Strength Development in Concrete Blocks Containing Flyash

by

AHMAD KAZEMI

A thesis
presented to the University of Manitoba
in partial fulfillment of the
requirements for the degree of
Master of Engineering
in
Civil Engineering

Winnipeg, Manitoba

ISBN 0-315-48019-X

STRENGTH DEVELOPMENT IN CONCRETE BLOCKS CONTAINING FLYASH

BY

AHMAD KAZEMI

An Engineering Report submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF ENGINEERING

I hereby declare that I am the sole author of this thesis.

I authorize the University of Manitoba to lend this thesis to other institutions or individuals for the purpose of scholarly research.

AHMAD KAZEMI

I further authorize the University of Manitoba to reproduce this thesis by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

AHMAD KAZEMI

The University of Manitoba requires the signatures of all persons using or photocopying this thesis. Please sign below, and give address and date.

ABSTRACT

This study investigates the strength development in locally-produced concrete blocks containing flyash as partial replacement for cement. Compressive strength tests were conducted on standard masonry blocks with different proportions of aggregates, flyash, and admixture in the concrete mix to determine the strength variation due to these substitutions. Cost analyses based on optimization techniques were performed to determine the most economical mix for production that would meet the strength requirement in this particular plant.

It was concluded from this study that early strength gain in concrete blocks depends not only on rapid hydration of cementitious material, but also on the degree of compaction of individual components in the mix. Test results showed that replacement of cement up to 50% with flyash coupled with a higher percentage of sand would meet the required 24-hour strength. It was also found that use of a higher proportion of admixture improves the hydration of cement, and in turn enhances the strength of the block at early ages. Cost analysis based on the cost of individual components in the mix showed that 50% replacement of cement with flyash is more economical than their present mix and satisfies the required standard strength.

ACKNOWLEDGEMENTS

I wish to express my sincerest gratitude to Professor John I. Glanville, Department of Civil Engineering at University of Manitoba, for his guidance, understanding and patience throughout the investigation and writing of this project.

The author wishes to thank Genstar Building Material Ltd., for providing the required testing blocks to make this investigation possible. Special thanks are extended to Alain Bonin and Denis Phaneuf, at the Genstar Building Material plant, for their kind assistance in producing the test batches and sharing their invaluable practical knowledge.

The author will always appreciate the generous support and assistance offered by his fellow graduate students, Shahab Shafai and Shokry Rashwan.

A special thanks is extended to Norma Lindsay, of the University of Manitoba, for being a constant source of help throughout my under-graduate and graduate studies.

I also wish to express very special appreciation to my family, and especially my brother , Masoud, whose unending support, has been my inspiration throughout my studies.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter I

INTRODUCTION

1.1 INTRODUCTION

This study investigates the strength gain in standard masonry blocks that contain flyash as a partial replacement for cement. Flyash is a by-product of power plants using powdered coal as a fuel. Since flyash has pozzolanic properties and is cheaper than portland cement, there is a considerable interest in the exploitation of its use as a partial replacement for portland cement. Flyash as a mineral admixture has been used in other concrete products for a long time. Partial replacement of cement with flyash is basically used for overall economy and, in some cases, it is used to; (i) improve ultimate strength, (ii) reduce heat of hydration in mass concrete structures, and (iii) improve pumpability of concrete.

However, use of flyash in concrete block masonry is fairly new, and research in this field is very limited. The reason for the lack of research in this field could be due to the assumption that flyash reduces the early strength development in the block. Even though it is believed that flyash is a substance that retards strength development, and that its strength gain due to the pozzolanic reaction does not start early enough for use in concrete block production, there are some flyashes that may exhibit equal performance to portland cement at early ages. In addition, advanced curing procedures and proper use of water-reducing admixtures are important factors in accelerating the early strength development in the production of concrete blocks.

Procedures involved in prodution also have a great effect on the quality of the final product. In mass concrete block production, consistency in the operation of machinery and the human judgement exercised in adjusting them is very important. For example, in a given 17 hour period of curing, the duration and temperature at various stages of curing has a major effect on the strength development of the block.

1.2 OBJECTIVE

The purpose of this project was to study the strength gain in concrete blocks based on variation in the mix components, and to review the procedures involved in concrete block production at a local plant. The economics of utilizing flyash as a partial replacement for portland cement were also investigated, and a recommendation for the most economical block for production at that plant was prepared.

1.3 SCOPE

There are many factors which affect the early strength development of the blocks such as the proportion of mix components and the procedures involved in production. This study mainly concentrates on the former factor. Compressive strength tests were conducted at 1, 7, and 28 days, in order to study the strength gain in concrete blocks with various proportions of aggregates, flyash, and admixture. Prior to these compressive strength tests, sieve analysis was also performed on fine and coarse aggregates to determine their gradations.

In addition, cost analysis based on the optimization technique was used to recommend the most economical concrete block mix for production for this particular plant.

Chapter II

MATERIAL PROPERTIES AND PRODUCTION PROCEDURES

2.1 INTRODUCTION

The proportions of components in concrete block mix have a great influence on the strength development of the concrete block. The main ingredients in a concrete mix for block production are; cement, aggregates, flyash, and chemical admixtures. Cement due to its cementitious value is the most essential component of the mix. Partial replacement of cement with flyash as a cementitious material tends to improve the quality of the block and it also reduces the cost of the production. The proportions of fine and coarse aggregates in the mix are very important since they affect the quality and appearance of the final product. Chemical admixtures such as water-reducing agents are known to improve cement hydration and, in turn, the early strength development that may be affected by the presence of flyash. Admixtures are also used to improve the texture and appearence of the concrete block.

Procedures and methods involved in the production of masonry block also effect the quality of the final product. In an automated or semi-automated plant, regular inspection is necessary to make sure that the machinery is operating accuratly and consistently. Human judgement is also a big factor; experienced and knowledgable operators are needed to make the necessary adjustments based on their observations and their testings. Concrete block mix has a zero slump, and therefore, the amount of moisture in the mix has to be checked constantly. The degree of vibration and compaction in molding the block, the performance of the mixer in producing a uniform mix, and temperature in different stages of the curing process are only a few aspects that have to be monitored regularly in producing a quality block.

This chapter will review the physical and chemical properties of the individual mix component and review several stages in production of concrete block masonry.

2.2 CEMENT

The type 10 cement which is used for general concrete construction is also used in concrete block mix. The type 30 cement which produces higher early-strength could be very beneficial in concrete block mix. However, this type of cement is not generally used since, due to its rapid hydration, it could damage the machinery. The rate of hydration of cement mainly depends on its chemical composition. The major chemical components in cement are(1):

1. Tricalcium Silicate $3CaO.SiO_2$ (C_3S)

C_3S is mostly responsible for the early strengths in the concrete mix.

2. Dicalcium Silicate $2CaO.SiO_2$ (C_2S)

   C_2S in the mix hydrates very slowly which, in turn, is responsible for the long term strength.

3. Tricalcium Aluminate $3CaO.Al_2O_3$ (C_3A)

   C_3A hydrates very rapidly and controls the setting time. This portion of cement is attacked by sulfates.

4. Tetracalcium Aluminoferrite $4CaO.Al_2O_3Fe_2O_3$ (C_4AF)

   C_4AF has little effect on the properties of cement other than contributing to colour.

The early strength of the concrete depends on the amount of C_3S but the long term strength depends on the sum of both C_2S and C_3S content. Portland cement consists essentially of crystalline compounds of calcium combined with silica, alumina, iron oxide and sulfate. The approximate composition and amount of principal minerals in type 10 cement are (2): C_3S= 50% , C_2S= 25% , C_3A= 10% , C_4AF= 8% , CSH_2= 5% . When water is added to cement the above minerals begin to ionize and form the hydrated products.

The chemical reactions of hydration of cement compounds are very complex and generally do not proceed to completion. However, the hydration of the silica minerals in cement is highly cementitious and constitutes about 60 to 65% of the total solids in a fully hydrated cement. The other product, calcium hydroxide, contributes little to the cementitious properties of concrete product. The calcium hydroxide is also more soluble and alkaline, and thus it is easily subjected to attack by water or acidic solutions. However, as discussed below, flyash consumes this calcium hydroxide and strengthens the concrete product.

2.3 AGGREGATES

Aggregates in concrete blocks are basically coarse aggregate (6mm stone) and fine aggregate (sand). The coarse aggregate is about 40% of total aggregate in the mix and the remaining 60% is fine aggregate. Nevertheless, these percentages could vary according to their individual gradation and the desired strength and texture. There are basically three types of sand: fine drift, medium, and coarse sand. Medium sand is generally used in producing concrete block masonry units. Medium sand is graded up to the no. 8 sieve, and its fineness modulus is between 2.5 to 3.0.

According to ASTM C33, the maximum size of the coarse aggregate should be less than 1/3 of the thinnest section of the block. The coarse aggregate usually is graded up to the no. 4 sieve, with a fineness modulus of 5.0 to 5.75. Table 2.1, shows typical gradations of sand and the coarse aggregate and their desired combinations with a fineness modulus of 3.7 (3).

TABLE 2.1

Aggregate Gradation (3)

Sieve No.	Sand %Retn.	Sand Accum.%	Stone %Retn.	Stone Accum.%	Combination Ideal
3/8	0	0	0	0	0
4	0	0	63	63	25
8	10	10	30	93	15
16	19	29	2	95	15
30	21	50	1	96	15
50	33	83	1	97	15
100	12	95	1	98	10
Pan	5		2		5
Total	100	267	100	542	100
	F.M.=2.67		F.M.=5.42		

The ideal gradations of concrete block mix can be divided into 3 groups: coarse, medium, and fine. The coarse group which contains about 40% of the total blend, comprises the percentage retained on sieves no. 4 and 8. The medium group represents 45% of the total blend, which is the amount retained on sieves no. 16, 30, and 50. The fine group represents the no. 100 sieve and the pan size, and it forms the remainding 15%. The presence of the fine group is important to bind the concrete into a tight mass. Fine particles also permit homogenous mixing and the desirable smooth and even surfaces of the block. Figure 2.1, shows the suggested and practical limits in aggregate gradation for normal weight concrete blocks(3).

The proportioning of the aggregate is based on their fineness modulus(F.M.), which is calculated according to the formula below(3):

$$x = 100 * (A - B / A - C)$$

where:

x = Desired percentage of the fine aggregate

A = F.M. of the coarse aggregate.

B = F.M. of desired or combined aggregates (3.70).

C = F.M. of the fine aggregate.

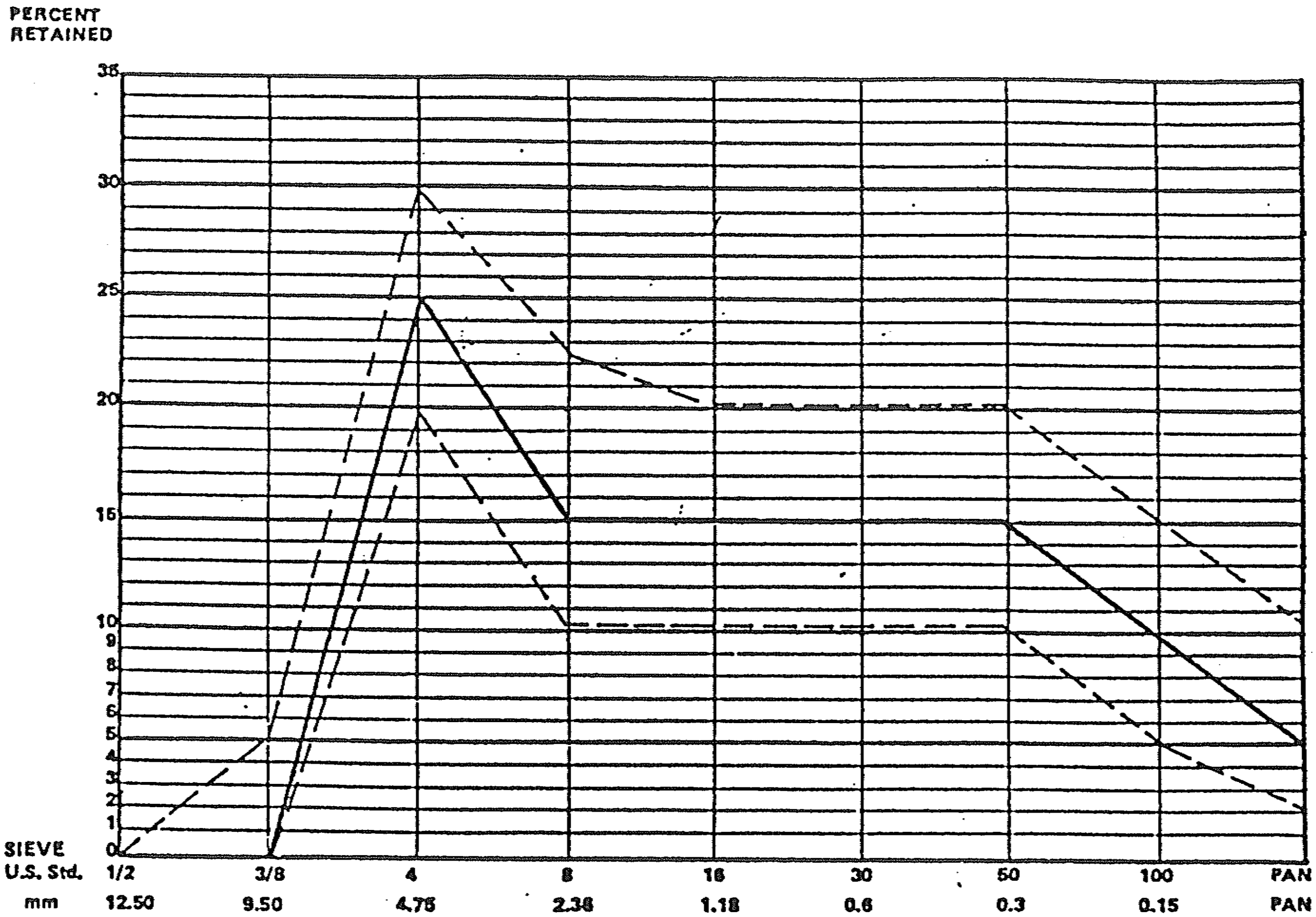

Figure 2.1: Suggested and Practical Aggregate Gradation (3)

2.4 FLYASH

Flyash is produced during the combustion of powdered coal in power plants. As coal passes through the high temperature zone in the furnace, the volatile matter and carbon are burned off and most of the mineral impurities such as clay, shale, quartz, and feldspar generally fuse and remain in suspension. The fused matter is quickly transported to a lower temperature zone where it solidifies as spherical particles. Flyash consists of glassy spheres of 1 to 100 μm, and the typical particle size is under 20 μm (2).

Flyash is a pozzolan and according to ASTM C595, a pozzolan is defined as " A siliceous or siliceous and aluminous material which in itself possess little or no cementitious value but will, in finely divided form and in presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties ". The reaction of pozzolan with lime is called the pozzolanic reaction. Flyash due to its fine particle size and generally noncrystalline character shows pozzolanic activity. There are two distinctive groups of flyashes: the lime-rich (High-Calcium flyash), and the lime-poor (Low-Calcium flyash). This grouping is associated with the origin of the flyashes from lignite type and sub-bituminous to bituminous coal formation. This difference is mainly in their calcium content. The lime-rich flyashes usually have 15 to 35% CaO, whereas, the lime-poor flyashes have less than 5%

CaO. The ASTM C618, classifies these two groups indirectly based on their non-calcium oxides (silica + alumina + iron) as class F and class C. The minimum requirement of the non-calcium oxides in class F and C are 70% and 50% respectively. Table 2.2, shows typical compositions of two types of flyashes in North America in comparison with type 10 cement

TABLE 2.2

Oxide Analysis

	cement	lime-poor	lime-rich	Genstar-flyash
SiO_2	22	48	38	43.6
Al_2O_3	6	28	22	13.4
Fe_2O_3	3	9	4	6.9
CaO	63	4	24	22.7
MgO	3	2	5	
SO_3	2	1	3	2.5
LOI	1	5	1	0.1

and flyash being used at Genstar Building Material plant. The chemical compositions of the two groups of flyash are also shown in figure 2.2, in the CaO, SiO_2, and Al_2O_3 phase diagram(5). As can be seen from the diagram, the lime-rich flyashes are in the portland cement/blast furnace slag ranges of composition, therefore they possess enough free lime for hydration. The lime-poor flyashes are in the range of blast furnace slag composition up toward the zero CaO line. Another difference between the two groups of flyash is in the amount of carbon content. The low-calcium flyashes have 2 to 10% unburned carbon while the high-calcium flyashes have less than 1% carbon. The amount of carbon in flyash can be determined by the loss on ignition test. Carbon is capable of absorbing large amounts of water from the solution. Therefore, flyash with high carbon content requires more water (4).

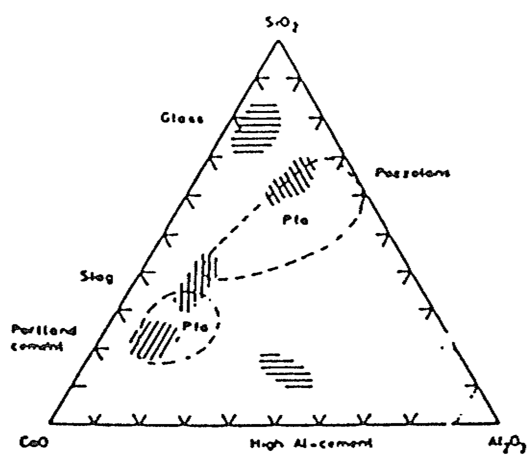

Figure 2.2: Phase Diagram (5)

The chemical composition of flyashes could change due to the local raw materials. However, this normally has little influence on the pozzolanic and cementitious properties of the material (2). The rate of hydration of flyash generally depends on the mineralogical composition and particle characteristics of flyash rather than its chemical composition. The minerals in low-calcium flyashes are generally less active than the minerals in high-calcium flyashes (6). The particles in high-calcium flyash have a rough texture and in turn, larger surface area for reactivity than the smooth spheres in low-calcium flyashes. The low-calcium flyashes show a cleaner appearance because there is lower surface deposit of alkalis (7).

2.4.1 Effect of Flyash on Concrete Strength

Concrete blocks are produced through substantial vibration and pressure, and they experience a lengthy curing process which could alter their strength drastically. The amount of flyash used in concrete block production is normally determined by trial-and-error. Research in this field is very scarce. However, there are numerous studies on the effect of flyash on the strength of normal concrete products which is briefly discussed below. There are two factors that affect the strength of concrete: (a) the presence of large voids in the hydrated cement paste, and (b) microcracks at the aggregate/cement transition zone. Partial replacement of cement with flyash generally improves the strength of the concrete. This is achieved through transformation of large pores into finer pores and also reduction of microcracking in the transition zone (8,9,11). This is associated with the pozzolanic reaction of flyash which consumes the calcium hydroxide produced during the cement hydration and strengthen the transition zone, and reduce the larger pores within the concrete. The transition zone contains large amounts of calcium hydroxide and it is generally less dense than the bulk paste, and is more prone to microcracks. Therefore, it is the weakest part of the concrete. According to several researchers (10,12,13), the presence of flyash reduces the amount of calcium hydroxide in the transition zone.

In general, the strength development is a function of the porefilling proccess which takes place with the formation of the hydration products. Therefore, the strength development is related to; mineralogical composition and particle characteristics of the flyash, composition of portland cement, concrete mix proportion, water to cement+flyash ratio, and curing temperature and humidity.

2.5 CHEMICAL ADMIXTURES

Chemical admixtures have been used in concrete products for a long time. The principal active components of the admixtures are surface-active agents. The substances give cement particles a negative charge which leads to repulsion between the particles and results in stabilizing their dispersion(1). The dispersion of the cement particles leads to exposing a greater surface area, which in turn increases the hydration of cement at the early ages. The admixtures have little effect on the flyash-lime reaction, but their presence is important in utilizing the remainder of the cement in the mix. The admixtures generally reduce the mixing water by about 5 to 10%, but the actual decrease in mixing water depends on cement content, type of aggregate, and the presence of flyash. It is apparent that trial mixes containg the actual materials are essential in order to determine the type and quantity of the admixture.

Master Builder (14), the producer of different types of admixtures, claims that proper use of admixtures could improve the quality and production of concrete block in a given plant. The admixtures could be a strength-enhancing admixture, texturizing admixture, accelerating admixture, or a combination of products. Following are some of the features associated with Lubrilith 30, which is a combination product and it is being used at Genstar concrete block plant in Winnipeg.

1. Development of higher early strength.
2. Increases compressive strength at all ages.
3. Improves cohesiveness (moldability of the mix).
4. Improves block appearence (texture, color, and uniformity in the block)
5. Faster and smoother machine operation.

The quantity and cost of admixtures are very small compared to the overall improvement of the product. Therefore, use of admixture is essential in today's competitive concrete block production.

2.6 AGGREGATE WEIGHT VARIATION

In order to produce a uniform block, the proportion of the mix components must be kept constant. However, this proportion could be easily altered due to the amount of moisture in the aggregates. It is important to note that, while no-slump concrete block mixes appear to be dry the water/cement ratio is about 0.5 and the amount of water in the mix, based on the dry weight, is about 6% of the total aggregates (3). In an automated plant the mixer, through electric conductivity, determine the amount of moisture in the aggregates and automatically adds the additional required water to the mix.

The amount of added water gives some idea about the moisture in the aggregates. For instance, if a dry batch requires about 240 litres of water, but the meter shows only 80 litres of water being added, it is obvious that 160 litres of entrapped moisture was weighed over the scales and assumed to be the aggregates. This amount of water (160*2.2=352 lbs) in the batch leads to a smaller yield, and use of more cement per block, which is not economical and strengthen the block more than it is necessary.

2.7 MIXING

The mixing phase of concrete is one of the major factors in producing a good quality concrete block. Proper mixing blends all the ingredients of the concrete mix to produce uniform mixes of the lowest slump practical for production. Therefore, equipment and methods used should be capable of effectively mixing the concrete materials.

For a normal concrete mix, the recommended mixing time is 1 minute for one cubic yard plus 1/4 minute for each additional one. However, final mixing time should be based on the performance of the mixer(15). The mixing time in concrete block production is longer, due to the fact that uniform texture and a smooth surface are very important in quality of the block. The mixing time for a concrete block mix is divided into two parts (a) drymixing, and (b) wetmixing. Drymixing is when the mixer is charged with aggregates first and then the cementitious materials. The minimum drymixing time is about 1 minute. Wetmixing is when the water is added to the mix, and mixing should continue for 2 to 4 minutes. Note that mixing water must be pure enough for drinking and has to be added evenly to the mix. When tempering water is required to bring the mix to the right consistancy, an additional minute of mixing is necessary (3).

2.8 CURING

The primary purpose of accelerated curing of concrete is early strength development. ACI committee 517 (23) deals with curing of structural concrete material such as, concrete block, pipe and precast concrete. The masonry blocks are made with zero slump mix and they are molded through intense vibration and pressure. They also have small mass compared to their surface area which leads to rapid heat transfer and moisture evaporation. Therefore, the curing procedure is very important in accelerating the hydration of the cementitious materials.

In concrete block production, steam at atmospheric pressure (low-pressure steam curing), has the advantage over other methods of accelerated curing (16). In low pressure steam curing, the kiln is near saturation in regard to moisture. The evaporation of moisture from the products is also minimized, which is very important in demolded products. In order to acquire the minimum block strength requirement in 24 hours, the curing procedure of concrete block has been divided into several stages as follows.

2.8.1 Presetting

From the time the concrete blocks are stripped from the mold to the time steaming begins is called the preset time. During this period, the block must withstand several material handling operations. The initial setting of concrete must also be attained during this stage, before the application of steam or heat. At this stage, it is mostly the mix cohesiveness rather than the cement hydration which is holding the block's shape. Since flyash increases the cohesiveness of the mix, use of flyash improves the green strength of the block during this preset time. Nevertheless, flyash is a retardant substance and delays the initial setting of the concrete and could benefit from an extended preset time.

The length of the presetting period depends on the type of aggregates and the seasonal temperature. The minimum recommanded presetting time is 2 hours (16), and higher during the winter time. For the best results during the preset time, the temperature of the green concrete should not be less than 65 °F (18.3°C). The minimum temperature at which the concrete will start normal hydration is about 50°F (10° C). The presetting period is very important in strength gain and in preventing surface cracks in the block.

2.8.2 Steaming

Moisture is essential in curing of all concrete products. During steaming, moisture is generally provided through steam condensation. The steaming period is divided into two phases: (i) presteaming, and (ii) maximum temperature steaming (16). The temperature at the presteaming phase is kept between 60-100°F to avoid possible internal stresses that may occur during the high-temperature rise. The duration of presteaming depends mainly on aggregate type and the temperature of block during the preset time.

After the presteaming period, the temperature of the kiln is increased at a rate of 60°F/hr, until the equilibrium temperature has been reached (temperature of block equal to temperature of the kiln). The equilibrium temperature is usually about 170°F, but the correct temperature has to be checked through an equilibrium test. When the equilibrium temperature is reached in the kiln the steaming must stop, because steaming beyond the equlibrium temperature results in greater vapour pressure in the block than in the surrounding air and moisture is forced out of the block. It is important in both presteaming and temperature rise that the relative humidity of the kiln be above 90% (16).

2.8.3 Soaking

After equilibrium is reached and the steam has been shut off the blocks stay in the kiln for a period of time known as the soaking period. During this period, the temperature drop should be about 5 $^{\circ}$F/hr (16). As the temperature drops off the relative humidity increases and deposits moisture on the block. The soaking period is very important in the hydration of the cement, since the blocks are cured in high temperature and moisture.

2.8.4 Drying

The drying cycle follows the soaking period. Drying or carbonation treatment of masonry units causes the initial shrinkage, which tends to stablize the moisture content and the volume of the block. The duration of the drying cycle depends on the desired moisture content, which generally varies with the type of aggregates. The drying temperature should be under 250°F (121°C), since the higher temperature may have a serious effect on structure of the kiln. Generally if the drying cycle is part of the curing process, the minimum 12 hr requirement of steaming and soaking can be reduced (16).

Chapter III

TESTS AND PROCEDURES

3.1 INTRODUCTION

There are many factors involved in the production of good quality concrete blocks. Economical reasons, marketability of the product and standard strength requirements are some of the aspects of production that have to be kept in mind. Due to the substantial cost associated with production of trial batches, the number of tests in this investigation were limited. For the same reason the objective of the proposed test batches was to modify and improve the present mix. The present mix batches for normal concrete block contain 360 lbs. of cement and 240 lbs. of flyash which is 40% of the total cementitious material. The aggregates in the mix are 1800 lbs. of coarse aggregate and 3200 lbs. of sand which forms 36% and 64% of the total aggregate respectivly. The amount of admixture used in every batch was 16 ounces of Lubrilite 30.

The aggregates used by the industry are from a privatly owned pit and gradation of the aggregates were not known. Therefore, sieve analyses were conducted to determine the gradation of aggregates in the mix. The compressive strength tests were conducted to study mainly the variation in strength gain due to different mix proportion. Strength tests involved an examination of the effect of:

I) Aggregate proportion

II) Flyash-Cement replacement

III) Admixture content

The most important factor in the compressive strength tests was the required 24-hour strength of the block of 1000 psi. The early strength gain in concrete block is essential in the cubing process and in keeping up with market demand during the summer. The following sections will describe the sieve analysis and compression tests on different proportions of individual components in the mix.

3.2 SIEVE ANALYSIS

In order to study the aggregate gradation in the Genstar's concrete block mix, sieve analyses were conducted on coarse and fine aggregates. The coarse aggregate is 6 mm stone, called Buck Shot, and the fine aggregate is basically concrete sand. For sieve analysis, samples of coarse and fine aggregates were oven dried at a temperature of 220 °F. Approximatly 2.5 pounds was used for each analysis and the percentage retained and the accumulative percentage retained [1] were calculated and recorded. Also the fineness modulus

---

[1] The percentage retained in the pan size is not added to the accumulative percentage retained.

of both aggregates were found by dividing the accumulative percentage retained by 100.

Results of sieve analyses on the coarse aggregate, table 3.1, show that the percentage retained on sieves #4, and #8 are much lower than the recommended values of table 2.1. However, the percentage retained on sieves #16, #30, and #50 are much higher. The gradation in sand, table 3.2, also varies greatly from the recommended values. It appears that the sand being used by the industry is coarser than the suggested type.

TABLE 3.1

Sieve Analysis on Stone

Weight of The Sample (Oven Dry)=2.36 lbs

Sieve No.	Wt. Retn. (lbs)	%Reta.	Accum.% Reta.
3/8	0.0	0.0	0.0
4	0.52	22.0	22.0
8	1.28	54.2	76.2
16	0.38	16.1	92.3
30	0.10	4.2	96.5
50	0.04	1.7	98.2
100	0.02	0.8	99.0
Pan	0.02	0.8	
Total	2.36	99.8	484.2

F.M.=4.84

TABLE 3.2

Sieve Analysis on Sand

Weight of The Sample (Oven Dry)= 2.50 lbs

Sieve No.	Wt. Retn. (lbs)	%Retn.	Accum.% Retn.
3/8	0.00	0.0	0.0
4	0.04	1.6	1.6
8	0.36	14.3	15.9
16	0.52	20.6	36.5
30	0.58	23.0	59.5
50	0.50	19.8	79.3
100	0.36	14.3	93.6
Pan	0.16	6.3	
Total	2.52	99.9	286.4

F.M.=2.86

TABLE 3.3

Gradation of Combined Aggregate

Sieve No.	Stone 36%	Sand 64%	Total	Accum.% Retan.
3/8	0.0	0.0	0.0	0.0
4	7.9	1.0	8.9	8.9
8	19.5	9.2	28.7	37.6
16	5.8	13.2	19.0	56.6
30	1.5	14.7	16.2	72.8
50	0.6	12.7	13.3	86.1
100	0.3	9.2	9.5	95.6
Pan	0.3	4.0	4.3	

Total=357.6
F.M. =3.58

At the time of the investigation, the industry was using 36% stone and 64% sand, and based on this ratio the gradation of the combined aggregate in the mix was calculated and is shown on table 3.3. Figure 3.1, shows the gradation of the combined aggregate which has been superimposed on recommended and practical boundaries of aggregate gradation for concrete block mix (fig. 2.1). The result indicates a deficiency of larger aggregate size which could be rectified by increasing the percentage of coarse aggregate in the mix.

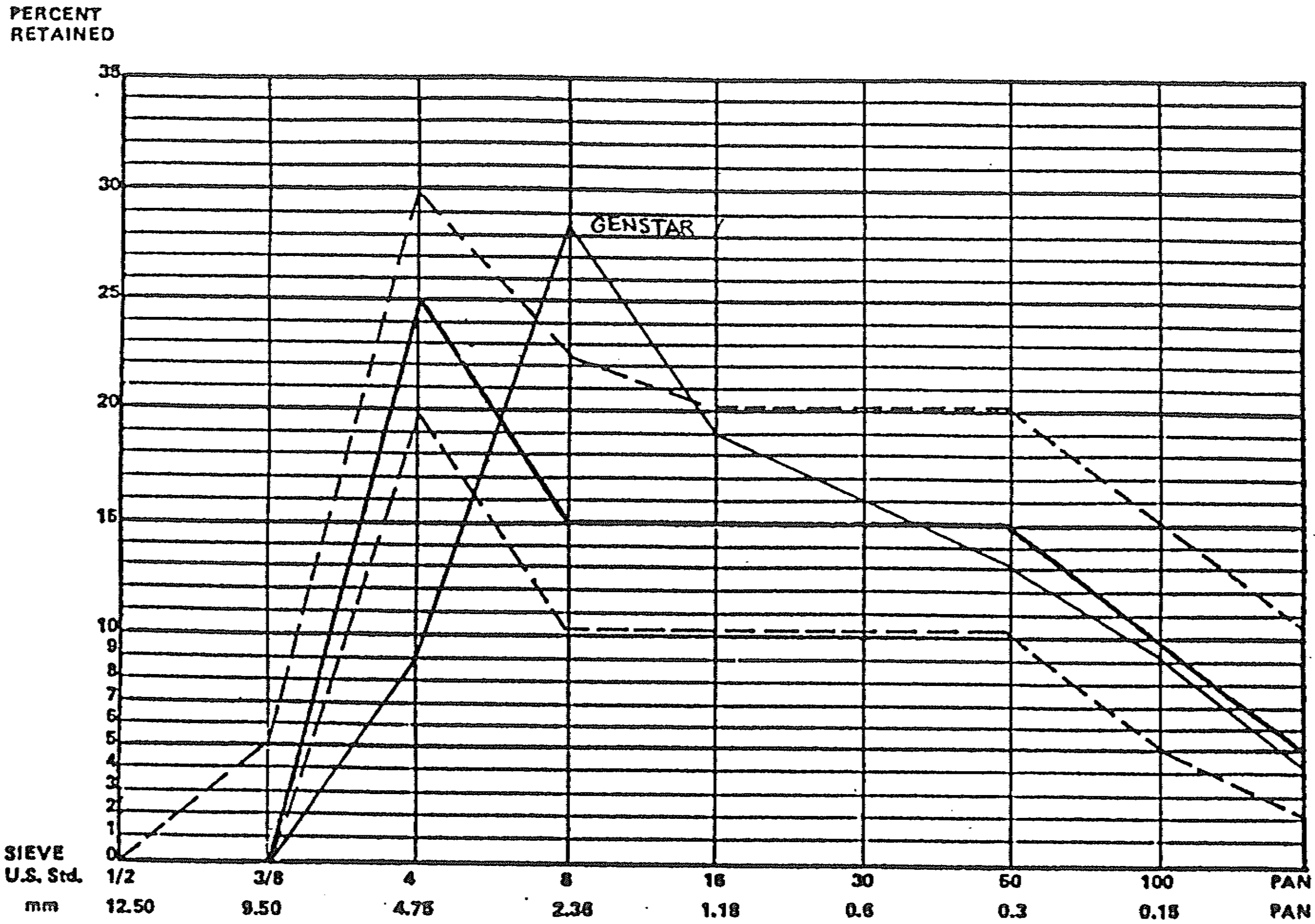

Figure 3.1: Genstar Aggregate Gradation Superimposed on Fig. 2.1

3.3 COMPRESSIVE STRENGTH TESTS PROCEDURES

The test batches were monitored closely; production time, the temperature, cycle time, and the amount of water added to the mix were recorded for every test batch. The curing process consisted of 3 hours of presetting, 2.5 hours of steaming at 160-180 °C temperature, 4 hours of soaking, and 7 hours of venting. The blocks were produced and cured at the Genstar Building Material plant and transfered to the University of Manitoba for capping and testing. Moisture content was determined for all test batches by taking a sample of the mix, after being discharged from the mixer, and before being transfered to the hopper. The samples were oven dried at 220 °F temperature and the moisture content and W/C+F [2] were calculated.

For compression tests, prior to testing, all the specimens were weighed and capped by Plaster of Paris for a uniform and smooth surface. Each time the Plaster of Paris was spread evenly on a steel plate surface which was lightly coated with oil. The blocks are then placed on the capping paste and firmly pressed down in a single motion. The thickness of capping was kept below 3 mm. According to ASTM C140-75, the plaster of paris should dry for at least two hours before testing. However, for 24-hour tests, this was not possible and the cappings were not completly dry. The

---

[2] W/C+F is water over cementitious material, (ie. cement+flyash).

tests were conducted in a compression testing machine with a capacity of 300 Kips and care was taken to center every specimen under the load. For 1 and 7-day tests, the rate of loading was rapid up to 45,000 lbs., then it was reduced to 1000 lbs/sec up to the failure. The rate of loading for 28-day tests was rapid up to 80,000 lbs.

3.4 AGGREGATE PROPORTION TESTS

The results of sieve analysis indicated that a higher percentage of coarse aggregate (greater than 36%) could be used in the mix. By increasing the coarse aggregate, it was also hoped to reduce the amount of moisture required for the mix, which in turn could improve the strength in the block. However, the texture and appearance of the block was the main concern and had to satisfy market standards. Therefore, the compressive strength test on different percentage of coarse and fine aggregates was conducted not only to study the strength gain in the block but also to observe any variation in the texture of the block.

The present mix batches contain 36% of stone and 64% of sand. The proposed test batches were to try 38% and 40% stone in the mix. Table 3.4, shows the moisture variation in trial batches. The increase in percentage of stone does not clearly indicate a reduction in moisture content. In fact the moisture content compared to the present mix appears to reduce with 38% stone and increase with 40% stone, as shown on figure 3.2.

TABLE 3.4

Moisture Variation in Aggregate Tests

	Test No.1	Test No.2	Test No.3
% Stone	36	38	40
Water Added (litre)	41	41	43
No. of Cycles/Min.	6.4	6.5	6.5
% Moisture	4.77	4.62	5.04
Water in Batch	255	247	269
W/C+F	0.43	0.41	0.45

Table 3.5, shows the result of compressive strength tests at ages of 1, 7, and 28 days. The results are based on average of three specimens. It is interesting to note that the average weight of the block seems to reduce with increase in percentage of the stone. This could be due to the better compaction in mixes with a higher sand content. The reduction in average weight of the block at 28 days is clearly caused by drying shrinkage.

Plotting the different percentage of stone against the compressive strength, figure 3.3, does not show clearly the trend in variation of 24-hour compressive strength. However, careful investigation indicates that the 24-hour strength seems to reduce with the increase in percentage of stone. As was expected for the 7-day tests, the compressive strength appears to increase with increase in percentage of stone. The 28-day tests basically have the same compressive strength pattern as the 24-hour tests, and the mix with 40% stone shows higher strength than the other two combinations.

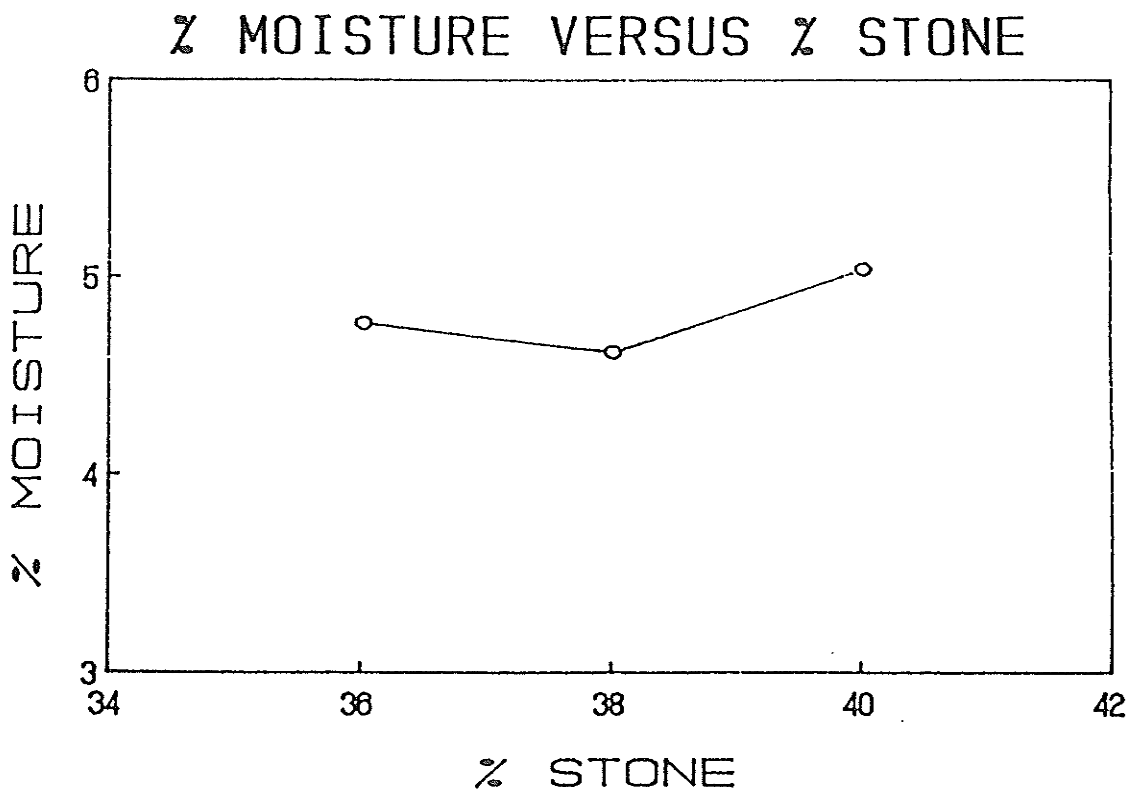

Figure 3.2: Moisture Variation in Aggregate Tests

The difference in strength gain from 1-day to 28-days seems to increase with the increase in the percentage of stone. This increase is 580, 604, and 636 psi for 36, 38, and 40% stone respectively. Figure 3.4, shows a plot of compressive strength against time for these three test batches. As shown in this figure all three test batches behaved in a similar fashion. The difference in compressive strength of these test batches are only 96, 61, and 122 psi. at 1, 7, and 28 days of testing respectively.

TABLE 3.5

Compressive Strength Result in Aggregate Tests

Test No.1
Stone=1800 lbs (36%) , Sand=3200 lbs (64%)

Testing Date	Ave. Weight (lbs.)	Age (Day)	Ave. Ult. Load (lbs.)	Ave. Ult. Strength (PSI)
Dec. 16	39.2	1	105300	917
Dec. 22	38.8	7	139300	1213
Jan. 12	38.3	28	172000	1497

Test No.2
Stone=1900 lbs (38%) , Sand=3100 lbs (62%)

Testing Date	Ave. Weight (lbs.)	Age (Day)	Ave. Ult. Load (lbs.)	Ave. Ult. Strength (PSI)
Dec. 16	39.1	1	94300	821
Dec. 22	38.5	7	143300	1248
Jan. 12	38.1	28	163700	1425

Test No.3
Stone=2000 lbs (40%) , Sand=3000 lbs (60%)

Testing Date	Ave. Weight (lbs.)	Age (Day)	Ave. Ult. Load (lbs.)	Ave. Ult. Strength (PSI)
Dec. 16	38.9	1	105000	911
Dec. 22	38.5	7	146300	1274
Jan. 12	38.3	28	177700	1547

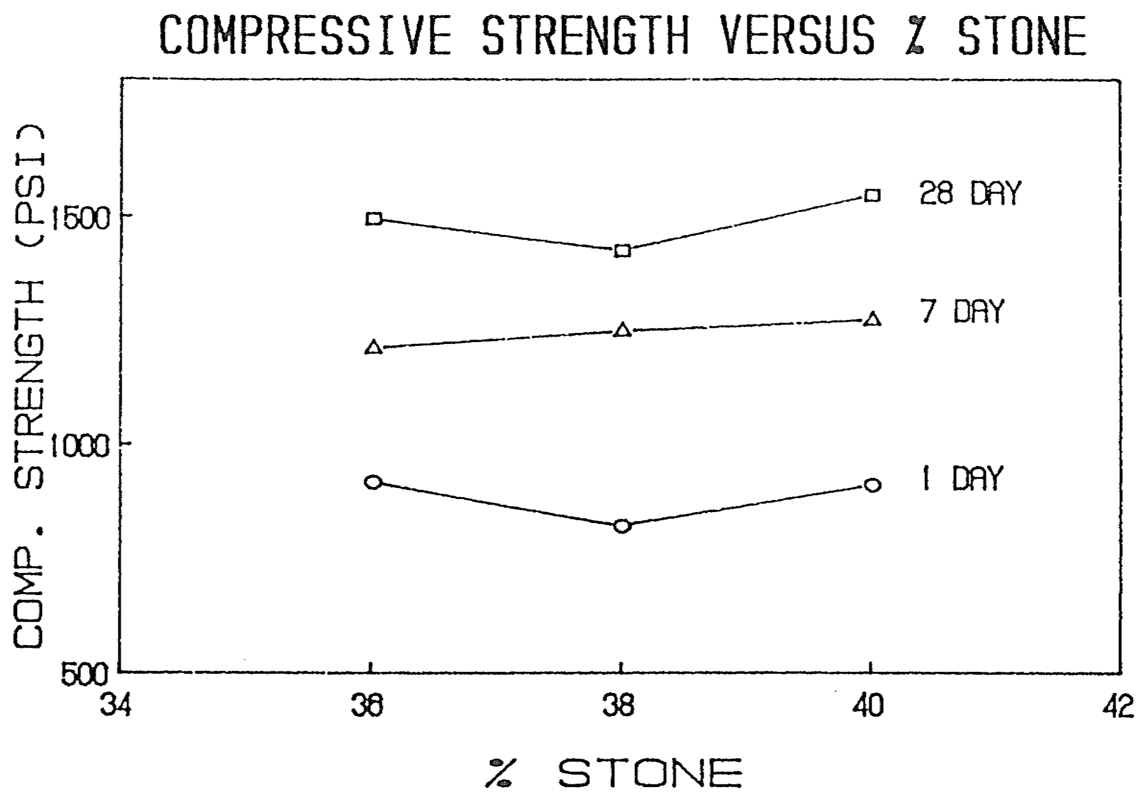

Figure 3.3: Compressive Strength Versus % Stone

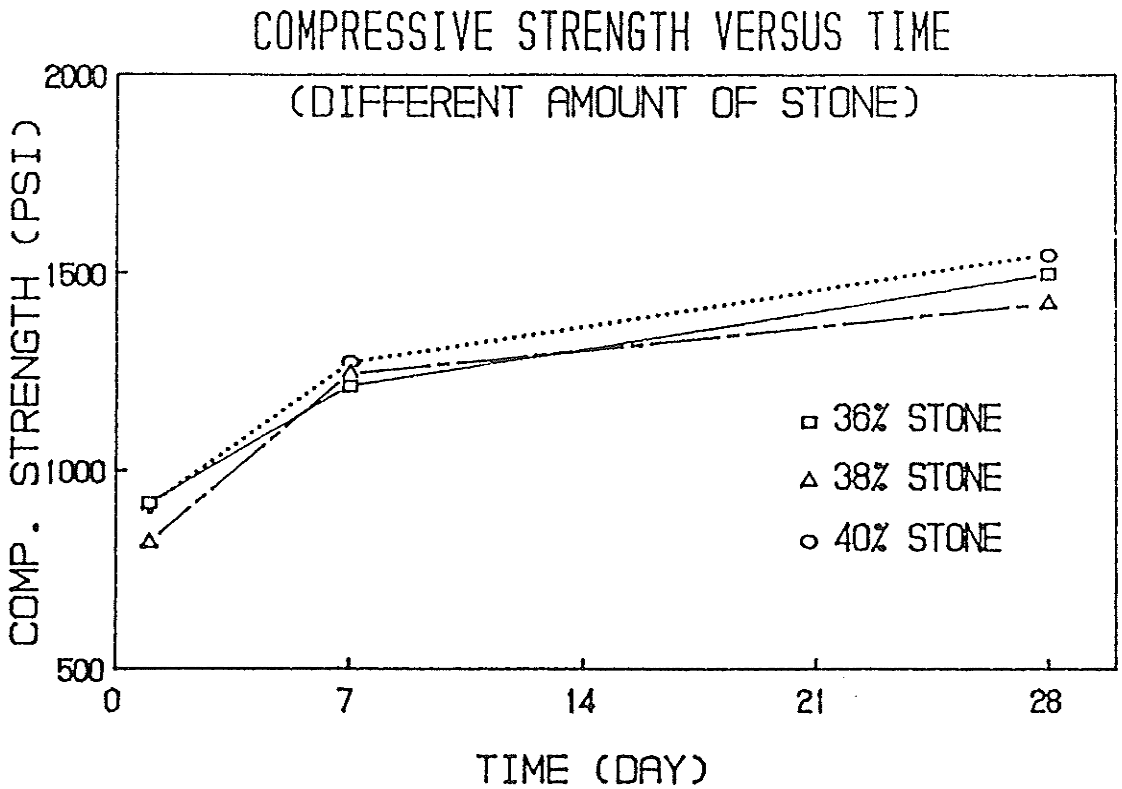

Figure 3.4: Compressive Strength Versus Time

3.5 FLYASH-CEMENT REPLACEMENT TESTS

At the beginning of this project, the industry was producing concrete block with 33% flyash as partial replacement for cement. Tests conducted on 40% flyash replacement at the company's request were confirmed to satisfy the required 24-hour compressive strength, which is 1000 psi. However, further testing was needed to study the effect of this particular flyash on moisture content and final strength of the concrete block.

The trial batches were made with no flyash replacement as a control set and with 33%, 40%, 45%, and 50% replacement. The 40% replacement is actually the test number 3 from the previous stage. The aggregate proportions used in those tests were 40% stone to 60% sand. Table 3.6 and figure 3.5, show the moisture variation due to the different

TABLE 3.6

Moisture Variation in Flyash-Cement Replacement Tests

	Test No.4	Test No.5	Test No.6	Test No.7
% Flyash	0	33	45	50
Water Added	31	39	42	48
Cycles/Min.	5.8	6.2	6.4	6.2
% Moisture	4.45	4.85	4.71	4.36
Water in Batch	239	259	252	234
W/C+F	0.40	0.43	0.42	0.39

percentages of flyash replacements. The result of the moisture test demonstrates that there is an increase in moisture

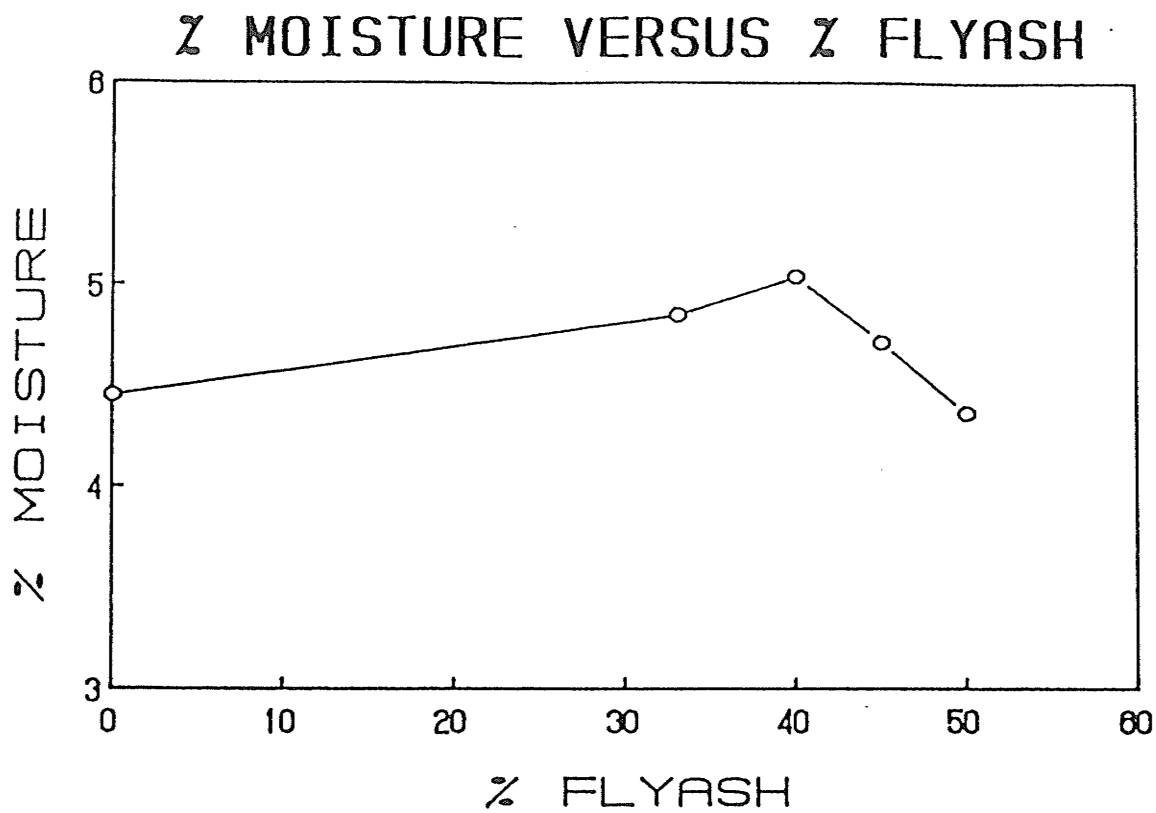

Figure 3.5: Moisture Variation in Flyash/Cement Replacement Test

content with an increase in the amount of flyash up to about 40% . However, the moisture content seems to reduce at higher flyash replacements.

The compressive strength test results on different percentages of flyash is shown on table 3.7. Figure 3.6, also shows the variation graphically for 1, 7, and 28 day tests. The average weight of the blocks seems to increase with an increase in flyash content. This could be due to smaller flyash particles and subsequently a better compaction of the blocks. The direct relationship between the moisture content and the 24-hour compressive strength tests is very clear. The compressive strength seems to increase with reduction in moisture content. As the amount of flyash increases in the mix, the 24-hour compressive strength appears to decrease up to about 40% replacement and increase at 45% and 50% flyash replacement. It is interesting to note that, 50% flyash replacement has the same 24-hour compressive strength as the control set. It appears that the lack of cement content at 50% replacement has been nullified with better compaction of relatively smaller flyash particles. The average weight of the blocks for the control set (0% flyash) and 50% flyash replacement at 1-day is 38.1 and 39.8 lbs. respectivly.

The compressive strength tests at 7 and 28-days generally followed the same pattern as the 24-hour tests. However, the rate of strength gain for 50% flyash replacement was very gradual in the first week, but it seemed to recover most of the strength at 28-days. The graph of compressive strength against time for different percentages of flyash is shown in figure 3.7. The strength gain for 50% flyash replacement is evident from this graph.

TABLE 3.7

Compressive Strength Results In Flyash-Cement Replacment Test

Test No.4
Cement=600 lbs (100%) , Flyash=0 lbs (0%)

Testing Date	Ave. Weight (lbs.)	Age (Day)	Ave. Ult. Load (lbs.)	Ave. Ult. Strength (PSI)
Dec. 17	38.1	1	130300	1135
Dec. 23	37.9	7	174000	1515
Jan. 13	37.5	28	202700	1765

Test No.5
Cement=400 lbs (66%) , Flyash=200 lbs (33%)

Dec. 17	39.1	1	111700	972
Dec. 23	38.7	7	164000	1428
Jan. 13	38.3	28	191300	1666

Test No.6
Cement=330 lbs (55%) , Flyash=270 lbs (45%)

Dec. 17	39.3	1	115700	1007
Dec. 23	38.8	7	169700	1477
Jan. 13	38.4	28	192700	1678

Test No.7
Cement=300 lbs (50%) , Flyash=300 lbs (50%)

Dec. 19	39.8	1	131300	1143
Dec. 25	39.5	7	159000	1384
Jan. 15	39.3	28	194000	1689

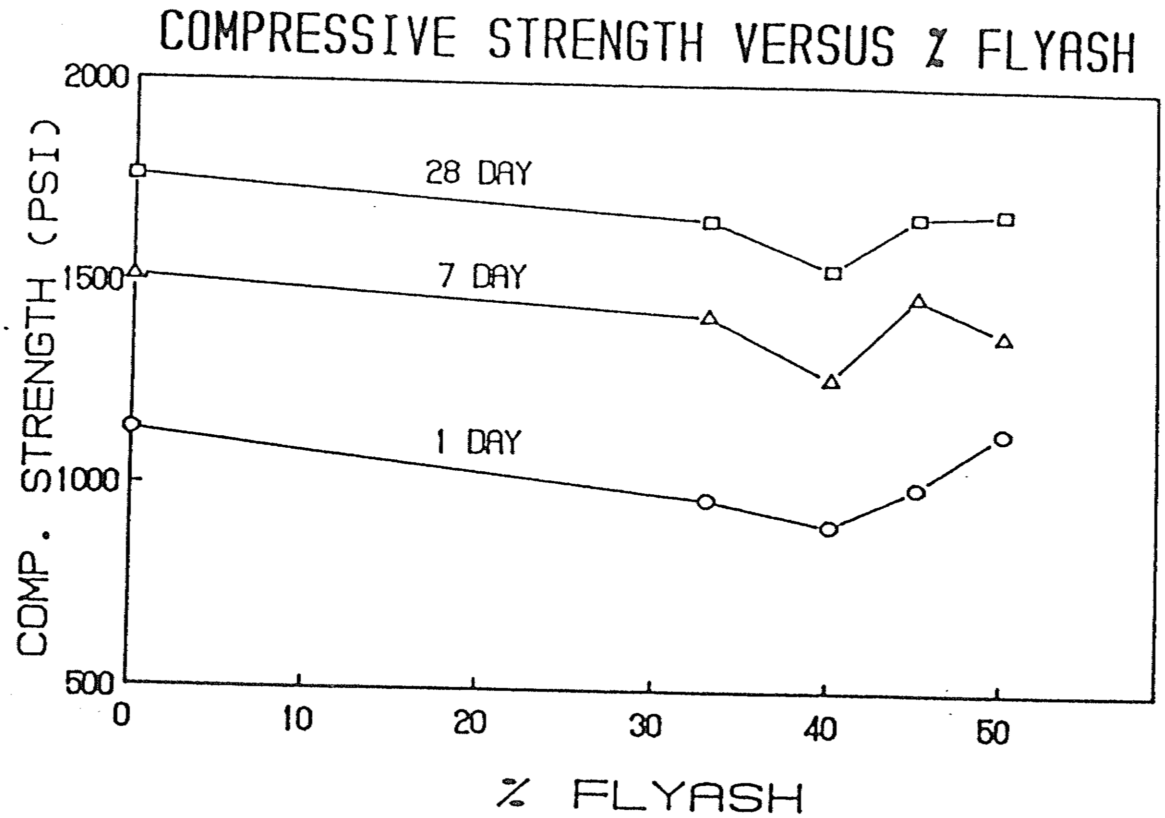

Figure 3.6: Compressive Strength Versus % Flyash Replacement

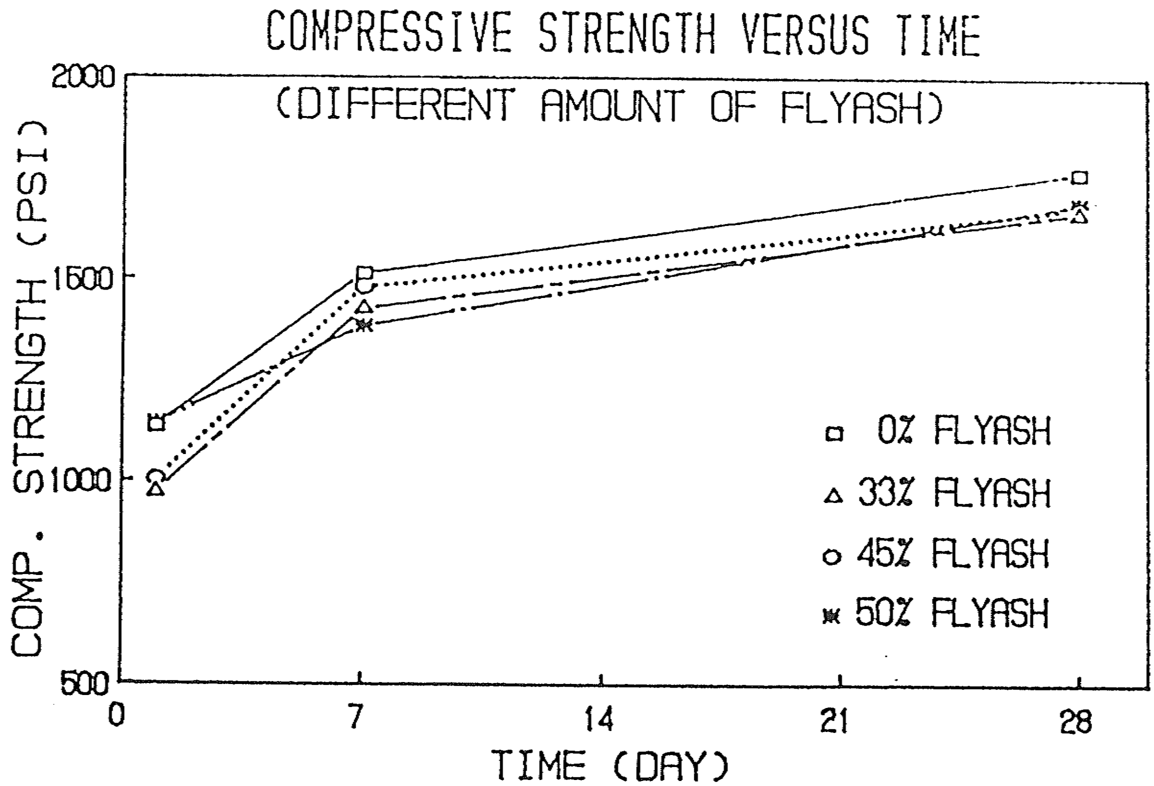

Figure 3.7: Compressive Strength Versus Time

3.6 ADMIXTURE TESTS

The proper use of admixture can be very beneficial in concrete block production, resulting in better utilization of cement, improving the cohesiveness and developing a higher early strength. At the present time, in every batch, industry is using 16 ounces of Lubrilith 30, which appears to have the above characteristics. The main concern of this project was the quantity of the admixture being used. The producer of this product, Master Builder, suggests that the amount Lubrilith 30 in the mix be between 190-500 ml/100 Kg. of cement. Therefore, based on 40% flyash replacement, the amount of admixture should be between 11 to 29 ounces. Test batches with higher amount of admixture, 20 and 24 ounces, were suggested to study the effect of admixture in the mix. Each batch contained 40% stone and there was 40% flyash replacement.

Table 3.8 and figure 3.8, show the moisture variation in trial batches. Results indicate that there is a reduction in moisture content due to the increase in the amount of admixture. More important are the results of compressive strength tests which indicates a substantial increase in 24-hour strength, as shown in table 3.9 and figure 3.9. The increase in the amount of admixture from 16 ounces to 20 and 24 ounces, has improved the 24-hour compressive strength by 10 and 14% respectively.

TABLE 3.8

Moisture Variation in Admixture Tests

	Test No.8	Test No.9	Test No.10
Admixture (oz.)	16	20	24
Water Added (l)	50	50	48
Cycle/Min.	6.2	6.1	6.2
% Moisture	4.67	4.48	4.44
Water in Batch	250	240	238
W/C+F	0.42	0.40	0.40

The improvement in compressive strength due to the increase in admixture is also clear in 7-day tests. However, the-28 day tests show that the compressive strength is almost identical in all three cases. This indicates the effect of admixture in speeding up the hydration of cement within the first 24 hours. The difference in compressive strength at 1, 7, and 28-day are 160, 72, and 23 psi respectively is shown in figure 3.10.

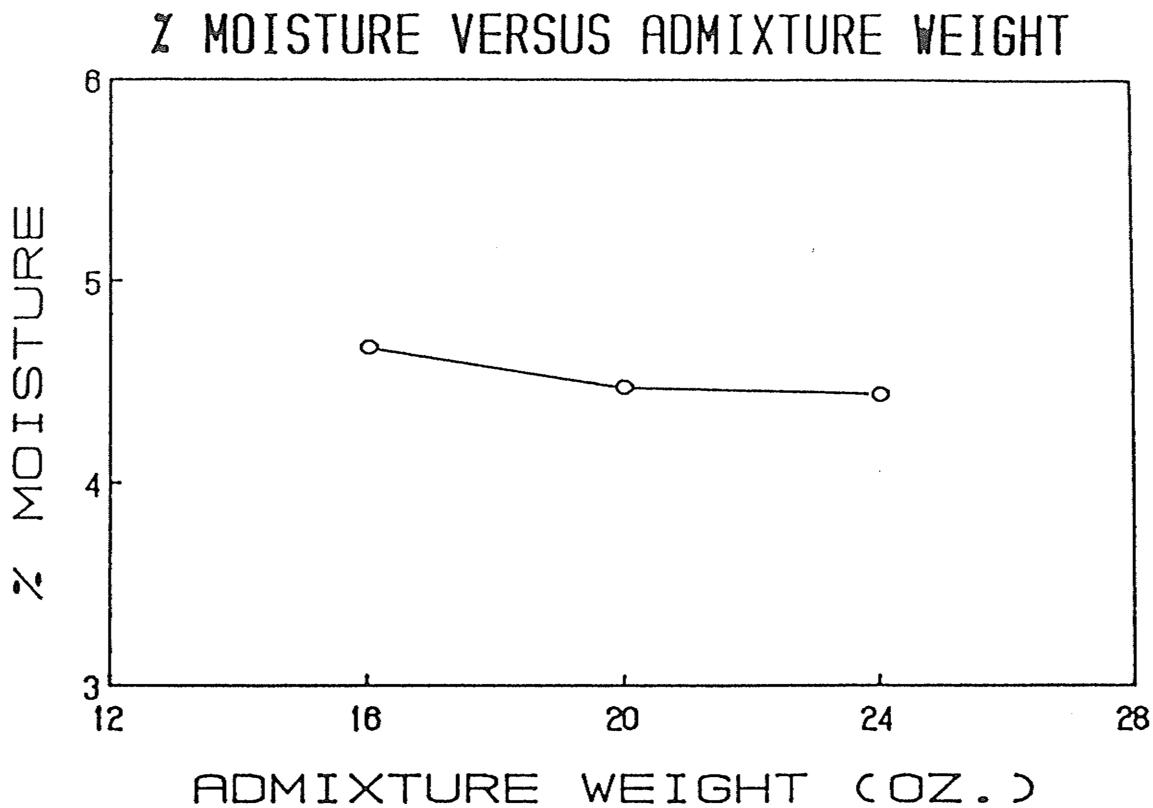

Figure 3.8: Moisture Variation in Admixture tests

TABLE 3.9

Compressive Strength Result in Admixture Tests

Test No.8
Admixture = 16 oz.

Testing Date	Ave. Weight (lbs.)	Age (Day)	Ave. Ult. Load (lbs.)	Ave. Ult. Strength (PSI)
Dec. 19	39.3	1	132000	1149
Dec. 25	39.3	7	170700	1486
Jan. 15	38.9	28	233700	2035

Test No.9
Admixture = 20 oz.

Testing Date	Ave. Weight (lbs.)	Age (Day)	Ave. Ult. Load (lbs.)	Ave. Ult. Strength (PSI)
Dec. 19	39.9	1	145000	1262
Dec. 25	39.4	7	174700	1521
Jan. 15	39.2	28	231000	2012

Test No.10
Admixture = 24 oz.

Testing Date	Ave. Weight (lbs.)	Age (Day)	Ave. Ult. Load (lbs.)	Ave. Ult. Strength (PSI)
Dec. 19	39.7	1	150300	1309
Dec 25	39.5	7	179000	1558
Jan. 15	39.4	28	231300	2014

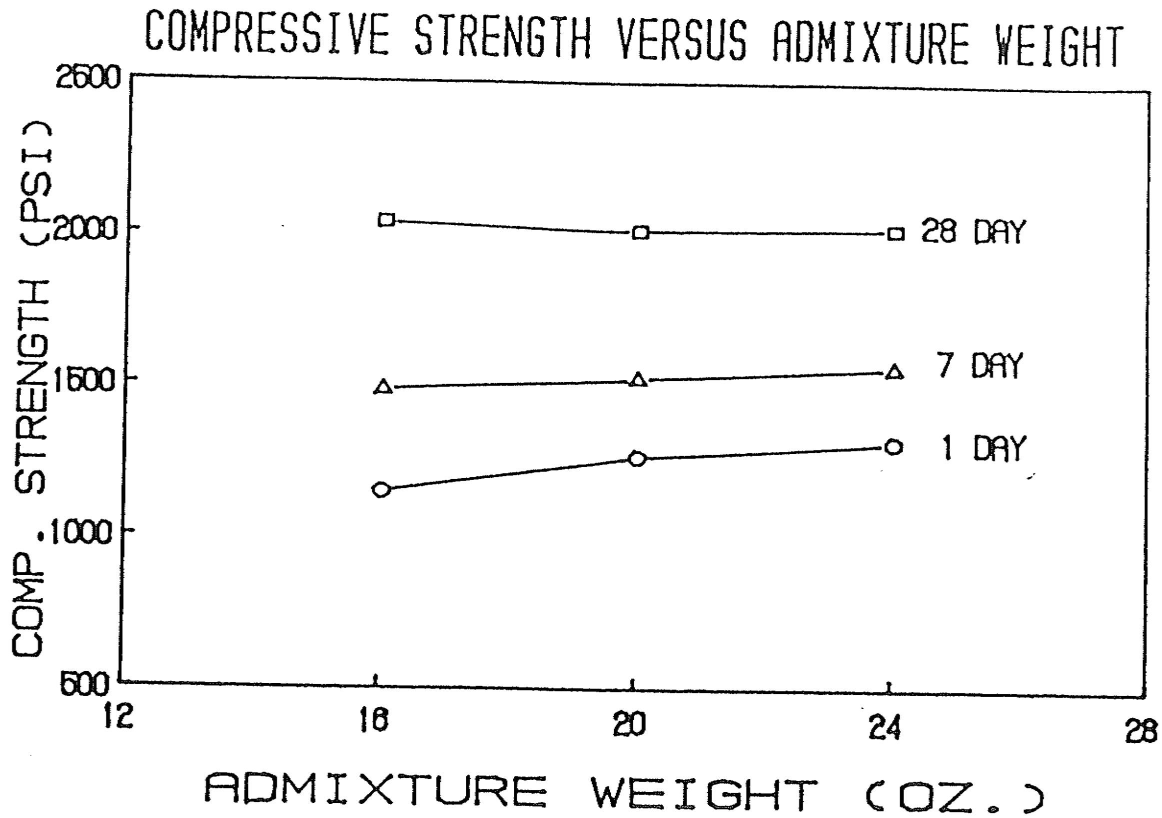

Figure 3.9: Compressive Strength Versus Amount of Admixture

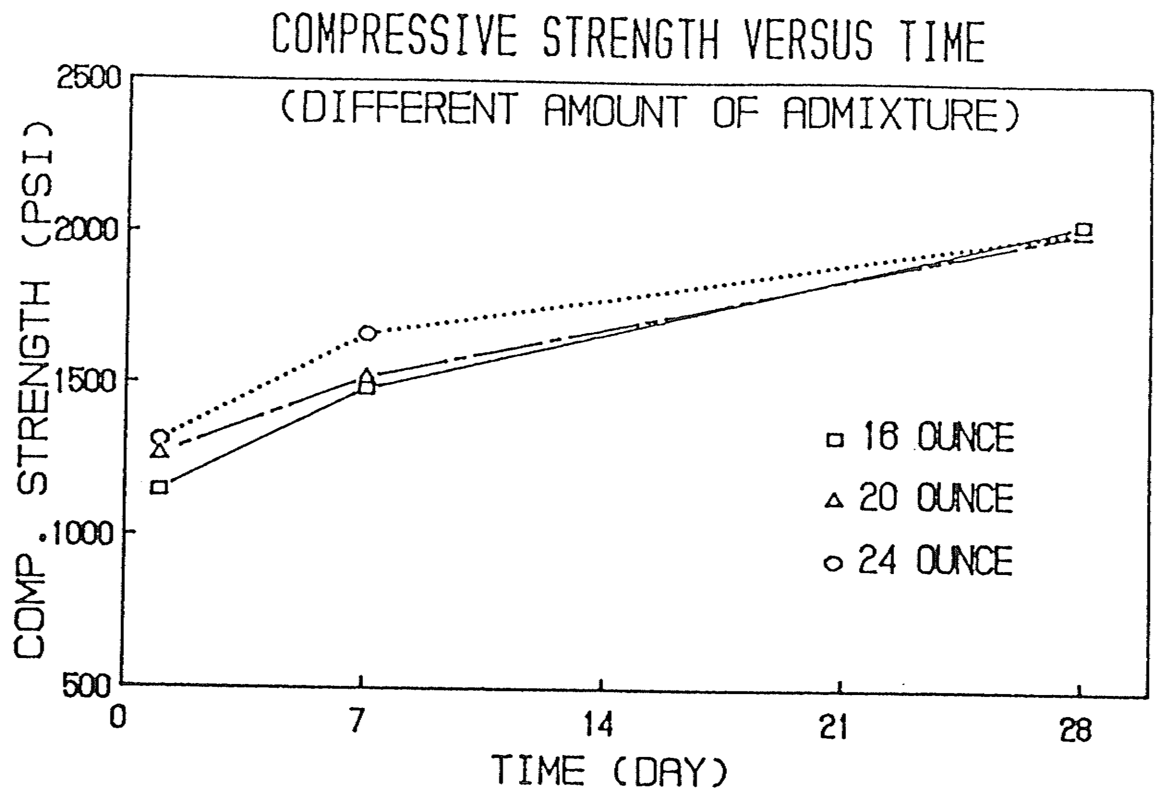

Figure 3.10: Compressive Strength Versus Time

Chapter IV
COST OPTIMIZATION

4.1 INTRODUCTION

In mass concrete block production, small changes in the cost of materials or the speed of operation could result in substantial changes in revenue. There are many factors affecting the speed of operation, such as the capacity of the plant with respect to machinery output, the number of kilns, and the manpower. However, the main concern of this project is to minimize the cost of raw materials based on the 24-hour compressive strength resulting from the tests.

Optimization techniques have been applied to evaluate the most economical and practical concrete block mix for this particular plant. The computer software package GINO (General INteractive Optimizer) is used to solve the nonlinear model derived for this analysis. Clearly, the objective of this model is to minimize the cost of the material in every batch, and the main constraint of the model is the required 24-hour compressive strength which must be above the 1000 psi. Minor adjustments in test results were necessary in formulating the model.

4.2 MODEL CONSTRUCTION

The model contains several relationships which are derived from the test results. Popovics (17), based on the Bolomey formula for European portland-pozzolan cement has found a relationship to estimate the 28-day compressive strength of concrete containing flyash. The general form of this formula is:

$$f'c=B[(c+p)/w-0.5]-C*F^{n} \qquad (1)$$

where:

F =Flyash content in the cementitious material
=100 p/(c+p), percent by weight

B,C,and n =Empirical parameters which are independent of the pozzolan content.

Since the 24-hour compressive strength (fc) generally follows the same pattern as the 28-day strength, the above formula is used to find a relationship for the model. The results of flyash-cement tests are used to derive the empirical parameters in the above formula:

Substituting the results of test #4 in equation (1)

fc=1135 psi, w/c+p=0.40, F=0 (test #4)

$$1135=B(1/.40-0.5)$$

$$B=567.5$$

From test #5 and test #6 we have:

fc=972 psi, w/c+p=.43, F=33% (test #5)

fc=1007 psi, w/c+p=.42, F=45% (test #6)

Substituting the above values in equation (1) we get:

$$972=567.5(1/.43-0.5)-C(33)^{n} \qquad (2)$$

$$1007=567.5(1/.42\ -0.5)-C(45)^{n} \qquad (3)$$

Solving the equations (2) and (3) simultaneously we find:

$$C=122.25 \text{ and } n=-0.185$$

Therefore, the general equation becomes:

$$fc=567.5(c+p/w\ -0.5)-122.25(F)^{-0.185}$$

Linear relationships are used to formulate the other parameters, such as, w/c+p "vs" % flyash, fc "vs" amount of stone, fc "vs" % flyash, and fc "vs" amount of admixture. Regression lines are used to determine the variations in the above variables. Figures 4.1 to 4.4, show these regression lines and their corresponding equations. The boundary conditions used in modeling the problem are based on the constant proportion of aggregates to cementitious material (Aggregates=5000 lbs and cement+flyash=600 lbs), and within the tested proportions. The optimization model and its solution are shown below:

MODEL:

```
1) MIN=5.37*WC+2.35*WF+.48*WST+.33*WSD+64*WAD;
2) FC>567.5*((WC+WF)/W-.5)-122.25*(1/F^-0.185);
3) F=100*WF/(WF+WC);
4) W/(WC+WF)>.500-.002*F;
5) FC>1028.5-.035*WST;
6) FC>942.2+1.120*F;
7) FC<725.3+276*WAD;
8) WC+WF=600;
```

```
  9) WST+WSD=5000;
 10) WST>1800;
 11) WST<2000;
 12) WSD>3000;
 13) WSD<3200;
 14) WAD>1.0;
 15) WAD<1.5;
 16) F>33;
 17) F<50;
 18) W>220;
 19) W<320;
 20) FC>1000;
END
```

Abbreviations used in the model are as follows:

WC = Weight of cement (Lbs.)

WF = Weight of flyash (Lbs.)

WST= Weight of stone (Lbs.)

WSD= Weight of sand (Lbs.)

WAD= Weight of admixture (Lbs.)

W = Weight of water (Lbs.)

F = Percentage of flyash replacement for cement

FC = 24-hour compressive strength (psi)

SOLUTION STATUS: OPTIMAL TO TOLERANCES. DUAL CONDITIONS: SATISFIED.

OBJECTIVE FUNCTION VALUE

1) 4299.999960

VARIABLE	VALUE	REDUCED COST
WC	300.000000	.000000
WF	300.000000	.000000
WST	1800.000000	.000000
WSD	3200.000000	.000000
WAD	1.000000	.000000
FC	1000.000000	.000000
W	250.000000	.000000
F	50.000000	.000000

ROW	SLACK OR SURPLUS	PRICE
2)	173.841570	.000000
3)	.000000	-18.120009
4)	.016667	.000000
5)	34.500000	.000000
6)	1.799988	.000000
7)	1.299988	.000000
8)	.000000	-3.860000
9)	.000000	-.330000
10)	.000000	-.150000

11)	200.000000	.000000
12)	200.000000	.000000
13)	.000000	.000000
14)	.000000	-64.000000
15)	.500000	.000000
16)	17.000000	.000000
17)	.000000	18.120009
18)	30.000000	.000000
19)	70.000000	.000000
20)	.000000	.000000

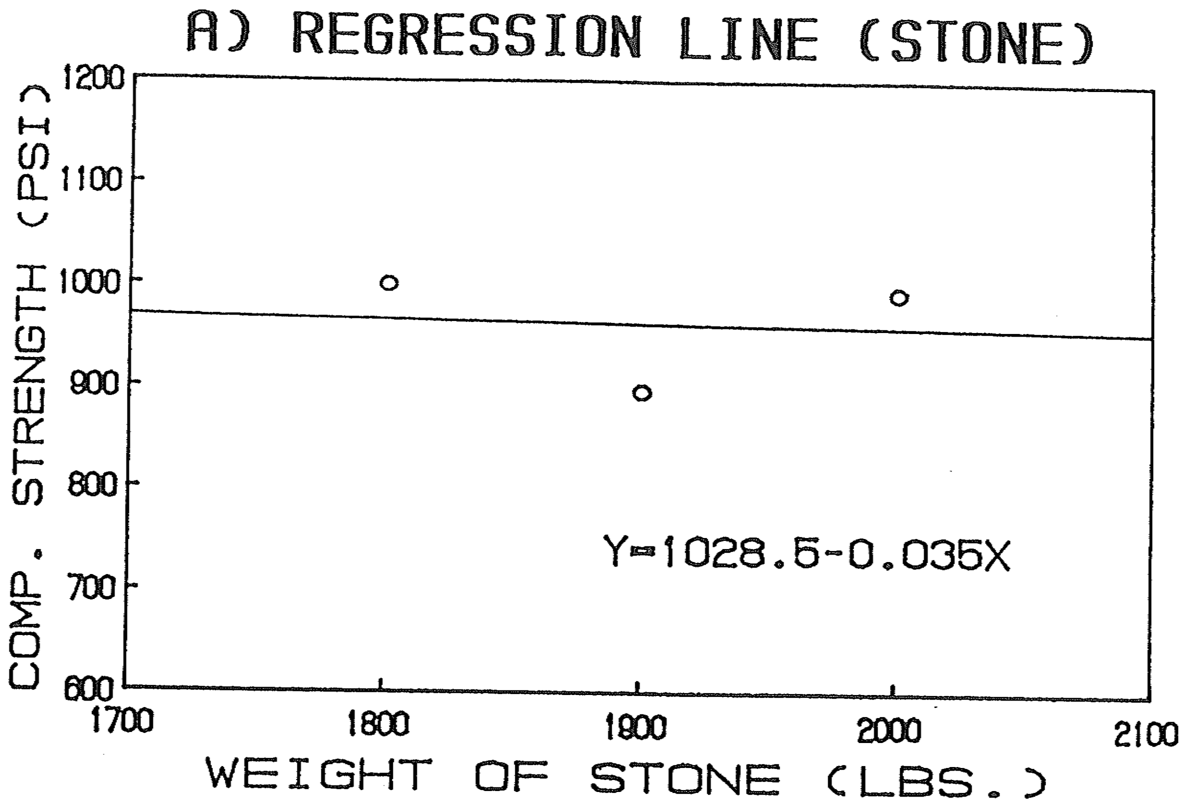

Figure 4.1: Regression Line (Stone "vs" Compressive Strength)

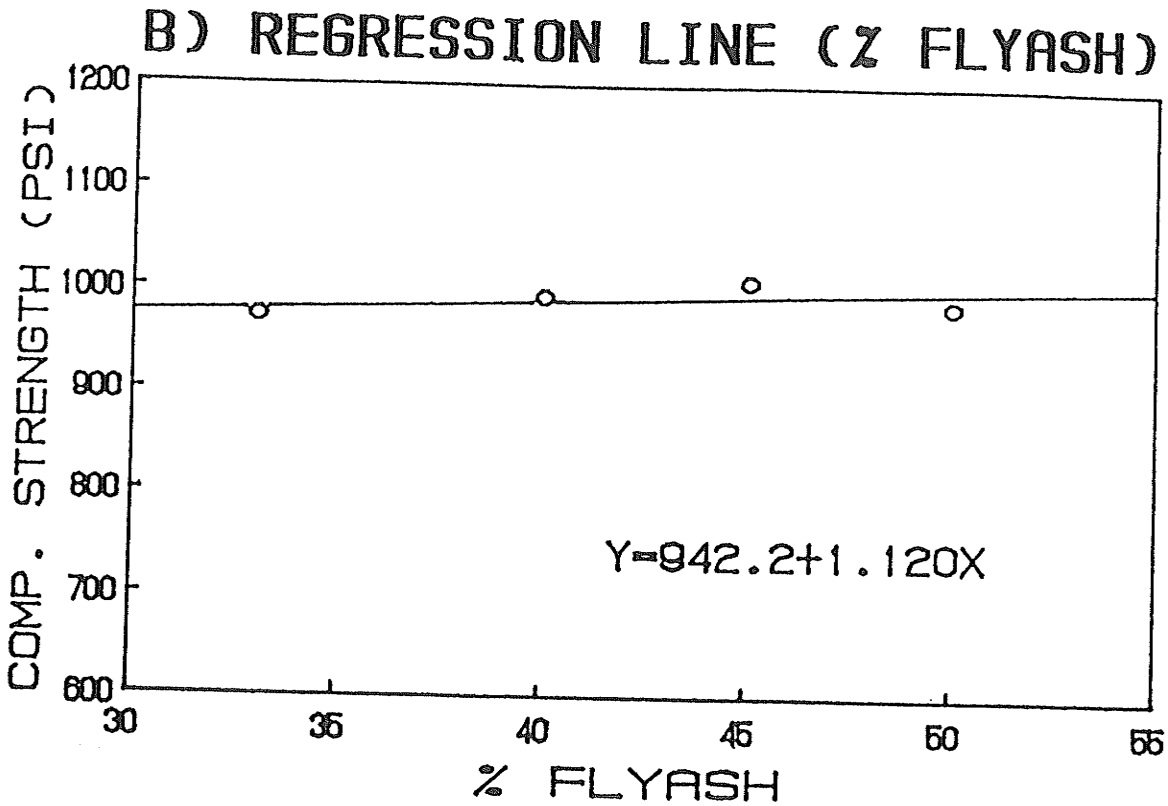

Figure 4.2: Regression Line (% Flyash "vs" Compressive Strength)

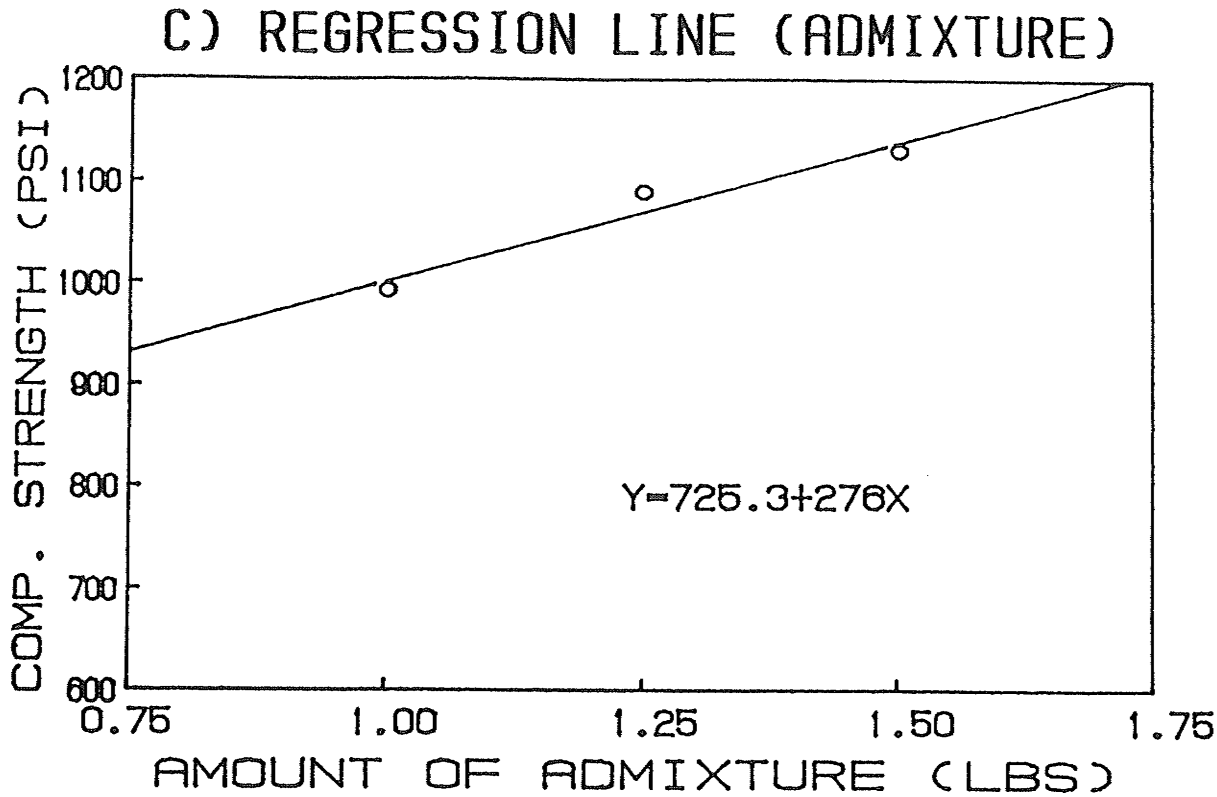

Figure 4.3: Regression Line (Admixture "vs" Compressive Strength)

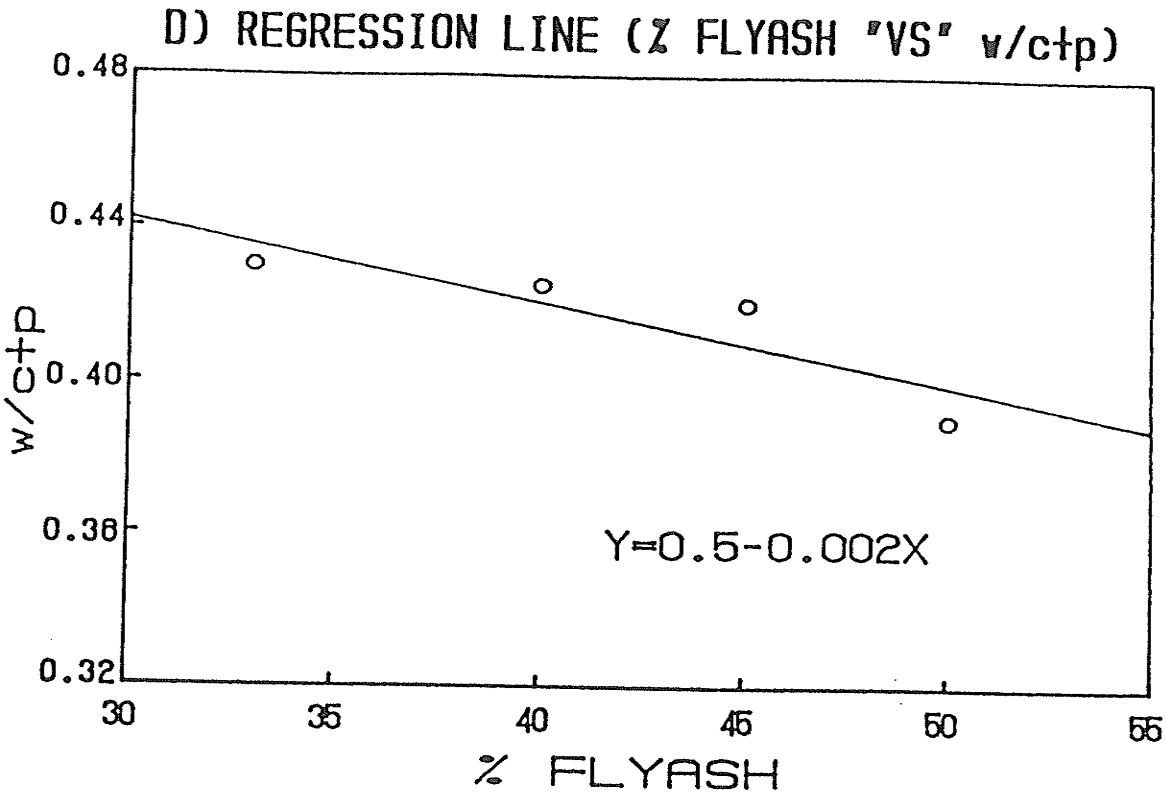

Figure 4.4: Regression Line (% Flyash "vs" w/c+p)

4.3 RESULTS AND DISCUSSION

The model and its optimal solution demonstrate that based on a compressive strength of 1000 psi, the most economical mix contains 50% flyash as cement replacement with 1800 lbs of stone and 3200 lbs sand. The amount of admixture is 16 ounces. However, as a safety factor, the use of 24 ounces of admixture is recommended in every batch. Table 4.1, shows the amount and the cost of individual components in a given batch based on the present mix, optimal, and re-

TABLE 4.1

Present, Optimal, and Recommended Mix Proportions

	Present		Optimal		Recommended	
	Weight (lbs.)	Cost ($)	Weight (lbs.)	Cost ($)	Weight (lbs.)	Cost ($)
cement	360	19.33	300	16.11	300	16.11
Flyash	240	5.64	300	7.05	300	7.05
Stone	2000	9.60	1800	8.64	1800	8.64
Sand	3000	9.90	3200	10.56	3200	10.56
Admix.	1	0.64	1	0.64	1.5	0.96
Total		45.11		43.00		43.32

commended proportions. The block machine produces 3 blocks/cycle at a rate of 6 cycles/min. Assuming 7 hours of operation in each days shift, about 7500 blocks are produced daily. Each batch contains about 5600 lbs of raw material which produces about 140 blocks. Thus, the number of batches produced every day is approximately 53 (7500/140). Comparing the price of the present batch with the optimal and recommended mix, the daily reduction in cost of the materials are $111.8 and $94.9 dollars respectively. Assuming the plant operates 20 days a month and 10 months a year, the annual reduction in material cost could be as high as $20,000 dollars. This figure could be even higher during peak periods at the plant, when it operates two daily shifts.

Chapter V

CONCLUSIONS AND RECOMMENDATIONS

In general the strength of the block is affected either by the material proportions or the procedures involved in production. This study mainly concentrates on the former case. Sieve analyses conducted on the coarse and fine aggregates showed that there was a deficiency of larger aggregate size in the mix. Therefore, it was decided to rectify this deficiency by increasing the percentage of the stone. However, the variation in the texture of the block was the major concern. Tests conducted on different proportions of aggregates showed that increasing the percentage of stone from 36% to 40% improves the 28-day strength by about only 3% . This is generally due to the lower surface area of stone than sand. However, a higher percentage of stone seems to reduce the 24-hour compressive strength since this appears to be associated with the degree of compaction of individual components in the mix, where sand is a better filler than stone. There is also a slight variation in the texture of the block, but this depends on the market requirments. For example, a smooth block surface is required for a painted finish. Stone is also a more expensive material than sand. Therefore it is recommended that a lower percentage of stone be used as long as the 28-day strength is satisfied.

The presence of flyash as a partial replacement of cement can be very beneficial in concrete block production. Type C flyash, used in these tests, appears to perform admirably, especially from the standpoint of the 24-hour compressive strength. Again, flyash with a particle size finer than cement is a better void filler, and the variation in 24-hour strength depends mainly on the degree of compaction rather than entirely on the cement content. Comparisons between a mix with no flyash (Test #4) and the 50% flyash replacement (Test #7) indicates clearly that similar 24-hour compressive strengths can be achieved by both mixes. The strength gain in a high-percentage flyash mix (50% flyash), which includes the pozzolanic reaction, appears to be slow in the first week but it seems to recover most of its strength at 28 days.

Chemical admixtures such as Lubrilite 30, which was used in these tests, can significantly improve the 24-hour compressive strength. The effect of chemical admixtures in the dispersion of cement particles seems to improve the cement hydration in the early ages. The quantity and the cost of admixture in every batch is very small. Therefore, considering its importance in the 24-hour compressive strength, it is recommended that the 24 ounces of admixture be used with every batch. Test results show that by increasing the amount of admixture from 16 ounces to 20 and 24 ounces improves the 24-hour compressive by about 10 and 14% respectively. However, the 28-day strengths of the above tests were almost identical, which suggests that the admixture has only speeded up the hydration process of cement which otherwise would have occured more gradually.

The procedures involved in the production of concrete block could have a major effect on the end product. Concrete blocks produced with the same mix proportions, but on two different occasions, may have different compressive strengths. Human judgement in operating the machinery, and the duration and temperature at different stages of the curing process, such as presetting and steaming, are the main cause of the variation. For instance, the tests conducted for this study were carried out over 3 days. The compressive strength test results for first two days were in the same range, but the results from the third day were slightly higher, which created some difficulty in analysis. Comparing the test results of different proportions of cement and flyash (Test #5 and Test #6), which were produced on the same day, indicates little difference in compressive strength for 33% and 45% flyash substitutions (Figure 5.1). However, comparing the 40% and 50% flyash replacement in tests #7 and #8, which were produced on the third day, a difference in strength at 7 and 28-days was noted for 50% flyash replacement (Figure 5.2). Note that the 24-hour compressive strength is almost identical in both cases.

The surrounding temperature also influences the cement hydration and, in turn, the strength of the block. Figure 5.3 shows the variation in compressive strength tests conducted for similar mix proportions in the summer and in the winter. The reduction in compressive strength during the winter season is very obvious. Adjustments in the mix, and especially in the curing process, is required to ensure the strength of the block during the winter.

Further investigation is necessary for a better understanding of strength gain in concrete blocks containing flyashes. Major recommendations suggested for future tests and studies are as follows:

1. More extensive tests, with 50% flyash replacement, are necessary to study the strength gain more accurately. Blocks produced with 50% flyash could lack the required 28-day strength.
2. Tests to study the effect of other admixtures should also be undertaken.
3. The speed of operation namely the cycle-time should also be investigated. The speed of operation seems to improve with increase in percentage of flyash. The cycle-time recorded for these test-batches were not a true representative, because the machinery was not adjusted accordingly.
4. Further study of the curing process can be very beneficial for a better understanding of the strength de-

velopment in concrete blocks at early ages. Duration and temperature at various stages of curing have a grate effect on the strength development of the block. For example, deficiencies or excesses in steaming period could have a detrimental effect in the strength of the block.

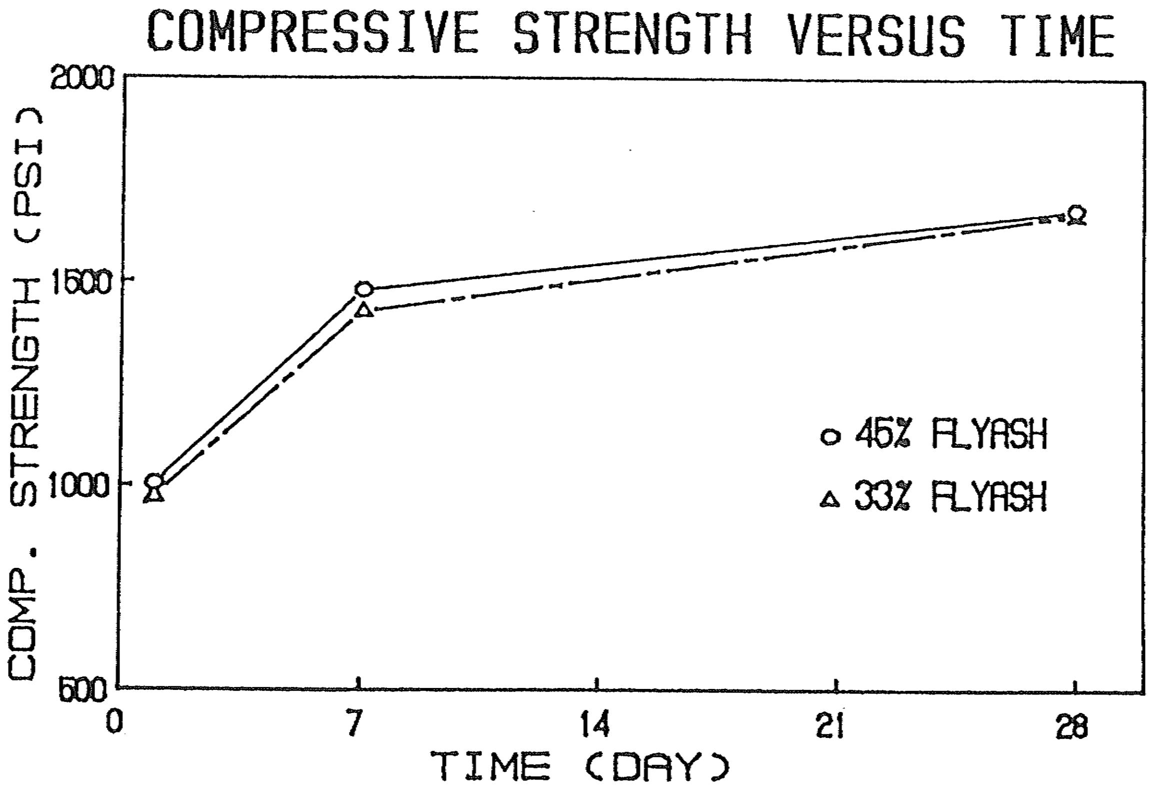

Figure 5.1: Strength variation in 33% and 45% Flyash Replacement

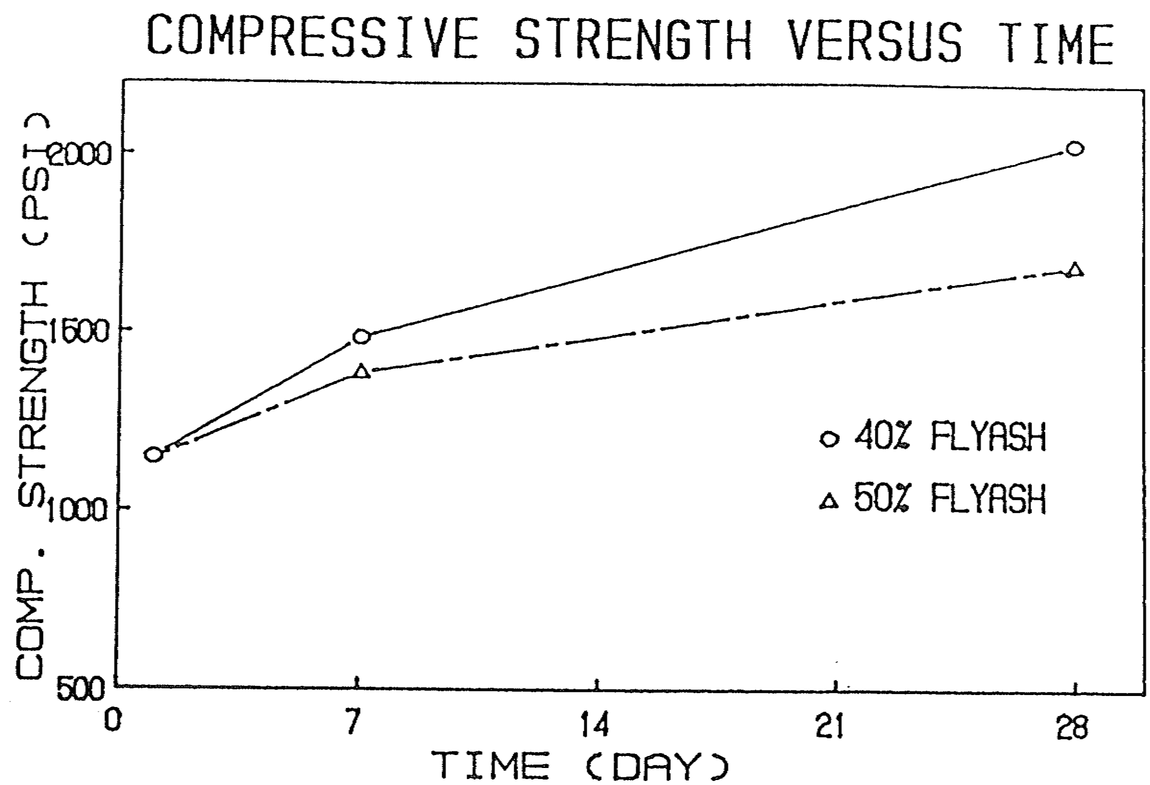

Figure 5.2: Strength Variation in 40% and 50% Flyash Replacement

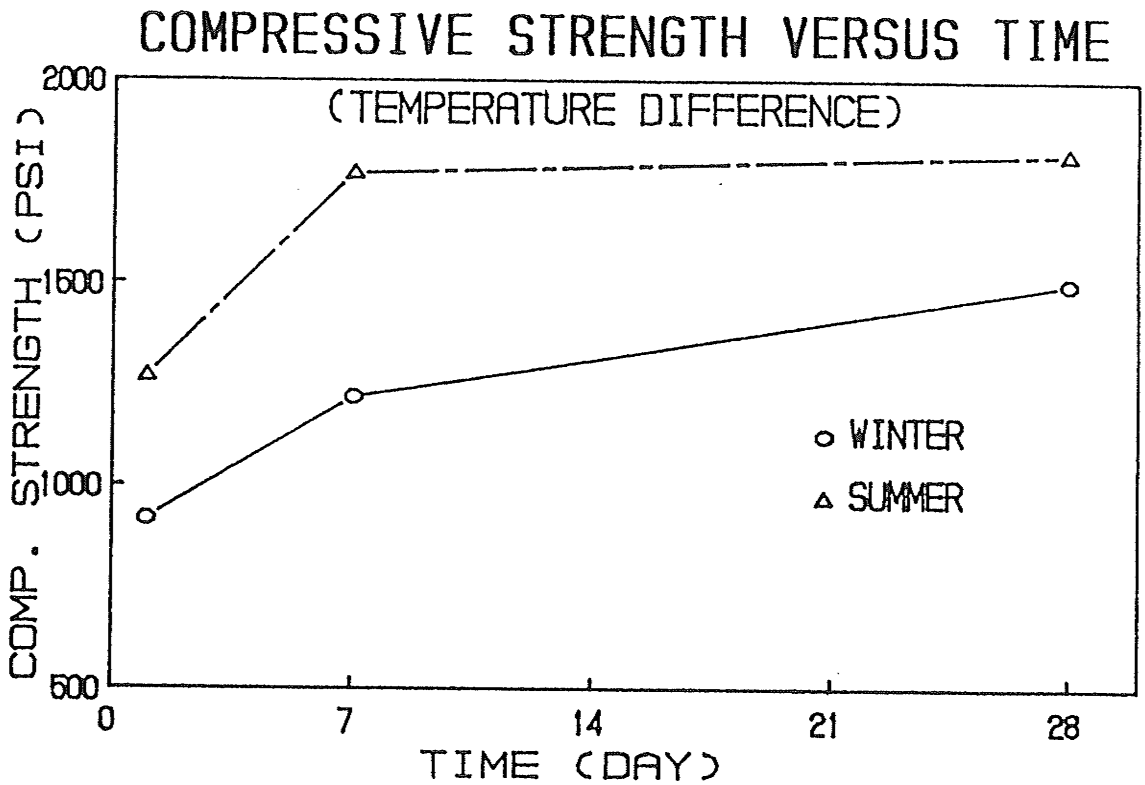

Figure 5.3: Strength Variation in Summer and Winter

REFERENCES

1- Neville, A.M.,"Properties of Concrete", Sir Isaac Pitman and Sons LTD, London, 1963

2- Mehta, P.K., "Pozzolanic and Cementitious By-products as Mineral Admixtures for Concrete- A Critical Revieew", First International Conference on the Use of Fly Ash, Silica Fume, Slag and Other Mineral By-Products in Concrete, ACI, Publication SP 79, Vol.1,1983

3- Besser Compony,'Material and Methods Used in the Manufacture of Concrete Masonry Units', Alpina, Michigan, 1985

4- CSA Standards, CAN3-A23.5-M82, 'Supplementary Cementing Materials and Their Use in Concrete Construction',1982

5- Idorn, G.M., "International Aspects of Development of the Uses of Fly Ash in Cement", Paper N6.1, Material Research Society, Boston, Nov. 1982

6- Diamond, S., "The Characterization of Fly Ashes", Proceedings, Symposium on Effects of Fly Ash Incorporation in Cement and Concrete, Material Research Society, Editor: S. Damond, 1981, pp. 12-23

7- Mortureux, B., Hornain, H., Gautier, E., and Regourd, M., "Comparison of the Reactivity of Different Pozzolans", Proceedings, Seventh International Congress on the Chemistry of Cement Paris, V.3, 1980, pp. 110-115

8- Diamond, S., Lopez-Flores, F., "On the Distribution Between Physical and Chemical Characteristics Between Lignitic and Bituminous Fly Ashes", Proceeding, Symposium on Effect of Fly Ash Incorporation in Cement and Concrete, Materials Research Society, Editor: S. Diamond, 1981, pp.34-44

9- Manmohan, D., Mehta, P.K., "Influance on Pozzolanic, Slag, and Chemical Admixtures on Pore Size Distribution and Permeability of Hardened Cement Paste", Cement, Concrete, and Aggregates, Vol.3, No.1, 1981, pp.63-67

10-Feldman, R., "Pore Structure Formation During Hydration of Fly Ash and Slag Cement Blends", Proceeding, Symposium on Fly Ash Incorpration in Cement and Concrete, Material Research Society, Editor: S. Diamond, 1981

11-Diamond, S., Lopez-Flores, F.,"Comparative Studies of the Effect of Lignitic and Bituminous Fly Ashes in Hydrated Cement Systems", Proceedings, Symposium on Fly Ash Incorporation in Cement and Concrete, Material Research society, Editor: S. Diamond, 1981, pp. 112-123

12-Massazza, F., "Structure of Pozzolans and Fly Ash, and Hydration of pozzolanic and Fly Ash Cements - General Report", Proceedings, Seventh International Congress on the Chemistry of Cements. Vol.4, Paris 1980, pp.85-96

13-Diamond, S., "Long-term Status of Calcium Hydroxide Saturation of Pore Solution in Hardend Cements", Cement and Concrete Research, Vol.5, No.6, 1975, pp.607-616

14-Master Builder Company, The Manufacture of Concrete Block. Toronto, Canada, 1984

15-Measuring, Mixing, Transporting, and Placing. ACI Committee 304-11, Detroit, 1981.

16-Accelerated Curing of Concrete at Atmospheric-State of art, ACI, Committee 517, U.S.A., 1980.

17-Popovic, S.,"Strength Relationships for Flyash Concrete", ACI Journal, 1981.