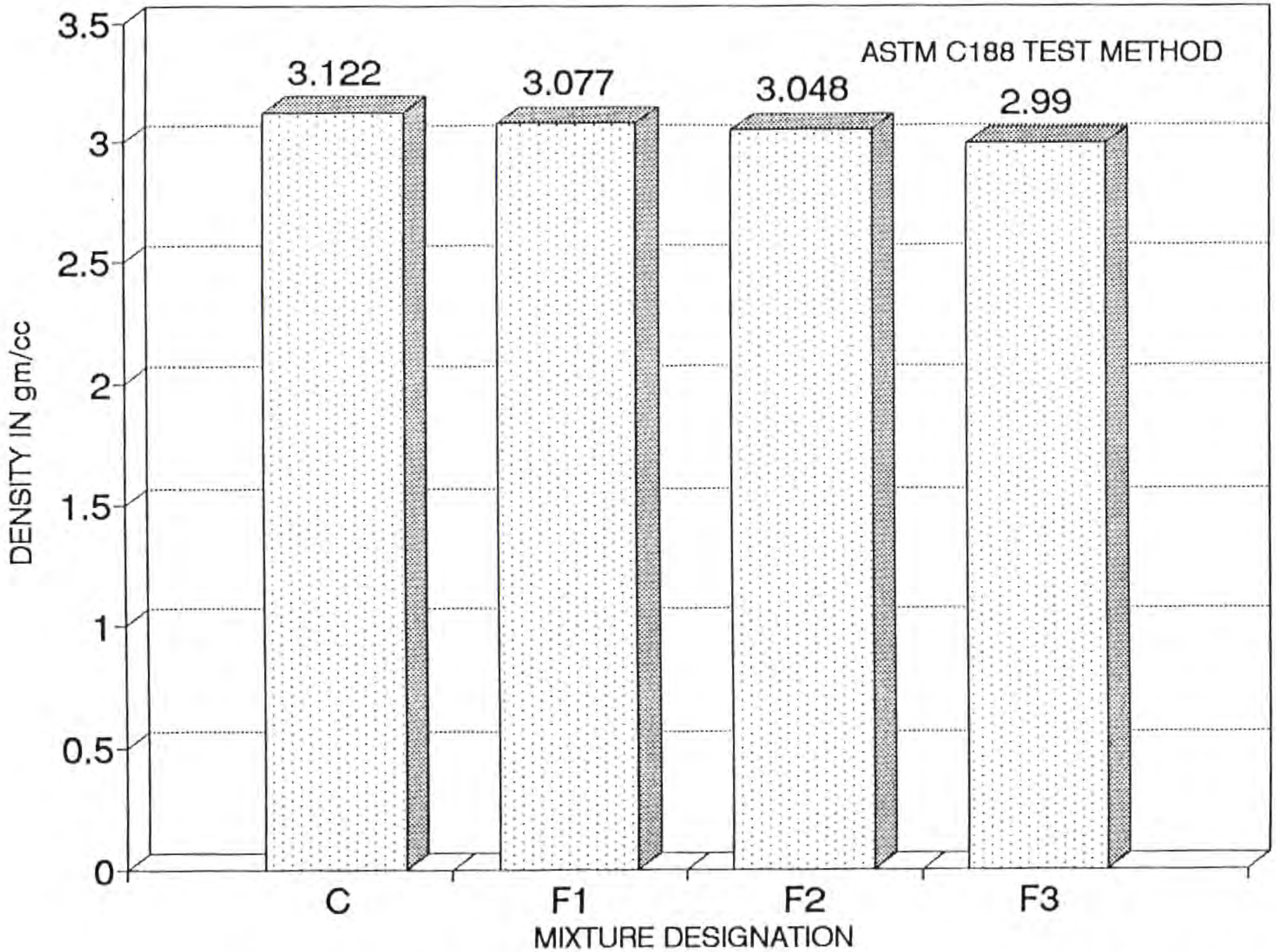

Figure 42 Comparison of density of cement blended with class F Fly Ash

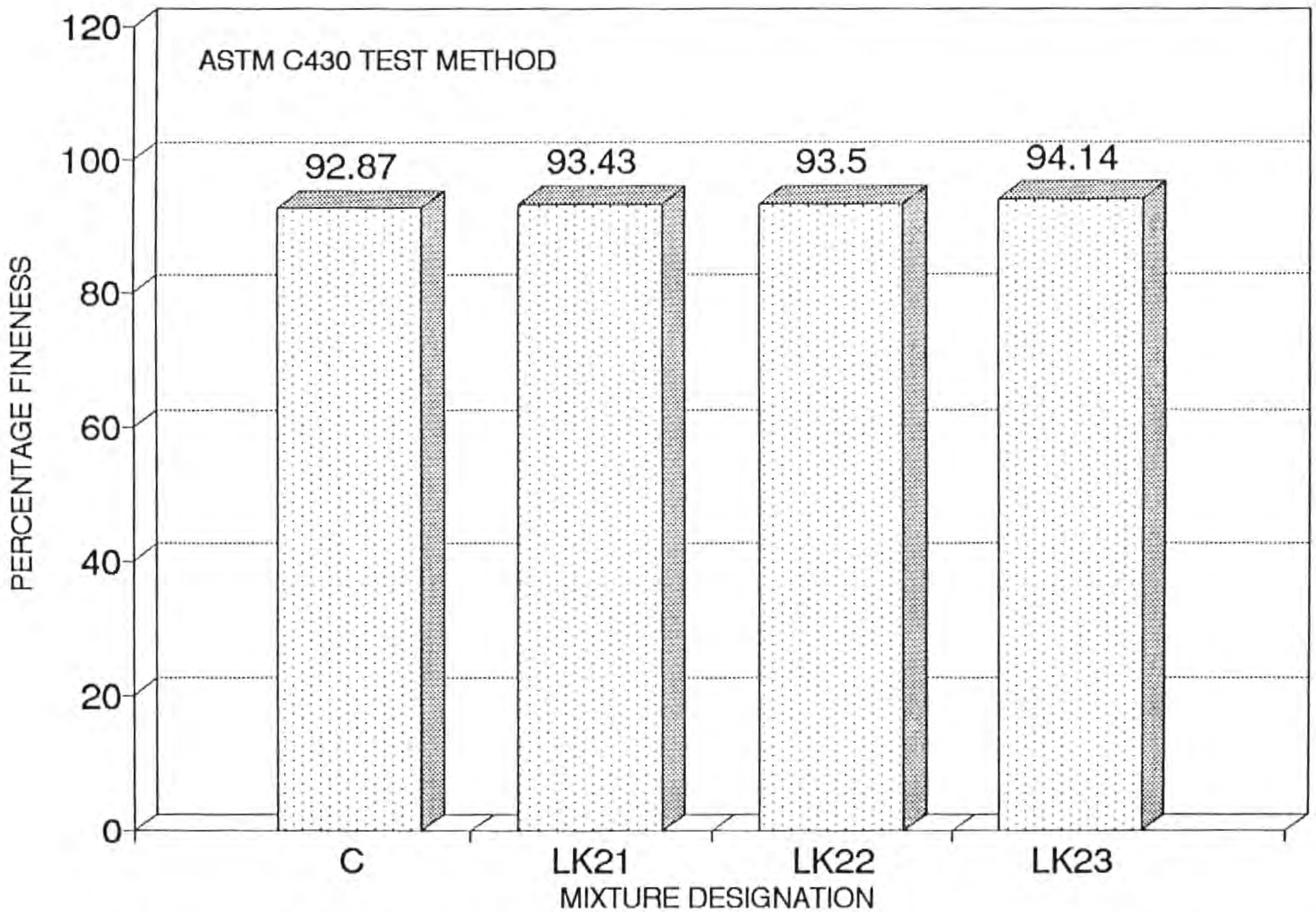

Figure 43 Comparison of fineness of cement blended with LK2 by sieve No.325

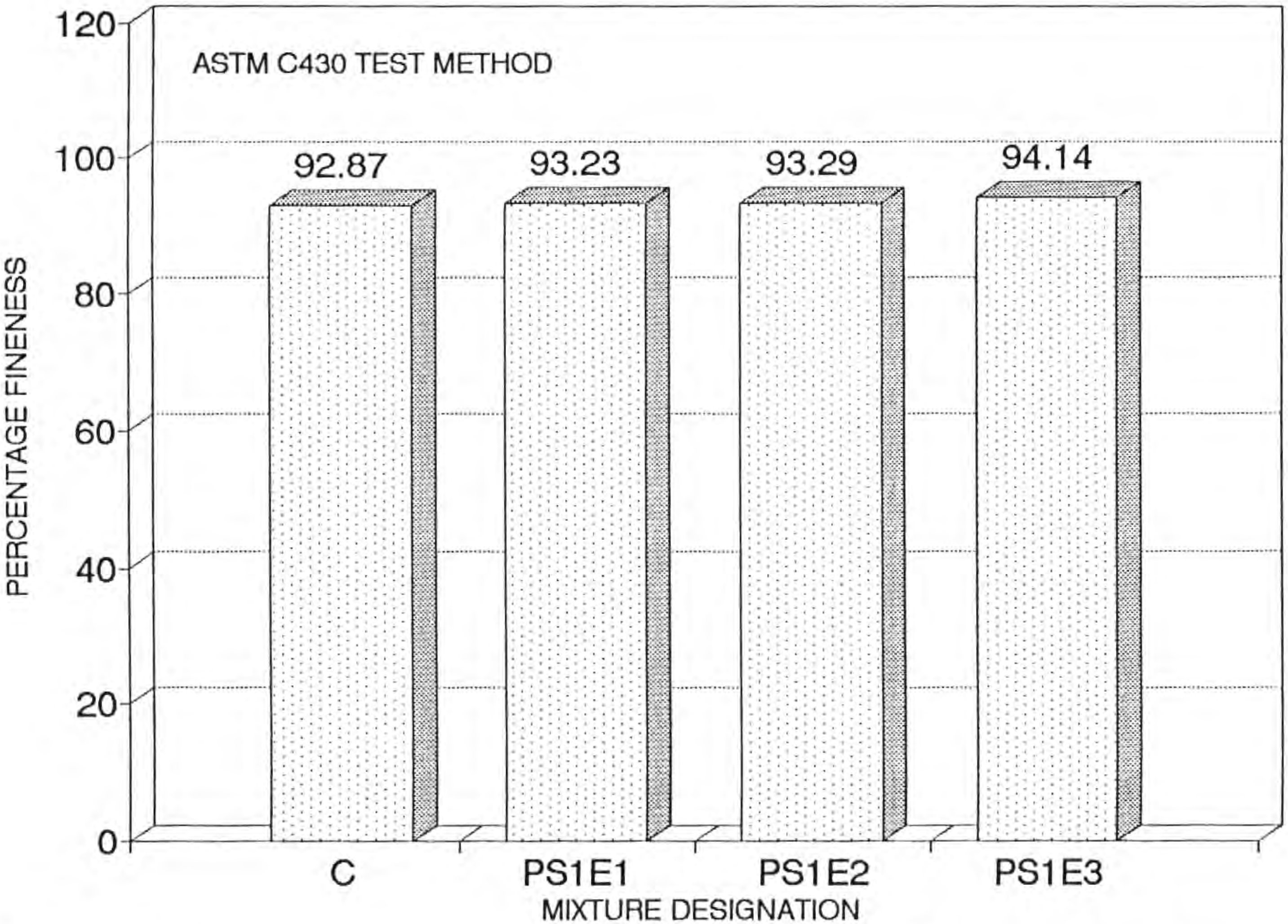

Figure 44 Comparison of fneness of cement blended with PS1E by sieve No.325

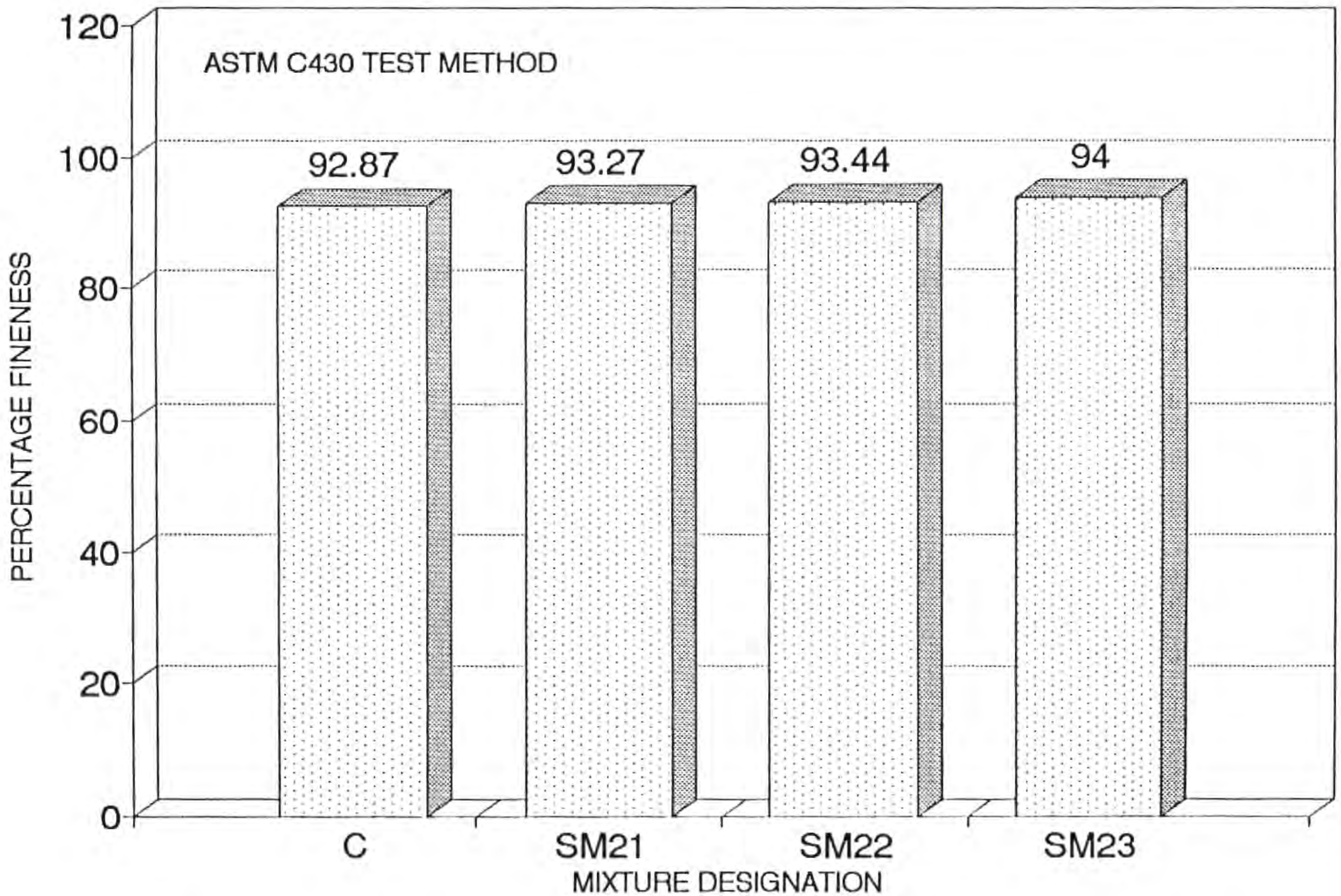

Figure 45 Comparison of fineness of cement blended with SM2 by sieve No.325

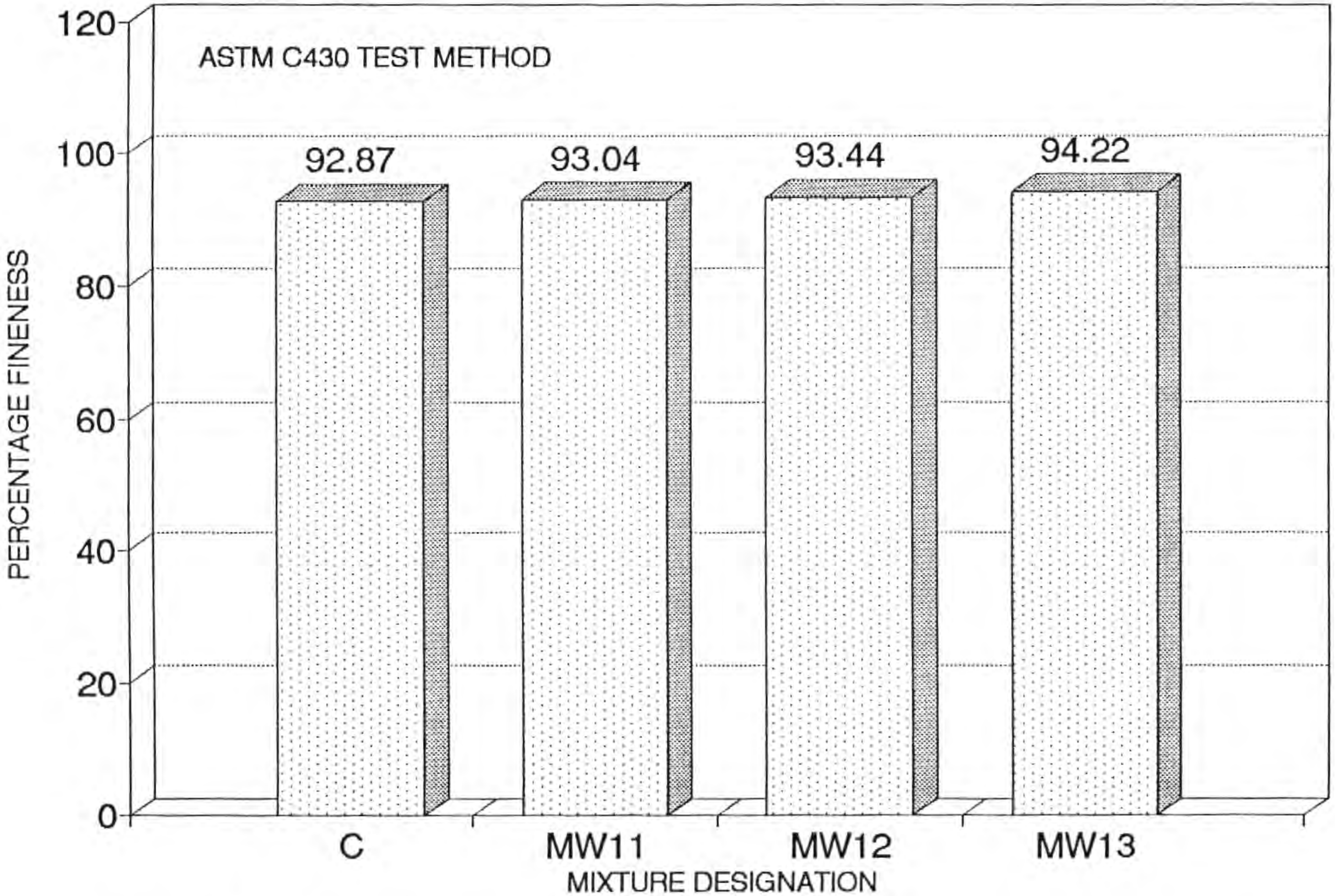

Figure 46 Comparison of fineness of cement blended with MW1 by sieve No.325

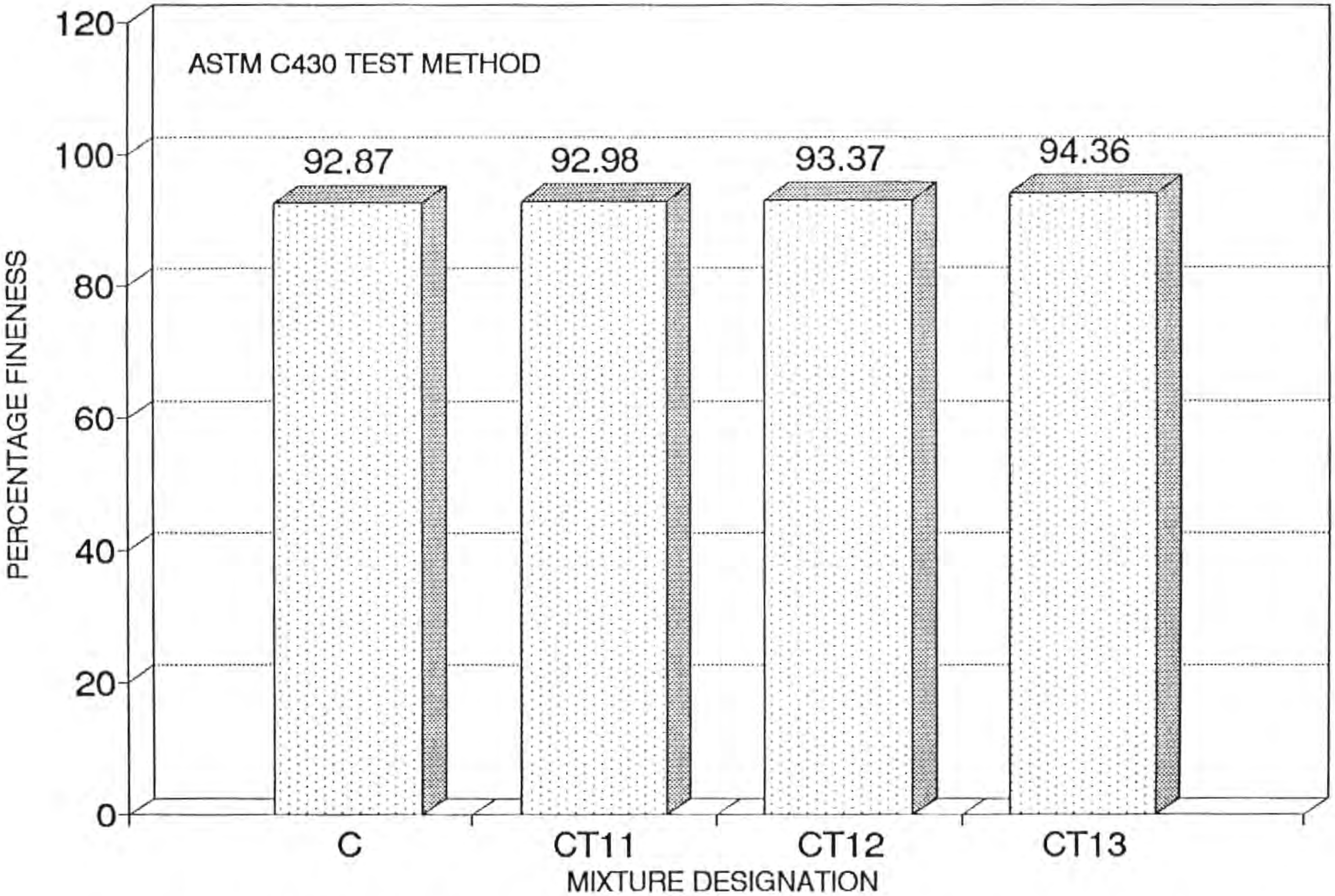

Figure 47 Comparison of fineness of cement blended with CT1 by sieve No.325

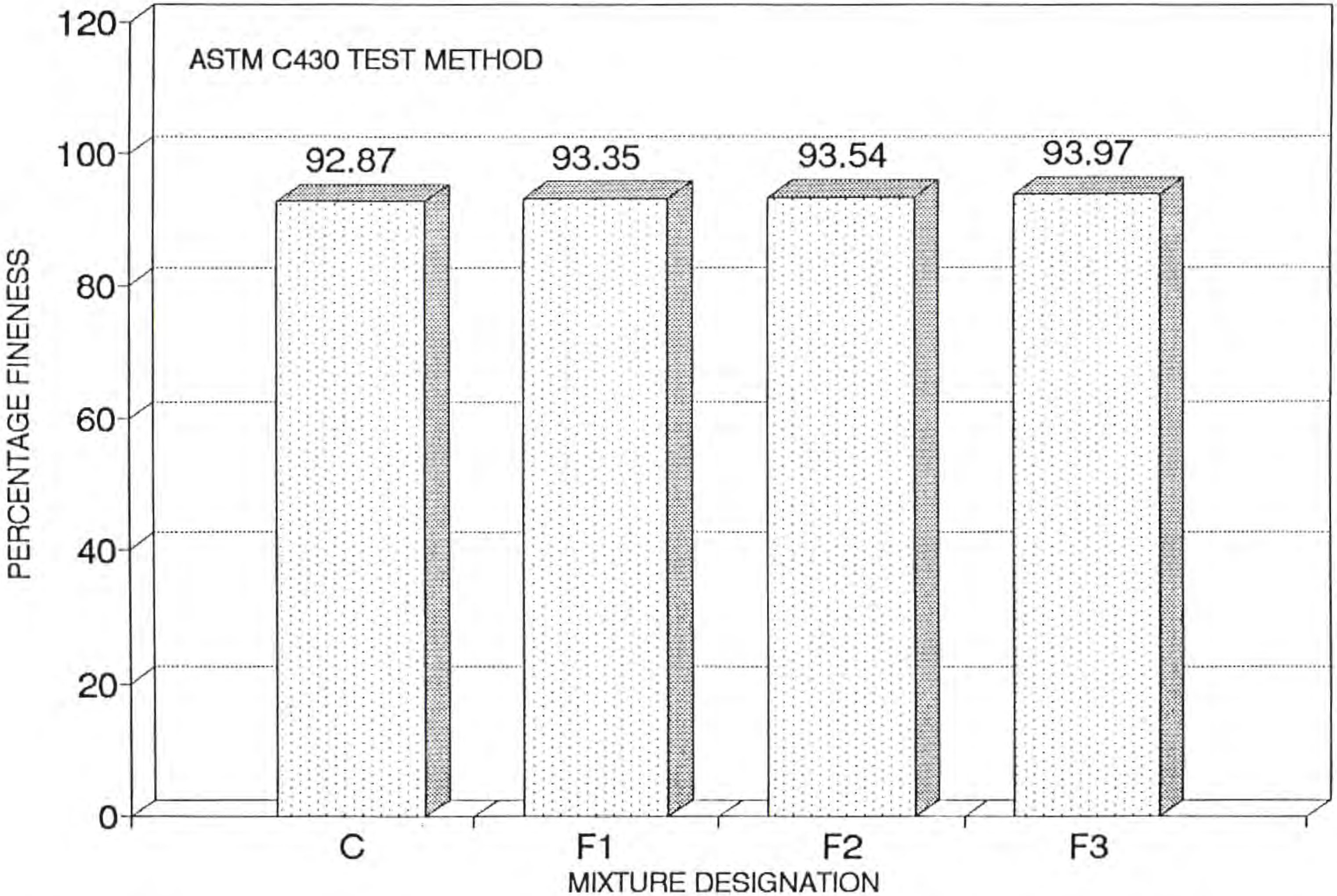

Figure 48 Comparison of fineness of cement blended with class F flyash by No.325 sieve

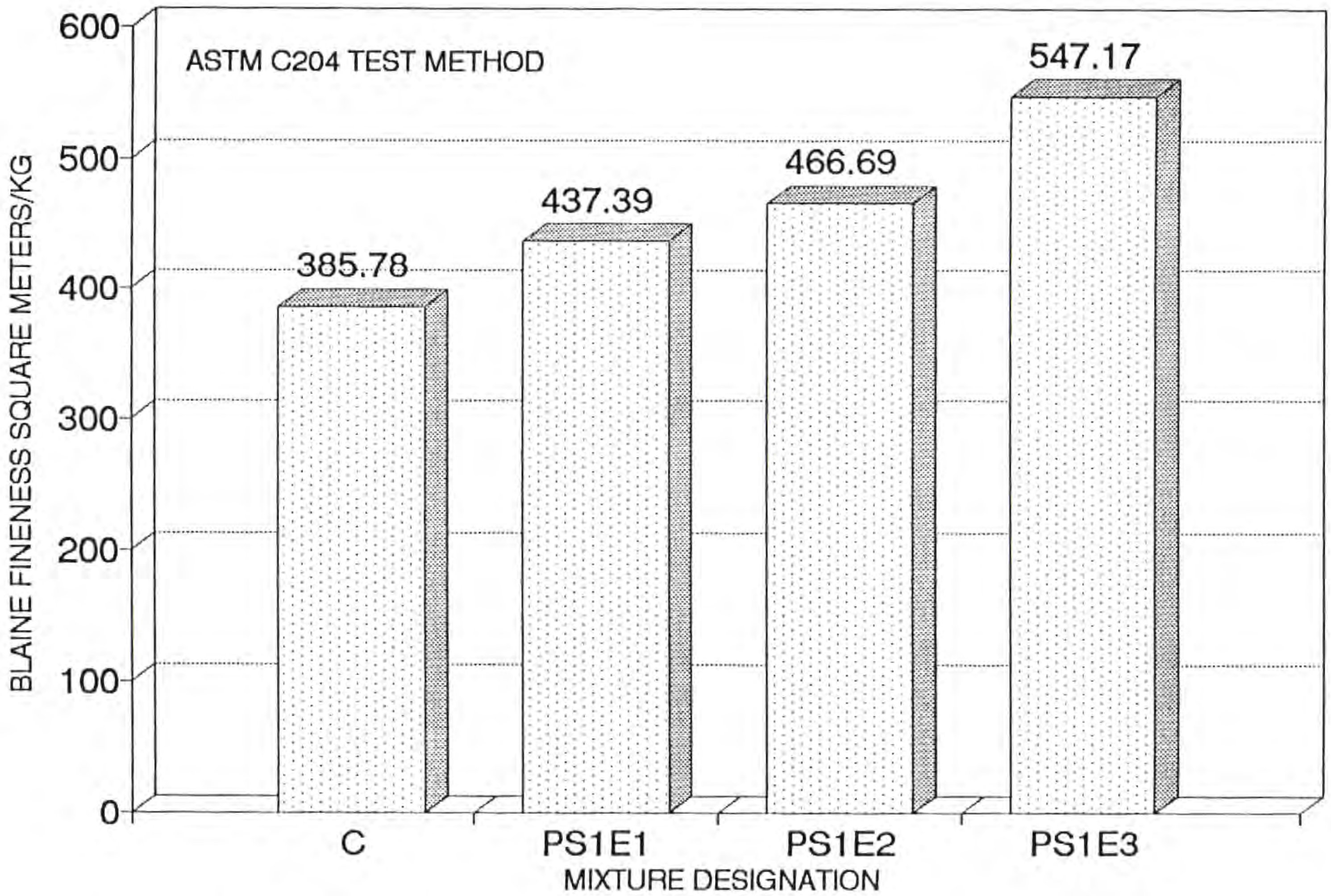

Figure 50 Comparison of Blaine fineness of cement blended with PS1E

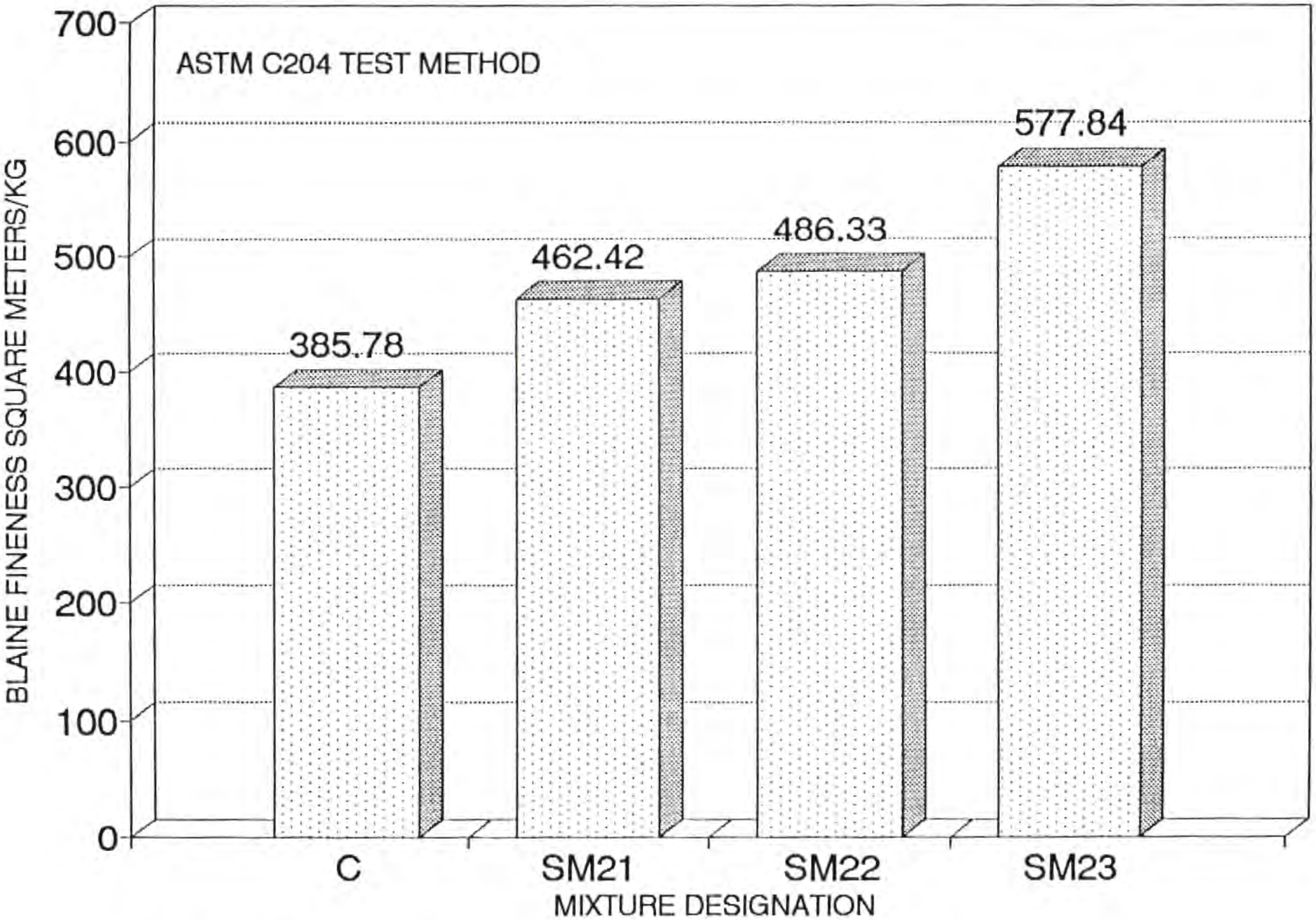

Figure 51 Comparison of Blaine fineness of cement blended with SM2

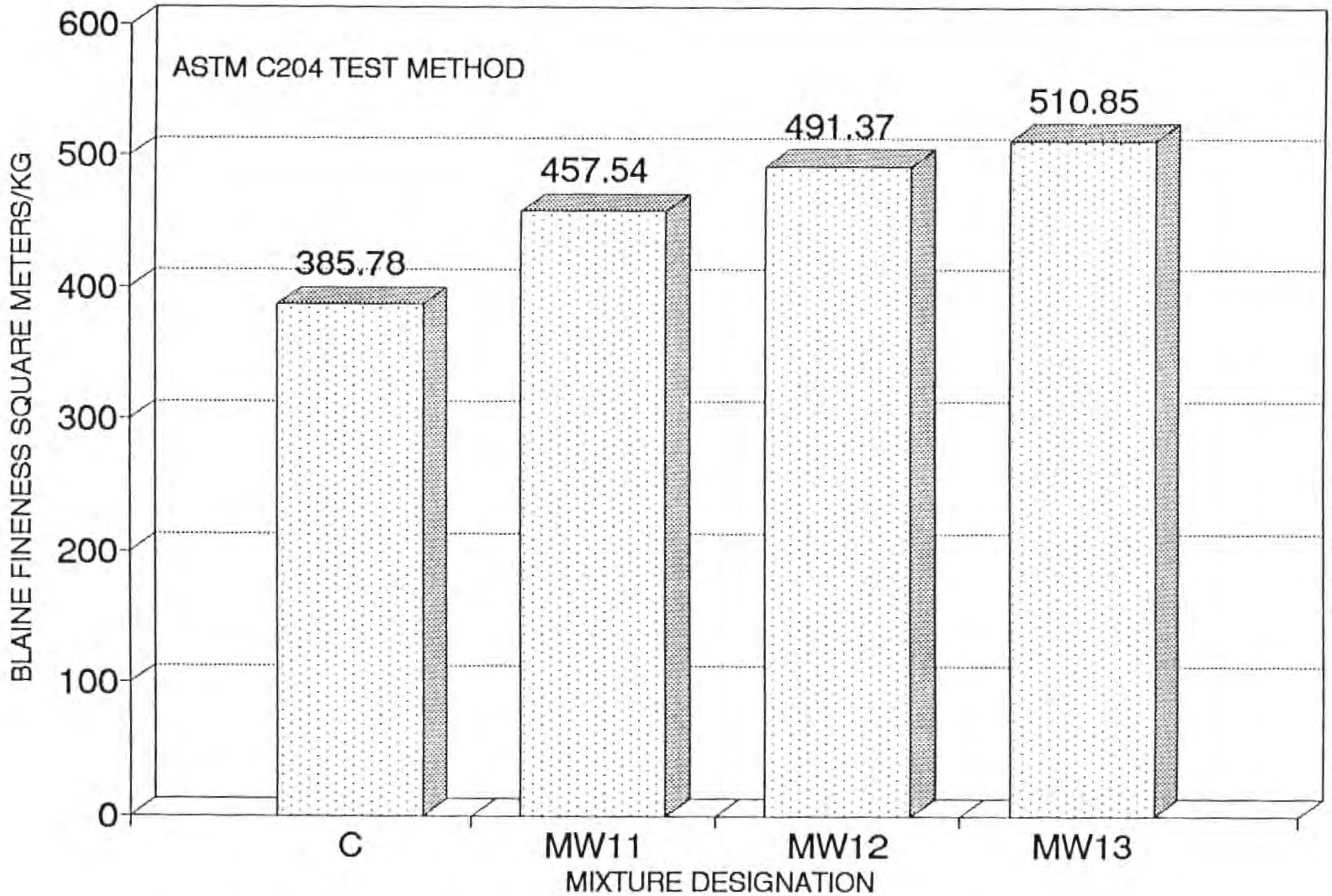

Figure 52 Comparison of Blaine fineness of cement blended with MW1

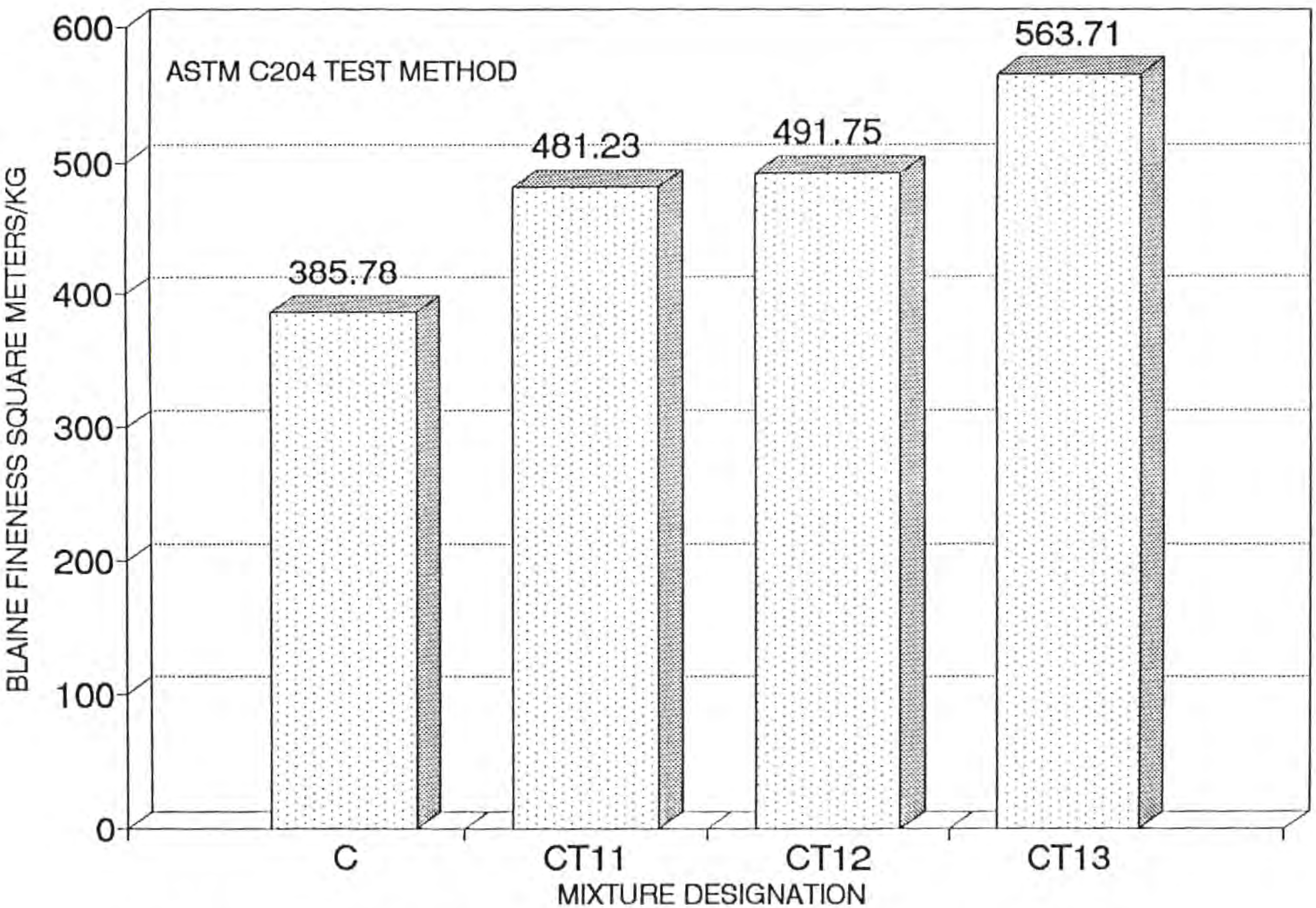

Figure 53 Comparison of Blaine fineness of cement blended with CT1