EFFECT OF WATER CEMENT RATIO ON COMPRESSIVE STRENGTH, POROSITY AND CHLORIDE MIGRATION OF DIFFERENT MORTAR SAMPLE

By

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FINAL PROJECT REPORT

Submitted to the Civil Engineering Program
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

Dr Nasir Shafiq
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2005

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.

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Nurazirah Hasan

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Firstly, I would like to thank to Allah SWT for giving me the opportunity to finish my final year project successfully.

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ABSTRACT

Mortar has been widely used in building construction as a finishes and as a binder to bind masonry units together. The strength and the resistance to environmental attack such as salt water are very important. Water cement ratio is one of the common criteria that may affect the durability and others of mortar. This study presents the effect of water cement ratio on the development of compressive strength, total porosity and the migration of chloride into mortar samples.

The compressive strength test result shows that water cement ratio has inverse relationship with the development of compressive strength and a direct relationship with the total porosity. For water cement ratio ranging from 0.3 to 0.5, there was increase in compressive strength approximately 30% - 35% for all mortar samples and the total porosity was reduce to 3% to 5%.

For chloride migration test, the rate of chloride migration is too fast. The samples are too small which is $50mm^{3}$; a full penetration was achieved for all types of samples.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

This report presents the results of the affect of water cement ratio on compressive strength, porosity and chloride migration for different mortar samples. It contains how the behavior of strength, porosity and migration of chloride ions as the water cement ratio is increase in different cement sand ratios.

Mortar is a mixture of sand, cement and water. It is widely use in construction as a material to bind or to hold two masonry units together such as to bind bricks, stones, concrete blocks and glass blocks together. Beside that, the usage of mortar is for plastering purposes, application for surface facing such as for pavement or floor, walls, and other architecture elements. Mortar plays an important role in construction works, it is important to analyze the effect of water cement ratio to the characteristic of mortar.

To concern about the effect of water cement ratio to mortar properties, a few experiments such as strength test, porosity test and chloride migration test were conducted and the results was discussed at the end of this report. The discussion part is mainly discussed how the water cement ratio will effect the strength, porosity and migration of chloride ions for mortar.

1.2 Problem Statement

As mentioned before, mortar is very important and has been widely use in construction. With the increase interest in performance of construction materials, achieving a good bond and acceptable bond strength in masonry unit is becomes an essential requirement. This is because mortar-unit joint is commonly acted as a plane of weakness that may affect masonry strength, serviceability and durability.

In marine construction, the attack of seawater to the structure cannot be ignored because a lot of problems may occur. One of most common problem is a corrosion of the reinforced steel. It means that the resistance of mortar to the environmental attack is significantly important.

Through the previous discussion, water cement ratio is very important and may give an effect to the strength and resistance to the environmental attack. It is important to know at what water cement ratio the mortar will be in the best condition and how it will affect the mortar strength, durability and workability.

So in this report, the effect of water cement ratio on compressive strength, porosity and migration of chloride ions is investigated and discussed. To get the results, a few experiments are conducted as mentioned before.

1.3 Objectives and Scope of Study

The objective of the project is mainly to investigate the effect of water cement ratio on compressive strength, porosity and chloride migration of mortar for 3 day, 7 day, 28 day and 90 day of mortar ages for different types of mortar samples. There are three different mortar samples that have different cement sand ratio which is 1:4, 1:5 and 1:6 need to be prepared with four different water cement ratio which is 0.3, 0.35, 0.4, 0.5. Figure 1.1

shows clearly total of mortar samples for 3 different experiments that need to be conducted.

This project is mainly divided into two parts which are:-

i. Research – In this part, it required the research of the effect of water cement ratio on the properties of mortar.

ii. Experimental / testing – in this part, several tests need to be conducted by using the machinery provided to determine the compressive strength, porosity, and chloride migration test.

The project is expected to be completed in the given time frame and the Gantt chart has been prepared. It is required to follow the schedule to complete the project within the given period for having a good time management and not delaying for any reports that need to be submitted.

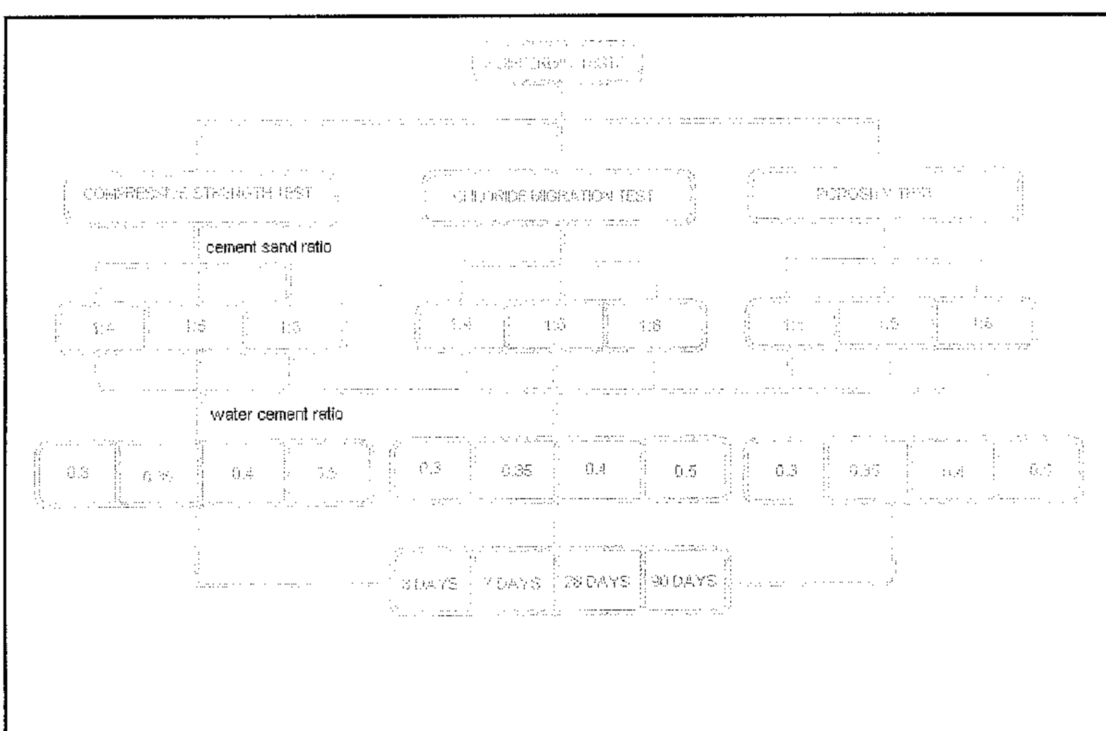

***Figure 1.1**: Total Mortar Samples for 3 different Experiments*

CHAPTER 2
LITERATURE REVIEW/THEORY

Mortar is a mixture of cement, sand and water, together with other materials introduced to enhance the properties of the mortar such as setting time, water retention and workability. In construction, mortar has been used in finishing phase where applying mortar to cover the surface of floor, walls, and other architecture elements. Besides, mortar is use to bind masonry units into a singles element, developing a complete, strong and durable bond.

Because concrete and mortar contains the same principle ingredients, it is assume that a good concrete practice is also good for mortar practice. In reality, mortar differs from concrete in working consistencies, method of placement, and structural performance. As mentioned before, mortar is use to bind masonry units into a singles element, developing a complete, strong and durable bond. However, for concrete, it is a structural element in itself.

Mortar is usually placed between absorbent masonry units, and loses water when contact with the units. Concrete is usually placed in non-absorbent metal or wooden forms, which absorb little water. The importance of the water cement ratio for concrete is significant, whereas for mortar it is less important compared to concrete. Mortar that has a high water cement ratio when mixed is change to a lower value when it has come in contact with the absorbent units.

Historically, mortar has been made from variety types of materials such as burned gypsum and sand in ancient Egypt. Currently, the basic dry ingredients for mortar include portland cement, mortar cement, masonry cement, hydrated lime, and sand. Each of these materials makes a definite contribution to mortar performance. For the study, Portland cement is being use. Portland cement, a hydraulic cement is the principle cementitious ingredient for mortars. It contributes to durability, high strength, and early setting of the mortar. Portland cement used in masonry mortar should conform to ASTM C 150, Specification for Portland Cement. Out of eight types covered by ASTM C 150, only three are recommended for use in masonry mortars:

Type I	For general use when the special properties of Types II and III are not required
Type II	For use when moderate sulfate resistance of moderate heat of hydration is desired
Type III	For use when early strength is desired

Sand and water is also use in a mixing of mortar. Sand acts as a filler, providing for an economical mix and controlling shrinkage. Gradation limits of sand size are given in ASTM C 144, Specification for Aggregates for Masonry Mortar. To mix the entire ingredient together, water that is suitable for masonry mortar must clean, portable and free form deleterious acids, alkalies or organic materials.

2.1 Physical Properties of Mortar

In general, mortars have two sets of properties; those in plastic state and those in hardened state. The plastic properties help to determine the mortar's compatibility with brick and its construction suitability. Properties of plastic mortars include workability, water retention, initial flow and flow after suction. Properties of harden mortars help determine the performance of the finished masonry. Hardened properties include bond strength, durability, extensibility and compressive strength.

Bond strength. Bond strength is important properties of hardened mortar. Both strength and the extent of bond are important. There are a few criteria that may affect the bond strength such as texture of the bricks, suction of the bricks, air content of the mortar, water retention of the mortar, pressure applied to the joint during forming, mortar proportions and method of curing. Brick texture can provide a mechanical bond between the brick and mortar. Mortar bond is greater to roughened surfaces than to smooth surfaces. Sanded and coated surfaces can reduce the bond strength depending upon the amount and type of material on the surface and its adherence to the surface.

Available information indicates a definite relationship exist between air content and bond strength of mortar. Provided other parameters are held constant, as air content is increased, compressive strength and bond strength are reduced, while workability and resistance to freeze-thaw deterioration are increased.

Compressive Strength. Same as concrete, the compressive strength of mortar primarily depends on the cement content and the water cement ratio. The proportion of cement and water gives an affect to the strength of mortar. Compressive strength increases with an increase in cement content of mortar and decreases with an increase in water content. Figure 2.1 shows the relationship between compressive strength and water cement ratio. As the age of the concrete is high, the strength of mortar is also increase. The relationship between compressive strength and age of curing are as shown in Figure 2.2 .

Compressive strength is measured by testing 2 in. (50mm) mortar cubes or 2 in. (50mm) and 3 in. (75mm) diameter cylinders. Procedures for moulding and testing cubes and cylinders appear in ASTM C 109 and ASTM C780, respectively. Because the test are relatively simple and because they give consistent, reproducible results, compressive strength is considered one basis for comparing mortars.

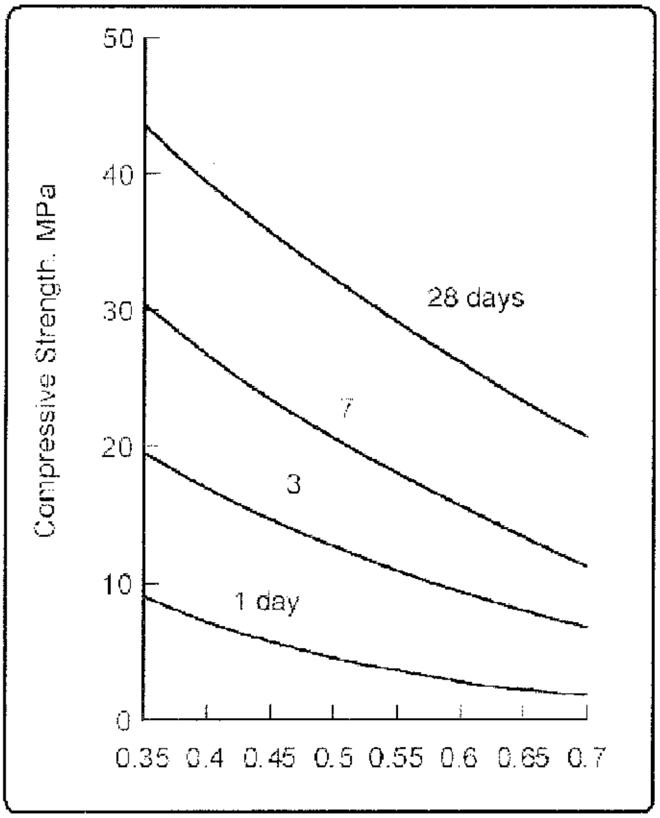

***Figure 2.1**: Influence of water cement ratio and moist curing age on mortar strength*

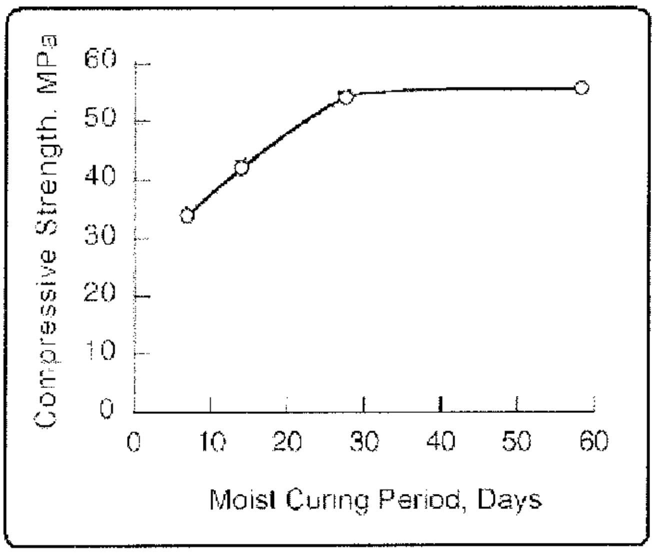

***Figure 2.2**: Relationship between compressive strength of mortar and moist curing age*

Porosity. Porosity is the ratio of the volume of voids in the mortar to the total volume of the mortar in percentage. In general, as shown in Figure 2.3 there is a fundamental inverse relationship between porosity and strength for mortar. The formula used to calculate total porosity of mortar is as shown below. W_{sa}, W_{sw} and W_d represent weight of saturated surface dry samples in air, weight of saturated surface dry samples in water, and weight of oven dry samples respectively. The weight of saturated surface dry samples in air is get after 50mm diameter x 40mm depth cylinder was takes out from the vacuum desiccators. The function of vacuum desiccators is to suck out the air inside the mortar samples and filled the voids with water. Figure 2.4 shows the vacuum saturation apparatus.

Formula: Total Porosity (%) = $[(W_{sa} - W_{sd}) / (W_{sa} - W_{sw})] \times 100$

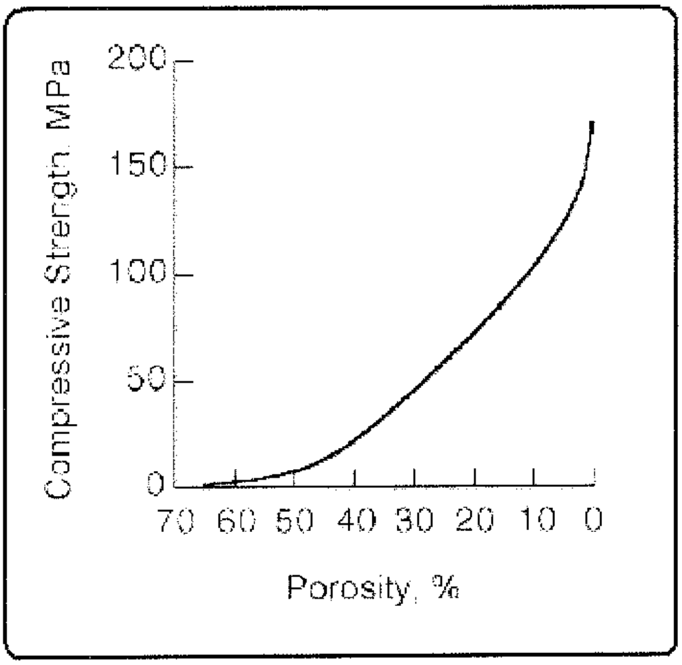

Figure 2.3: *The inverse relationship between porosity and strength of mortar*

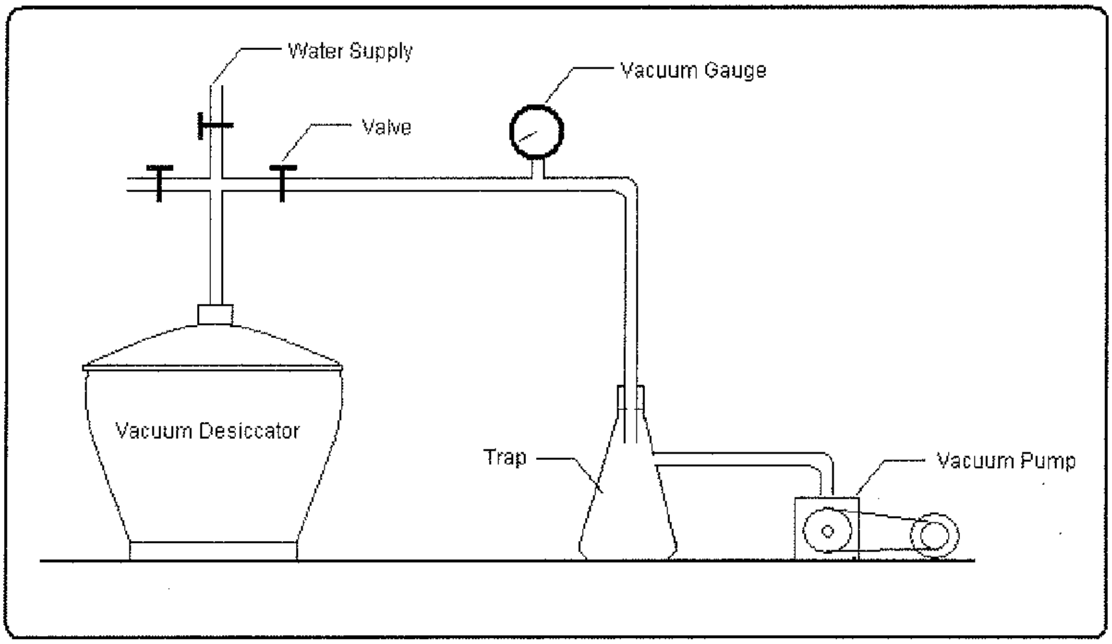

Figure 2.4: Vacuum Saturation Apparatus

Durability. The resistance to chloride penetration is one of the most important properties of concrete and mortar with respect to durability of reinforced concrete structures. The present of chloride ions in building materials can lead to corrosion of steel bar for reinforce concrete structure. The effect of mortar's porosity on its resistance to migration of ions is quite complex. In determining the rate of ingress of an aggressive medium into concrete, the distribution of pores in the mortar samples has to be considered, especially their size and connectivity.

In concrete and mortar this pore structure is affected by the presence of the aggregate. Using mercury intrusion porosimetry (MIP), Winslow and Liu [1] showed that the pore structure of paste developed in the presence of aggregate is quite different from that of neat cement paste. The aggregate-paste interface, or "transition zone", has a definite effect on the pore size distribution due to its considerably higher porosity and the larger pores that it contains. The effects of the transition zones on the transport properties should depend on the aggregate content.

When the transition zones are isolated by a less porous bulk paste, the rate of transport should be significantly lower than if the transition zones overlap, which would create a continuous path of low resistance to penetration. This interconnection has been referred to as "percolation". As evidence of such percolation, Winslow et al. [2] observed that the MIP results for mortars depend on the sand content, with the intrusion curves for sand contents higher than some critical value showing a disproportionate increase in the volume of larger pores.

CHAPTER 3
METHODOLOGY

3.1 Work Breakdown Structure (WBS) and Work Flow

As stated before, the project is expected to be completed in a given time frame. So, in order for the project to be completed successfully and according to the objectives, certain approaches and methodologies are taken. Figure 3.1 shows the step that the student has organized to achieve the project objective. Table 3.1 and Figure 3.2 show the code used and activity involved, and work flow diagram respectively. The flow of the works is shown in Gantt chart in Appendix 1.

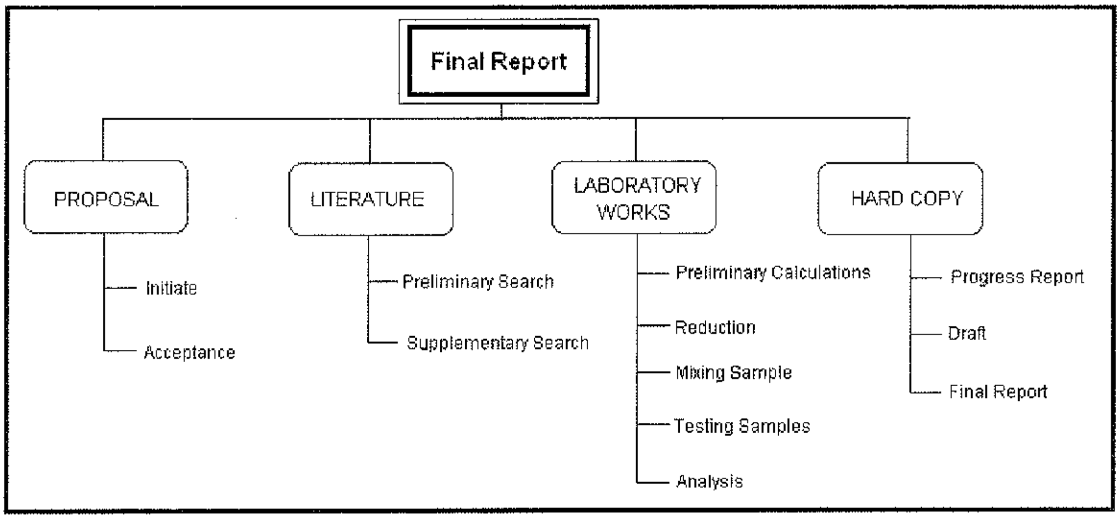

Figure 3.1: *Work Breakdown Structure*

Code	Activity
A	Start proposal
B	Acceptance of proposal
C	Preliminary literature review research work
D	Preliminary Report
E	Preliminary Calculations for preparing samples
F	Prepare progress report
G	Preliminary sample reduction
H	Supplementary literature review research
I	Mixing sample
J	Testing sample
K	Analysis of results
L	Prepare draft final report
M	Prepare final report
N	Oral presentation

Table 3.1: *Code and Activity*

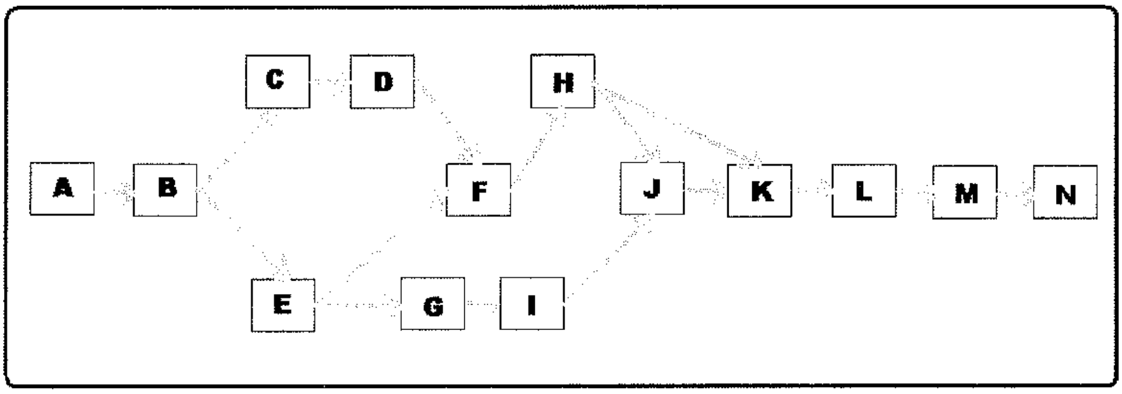

Figure 3.2: *Work Flow Diagram*

3.2 Procedure Identification

For this project, there are three types test is conducted in order to achieve the objective of this project, which is compressive strength test, chloride migration test and porosity test. Compressive strength test is to find the maximum compressive load per unit area of the mortar. The basic test for the compressive strength of mortar is determined by testing 2 inch (50mm) cubes of laboratory prepared mortar cured under control condition. The strength of mortar is tested for 3, 7, 28 and 90 day and 3 samples of mortar specimen are prepared for 0.3, 0.35, 0.40 and 0.50 of water cement ratio.

For chloride migration test, the effect of chloride is tested for 3, 7, 28 and 90 day and at least 2 samples of specimen are prepared. The specimen is stored in different curing test that contains 3% of salt by weight of water. To indicate the presence of chloride ions for each sample, the specimen will be broke into two parts and sprayed by using silver nitrate solution. The change in color from colorless to dark color surface shows the presence of chloride ions in the specimen. Then, the length of the chloride migration (as shown in Figure 3.3) is measured.

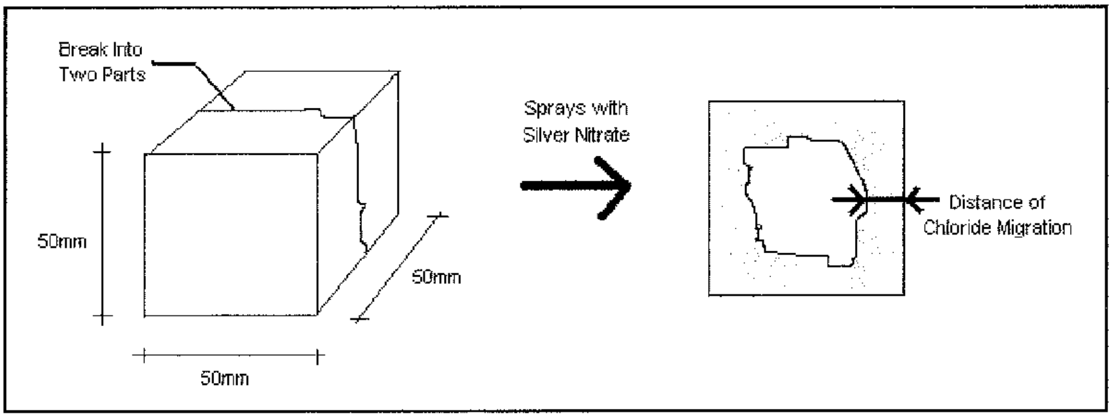

Figure 3.3: *Chloride Migration Test*

For another test, which is porosity test, a few sets of concrete slab are cast to obtain the cored concrete for porosity test. As similar to compressive strength test, the total number of porosity determination or porosity test will also be conducted for 3, 7, 28 and 90 day. The details dimension for concrete slab and cored concrete are as shown in Figure 3.4 below.

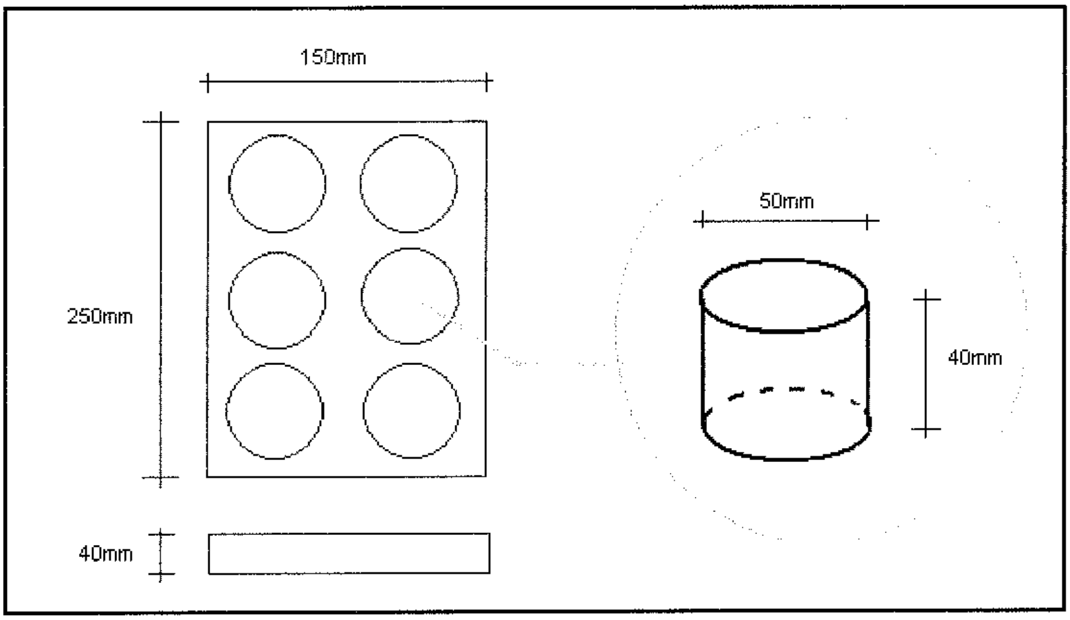

Figure 3.4: *Dimension of Concrete Slab and Cored Concrete*

3.3 Equipment Used

3.3.1 for compressive Strength Test

- Metal platform
- a pair of shovels
- steel hand scoop
- 50 x 50 x 50mm size of steel mould for test cubes
- a compressive testing machine
- Mortar Mixer

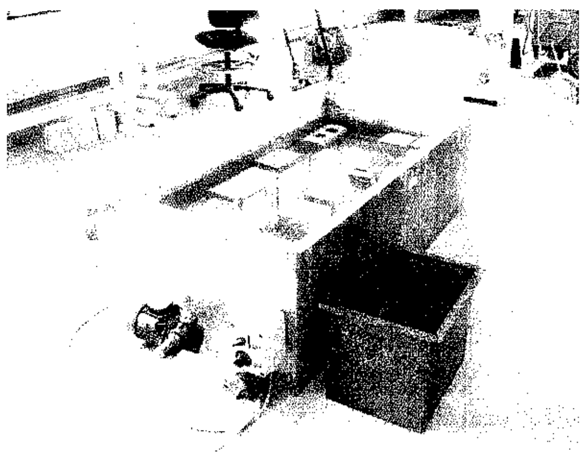

Figure 3.5: *Curing Tank*

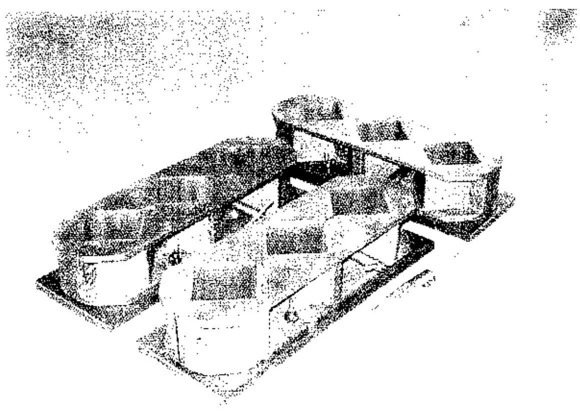

Figure 3.6: *50mm cubic mould*

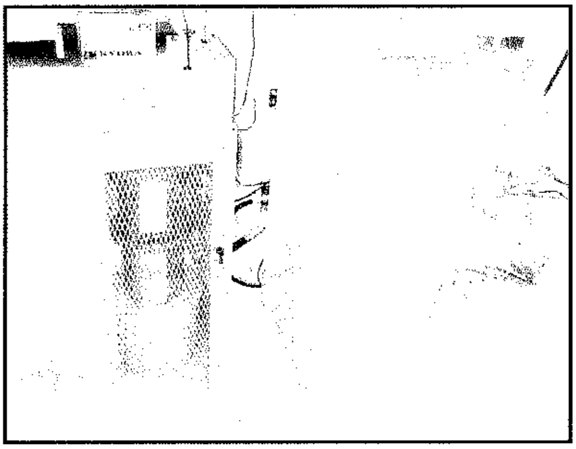

Figure 3.7: *Compressive Testing Machine*

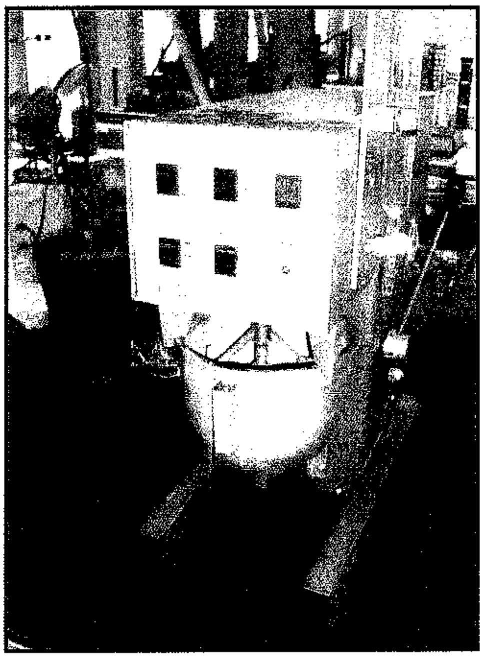

Figure 3.8: *Mortar Mixer*

3.3.2 For Porosity Test

- Vacuum Pump
- Drying Oven
- Electronic Buoyancy Balance

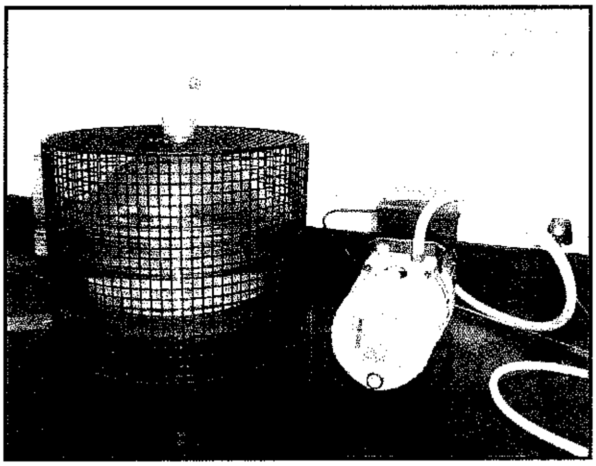

Figure 3.9: *Vacuum Pump*

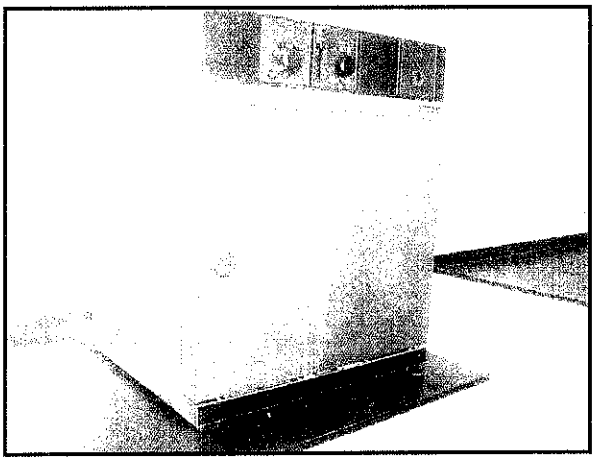

Figure 3.10: *Dry Oven*

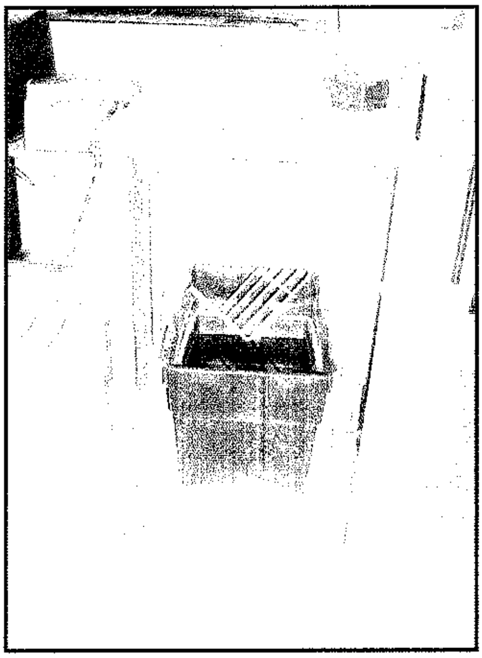

Figure 3.11: Electronic Buoyancy Balance

CHAPTER 4
CALCULATION

4.1 Calculation of Weight of Cement, Sand and Water

For all types of samples, the example of calculation is as shown below. Table 4.1 show the weight of cement, sand and water for 1:4, 1:5 and 1:6 cement sand ratio with different water cement ratios.

Example of calculation for *x:y* cement sand ratio with *z* water cement ratio

Percentage of cement content = $x/(x+y)$ X 100% = a %
Percentage of sand content = $y/(x+y)$ X 100% = b %

Volume of 20 cubes (using 50 x 50 x 50 mm cube size)
$V_{20} = 0.05 \times 0.05 \times 0.05 \times 20\ m^3$
$= 0.0025\ m^3$

Density of mortar, $\rho_m = 2400 kg/m^3$

Weight of 20 cubes, W20 = $2400\ kg/m^3 \times 0.0025\ m^3 = 6kg$

For 20 cubes, the total weight = 6.3 kg (including 5% tolerance)

So, weight of cement content = a % X 6.3kg = c kg
Weight of sand content = b % X 6.3 kg = d kg
Weight of water = $z \times c$ = e kg x 1000L = f liter

For 1:4(cement: sand), 0.3 w/c ratio		For 1:5(cement: sand), 0.3 w/c ratio		For 1:6(cement: sand), 0.3 w/c ratio	
Sand, kg	5.04	Sand, kg	5.25	Sand, kg	5.40
Cement, kg	1.26	Cement, kg	1.05	Cement, kg	0.90
Water, L	378	Water, L	315	Water, L	270
For 1:4(cement: sand), 0.35 w/c ratio		**For 1:5(cement: sand), 0.35 w/c ratio**		**For 1:5(cement: sand), 0.35 w/c ratio**	
Sand, kg	5.04	Sand, kg	5.25	Sand, kg	5.40
Cement, kg	1.26	Cement, kg	1.05	Cement, kg	0.90
Water, L	441	Water, L	368	Water, L	315
For 1:4(cement: sand), 0.4 w/c ratio		**For 1:5(cement: sand), 0.4 w/c ratio**		**For 1:5(cement: sand), 0.4 w/c ratio**	
Sand, kg	5.04	Sand, kg	5.25	Sand, kg	5.40
Cement, kg	1.26	Cement, kg	1.05	Cement, kg	0.90
Water, L	504	Water, L	420	Water, L	360
For 1:4(cement: sand), 0.5 w/c ratio		**For 1:5(cement: sand), 0.5 w/c ratio**		**For 1:5(cement: sand), 0.5 w/c ratio**	
Sand, kg	5.04	Sand, kg	5.25	Sand, kg	5.40
Cement, kg	1.26	Cement, kg	1.05	Cement, kg	0.90
Water, L	630	Water, L	525	Water, L	450

Table 4.1: *Table of Weight of Cement, Sand and Water*

4.2 Porosity Test Data and Calculations

Weight of saturated surface dry samples in air, W_{sa}

Weight of saturated surface dry samples in water, W_{sw}

Weight of oven dry samples, W_d

Formula: $\frac{W_{sa} - W_d}{W_{sa} - W_{sw}} \times 100\%$

Table 4.2: Results for 0.30 water cement ratio

For 1:4 (cement: sand)				
Weight (g)/Age	**3days**	**7days**	**28days**	**90days**
W_{sa}	202.8	203.75	210.1	203.65
W_{sw}	79.25	67.6	71.6	66.6
W_d	192.95	193.6	194.2	186.54
Porosity (%)	7.97	7.46	11.48	12.48
For 1:5 (cement: sand)				
Weight/Age	**3days**	**7days**	**28days**	**90days**
W_{sa}	215.82	220.35	219.45	216.55
W_{sw}	83.1	80.3	81.3	79.9
W_d	204.71	205	203	197.55
Porosity	8.37	10.96	11.91	13.90
For 1:6 (cement: sand)				
Weight/Age	**3days**	**7days**	**28days**	**90days**
W_{sa}	216.4	210.9	214.8	250.35
W_{sw}	70.2	71.45	77.9	77.1
W_d	200.1	193.7	196.4	190.55
Porosity	11.15	12.33	13.44	18.70

Table 4.3: Results for 0.35 water cement ratio

For 1:4 (cement: sand)				
Weight (g)/Age	**3days**	**7days**	**28days**	**90days**
W_{sa}	199.74	200.2	199.6	202.5
W_{sw}	68.89	66.3	70.2	72.25
W_d	187.51	183.85	182.65	185.05
Porosity (%)	9.35	12.21	13.10	13.40
For 1:5 (cement: sand)				
Weight/Age	**3days**	**7days**	**28days**	**90days**
W_{sa}	209.78	210.35	215	216
W_{sw}	72.54	72.95	79	79.9
W_d	196.5	190.8	193.3	191.9
Porosity	9.68	14.23	15.96	17.71
For 1:6 (cement: sand)				
Weight/Age	**3days**	**7days**	**28days**	**90days**
W_{sa}	210.24	213.45	210.8	207.95
W_{sw}	73.31	71.45	76.4	75
W_d	192.7	193.7	187.9	182.55
Porosity	12.81	13.91	17.04	19.10

Table 4.4: Results for 0.4 water cement ratio

For 1:4 (cement: sand)				
Weight (g)/Age	**3days**	**7days**	**28days**	**90days**
W_{sa}	200.94	204.9	204.85	203.65
W_{sw}	73.23	69.2	74.35	73.5
W_d	188.14	188.12	187.65	179.98
Porosity (%)	10.02	12.37	13.18	18.19
For 1:5 (cement: sand)				
Weight/Age	**3days**	**7days**	**28days**	**90days**
W_{sa}	203.45	194.45	205	201.65
W_{sw}	70.64	66	70.8	69.05
W_d	188.9	179.1	176.8	173.05
Porosity	10.96	11.95	21.01	21.57
For 1:6 (cement: sand)				
Weight/Age	**3days**	**7days**	**28days**	**90days**
W_{sa}	206.92	207.55	206.3	204.6
W_{sw}	69.88	70.75	73.2	71.55
W_d	187.95	184.4	182.2	178.65
Porosity	13.84	16.92	18.11	19.50

Table 4.5: Results for 0.5 water cement ratio

For 1:4 (cement: sand)				
Weight (g)/Age	**3days**	**7days**	**28days**	**90days**
W_{sa}	199.25	200.6	197.2	203.65
W_{sw}	60.05	69.95	70.15	74.65
W_d	183.21	183.84	176	180.15
Porosity (%)	11.52	12.83	16.69	18.22
For 1:5 (cement: sand)				
Weight/Age	**3days**	**7days**	**28days**	**90days**
W_{sa}	195.3	212	189.5	193.5
W_{sw}	73.3	75.05	59.55	61
W_d	168.65	180.5	158.6	161.9
Porosity	21.84	23.00	23.78	23.85
For 1:6 (cement: sand)				
Weight/Age	**3days**	**7days**	**28days**	**90days**
W_{sa}	201.6	214.15	196.95	202.2
W_{sw}	70.25	76.55	66.15	69.15
W_d	181.1	187.65	171.55	174.05
Porosity	15.61	19.26	19.42	21.16

CHAPTER 5
RESULTS

Table 5.1: Results for 1:4 (cement: sand)

For 1:4 (cement: sand) with Water Cement Ratio 0.5					
Type of test/Age		**3days**	**7days**	**28days**	**90days**
Compressive Strength	Max. Load (kN)	N/A	N/A	4.15	13.23
	Stress (N/mm^2)	N/A	N/A	1.66	5.30
Chloride Migration		Full Penetrated	Full Penetrated	Full Penetrated	Full Penetrated
Porosity		11.52	12.83	16.69	18.22
For 1:4 (cement: sand) with Water Cement Ratio 0.4					
Type of test/Age		**3days**	**7days**	**28days**	**90days**
Compressive Strength	Max. Load (kN)	4.7	4.9	5.2	18.95
	Stress (N/mm^2)	1.88	1.96	2.08	7.58
Chloride Migration		Full Penetrated	Full Penetrated	Full Penetrated	Full Penetrated
Porosity		10.02	12.37	13.18	18.19
For 1:4 (cement: sand) with Water Cement Ratio 0.35					
Type of test/Age		**3days**	**7days**	**28days**	**90days**
Compressive Strength	Max. Load (kN)	5.1	8.8	9.5	10.57
	Stress (N/mm^2)	2.04	3.52	3.80	4.23
Chloride Migration		Full Penetrated	Full Penetrated	Full Penetrated	Full Penetrated
Porosity		9.35	12.21	13.10	13.40

For 1:4 (cement: sand) with Water Cement Ratio 0.3					
Type of test/Age		**3days**	**7days**	**28days**	**90days**
Compressive Strength	Max. Load (kN)	7.7	13.4	14.3	5.15
	Stress (N/mm^2)	3.08	5.36	5.72	2.057
Chloride Migration		Full Penetrated	Full Penetrated	Full Penetrated	Full Penetrated
Porosity		7.97	7.46	11.48	12.48

Table 5.2: Results for 1:5 (cement: sand)

For 1:5 (cement: sand) with Water Cement Ratio 0.5					
Type of test/Age		**3days**	**7days**	**28days**	**90days**
Compressive Strength	Max. Load(kN)	4.4	4.6	4.73	9.67
	Stress (N/mm^2)	1.76	1.84	1.89	3.87
Chloride Migration		Full Penetrated	Full Penetrated	Full Penetrated	Full Penetrated
Porosity		21.84	23.00	23.78	23.85
For 1:5 (cement: sand) with Water Cement Ratio 0.4					
Type of test/Age		**3days**	**7days**	**28days**	**90days**
Compressive Strength	Max. Load (kN)	4.96	5.46	6.00	11.3
	Stress (N/mm^2)	1.98	2.18	2.40	4.52
Chloride Migration		Full Penetrated	Full Penetrated	Full Penetrated	Full Penetrated
Porosity		10.96	11.95	21.01	21.57

For 1:5 (cement: sand) with Water Cement Ratio 0.35					
Type of test/Age		**3days**	**7days**	**28days**	**90days**
Compressive Strength	Max. Load(kN)	4.85	7.83	8.97	10.54
	Stress (N/mm^2)	1.94	3.13	3.59	4.22
Chloride Migration		Full Penetrated	Full Penetrated	Full Penetrated	Full Penetrated
Porosity		9.68	14.23	15.96	17.71
For 1:5 (cement: sand) with Water Cement Ratio 0.3					
Type of test/Age		**3days**	**7days**	**28days**	**90days**
Compressive Strength	Max. Load(kN)	8.93	17.20	18.87	19.20
	Stress (N/mm^2)	3.57	6.88	7.55	7.68
Chloride Migration		Full Penetrated	Full Penetrated	Full Penetrated	Full Penetrated
Porosity		8.37	10.96	11.91	13.90

Table 5.3: Results for 1:6 (cement: sand)

For 1:6 (cement: sand) with Water Cement Ratio 0.5					
Type of test/Age		**3days**	**7days**	**28days**	**90days**
Compressive Strength	Max. Load(kN)	9.57	9.98	11.77	13.35
	Stress (N/mm^2)	3.83	3.99	4.71	5.34
Chloride Migration		Full Penetrated	Full Penetrated	Full Penetrated	Full Penetrated
Porosity		15.61	19.26	19.42	21.16

For 1:6 (cement: sand) with Water Cement Ratio 0.4					
Type of test/Age		**3days**	**7days**	**28days**	**90days**
Compressive Strength	Max. Load (kN)	10.37	10.48	12.80	16.24
	Stress (N/mm^2)	4.15	4.19	5.13	6.50
Chloride Migration		Full Penetrated	Full Penetrated	Full Penetrated	Full Penetrated
Porosity		13.84	16.92	18.11	19.50
For 1:6 (cement: sand) with Water Cement Ratio 0.35					
Type of test/Age		**3days**	**7days**	**28days**	**90days**
Compressive Strength	Max. Load(kN)	11.2	11.85	16.03	17.65
	Stress (N/mm^2)	4.50	4.74	6.41	7.06
Chloride Migration		Full Penetrated	Full Penetrated	Full Penetrated	Full Penetrated
Porosity		12.81	13.91	17.04	19.10
For 1:6 (cement: sand) with Water Cement Ratio 0.3					
Type of test/Age		**3days**	**7days**	**28days**	**90days**
Compressive Strength	Max. Load(kN)	11.73	12.17	17.6	18.24
	Stress (N/mm^2)	4.69	4.87	7.05	7.30
Chloride Migration		Full Penetrated	Full Penetrated	Full Penetrated	Full Penetrated
Porosity		11.15	12.33	13.44	18.70

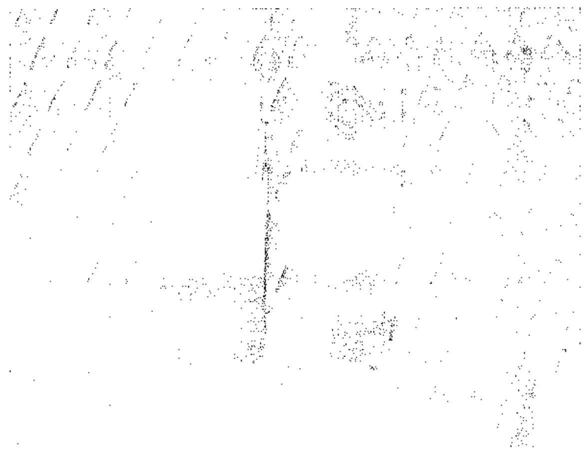

Figure 5.1: *Specimen in Curing Tank*

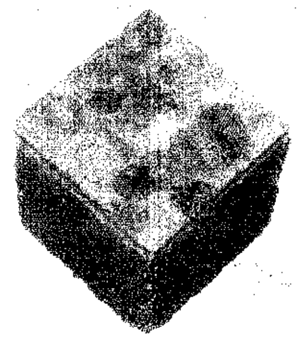

Figure 5.2: *Specimen before test (Compressive Strength Test)*

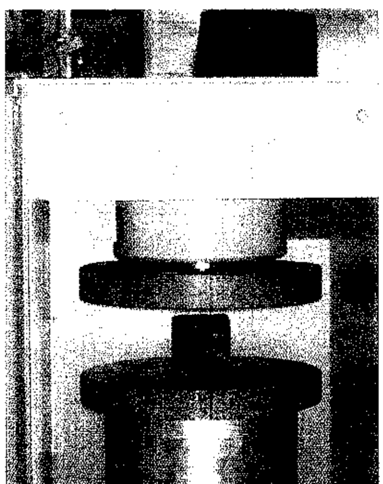

Figure 5.3: *Specimen is placed at the middle of Machine Plate*

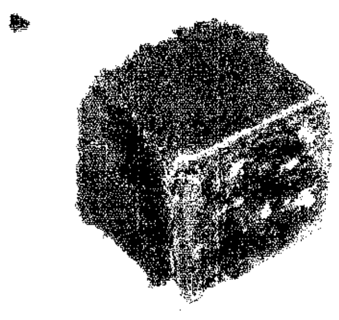

Figure 5.4: *Specimen after Testing (Compressive Strength Test)*

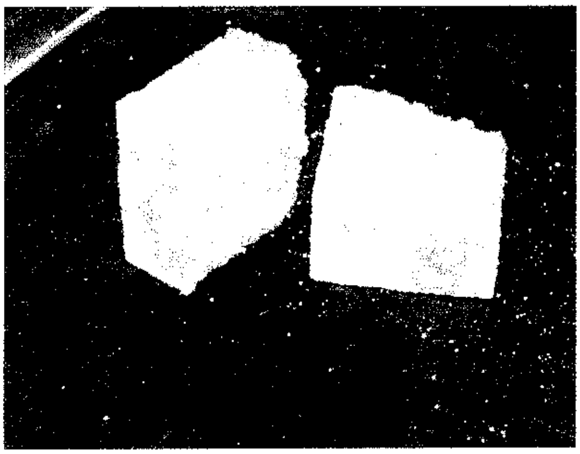

Figure 5.5: *Specimen is broke into two (Chloride Migration Test)*

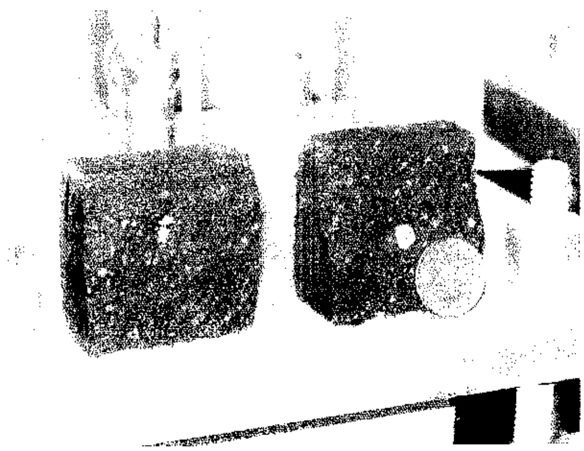

Figure 5.6: *Specimen is sprayed with Silver Nitrate*

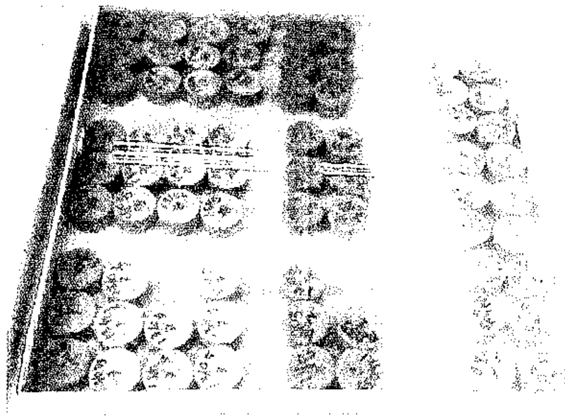

Figure 5.7: *Specimen in Curing Tank (Porosity Test)*

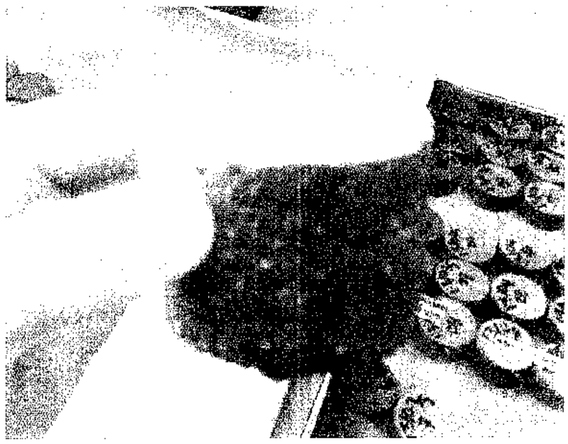

Figure 5.8: *Specimen for Porosity Test*
(50mm Diameter x 40mm Depth)

CHAPTER 6
DISCUSSION

From the results obtain in Table 5.1, Table 5.2 and Table 5.3, compressive strength against water cement ratio and compressive strength against concrete age graphs is plotted. The graphs are as shown in Figure 6.1, Figure 6.2, and Figure 6.3. From Table 5.1, Table 5.2 and Table 5.3, the strength for 0.5 to 0.3 water-cement ratio is increasing approximately 10% to 30%. For each of the samples, the strength is also increasing as the age of the mortar is increases as shown in Table 5.1, Table 5.2 and Table 5.3.

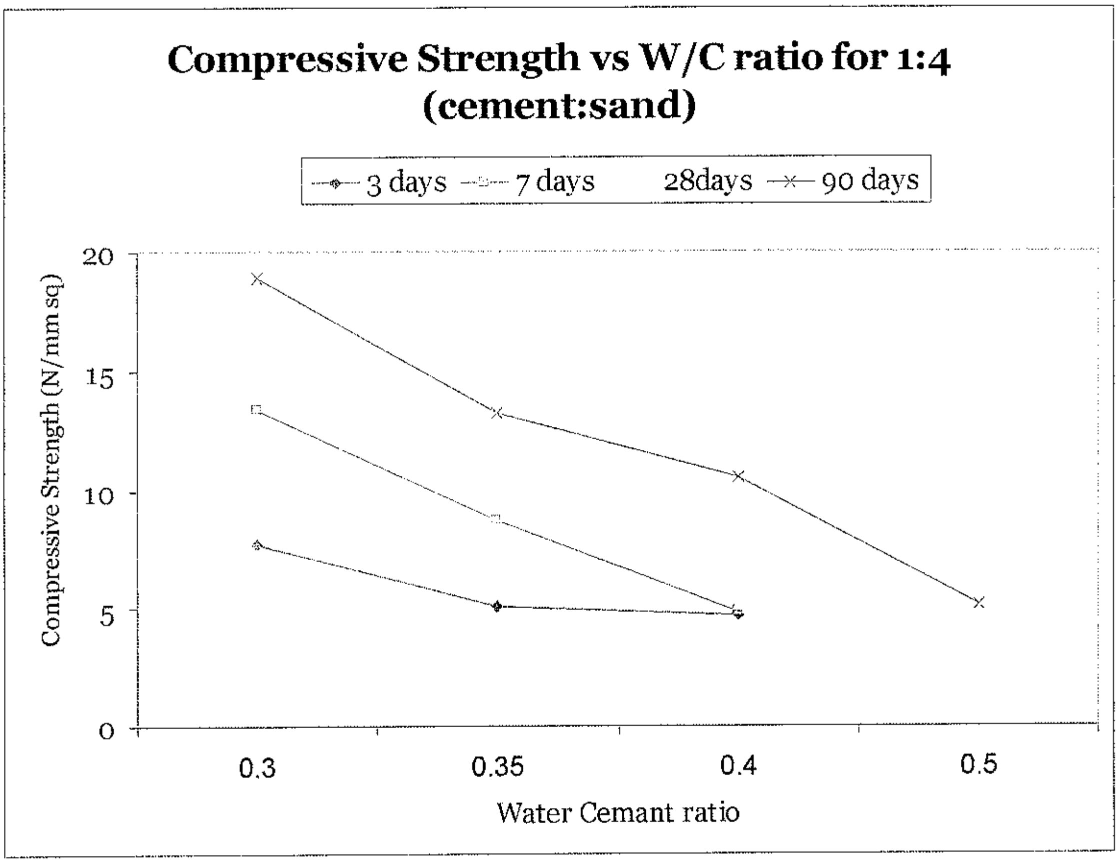

Figure 6.1: Compressive Strength vs Water Cement Ratio for 1:4 (Cement: Sand) graph

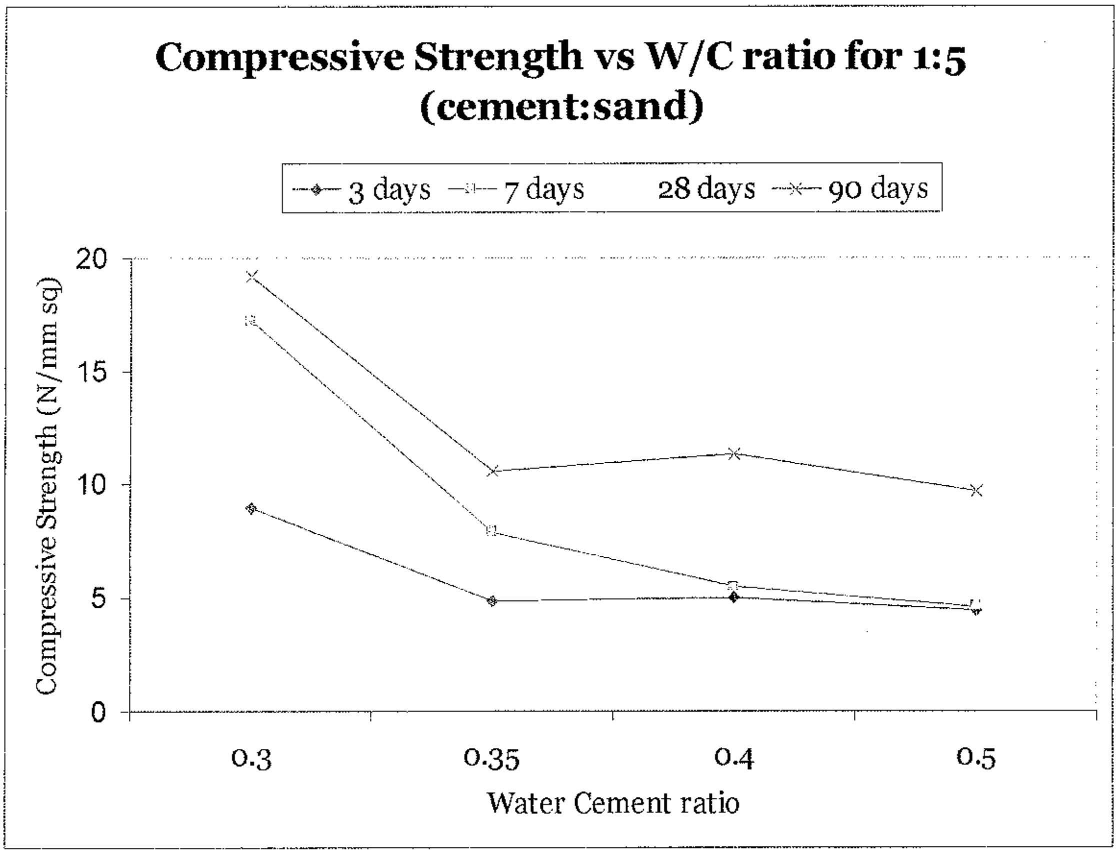

***Figure 6.2:** Compressive Strength vs Water Cement Ratio for 1:5 (Cement: Sand) graph*

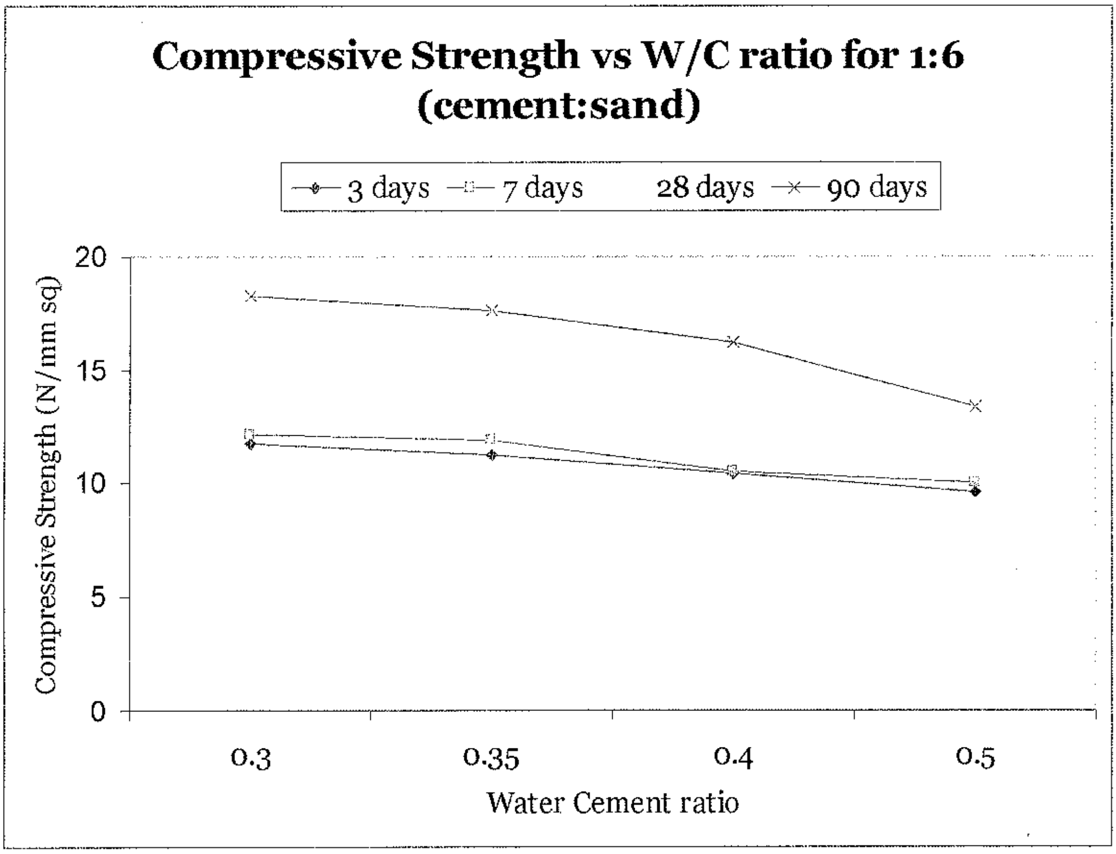

Figure 6.3: *Compressive Strength vs Water Cement Ratio for 1:6 (Cement: Sand) graph*

For the results obtained in porosity test: which is in Table 5.1, Table 5.2 and Table 5.3, the graph of porosity versus water cement ratio is plotted in Figure 6.4, Figure 6.5 and Figure 6.6. Table 5.1, Table 5.2 and Table 5.3 shows that total porosity increasing from 0.3 to 0.5 water cement ratio approximately 10 % to 50 %. Total porosity also increasing as the age of mortar increases.

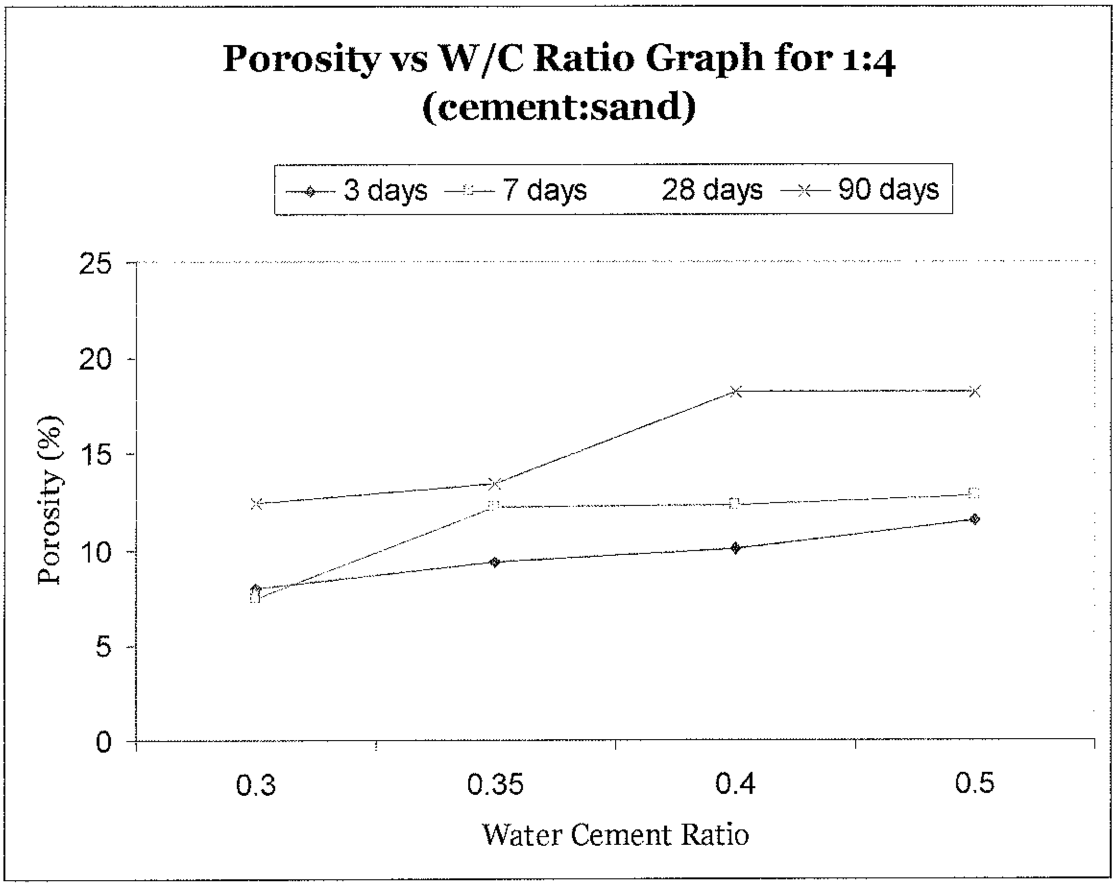

Figure 6.4: *Porosity vs Water Cement ratio for 1:4 (Cement: Sand) graph*

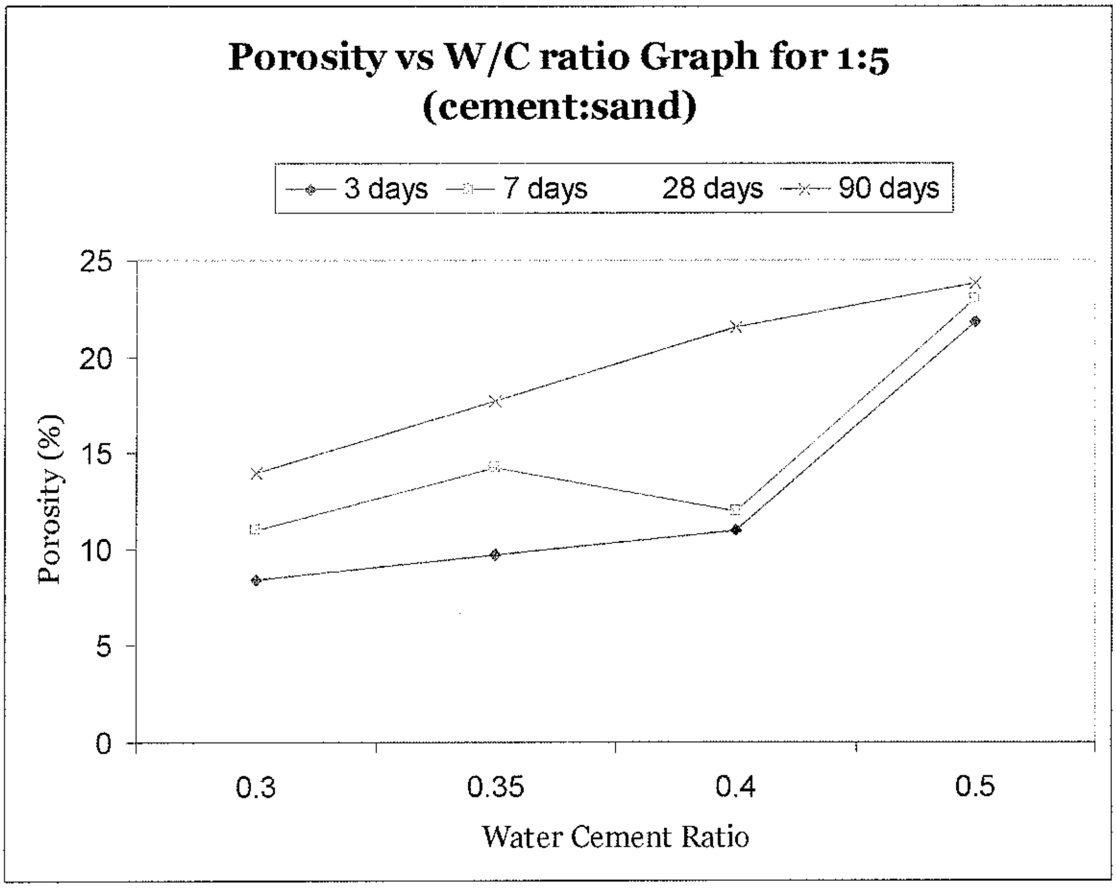

Figure 6.5: *Porosity vs Water Cement ratio for 1:5 (Cement: Sand) graph*

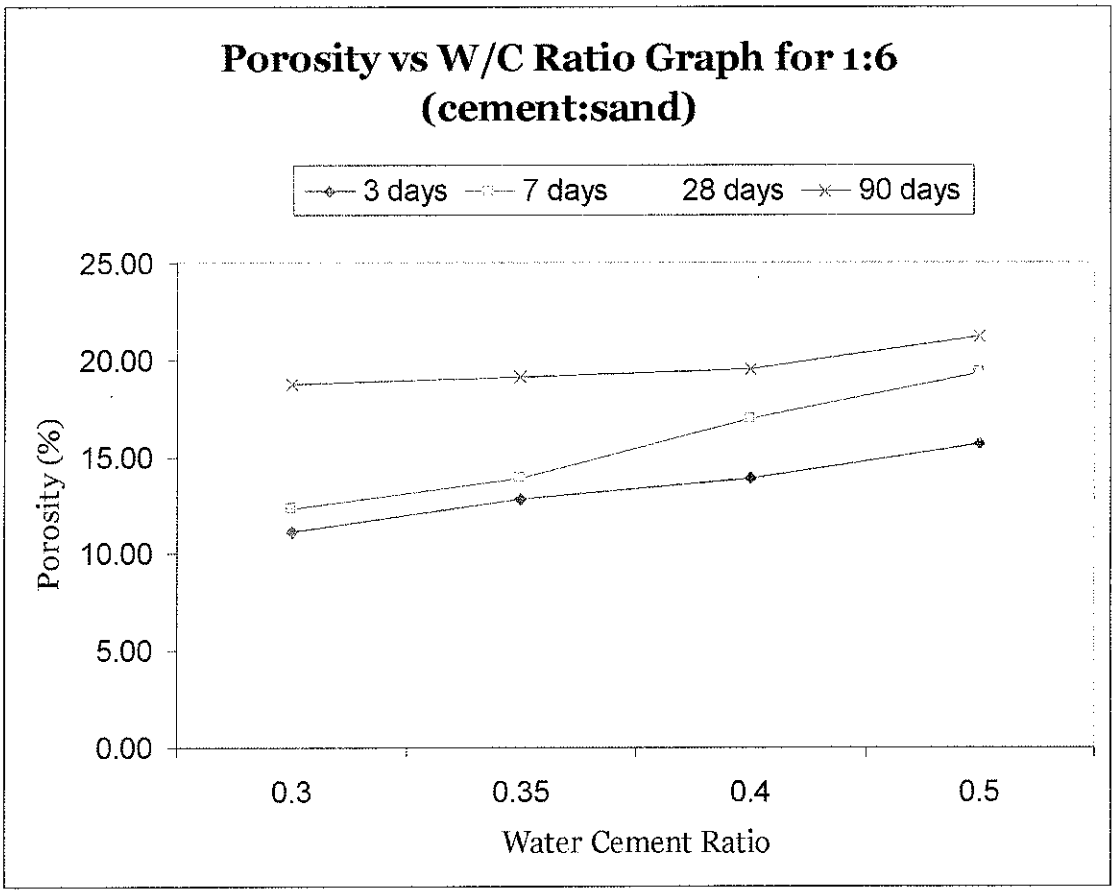

Figure 6.6: *Porosity vs Water Cement ratio for 1:6 (Cement: Sand) graph*

There is a direct relation between compressive strength and porosity. From graph compressive strength against porosity, Figure 6.7, Figure 6.8 and Figure 6.9 show that the strength is decreasing as the porosity is increases. The number of pores inside the mortar affects the mortar strength. To reduce the number of pores, the mortar should be fully compacted.

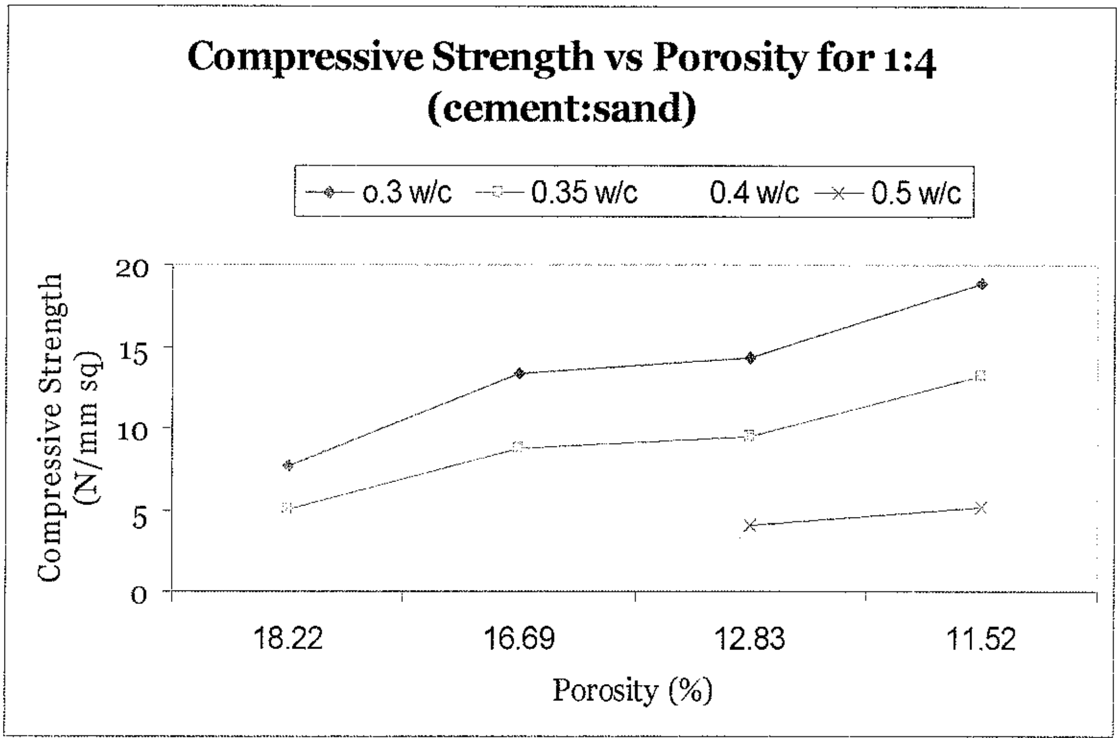

Figure 6.7: *Compressive Strength vs Porosity for 1:4 (Cement: Sand) graph*

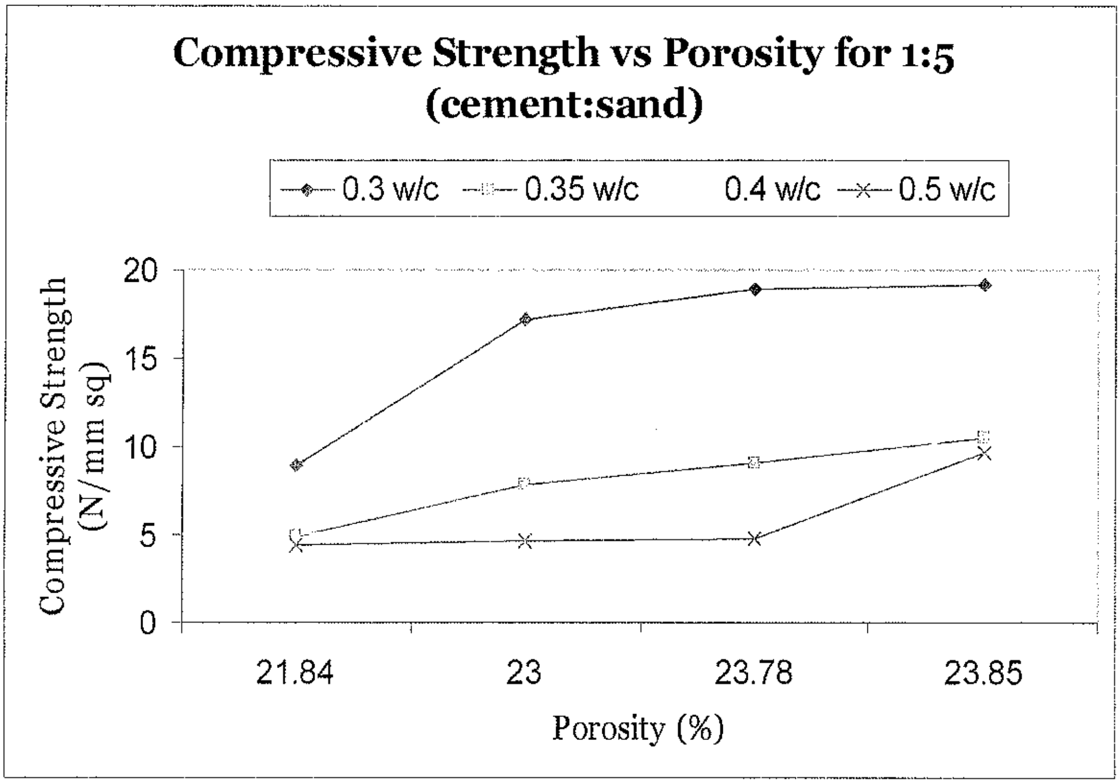

Figure 6.8: *Compressive Strength vs Porosity for 1:5 (Cement: Sand) graph*

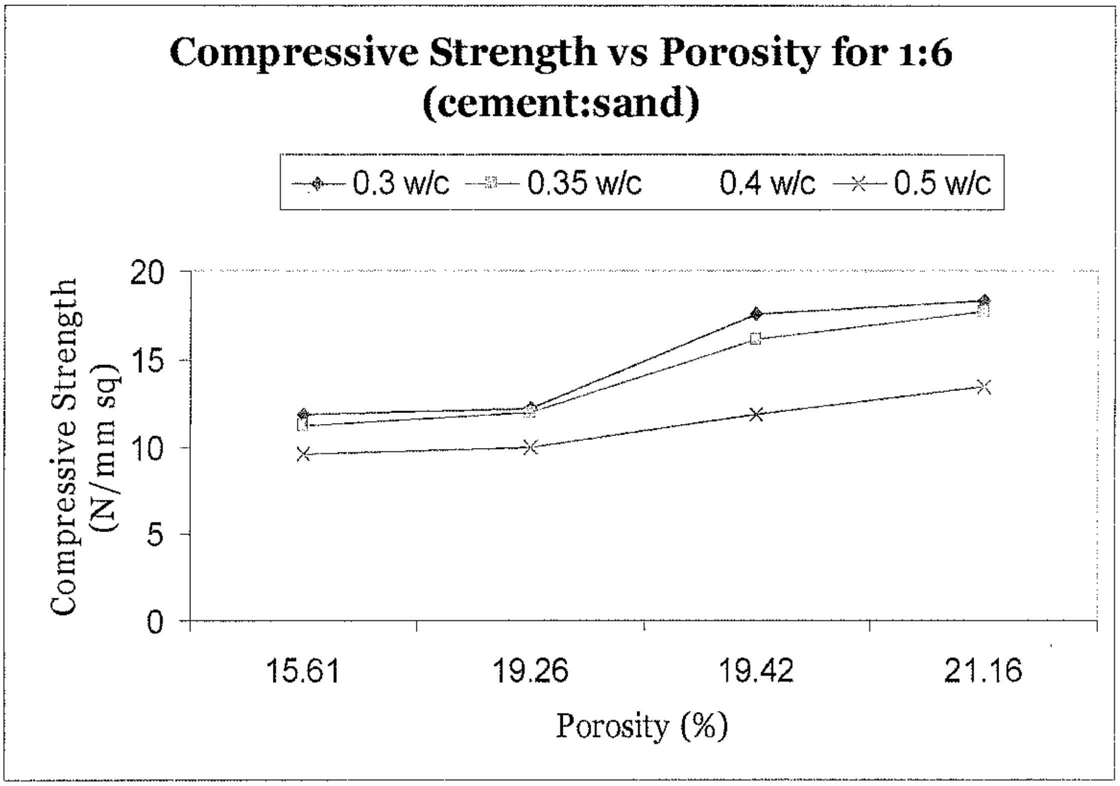

Figure 6.9: *Compressive Strength vs Porosity for 1:6 (Cement: Sand) graph*

For chloride migration test, the penetration of chloride ions is determined by using silver nitrate. For all the mortar samples, the result shows that all the samples were fully penetrate. As a conclusion, mortar does not have enough resistance to chlorides attack, weak and not suitable for marine or any construction that have a possibility of chloride attack. A low water cement ratio will results low rate of penetration of chloride ions. For chloride migration test, instead of using 50mm x 50mm x 50mm size of mortar, bigger size of mortar is recommended. It is because the migration of chloride ions is too fast for using a small size of specimen.

By observing the value obtained, if the percentage of porosity increasing, the strength of mortar will decrease. This is due to the number of pores in the samples. The value obtained in the test is not 100 percent accurate. This is because during the laboratory works, there are few things that may affect the results and it need to be considered. Below are some considerations that may affect the results of the experiment:

i. Sand used was in moist condition at the bottom of the pan; therefore it might be affecting the water/cement (w/c) ratio. The water/cement (w/c) ratio might be higher than 0.30 or 0.50 as required.

ii. Fine aggregate used has coarse aggregates in it. Therefore it might be affecting the proportion as calculated before.

iii. While adding cement, there is some that fly out and it will affect the water/cement (w/c) ratio. The water/cement (w/c) ratio might be higher than 0.30 or 0.50 as required.

CHAPTER 7
CONCLUSION AND RECOMMENDATION

The objective of this project is to find the effect of water cement ratio on compressive strength, porosity and chloride migration of different mortar samples. In this project, the water cement ratio trend is been controlled and the value used is 0.3, 0.35, 0.4 and 0.5. Because there are 3 different ratios for sand and cement had been used in this project which are 1:4, 1:5 and 1:6, the author need to prepare 80 specimens sample for each of sand and cement ratio.

As a conclusion of the results obtained, water cement ratio affect the strength and porosity of mortars. The trend of the strength and porosity graph for mortars is the same as concrete. The strength of mortar is decreasing as the water cement ratio increases. Porosity of mortar is increasing as the water cement ratio increases. There is a direct relation between porosity and compressive strength. As the value of porosity increasing, the strength of mortar is decreases. However, the compressive strength in mortar is not very important compared to its bond strength. There is a relation between bond strength and compressive strength of mortar where if the compressive strength is higher, bond strength will be reduced. To increase its bond strength, the addition of lime to the mixture is recommended.

For the chloride migration test, the observation shows that all the area is covered by chlorine ions, means that the mortar is fully penetrated. The figure 5.6 shows the color on the mortar surface after it is sprayed with silver nitrate solution. From the results obtained, it shows that the mortar does not have a good resistance to chloride attack and water cement ratio does not affect the migration of chloride ions in mortar. But it is recommended using bigger size of mortar samples to investigate the effect of water cement ratio.

From the study of the effect of water cement ratio to the compressive strength, porosity and chloride migration, development of compressive strength has an inverse relationship with water cement ratio and directly related with the porosity of mortar. Porosity of mortar has a direct relationship with water cement ratio, where the value of porosity will increase as the water cement ratio increases. Form this study; there is no relation between water cement ratio and rate of chloride migration in mortar.

CHAPTER 8

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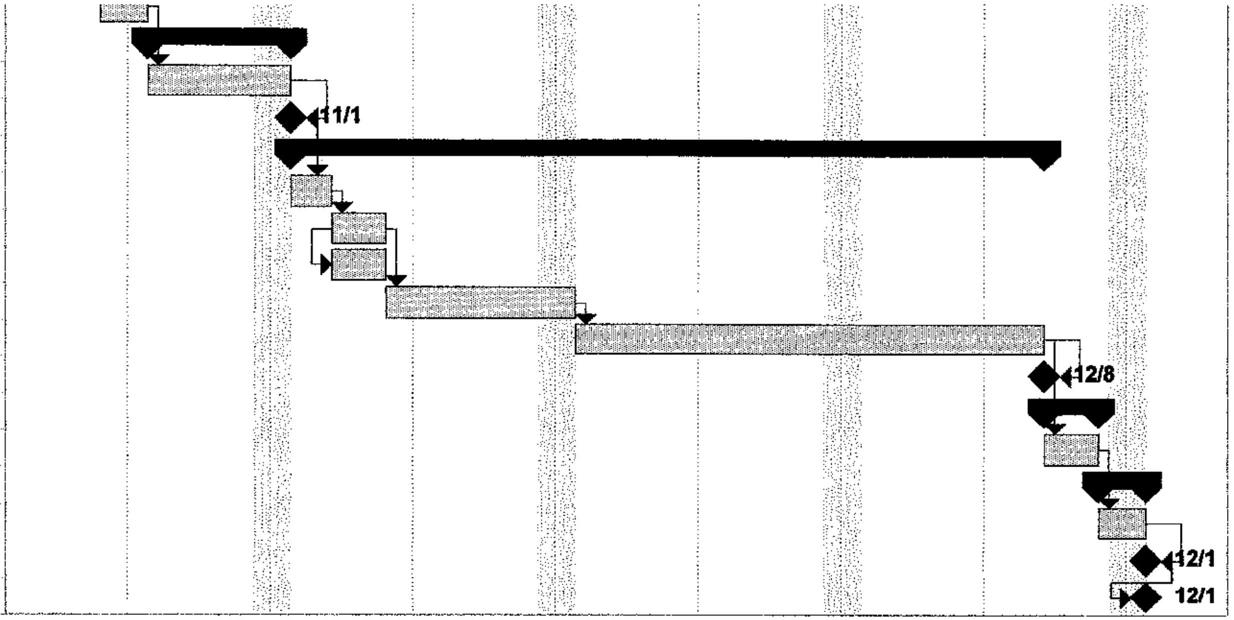
CHAPTER 9

Appendix 1

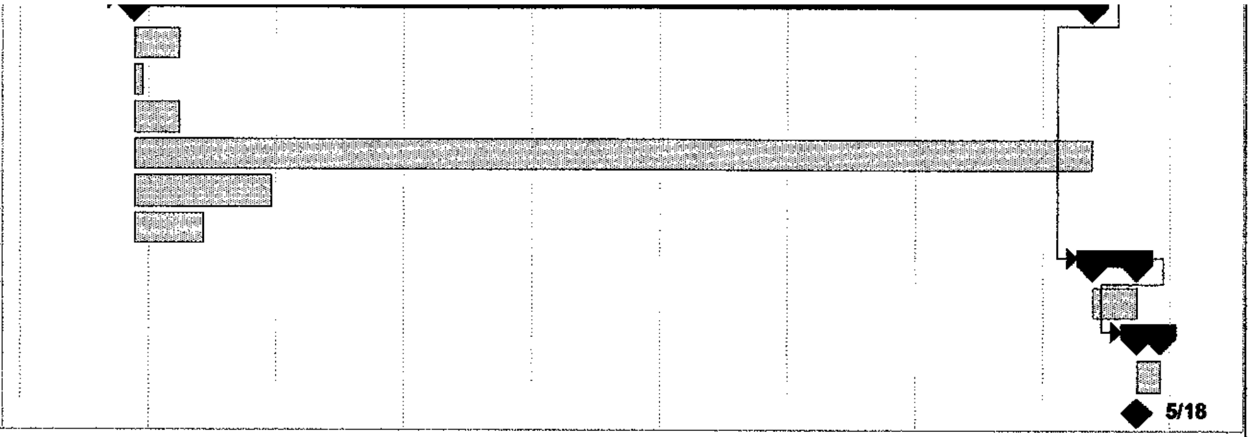
4	**Preliminary Research Work**
5	Preliminary literature review research work
6	Submission of Preliminary report
7	**Start of Laboratory Work**
8	Preliminary calculations for preparing samples
9	Preliminary sample reduction
10	Supplementary literature review research
11	Mixing sample
12	Testing sample
13	Submission of Progress Report
14	**Results Analysis**
15	Analysis of testing results data
16	**Interim Report**
17	Prepare first draft interim report
18	Submission of Interim Report
19	Submission of Interim Report



Project: Gantt Chart for FYP1
Date: Mon 6/13/05

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

4	Preliminary sample reduction
5	Preliminary calculations for preparing samples
6	Supplementary literature review research
7	Mixing sample
8	Testing sample
9	Submission of Progress Report
10	**Results Analysis**
11	Analysis of testing results data
12	**Final Report**
13	Prepare first draft final report
14	Submission of Final Report



Project: gantt chary for FYP2
Date: Mon 6/13/05

Task		Milestone		External Tasks	
Split		Summary		External Milestone	
Progress		Project Summary		Deadline	

CHAPTER 10

Appendix 2

a) Specimen Preparation

1. cement and sand is mixed together until uniform on the metal platform
2. water is added and mixed thoroughly until the mixture appears uniform in color
3. the mixture is poured and compacted into 50 x 50 x 50 mm test cubes and covered with damp cloth to prevent evaporation and kept in the curing room for 24 hours
4. after 24 hours, the specimen is removed from the moulds and stored in the curing tank until they are to be tested (3,7,28,90 days)
5. for chloride migration test, the specimen is stored in different curing tank that contains 3% of salt by weight of water
6. 3 cubes is prepared for compressive strength test and 2 cubes for chloride migration test

b) Compressive Strength Test

1. the test cube is removed from the curing tank and wiped with a damp cloth
2. the cube is placed centrally on the lower platen of the test machine with the rough top surface of the test cube is faced in front
3. the test machine is set correctly and the maximum loading is recorded
4. the compressive strength is calculated by dividing the maximum load by the cross sectional area of the cube

c) Chloride Migration Test

1. the test cube is removed from the curing test that contains 3% of salt by weight of water and wiped with a damp cloth
2. the cube is broke into 2 parts equally and sprayed by phenolphthalein to indicate presence of chloride in the specimen

d) Porosity Test

1. test cube is removed from the cuing test and put into vacuum pump and leave it for 6 hours (vacuum pump is activated)
2. after reaching 6 hours, the vacuum pump is stopped and the sample are left overnight in the water (24 hours).
3. after 24 hours, the samples are removed from the desecrator and wipe out the water particles at sample surface level with dry cloth.
4. weight the samples.
   a. Weight of saturated surface dry samples in air - Wsa
   b. Weight of saturated surface dry samples in water - Wsw

5. after weight the samples, then put all the samples inside oven with a maintain temperature of 1000C for 24 hours to obtain the value of:
   a. weight of oven dry samples - Wd

6. then, calculate total porosity by using formula below:
   a. Total Porosity, $P = \frac{Wsa - Wd}{Wsa - Wsw} \times 100$