Effectiveness of Super-plasticizer on High Volume Fly Ash Concrete

by

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CERTIFICATION OF APPROVAL

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Approved by,

(AP Dr Nasir Shafiq)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

TAY LEE PENG

ABSTRACT

This research project was aimed to determine the optimum super-plasticizer dosage for producing highly workable, high strength, low porosity and low gas permeability concrete containing high volume fly ash (60%) as partial cement replacement. The trial mix with 100% cement was initiated with a water cement ratio of 0.27, which gave very dry mix with negligible slump value. The mix resulted quite poor quality hardened concrete cubes. Then on the next trial, the mix was also not very successful. Finally a mix with 0.4 water cement ratio yielded targeted results and chosen as the final mix water ratio. Super-plasticizer dosage of 0%, 0.5%, 1%, 1.5%, 2%, 2.5% and 3% were tested. It is found that super-plasticizer dosage in the range of 1.5% to 2.5% has given the optimum characteristics of concrete including strength, porosity and the gas permeability up to 90 days and 1.5% yields the optimum dosage of super-plasticizer.

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I am grateful to receive help and guidance from many people throughout the process of accomplishing this research project. There are many people I would like to acknowledge but I would like to particularly thanks my supervisor, AP Dr Nasir Shafiq for his guidance and freely share his knowledge with me. I would also like to acknowledge the lab technicians help which are Mr. Johan, Mr. Meor and Mr. Zaini.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

High strength concrete with enhanced durability is becoming more popular these days. The integration of high volume fly ash concrete (HVFAC) with super-plasticizer is an appropriate combination for producing high workability and strength development for places with hot weather, huge masonry projects, inaccessible areas, floor or road slabs and places which need very rapid placing.

Fly ash concrete or known as PFA is the most common artificial pozzolan. It is formed from precipitated electro statically or mechanically exhausted gasses of coal-fired power stations. It has higher fineness than ordinary Portland cement. Since there is abundant of fly ash worldwide, high volume fly ash concrete or HVFAC is becoming more popular because it only needs low water content to cementitious materials ratio and act as cement replacement materials. Fly ash is good for strengthening the cement paste and filling up voids, thus improving impermeability of the concrete. Besides that, it is good for workability, reduces bleeding and more durable.

Fly ash needs lower water content in order to produce higher strength but lower water content will reduce its workability. In order to counter this problem, super-plasticizer maybe used to increase workability in low water content cement and at the same time increases its durability too. This research study was conducted on high volume fly ash concrete; an amount of 60% of PFA was replaced for OPC.

The type of super-plasticizer used in this research is sulphonated naphthalene-formaldehyde. It is water soluble organic polymers and is expensive. This super-plasticizer may reduce the water content for a given workability from 25 to 35 percent and increase its 24 hours strength by 50 to 70 percent. Besides that, it will leave the mix remaining cohesive and is not subjected to excessive bleeding or segregation.

1.2 Problem Statement

- Since high volume mineral admixtures are becoming popular in producing high performance concrete, but sometimes in order to achieve the required workability, high water ratio is needed, which may affect its strength.

- In order to obtain the required workability and high strength of concrete, water reducing admixtures are required to reduce the water cement ratio.

1.3 Objectives and Scope of Study

The objectives of this research study are:

- To determine the optimum super-plasticizer dosage for producing highly workable and high strength concrete for high volume fly ash concrete with better porosity and permeability than normal concrete mix design.

The scope of this research included:

- 60% of replacement cement with fly ash, water ratio of 0.27, 0.32 and 0.4, course aggregates of 14mm and fine aggregates.

- All the above materials were fixed, but dosage of super-plasticizer ranges from 0% to 3%. The water cement ratio was firstly fixed to 0.27 but it was changed to 0.32 and then 0.4. The final mix designs were included in Appendix 1-1.

- The test results were based on the average of three samples test. With the limited lab equipments and time frame, this research has been divided into two sessions. For the first semester, three control mixes and four others mixes with 0%, 0.5%, 1.5% and 2.5% of super-plasticizer have been carried out; while 1%, 2% and 3% of super-plasticizer will be carry out this semester.

CHAPTER 2

LITERATURE REVIEW OR THEORY

2.1 Fly Ash Concrete

Coal is a complex heterogeneneous material and its end product is widely use in the industry. When pulverized fly ash is burnt to generate electricity, it produces large quantities of fly ash and bottom ash. This fine ash is generally used in the construction sectors.

Fly ash is collected from either mechanical or electrostatic separators. It has siliceous and aluminous properties just like a pozzolans. It then reacts with the moisture, calcium hydroxide at ambient temperature to form cementitious properties. However, it has its own limitation. Dhir et al.[1] has shown that use of coarser fly ash leads to a reduction in compressive strength for equal water cement ratio. This effect increases with decreasing w/(PC+FA) ratio. Generally, a 5% increase in 45mm sieve retention will lead to a strength reduction of between 0.4 and 1.5N/mm^2 for typical PC+FA content.

However, replacement of high volume of fly ash into cement will produce different properties of cement. Çolak*[2], found out that blended Portland cement with a high proportion of natural pozzolans, with increase water content causes the porosity to increase with an accompanying decrease in compressive strength. It is proven by Pretorius and Kearsley[3], with their tests on slurries containing high volumes of PFA - HVPFA (the cement are replaced up to 67% by fly ash) with j-tube test were proved to be rather sensitive and difference in workability at very small water/binder ratio will cause increments. It was found that water/binder ratio was the main contributing parameter to compressive strength.

2.2 Super-plasticizer

Sulphonated naphthalene-formaldehyde super-plasticizer is water soluble and contain organic polymer compound. Super-plasticizer has a strong effect on cement containing fly ash, producing good fluidity and early strength development. It may produce more workable cement paste with the same amount of water. Pretorius and Kearsley[3] found out that high strength can be achieved in concrete by incorporating a high percentage of fly ash with super-plasticizer.

But too much of super-plasticizer will have adverse effect on the cement. Neville[4], state that to increase workability of the mix, the normal, dosage of the super-plasticizers is between 1 and 3 liters per cubic meter of concrete. When super-plasticizers are used to reduce the water content of the mix, the dosage is much higher: 5 to 20 litres per cubic meter of concrete. While Collepardi, Monosi and Pauri[5], state that in general, when used in form of a 40% aqueous solution, the dosage rate of Sulphonated Naphtalene Polymer SNP or Sulphonated Melamine Polymer SMP superplasticizers is about 1% by weight of cement. Higher dosage rates such as 2 to 4% could cause retarding effect on cement hydration at early age.

Super-plasticizer is better to be incorporated with fly ash and low water ratio, according to Bouzoubaâ and Fournier[6]. The result shows that for a slump for class F fly ash is approximately 100mm, the addition of super-plasticizer results in decrease of the W/CM, but an increase in the air content of the concrete mixtures. For example, for the concrete mixtures made with 300 kg of total CM, the increase in the dosage if the super-plasticizer from 0 to 3 L/m^3 decreased the W/CM from 0.46 to 0.33, but results in an increase in the entrapped air content of the concrete from 1.3 to 3.1%.

2.3 Porosity

Porosity will determine the durability of the concrete and its resistance to alkali attack. This property is very important especially to structure near or at the coast. Thus, we have to take serious consideration into this parameter also.

In Khatib and Mangat[7] research, they examined the influence of one type of super-plasticizer on porosity and its pore size distribution under different curing temperature (high and normal temperature). The test results shown super-plasticizer reduced the total pore volume and refines the pore structure too. The dominant pore size is unaffected and the threshold diameter is reduced in the presence of super-plasticizer. Less pore volume and finer pore structure are obtained when cement paste is subjected to initial curing as compared with initially dry curing.

2.4 Permeability

Permeability of concrete is also one of the most important parameter to determine its durability. As less permeable the concrete, its resistance to alkali attack will increase too. Permeability takes into account the movement of gasses into concrete interior. According to Neville[4], despite higher porosity of the interface zone, the permeability of concrete is controlled by the bulk of the hardened cement paste, which is the only continuous phase in concrete. Malhotra and Mehta[8], state that fly ash concrete results in smaller crystalline products and finer pores in the hydrated cement paste especially at the aggregate/ paste interface, leading to a decrease in permeability.

Naik, Singh and Hossain[9] state that, it is not always the case where the permeability for HVFAC will be always lower than ordinary Portland cement mix, but at a longer time span, its permeability will be lower than ordinary Portland cement permeability.

CHAPTER 3
METHODOLOGY

3.1 Materials

In order to obtain the optimum dosage of super-plasticizer used in high volume of fly ash concrete, different percentage of super-plasticizer are use with the fix amount of OPC, fly ash (Appendix 1-2 shows the used Fly Ash properties), course and fine aggregates and water cement ratio. But firstly the trial error of water cement ratio was conducted in order to achieve yielded targeted results and chosen as the final mix water ratio for this research. Table 1 below showed mix design for all type of Control Mix (CM) with different water cement ratio.

Table 1: Table of Mix Design for Control Mixes only.

MIX DESIGN (for Control Mixes)			
MIX TYPE	**CM 1**	**CM 2**	**CM 3**
OPC (kg/m^3)	340	340	340
PFA (kg/m^3)	0	0	0
CA 14mm (kg/m^3)	1190	1190	1190
SAND (kg/m^3)	765	765	765
W/C	0.27	0.32	0.4
WATER (kg/m^3)	92	109	136
SUPERPLASTICISER (kg/m^3)	0% 0	0% 0	0% 0

Finally the most suitable water cement ratio for CM have been fixed to 0.4 because the mix design for CM 1 and CM 2 were too dry, porous and brittle. It may be due to the hot weather in Tronoh.

Table 2: Table of Mix Design for water cement 0.4 only.

MIX DESIGN								
MIX TYPE	CM 3	0 SP	0.5 SP	1 SP	1.5 SP	2 SP	2.5 SP	3 SP
OPC (kg/m^3)	340	136	136	136	136	136	136	136
PFA (kg/m^3)	0	204	204	204	204	204	204	204
CA 14mm (kg/m^3)	1190	1190	1190	1190	1190	1190	1190	1190
SAND (kg/m^3)	765	765	765	765	765	765	765	765
W/C	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
WATER (kg/m^3)	136	136	136	136	136	136	136	136
SUPERPLASTICISER	0%	0%	0.50%	1.00%	1.50%	2.00%	2.50%	3.00%
(kg/m^3)	0	0	1.7	3.4	5.1	6.8	8.5	10.2

Table 3: Table of Sample Requirements.

Test	Sample Type	3 days	7 days	28 days	90 days
Compressive Strength	150 x 150 x 150 mm	3	3	3	3
Porosity	50mm disc x 50mm thick	3	3	3	3
Gas Permeability	50mm disc x 40mm thick	3	3	3	3

Table 2 above shows the final mix design for this research, while Table 3 shows the number of sample used for each testing. The complete mix design and requirements can be found in Appendix 1-1.

Note: Proper storage of materials is crucial because it will affect the results due to its low water cement ratio properties. Thus, OPC and fly ash were stored in an air-tight container while the course and fine aggregates were kept in normal room temperature in the lab.

3.2 Procedure and Equipments

All procedures were executed at room temperature and according to BS when is applicable.

3.2.1 Mixing Concrete

The mixing and sampling of fresh concrete in the laboratory was base on BS 1881: Part 125: 1986 by using a non-porous metal platform, a pair of shovel, a steel scoop and concrete mixer. The cement, sand, course aggregate and PFA were first weighted then mixed together with water and super-plasticizer by using concrete mixer at room temperature. The same procedure were repeated for other mixes (refer to Appendix 1-1 for each mix design requirements).

3.2.2 Slump test for workability

After mixing concrete, the fresh concrete was tested for its workability by slump test as recommended by BS 1881: Part 102: 1983. The mix was filled into a clean truncated mould (diameter at the top: 100mm, diameter at the bottom: 200mm, height: 300mm) by four equal layers and each layer was rod 25 times with a round steel rod. After the top layer has been rod, the excess concrete on the top of the moulds were stroked away. Then, the moulds were lifted carefully vertically and difference between the height of the slumped concrete and mould were measured as its workability.

3.2.3 Casting and curing cubes

After mixing and slump test, the mix were cast and cured in 12 nos. of 150mm x 150mm x 150mm internal size steel moulds (for compressive strength test) and 3 nos. of 450mm x 300mm x 50mm wooden mould (for porosity and gas permeability test). The casting of cubes as recommended by BS 1881: Part 111: 1983 by using vibrator machine. The moulds were filled with concrete mixed earlier into three layers and each layer was tamped 25 times. The excess concrete on the top of the mould were then stroked away in order to level its surface. After that, it is cover with polythene sheet for 24 hours at room temperature. Finally, after 24 hours, the samples were carefully removed from the moulds and put into curing tank at room temperature too.

3.2.4 Compressive strength test

Each sample was tested for its compressive strength (crushing strength) according to BS 1881: Part 116: 1983 by using compressive testing machine. 3 cubes were used for each testing. Before testing, each sample was weighted and put into the compressive machine with increasing load from $0.2N/mm^2s$ to $0.4N/mm^2s$ until it broke. Lastly, the crushed strength was recorded.

3.2.5 Porosity test

The measurement of total porosity by vacuum saturation is similar to RILEM 1984 by using desiccator. For porosity testing, 3 samples were cored from the concrete mix slab and put in the desiccator in air vacuum form for 30 minutes. After that, the samples were submerged in water and vacuum for another 6 hours before being left overnight. Each sample was then weight in air and weight in water and recorded. Lastly, the samples were put into oven for 24 hours in order to get its oven dry reading.

With all the available data, it is used to calculate the total porosity in each sample. Below is the formula used for measurement of total porosity in a sample.

$$\textbf{Formula:} \quad P(\%) = \frac{W_{SA} - W_d}{W_{SA} - W_{SW}} \times 100\%$$

Where; P = porosity in percentage (%)

W_{sa} = weight of saturated dry samples in air (g)

W_d = weight of oven dry (g)

W_{sw} = weight of saturated surface dry samples in water (g)

3.2.6 Permeability test

The ease with which gases penetrate into concrete by diffusion is used in UTP Pneumatic Concrete Permeameter (Figure 1 below) design. It is formulated by modifying Darcy's equation (proposed by Grube and Lawrence).

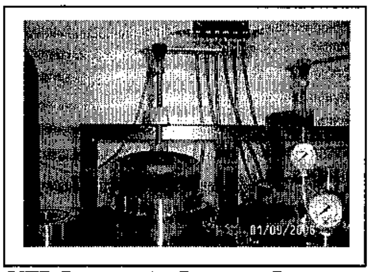

Figure 1: UTP Pneumatic Concrete Permeameter.

For each mix, 3 samples were tested and put into the permeameter cell for flow readings taken at every 30 minutes interval for five times for each sample. This is important in order to get a steady state reading for each sample. During the testing, permeameter cell must always be air tight (in order to prevent any leakage) and clean from dust.

Following were the formula used for measurement of permeability in this research.

Formula: $Permeability\ \ coefficient,\ \ k\ \ (m^2) = \ \ 2P_2VL\mu A(P_1^2 - P_2^2)$

Where; P_1 = inlet pressure bar

P_2 = outlet pressure bar

= 1 bar

A = area (m^2)

L = length (m)

μ = viscosity of gas

= 2.04×10^{-5} Ns/m^2

V = flow (cm^3/s)

CHAPTER 4
RESULTS and DISCUSSION

4.1 Results

Table 4 below showed the available test results.

Table 4: Summary of test result for 0.27 and 0.32 water cement ratios.

Sample	Slump (mm)	Age (days)	Stress (MPa)	Porosity (%)	Permeability (m^2)
CM 1		3	0.43	N/A	N/A
	0	7	0.48	N/A	N/A
		28	1.78	N/A	N/A
(0.27)		90	1.86	N/A	N/A
CM 2		3	3.51	N/A	N/A
	0	7	4.34	N/A	N/A
		28	7.29	N/A	N/A
(0.32)		90	7.30	N/A	N/A
0 SP		3	2.26	N/A	N/A
	0	7	2.86	N/A	N/A
		28	5.65	N/A	N/A
(0.32)		90	9.40	N/A	N/A
0.5 SP		3	4.91	N/A	N/A
	0	7	8.99	N/A	N/A
		28	11.41	N/A	N/A
(0.32)		90	17.22	N/A	N/A

Note : The porosity test results for water/cement ratio 0.27 and 0.32 were not available because the samples for both these water cement ratio are too porous.

The pores can be seen by naked eye (refer to Figure 2 and 3 below).

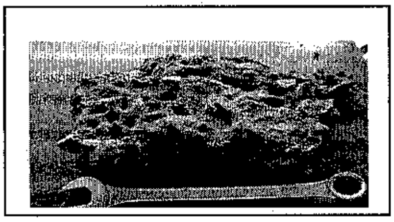

Figure 2: CM 1 porous slab (0.27 w/c ratio)

Figure 3: CM 2 porous slab (0.32 w/c ratio)

It is very obvious that both the mixes, for CM 1 and CM 2 were porous. The slabs break easily when it is taken out from mould and for coring. Thus, by visual inspection, the mixes were too porous and brittle and porosity test could not be conducted. It is also the same for water cement ratio of 0.32 for 0 SP and 0.5 SP (refer to Appendix 2-1 for detail picture). All the samples with these water cement ratio were very stiff (low workability) and very porous too. Thus the water cement ratio was increased to 0.4.

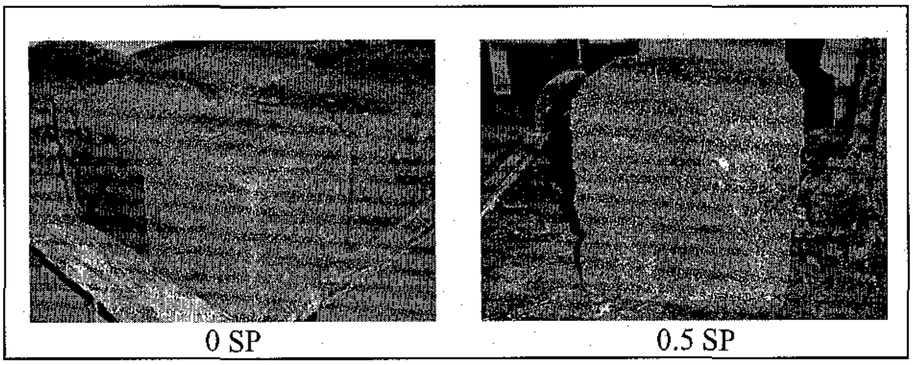

Figure 4: Samples of water cement ratio 0.32.

Table 5: Summary of test result 0.4 water cement ratios.

Sample	Slump (mm)	Age (days)	Stress (MPa)	Porosity (%)	Permeability (m^2)
CM 3 (0.4)	16	3	20.17	9.84	2.028E-14
		7	33.06	9.43	
		28	34.30	8.79	
		90	38.24	8.02	
0 SP	13	3	12.81	11.24	5.894E-15
		7	20.89	11.21	
		28	23.95	10.51	
(0.4)		90	23.98	10.22	
0.5 SP	0	3	10.54	10.99	1.858E-14
		7	13.91	10.86	
		28	19.10	9.83	
(0.4)		90	23.69	8.38	
1 SP	30	3	3.68	11.00	2.303E-14
		7	7.05	10.76	
		28	10.24	11.61	
(0.4)		90	23.70	10.80	
1.5 SP	115	3	5.80	11.76	1.292E-14
		7	7.05	10.80	
		28	12.10	10.39	
(0.4)		90	35.80	8.39	
2 SP	135	3	3.15	10.47	1.495E-14
		7	5.34	11.48	
		28	10.75	12.16	
(0.4)		90	21.76	9.35	
2.5 SP	178	3	6.43	13.06	8.954E-15
		7	6.66	12.57	
		28	13.72	9.46	
(0.4)		90	24.54	9.21	
3 SP	293	3	5.11	12.98	1.913E-14
		7	8.17	12.03	
		28	13.21	11.63	
(0.4)		90	24.59	8.75	

Note: Proper storage of materials is crucial because it will affect the results due to its low water cement ratio properties. The cement and fly ash must be kept air-tight and aggregates must be free from excessive dust and high temperature.

4.2 Discussion

4.2.1 Workability

Figure 5 below; represent the slump test results for all mixes. Although with the same water content in some of the mixes, the workability varies form 0 mm (stiff) to 293 mm (collapse slump).

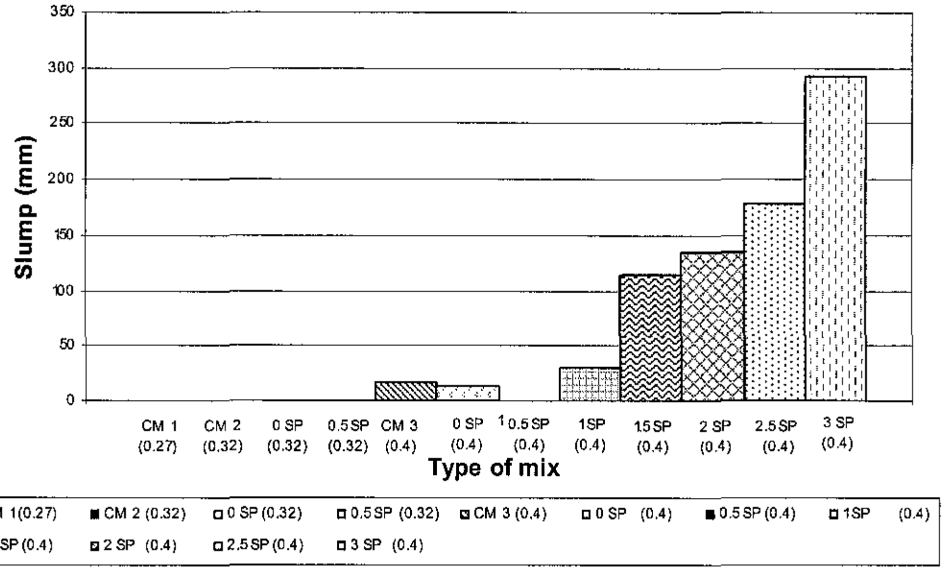

Figure 5 : Slump results for all mix.

By referring to Figure 5 above, water cement ratio of 0.27 and 0.32 mixes were stiff, all of them have 0 mm slump. Besides that, they dry very fast during mixing and were very porous too (refer Figure 6 and 7 below).

Figure 6: Slump test for CM 1
No slump (stiff).

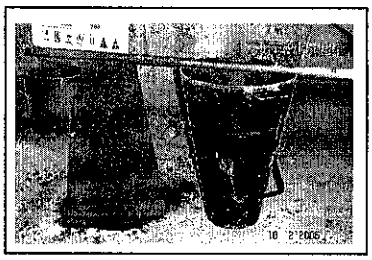

Figure 7: Slump test for CM 2
No slump (stiff).

Detail picture for each slump test of 0.27 and 0.32 water cement ratios are available in Appendix 2-1. Meanwhile, with the increase of water cement to 0.4, a workable and cohesive mix was obtained (refer Figure 8 below).

Figure 8: Slump test for CM 3
6mm slump ~ Low workability.

As percentage of super-plasticizer increased, the mix becomes more workable and flowable for 0.4 water cement ratios. The slump test shows an increase of workability as the dosage of super-plasticizer increases too from 0 mm slump to 293 mm slump. The slump test pictures for 0.4 water cement ratio are in Appendix 2-2.

Normal state surface of cement grain contain a combination of positive and negative charges. Super-plasticizer which possesses high negative charge increased workability by deflocculating the cement gel and hence allowing high dispersion. Thus super-plasticizer increases mobility and workability of cement paste.

Figure 9 to Figure 12 below shows the comparison between OPC (CM 3) with HVFA concrete only (0 SP) and HVFA concrete with 1.5% and 3% of super-plasticizer (1.5 SP and 3 SP).

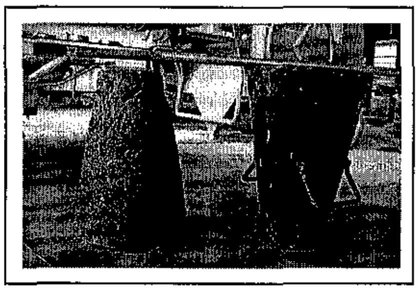

Figure 9: Slump test for CM 3
Slump = 6mm ~ Low workability.

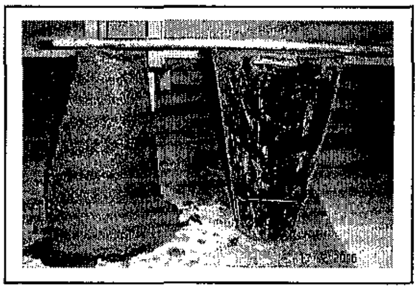

Figure 10: Slump test for 0SP
Slump = 13mm ~ Low workability.

Figure 11: Slump test for 1.5SP
Slump = 115mm ~ High workability.

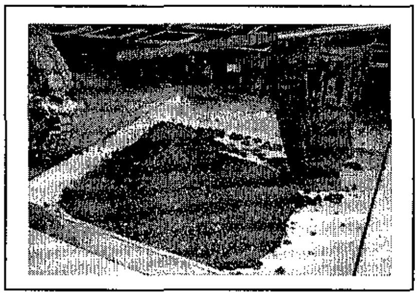

Figure 12: Slump test for 3SP
Slump = 293mm ~ Collapse slump.

Thus from Figure 5 and slump test pictures above, we can observe that super-plasticizer has a significant influence in the workability; the higher the dosage of super-plasticizer, the higher the workability and its cohesiveness. But from 2.5 SP to 3 SP, the mix have collapse slump. Figure 13 below shows a very wet mix which causes bleeding and segregation for 2.5 SP mix.

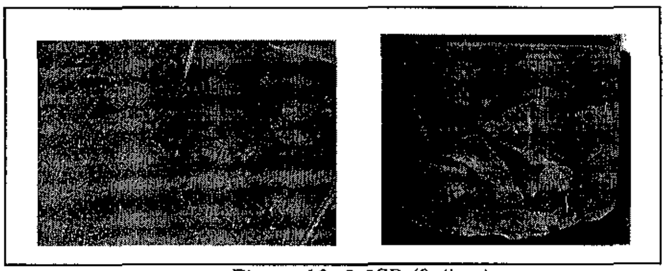

Figure 13: 2.5SP (0.4) mix.

4.2.2 Compressive Strength

The compressive strength for Control Mix 3 (CM 3) is the highest as compared to CM 1 and CM 2. It is due to the optimum dosage of water into the mix and proper storage of materials. The results are represented in Figure 14 below. CM 3 strength higher than CM 2 at day 3 by 82.2% and CM 3 strength increases gradually starting from day 3 till day 28.

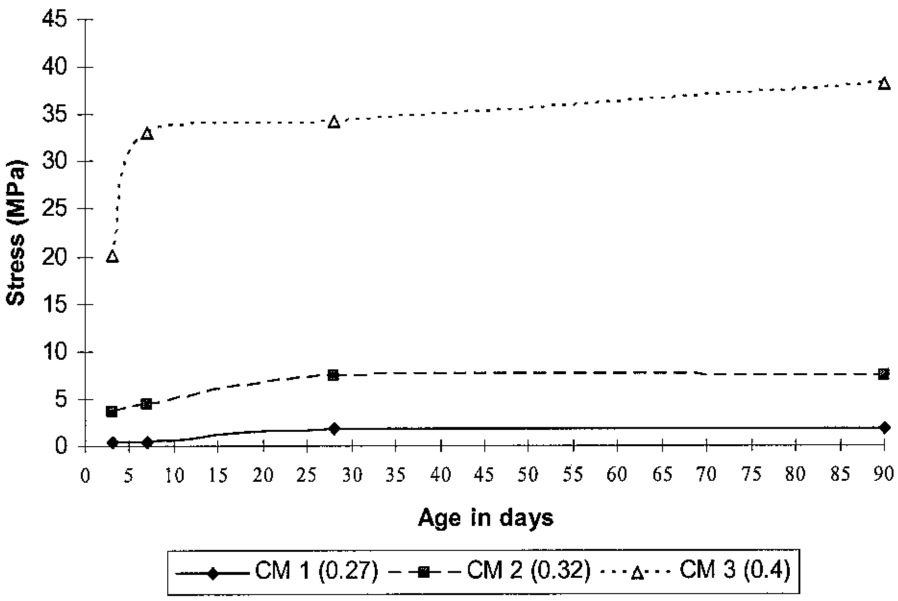

Figure 14: Compressive strength results for Control Mix.

CM 1 and CM 2 have very low strength development because the aggregates are too dry and they absorbed most of the water before it can react with cement. Besides that, the cement too has already undergoes some reaction in the room temperature before being used. It is due to the hot weather here in Tronoh and there is not any proper storage for the materials because the materials are left exposed to heat, rain and dusts. Therefore, the samples for water cement ratio of 0.27 and 0.32 were too dry and not sufficient to carry out this experiment.

The compressive strength for water cement ratio of 0.32 is represented in Figure 15 below. It shows that 0.5 SP (high volume fly ash with 0.5% super-plasticizer cement) have the highest strength, follow by CM 2 (cement only) and 0 SP (high volume fly ash cement only).

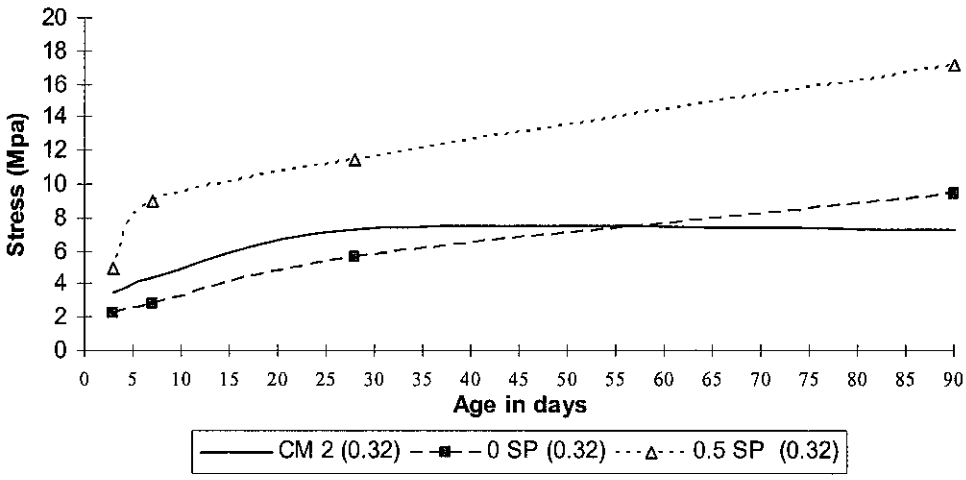

Figure 15: Compressive strength results for 0.32 w/c.

There is only an increase of 38.9% between CM 2 and 0.5 SP at day 28. 0 SP sample strength increases slowly from day 3 to day 7, but increases drastically from day 7, while 0.5 SP samples increases its strength since day 1 till day 28. The 0.5% super-plasticizer has increase the cement strength by 50.5% as compared to 0 SP samples at day 28. This proof that super-plasticizer does in deed improve early strength development in HVFA concrete. Therefore, I can conclude that 0.5% of super-plasticizer for water cement ratio of 0.32; have increase the compressive strength of the samples.

After casting samples for 0.32 water cement ratio the storage of materials as stated previously was implemented. It is found that later mixes strength development pattern varied from the result for water cement ratio of 0.32.

According to Figure 16 below, with or without super-plasticizer from day 3 to day 90; the compressive strength for all the samples was lesser than the CM 3 (Control Mix). The highest compressive strength is CM 3, followed by 0 SP, 0.5 SP, 3 SP, 2.5 SP, 1.5 SP, 1 SP and lastly 2 SP for 28th day strength. Not all the 90th days strength is available now, but the highest 90th day strength is 1.5 SP.

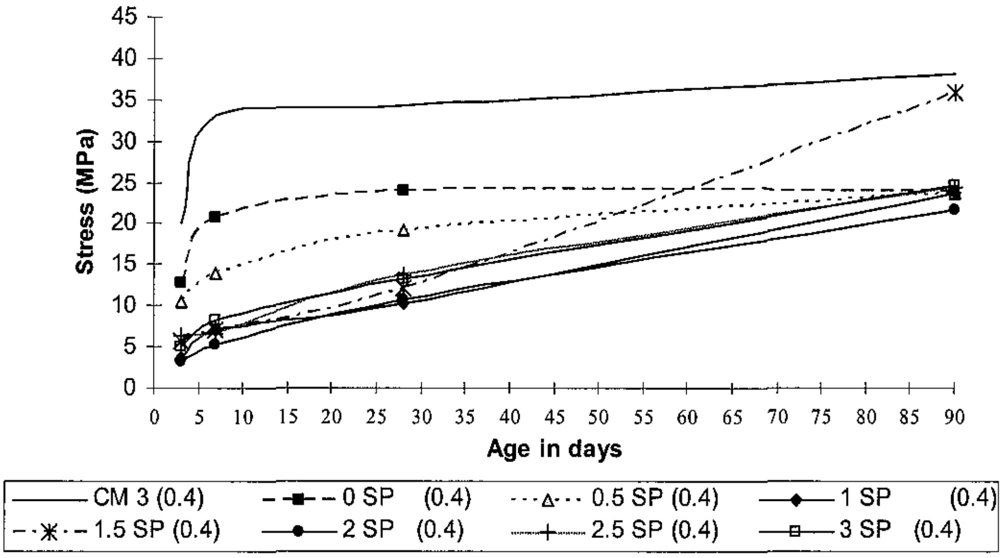

Figure 16: Compressive strength results for 0.4 w/c.

It is normal for all the mixes with super-plasticizer and high volume of fly ash to be lower than ordinary cement paste; this is due to the low and slow development of early strength of pozzolan. According to Pretorius and Kearsley[3], high volume PFA content have a reduced early age strengths for up to 3 months.

On the 28th day results, 0.5 SP have the highest strength compare with the rest of the mix with super-plasticizer but its strength development is still lower than CM 3 by 44.3%. There is not much different in strength development on the 28th day between 2.5 SP and 3 SP. The rest of the available 90th results are almost the same, but 1.5 SP shows extra ordinary strength development (only 6.3% different from CM). Its strength increase drastically after 28th day and maybe it will further increase its strength to be higher than Control Mix after day 90 because hydration process still going on in the mix because fly ash have lower heat of hydration as compare to Ordinary Portland Cement.

4.2.3 Porosity

Neville[4] state that strength of concrete is a function of the volume of voids in it. Most strength of concrete is influenced by volume of all voids in concrete: entrapped air, capillary pores, gel pores and entrained air but not all.

According to Figure 17 below, the lowest porosity on day 28 beside control mix is achieved by 2.5 SP; it shows a drastic reduce of porosity from day 7 onwards. Its porosity has reduced from 12.57 to 9.46%, which are 3.11% difference (7.08% different from CM), after that followed by 0.5 SP, 1.5 SP, 0 SP, 1 SP, 3SP and lastly 2 SP for day 28th results.

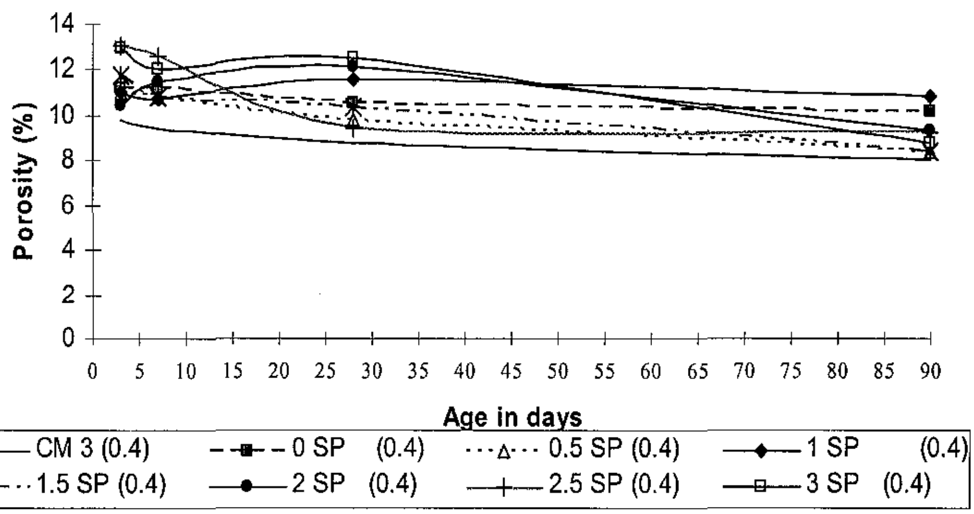

Figure 17: Porosity results for 0.4 w/c.

The lowest porosity among all the 90th day mix with super-plasticizer is 0.5 SP, with only 8.38% and followed by 1.5 SP with 8.39%. It is then followed by 3 SP, 2.5 SP, 2 SP, 0 SP and 1 SP. The porosity percentage may reduce after 90th day because fly ash and super-plasticizer are still reacting with each other and hydration process is still going on.

4.2.4 Permeability

Permeability indicates the ease which fluids, can enter into and move through the concrete. Lower permeability will give many advantages to the concrete, such as high durability, high resistance to sulfate and chloride attack. HVFAC and super-plasticizer can decrease concrete permeability.

Figure 18 below shows permeability results for all 28th day 0.4 water cement ratios. From Figure 17, 2.5 SP have the lowest permeability (8.954E-15) follow by 1.5 SP, 2 SP, 0.5 SP, 3 SP and lastly 1 SP.

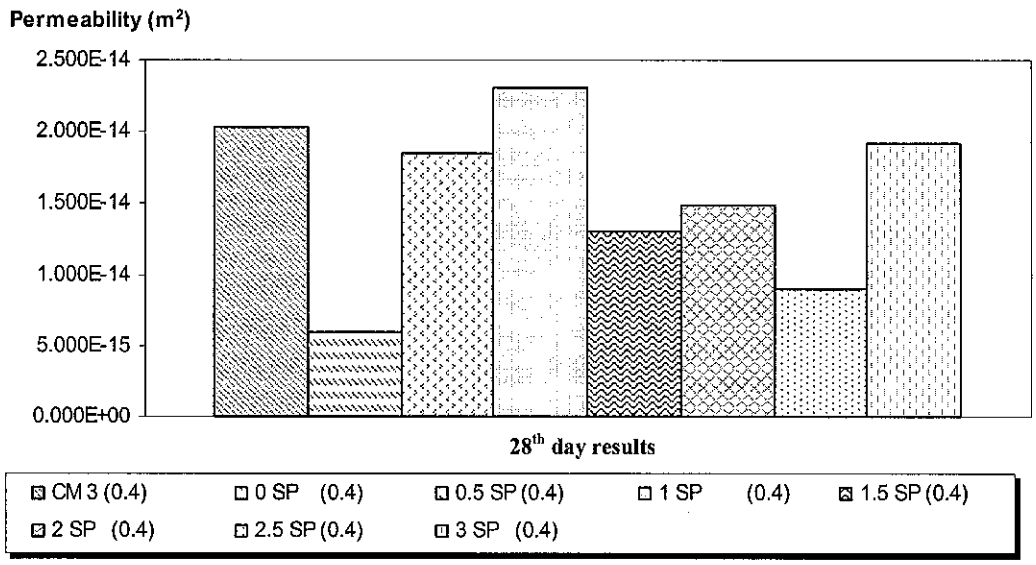

Figure 18: Permeability test results for 0.4 w/c.

If we compare the result of 0.5 SP 28th day result with 90th result both for porosity and permeability, lower porosity will not necessary have low permeability. Neville[4], it is because permeability is controlled by bulk of hardened cement paste which is only the continuous phase in concrete.

From the results and discussion shown above, theoretically strength of concrete is proportionate to permeability and not proportional to porosity. Permeability is the ease of liquid, ion and gas flow into the concrete, while porosity is the measurement percentage of voids in the concrete. For example, for the same amount of voids in two different sample (refer to Figure 19 below), the sample on the left might have low permeability and high strength than sample on the right. This is due to the distribution of pore, size and connectivity of pores in the concrete.

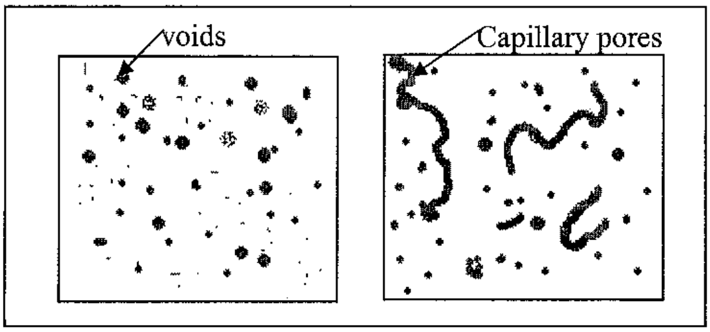

Figure 19: Comparison of pores distribution and connectivity between two same porous samples.

At day 90, the results show that 1.5 SP strength is the highest with higher porosity and lower permeability as compared to 0.5 SP. It is due to the pore size; distribution and connectivity of pores gel.

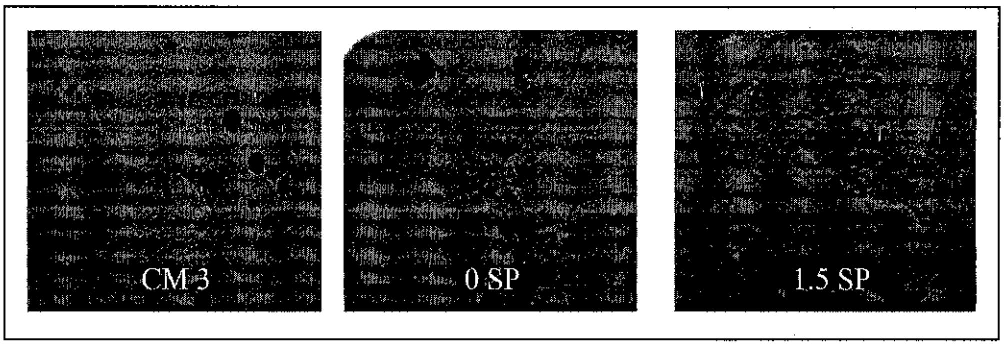

Figure 20: Comparison of pores distribution and connectivity between CM 3, 0 SP and 1.5 SP.

Incorporation of super-plasticizer into concrete mix will refine the pore structures and reduce total pore volume, according to Khatib* and Mangat[7]. Their theory is proven to be true by referring to Figure 20 above. From Figure 20 it is obvious that 1.5 SP pore size have reduced and finer as compared to CM 3 and 0 SP. The CM 3 (OPC) has more and bigger pores, but with the incorporation of high volume of fly ash (0 SP) into it, the pore becomes smaller and lesser. Fly ash act as filler and fill in between the cement paste pores. But with the incorporation of super-plasticizer with high volume of fly ash concrete (1.5 SP), the pore size are finer.

Hence from the discussion above we can conclude that strength of concrete is proportionate to pores distribution and size, rather then total amount of pores. Meanwhile, durability is proportionate to permeability and strength of concrete. Less permeable concrete, higher resistance to sulphate and chloride attack.

Table 6: Comparison between the maximum dosage ranges of super-plasticizer.

Samples	**1.5 SP**		**2 SP**		**2.5SP**	
Age in days	28th	90th	28th	90th	28th	90th
Workability						
Compressive strength						
Porosity						
Permeability		N/A		N/A		N/A

Legend:

Poor
Moderate
Good

According to Table 6 above, it seems like 2.5 SP has the maximum super-plasticizer dosage for 28th day results, but for 90th day result, 1.5 SP gave a better results. 2.5 SP (refer to Figure 12 above) shows some bleeding on top of the concrete cubes although it is very cohesive. Thus during mixing and handling, both of these ratio need extra handling and care.

We always want to have mix which is workable, strong and durable so that it can resist the harsh environment impact on it and low maintenance. Hence with the available results, 1.5 SP is the maximum super-plasticizer dosage.

CHAPTER 5
CONCLUSION

From this research following conclusions were drawn:

- High volume of fly ash (60%) resulted low early strength as compared to 100% ordinary concrete. This is due to the retarding composition in the fly ash and in order to counter this problem, chemical admixtures – high range water reducer (super-plasticizer) was added into the mixture to accelerate the early strength development while increasing its workability, compressive strength and porosity with lower water ratio.

- High volume of fly ash (60%) resulted in reduced workability as compared to 100% ordinary concrete. Super-plasticizer was used to increased workability. Workability increased as amount of super-plasticizer increased, but more than 2.5% of super-plasticizer will result in bleeding and segregation.

- Based on the experimental results a dosage of 1.5% of super-plasticizer was obtained as optimum for producing workable, high strength and durable concrete.

CHAPTER 6
RECOMMENDATION

- It is recommended that smaller dosage of super-plasticizer ranges from 1.5% to 2.5% are use to get a more precise optimum dosage.

- It will also be better to compare the different effect between super-plasticizer and plasticizer. This is important in order to determine that super-plasticizer is significant enough to produce high strength concrete with low water ratio in a more economical way than plasticizer since plasticizer is cheaper than super-plasticizer.

- Besides that, we should further increase the experiment test results up to 360 days in order to get a better and precise optimum strength development because durability played important roles in structures. This is because pozzolans are well known for its slow development and its retarding process can be as slow as up to three months.

- More research projects should be conducted for the usage of fly ash as cement replacement materials in Malaysia climate.

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APPENDICES

APPENDIX 1-1 : Complete mix design and requirements.

MIX DESIGN 1 (0.27 & 0.32)				
MIX TYPE	CM 1	CM 2	0 SP	0.5 SP
OPC (kg/m^3)	340	340	136	136
PFA (kg/m^3)	0	0	204	204
CA 14mm (kg/m^3)	1190	1190	1190	1190
SAND (kg/m^3)	765	765	765	765
W/C	0.27	0.32	0.32	0.32
WATER (kg/m^3)	92	109	109	109
SUPERPLASTICISER	0%	0%	0%	0.50%
(kg/m^3)	0	0	0	1.7

MIX DESIGN 2 (0.4)										
MIX TYPE	CM 1	CM 2	CM 3	0 SP	0.5 SP	1 SP	1.5 SP	2 SP	2.5 SP	3 SP
OPC (kg/m^3)	340	340	340	136	136	136	136	136	136	136
PFA (kg/m^3)	0	0	0	204	204	204	204	204	204	204
CA 14mm (kg/m^3)	1190	1190	1190	1190	1190	1190	1190	1190	1190	1190
SAND (kg/m^3)	765	765	765	765	765	765	765	765	765	765
W/C	0.27	0.32	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
WATER (kg/m^3)	92	109	136	136	136	136	136	136	136	136
SUPERPLASTICISER	0%	0%	0%	0%	0.50%	1.00%	1.50%	2.00%	2.50%	3.00%
(kg/m3)	0	0	0	0	1.7	3.4	5.1	6.8	8.5	10.2

MATERIALS REQUIREMENTS (0.4)										
MIX TYPE	CM 1	CM 2	CM 3	0 SP	0.5 SP	1 SP	1.5 SP	2 SP	2.5 SP	3 SP
OPC (kg)	16.5	16.5	16.5	6.6	6.6	6.6	6.6	6.6	6.6	6.6
PFA (kg)	0	0	0	9.9	9.9	9.9	9.9	9.9	9.9	9.9
CA 14mm (kg)	57.7	57.7	57.7	57.7	57.7	57.7	57.7	57.7	57.7	57.7
SAND (kg)	37.1	37.1	37.1	37.1	37.1	37.1	37.1	37.1	37.1	37.1
WATER (kg)	4.5	5.28	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
SUPERPLASTICISER (g)	0	0	0	0	82	165	247	330	412	495

APPENDIX 1-2 : Fly Ash properties.

for info only.

SLAG CEMENT SDN BHD

(Company No: 368743-P)

PULVERISED-FUEL ASH
TEST CERTIFICATE
Chemical & Physical Properties

Despatched Sample Date : 25-Feb-05

Test Type			BS EN 450 : 1995	Result
45 µm Sieve Residue		(%)	Max 40.0	22.32
Loss On Ignition	(LOI)	(%)	Max 6.0	4.21
Sulphuric Anhydride	(SO_3)	(%)	Max 3.0	0.88
Silica	(SiO_2)	(%)	Min 25.0	51.19
Chloride	(Cl^-)	(%)	Max 0.10	0.01
Free Calcium Oxide	(CaO)	(%)	Max 1.0	0.05
Activity Index : 28 Days		(%)	Min 75	84
: 90 Days		(%)	Min 85	97
*Soundness		(mm)	Max 10.0	N/A
Density		(kg/m^3)	-	2290
Magnesium Oxide	(MgO)	(%)	-	2.40
Iron Oxide	(Fe_2O_3)	(%)	-	6.60
Aluminium Oxide	(Al_2O_3)	(%)	-	24.00
Calcium Oxide	(CaO)	(%)	-	5.57
Potassium Oxide	(K_2O)	(%)	-	1.14
Sodium Oxide	(Na_2O)	(%)	-	2.12

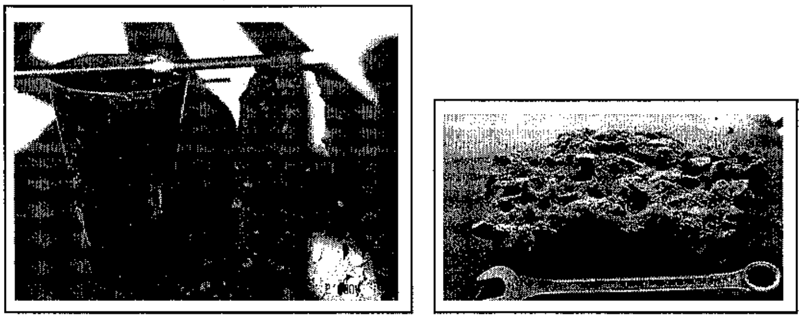
Remarks : * Accordance to BS EN 450 : 1995 : Clause 4.2.5 - Soundness Test is required only if Free Calcium Oxide exceeds 1.0% by mass.

The product complies with BS EN 450 : 1995 based on compliance to all requirements.

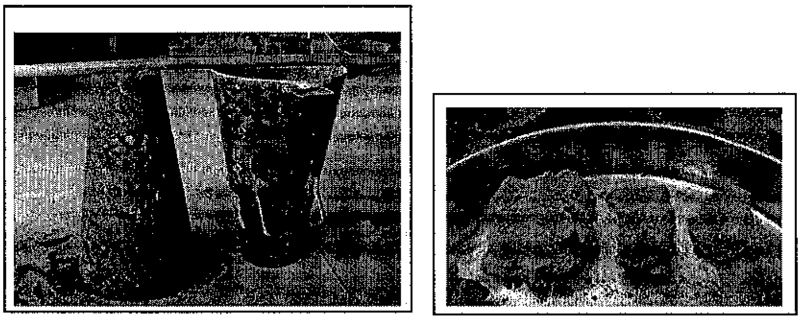
Signed : ____________ Date : 1-Jun-05

(QC Manager)

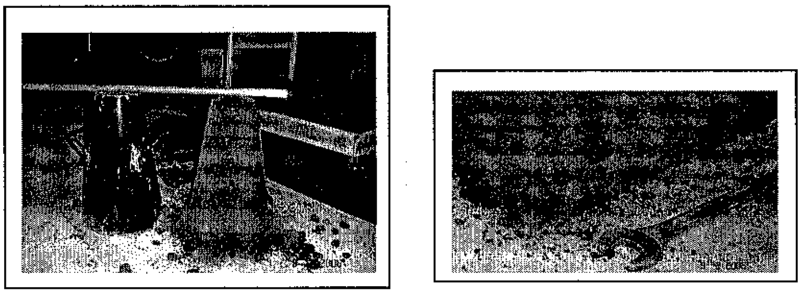
APPENDIX 2-1 : Slump test for all 0.27 and 0.32 water cement ratio mix.



Slump test and concrete slab for CM 1.
Slump = 0mm ~ No slump (stiff).



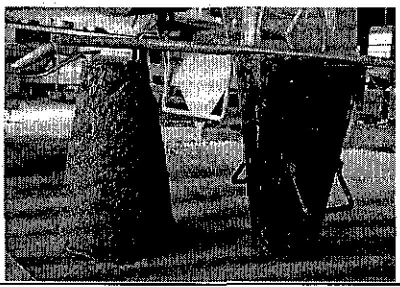
Slump test and samples for CM 2.
Slump = 0mm ~ No slump (stiff).



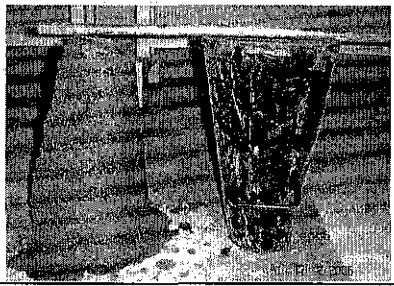
Slump test and concrete slab for 0SP.
Slump = 0mm ~ No slump (stiff).

Slump test and samples for 0.5SP.
Slump = 0mm ~ No slump (stiff).

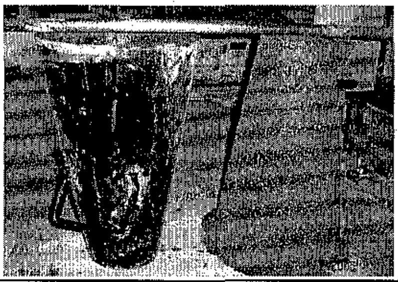
APPENDIX 2-2 : Slump test for all 0.4 water cement ratio mix.



Slump test for CM 3.
Slump = 16mm ~ Low workability.



Slump test for 0SP.
Slump = 13mm ~ Low workability.

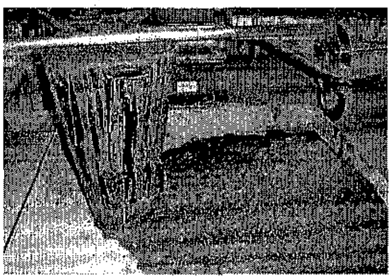


Slump test for 0.5SP.
Slump = 0mm ~ No slump (cohesive).

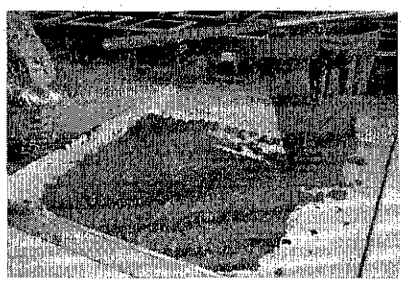
Slump test for 1SP.
Slump = 30mm ~ High workability.

Sslump test for 1.5SP.
Slump = 115mm ~ High workability.

Slump test for 2SP.
Slump = 135mm ~ High workability.



Slump test for 2.5SP.
Slump = 178mm ~ Very high workability.



Slump test for 3SP.
Slump = 293mm ~ Collapse slump.