FINAL REPORT

Parametric Study on Effects of Water-Cement Ratio to Compressive Strength of RHA Mortar

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9775

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JANUARY 2011

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

Approved by,

(Mr. V. Kalaikumar)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2011

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.

ADILHAKIMIN BIN ANWAR

ABSTRACT

The main objective of this research is to investigate the effects of using Rice Husk Ash (RHA) as a partial cement replacement material in mortar mixes. Water to cement ratio (w/c) were varied namely 0.50 and 0.55 while RHA content were differed from 0% to 45% at increment of 5%. The studied binder:sand ratio (b:s) was varied at 1:3 and 1:4. Compressive strengths of the mixes were determined at 7, 28 and 60 days. In addition, the water absorption and initial water suction rate of mix samples were also investigated. The obtained results show that most of the mortar mixes up to 20% of RHA replacement level achieved higher strength compared to other mixes with RHA replacement level exceeding of 20%. Furthermore, this study showed that mixes with w/c of 0.55 possesses higher strength.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Portland Cement or Ordinary Portland Cement (OPC) is a component in concrete and cement brick production. It works as a binder because of its crystalline silicate available on its chemical structure. However, the limited resources and production of cement as well as high price inspired researchers to find alternatives for a binder material, which in this case, Rice Husk Ash provides silica in amorphous form and is used for this study (Alireza, 2010).

According to Bronzeoak Report in 2003, Rice Husk Ash (RHA) is a by-product produced in rice mill and is abundantly available in Malaysia. RHA with its amorphous silica properties had successfully applicable not only to concrete and cement industry, but it also commonly used in water purification, vulcanizing rubber and as refractory bricks in furnace which are exposed to extreme temperatures (Bronzeoak, 2003).

1.2 Problem Statement

According to an article issued by Renewable COGEN Asia in 2009, rice husk contains up to 20% of ash, which creates disposal problem. Rice husk as the by-product is thrown out as waste and burnt out which released carbon dioxide gases into atmosphere. Besides air pollution, these disposal activities of rice husk contribute to enormous waste of monetary cost, time and energy. It is also reported that rice husk ash produced in rice mill production process contributes to disposal and environmental problem (Jha, 2006).

Furthermore, cement production produced 5% of the total greenhouse gases in the atmosphere, mainly carbon dioxide. The cement industry which involves cement kilns, emit hazardous air pollutants which affect the environment seriously from the quality of air and health of society (Air Quality Articles, 2007). Hence, this project is significant in effort to minimize the cost of construction and utilizing waste material which will reduce environmental pollution.

1.3 Objectives

The objectives of this research are listed as follows:

1. To investigate the effect of water-cement ratio in the RHA mortar for varied RHA replacement on the compressive strength of samples.
2. To study on the water absorption and initial rate of suction for RHA mortar samples for varied water-cement ratio.

1.4 Scope of Work

In this research, the scope of study and research which related to the topic includes preparing RHA in the highway engineering laboratory. RHA sources are available in the university and were ground using LA (Los Angeles) equipment before applying into the experiments.

RHA mortar samples were prepared with accordance to standard procedure as in ASTM C 109: Standard Test Method for Compressive Strength of Hydraulic Cement Mortars. Also, the percentage of RHA content as cement replacement were varied from 0% (control specimen), 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40% and 45%.

Binder:sand proportion (b:s) were varied by 1:3 and 1:4 while water-cement ratio (w/c) value were alternated by 0.5 and 0.55. Furthermore, water absorption and initial rate of suction were conducted for all samples according to ASTM C642 and ASTM C1585 respectively.

CHAPTER 2

LITERATURE REVIEW

In this section, the field related to this project based on previous study by other researchers and students will be summarized accordingly. The past researches or field that are related to this project are listed as follow:

- Mortar
- Rice Husk Ash (RHA) as cement replacement material
- Water-cement ratio

The explanation and topic related to those fields will be discussed in detail in the next section.

2.1 Mortar

Oxford Dictionary (2001) defined mortar as a mixture of lime with cement, sand and water, used in building to bond bricks or stones.

Hence, some of the important journals by past researchers and scientists which are related to mortar and bricks are studied and summarized in a practical way to correlate with this project of RHA mortar.

2.1.1 Paper Sludge and Palm Oil Fuel Ash (POFA) Brick

Ismail et al. (2009) had conducted a study on the effect of brick properties when it was comprised with paper sludge and palm oil fuel ash (POFA); waste materials abundantly available from paper mill and palm oil production mill respectively in Malaysia. The study was based on an experimental work, where six 215 mm x 103 mm x 65 mm brick specimens were prepared with various proportions of cement; sludge paper and POFA. Curing periods of 7, 28 and 84 days were applied and compressive strengths of all the prepared samples were measured. The result revealed that the paper sludge-POFA brick made with 60% cement and 40% replacement of 20% paper sludge and 20% POFA satisfies the minimum strength requirements of BS 6073 Part 2: 2008 which is 7 N/mm^2. The Figure 2.1 below summarized the compressive strength of the experimental work:

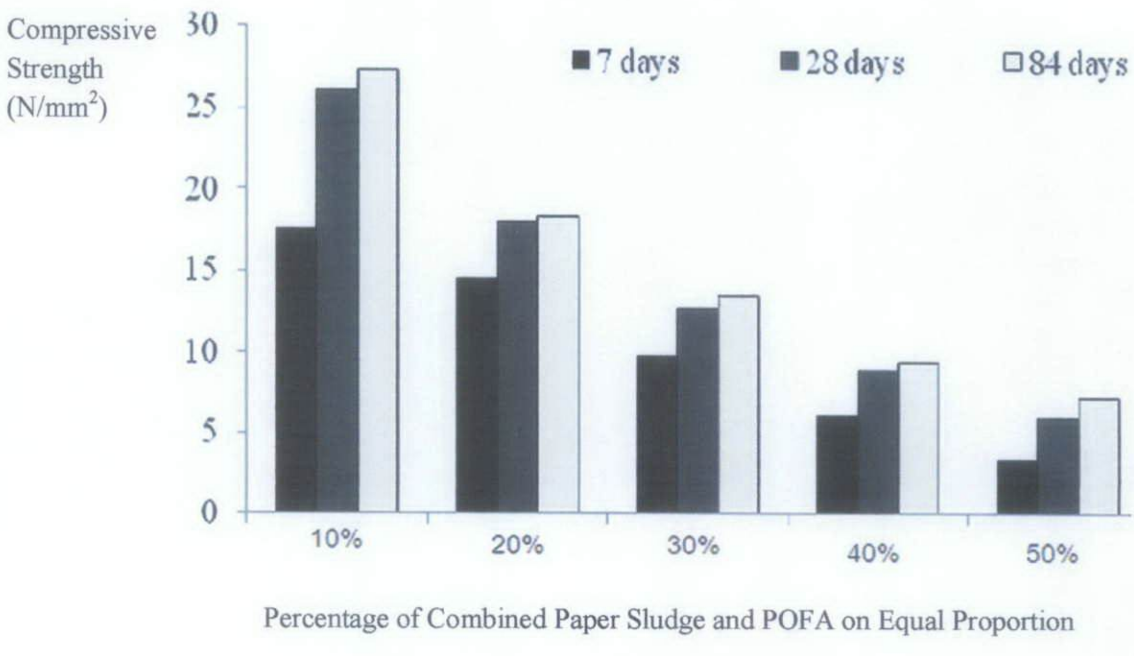

Figure 2.1: Compressive Strength of Mixes (Ismail, 2009)

2.1.2 Hardened Expanded Polystyrene Beads Concrete Bricks

In 2003, Idawati et. al. carried out an experimental work related to a hardened concrete brick incorporated with polystyrene beads. The project aims to produce lightweight concrete bricks by using the expandable polystyrene. Polystyrene is selected due to its lightweight properties, with good energy absorbing characteristic and good thermal insulator leading mainly to non-structural applications. The methodology from their research is an experimental study, in which the cement used was Ordinary Portland Cement, fine sand, polystyrene beads (2.36mm) supplied by BASF (Malaysia) and tap water. Five different specimens of 215 mm x 102.5 mm x 65 mm concrete bricks were prepared with one of them is reserved as the control one, which it contains none of the replacement material for the sand. From the result, it is apparent that polystyrene concrete bricks with densities less than 1800 kg/m^3 have very low strength. Besides, polystyrene concrete brick is very prone to segregation where placing and compacting can be hard using vibratory compaction techniques. Table 2.1 below summarizes the compressive strength of the samples from the experimental work:

Table 2.1: 7-days and 28-days Compressive Strength Result (Idawati, 2003).

Specimen ID	Mix ratio (Binder:sand: Polystyrene)	7-days compressive strength (N/mm^2)	28-days compressive strength (N/mm^2)	28-days percentage reduction in strength (%)
PC	1:3:0	16.3	19.0	0
P1	1:2.5:0.5	14.8	15.3	19.5
P2	1:2:1	13.8	14.0	8.5
P3	1:1.5:1.5	5.3	6.8	51.4
P4	1:1:2	4.3	5.1	25.0

2.2 Rice Husk Ash (RHA)

Bronzeoak (2003) had published a market study report regarding rice husk ash (RHA) potential as global market material. Based on the report, approximately 600 million tonnes of rice paddy is produced each year. On average 20% of the rice paddy is husk, giving an annual total production of 120 million tonnes. In the majority of rice producing countries much of the husk produced from the processing of rice is either burnt or dumped as a waste.

The treatment of rice husk as a 'resource' for energy production is a departure from the perception that husks present disposal problems. The concept of generating energy from rice husk has great potential, particularly in those countries that are primarily dependant on imported oil for their energy needs. Rice husks are one of the largest readily available but most under-utilized biomass resources, being an ideal fuel for electricity generation (Bronzeoak Report, 2003).

Rice husk is high in ash compared to other biomass fuels. The ash contains 92 to 95% silica, highly porous and lightweight, with a very high external surface area. Its absorbent and insulating properties are useful to many industrial applications. RHA is a general term describing all types of ash produced from burning rice husks (Bronzeoak Report, 2003).

It is also reported in Bronzeoak Report (2003) that silica in the ash undergoes structural transformations depending on the conditions (time and temperature) of combustion. At 550°C – 800°C amorphous ash is formed and at temperatures greater than this, crystalline ash is formed. These types of silica have different properties and it is important to produce ash of the correct specification for the particular end use.

Thus in this report, some of the past researches and findings incorporated with rice husk ash as the replacement material for cement is gone through and summarized to relate with the project of incorporating RHA in brick, with various water-cement ratio.

2.2.1 Sandcrete Block Incorporating RHA

In 2006, Oyetola and Abdullahi had investigated the use of Rice Husk Ash (RHA) in low-cost sand block production and its effects on the final product by manipulating different percentage of RHA content. The methodology from their research is such that RHA was prepared using charcoal from burning firewood. Preliminary analysis of Ordinary Portland Cement (OPC) and RHA hollow sandcrete blocks was conducted to confirm their suitability for block-making. 150mm x 450mm hollow sandcrete blocks were cast cured and crushed for 1, 3, 7, 21, 28 days at 0, 10, 20, 30, 40 and 50% replacement levels. From the experiment, it shows that the optimum replacement level of OPC with RHA is at 20%. Besides, for a given mix, the water requirement increases as the rice husk ash content increases and the setting times of OPC/RHA paste increases as the ash content increases. Moreover, the compressive strength of the blocks for all mix increases with age at curing and decreases as the RHA content increases. Table 2.2 below summarized the result obtained from their experimental work:

Table 2.2: Compressive Strength of Blocks (Oyetola, 2006)

Age At Curing % Replacement Level	Compressive Strength (N/mm^2)						Remarks
	1 Day	3 Days	7 Days	14 Days	21days	28 Days	
100%OPC, 0%RHA	0.51	0.91	1.60	2.78	3.63	4.60	The compressive strength generally increases with age at curing and decreases as the RHA content increases.
90%OPC, 10%RHA	0.40	0.70	1.31	2.43	3.35	4.09	
80%OPC, 20%RHA	0.25	0.55	1.14	2.02	2.91	3.65	
70%OPC, 30%RHA	0.15	0.36	0.74	1.35	1.79	2.07	
60%OPC, 40%RHA	0.00	0.15	0.38	0.65	0.91	1.05	
5O%OPC, 50%RHA	0.00	0.06	0.30	0.40	0.42	0.59	

2.2.2 Strength and Porosity of Mortar Containing Rice Husk Ash

Rice Husk Ash (RHA) content as partial cement replacement material in mortar mixes affects the compressive strength of the mortar after it is cured, (Rashid, 2006). The methodology was an experimental study, in which the cement used was Ordinary Portland Cement Type-1 and Rice Husk Ash was obtained from available small rice milling industry in Bangladesh. The silicon oxide content in the RHA is 90.2%, which would be responsible in hydration process to produce aluminosilicate as its binder chemical properties. The compressive strengths of the specimens as well as the controlled specimen were recorded accordingly. The result shows that at some percentage of RHA replacement to cement in the mortar mixture, compressive strength of the sample increases as percentage of RHA content increases. However, as the percentage increased more than 15% to 20%, the compressive strengths of the samples start to decrease while the maximum compressive strength of sample was achieved at 15% RHA content. In addition to that, at 30% replacement level of OPC by RHA, the porosity of mortar is increased at 28 and 90 days as compared to OPC mortar. Table 2.3 below summarized the result acquired by the experimental work.

Table 2.3: Compressive Strength of Mortar Samples (Rashid, 2006)

Mix ID	Symbol	Compressive Strength (psi)			
		3 days	7 days	28 days	90 days
1	OPC	3481 -100.00	4006-100.00	5291-100.00	5531-100.00
2	10RHA	3218 -92.40	4083-102.00	5511-104.20	5744-103.90
3	15RHA	3172-91.10	3964-99.00	5498-103.90	6102-110.30
4	20RHA	3185-91.50	3827-95.50	5408-102.20	5946-107.50
5	25RHA	3017-86.70	3860-96.40	5173-97.80	5687-102.80
6	30RHA	2868-82.40	3779-94.30	4968-94.20	5638-101.90

2.3 Water-Cement Ratio

An analytical study was performed by Bentz and Aitcin (2008) discussing about the effects of water-cement ratio on the strength of concrete particles and the effect of the bondage that is built between cement and water particles. As in analytical research, the methodology from their research is by using scientific materials and computational data analysis, in which three sample of cements were selected with cement ratio (w/c) of 0.35 and 0.50. Meanwhile, the Particle Size Distribution (PSD) of the samples are taken and measured using wet diffraction method by using isopropanol as the solvent. It is found that the lower content of w/c gives smaller pore size inside the concrete and generates a higher degree of capillary stresses inside the concrete as well. Meanwhile, higher content of w/c gives larger pore which the radius of the pores generates smaller capillary stresses to the concrete. However, as the hydrating cement pastes continue to self-desiccate or lose additional water to drying, smaller and smaller pores will be emptied and possibly local or global crack could occur because its stresses had exceed the strength of the material. From the research, it was found out that the water to cement ratio of a concrete sample is inversely proportional to strength that is gained by the concrete. Figure 2.2 below shows the water volume fraction for the three cement samples at w/c of 0.35 and 0.50.

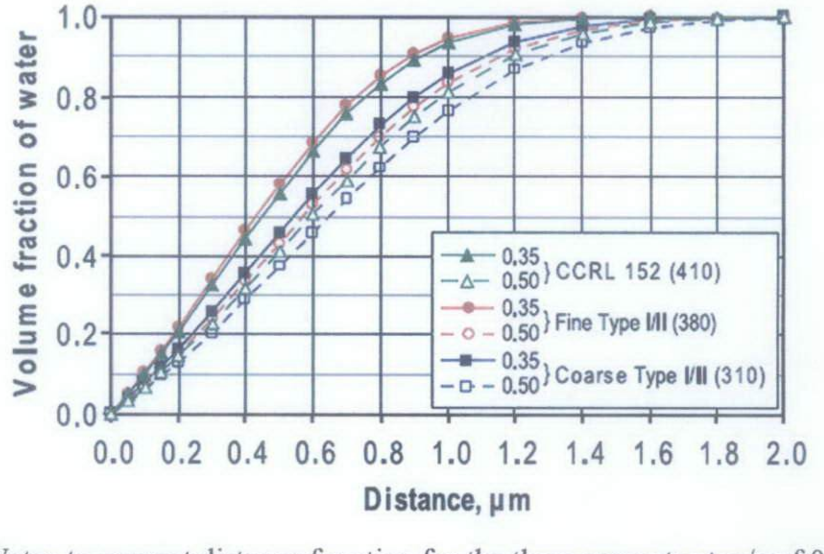

Figure 2.2: Water-to-cement distance function for the three cements at w/c of 0.35 and 0.50.

CHAPTER 3

METHODOLOGY

The sequence in this experimental work is important as it involves work planning, sampling and testing of samples. This section contain two parts, firstly the explanation for the activities conducted in this research and followed by flow chart of main event in the experimental work.

3.1 Description of Work

3.1.1 Preparation and Calculation of Design Mixes

1. Cement

For this project, the type of cement used for the casting of samples is Ordinary Portland Cement (OPC) Type-1, which comprised of Portland Cement and up to 5% of minor additional constituents, according to BS EN 197-1: 2000. All samples are casted and mixed by using this type of cement and of Tasek brand to ensure that it would not vary the compressive strength or impose other effects to the experimented mixes.

2. Sand

Sands acquired and used throughout this experiment are obtained from the UTP Concrete Laboratory. Before sieving, the sands were kept in the laboratory for about two days because dried sands are much easier to be sieved later. After that, the sands are sieved to obtain the specified size of 2.36 mm and below. Before mixing the samples, the moisture content and water absorption value of the sand are taken as an analytical consideration with the varied water-cement ratio in this experimental work.

3. Rice Husk Ash (RHA)

Rice husk ash is a by-product from rice milling process (Bronzeoak, 2003). At the same time, it a waste material generally disposed by damping and open-burning (Jha, 2006). In this experiment, the rice husk ashes are obtained originally from BERNAS's factory where it has already gone through open burning process and the RHA is ground by using Los Angeles apparatus before it is used as replacement material in the samples (Liyana, 2010). For this project, cement is partially replaced by RHA by 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40% and 45%.

4. Water

The water used during the mixing of the samples is from tap water and the water-cement ratio in this project is varied by 0.50 and 0.55.

3.1.2 Mix Design Proportioning

Totally, there are 40 different mixes were investigated in this research based on the variables of water-cement ratio, RHA percentage replacement to cement and cement to aggregate proportioning. The following Table 3.1 to 3.4 summarized the mix proportioning for the mixes.

Table 3.1: Mix Proportion of RHA mortar (w/c = 0.50, binder:sand = 1:3)

Mix ID	% RHA	RHA (g)	Cement (g)	Sand (g)	Water (g)	Total Mass (g)
CB	0	0	66.667	200	33.333	300
R5	5	3.333	63.333	200	33.333	300
R10	10	6.667	60.000	200	33.333	300
R15	15	10.000	56.667	200	33.333	300
R20	20	13.333	53.333	200	33.333	300
R25	25	16.667	50.000	200	33.333	300
R30	30	20.000	46.667	200	33.333	300

R35	35	23.333	43.333	200	33.333	300
R40	40	26.667	40.000	200	33.333	300
R45	45	30.000	36.667	200	33.333	300

Table 3.2: Mix Proportion of RHA mortar (w/c = 0.50, binder:sand = 1:4)

Mix ID	% RHA	RHA (g)	Cement (g)	Sand (g)	Water (g)	Total Mass (g)
CB	0	0	54.545	218.18	27.27	300
R5	5	2.727	51.818	218.18	27.27	300
R10	10	5.455	49.091	218.18	27.27	300
R15	15	8.182	46.364	218.18	27.27	300
R20	20	10.909	43.636	218.18	27.27	300
R25	25	13.636	40.909	218.18	27.27	300
R30	30	16.364	38.182	218.18	27.27	300
R35	35	19.091	35.455	218.18	27.27	300
R40	40	21.818	32.727	218.18	27.27	300
R45	45	24.545	30.000	218.18	27.27	300

Table 3.3: Mix Proportion of RHA mortar (w/c = 0.55, binder:sand = 1:3)

Mix ID	% RHA	RHA (g)	Cement (g)	Sand (g)	Water (g)	Total Mass (g)
CB	0	0	65.934	197.80	36.26	300
R5	5	3.297	62.637	197.80	36.26	300
R10	10	6.593	59.341	197.80	36.26	300
R15	15	9.890	56.044	197.80	36.26	300
R20	20	13.187	52.747	197.80	36.26	300
R25	25	16.484	49.451	197.80	36.26	300
R30	30	19.780	46.154	197.80	36.26	300
R35	35	23.077	42.857	197.80	36.26	300
R40	40	26.374	39.560	197.80	36.26	300
R45	45	29.670	36.264	197.80	36.26	300

Table 3.4: Mix Proportion of RHA mortar (w/c = 0.55, binder:sand = 1:4)

Mix ID	% RHA	RHA (g)	Cement (g)	Sand (g)	Water (g)	Total Mass (g)
CB	0	0	54.054	216.22	29.73	300
R5	5	2.703	51.351	216.22	29.73	300
R10	10	5.405	48.649	216.22	29.73	300
R15	15	8.108	45.946	216.22	29.73	300
R20	20	10.811	43.243	216.22	29.73	300
R25	25	13.514	40.541	216.22	29.73	300
R30	30	16.216	37.838	216.22	29.73	300
R35	35	18.919	35.135	216.22	29.73	300
R40	40	21.622	32.432	216.22	29.73	300
R45	45	24.324	29.730	216.22	29.73	300

3.1.3 Details of Specimen

The mould that is used for the casting of specimen is having a dimension of 50mm x 50mm x 50mm. Nine samples are prepared for each mix and at every measurement of compressive strength for particular duration, three cubes are tested to improve the accuracy of the compressive strength by taking its average value.

3.1.4 Mixing of Samples

The mixing of the samples for the designed mixes was performed according to ASTM C 109: Standard Test Method for Compressive Strength of Hydraulic Cement Mortars. The procedures of mixing taken from the code are described by referring to Practice C 305. The mixing of mortar could be performed by hand-mix or mechanically-mix with mortar mixer.

3.1.5 Casting and Curing

Before the mix is poured into the 50mm x 50mm x 50mm moulds, a thin-layered of lubricant oil must be applied first to the surface of the moulds. This is to ensure that the mix containing cement will not stick on the surface of the mould and to ensure that the demoulding process of the samples later would be much easier.

The curing process of casted samples is done to ensure the hydration process of the mixture is achieved and shrinkage cracking due to temperature fluctuation is avoided so that the brick can achieve its maximum strength (Liyana, 2010).

3.1.6 Material Testing

3.1.6.1 Mortar Compression Test

Digital Compression Testing Machine is used to perform the sample compressive test which a constant rate of load is applied on the area of sample surface. The maximum load that the sample can resist before failure is taken the compressive strength of the sample. Two samples are tested and average value is taken to improve result accuracy. The compressive test method was based on ASTM C109: Standard Test Method for Compressive Strength of Hydraulic Cement Mortars.

3.1.6.2 Hydrometer Test

This test was proceed after sieve analysis take place to RHA samples according to BS 1377 to determine the Particle Size Distribution (PSD) of RHA samples. According to BS 1377 (1990): Methods of Test for Soils for Civil Engineering Purposes, the sample that necessarily to be tested using Hydrometer Test must be sieved by 63 micron sieve. In summary, after 150g of RHA samples were sieved, the remaining RHA that retained on the pan will undergo hydrometer test to determine PSD on the finer particles. This test were repeated on sand and cement samples.

3.1.6.3 Water Absorption and Initial Suction Rate

According to ASTM C642 (1997): Standard Test Method for Density, Absorption and Voids in Hardened Concrete; water absorption test can be conducted to determine the water content in the mortar samples. Meanwhile, initial suction rate of water (IRS) is conducted to determine the volume of water that a mortar samples absorb for close interval of time upon contact with water depth of 1 mm to 3mm which was referred to ASTM C1585 (2004): Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concrete.

3.1.6.4 Water Content of Fine Aggregate

This test is done to determine the water content in sand by oven drying method as per IS: 2720 (Part II) – 1973. The water content (w) of a sand sample is equal to the mass of water divided by the mass of solids.

The procedure is as follow:

1. The container is cleaned, dried and weighed with the lid (Weight 'W_1').
2. The required quantity of the wet sand specimen is placed into the container and weighed with the lid (Weight 'W_2').
3. The container is placed without its lid, in the oven till its weight becomes constant (Normally for 24 hours).
4. The container is removed when the sand has dried, from the oven.
5. The weight 'W_3'of the container with the lid and the dry sand sample is determined.

The calculation of water content is, $w\ \% = [W_2 - W_3] / [W_3 - W_1] * 100\%$

3.2 Methodology and Main Process

The methodology and main process of this research can be summarized as flow chart below.

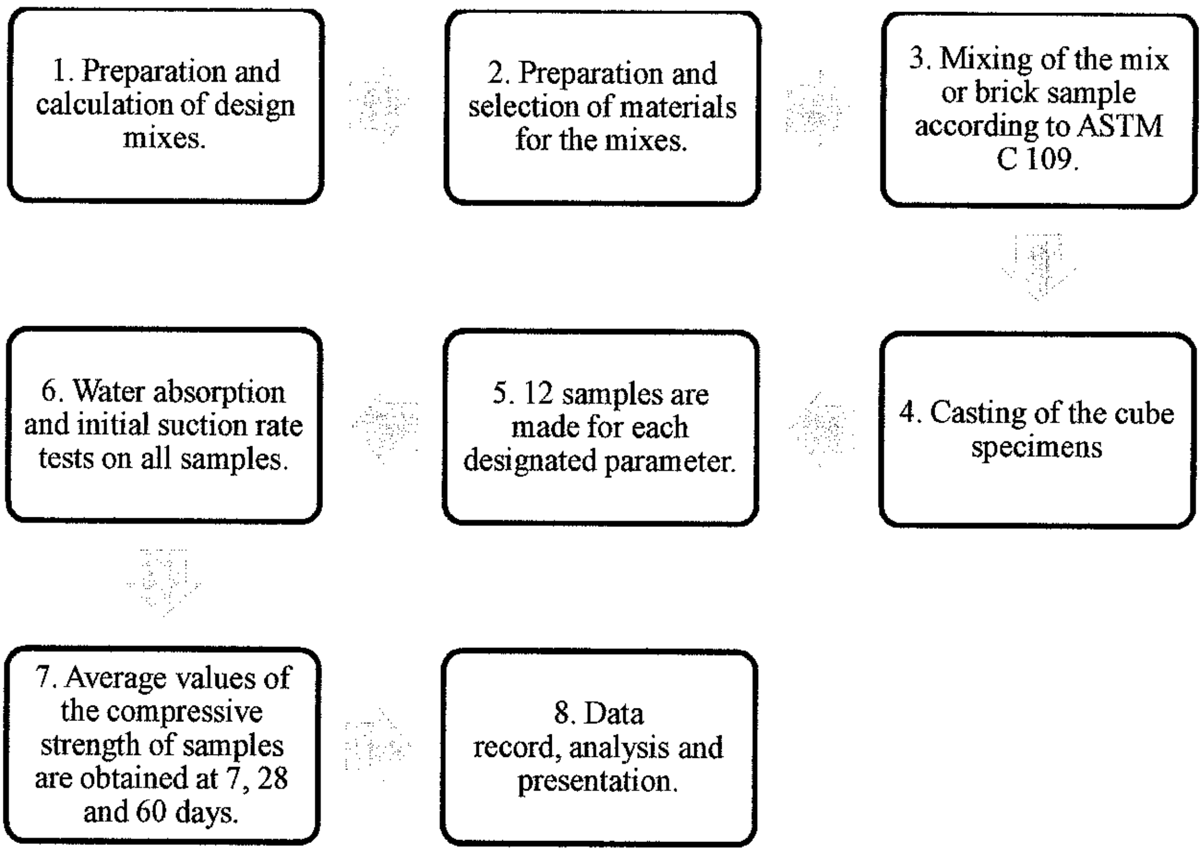

Figure 3.1: Flow Chart in Experimental Work

CHAPTER 4

RESULT AND DISCUSSION

This chapter presents results for the compressive strength, particle size distribution of RHA, cement and sand, initial rate of suction and water absorption of mortar samples. The results were analyzed and interpreted through process discussed earlier as in previous chapter.

4.1 Compressive Strength

The compressive strength of mortar samples was determined based on ASTM C109 and tabulated accordingly as in Appendix II. Table 4.1, 4.2, 4.3 and 4.4 summarized the compressive strength for the mortar mixes of various designated mixes.

Table 4.1: Compressive Strength for RHA mortar (w/c = 0.50, binder:sand = 1:3)

%RHA	Average Strength (MPa)		
	7-day	28-day	60-day
0	27.2	29.7	44.7
5	21.4	22.2	21.9
10	10.0	12.2	20.3
15	12.3	16.1	18.9
20	21.1	23.8	30.1
25	14.4	20.2	15.3
30	9.5	19.0	17.3
35	9.4	13.0	20.9
40	11.0	16.9	15.7
45	6.0	15.5	16.3

Table 4.2: Compressive Strength for RHA mortar (w/c = 0.50, binder:sand = 1:4)

%RHA	Average Strength (MPa)		
	7-day	28-day	60-day
0	20.6	24.4	26.5
5	28.1	31.5	29.8
10	22.9	22.4	23.0
15	16.5	20.6	18.0
20	18.0	18.0	17.7

25	8.3	15.1	14.5
30	7.1	15.1	14.2
35	7.5	12.4	13.9
40	5.6	9.7	8.0
45	6.1	11.2	9.2

Table 4.3: Compressive Strength for RHA mortar (w/c = 0.55, binder:sand = 1:3)

%RHA	Average Strength (MPa)		
	7-day	**28-day**	**60-day**
0	35.3	36.2	47.5
5	25.5	35.3	24.2
10	14.5	22.5	20.4
15	17.4	26.4	19.0
20	4.0	23.4	20.5
25	4.2	13.6	11.8
30	4.1	20.5	19.6
35	13.9	20.9	18.1
40	12.9	17.2	12.6
45	4.7	11.4	10.3

Table 4.4: Compressive Strength for RHA mortar (w/c = 0.55, binder:sand = 1:4)

%RHA	Average Strength (MPa)		
	7-day	**28-day**	**60-day**
0	17.1	20.4	23.1
5	20.6	32.1	22.6
10	19.9	32.1	26.4
15	16.5	21.1	15.9
20	20.0	31.8	24.3
25	18.5	29.8	29.1
30	13.8	19.6	15.7
35	11.3	18.3	18.0
40	9.8	16.5	13.5
45	9.2	15.9	13.2

It was observed that the strength for mortar increases from 7 days of curing to 28 days of curing. However, it should be noted that there were decreased value of compressive strength from 28 days to 60 days of curing as presented in Table 4.1 to Table 4.4 in most of the mixes. This phenomenon might be due to the fact that a rise in the curing temperature speeds up the chemical reactions of hydration which appears to form products of a poorer physical structure, probably more porous, so that a proportion of the pores will always remain unfilled (Ungsongkhun, 2009). It could be justified by Sung-Sik Park in 2010 that the concrete or mortar system becomes weak because, if water is added, calcium silicate hydrate C–S–H gel moves gradually farther away and as a result van der Waals forces become weak. Additionally, the moisture can weaken the union of Si–O–Si when stresses are applied and thus weakening the mechanical interlocking between particles as it acts as a lubricant.

Figure 4.1, 4.2 and 4.3 show the graphical interpretation of the compressive strength of mortar samples on 7, 28 and 60 days curing time.

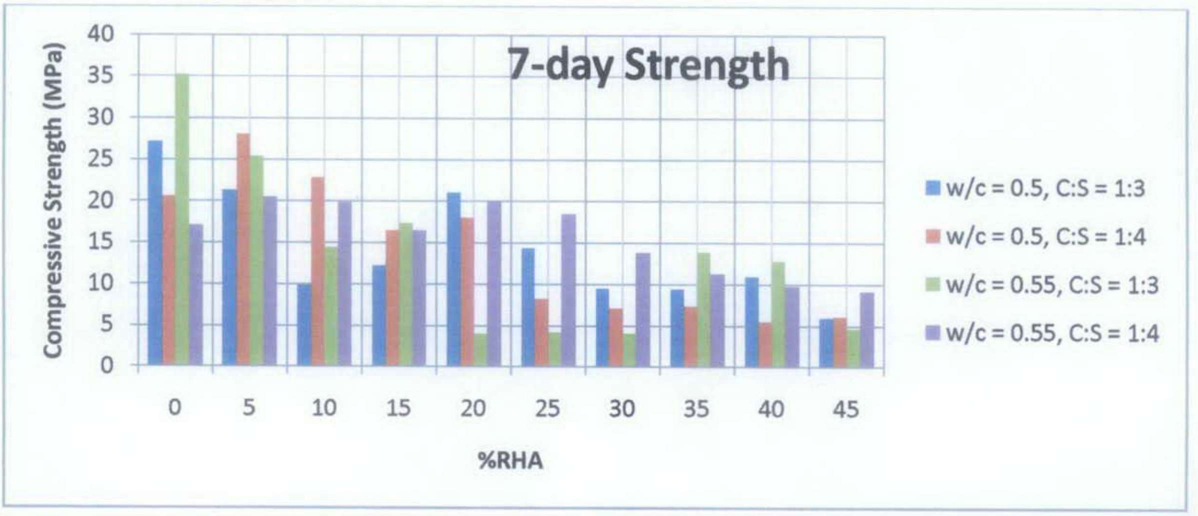

Figure 4.1: 7-day Compressive Strength of Mortar Samples

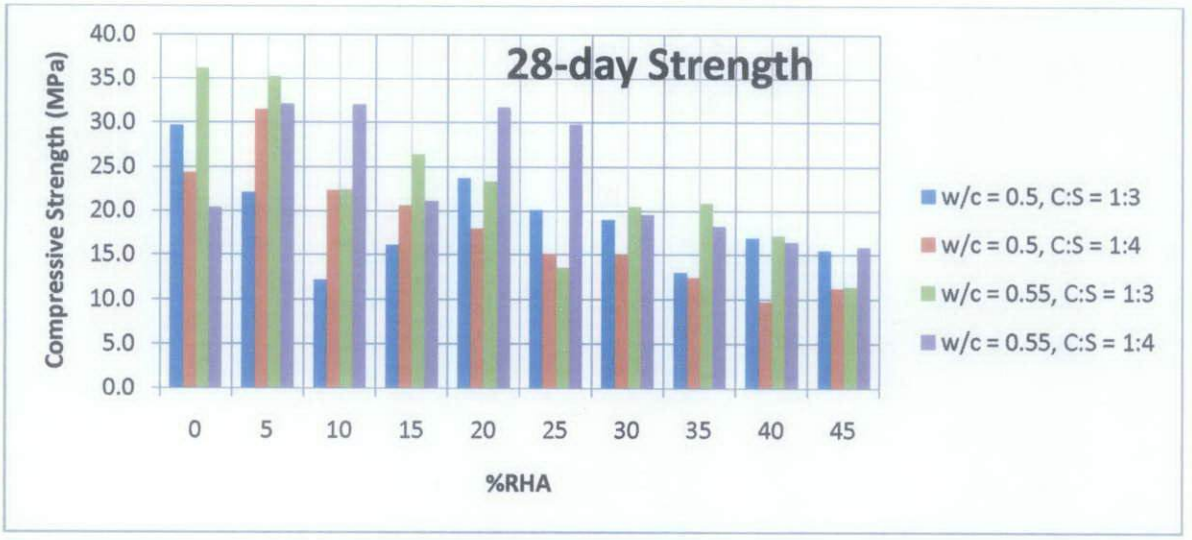

Figure 4.2: 28-day Compressive Strength of Mortar Samples

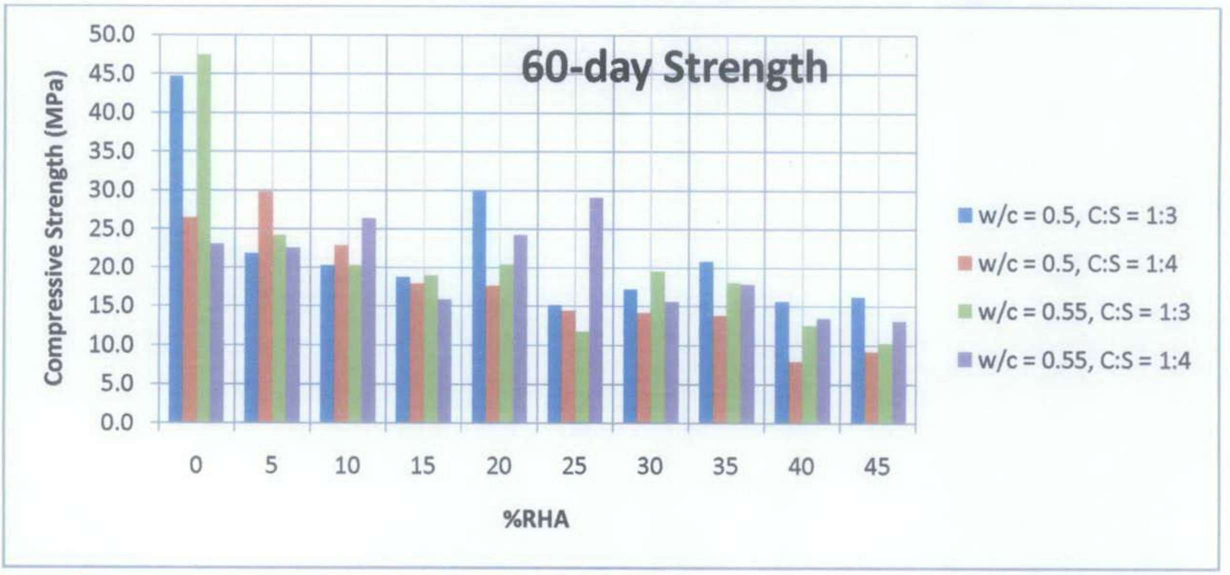

Figure 4.3: 60-day Compressive Strength of Mortar Samples

It is apparent from Figure 4.1 to Figure 4.3, which in control mortar samples, designated mix with w/c of 0.55 and b:s of 1:3 developed higher strength than mix with w/c of 0.50 and b:s of 1:3. From conducted test before on the water content or moisture content of sand samples in the laboratory as in Appendix VI, it shows that the sand sample used for the mix with w/c of 0.55 and b:s of 1:3 has water content of 0.51%. Meanwhile, mix with w/c of 0.5 and b:s of 1:3 was contained by sand sample that has the water content of 0.65%. Hence, it affects the bonding of

C-S-H particles to be farther apart as water content is increased in a mixture, resulting to lower strength as increased result in porosity (Sung-Sik, 2010).

From preceding figures, it can be seen that most mortar samples show increased in value of compressive strength as replacement level of RHA is at 20%. From Figure 4.1, the maximum compressive strength at 20% of RHA replacement level was recorded by mix with w/c of 0.5 and b:s of 1:3 about 21.1 MPa. Meanwhile, at 28-day as in Figure 4.2, it illustrates that maximum compressive strength at 20% RHA replacement level was measured by mix with w/c of 0.55 and b:s of 1:4 which is 31.8 MPa. Additionally, it is shown in Figure 4.3 that the highest strength at 20% of RHA replacement level was obtained by mix with w/c of 0.5 and b:s of 1:3 which is 30.1 MPa.

The lowest value of 7-day compressive strength was recorded by mortar with w/c of 0.55 and binder:sand of 1:3 which is 4.0 MPa at 20% RHA replacement level. In 28-day compressive strength, the lowest value was measured by mix with w/c of 0.50 and binder:sand of 1:4 which is 9.7 MPa at 40% RHA replacement level. The same mix also shows minimum value of 60-day compressive strength which is 8.0 MPa at 40% RHA replacement level.

The average 28-day compressive strength of mixes with water to cement ratio of 0.5 and 0.55 is presented in Table 4.5 below.

Table 4.5: Average 28-day Compressive Strength of Mixes (MPa)

b:s	w/c	%RHA									
		0	5	10	15	20	25	30	35	40	45
1:3	0.50	29.7	22.2	12.2	16.1	23.8	20.2	9.5	9.4	11.0	6.0
	0.55	24.4	31.5	22.4	20.6	18.0	15.1	15.1	12.4	9.7	11.2
1:4	0.50	36.2	35.3	22.5	26.4	23.4	13.6	20.5	20.9	17.2	11.4
	0.55	20.4	32.1	32.1	21.1	31.8	29.8	19.6	18.3	16.5	15.9

From preceding table, it reveals that 6 mixes out of 10 from b:s of 1:3 and w/c of 0.55 were having higher compressive strength compared to same proportion of b:s but w/c of 0.5. In b:s of 1:4, 50% from total mixes were having higher compressive strength compared to mixes with w/c of 0.5.

4.2 Particle Size Distribution of RHA, Cement and Sand Samples

In previous Figure 4.1, 4.2 and 4.3, there is a clear trend of decreasing value of compressive strength of the mortar samples when RHA replacement level increases. This is probably due to the different fineness of particle size between cement and RHA which is illustrated as in Figure 4.4 below. The Particle Size Distribution analysis below is prepared based on the data obtained from sieve analysis and hydrometer test as presented in Appendix III.

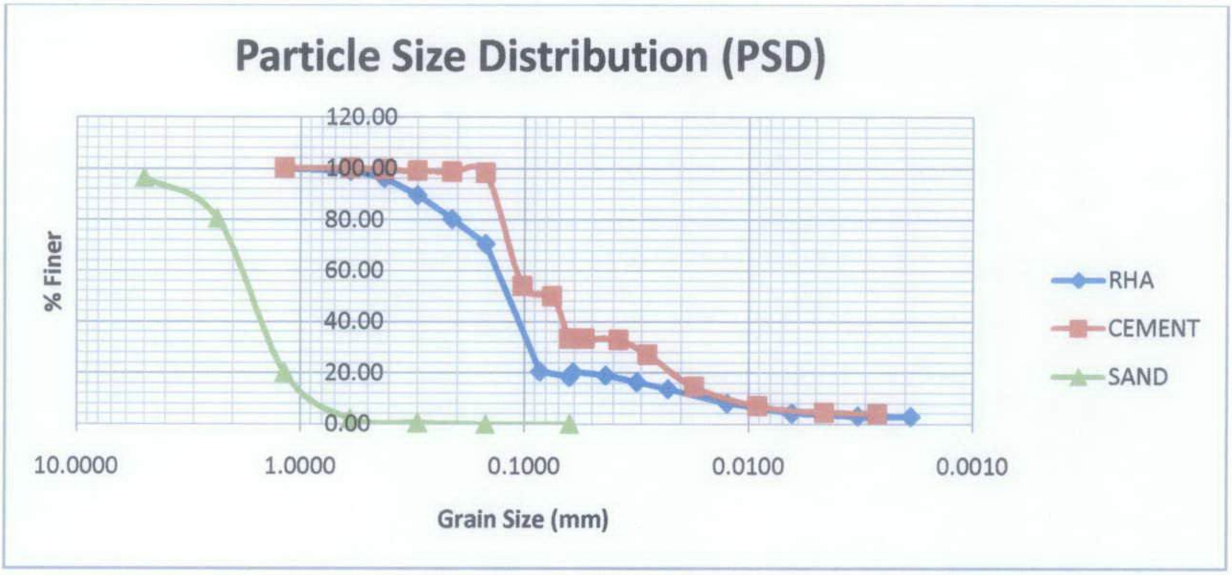

Figure 4.4: Particle Size Distribution of RHA, Cement and Sand Samples

From Figure 4.4 above, it shows that cement is the finest material, followed by RHA and sand. This might lead to the reasons that as RHA replacement level increases in mortar, there is more space or porosity between the particles in the mixture. The microfiller effect comes in as the water inside filled the pores leaves out during the curing process. The volume of water inside the mix increases as the space between the particles increases. Hence, as the volume of pores increases in mortar, the compressive strength of mortar subsequently decreases (Neville, 1995). According to Goldman and Bentur in 1992, particle having low size even lower than cement could modify the microstructure of the transition zone in mortar sample, making it much denser and stronger.

4.3 IRS and Absorption with Compressive Strength

From the experimental work, the IRS data for all mortar samples are accumulated and presented in table form as in Appendix IV. Meanwhile, the absorption data for all mortar samples are presented in Appendix V. In this section, the relationship of these two parameters with compressive strength of mortar samples is going to be investigated.

Table 4.6, 4.7, 4.8 and 4.9 summarized the values of compressive strength, IRS and absorption for all mixes with their RHA replacement levels.

Table 4.6: Compressive Strength, IRS and Absorption for Mortar Mix (w/c = 0.5, b:s = 1:3)

%RHA	Strength (MPa)	IRS ($mm/s^{1/2}$)	Absorption (%)
0	27.2	0.069	9.1
5	21.4	0.031	9.2
10	10.0	0.210	11.9
15	12.3	0.050	11.1
20	21.1	1.491	13.6
25	14.4	0.326	14.1
30	9.5	0.122	14.4
35	9.4	0.713	16.4
40	11.0	0.891	17.5
45	6.0	0.816	18.8

Table 4.7: Compressive Strength, IRS and Absorption for Mortar Mix (w/c = 0.5, b:s = 1:4)

%RHA	Strength (MPa)	IRS ($mm/s^{1/2}$)	Water Absorption (%)
0	20.6	0.135	10.4
5	28.1	0.086	9.9
10	22.9	0.342	12.5
15	16.5	0.722	14.0
20	18.0	0.722	14.7
25	8.3	0.981	14.9
30	7.1	1.739	19.0

35	7.5	1.252	12.8
40	5.6	0.818	19.4
45	6.1	0.373	21.6

Table 4.8: Compressive Strength, IRS and Absorption for Mortar Mix (w/c = 0.55, b:s = 1:3)

%RHA	Strength (MPa)	IRS ($mm/s^{1/2}$)	Water Absorption (%)
0	35.3	0.117	9.3
5	25.5	0.030	9.2
10	14.5	0.026	8.9
15	17.4	0.051	10.7
20	4.0	0.024	10.5
25	4.2	0.022	11.0
30	4.1	0.015	11.3
35	13.9	0.045	12.1
40	12.9	0.064	12.5
45	4.7	0.048	7.1

Table 4.9: Compressive Strength, IRS and Absorption for Mortar Mix (w/c = 0.55, b:s = 1:4)

%RHA	Strength (MPa)	IRS ($mm/s^{1/2}$)	Water Absorption (%)
0	17.1	0.009	10.5
5	20.6	0.032	8.6
10	19.9	0.028	8.8
15	16.5	0.042	8.2
20	20.0	0.040	10.2
25	18.5	0.040	10.3
30	13.8	0.007	11.8
35	11.3	0.011	12.2
40	9.8	0.239	13.0
45	9.2	0.577	13.3

From these results, further analysis of finding the relationship between IRS and absorption of mortar samples to compressive strength is shown as a line graph as presented in Figure 4.5 to Figure 4.8.

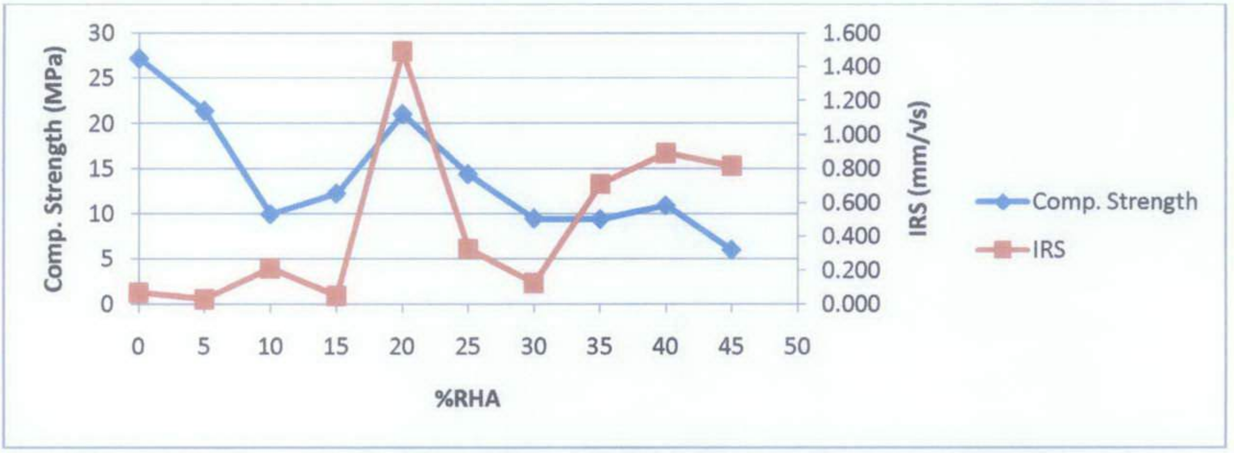

Figure 4.5: Compressive Strength and IRS for Mortar Mix (w/c = 0.50, b:s = 1:3)

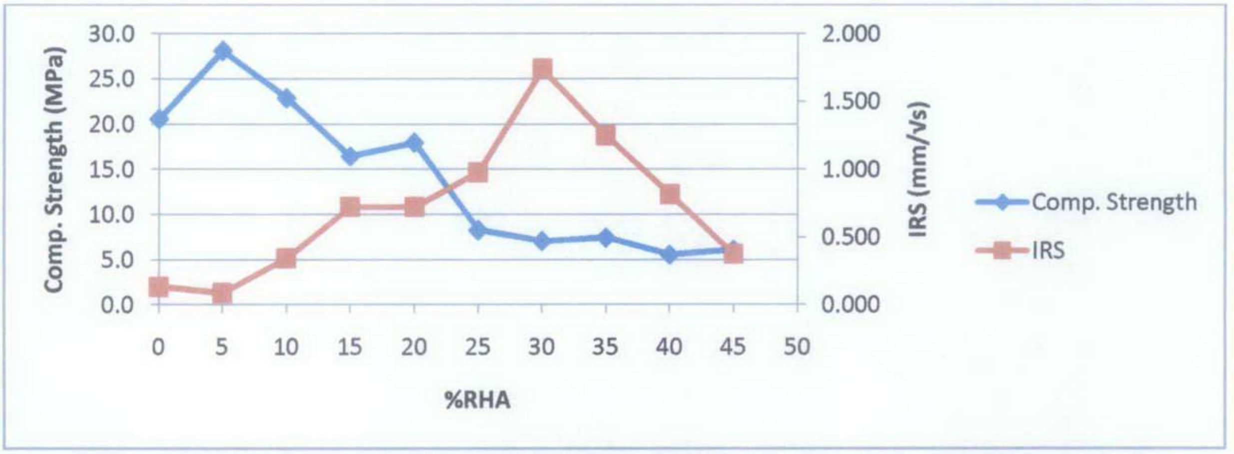

Figure 4.6: Compressive Strength and IRS for Mortar Mix (w/c = 0.50, b:s = 1:4)

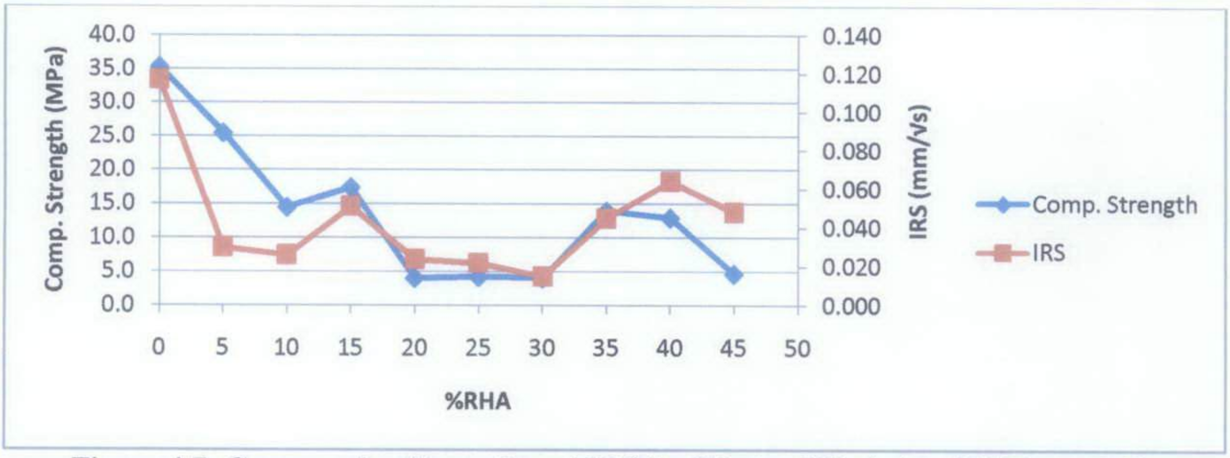

Figure 4.7: Compressive Strength and IRS for Mortar Mix (w/c = 0.55, b:s = 1:3)

Figure 4.8: Compressive Strength and IRS for Mortar Mix (w/c = 0.55, b:s = 1:4)

Based on the graph of Figure 4.5, 4.6, 4.7 and 4.8, it can be seen that there is a relationship between IRS and compressive strength of mortar mixes. It is apparent in Figure 4.6 compressive strength decreases as IRS increases up to 30% of RHA replacement level. Likewise, Figure 4.8 shows in clear way that compressive strength of mortar decreases as IRS increases rapidly from 35% to 45% of RHA replacement level. However, for b:s of 1:3 as illustrated in Figure 4.5 and Figure 4.7, the relationship is rather directly correlated because IRS and compressive strength are likely to be in the similar pattern as RHA replacement level increases.

There is no solid evidence to prove that IRS increases as RHA replacement level increases based on the fluctuating results of IRS obtained in Figure 4.5 to Figure 4.8. However, absorption is basically increases as RHA replacement level increases. It is depicted in the Figure 4.9, 4.10, 4.11 and 4.12 below.

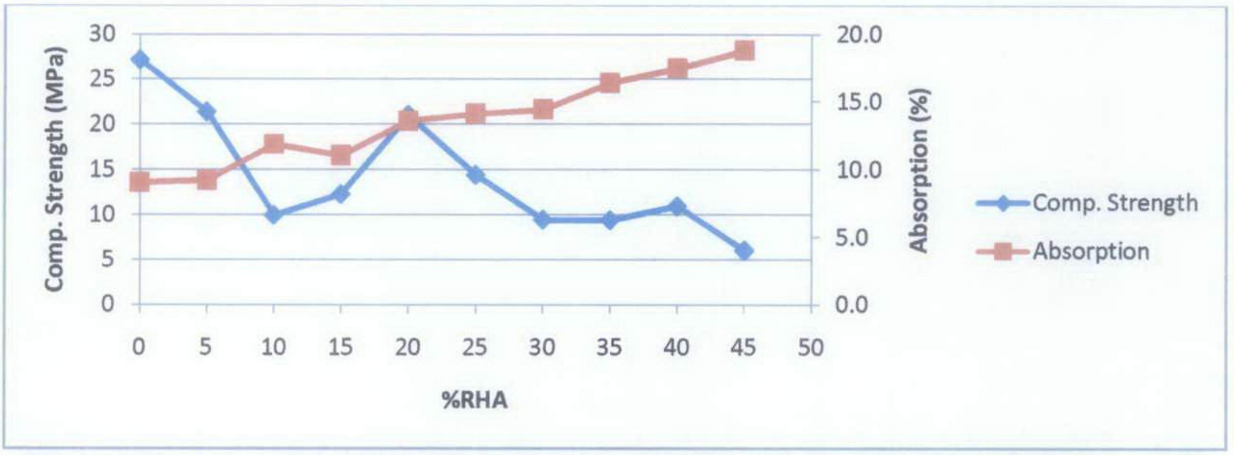

Figure 4.9: Compressive Strength and Absorption for Mortar Mix (w/c = 0.50, b:s = 1:3)

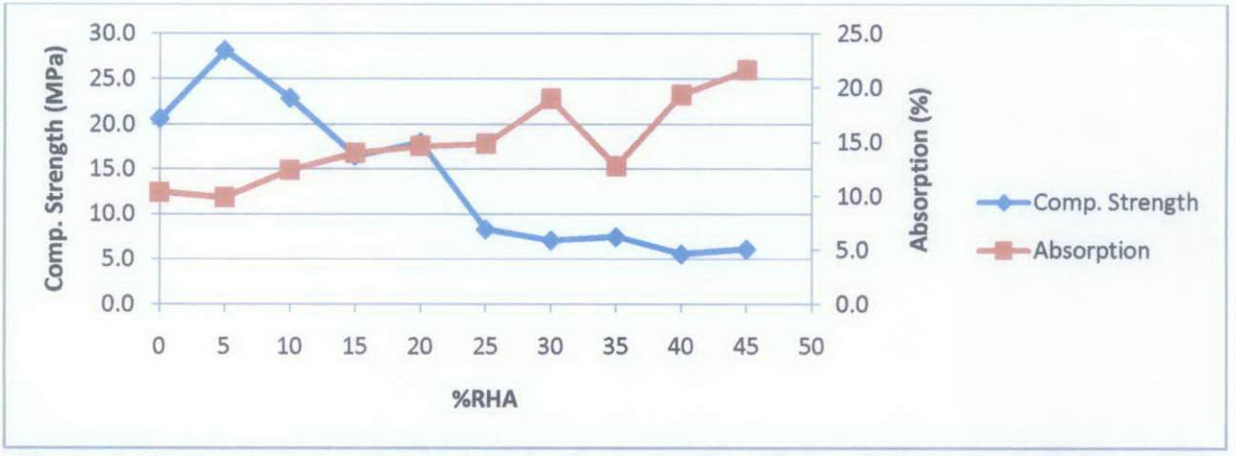

Figure 4.10: Compressive Strength and Absorption for Mortar Mix (w/c = 0.50, b:s = 1:4)

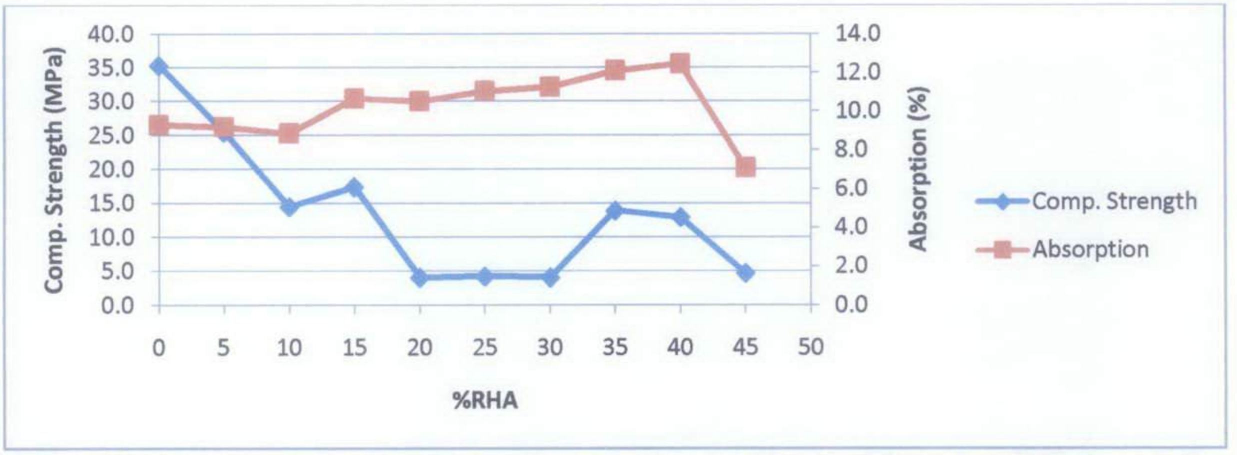

Figure 4.11: Compressive Strength and Absorption for Mortar Mix (w/c = 0.55, b:s = 1:3)

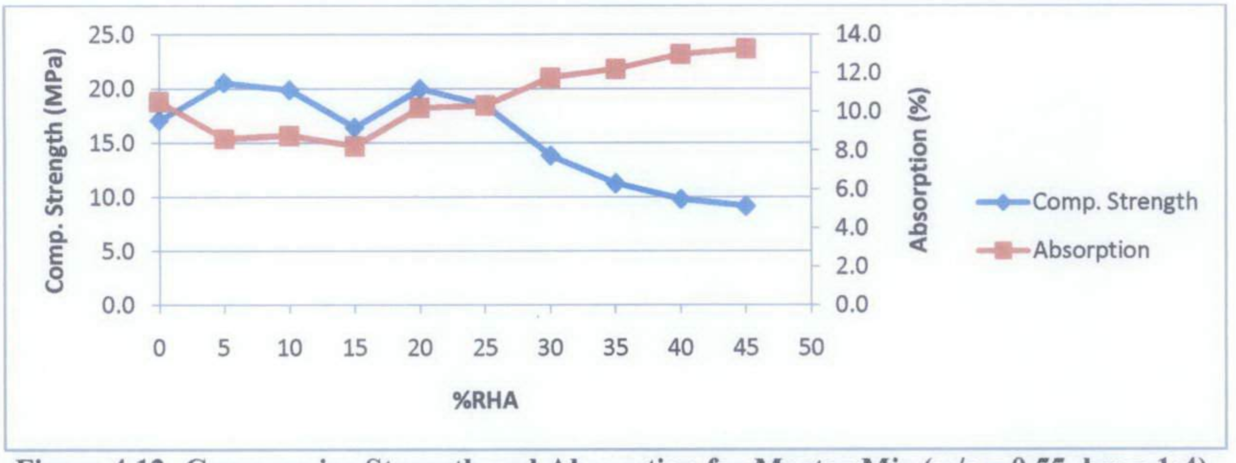

Figure 4.12: Compressive Strength and Absorption for Mortar Mix (w/c = 0.55, b:s = 1:4)

Figure 4.9 to Figure 4.12 reveal that not only absorption increases as RHA replacement level increases, but it also shows that compressive strength of mortar mix decreases as absorption increases. The inclination trend of absorption with RHA replacement level might be due to amorphous form of silica in RHA which it requires more water to complete hydration process with cement and sand to form C-S-H bond (Alireza, 2010).

4.4 Project Viability and Economic Benefit

In approximating the total cost for the RHA brick, it has to include machinery, equipment cost, labor cost and materials cost. Considering the current price of cement in local market, the material cost in making up RHA brick could cost to RM0.10 per brick. However, assuming the other costs included, RHA brick is estimated to cost roughly about RM0.25 per brick.

<u>Ordinary Portland Cement (OPC)</u>

The market price of 50kg of OPC is RM17.00 each. For this project, the cost to cover the total OPC needed for total 40 mixes are calculated as follow:

Cost OPC/50kg	=	RM17.00
Total OPC for 40 mixes	=	87.192 kg (rounded to 100kg for market pack availability)
Total cost of project	=	RM17.00/50kg x 100kg
	=	RM34.00

Compared to market price of several brick types available in Malaysia, the RHA brick is much cheaper as it reduces the usage of cement in its production process. Considering RHA with 45% replacement of cement with binder:aggregate proportion of 1:3 and w/c of 0.5, the cost per brick is estimated to be RM0.10 (0.293kg/50kg x RM17.00). It is much cheaper than the clay brick which costs around RM0.45 to RM0.60 per unit, and much cheaper than cement brick which costs around RM0.30 to RM0.35 per unit according to a local supplier, Hiap Lee Clay Pavers and Bricks Sdn. Bhd.

Table 4.10 summarizes the price of clay and cement brick as provided by local suppliers and the discount comparison to RHA brick.

Table 4.10: Types of Brick and Discount Comparison to RHA Brick

Types of Brick	RHA	Clay	Cement
Cost per brick (RM)	0.25	0.45 – 0.60	0.30 – 0.35
Local Supplier	-	Hiap Lee Clay Pavers. Sdn. Bhd.	Bricks Sdn. Bhd.
Discount Comparison (%)	Minimum	44	17
	Maximum	58	29

Table 4.10 shows that there is significant profit margin when comparing clay and cement brick to RHA brick. As compared to clay brick, RHA brick could save up to 58% from total brick production cost while compared to cement brick, RHA decreases total brick production cost up to 29%.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The following conclusions can be drawn from the present study:

- RHA affects compressive strength of mortar where obtained results show optimum level of RHA replacement level is achieved at 20%. Samples with w/c of 0.55 achieved high strength, particularly with binder:sand proportion of 1:4 at 20% RHA replacement level.
- There is indirectly proportional correlation between IRS and compressive strength of mortar mixes.
- It is observed from the experimental work that absorption increases when RHA replacement level increases, however the compressive strength shows unlikely trend at which decreases when absorption increases in mortar samples.

There are generally two recommendations for continuation of this project, which are:

i) to investigate the properties and behavior of RHA when it gets mixed with water,

ii) to study and relate the effect of porosity in mortar samples to compressive strength.

These recommendations are suggested to improve on the qualitative and quantitative analysis of this project. Additionally, it can enhance our understanding on the optimum level of RHA in mortar mixes and perhaps an accurate percentage can be obtained to achieve higher strength of mortar mixes compared to present statistic values from this experimental work research.

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APPENDICES

APPENDIX I: RESULTS OF MORTAR SAMPLES DENSITY

a) Water/cement ratio = 0.50, Binder:sand proportion = 1:3

Curing Duration	%RHA	Mass (g)			Avg (g)	Density (kg/m^3)
		Sample 1	Sample 2	Sample 3		
7 days	0	2270.00	2240.00	2270.00	2260.00	2260.00
	5	2237.53	2078.21	2130.69	2148.81	2148.81
	10	259.25	243.19	250.70	251.05	2008.37
	15	260.90	264.30	259.02	261.41	2091.25
	20	280.57	284.07	268.94	277.86	2222.88
	25	253.24	251.47	272.33	259.01	2072.11
	30	262.53	258.41	256.29	259.08	2072.61
	35	258.10	252.48	255.85	255.48	2043.81
	40	258.05	257.89	254.09	256.68	2053.41
	45	262.42	257.36	255.63	258.47	2067.76
28 days	0	2198.00	2320.00	2250.00	2256.00	2256.00
	5	2178.00	2342.00	2248.00	2256.00	2256.00
	10	257.87	265.68	264.74	262.76	2102.11
	15	262.64	257.58	259.23	259.82	2078.53
	20	271.30	266.78	272.57	270.22	2161.73
	25	261.96	268.70	269.81	266.82	2134.59
	30	263.78	261.42	262.69	262.63	2101.04
	35	262.13	270.11	261.41	264.55	2116.40
	40	257.80	265.09	261.55	261.48	2091.84
	45	265.07	259.45	261.89	262.14	2097.09
60 days	0	2260.43	2271.65	2313.00	2281.69	2281.69
	5	2226.07	2273.87	2091.71	2197.22	2197.22
	10	272.80	263.02	277.64	271.15	2169.23
	15	257.26	261.34	264.25	260.95	2087.60
	20	272.30	273.82	273.92	273.35	2186.77
	25	258.92	257.41	258.08	258.14	2065.09
	30	263.15	267.90	267.65	266.23	2129.87
	35	257.05	261.59	265.52	261.39	2091.09
	40	262.05	259.32	260.37	260.58	2084.64
	45	262.09	267.69	260.59	263.46	2107.65

b) **Water/cement ratio = 0.50, Binder:sand proportion = 1:4**

Curing Duration	%RHA	Mass (g)			Avg (g)	Density (kg/m^3)
		Sample 1	Sample 2	Sample 3		
7 days	0	2208.00	2187.00	2203.00	2199.33	2199.33
	5	280.43	285.64	286.12	284.06	2272.51
	10	270.29	273.17	274.21	272.56	2180.45
	15	277.14	272.41	274.66	274.74	2197.89
	20	271.88	273.01	271.57	272.15	2177.23
	25	259.50	258.30	256.86	258.22	2065.76
	30	263.00	263.60	262.60	263.07	2104.53
	35	250.24	249.98	258.20	252.81	2022.45
	40	247.29	261.28	263.07	257.21	2057.71
	45	255.40	250.33	261.31	255.68	2045.44
28 days	0	2210.00	2177.00	2165.00	2184.00	2184.00
	5	279.92	281.77	279.24	280.31	2242.48
	10	269.90	284.73	279.86	278.16	2225.31
	15	275.14	274.88	276.03	275.35	2202.80
	20	273.97	289.97	289.92	284.62	2276.96
	25	261.00	263.00	257.00	260.33	2082.67
	30	263.00	257.00	255.00	258.33	2066.67
	35	257.00	255.00	260.00	257.33	2058.67
	40	250.00	249.00	246.00	248.33	1986.67
	45	243.00	244.00	240.00	242.33	1938.67
60 days	0	2223.61	2240.53	2322.00	2262.05	2262.05
	5	284.30	280.64	277.48	280.81	2246.45
	10	280.58	287.63	277.83	282.01	2256.11
	15	284.13	279.66	277.96	280.58	2244.67
	20	284.85	277.44	276.42	279.57	2236.56
	25	255.92	265.36	258.27	259.85	2078.80
	30	264.17	260.80	262.65	262.54	2100.32
	35	257.27	258.70	259.19	258.39	2067.09
	40	258.48	260.31	244.51	254.43	2035.47
	45	256.24	256.70	260.49	257.81	2062.48

c) **Water/cement ratio = 0.55, Binder:sand proportion = 1:3**

Curing Duration	%RHA	Mass (g)			Avg (g)	Density (kg/m^3)
		Sample 1	Sample 2	Sample 3		
7 days	0	2316.00	2251.00	2321.00	2296.00	2296.00
	5	275.82	275.54	275.44	275.60	2204.80
	10	271.47	267.14	268.48	269.03	2152.24
	15	264.39	269.47	270.46	268.11	2144.85
	20	268.91	273.63	269.67	270.74	2165.89
	25	257.57	260.62	262.56	260.25	2082.00
	30	263.55	273.31	265.85	267.57	2140.56
	35	254.69	261.79	258.73	258.40	2067.23
	40	258.14	251.24	256.63	255.34	2042.69
	45	243.27	250.81	251.78	248.62	1988.96
28 days	0	2272.00	2320.00	2231.00	2274.33	2274.33
	5	275.00	277.00	271.00	274.33	2194.67
	10	270.00	270.00	273.00	271.00	2168.00
	15	268.00	267.00	265.00	266.67	2133.33
	20	267.00	261.00	260.00	262.67	2101.33
	25	253.00	257.00	255.00	255.00	2040.00
	30	251.00	252.00	259.00	254.00	2032.00
	35	252.00	258.00	255.00	255.00	2040.00
	40	251.00	249.00	248.00	249.33	1994.67
	45	248.00	249.00	252.00	249.67	1997.33
60 days	0	2278.11	2304.83	2257.23	2280.06	2280.06
	5	282.28	279.01	280.47	280.59	2244.69
	10	270.07	272.99	276.32	273.13	2185.01
	15	268.75	270.64	279.29	272.89	2183.15
	20	277.60	270.59	273.73	273.97	2191.79
	25	280.38	277.78	264.98	274.38	2195.04
	30	264.32	265.12	278.29	269.24	2153.95
	35	265.86	261.51	262.10	263.16	2105.25
	40	253.41	254.87	255.81	254.70	2037.57
	45	250.38	234.56	248.51	244.48	1955.87

d) **Water/cement ratio = 0.55, Binder:sand proportion = 1:4**

Curing Duration	%RHA	Mass (g)			Avg (g)	Density (kg/m^3)
		Sample 1	Sample 2	Sample 3		
7 days	0	2302.00	2197.00	2249.00	2249.33	2249.33
	5	277.83	278.72	268.60	275.05	2200.40
	10	271.91	279.74	278.73	276.79	2214.35
	15	272.98	274.02	274.67	273.89	2191.12
	20	282.88	281.54	274.91	279.78	2238.21
	25	281.54	278.32	271.84	277.23	2217.87
	30	273.21	270.91	268.67	270.93	2167.44
	35	261.45	266.10	269.18	265.58	2124.61
	40	266.62	261.95	266.22	264.93	2119.44
	45	264.23	265.01	263.60	264.28	2114.24
28 days	0	2276.00	2293.00	2133.00	2234.00	2234.00
	5	271.00	270.00	281.00	274.00	2192.00
	10	271.00	268.00	272.00	270.33	2162.67
	15	269.00	268.00	264.00	267.00	2136.00
	20	269.00	265.00	263.00	265.67	2125.33
	25	263.00	267.00	261.00	263.67	2109.33
	30	262.00	259.00	252.00	257.67	2061.33
	35	261.00	258.00	259.00	259.33	2074.67
	40	260.00	257.00	255.00	257.33	2058.67
	45	255.00	249.00	253.00	252.33	2018.67
60 days	0	2201.18	2262.00	2259.40	2240.86	2240.86
	5	272.05	276.59	272.57	273.74	2189.89
	10	285.55	282.46	278.17	282.06	2256.48
	15	273.18	276.05	275.01	274.75	2197.97
	20	280.05	282.33	284.83	282.40	2259.23
	25	278.61	279.10	277.28	278.33	2226.64
	30	269.03	276.45	269.31	271.60	2172.77
	35	268.79	267.20	269.96	268.65	2149.20
	40	264.03	266.85	262.10	264.33	2114.61
	45	268.22	270.15	272.88	270.42	2163.33

APPENDIX II: RESULTS OF MORTAR SAMPLES COMPRESSIVE STRENGTH

a) Water/cement ratio = 0.50, Binder:sand proportion = 1:3

% RHA	RHA (g)	Cement (g)	Sand (g)	Water (g)	Total Mass (g)	Cast Date	7-day			28-day			60-day		
0	0	66.667	200	33.333	300	4-Oct	11-Oct			1-Nov			3-Dec		
	Maximum Compressive Load (kN)						280.40	281.50	255.40	229.80	335.40	324.70	459.00	455.30	427.30
	Compressive Strength (MPa)						28.04	28.15	25.54	22.98	33.54	32.47	45.90	45.53	42.73
5	3.333	63.333	200	33.333	300	2-Dec	9-Dec			30-Dec			31-Jan		
	Maximum Compressive Load (kN)						244.50	176.40	220.90	231.40	220.50	212.70	222.50	209.20	225.10
	Compressive Strength (MPa)						24.45	17.64	22.09	23.14	22.05	21.27	22.25	20.92	22.51
10	6.667	60.000	200	33.333	300	8-Dec	15-Dec			5-Jan			6-Feb		
	Maximum Compressive Load (kN)						35.50	24.50	14.70	30.10	38.90	22.30	52.10	52.50	48.00
	Compressive Strength (MPa)						14.22	9.81	5.89	12.04	15.56	8.92	20.84	21.00	19.20
15	10.000	56.667	200	33.333	300	8-Dec	15-Dec			5-Jan			6-Feb		
	Maximum Compressive Load (kN)						31.10	35.10	26.00	46.30	29.20	45.60	45.90	50.10	45.40
	Compressive Strength (MPa)						12.44	14.04	10.40	18.52	11.68	18.24	18.36	20.04	18.16
20	13.333	53.333	200	33.333	300	8-Dec	15-Dec			5-Jan			6-Feb		
	Maximum Compressive Load (kN)						50.10	55.30	52.50	60.30	53.40	64.50	82.70	78.20	64.80
	Compressive Strength (MPa)						20.04	22.13	21.00	24.12	21.36	25.80	33.08	31.28	25.92
25	16.667	50.000	200	33.333	300	8-Dec	15-Dec			5-Jan			6-Feb		
	Maximum Compressive Load (kN)						37.30	37.80	33.00	35.50	51.20	64.50	22.50	37.50	54.40
	Compressive Strength (MPa)						14.91	15.14	13.22	14.20	20.48	25.80	9.00	15.00	21.76
30	20.000	46.667	200	33.333	300	8-Dec	15-Dec			5-Jan			6-Feb		
	Maximum Compressive Load (kN)						50.80	9.20	11.00	52.90	44.90	44.80	30.10	47.90	51.40
	Compressive Strength (MPa)						20.33	3.68	4.40	21.16	17.96	17.92	12.04	19.16	20.56
35	23.333	43.333	200	33.333	300	8-Dec	15-Dec			5-Jan			6-Feb		
	Maximum Compressive Load (kN)						32.40	25.60	12.60	29.80	29.40	38.00	48.40	63.30	45.10
	Compressive Strength (MPa)						12.95	10.26	5.06	11.92	11.76	15.20	19.36	25.32	18.04
40	26.667	40.000	200	33.333	300	9-Dec	16-Dec			6-Jan			7-Feb		
	Maximum Compressive Load (kN)						24.60	26.40	31.30	40.50	46.20	40.10	39.50	37.70	40.70
	Compressive Strength (MPa)						9.84	10.57	12.51	16.20	18.48	16.04	15.80	15.08	16.28
45	30.000	36.667	200	33.333	300	9-Dec	16-Dec			6-Jan			7-Feb		
	Maximum Compressive Load (kN)						27.20	9.10	8.90	39.00	35.10	42.50	44.80	37.30	40.00
	Compressive Strength (MPa)						10.86	3.63	3.56	15.60	14.04	17.00	17.92	14.92	16.00

b) Water/cement ratio = 0.50, Binder:sand proportion = 1:4

% RHA	RHA (g)	Cement (g)	Sand (g)	Water (g)	Total Mass (g)	Cast Date	7-day			28-day			60-day		
0	0	54.545	218.18	27.273	300	5-Oct	12-Oct			2-Nov			4-Dec		
	Maximum Compressive Load (kN)						207.10	195.70	214.10	250.80	244.40	237.50	264.60	275.30	255.40
	Compressive Strength (MPa)						20.71	19.57	21.41	25.08	24.44	23.75	26.46	27.53	25.54
5	2.727	51.818	218.18	27.273	300	9-Dec	16-Dec			6-Jan			7-Feb		
	Maximum Compressive Load (kN)						69.20	71.30	70.40	84.80	71.40	80.20	84.70	66.00	72.60
	Compressive Strength (MPa)						27.68	28.52	28.16	33.92	28.56	32.08	33.88	26.40	29.04
10	5.455	49.091	218.18	27.273	300	9-Dec	16-Dec			6-Jan			7-Feb		
	Maximum Compressive Load (kN)						50.30	60.20	61.50	56.90	63.40	47.50	61.00	51.00	60.40
	Compressive Strength (MPa)						20.12	24.08	24.60	22.76	25.36	19.00	24.40	20.40	24.16
15	8.182	46.364	218.18	27.273	300	9-Dec	16-Dec			6-Jan			7-Feb		
	Maximum Compressive Load (kN)						42.10	36.90	44.90	52.50	49.80	52.50	46.50	43.50	44.80
	Compressive Strength (MPa)						16.84	14.76	17.96	21.00	19.92	21.00	18.60	17.40	17.92
20	10.909	43.636	218.18	27.273	300	9-Dec	16-Dec			6-Jan			7-Feb		
	Maximum Compressive Load (kN)						42.10	43.20	49.70	45.90	44.40	44.90	51.90	50.50	30.30
	Compressive Strength (MPa)						16.84	17.28	19.88	18.36	17.76	17.96	20.76	20.20	12.12
25	13.636	40.909	218.18	27.273	300	16-Dec	23-Dec			13-Jan			14-Feb		
	Maximum Compressive Load (kN)						28.00	22.00	12.10	29.43	41.13	42.93	34.30	40.70	33.40
	Compressive Strength (MPa)						11.20	8.80	4.84	11.77	16.45	17.17	13.72	16.28	13.36
30	16.364	38.182	218.18	27.273	300	16-Dec	23-Dec			13-Jan			14-Feb		
	Maximum Compressive Load (kN)						11.30	18.40	23.40	40.23	38.35	34.40	32.90	37.70	36.00
	Compressive Strength (MPa)						4.52	7.36	9.36	16.09	15.34	13.76	13.16	15.08	14.40
35	19.091	35.455	218.18	27.273	300	16-Dec	23-Dec			13-Jan			14-Feb		
	Maximum Compressive Load (kN)						27.20	14.20	14.50	30.60	36.43	26.20	33.90	36.90	33.40
	Compressive Strength (MPa)						10.88	5.68	5.80	12.24	14.57	10.48	13.56	14.76	13.36
40	21.818	32.727	218.18	27.273	300	16-Dec	23-Dec			13-Jan			14-Feb		
	Maximum Compressive Load (kN)						12.00	10.70	19.10	22.78	24.10	26.03	23.80	19.50	16.90
	Compressive Strength (MPa)						4.80	4.28	7.64	9.11	9.64	10.41	9.52	7.80	6.76
45	24.545	30.000	218.18	27.273	300	16-Dec	23-Dec			13-Jan			14-Feb		
	Maximum Compressive Load (kN)						13.50	13.30	19.20	26.40	29.33	28.30	20.20	26.10	22.90
	Compressive Strength (MPa)						5.40	5.32	7.68	10.56	11.73	11.32	8.08	10.44	9.16

c) Water/cement ratio = 0.55, Binder:sand proportion = 1:3

% RHA	RHA (g)	Cement (g)	Sand (g)	Water (g)	Total Mass (g)	Cast Date	7-day			28-day			60-day		
0	0	65.934	197.80	36.26	300	12-Oct	19-Oct			9-Nov			11-Dec		
	Maximum Compressive Load (kN)						316.2	377.5	364.5	368.4	363.6	354.3	424.3	527.9	474.1
	Compressive Strength (MPa)						31.62	37.75	36.45	36.84	36.36	35.43	42.43	52.79	47.41
5	3.297	62.637	197.80	36.26	300	15-Dec	22-Dec			12-Jan			13-Feb		
	Maximum Compressive Load (kN)						65.00	59.70	66.30	96.63	82.40	85.65	67.30	76.20	38.20
	Compressive Strength (MPa)						26.00	23.88	26.52	38.65	32.96	34.26	26.92	30.48	15.28
10	6.593	59.341	197.80	36.26	300	15-Dec	22-Dec			12-Jan			13-Feb		
	Maximum Compressive Load (kN)						44.90	33.90	29.70	61.85	53.33	53.33	39.90	58.00	54.90
	Compressive Strength (MPa)						17.96	13.56	11.88	24.74	21.33	21.33	15.96	23.2	21.96
15	9.890	56.044	197.80	36.26	300	15-Dec	22-Dec			12-Jan			13-Feb		
	Maximum Compressive Load (kN)						44.20	46.80	39.40	60.55	66.60	71.15	46.20	43.60	53.00
	Compressive Strength (MPa)						17.68	18.72	15.76	24.22	26.64	28.46	18.48	17.44	21.2
20	13.187	52.747	197.80	36.26	300	15-Dec	22-Dec			12-Jan			13-Feb		
	Maximum Compressive Load (kN)						11.30	9.20	9.60	59.73	58.48	57.10	42.80	50.80	60.20
	Compressive Strength (MPa)						4.52	3.68	3.84	23.89	23.39	22.84	17.12	20.32	24.08
25	16.484	49.451	197.80	36.26	300	15-Dec	22-Dec			12-Jan			13-Feb		
	Maximum Compressive Load (kN)						12.10	11.00	8.60	30.60	34.95	36.60	33.60	31.70	23.20
	Compressive Strength (MPa)						4.84	4.4	3.44	12.24	13.98	14.64	13.44	12.68	9.28
30	19.780	46.154	197.80	36.26	300	15-Dec	22-Dec			12-Jan			13-Feb		
	Maximum Compressive Load (kN)						9.80	10.70	10.00	51.25	53.53	49.05	41.20	43.20	62.40
	Compressive Strength (MPa)						3.92	4.28	4.00	20.50	21.41	19.62	16.48	17.28	24.96
35	23.077	42.857	197.80	36.26	300	20-Dec	27-Dec			17-Jan			18-Feb		
	Maximum Compressive Load (kN)						36.60	39.10	28.40	62.40	46.30	47.80	44.50	40.30	51.00
	Compressive Strength (MPa)						14.64	15.64	11.36	24.96	18.52	19.12	17.8	16.12	20.4
40	26.374	39.560	197.80	36.26	300	20-Dec	27-Dec			17-Jan			18-Feb		
	Maximum Compressive Load (kN)						27.00	34.50	35.10	50.20	38.48	40.28	30.60	38.60	25.40
	Compressive Strength (MPa)						10.8	13.8	14.04	20.08	15.39	16.11	12.24	15.44	10.16
45	29.670	36.264	197.80	36.26	300	20-Dec	27-Dec			17-Jan			18-Feb		
	Maximum Compressive Load (kN)						13.10	9.30	12.50	30.40	29.70	25.33	28.60	18.60	30.30
	Compressive Strength (MPa)						5.24	3.72	5.00	12.16	11.88	10.13	11.44	7.44	12.12

d) Water/cement ratio = 0.55, Binder:sand proportion = 1:4

% RHA	RHA (g)	Cement (g)	Sand (g)	Water (g)	Total Mass (g)	Cast Date	7-day			28-day			60-day		
0	0	54.054	216.22	29.730	300	14-Oct	21-Oct			11-Nov			13-Dec		
	Maximum Compressive Load (kN)						185.6	152.2	176.5	195.2	214.1	202.4	230.3	236.5	225.7
	Compressive Strength (MPa)						18.56	15.22	17.65	19.52	21.41	20.24	23.03	23.65	22.57
5	2.703	51.351	216.22	29.730	300	20-Dec	27-Dec			17-Jan			18-Feb		
	Maximum Compressive Load (kN)						60.60	58.20	35.40	85.13	71.90	83.80	65.30	47.10	57.30
	Compressive Strength (MPa)						24.24	23.28	14.16	34.05	28.76	33.52	26.12	18.84	22.92
10	5.405	48.649	216.22	29.730	300	20-Dec	27-Dec			17-Jan			18-Feb		
	Maximum Compressive Load (kN)						54.60	44.40	50.30	78.15	85.08	77.35	51.00	63.90	83.30
	Compressive Strength (MPa)						21.84	17.76	20.12	31.26	34.03	30.94	20.4	25.56	33.32
15	8.108	45.946	216.22	29.730	300	20-Dec	27-Dec			17-Jan			18-Feb		
	Maximum Compressive Load (kN)						37.30	42.40	43.70	53.85	54.50	50.15	44.80	42.90	31.70
	Compressive Strength (MPa)						14.92	16.96	17.48	21.54	21.80	20.06	17.92	17.16	12.68
20	10.811	43.243	216.22	29.730	300	21-Dec	28-Dec			18-Jan			19-Feb		
	Maximum Compressive Load (kN)						44.20	53.50	52.40	76.18	79.78	82.35	53.90	73.90	54.30
	Compressive Strength (MPa)						17.68	21.4	20.96	30.47	31.91	32.94	21.56	29.56	21.72
25	13.514	40.541	216.22	29.730	300	21-Dec	28-Dec			18-Jan			19-Feb		
	Maximum Compressive Load (kN)						46.30	43.90	48.60	75.08	78.43	70.20	73.60	61.20	83.70
	Compressive Strength (MPa)						18.52	17.56	19.44	30.03	31.37	28.08	29.44	24.48	33.48
30	16.216	37.838	216.22	29.730	300	21-Dec	28-Dec			18-Jan			19-Feb		
	Maximum Compressive Load (kN)						32.70	36.00	35.10	46.23	53.60	46.85	47.20	36.00	34.30
	Compressive Strength (MPa)						13.08	14.40	14.04	18.49	21.44	18.74	18.88	14.4	13.72
35	18.919	35.135	216.22	29.730	300	21-Dec	28-Dec			18-Jan			19-Feb		
	Maximum Compressive Load (kN)						31.10	22.90	30.60	44.95	45.18	46.83	38.90	44.20	51.60
	Compressive Strength (MPa)						12.44	9.16	12.24	17.98	18.07	18.73	15.56	17.68	20.64
40	21.622	32.432	216.22	29.730	300	21-Dec	28-Dec			18-Jan			19-Feb		
	Maximum Compressive Load (kN)						23.50	26.40	23.90	39.95	45.45	38.13	36.10	27.80	37.50
	Compressive Strength (MPa)						9.4	10.56	9.56	15.98	18.18	15.25	14.44	11.12	15.00
45	24.324	29.730	216.22	29.730	300	21-Dec	28-Dec			18-Jan			19-Feb		
	Maximum Compressive Load (kN)						23.80	22.20	23.00	37.93	39.43	41.85	29.90	33.00	35.90
	Compressive Strength (MPa)						9.52	8.88	9.20	15.17	15.77	16.74	11.96	13.2	14.36

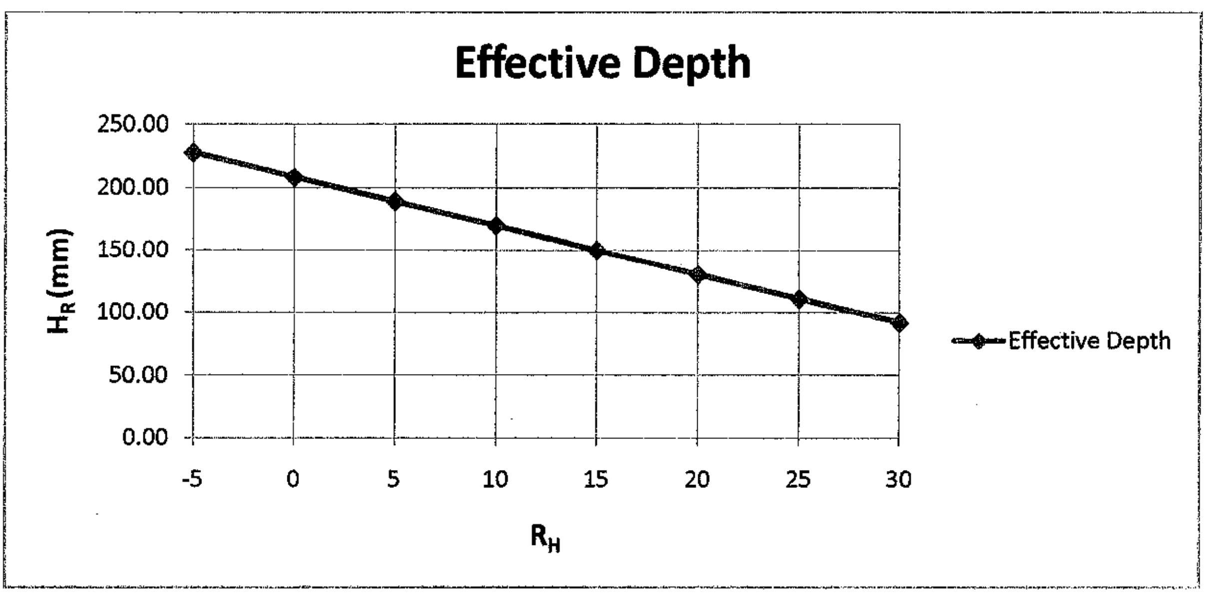
APPENDIX III: SIEVE ANALYSIS AND HYDROMETER TEST DATA

a) Calibration of Hydrometer

Volume, V_h =	66.9	mL
Length, L =	350	mm
Neck ,N =	25	mm
Height, h =	160	mm

No.	Distance (mm)	H	H_R	R_h	Rh
d_7	136.0	161.0	227.99	0.995	-5
d_6	116.5	141.5	208.49	1.000	0
d_5	97.0	122.0	188.99	1.005	5
d_4	78.0	103.0	169.99	1.010	10
d_3	58.0	83.0	149.99	1.015	15
d_2	38.5	63.5	130.49	1.020	20
d_1	19.0	44.0	110.99	1.025	25
d	0.0	25.0	91.99	1.030	30

b) Effective Depth of Hydrometer



$H_R = 208.49 - 3.88571R_H$

c) Meniscus Correction

Below plane = 1.0000 g/mL

Above plane = 0.9995 g/mL

Correction = 0.0005 g/mL

d) Viscosity

T (°C)	n (mPa.s)
10	1.304
15	1.137
20	1.002
25	0.891
30	0.798

e) Calibration and Data Sampling

Hydrometer no. =	151	H	
Meniscus correction, C_m =	0.5		
Reading in dispersant, R_o =	-0.01		
Dry mass of sample, m =	27.95	g	
Specific gravity of RHA =	2.13		(Oyetola, 2006)
Density of RHA =	2130	kg/m^3	
RHA p_s =	2.13	Mg/m^3	
Density of Cement =	1506	kg/m^3	(Pozzocrete, 2009)
Cement p_s =	1.506	Mg/m^3	
Water temperature =	22.4	°C	
Viscosity of water, n =	0.94872	mPa.s	

RHA Sample

a) Sieve Analysis

Diameter (mm)	Retained Mass (g)	%Retained	%Passing
1.180	0	0.00	100.00
0.600	1.58	1.05	98.95
0.425	4.05	2.69	96.26
0.300	10.07	6.69	89.57
0.212	13.98	9.28	80.29
0.150	14.57	9.68	70.61
0.063	78.37	52.05	18.56
Pan	27.95	18.56	0.00

b) Hydrometer Analysis

Date	**Time**	**Elapsed Time, t min**	**Temperature, °C**	**Water Viscosity, n mPa.s**	**Relative Density**	**Reading, R_h'**	**$R_h' + C_m = R_h$**	**Effective Depth, H_r mm**	**Particle Diameter, D mm**	**$R_h' - R_o = R_d$**	**% finer than D, K%**	**% Adjusted**
23/3/11	1016	0.0	22.4	0.9487	1.0170	17.0	17.5	140.5	-	-	-	-
	1016	0.5	22.4	0.9487	1.0165	16.5	17.0	142.4	0.0855	16.51	111.34	**20.67**
	1017	1.0	22.4	0.9487	1.0163	16.3	16.8	143.2	0.0606	16.31	110.00	**20.42**
	1018	2.0	22.4	0.9487	1.0153	15.3	15.8	147.1	0.0435	15.31	103.25	**19.17**
	1020	4.0	22.4	0.9487	1.0132	13.2	13.7	155.3	0.0316	13.21	89.09	**16.54**
	1024	8.0	22.4	0.9487	1.0110	11.0	11.5	163.8	0.0229	11.01	74.25	**13.78**
	1046	30.0	22.3	0.9509	1.0065	6.5	7.0	181.3	0.0125	6.51	43.90	**8.15**
	1246	120.0	22.3	0.9509	1.0035	3.5	4.0	192.9	0.0064	3.51	23.67	**4.39**
	1846	480.0	22.1	0.9554	1.0025	2.5	3.0	196.8	0.0033	2.51	16.93	**3.14**
24/3/11	1016	1440.0	21.8	0.9620	1.0022	2.2	2.7	198.0	0.0019	2.21	14.90	**2.77**

Cement Sample

a) Sieve Analysis

Diameter (mm)	Retained Mass (g)	%Retained	%Passing
1.180	0	0.00	100.00
0.600	0.05	0.03	99.97
0.425	0.78	0.52	99.44
0.300	0.62	0.42	99.03
0.212	0.52	0.35	98.68
0.150	0.83	0.56	98.12
0.063	96.78	64.96	33.16
Pan	49.4	33.16	0.00

b) Hydrometer Analysis

Date	Time	Elapsed Time, t min	Temperature, °C	Water Viscosity, n mPa.s	Relative Density	Reading, R_h'	$R_h' + C_m = R_h$	Effective Depth, Hr mm	Particle Diameter, D mm	$R_h' - R_o = R_d$	% finer than D, K%	% Adjusted
12/4/2011	1000	0.0	27	0.8538	1.0300	30.0	30.5	90.0	-	-	-	-
	1000	0.5	27	0.8538	1.0270	27.0	27.5	101.6	0.1024	27.01	162.73	53.96
	1001	1.0	27	0.8538	1.0250	25.0	25.5	109.4	0.0751	25.01	150.68	49.96
	1002	2.0	27	0.8538	1.0245	24.5	25.0	111.3	0.0536	24.51	147.67	33.16
	1004	4.0	27	0.8538	1.0243	24.3	24.8	112.1	0.0380	24.31	146.46	32.76
	1008	8.0	27	0.8538	1.0215	21.5	22.0	123.0	0.0282	21.51	129.59	27.17
	1030	30.0	27	0.8538	1.0073	7.3	7.8	178.2	0.0175	7.31	44.04	14.60
	1200	120.0	27	0.8538	1.0035	3.5	4.0	192.9	0.0091	3.51	21.15	7.01
	1800	480.0	27	0.8538	1.0023	2.3	2.8	197.6	0.0046	2.31	13.92	4.61
13/4/11	1000	1440.0	27	0.8538	1.0020	2.0	2.5	198.8	0.0027	2.01	12.11	4.02

Tabulated Particle Size Data for RHA and Cement

RHA		Cement	
Sieve (mm)	% Passing	Sieve (mm)	% Passing
1.1800	100.00	1.1800	100.00
0.6000	98.95	0.6000	99.97
0.4250	96.26	0.4250	99.44
0.3000	89.57	0.3000	99.03
0.2120	80.29	0.2120	98.68
0.1500	70.61	0.1500	98.12
0.0855	20.67	0.1024	53.96
0.0630	18.56	0.0751	49.96
0.0606	20.42	0.0630	33.16
0.0435	19.17	0.0536	33.16
0.0316	16.54	0.0380	32.76
0.0229	13.78	0.0282	27.17
0.0125	8.15	0.0175	14.60
0.0064	4.39	0.0091	7.01
0.0033	3.14	0.0046	4.61
0.0019	2.77	0.0027	4.02

Sand Sample

a) Sieve Analysis

Sieve size (mm)	Retained Mass (g)	%Retained	%Passing
5.000	17	3.4	96.6
2.360	80	16.1	80.5
1.180	300	60.2	20.3
0.600	90	18.1	2.2
0.300	8	1.6	0.6
0.150	3	0.6	0.0
0.063	0	0.0	0.0
Pan	0	0.0	0.0

b) Hydrometer Analysis

Not applicable since no retention of particle on pan.

APPENDIX IV: INITIAL RATE OF SUCTION (IRS) DATA

a) Mass Changes in Short Time Interval

i. Water-cement ratio: 0.50

Binder:sand	%RHA	Mass, M (g) at Time, t (min)					
		0	60	120	300	600	1200
1:3	0	258.33	259.07	259.12	259.33	259.46	259.76
	5	245.02	245.63	245.54	245.64	245.69	245.95
	10	232.96	234.51	234.78	235.29	235.68	236.68
	15	248.31	249.08	249.18	249.20	249.34	249.63
	20	217.80	231.07	234.48	237.83	241.61	246.08
	25	229.99	233.80	234.55	235.09	235.81	237.24
	30	224.04	225.70	225.86	225.92	226.21	227.05
	35	205.42	209.77	211.93	213.16	214.63	217.30
	40	211.76	224.07	226.63	228.08	230.01	233.48
	45	205.49	211.07	214.46	215.13	217.22	219.85
1:4	0	247.13	248.48	248.82	248.94	249.33	249.91
	5	239.63	240.11	240.19	240.40	240.65	240.96
	10	232.67	236.02	237.00	237.30	238.15	239.71
	15	197.50	208.77	210.61	211.15	212.81	216.67
	20	215.03	231.63	234.31	235.11	237.19	239.19
	25	186.87	196.14	198.28	200.30	203.35	205.83
	30	170.29	193.58	195.60	199.26	206.39	209.85
	35	203.50	213.09	217.15	220.51	223.65	225.43
	40	188.83	198.25	201.62	203.47	204.81	206.84
	45	176.20	203.61	207.71	207.94	207.99	208.12

ii. Water-cement ratio: 0.55

Binder:sand	%RHA	Mass, M (g) at Time, t (min)					
		0	**60**	**120**	**300**	**600**	**1200**
1:3	0	257.84	258.40	258.49	258.56	258.57	259.82
	5	253.47	253.80	253.85	253.94	253.97	254.12
	10	255.81	256.17	256.20	256.24	256.37	256.41
	15	247.68	248.02	248.12	248.22	248.41	248.51
	20	252.65	253.12	253.13	253.19	253.24	253.37
	25	247.36	247.82	247.88	247.90	247.98	248.05
	30	238.58	239.01	239.05	239.09	239.10	239.18
	35	238.94	239.33	239.41	239.43	239.55	239.82
	40	237.20	237.75	237.98	238.01	238.25	238.42
	45	235.13	235.72	235.77	235.81	235.92	236.25
1:4	0	256.62	264.15	264.22	264.24	264.25	264.25
	5	255.56	256.12	256.23	256.28	256.32	256.48
	10	252.58	253.17	253.25	253.27	253.39	253.45
	15	253.32	254.04	254.19	254.29	254.30	254.51
	20	244.46	245.14	245.19	245.22	245.32	245.58
	25	239.95	240.61	240.70	240.75	240.87	241.03
	30	233.95	234.44	234.45	234.49	234.50	234.51
	35	232.82	233.59	233.62	233.63	233.64	233.72
	40	235.35	236.57	236.98	237.36	237.95	239.07
	45	225.22	230.13	231.69	232.63	234.10	236.12

b) Result of IRS

i. Water-cement ratio: 0.50, binder:sand proportion: 1:3

%RHA	Test Time (s)	√Time ($s^{1/2}$)	Mass (g)	Δ Mass (g)	Δ Mass/area/density of water = I (mm)
0	0	0	258.33	0.00	0
	60	8	259.07	0.74	0.2971
	120	11	259.12	0.79	0.3172
	300	17	259.33	1.00	0.4016
	600	24	259.46	1.13	0.4538
	1200	35	259.76	1.43	0.5742
5	0	0	245.02	0.00	0
	60	8	245.63	0.61	0.2449
	120	11	245.54	0.52	0.2088
	300	17	245.64	0.62	0.2490
	600	24	245.69	0.67	0.2690
	1200	35	245.95	0.93	0.3734
10	0	0	232.96	0.00	0
	60	8	234.51	1.55	0.6224
	120	11	234.78	1.82	0.7308
	300	17	235.29	2.33	0.9356
	600	24	235.68	2.72	1.0922
	1200	35	236.68	3.72	1.4938
15	0	0	248.31	0.00	0
	60	8	249.08	0.77	0.3092
	120	11	249.18	0.87	0.3493
	300	17	249.20	0.89	0.3574
	600	24	249.34	1.03	0.4136
	1200	35	249.63	1.32	0.5300
20	0	0	217.80	0.00	0
	60	8	231.07	13.27	5.3286
	120	11	234.48	16.68	6.6979
	300	17	237.83	20.03	8.0431
	600	24	241.61	23.81	9.5609
	1200	35	246.08	28.28	11.3559
25	0	0	229.99	0.00	0
	60	8	233.80	3.81	1.5299
	120	11	234.55	4.56	1.8311

	300	17	235.09	5.10	2.0479
	600	24	235.81	5.82	2.3370
	1200	35	237.24	7.25	2.9112
30	0	0	224.04	0.00	0
	60	8	225.70	1.66	0.6666
	120	11	225.86	1.82	0.7308
	300	17	225.92	1.88	0.7549
	600	24	226.21	2.17	0.8714
	1200	35	227.05	3.01	1.2087
35	0	0	205.42	0.00	0
	60	8	209.77	4.35	1.7467
	120	11	211.93	6.51	2.6141
	300	17	213.16	7.74	3.1080
	600	24	214.63	9.21	3.6983
	1200	35	217.30	11.88	4.7704
40	0	0	211.76	0.00	0
	60	8	224.07	12.31	4.9431
	120	11	226.63	14.87	5.9711
	300	17	228.08	16.32	6.5533
	600	24	230.01	18.25	7.3283
	1200	35	233.48	21.72	8.7217
45	0	0	205.49	0.00	0
	60	8	211.07	5.58	2.2407
	120	11	214.46	8.97	3.6019
	300	17	215.13	9.64	3.8710
	600	24	217.22	11.73	4.7102
	1200	35	219.85	14.36	5.7663

ii. Water-cement ratio: 0.50, binder:sand proportion: 1:4

%RHA	Test Time (s)	√Time ($s^{1/2}$)	Mass (g)	Δ Mass (g)	Δ Mass/area/density of water = I (mm)
0	0	0	247.13	0.00	0
	60	8	248.48	1.35	0.5421
	120	11	248.82	1.69	0.6786
	300	17	248.94	1.81	0.7268
	600	24	249.33	2.20	0.8834
	1200	35	249.91	2.78	1.1163
5	0	0	239.63	0.00	0
	60	8	240.11	0.48	0.1927
	120	11	240.19	0.56	0.2249
	300	17	240.40	0.77	0.3092
	600	24	240.65	1.02	0.4096
	1200	35	240.96	1.33	0.5341
10	0	0	232.67	0.00	0
	60	8	236.02	3.35	1.3452
	120	11	237.00	4.33	1.7387
	300	17	237.30	4.63	1.8592
	600	24	238.15	5.48	2.2005
	1200	35	239.71	7.04	2.8269
15	0	0	197.50	0.00	0
	60	8	208.77	11.27	4.5255
	120	11	210.61	13.11	5.2643
	300	17	211.15	13.65	5.4812
	600	24	212.81	15.31	6.1477
	1200	35	216.67	19.17	7.6977
20	0	0	215.03	0.00	0
	60	8	231.63	16.60	6.6657
	120	11	234.31	19.28	7.7419
	300	17	235.11	20.08	8.0631
	600	24	237.19	22.16	8.8984
	1200	35	239.19	24.16	9.7015
25	0	0	186.87	0.00	0
	60	8	196.14	9.27	3.7224
	120	11	198.28	11.41	4.5817
	300	17	200.30	13.43	5.3928

	600	24	203.35	16.48	6.6176
	1200	35	205.83	18.96	7.6134
30	0	0	170.29	0.00	0
	60	8	193.58	23.29	9.3521
	120	11	195.60	25.31	10.1633
	300	17	199.26	28.97	11.6329
	600	24	206.39	36.10	14.4960
	1200	35	209.85	39.56	15.8854
35	0	0	203.50	0.00	0
	60	8	213.09	9.59	3.8509
	120	11	217.15	13.65	5.4812
	300	17	220.51	17.01	6.8304
	600	24	223.65	20.15	8.0913
	1200	35	225.43	21.93	8.8060
40	0	0	188.83	0.00	0
	60	8	198.25	9.42	3.7826
	120	11	201.62	12.79	5.1358
	300	17	203.47	14.64	5.8787
	600	24	204.81	15.98	6.4168
	1200	35	206.84	18.01	7.2319
45	0	0	176.20	0.00	0
	60	8	203.61	27.41	11.0065
	120	11	207.71	31.51	12.6529
	300	17	207.94	31.74	12.7452
	600	24	207.99	31.79	12.7653
	1200	35	208.12	31.92	12.8175

iii. Water-cement ratio: 0.55, binder:sand proportion: 1:3

%RHA	Test Time (s)	√Time ($s^{1/2}$)	Mass (g)	Δ Mass (g)	Δ Mass/area/density of water = I (mm)
0	0	0	257.84	0.00	0
	60	8	258.40	0.56	0.2249
	120	11	258.49	0.65	0.2610
	300	17	258.56	0.72	0.2891
	600	24	258.57	0.73	0.2931
	1200	35	259.82	1.98	0.7951
5	0	0	253.47	0.00	0
	60	8	253.80	0.33	0.1325
	120	11	253.85	0.38	0.1526
	300	17	253.94	0.47	0.1887
	600	24	253.97	0.50	0.2008
	1200	35	254.12	0.65	0.2610
10	0	0	255.81	0.00	0
	60	8	256.17	0.36	0.1446
	120	11	256.20	0.39	0.1566
	300	17	256.24	0.43	0.1727
	600	24	256.37	0.56	0.2249
	1200	35	256.41	0.60	0.2409
15	0	0	247.68	0.00	0
	60	8	248.02	0.34	0.1365
	120	11	248.12	0.44	0.1767
	300	17	248.22	0.54	0.2168
	600	24	248.41	0.73	0.2931
	1200	35	248.51	0.83	0.3333
20	0	0	252.65	0.00	0
	60	8	253.12	0.47	0.1887
	120	11	253.13	0.48	0.1927
	300	17	253.19	0.54	0.2168
	600	24	253.24	0.59	0.2369
	1200	35	253.37	0.72	0.2891
25	0	0	247.36	0.00	0
	60	8	247.82	0.46	0.1847
	120	11	247.88	0.52	0.2088
	300	17	247.90	0.54	0.2168

	600	24	247.98	0.62	0.2490
	1200	35	248.05	0.69	0.2771
30	0	0	238.58	0.00	0
	60	8	239.01	0.43	0.1727
	120	11	239.05	0.47	0.1887
	300	17	239.09	0.51	0.2048
	600	24	239.10	0.52	0.2088
	1200	35	239.18	0.60	0.2409
35	0	0	238.94	0.00	0
	60	8	239.33	0.39	0.1566
	120	11	239.41	0.47	0.1887
	300	17	239.43	0.49	0.1968
	600	24	239.55	0.61	0.2449
	1200	35	239.82	0.88	0.3534
40	0	0	237.20	0.00	0
	60	8	237.75	0.55	0.2209
	120	11	237.98	0.78	0.3132
	300	17	238.01	0.81	0.3253
	600	24	238.25	1.05	0.4216
	1200	35	238.42	1.22	0.4899
45	0	0	235.13	0.00	0
	60	8	235.72	0.59	0.2369
	120	11	235.77	0.64	0.2570
	300	17	235.81	0.68	0.2731
	600	24	235.92	0.79	0.3172
	1200	35	236.25	1.12	0.4497

iv. Water-cement ratio: 0.55, binder:sand proportion: 1:4

%RHA	Test Time (s)	√Time ($s^{1/2}$)	Mass (g)	Δ Mass (g)	Δ Mass/area/density of water = I (mm)
0	0	0	256.62	0.00	0
	60	8	264.15	7.53	3.0237
	120	11	264.22	7.60	3.0518
	300	17	264.24	7.62	3.0598
	600	24	264.25	7.63	3.0638
	1200	35	264.25	7.63	3.0638
5	0	0	255.56	0.00	0
	60	8	256.12	0.56	0.2249
	120	11	256.23	0.67	0.2690
	300	17	256.28	0.72	0.2891
	600	24	256.32	0.76	0.3052
	1200	35	256.48	0.92	0.3694
10	0	0	252.58	0.00	0
	60	8	253.17	0.59	0.2369
	120	11	253.25	0.67	0.2690
	300	17	253.27	0.69	0.2771
	600	24	253.39	0.81	0.3253
	1200	35	253.45	0.87	0.3493
15	0	0	253.32	0.00	0
	60	8	254.04	0.72	0.2891
	120	11	254.19	0.87	0.3493
	300	17	254.29	0.97	0.3895
	600	24	254.30	0.98	0.3935
	1200	35	254.51	1.19	0.4778
20	0	0	244.46	0.00	0
	60	8	245.14	0.68	0.2731
	120	11	245.19	0.73	0.2931
	300	17	245.22	0.76	0.3052
	600	24	245.32	0.86	0.3453
	1200	35	245.58	1.12	0.4497
25	0	0	239.95	0.00	0
	60	8	240.61	0.66	0.2650
	120	11	240.70	0.75	0.3012
	300	17	240.75	0.80	0.3212

	600	24	240.87	0.92	0.3694
	1200	35	241.03	1.08	0.4337
30	0	0	233.95	0.00	0
	60	8	234.44	0.49	0.1968
	120	11	234.45	0.50	0.2008
	300	17	234.49	0.54	0.2168
	600	24	234.50	0.55	0.2209
	1200	35	234.51	0.56	0.2249
35	0	0	232.82	0.00	0
	60	8	233.59	0.77	0.3092
	120	11	233.62	0.80	0.3212
	300	17	233.63	0.81	0.3253
	600	24	233.64	0.82	0.3293
	1200	35	233.72	0.90	0.3614
40	0	0	235.35	0.00	0
	60	8	236.57	1.22	0.4899
	120	11	236.98	1.63	0.6545
	300	17	237.36	2.01	0.8071
	600	24	237.95	2.60	1.0440
	1200	35	239.07	3.72	1.4938
45	0	0	225.22	0.00	0
	60	8	230.13	4.91	1.9716
	120	11	231.69	6.47	2.5980
	300	17	232.63	7.41	2.9755
	600	24	234.10	8.88	3.5658
	1200	35	236.12	10.90	4.3769

APPENDIX V: WATER ABSORPTION DATA OF MORTAR SAMPLES

a) Water-cement ratio: 0.50, Binder:sand proportion: 1:3

%RHA	Sample ID	Initial Dry Weight (g)	Final Immersed Weight (g)	Water Absorption (%)	Avg. % Absorption
0	1	258.33	282.40	9.3	9.1
	2	260.03	282.82	8.8	
	3	260.96	284.82	9.1	
5	1	245.02	269.29	9.9	9.2
	2	248.20	272.73	9.9	
	3	244.04	263.31	7.9	
10	1	232.96	260.61	11.9	11.9
	2	239.12	265.46	11.0	
	3	238.00	268.28	12.7	
15	1	248.31	275.88	11.1	11.1
	2	248.17	274.85	10.8	
	3	239.51	266.61	11.3	
20	1	217.80	249.84	14.7	13.6
	2	226.31	256.45	13.3	
	3	232.20	261.88	12.8	
25	1	229.99	261.50	13.7	14.1
	2	226.92	261.34	15.2	
	3	226.30	256.83	13.5	
30	1	224.04	256.40	14.4	14.4
	2	228.83	260.32	13.8	
	3	213.59	245.88	15.1	
35	1	205.42	242.50	18.1	16.4
	2	214.11	247.96	15.8	
	3	208.40	240.31	15.3	
40	1	211.76	248.88	17.5	17.5
	2	207.26	242.94	17.2	
	3	190.55	224.28	17.7	
45	1	205.49	245.83	19.6	18.8
	2	205.79	244.29	18.7	
	3	186.56	220.38	18.1	

b) Water-cement ratio: 0.50, Binder:sand proportion: 1:4

%RHA	Sample ID	Initial Dry Weight (g)	Final Immersed Weight (g)	Water Absorption (%)	Avg. % Absorption
0	1	247.13	271.54	9.9	10.4
	2	236.69	261.99	10.7	
	3	239.64	265.01	10.6	
5	1	239.63	263.53	10.0	9.9
	2	239.34	263.30	10.0	
	3	241.51	264.93	9.7	
10	1	232.67	259.62	11.6	12.5
	2	226.40	256.98	13.5	
	3	232.61	261.25	12.3	
15	1	197.50	224.83	13.8	14.0
	2	215.30	245.26	13.9	
	3	201.11	229.87	14.3	
20	1	215.03	245.92	14.4	14.7
	2	191.76	218.84	14.1	
	3	213.97	247.13	15.5	
25	1	185.37	213.14	15.0	14.9
	2	186.87	211.17	13.0	
	3	184.56	215.23	16.6	
30	1	170.29	212.31	24.7	19.0
	2	185.88	211.25	13.6	
	3	195.24	231.50	18.6	
35	1	182.76	197.68	8.2	12.8
	2	203.50	235.19	15.6	
	3	202.03	231.66	14.7	
40	1	188.83	223.93	18.6	19.4
	2	187.83	222.14	18.3	
	3	185.75	225.35	21.3	
45	1	176.60	212.63	20.4	21.6
	2	175.36	205.38	17.1	
	3	174.92	222.85	27.4	

c) Water-cement ratio: 0.55, Binder:sand proportion: 1:3

%RHA	Sample ID	Initial Dry Weight (g)	Final Immersed Weight (g)	Water Absorption (%)	Avg. % Absorption
0	1	257.84	282.49	9.6	9.3
	2	256.75	283.35	10.4	
	3	258.31	278.94	8.0	
5	1	253.47	277.20	9.4	9.2
	2	252.16	275.35	9.2	
	3	255.27	278.30	9.0	
10	1	255.81	277.06	8.3	8.9
	2	256.44	279.35	8.9	
	3	251.78	275.27	9.3	
15	1	247.68	272.38	10.0	10.7
	2	246.89	275.67	11.7	
	3	244.35	269.57	10.3	
20	1	252.65	277.60	9.9	10.5
	2	251.97	283.20	12.4	
	3	253.13	276.67	9.3	
25	1	247.36	273.01	10.4	11.0
	2	244.76	275.12	12.4	
	3	231.51	255.45	10.3	
30	1	238.58	266.25	11.6	11.3
	2	240.76	266.13	10.5	
	3	230.05	256.87	11.7	
35	1	238.94	267.50	12.0	12.1
	2	237.67	265.35	11.6	
	3	235.55	265.31	12.6	
40	1	237.20	266.10	12.2	12.5
	2	235.76	265.97	12.8	
	3	239.11	268.65	12.4	
45	1	253.13	264.40	4.5	7.1
	2	255.25	269.33	5.5	
	3	245.67	273.31	11.3	

d) Water-cement ratio: 0.55, Binder:sand proportion: 1:4

%RHA	Sample ID	Initial Dry Weight (g)	Final Immersed Weight (g)	Water Absorption (%)	Avg. % Absorption
0	1	256.62	283.73	10.6	10.5
	2	253.49	280.55	10.7	
	3	249.37	275.18	10.4	
5	1	255.56	277.26	8.5	8.6
	2	257.76	280.45	8.8	
	3	239.54	260.04	8.6	
10	1	252.58	274.74	8.8	8.8
	2	255.45	277.31	8.6	
	3	249.89	272.49	9.0	
15	1	253.52	274.85	8.4	8.2
	2	255.19	276.29	8.3	
	3	261.62	282.55	8.0	
20	1	244.46	268.58	9.9	10.2
	2	245.78	271.16	10.3	
	3	239.59	264.75	10.5	
25	1	239.95	264.18	10.1	10.3
	2	242.62	266.45	9.8	
	3	241.44	268.22	11.1	
30	1	233.95	261.37	11.7	11.8
	2	229.51	257.72	12.3	
	3	225.17	250.62	11.3	
35	1	232.82	260.2	11.8	12.2
	2	230.15	255.47	11.0	
	3	225.38	256.71	13.9	
40	1	235.35	264.39	12.3	13.0
	2	238.51	270.05	13.2	
	3	231.26	262.36	13.4	
45	1	225.22	255.2	13.3	13.3
	2	219.86	250.16	13.8	
	3	230.16	259.45	12.7	

APPENDIX VI: WATER CONTENT OF SAND SAMPLES

Sample 1: w/c = 0.50, b:s = 1:3

Sample 2: w/c = 0.55, b:s = 1:4

No.	Description	Sample No.	
		1	2
1	Weight of Empty Container, W_1 (g)	20.68	20.68
2	Weight of Container + Wet Soil, W_2 (g)	48.68	59.80
3	Weight of Container + Dry Soil, W_3 (g)	48.50	59.60
CALCULATION			
1	Weight of Water (g) = W_2 - W_3	0.18	0.20
2	Weight of Dry Soil (g) = W_3 - W_1	27.82	38.92
3	Water content, w = (W2 - W3)/(W3 - W1) * 100%	0.65	0.51

APPENDIX VII: PROPOSED GANTT CHART

No	Activities	Week																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Project Topic Selection																				
2	Preliminary Research Work																				
3	Progress Report																				
4	Material Preparation																				
5	Water Content & Absorption																				
6	Control Brick Mixing & Casting																				
7	7-days Compressive Strength																				
8	Data Record & Analysis																				
9	Interim Report																				
10	Oral Presentation																				
11	Remaining Samples Casting																				

a) Gantt Chart of the Project in Final Year Project 1

No	Activities	Week														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	7-days Compressive Strength															
2	28-days Compressive Strength															
3	Progress Report 1															
4	60-days Compressive Strength & Water Absorption & Initial Rate of Suction Tests															
5	Progress Report 2															
6	Data Record & Analysis															
7	Poster Presentation															
8	Dissertation (Soft Bound)															
9	Oral Presentation															
10	Final Report and Dissertation (Hard Bound)															

b) Gantt Chart of the Project in Final Year Project 2