CHARACTERIZATION OF PROPERTIES OF MORTARS CONTAINING CLAY BRICK AGGREGATE

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Jerry Gao, Ph.D.
Chair

Eric Asa, Ph.D.

Mijia Yang, Ph.D.

Zhi Ge, Ph.D.

Approved:

04/12/2017
Date

Jerry Gao Ph.D.
Department Chair

ABSTRACT

Recycling clay brick becomes extremely urgent with the demolishment of residential buildings, and the most common processing option of clay brick waste is buried in landfills which lead to serious environmental pollution. Meanwhile, the process of recycling clay brick is immature and there is limited knowledge and standards of recycling clay brick waste.

This thesis reports an experiment to test physical and mechanical prosperities of clay brick aggregate (CBA). Mortar specimens were conducted by using different prewetting times, replacement rates and water/cement ratios. Absorption and water-releasing abilities were discussed; compressive strength and flexural strength were conducted for strength test. Flowability and internal humidity tests were also presented.

The results demonstrated that mortar specimens with 30% of replacement rate of CBA, and 0.28 of water/cement ratio of mixes present the optimal workability. By comparing with recycled concrete aggregate (RCA), CBA also showed satisfactory performance in the mortar specimens.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER ONE: INTRODUCTION

1.1. Background

Clay brick was a common construction material in the last century, especially in China, which has more than 2000 years' history of application (Li, 1995). Before concrete being widely used as construction material all over the world, during the last century, clay brick was used as the most common construction material in residential buildings. In the early twentieth century, 520 billion clay bricks were produced in China, and 80 billion clay bricks were manufactured in the USA (Li, 1995). The concept of recycling clay brick was created with the accelerated development of the economy and the growth of the population in the past decades, numerous old residential buildings, especially because many one to two story houses were demolished to build new high-rise residential buildings in order to reduce land use.

Reusing clay brick aggregate (CBA) in concrete to eliminate the disposal of demolition waste from extensive housing demolition has been receiving researchers' attention since concrete became the most common construction material in most countries because of its economic and practical characteristics (Bektas, Wang & Ceylan, 2009). On the other hand, the increasing demand of aggregate in concrete, with the enormous tension in energy resources and economic growth, also caught the attention of builders all over the world. Meanwhile, communities pay more attention to environmental protection than ever before (Khalaf, 2006).

Some experimental investigations were conducted to observe the physical and mechanical properties of CBA by reusing the dumped clay brick waste in concrete as fine or coarse aggregate to replace natural aggregate (sand was used in this thesis). Recycled CBA applications in concrete may not only reduce the environmental pollution, but also decrease wasted energy in concrete production: raw materials, electrical power, and fuel energy (Ge, Gao, Sun, & Zheng, 2012).

Advantages with the application of clay brick are also addressed in the existing articles. One advantage that helped clay brick achieved a large production is excellent temperature resistance. According to the traditional manufacturing process, clay bricks are fired at high temperatures. They are built into the main walls body of residential buildings because of clay brick fireproofing property. As a result of high temperature resistance (approx. 1700 ℃), the physical performance of clay brick is more stable than other materials (Li, 1995). Another economical advantage of clay brick is it can be obtained locally. Meanwhile, the weight of clay brick is lighter than concrete. Moreover, clay brick has a high porosity, which leads to a high water absorbing ability and high permeability (Bazaz & Khayati, 2012).

1.2. Problem Statement and Purpose of Study

However, the recycling of clay brick still remains in experimental stages because of limited correlative knowledge of the physical and mechanical properties of CBA and the lack of standards for the application of CBA (Fouad, 2006). High porosity of CBA may lead to low strength and durability of the concrete, thus, less than 5% of clay bricks from demolition sites was separated from other construction and demolition wastes and reused as a recycled building material (Bazaz, & Khayati, 2012). Furthermore, high clay brick replacement level may result in the failure of compressive and flexural strength in new concrete and may also affect the stability of concrete structures (Poon & Chan, 2005). On the other hand, the process to separate clay brick waste from other construction rubbishes is not only costly but also involves technical difficulties (Yang, Du,

& Bao, 2011). Moreover, since clay brick may be recycled from many different demolition wastes, the chemical components and properties will be different from each other, which may lead to negative effects on the workability of the concrete containing CBA. Meanwhile, relevant research on chemical properties of CBA is limited (Cheng, 2016).

The purpose of study in this thesis is focused on the physical and mechanical properties of the mortars containing CBA. An experiment was designed to observe the characteristics, strength properties and internal curing of the mortars. Three prewetting times were involved to test whether or not prewetting of CBA affects the mortar specimens' workability. Three replacement levels of the weight of sand by using CBA were demonstrated to address the optimal replacement proportion. Three water/cement ratios were also tested to address the best w/c ratio, which could help the mortar specimens to achieve highest strength.

1.3. Research Methodology

As mentioned above, this research was developed to collect more information about reusing clay brick aggregate as fine aggregate in mortar specimens. The detailed methodology of this research is showed below:

1. A literature review was conducted first, the statement of problem was summarized and then the scope of this study was narrowed.

2. Experiments were designed based on three factors: prewetting time, replacement rate, and w/c ratio.

3. Performed the experiments, which involved six tests in this research and then analyzed the results for tests (based on ASTM Standards). Twelve mixes were carried out in order to observe

the absorbing ability, water-releasing characteristics in four humidity environments, strength tests, fluidity loss, and internal humidity.

4. A comparison of the properties of recycled concrete aggregate (RCA) and CBA in the mortar specimens were discussed.

5. Summarized results in the conclusion and suggested some recommendations for future research according to the limitations of this research and literature review. Figure 1.1 shows the methodology in this thesis.

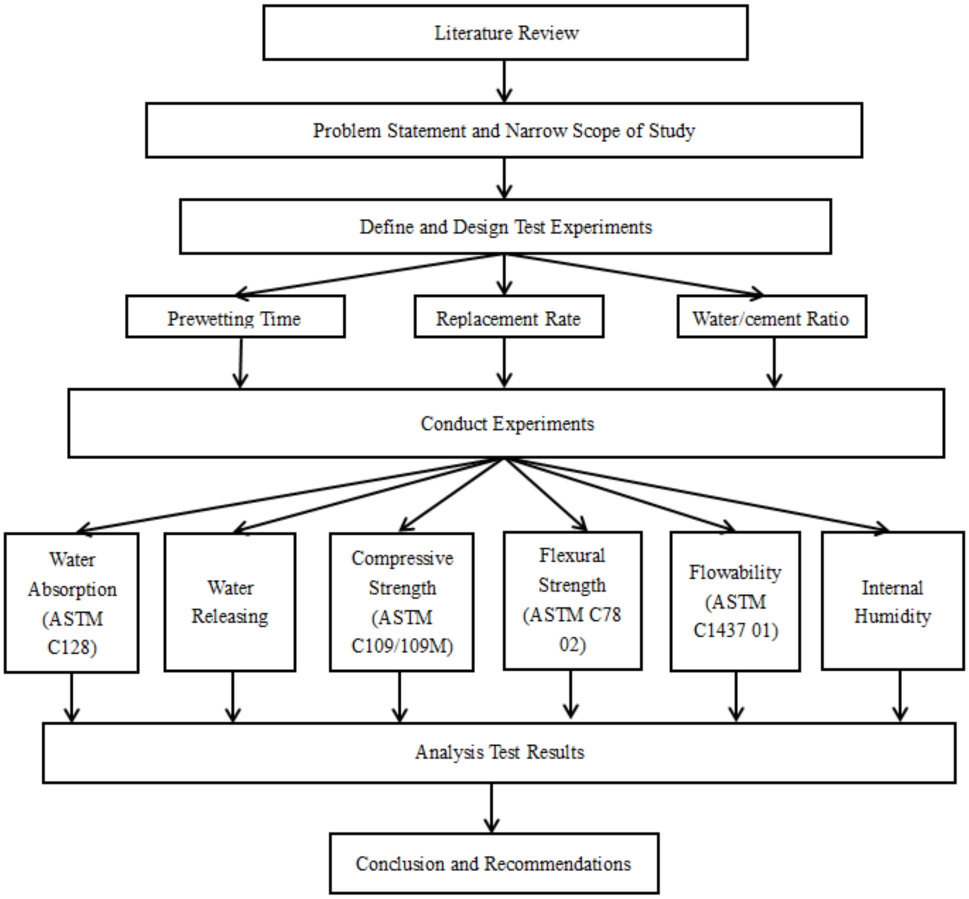

Figure 1.1. Methodology of research

1.4. Contents Organization

This research is reported in five chapters. Chapter One indicates an introduction, background, and purpose of the thesis. Chapter Two presents the review of the existing literature review of the research and experimental works of clay brick. Chapter Three covers the elements of the experimental work related to the research. Chapter Four presents the results and discussion of the experimental tests. Chapter Five states a comparison between RCA and CBA according to the water absorption, water-releasing ability, flowability, and internal humidity. Chapter Six summarizes conclusions and future recommendations.

CHAPTER TWO: LITERATURE REVIEW

2.1. General

Clay brick was the traditional material used to construct residential buildings globally. However, due to increased demolition of old residential buildings to construct new buildings using concrete, waste clay brick has increased and is currently a major environmental hazard (Ge et. al., 2012). Researchers are presently exploring new methods to use waste clay brick aggregate to reduce pollution and consequently protect the health of the population (Ge et al., 2012). This section of the thesis summarizes the literature review on CBA as fine aggregate and coarse aggregate in concrete or mortar and it outlines some of the physical and mechanical properties of CBA.

2.2. Physical and Mechanical Properties of CBA

Numerous experimental studies were conducted to test the performance of concrete and mortar made of clay brick (Khalaf and DeVenny, 2002; Bektas et al., 2009; Zong et al., 2014). The physical and mechanical properties were the primary test goals in many of these studies.

Yang, Du, and Bao (2011) developed concrete by using RCA and crushed clay bricks (CCB) in high replacement levels to observe the physical and mechanical properties. The results showed CCB has a strong water absorbing ability when compared to RCA, and the specimen presented a high permeability up to 20% of replacement of CCB.

Khalaf and DeVenny (2002) reported their new tests to calculate the porosity and water absorption values by involving clay bricks in brick lumps. A positive linear relationship was observed based on a test with 24 hr submersion in cold water and another 5 hr in boiling water of CBA indicating clay brick had good porosity and water absorbing capacity.

Ge, Wang, Sun, Wu, and Guan (2015) showed the water absorption of fresh concrete is improved with increasing replacement rates of CBA, meanwhile, the autogenous shrinkage can be significantly reduced with around 10% of cement replace by clay brick powder. These lead authors to conclude that partial replacement of cement with CBA would not reduce the physical properties of concrete.

Zong, Fei, and Zhang (2014) presented the discussion of permeability of new recycled concrete combined with clay brick waste at various replacement levels of natural coarse aggregates. The outcome showed new recycled concrete was more permeable because CBA has high porosity.

2.3. Research of CBA as Coarse Aggregate

Clay brick can be crushed into coarse or fine aggregates to produce concrete or mortar mixes. Mansur, Wee, and Lee (1999) conducted an experiment using crushed brick as coarse aggregate in concrete and the results showed that high tensile strength and decreasing drying shrinkage were achieved with appropriate replacement rate of aggregate composition using crushed coarse clay brick aggregate.

Furthermore, Akhtaruzzaman and Hasnat (1983) performed an experiment using clay brick as up to 100% replacement of coarse aggregate in concrete based on four hardness tests: compressive strength, flexural strength, splitting tensile strength, and regular tensile strength. The new concrete achieved a high compressive strength (up to 5000 psi) with coarse CBA aggregate.

Khalaf (2006) used crushed clay brick as coarse aggregate in concrete, which showed a high strength. Meanwhile, prewetting crushed brick aggregate used in new concrete could achieve high workability.

Adamson, Razmjoo, and Poursaee (2015) found crushed bricks used as coarse aggregates in concrete do not reduce durability. The experimental test was designed for partial replacement of natural coarse aggregate with CBA, and the decline of resistance to chloride penetration was achieved by adding CBA in concrete.

2.4. Research of CBA as Fine Aggregate

As mentioned above, there are different course compositions of CBA used in concrete or mortar, sometimes, CBA may be reused as the finer composition to observe its performance in the concrete. Debieb and Kenai (2008) found concrete could be widely manufactured by using both coarse and fine CBA. The authors discussed several advantages of using CBA. For example, crushed bricks have greater water absorption than natural aggregate; slow shrinkage and increased water permeability. Moreover, the optimal replacement rate of CBA is between 25% to 50%.

2.5. Issues of Using CBA

CBA is not as widely used in concrete production due to the lack of knowledge of workability. The following articles indicate the shortages by using CBA and some recommendations for the future research. Yang et al. (2011) verified replacing over 50% weight of crushed clay brick aggregate would lead to a poor workability in the new concrete mixes. Meanwhile, the permeability was also decreased at 50% replacement rate.

Cheng (2016) presented a literature review of the existing articles and indicated recycling clay brick waste had significant meaning to environmental protection. However, the separation process of clay brick waste from other construction rubbish was not only costly but also involved technical difficulties (Yang et al. 2011).

Moreover, there were several types of research focus on the physical and mechanical properties of CBA, and the chemical properties of clay brick were expected to develop in the future (Cheng 2016).

CHAPTER THREE: EXPERIMENTAL STUDY

3.1. General

This experimental study was done in the Department of Construction Management at North Dakota State University in Fargo and the School of Civil Engineering in Shandong University, China.

This chapter presents experimental procedures to test the mechanical properties of twelve mixes of clay brick aggregate which was partially replaced as fine aggregate in different water/cement ratios, replacement rates, and prewetting time over three test age. Meanwhile, materials, experimental procedures, mechanical properties, and test methods are indicated in this chapter.

3.2. Materials

3.2.1. Cement

Ordinary Portland cement was used for this experimental work and it was stored in a fresh and dry container. Figure 3.1 shows the prepared clay brick aggregate, cement, and natural fine aggregate (sand).

Figure 3.1. Prepared clay brick aggregate, cement and natural fine aggregate (sand)

3.2.2. Clay Brick Aggregate (CBA)

In this research, clay brick aggregates were already crushed, sieved, and impurities were removed based on the requirements by standard sieves. Five standard particle sizes of CBA: 0.15, 0.3, 0.6, 1.18, and 2.36 were crushed and worked to test the physical and mechanical properties since CBA was used as the fine aggregate in this research. Figure 3.2 shows the crushed clay brick fine aggregate. The gradation of CBA is shown in Table 3.1, which followed ASTM C136 01. Meanwhile, the gradation of the natural fine aggregate (sand was used in this research) also followed the same standard as the gradation of CBA.

Table 3.1. The gradation of CBA

Sieve Size (mm)	Total Percentage of Material Passing (%)	Accumulated Percentage of Material Passing (%)	Water Absorption Rate (%)
2.36	10	10	17.96
1.18	26	36	17.72
0.6	32	68	17.57
0.3	18	86	15.03
0.15	14	100	7.56

Figure 3.2. Crushed clay brick aggregate

Before the mechanical tests began, all of the CBA were placed into an oven to dry for 24 hours. CBA was soaked in water to record the absorption rates of five particle sizes separately at 10 min., 20min., 30min., 1 hr, 2 hr, 12 hr, and 24 hr.

3.2.3. Natural Fine Aggregate

Another fine aggregate used in this research was natural sand from the local river in Jinan, China. Figure 3.3 shows the sieve shaker and sand; the particle size range of this sieve shaker was from 0.15 mm to 4.75 mm. The natural fine aggregate was sieved and graded in the same way as the CBA.

Figure 3.3. Sieve shaker and natural fine aggregate (sand)

3.2.4. Water-Reducing Admixture

The water-reducing admixture which was used in this research is called polycarboxylate superplasticizer. The percent of water-reducing admixture usage was only 0.6% since this polycarboxylate superplasticizer has a high water-reducing ratio at low dosage.

3.2.5. Water

The water used for this research was from local underground water, and it was not only used for mixing concrete cubes, but also used for curing in the moist room.

3.3. Experimental Design

3.3.1. Mix Proportions

Twelve groups of mixes were designed to observe the mechanical properties of CBA. There were three main factors: four different replacement rates, three prewetting times, and three water/cement ratios in the design. Meanwhile, a control group (water/cement ratio = 0.28, prewetting time = 0 min., 0% of replacement level) was designed to compare differences. The details are described below.

3.3.1.1. Replacement Rate

In this research, CBA was used as four different replacement rates in fine aggregate, 0%, 30%, 60%, and 100%, were designed. Meanwhile, the control group was designed with 0% of replacement (total of sand), 0 min., prewetting time and 0.28 of w/c ratio.

3.3.1.2. Prewetting Time

The design of prewetting time of CBA used in this investigation were 0 min., 10 min., and 24 hr to observe whether the prewetting of the aggregates affect the mechanical properties or not.

3.3.1.3. Water/cement Ratio (w/c)

There were three w/c ratios involved in the research, 0.28, 0.30, and 0.32. There was only one group mix for both w/c ratios of 0.30 and 0.32 with same replacement rate (30%) and with 24 hours prewetting.

3.3.2. Procedures

This study focused on six property tests of clay brick aggregate: (1). Absorption rate; (2). Water-releasing rate; (3). Compressive strength; (4). Flexural strength; (5). Fluidity loss; (6). Internal humidity. The procedures for these tests followed ASTM standards. Figure 3.4 shows the preparing materials and concrete mixer.

Figure 3.4. Preparing materials of the mixture

For absorption and water-releasing tests, all of the materials were oven-dried for 24 hr and prewetted over 24 hr before the test. For the compressive and flexural strength tests, to get more accurate data, each type of mixture had six samples, and the averages were calculated to indicate the final result. Each group also received two samples to be tested for flowability over four test periods. Internal humidity was tested continuously and consistently over ten days.

Before any tests were started, to prevent the impact of the external environment and to keep the integrity of specimens after different curing days, molds used for casting mortar specimens were cleaned by water and then oiled. Each mortar specimen was stored in the curing room at around 95% moisture and 68ºF (20℃) temperature, and these mortar specimens were only taken out every day to record data. Figure 3.5 shows the moist room used to for curing the specimens.

Figure 3.5. The curing room of concrete specimens

3.4. Physical and Mechanical Tests of CBA

3.4.1. Absorption Test

This test is designed to observe the water absorbing ability of CBA. Five fine sieve sizes of clay brick aggregates were tested separately in five volumetric flasks. All aggregates were washed by the water and dried in the oven for 24 hr to achieve a constant weight. Five fine particle sizes were weighed in 100g and placed into the volumetric flasks, then water was added rapidly until the water levels stabilized at one particular calibration line. Water was then refilled to the same calibration line at 10 min., 20 min., 30 min., 1 hr, 2 hr, 12 hr, and 24 hr. Meanwhile, the weights of the added water were recorded. After soaking for 24 hr, all of the aggregates were taken out and dried to achieve saturated surface-dry condition and weights were recorded. Figure 3.6 shows the test of absorption rate.

The absorption test in this research followed the standard of ASTM C128, ant the absorption rate for all clay brick fine aggregate and sand were indicated by the following equation:

$$\text{Absorption, \%} = 100\ [(S-A)/A] \tag{3.1}$$

Where:

A = mass of oven dry specimen, g

S = mass of saturated surface-dry specimen, g

Figure 3.6. The test of absorption rate

3.4.2. Water-releasing Test

The purpose of water-releasing test is focus on whether the water-releasing ability of CBA could help the mortar specimens to reduce the shrinkage or not. All particle sizes of CBA were soaked in the water over 24 hr first, then dried to achieve saturated surface-dry condition. 100g of each particle size was weighed and then placed into four different humidity environmental chambers. The humidity was controlled by four saturated saline solutions: K_2SO_4 (97.6%), KCl (85.1%), NaCl (75.5%), and NaBr (59.1%), and the temperature was controlled around 20℃(68ºF). Figure 3.7 shows four humidity environmental chambers below.

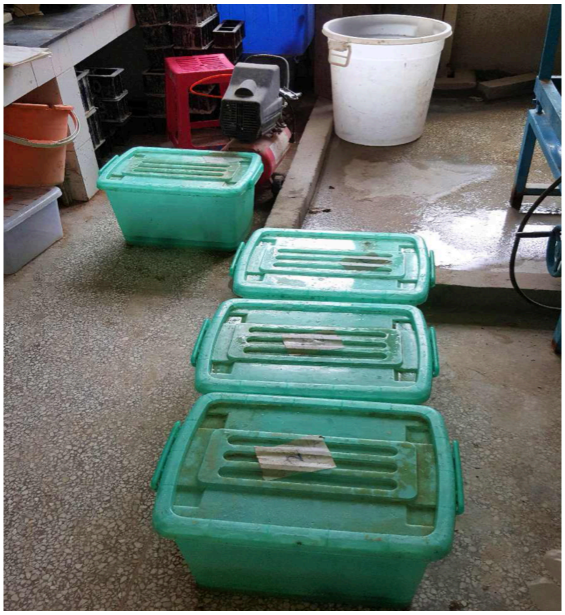

Figure 3.7. The humidity environmental chambers

Data was recorded at the same time over thirteen days, and the desorption rate was developed based on the data over ten days.

3.4.3. Compressive Strength Test

The compressive strength test was established on ASTM C109/C 109M and carried out in the lab of Transportation Engineering Department to make two-inch cube specimens. The primary purpose of this test was focus on the effects of different prewetting times, replacement rates and w/c ratios of the mortars contain CBA aggregate at the early age. Six specimens were involved in each test age and the average number was used for analysis of the compressive strength. The results of compressive strength and flexural strength were recorded at Day 3, Day 7, and Day 28. Figure 3.8 shows the testing machine, which was used to test the compressive and flexural strength at the same time.

Figure 3.8. The compression and flexing machine

3.4.4. Flexural Strength Test

As mentioned above, the flexural strength was tested by the same machine for compressive strength and the testing procedures were followed ASTM C 78 02. The mortar specimens were conducted in the prism models of 40 x 40 x 160 mm. Three specimens were made for each test age and the average number was used to do the analysis. Flexural strength was also recorded at three test ages: Day 3, Day 7, and Day 28. Figure 3.9 shows the test of flexural strength of the specimens with CBA.

Figure 3.9. The test of flexural strength

3.4.5. Flowability Test

Here were three dependent variables observed with the changes over time, they were prewetting times, replacement rates and w/c ratios. The flowability and fluidity loss of the mortar were recorded at 5 min., 15 min., 25 min., and 35 min., and all of the tests were presented under ASTM C 1437-01. Figure 3.9 shows the flow table used to verify the flowability of hydraulic cement mortar.

Figure 3.10. The flow table

3.4.6. Internal Humidity

The test of internal humidity had twelve specimens were prepared in 10 x 10 x 10 cm. This test was based on different prewetting time of the aggregates, various replacement percentages of clay brick aggregate, and three w/c ratios. At the beginning of this internal humidity test, all specimens were coated by paraffin to cut off from the air. The purpose was set to find the influence of internal curing of the concrete made with clay brick aggregate. Meanwhile, the data of over ten consecutive days was tested by the temperature and humidity sensor. Figure 3.10 shows the test of internal humidity by using the temperature and humidity sensor.

Figure 3.11. The temperature and humidity sensor

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. General

This section states the experimental result of the experiment. Meanwhile, the physical and mechanical properties of CBA are discussed based on the tests of water absorption, water-releasing test, compressive strength, flexural strength, flowability and internal humidity. Water absorption results were recorded at 10 min., 20 min., 30 min., 1 hr, 2 hr, 12 hr, and 24 hr. Water-releasing test was observed over ten days. The strength tests, flowability, and internal humidity were designed to test the effect of three factors: prewetting times (0 min., 10 min., 24 hr), replacement rates (30%, 60% and 100%), and water/cement ratios (0.28, 0.30, and 0.32) of the mortar specimens.

4.2. Mechanical Properties of Concrete Made with CBA

4.2.1. Water Absorption Test

Figure 4.1 presents the increasing water absorption rate with the increasing of particle sizes. 0.15 mm of CBA showed the poorest water absorbing ability, oppositely, 2.36 mm of CBA presented the biggest water absorption rate, which around 22% at 24 hr. Overall, the bigger particle size of CBA achieved the higher absorption rate. This result may cause by the bigger aggregate has more voids than smaller aggregate and these voids may could help the bigger particle size of CBA to absorb more water than the smaller size.

Furthermore, the overall result of this experimental test indicates using CBA in the mortar may lead to the high absorption of water at the early age. Since clay brick is one type of construction material with high porosity, which may reduce the strength and durability of concrete (Bazaz, & Khayati, 2012). But on the other hand, high porosity could help the new concrete to achieve high permeability and high internal humidity, which may also lead to the reduction of autogenous shrinkage inside the concrete (Zong, Fei. &Zhang, 2014). Table 4.1 displays the absorption rates of CBA and Figure 4.1 shows the curves of absorption rate for all particle sizes.

Table 4.1. Absorption rates of CBA at different times

Particle Size (mm)	Prewetting Time (hr)						
	0.17 (10min.)	0.33 (20min.)	0.5 (30min.)	1	2	12	24
2.36	2.57%	4.20%	5.48%	6.30%	9.22%	19.49%	21.35%
1.18	4.26%	5.32%	6.26%	7.33%	11.23%	19.62%	20.69%
0.6	4.30%	5.62%	6.81%	8.00%	12.66%	18.64%	19.12%
0.3	6.28%	9.66%	11.35%	12.32%	13.41%	15.22%	15.46%
0.15	5.87%	8.17%	9.07%	9.71%	10.34%	10.98%	11.11%

4.2.2. Water-releasing Test

The data of the water-releasing test of CBA over thirteen days are summarized in Table 4.1. The trends of the water-releasing rate in four humidity environments are also presented in Figure 4.2, 4.3, 4.4, and 4.5.

The observations of the figures are summarized below:

1. All these four figures present the increasing water-releasing rate with decreasing of the environmental humidity. Figure 4.5 shows the highest water-releasing rate for all particle sizes of CBA, which around 16% of the water-releasing rate by comparing with other three humid environments.

2. As shown in Figure 4.2, five particle sizes demonstrate a growing trend in thirteen days. 0.15 of particle size of CBA, which is the smallest particle size in this test was continually

increased over thirteen days and showed the highest water-releasing rate. But overall, the highest water-releasing rate in 97.6% of humidity is only achieved 3% of water-releasing rate, which shows the lowest water-releasing ability in four humidity environments. On the other hand, 59.1% of humidity achieved the highest water-releasing rate.

3. As Figure 4.5 shown, the water-releasing rate consistently climbed during the half of test. The growth became slow and approximately trends to be stable after day six between 11% to 15% of water-releasing rate.

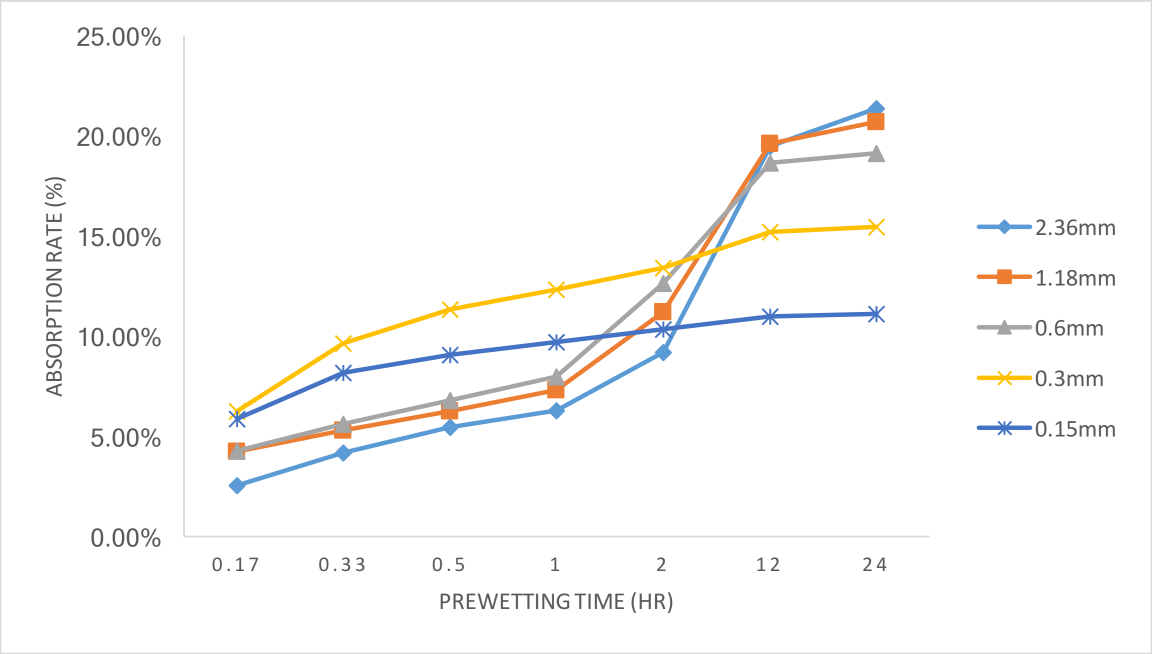

Figure 4.1. Absorption rate for all particle sizes

4. Overall, the four figures show different increasing trends of water-releasing rates, which caused by different internal humidity of the mortar specimens. High humidity environment led to the high internal humidity since the water is retained in the mortar, thus, more water will be released when the humidity environment is decreased.

Table 4.2. Results of water-releasing tests for five particle sizes

Water-releasing Rate (%)													
CBA Particle Size (mm)	Time (day)												
Humidity 97.6%	1	2	3	4	5	6	7	8	9	10	11	12	13
2.36	0.30	0.30	0.30	0.50	0.60	0.80	1.00	1.00	1.10	1.20	1.40	1.50	1.70
1.18	0.20	0.30	0.30	0.50	0.70	0.90	1.00	1.10	1.30	1.60	1.70	1.80	2.00
0.6	0.20	0.20	0.40	0.50	0.60	0.70	0.90	1.10	1.20	1.40	1.70	1.90	2.00
0.3	0.20	0.30	0.30	0.50	0.60	0.90	1.00	1.20	1.50	1.70	2.10	2.40	2.60
0.15	0.30	0.30	0.50	0.60	0.80	1.00	1.20	1.40	1.50	1.80	2.10	2.50	2.80
Humidity 85.1%	1	2	3	4	5	6	7	8	9	10	11	12	13
2.36	0.60	1.50	2.10	2.80	3.40	4.10	4.90	5.30	5.60	6.10	6.80	7.10	7.70
1.18	0.80	1.40	2.10	2.80	3.40	4.10	5.10	5.60	6.10	6.50	7.00	7.40	7.90
0.6	0.80	1.50	2.20	2.80	3.60	4.30	5.20	5.70	6.00	6.60	7.10	7.70	8.10
0.3	0.90	1.60	2.20	3.00	3.70	4.30	5.10	5.70	6.10	6.60	7.10	7.60	7.90
0.15	0.70	1.40	2.10	2.90	3.60	4.20	5.00	5.50	5.70	6.30	6.70	7.20	7.70

Table 4.2. Results of water-releasing tests for five particle sizes (continued)

Water-releasing Rate (%)													
CBA Particle Size(mm)	Time (day)												
Humidity 75.5%	1	2	3	4	5	6	7	8	9	10	11	12	13
2.36	1.30	2.60	4.70	6.00	6.50	6.70	7.00	7.40	7.90	8.40	8.80	10.00	9.50
1.18	1.40	2.50	4.10	5.10	5.50	5.90	6.30	6.60	7.10	7.60	8.00	8.30	8.60
0.6	1.40	2.50	3.60	4.70	5.00	5.50	5.90	6.20	6.60	7.10	7.50	7.90	8.20
0.3	0.50	1.00	1.30	1.90	2.50	3.00	3.60	4.70	5.30	5.70	7.00	6.80	7.70
0.15	1.30	2.60	3.90	5.40	5.60	6.00	6.40	6.80	7.80	8.00	8.20	8.60	8.90
Humidity 59.1%	1	2	3	4	5	6	7	8	9	10	11	12	13
2.36	2.30	4.40	6.70	8.70	10.30	12.30	13.40	13.90	13.90	14.10	14.20	14.20	14.20
1.18	2.50	4.60	6.80	8.80	11.00	12.90	13.70	14.40	14.50	14.90	14.50	14.40	14.40
0.6	2.30	4.50	6.80	8.60	10.90	12.90	13.90	14.40	14.40	14.50	14.40	14.40	14.50
0.3	2.20	4.80	7.10	9.50	11.50	13.30	14.30	14.50	14.60	14.70	14.70	14.60	14.70
0.15	2.20	4.50	6.50	8.50	10.20	11.30	11.90	12.00	12.10	12.90	12.90	13.00	13.00

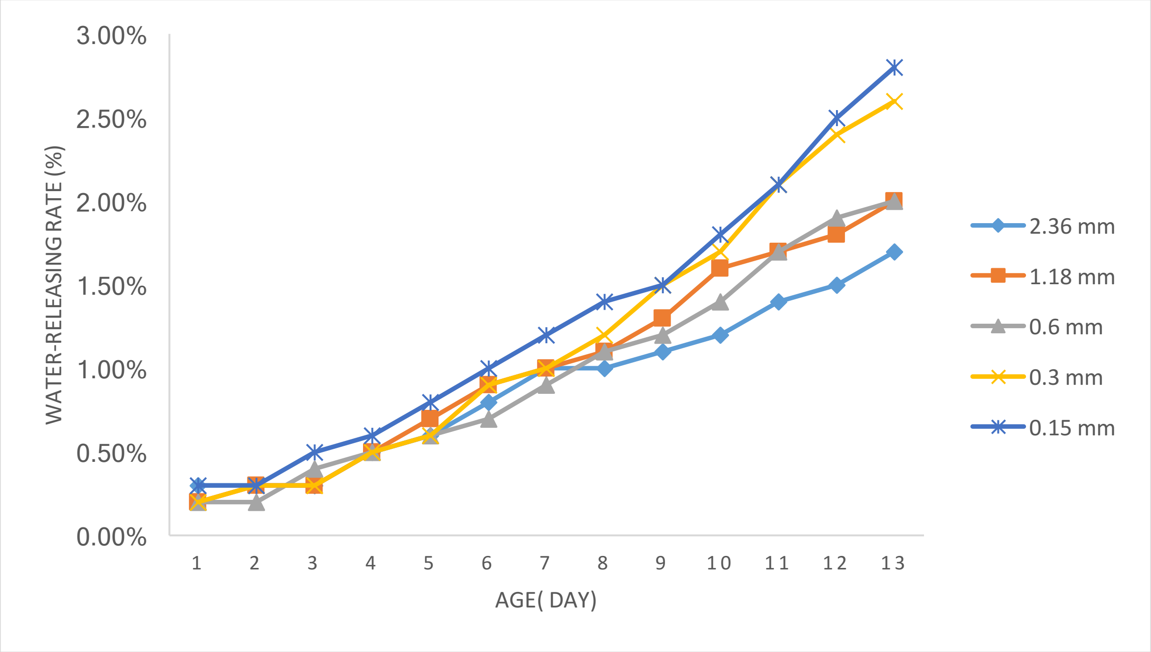

Figure 4.2. Humidity Chamber 01 (97.6%, K_2SO_4)

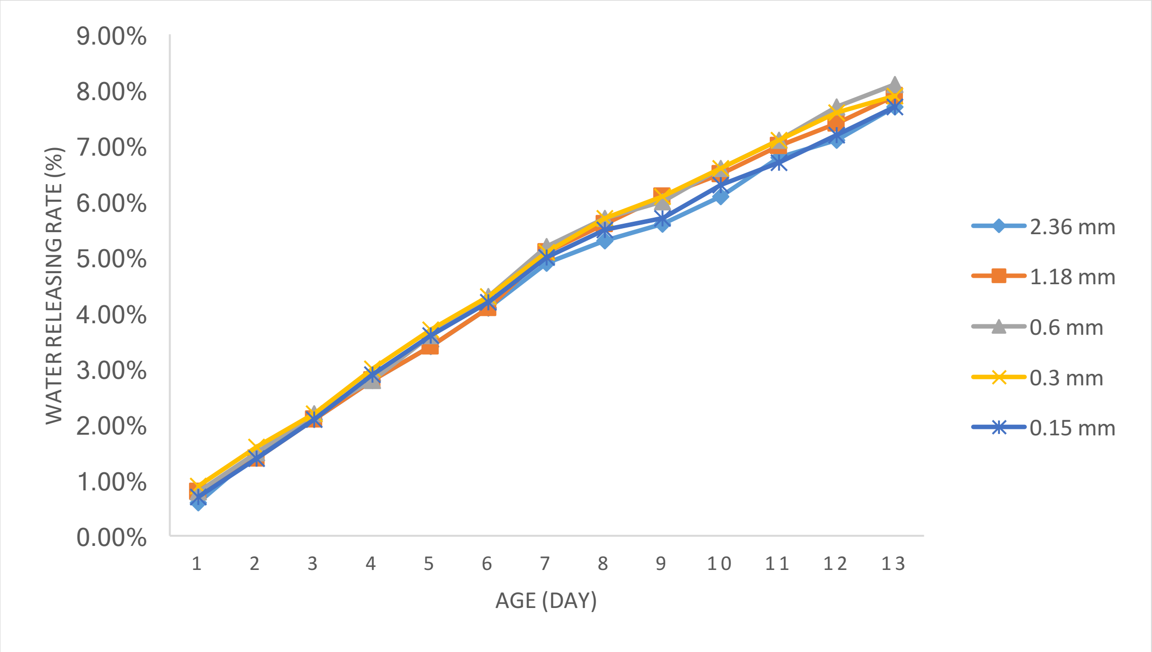

Figure 4.3. Humidity Chamber 02 (85.1%, KCl)

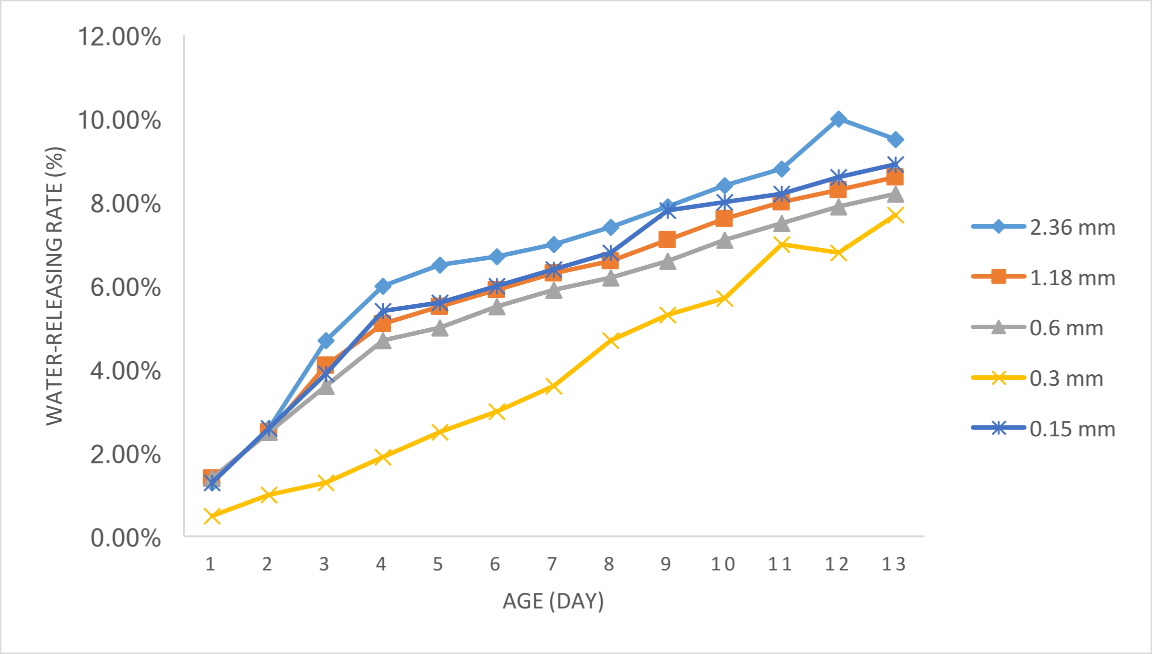

Figure 4.4. Humidity Chamber 03 (75.5%, NaCl)

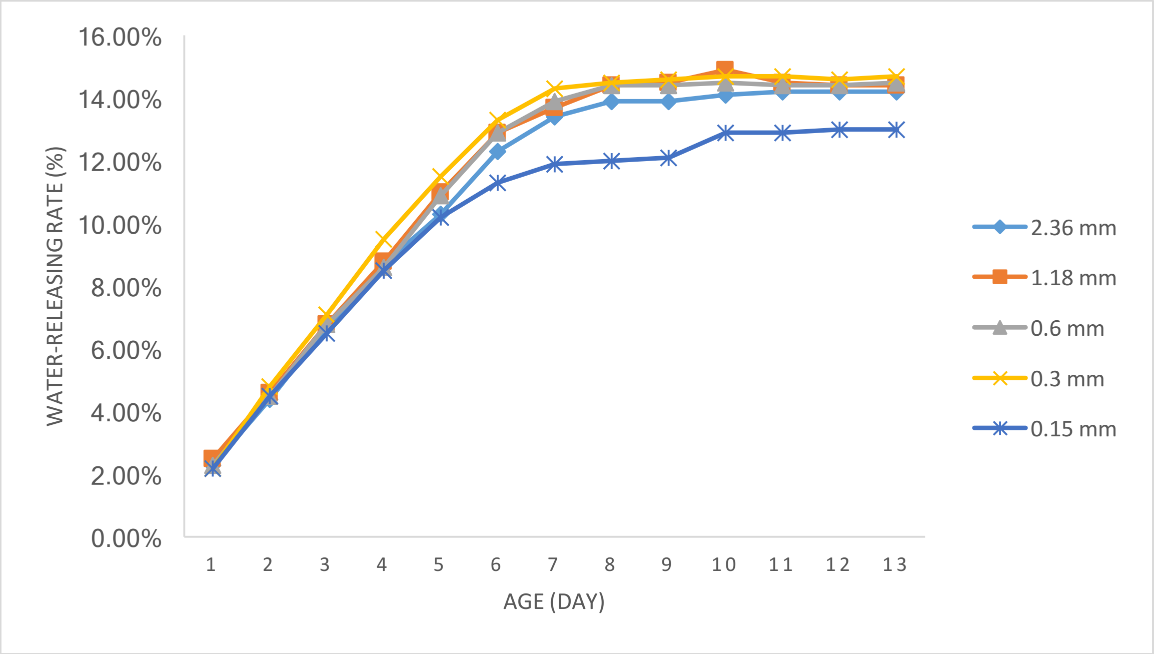

Figure 4.5. Humidity Chamber 04 (59.1%, NaBr)

4.2.3. Compressive Strength Test

The effect of prewetting time, replacement rate, and w/c ratio of the specimens are discussed in this section. Table 4.3 shows the data of compressive strength and flexural strength. All groups of specimens were compared with the control group (w/c = 0.28, no CBA, 0 min. prewetting time).

4.2.3.1. Effect of Prewetting time

Three prewetting times are designed to observe the regularity: 0 min., 10 min., and 24 hr. (with 30% replacement rate and 0.28 of w/c ratio). The compressive strength was recorded at Day 3, Day 7, and Day 28. Figure 4.6 shows the four compressive strengths based on three prewetting times of CBA and the control group. As shown in the figure, the curves show similar changing trends of compressive strength of the specimens, which were soaked in water for 10 min. and 24 hr. Meanwhile, the mortar specimens with non-soaked CBA (0 min. prewetting time) presents the lowest compressive strength in this figure. This result could be explained that prewetting of CBA before being reused may improve the compressive strength of in the new concrete since prewetting of aggregate could help mortar to increase its internal humidity and reduce the shrinkage, which cause by hydration reaction. The compressive strength of all-sand mortar specimen (no CBA used) was greater than any CBA mortar and this may cause by the high porosity of CBA since those voids inside the CBA, which may reduce the hardness of aggregate (Bazaz, & Khayati, 2012).

Table 4.3. Compressive strength (MPa) and flexural strength (MPa)

Compressive Strength (C.S.) and Flexural Strength (F.S.) (MPa)									
	Prewetting time		Time (day)						Note
			3		7		28		
			F.S.	C.S.	F.S.	C.S.	F.S.	C.S.	
Replac e-ment Rate	0 min.	30%	1.71	34.77	2.14	42.82	2.88	57.53	w/c=0.28, c/s=1:2, S.P 0.6%, Prewetting Time=0
		60%	1.59	38.4	1.78	39.96	2.92	50.48	
		100%	1.79	31.11	1.99	37.61	2.83	47.51	
	10 min.	30%	1.91	41.06	2.42	53.12	3.63	57.78	w/c=0.28, c/s=1:2, S.P 0.6%, Prewetting Time=10min.
		60%	2	37.57	2.22	41.26	3.15	52.27	
		100%	1.68	27.19	2.05	41.54	3.36	51.41	
	24 hr	30%	2.32	41.27	2.59	53.67	3.64	59.22	w/c=0.28, c/s=1:2, S.P 0.6%, Prewetting Time=24hr.
		60%	2.3	38.18	2.35	50	3.41	60.65	
		100%	1.7	32.19	2.17	34.04	3.49	55.38	
Different w/c Ratio		0.28	2.32	41.27	2.59	53.67	3.64	59.22	c/s=1:2, S.P 0.6%, RP=30%, Prewetting Time=24hr.
		0.30	1.86	42.9	2.49	38.3	3.25	64.8	
		0.32	1.71	40.38	2.27	41.45	2.94	65.79	
Prewetting Time		0 min.	1.71	34.77	2.14	42.82	2.88	57.53	w/c=0.28, c/s=1:2, S.P 0.6%, Replacement Rate=30%
		10 min.	1.91	41.06	2.42	53.12	3.63	57.78	
		24 hr	2.32	41.27	2.59	53.67	3.64	59.22	
Control Group		----	1.81	44.29	2.16	47.38	3.21	60.96	0.28, 0%, 0min.

4.2.3.2. Effect of Replacement Rate

Figure 4.7, 4.8 and 4.9 present the curves along with different replacement rates of compressive strength at three prewetting times. In general, the data of compressive strength for those specimens with CBA led to the lower compressive strength than the control group. However, the compressive strength was increased of those CBA by soaking in water for 10 min. and 24 hr. and achieved similar compressive strength as the control group. Especially for the specimens with 30% replacement rate of CBA, the compressive strength was significant improved by compared with 60% and 100% replacement rates. The specimens of 100% replacement rate of CBA shows the lowest compressive strength, which may draw researchers' attention to limit high replacement rate of CBA in concrete or mortar in the future research (Poon, & Chan, 2006).

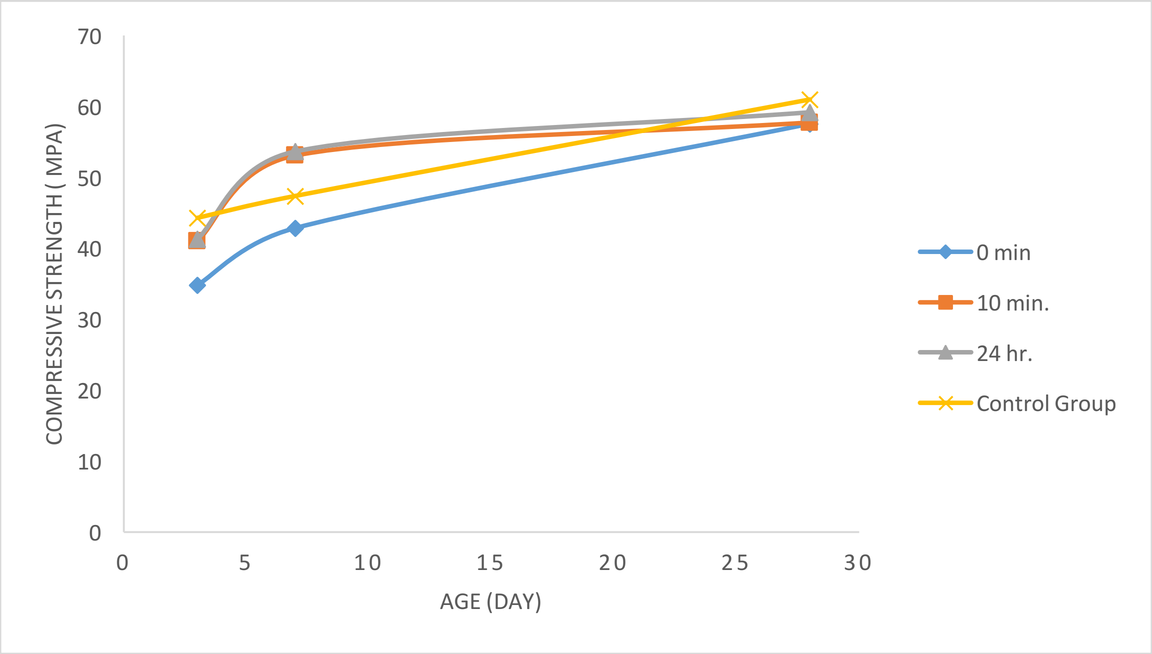

Figure 4.6. Compressive strength (MPa) based on different prewetting time of CBA (30% Replacement.)

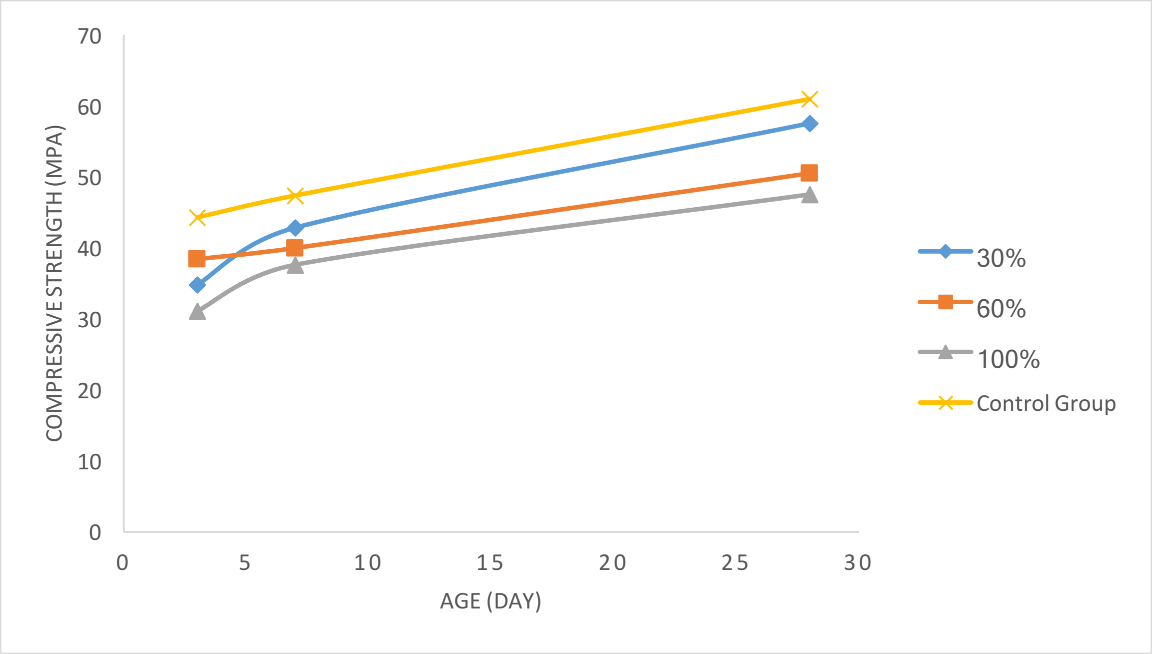

Figure 4.7. Compressive strength (MPa) based on different replacement rate of CBA (Prewetting time = 0 min.)

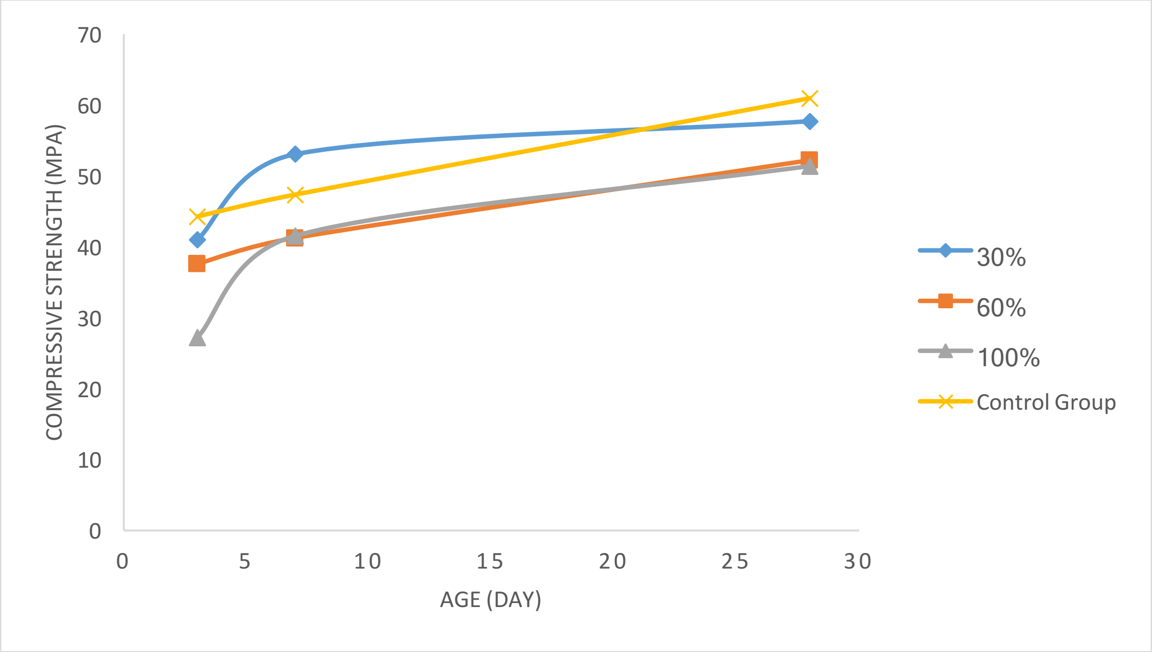

Figure 4.8. Compressive strength (MPa) based on different replacement rate of CBA (Prewetting time = 10 min.)

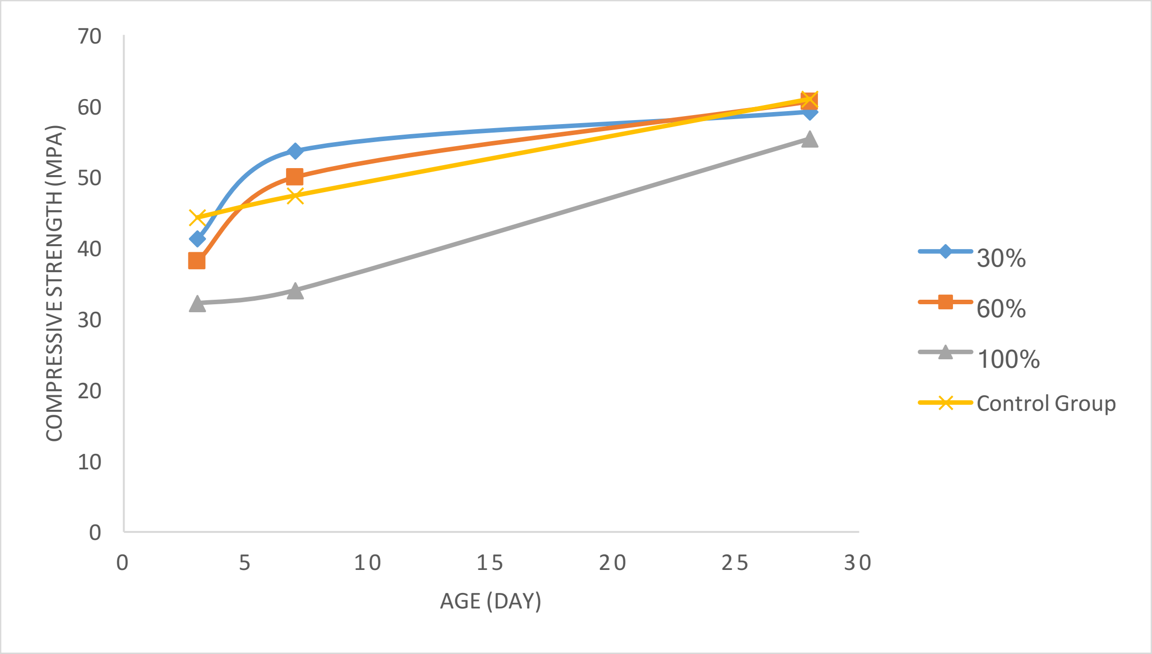

Figure 4.9. Compressive strength (MPa) based on different replacement rate of CBA (Prewetting time = 24 hr)

4.2.3.3. Effect of Water/Cement Ratio

The effect of various w/c ratios of compressive strength is demonstrated in Figure 4.10 at 30% replacement level of CBA. On the 3rd day, compressive strengths of three w/c ratios are very similar to each other. However, the compressive strength on the Day 7 showed significant differences between these three w/c ratios, specifically, the compressive strength of the specimens with 0.28 w/c ratio extremely greater than the control group and other two w/c ratios. At Day 28, the particular improved compressive strength could be observed with all three w/c ratio.

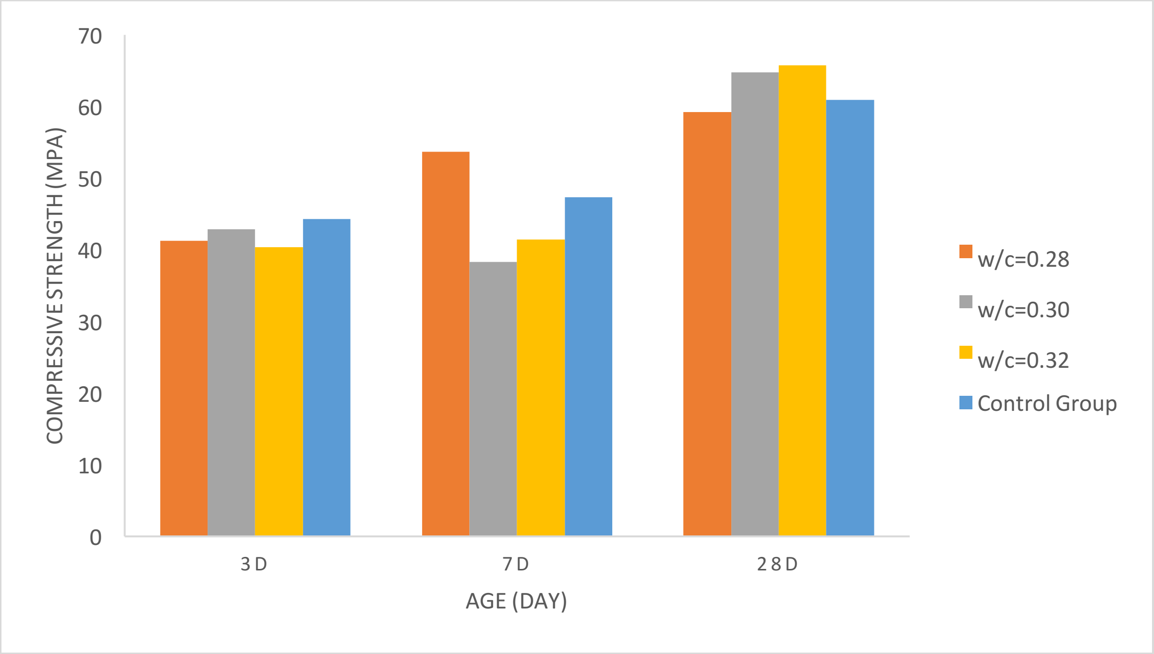

Figure 4.10. Compressive strength (MPa) based on different w/c ratio

4.2.4. Flexural Strength Test

The flexural strength of the mortar specimens was tested after the compressive strength and by using the same specimens. Analyzation of flexural strength were also designed based on different prewetting times, replacement rates, and w/c ratios by compared with the control group (w/c = 0.28, CBA not used, 0 min. prewetting time).

4.2.4.1. Effect of Prewetting time

Figure 4.11 shows the increasing flexural strength with extension of prewetting time of CBA. This result could be explained by the long prewetting time of CBA may lead to an increasing internal humidity of the mortar specimen since CBA showed the high water absorption ability as mentioned early. Meanwhile, 0 min. of prewetting time shows the lowest flexural strength, 10 min. and 24 hr. prewetting time present higher strength than the control group. This result may be caused by the increasing of internal humidity could help the mortar to achieve internal curing (Yang, Du, & Bao, 2011).

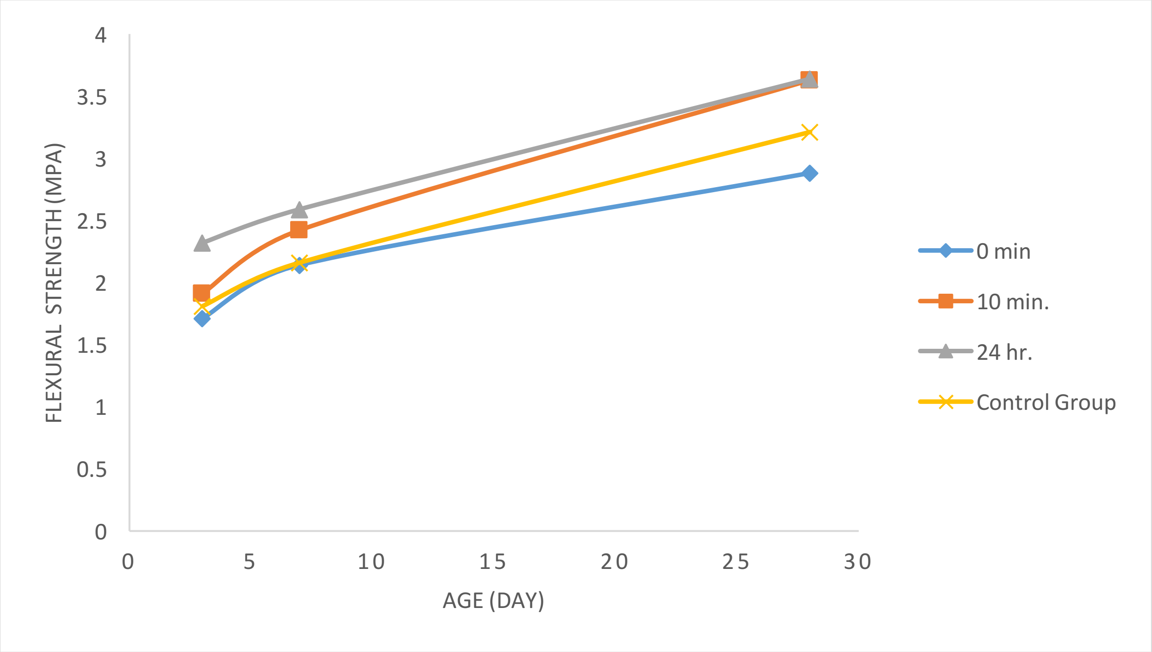

Figure 4.11. Flexural strength (MPa) based on different prewetting time of CBA (30% Replacement.)

4.2.4.2. Effect of Replacement Rate

Three replacement level (30%, 60%, 100%) in three prewetting times are shown in Figure 4.12, 4.13 and 4.14. The results were compared with the control group with 0% replacement of CBA in the specimen. Except 0 min. prewetting time, 30% replacement rate of CBA shows the highest flexural strength than other two replacement rates with 10 min. and 24 hr prewetting times. The increasing trends of three replacement rates are shown similar as three prewetting times as mentioned in section 4.2.4.1. The flexural strengths are all significate improved within 28 days curing. The reason may same as the effect of prewetting times since the high flexural strength might be caused by the internal curing of CBA with its increased internal humidity.

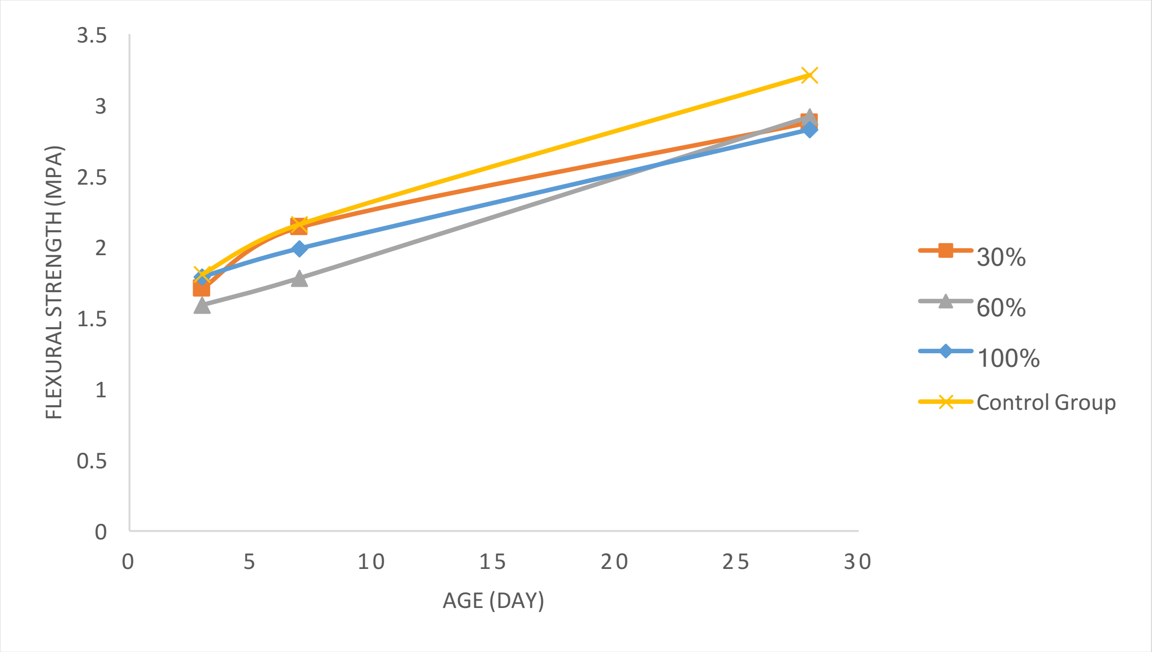

Figure 4.12. Flexural strength (MPa) based on different replacement rate of CBA (Prewetting time = 0 min.)

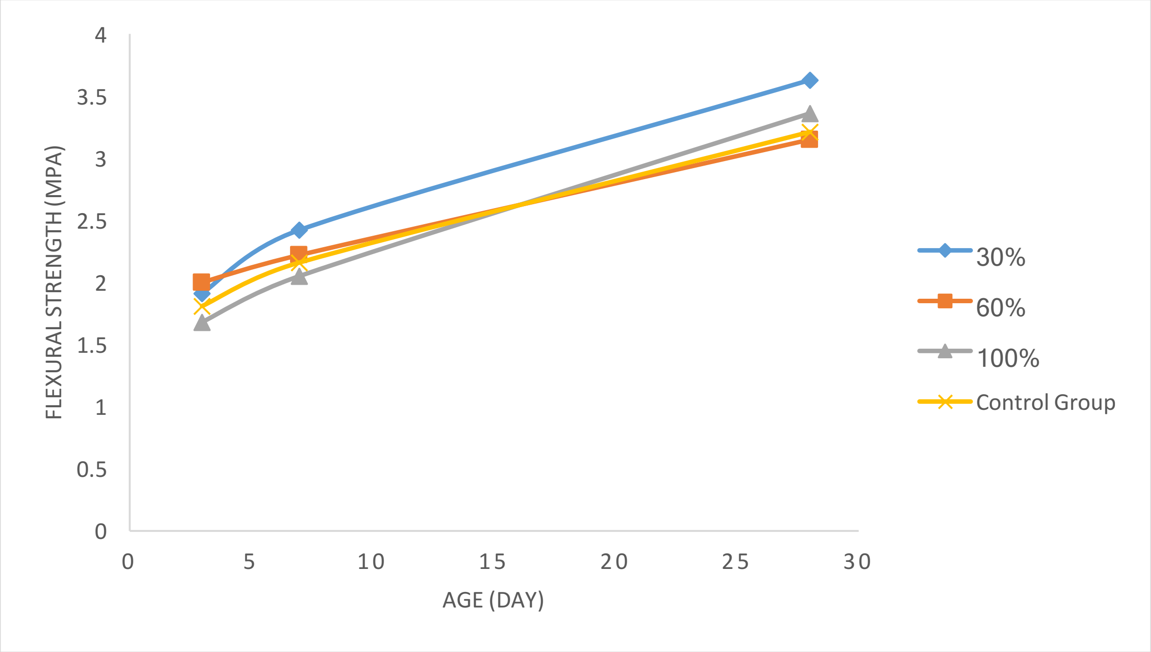

Figure 4.13. Flexural strength (MPa) based on different replacement rate of CBA (Prewetting time = 10 min.)

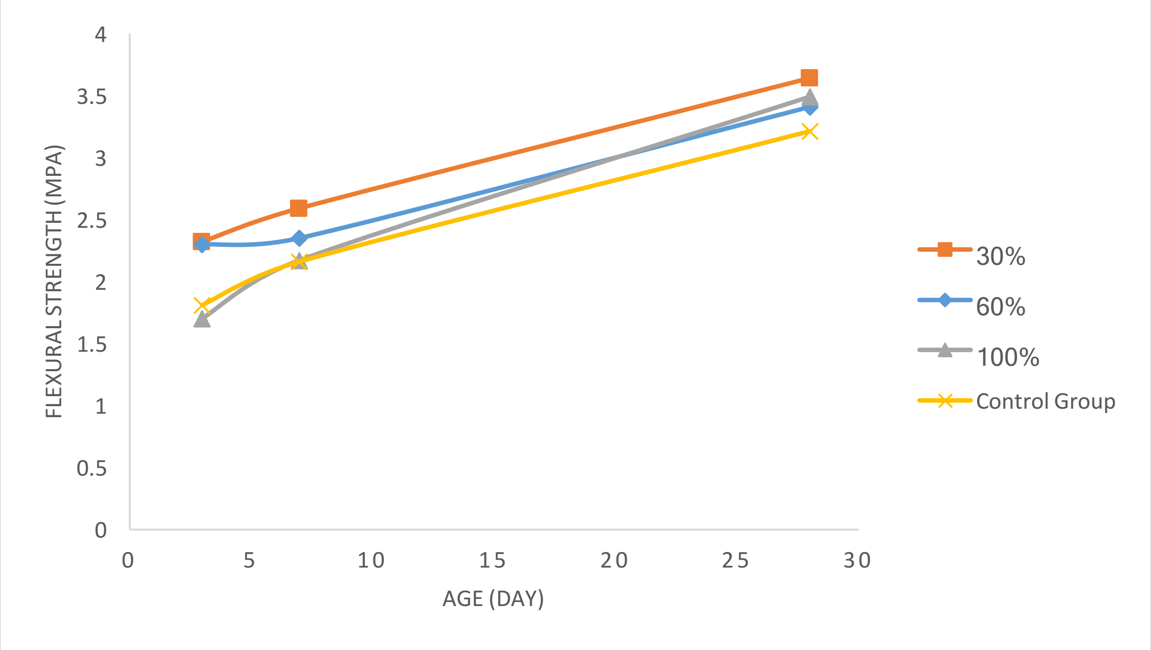

Figure 4.14. Flexural strength (MPa) based on different replacement rate of CBA (Prewetting time = 24 hr)

4.2.4.3. Effect of Water/Cement Ratio

The effect of w/c ratio of the flexural strength is plotted in Figure 4.15 with 30% replacement rate of CBA in the specimens. The improvement of flexural strength with 0.28 w/c ratio is shown in Figure 4.15. All of the flexural strengths were enhanced as curing days in increased. 0.32 of w/c ratio shows the lowest strength which may be caused by the low water content with high weight of cement.

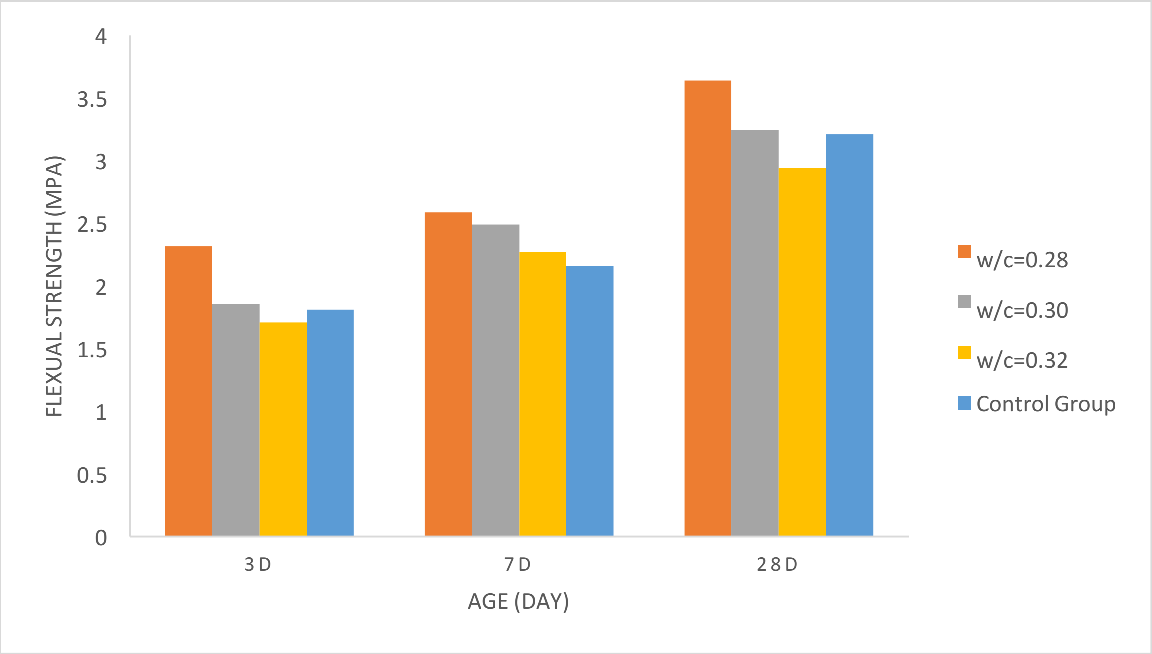

Figure 4.15. Flexural strength (MPa) based on different w/c ratio

4.2.5. Flowability Test

The data of flowability test was based on the effects of prewetting time of CBA, replacement rate, and w/c ratio (in Table 4.3). Each specimen was tested two times, and the average number was used to calculate the percentage of fluidity loss. A control group (w/c = 0.28, CBA not used, 0 min. prewetting time) was compared to observe the effect of those factors.

Table 4.4. Results of the fluidity loss

Fluidity Loss																			
	Flowability (mm)										Average Flowability (mm)				Fluidity Loss (%)				Note (S.P 0.6%, c/s=1:2)
	Pre. Time	Time/min	5		15		25		35		5	15	25	35	5	15	25	35	
		Diameter /mm	D1	D2	D1	D2	D1	D2	D1	D2	D	D	D	D	D	D	D	D	
Replace-ment Rate	0 min	30%	218	220	156	158	126	128	115	115	219	157	127	115	0	28	42	47	w/c=0.28 P.T.=0
		60%	258	268	242	244	164	162	138	136	263	243	163	137	0	8	38	48	
		100%	278	272	262	252	248	244	172	174	275	257	246	173	0	7	11	37	
	10 min	30%	202	206	154	155	126	128	120	122	204	155	127	121	0	24	38	41	w/c=0.28 P.T=10 min
		60%	158	166	136	134	106	105	98	96	162	135	105	97	0	17	35	40	
		100%	230	232	232	224	195	210	152	154	231	228	203	153	0	1	12	34	
	24 hr	30%	178	182	138	136	114	106	108	102	180	137	110	105	0	24	39	42	w/c=0.28 P.T=24hr
		60%	135	138	119	122	105	108	96	94	137	121	107	95	0	12	22	31	
		100%	182	174	182	181	143	145	114	108	178	182	144	111	0	-2	19	38	
Different w/c ratio		0.28	178	182	138	136	114	106	108	102	180	137	110	105	0	24	39	42	RR=30% P.T=24hr
		0.3	276	280	262	278	228	229	170	168	278	270	229	169	0	3	17	39	
		0.32	300	300	265	272	218	216	188	184	300	269	217	186	0	10	28	38	
Prewetting Time		0min	218	220	156	158	126	128	115	115	219	157	127	115	0	28	42	47	w/c=0.28 R.R=30 %
		10min	202	206	154	144	126	128	120	122	204	155	127	121	0	24	38	41	
		24hr	178	182	138	136	114	106	108	102	180	137	110	105	0	24	39	42	
Control Group		----	279	283	240	238	179	177	148	144	281	239	178	146	0	15	37	48	0.28, 0%, 0min

4.2.5.1. Effect of Prewetting time

For the prewetting time, the variable of replacement rate and w/c ratio remained unchanged over this period (30% replacement rate and 0.28 w/c ratio). The dramatic in increase of fluidity loss all the three prewetting time of CBA is shown in Figure 4.16. Overall, the changes of fluidity loss seem similar for these four groups, but the difference still can be observed from the broken lines in the figure. With the increase of prewetting time, the fluidity loss decreased. Meanwhile, the loss is growing rapidly at the beginning of test which may be caused by its high internal humidity, but the trend becomes tend to be gentle slope which may indicate the using of the saturated dry surface of CBA in concrete may reduce the fluidity loss (Bian, & Liu, 2013).

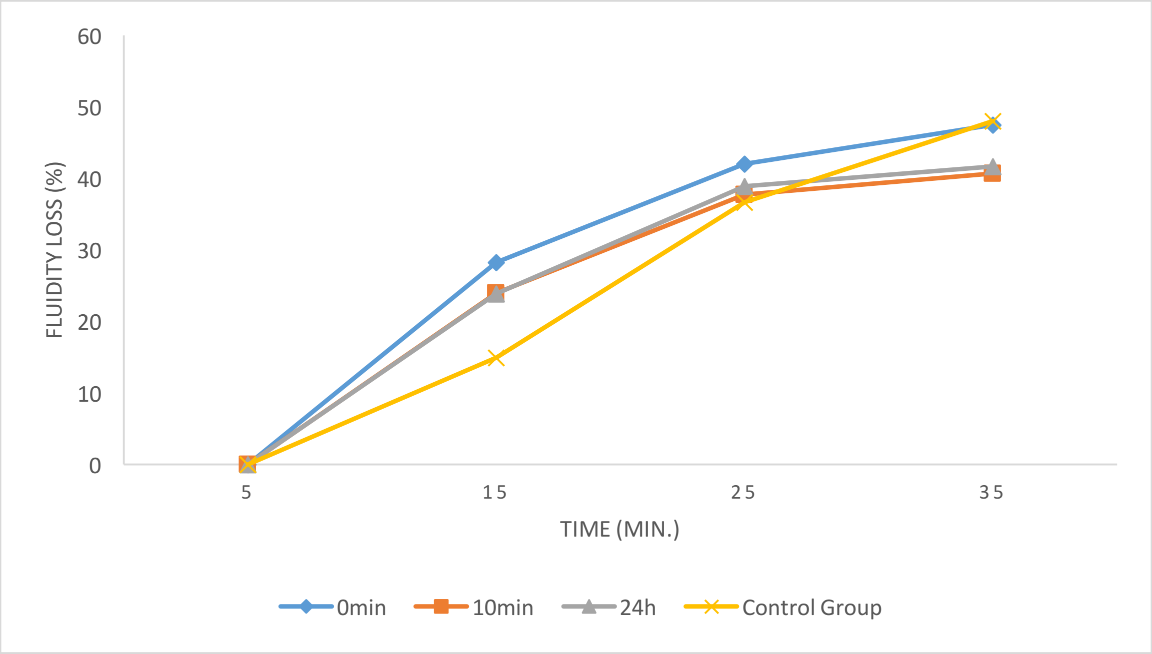

Figure 4.16. Fluidity loss (%) based on different prewetting time of CBA

4.2.5.2. Effect of Replacement Rate

Figure 4.17, 4.18, and 4.19 demonstrates the changes of fluidity loss based on the different replacement rate of CBA in the specimens. In general, the control group with 0% replacement rate achieve a high fluidity loss. When the replacement rate went up the loss decreased before 25 min. But after that, the fluidity loss decreased with the decreasing of replacement rate. This result presents that CBA has an excellent performance of flowability, and it may be used with an appropriate replacement level of fine aggregate in concrete.

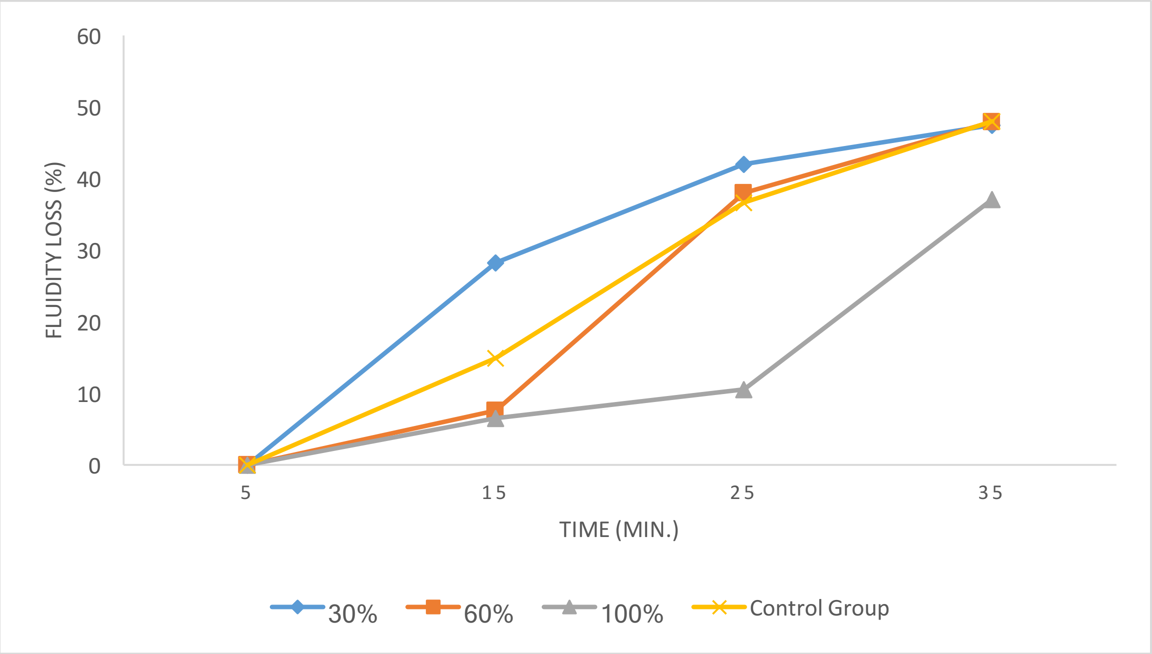

Figure 4.17. Fluidity loss (%) based on different replacement rate of CBA
(Prewetting time = 0 min.)

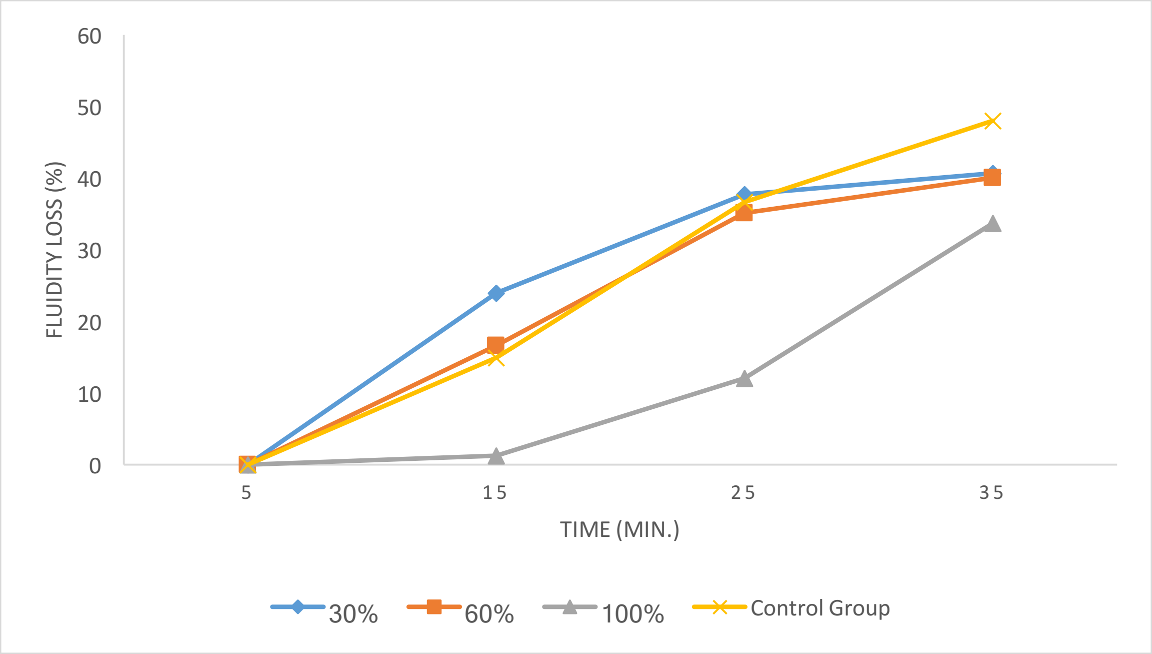

Figure 4.18. Fluidity loss (%) based on different replacement rate of CBA (Prewetting time = 10 min.)

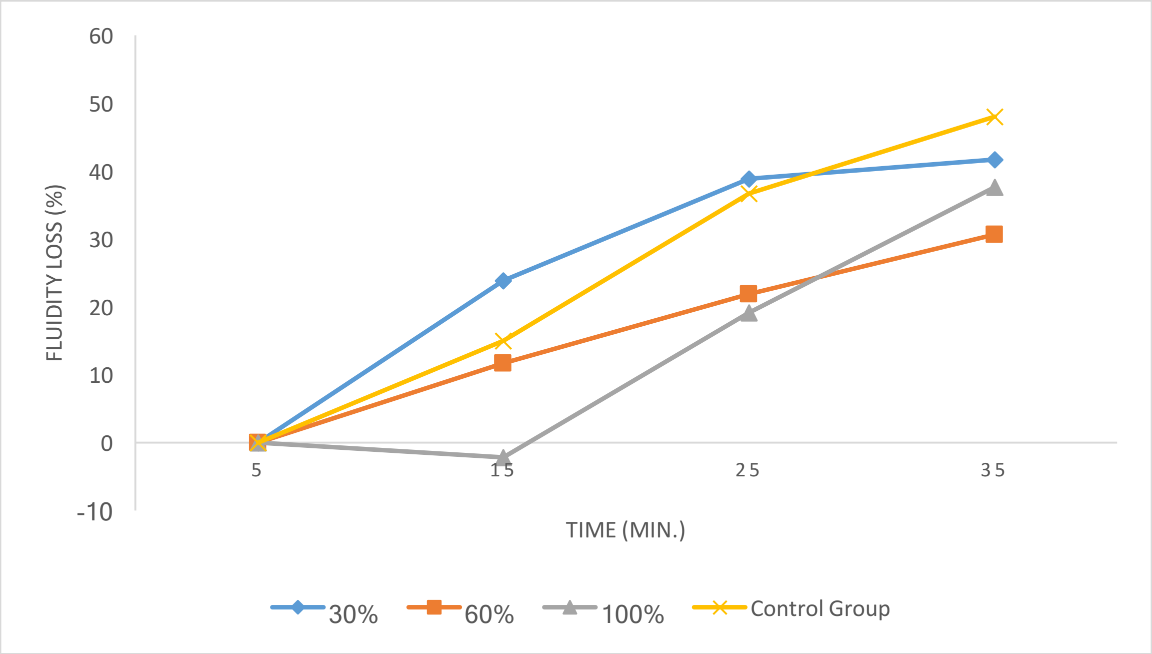

Figure 4.19. Fluidity loss (%) based on different replacement rate of CBA (Prewetting time =24 hr)

4.2.5.3. Effect of Water/Cement Ratio

Figure 4.20 shows the increasing trends of fluidity loss by three w/c ratios and a control group (30% replacement rate and 0.28 w/c ratio) at 30% substitution level, 0.28 of w/c ratio. Overall, w/c = 0.30 presented the lowest fluidity loss in comparison to 0.28 and 0.30 w/c ratios, but at 35 min. all these three w/c ratios get to the same point in the figure. For the prediction after 35 min., 0.28 of w/c ratio will lead to a reduced fluidity loss since it has the decreasing trend.

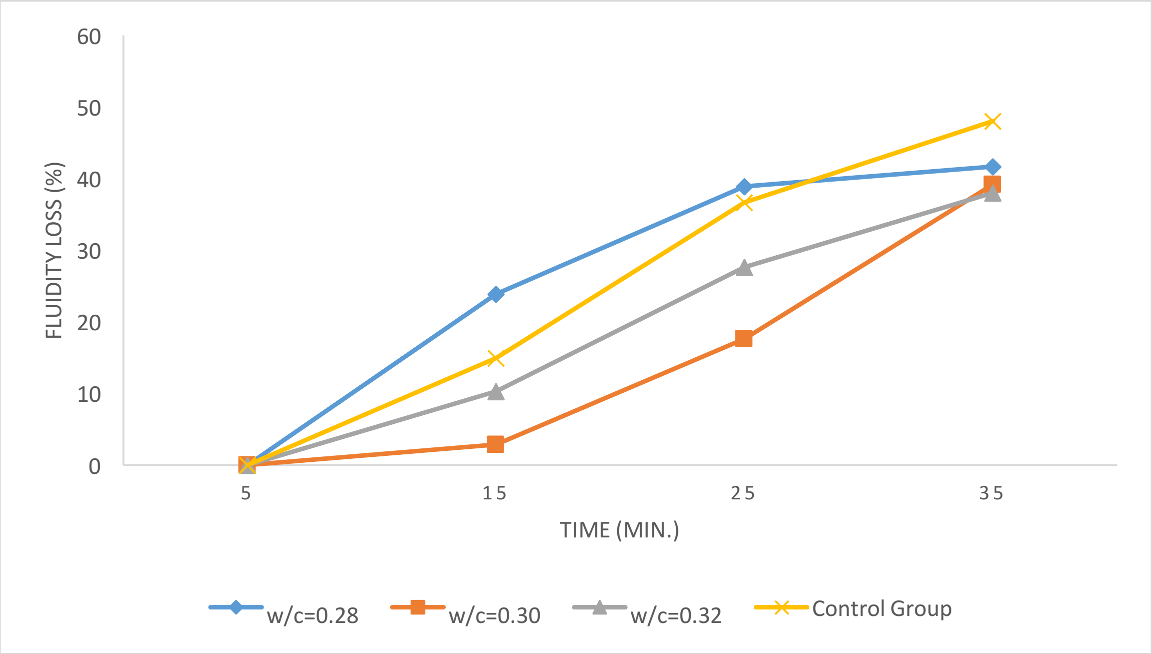

Figure 4.20. Fluidity loss (%) based on different w/c ratio

4.2.6. Internal Humidity

Table 4.4 states the result of internal humidity for all mixes over ten days. The effects of three factors were recorded: prewetting time of CBA (0 min., 10 min., 24 hr), replacement rate (30%, 60%, 100%), and w/c ratio (0.28, 0.30, 0.32). A control group was set to make the comparison in 0.28 of w/c ratio, 0% replacement rate of CBA, and non-presoaking of the aggregate.

The detailed description is discussed separately below.

Table 4.5. Results of internal humidity for all mixes

Internal Humidity Rate (%)														
				Time (day)										
	Prewetting time		Original Weight (g)	1	2	3	4	5	6	7	8	9	10	Note (S.P 0.6%)
Replacement Rate	0 min.	30%	100	91.2	93.5	91.1	90.6	89.8	89.7	92.8	91.9	93.1	94.2	w/c=0.28, c/s=1:2, Pre. Time=0
		60%	100	94.3	94.1	95.6	93.5	95.1	92.5	93.2	92.6	93.7	93.2	
		100%	100	95.8	96.5	96.7	93.8	95.5	94.3	94.8	93.7	94.7	94.3	
	10 min.	30%	100	96	95.7	93.2	90.4	94.2	94.2	94.5	91.5	92.8	93.7	w/c=0.28, c/s=1:2, Pre. Time=10min.
		60%	100	94.2	97	93.4	94.6	96	95	93.3	91.5	92.8	93.7	
		100%	100	96.9	97.1	94.1	95.8	96.6	96.6	96.2	94.2	94.3	95.2	
	24 hr	30%	100	96.2	94.4	93.9	94.5	94.8	93.6	91.6	85.3	92.2	92	w/c=0.28, c/s=1:2, Pre. Time=24hr.
		60%	100	97.1	96.7	96.8	96.3	95.1	96	93.9	92.2	95.1	93.8	
		100%	100	96.9	96	95.8	96.4	96.5	96.5	94.4	92.7	94.8	94.1	
Different w/c Ratio		0.28	100	96.9	96	95.8	96.4	96.5	96.5	94.4	92.7	94.8	94.1	c/s=1:2, RP=30%, Pre. Time=24hr.
		0.30	100	95.9	93.1	94.2	92.7	94.3	94.5	93.3	91.2	92.3	93.4	
		0.32	100	97.5	96.9	96.5	95.2	94	95.3	93.5	88.2	93.5	93.3	
Prewetting Time		0 min	100	91.2	93.5	91.1	90.6	89.8	89.7	92.8	91.9	93.1	94.2	w/c=0.28, c/s=1:2, R.R. =30%
		10 min.	100	96	95.7	93.2	90.4	94.2	94.2	94.5	91.5	92.8	93.7	
		24 hr	100	96.2	94.4	93.9	94.5	94.8	93.6	91.6	85.3	92.2	92	
Control Group		----	100	92	88.8	90.3	89.9	88.7	84	90.7	90.3	90.4	92.2	0.28, 0%, 0min.

4.2.6.1. Effect of Prewetting time

The test is designed to observe three prewetting times by replacing 30% by weight of sand with CBA and w/c ratio of 0.28. Figure 4.21 demonstrates the broken lines which represent the change of internal humidity of the specimens went down first then slowly increased after eight days. This result indicates that CBA has a high absorbing ability. Thus, the internal humidity decreased at the early age, but CBA also released water at the same time to keep the balance of moisture. Therefore, CBA could be considered to work as a type of material to reduce the shrinkage of the concrete based on CBA's good water-releasing ability (Mansur, Wee, & Cheran, 1999).

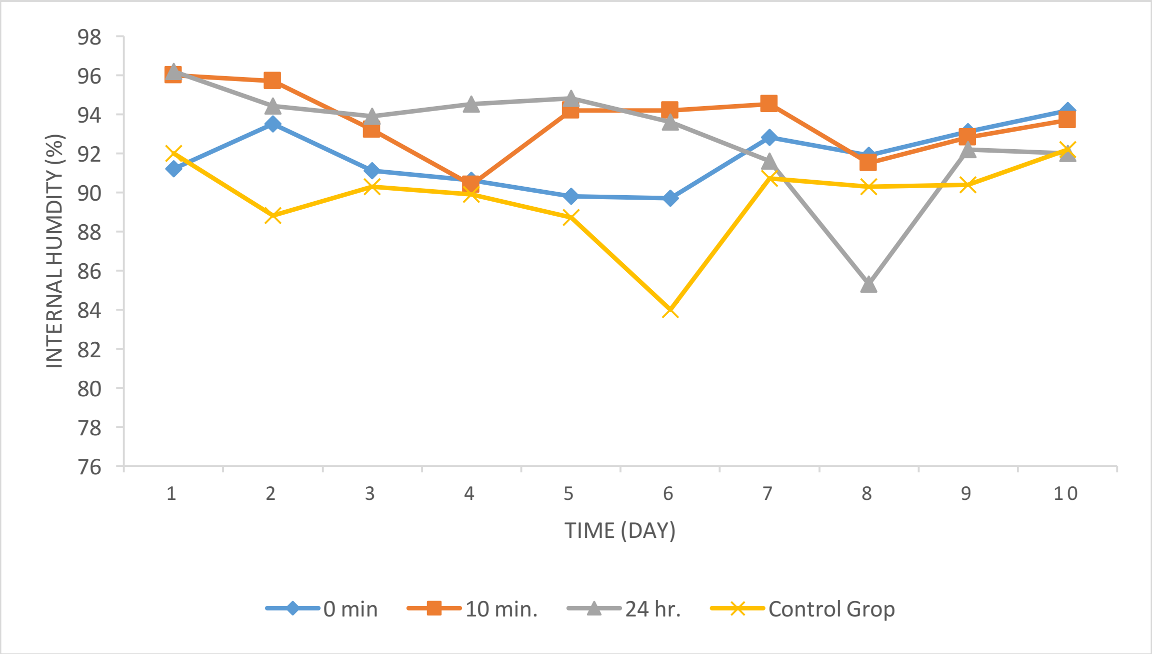

Figure 4.21. Internal humidity based on different prewetting time of CBA

4.2.6.2. Effect of Replacement Rate

The influence of different replacement ratios for internal humidity are shown in Figure 4.22, 4.23, and 4.24. The broken lines indicate the changes are based on three prewetting times

(0min., 10min., 24 hr). These three figures show the internal humidity was decreased firstly and then went up.

For all Figure 4.22, 4.23 and 4.24, the mortar specimens by replacing 100% weight with CBA showed a significantly high internal humidity ratio than other three replacement ratios. On the other hand, the control group with 0% replacement rate of CBA showed the weakness internal humidity. With the increasing of the replacement ratio, the loss of internal humidity rate went down. The effect of different replacement rates showed a positive result by using CBA in mortar; the aggregates absorbed the water firstly and then released water to keep the balance of internal humidity (Ge, Wang, Sun, Wu, & Guan, 2015).

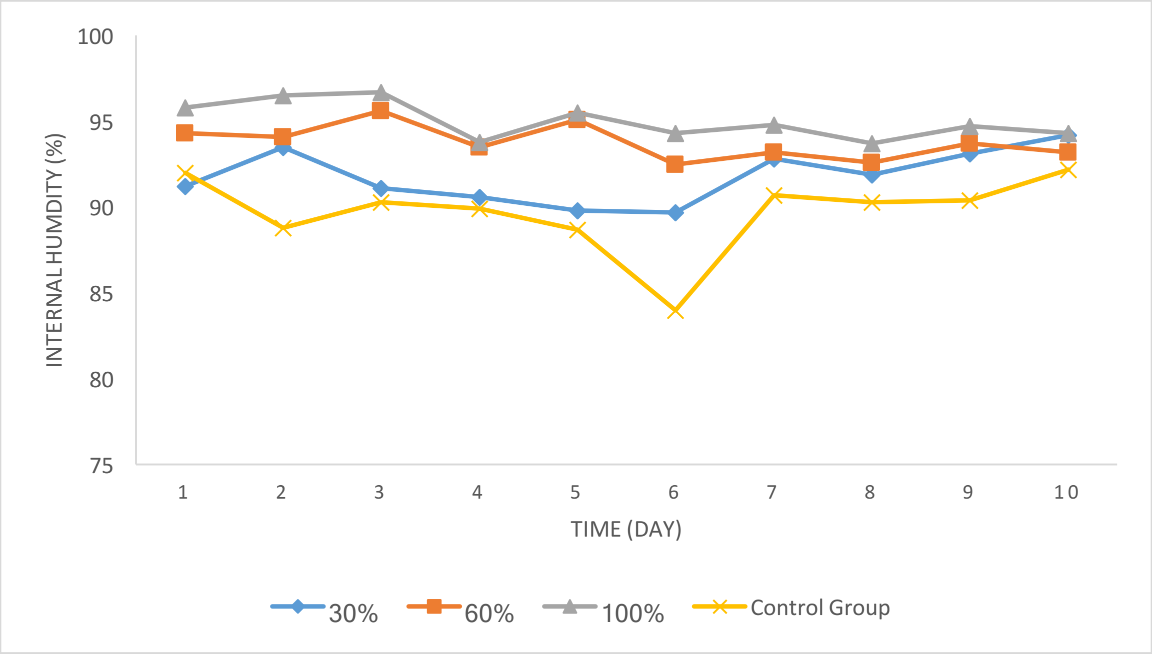

Figure 4.22. Internal humidity based on different replacement rate of CBA (Pre. Time = 0 min.)

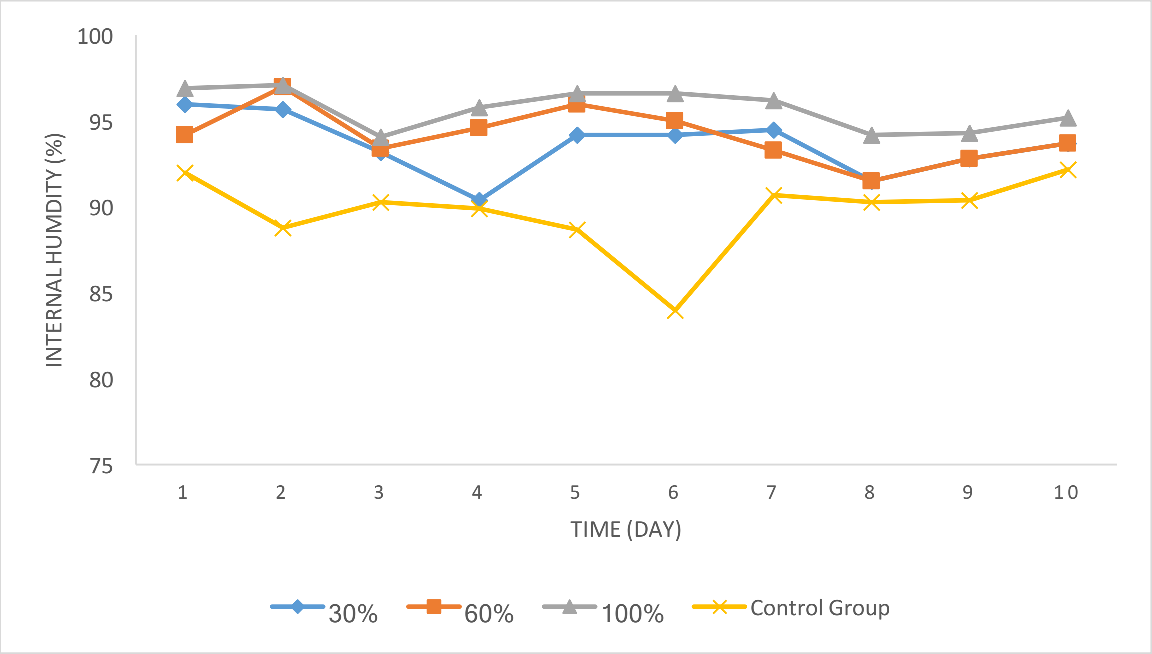

Figure 4.23. Internal humidity based on different replacement rate of CBA (Prewetting time = 10 min.)

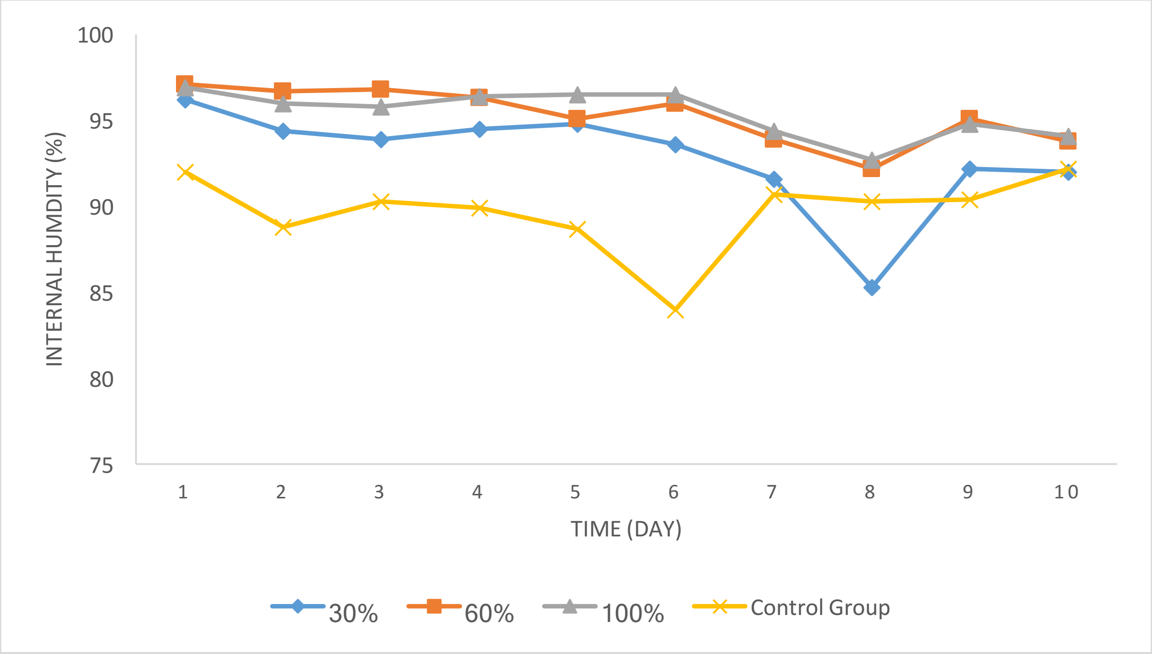

Figure 4.24. Internal humidity based on different replacement rate of CBA (Prewetting time =24 hr)

4.2.6.3. Effect of Water/Cement Ratio

Figure 4.25 shows the changes of internal humidity which were caused by different w/c ratios. The broken lines present a slightly decrease of internal humidity rate for 0.28, 0.30 and 0.32 of w/c ratio. The percentage of internal humidity was declined around 5%. All three w/c ratios showed a good internal humidity by compared to the control group (without CBA in the mortar). 0.28 of w/c ratio showed the smallest loss of humidity with around 2% decreasing of the total percentage loss in ten days.

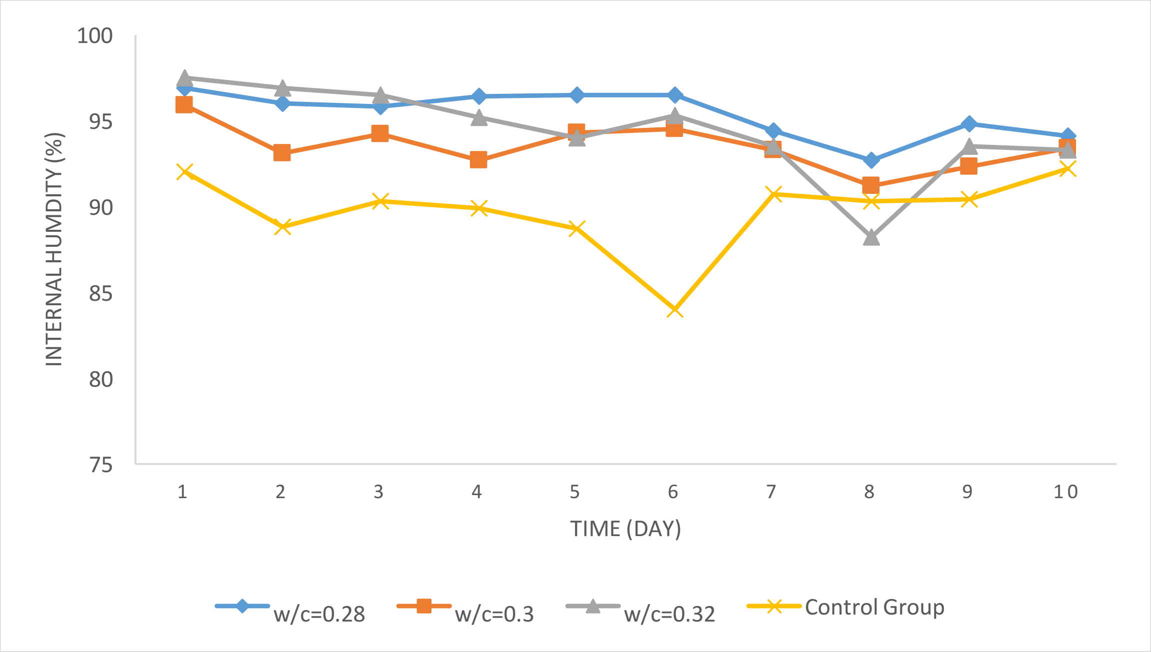

Figure 4.25. Internal humidity based on different w/c ratio

CHAPTER FIVE: A COMPARISON BETWEEN RECYCLED CONCRETE AGGREGATE AND CBA

5.1. General

This chapter shows the differences of physical and mechanical properties between Recycled Concrete Aggregate (RCA) and CBA when they were used in mortar. These two most common recycled waste products showed different physical properties according to a series of tests including water absorption, water-releasing ability, flowability, and internal humidity. Meanwhile, by the contrasting experiments, the workability of CBA in the production of new concrete may be further demonstrated. Detailed comparisons are shown below.

5.2. Comparisons

5.2.1. Water Absorption

Figure 5.1 shows the water absorption trend of RCA, which was dramatically increased with the reduction of particle size. Instead, the bigger particle size of CBA showed greater water absorption, the comparison is presented in Figure 5.2. Table 5.1 shows the data of water absorption rate at 10 min., 20 min., 30 min., 1 hr, 2 hr, 12 hr, and 24 hr. Overall, the trends of water absorption of RCA and CBA were similar since the rates were rapidly increased in the first two hours. After CBA and RCA were soaked in the water for 24 hr, CBA showed higher water absorption (up to 21.35%) than RCA. This result may be caused by the different internal structure of CBA and RCA. Since CBA is a type of construction material with high porosity, they are more voids inside of CBA than RCA allowing for greater absorption.

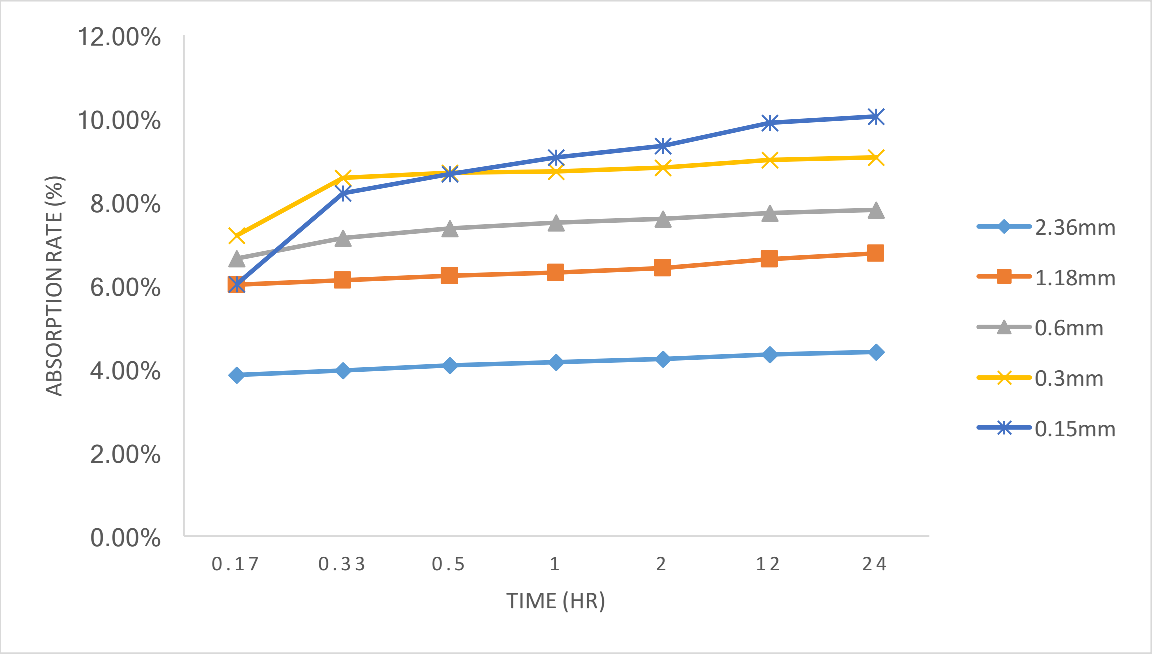

Figure 5.1. Water absorption rate of the fine particle sizes of RCA

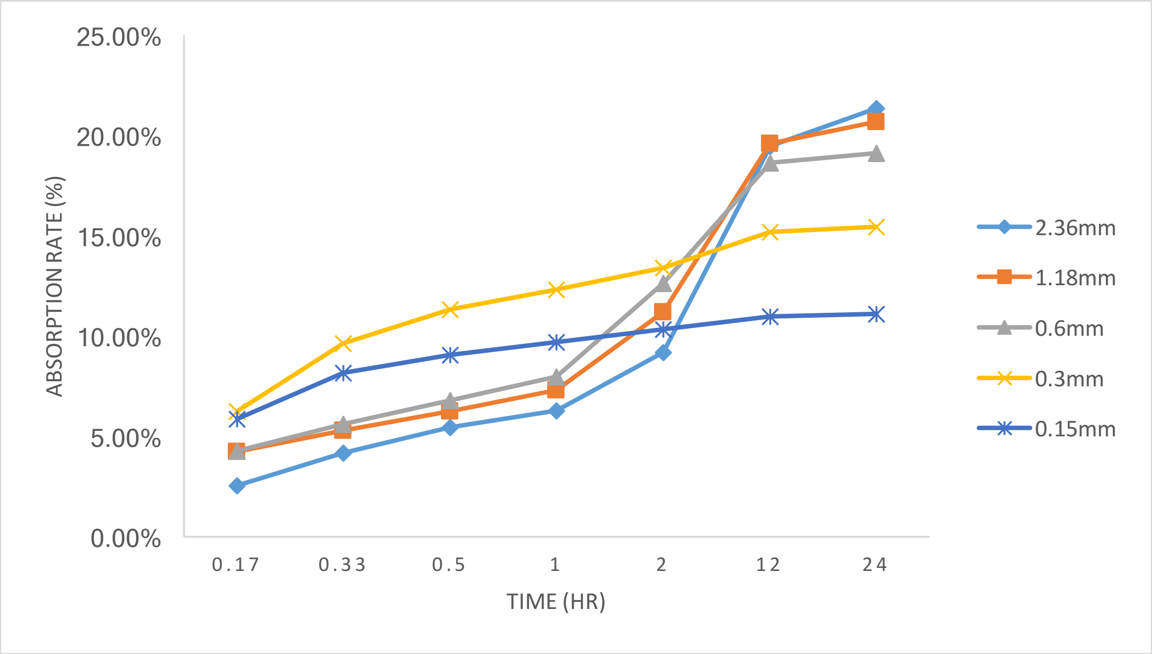

Figure 5.2. Water absorption rate of the fine particle sizes of CBA

Table 5.1. Absorption Rate of RCA and CBA

Water Absorption Rate (%)									
			Time (hr)						
	Particle Size (mm)	Drying weight (g)	0.17 (10min.)	0.33 (20min.)	0.5 (30min.)	1	2	12	24
CBA	2.36	85.70	2.57	4.20	5.48	6.30	9.22	19.49	21.35
	1.18	84.60	4.26	5.32	6.26	7.33	11.23	19.62	20.69
	0.6	83.70	4.30	5.62	6.81	8.00	12.66	18.64	19.12
	0.3	82.80	6.28	9.66	11.3	12.32	13.41	15.22	15.46
	0.15	78.30	5.87	8.17	9.07	9.71	10.34	10.98	11.11
RCA	2.36	95.76	3.87	3.98	4.09	4.18	4.25	4.35	4.42
	1.18	93.65	6.02	6.13	6.24	6.32	6.43	6.64	6.78
	0.6	92.74	6.66	7.14	7.37	7.52	7.60	7.75	7.82
	0.3	91.67	7.21	8.59	8.71	8.74	8.83	9.02	9.08
	0.15	90.86	6.05	8.22	8.68	9.08	9.35	9.91	10.05

5.2.2. Water-Releasing

The same particle sizes were examined to observe any valuable difference of the water-releasing ability between RCA and CBA. Figure 5.3, 5.4, 5.5, and 5.6 show four various humidity environments. The water-releasing curves for RCA and CBA were similar in 97.6% and 85.1% humidity environments. The water-releasing rates were consistently increased in the ten-day experiment. The highest water-releasing rate was 2.2% in 97.60% humidity environment.

As shown in Figure 5.3, 5.4, 5.5, and 5.6, the water-releasing rates were increased with decreasing humidity. CBA showed a significant increase the water-releasing rate and presented a steady trend after Day 6, which could help the mortar to achieve a more favorable internal curing.

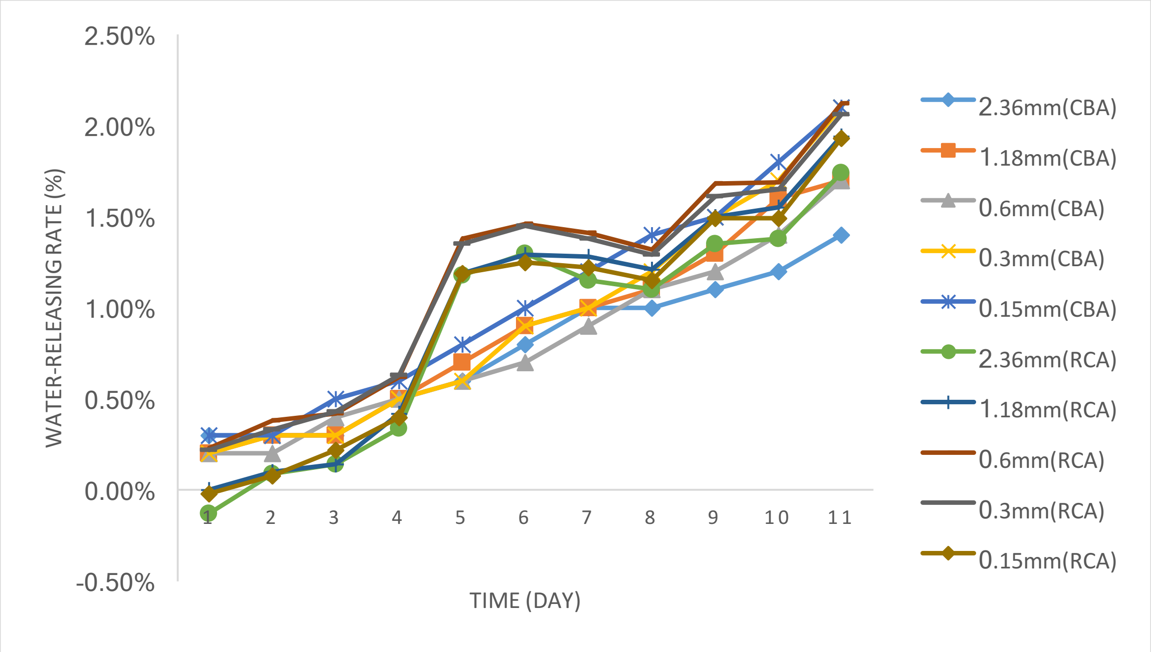

Figure 5.3. Water-releasing test of RCA and CBA in 97.6% Humidity Environment

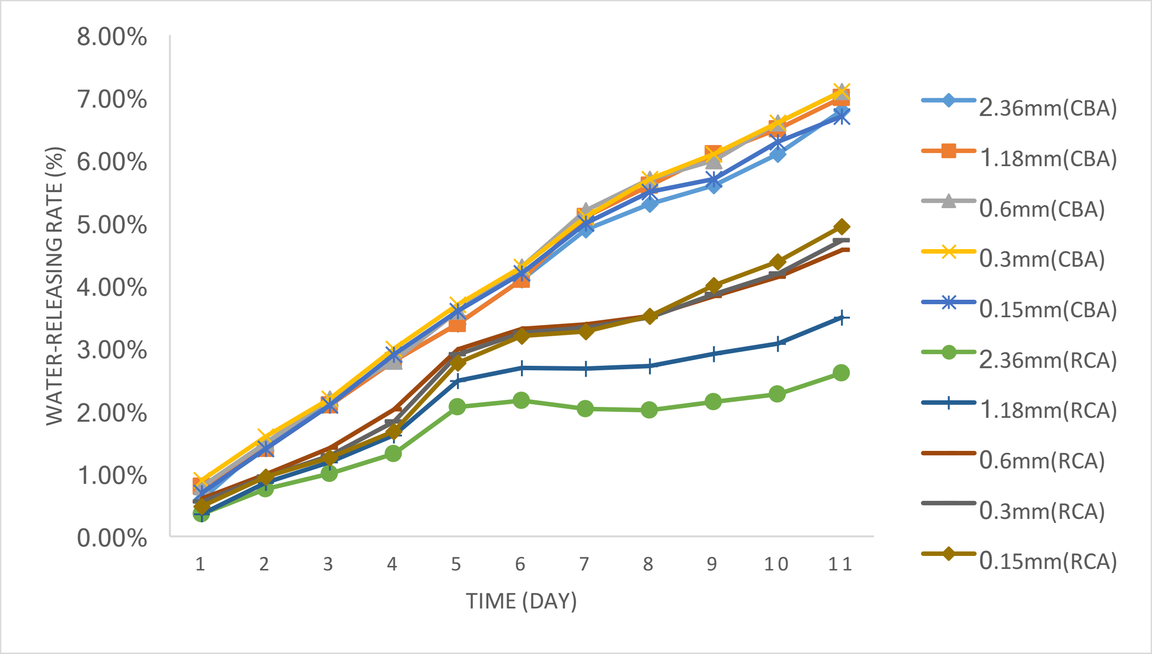

Figure 5.4. Water-releasing test of RCA and CBA in 85.1% Humidity Environment

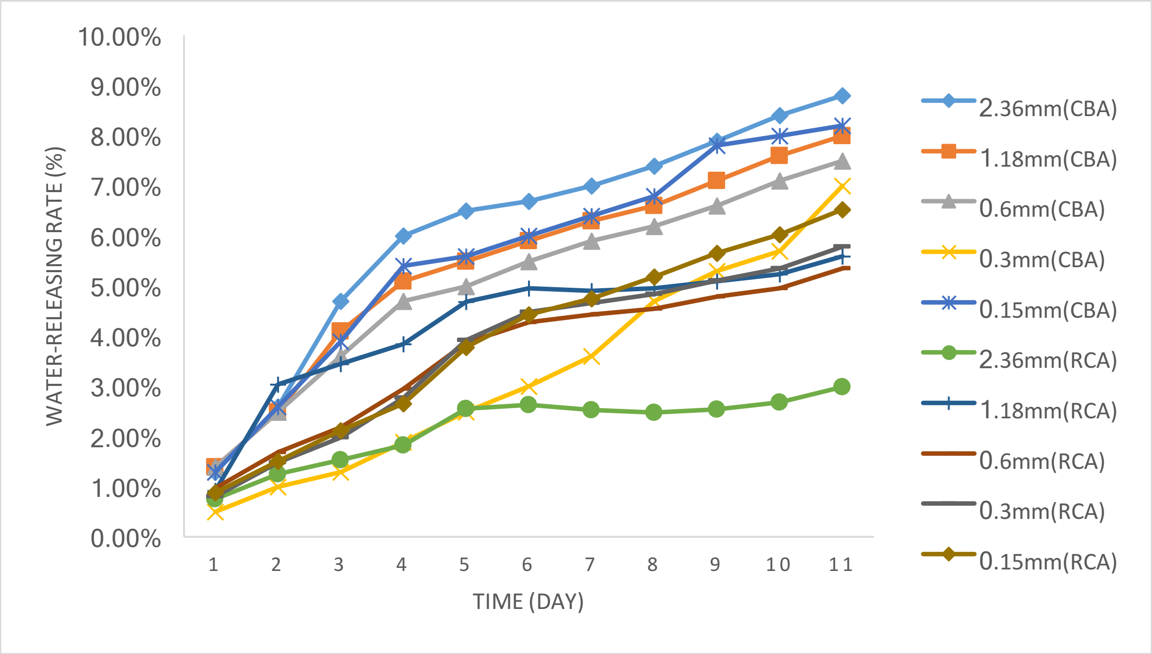

Figure 5.5. Water-releasing test of RCA and CBA in 75.5% Humidity Environment

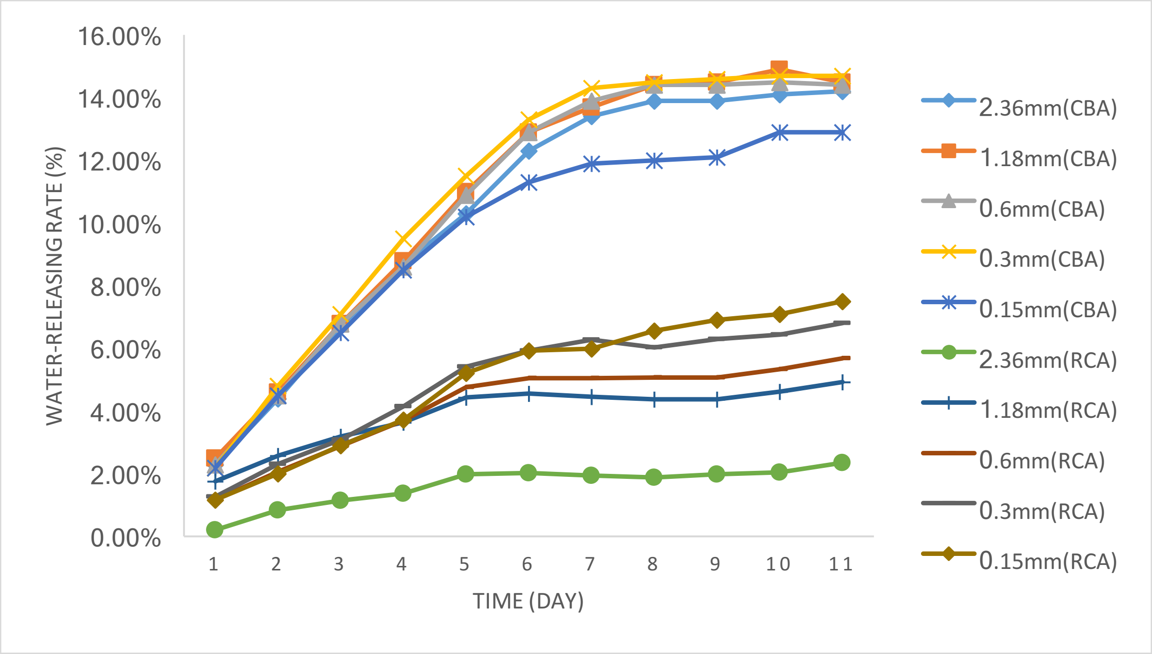

Figure 5.6. Water-releasing test of RCA and CBA in 59.1% Humidity Environment

Table 5.2 show the general water-releasing rates for RCA and CBA in four humid environments, which were achieved by four saturated saline solutions: 97.6% (K_2SO_4), 85.1% (KCl), 75.5% (NaCl), and 59.1% (NaBr). Overall, CBA presented a stronger water-releasing ability than RCA.

Table 5.2. Water-releasing rate of RCA and CBA

Water-releasing Rate (%)											
Particle Size (mm)	Time (day)										
Humidity 97.60%	1	2	3	4	5	6	7	8	9	10	11
2.36(CBA)	0.30	0.30	0.30	0.50	0.60	0.80	1.00	1.00	1.10	1.20	1.40
1.18(CBA)	0.20	0.30	0.30	0.50	0.70	0.90	1.00	1.10	1.30	1.60	1.70
0.6(CBA)	0.20	0.20	0.40	0.50	0.60	0.70	0.90	1.10	1.20	1.40	1.70
0.3(CBA)	0.20	0.30	0.30	0.50	0.60	0.90	1.00	1.20	1.50	1.70	2.10
0.15(CBA)	0.30	0.30	0.50	0.60	0.80	1.00	1.20	1.40	1.50	1.80	2.10
2.36(RCA)	-0.13	0.09	0.14	0.34	1.18	1.30	1.15	1.10	1.35	1.38	1.74
1.18(RCA)	0	0.10	0.14	0.42	1.19	1.29	1.28	1.21	1.50	1.55	1.94
0.6(RCA)	0.23	0.38	0.42	0.62	1.38	1.46	1.41	1.32	1.68	1.69	2.12
0.3(RCA)	0.22	0.33	0.43	0.63	1.35	1.45	1.38	1.29	1.61	1.65	2.06
0.15(RCA)	-0.02	0.08	0.22	0.40	1.19	1.25	1.22	1.15	1.49	1.49	1.93
Humidity 85.10%	1	2	3	4	5	6	7	8	9	10	11
2.36(CBA)	0.60	1.50	2.10	2.80	3.40	4.10	4.90	5.30	5.60	6.10	6.80
1.18(CBA)	0.80	1.40	2.10	2.80	3.40	4.10	5.10	5.60	6.10	6.50	7.00
0.6(CBA)	0.80	1.50	2.20	2.80	3.60	4.30	5.20	5.70	6.00	6.60	7.10
0.3(CBA)	0.90	1.60	2.20	3.00	3.70	4.30	5.10	5.70	6.10	6.60	7.10
0.15(CBA)	0.70	1.40	2.10	2.90	3.60	4.20	5.00	5.50	5.70	6.30	6.70
2.36(RCA)	0.36	0.76	1.00	1.32	2.07	2.17	2.04	2.02	2.15	2.27	2.61
1.18(RCA)	0.36	0.86	1.19	1.62	2.49	2.69	2.68	2.72	2.92	3.08	3.50
0.6(RCA)	0.61	0.99	1.41	2.03	2.99	3.31	3.38	3.52	3.83	4.14	4.57
0.3(RCA)	0.56	0.95	1.29	1.83	2.90	3.25	3.33	3.50	3.87	4.19	4.72
0.15(RCA)	0.48	0.95	1.26	1.68	2.77	3.20	3.27	3.52	4.01	4.39	4.95

Table 5.2. Water-releasing rate of RCA and CBA (continued)

Water-releasing Rate (%)											
Particle Size (mm)	Time (day)										
Humidity 75.50%	1	2	3	4	5	6	7	8	9	10	11
2.36(CBA)	1.30	2.60	4.70	6.00	6.50	6.70	7.00	7.40	7.90	8.40	8.80
1.18(CBA)	1.40	2.50	4.10	5.10	5.50	5.90	6.30	6.60	7.10	7.60	8.00
0.6(CBA)	1.40	2.50	3.60	4.70	5.00	5.50	5.90	6.20	6.60	7.10	7.50
0.3(CBA)	0.50	1.00	1.30	1.90	2.50	3.00	3.60	4.70	5.30	5.70	7.00
0.15(CBA)	1.30	2.60	3.90	5.40	5.60	6.00	6.40	6.80	7.80	8.00	8.20
2.36(RCA)	0.76	1.25	1.54	1.83	2.56	2.64	2.53	2.48	2.55	2.69	2.99
1.18(RCA)	0.93	3.04	3.45	3.85	4.69	4.96	4.91	4.96	5.10	5.24	5.60
0.6(RCA)	0.98	1.69	2.19	2.95	3.87	4.28	4.44	4.55	4.79	4.96	5.36
0.3(RCA)	0.81	1.48	1.98	2.77	3.92	4.48	4.67	4.85	5.11	5.35	5.79
0.15(RCA)	0.89	1.51	2.12	2.66	3.78	4.43	4.75	5.19	5.66	6.03	6.53
Humidity 59.10%	1	2	3	4	5	6	7	8	9	10	11
2.36(CBA)	2.30	4.40	6.70	8.70	10.30	12.30	13.40	13.90	13.90	14.10	14.20
1.18(CBA)	2.50	4.60	6.80	8.80	11.00	12.90	13.70	14.40	14.50	14.90	14.50
0.6(CBA)	2.30	4.50	6.80	8.60	10.90	12.90	13.90	14.40	14.40	14.50	14.40
0.3(CBA)	2.20	4.80	7.10	9.50	11.50	13.30	14.30	14.50	14.60	14.70	14.70
0.15(CBA)	2.20	4.50	6.50	8.50	10.20	11.30	11.90	12.00	12.10	12.90	12.90
2.36(RCA)	0.22	0.85	1.15	1.38	1.99	2.04	1.94	1.89	1.98	2.05	2.36
1.18(RCA)	1.77	2.59	3.19	3.65	4.45	4.57	4.47	4.37	4.37	4.63	4.94
0.6(RCA)	1.17	2.07	2.88	3.70	4.76	5.06	5.06	5.08	5.08	5.33	5.69
0.3(RCA)	1.27	2.32	3.10	4.16	5.42	5.93	6.28	6.03	6.29	6.45	6.81
0.15(RCA)	1.17	2.00	2.90	3.72	5.22	5.94	6.00	6.57	6.91	7.09	7.51

5.2.3. Flowability

The percentages of fluidity loss of RCA and CBA were compared based on a water to cement ratio of 0.28, replacing 30% of the weight of natural aggregate (sand is used in the experiment) with a 24 hr prewetting time of the aggregates. As shown in Figure 5.7 and Table 5.3, CBA showed a smaller fluidity loss rate than RCA. Less fluidity loss represented a more stable performance, thus, CBA could show a similar satisfactory workability as RCA when reused in concrete.

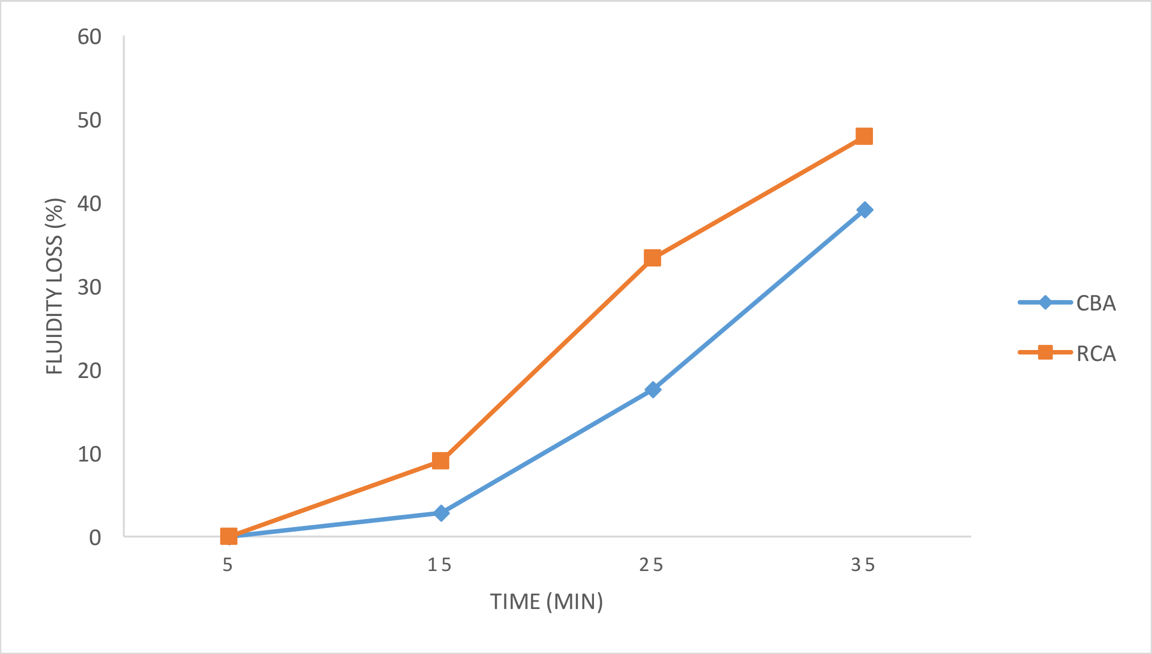

Figure 5.7. Different fluidity loss trends between RCA and CBA

5.2.4. Internal Humidity

Table 5.4 and Figure 5.8 summarize the comparison of internal humidity between RCA and CBA. The curves show in Table 5.4 and Figure 5.8 clearly demonstrate internal humidity of the mortar specimens. Using CBA may achieve better performance than RCA in concrete.

Table 5.3. Fluidity Loss of RCA and CBA

Flowability (mm)								
	Time (min)							
	5		15		25		35	
Diameter (mm)	D1	D2	D1	D2	D1	D2	D1	D2
CBA	276	280	262	278	228	229	170	168
RCA	245	250	223	227	163	167	132	126
Average Flowability (mm)								
Diameter (mm)	D		D		D		D	
CBA	278		270		229		169	
RCA	247.5		225		165		129	
Fluidity Loss (%)								
Diameter (mm)	D		D		D		D	
CBA	0		2.88		17.63		39.21	
RCA	0		9.09		33.33		47.88	

CBA showed a slow decrease of internal humidity in the first 8 days and an uptrend in the humidity after Day 8 (in Figure 5.8). On the other hand, RCA showed a consistent decreasing trend of internal humidity within the ten-day test. This result may indicate CBA could achieve a more positive internal curing than RCA.

Table 5.4. Internal humidity of RCA and CBA

Internal Humidity Rate (%)											
	Time (day)										
	1	2	3	4	5	6	7	8	9	10	Note
CBA	95.9	93.1	94.2	92.7	94.3	94.5	93.3	91.2	92.3	93.4	w/c=0.30, c/s=1:2, RP=30%, Prewetting Time=24hr.
RCA	94.6	94.3	93.9	92.7	92.2	92.5	91.7	90.7	89.9	89.6	

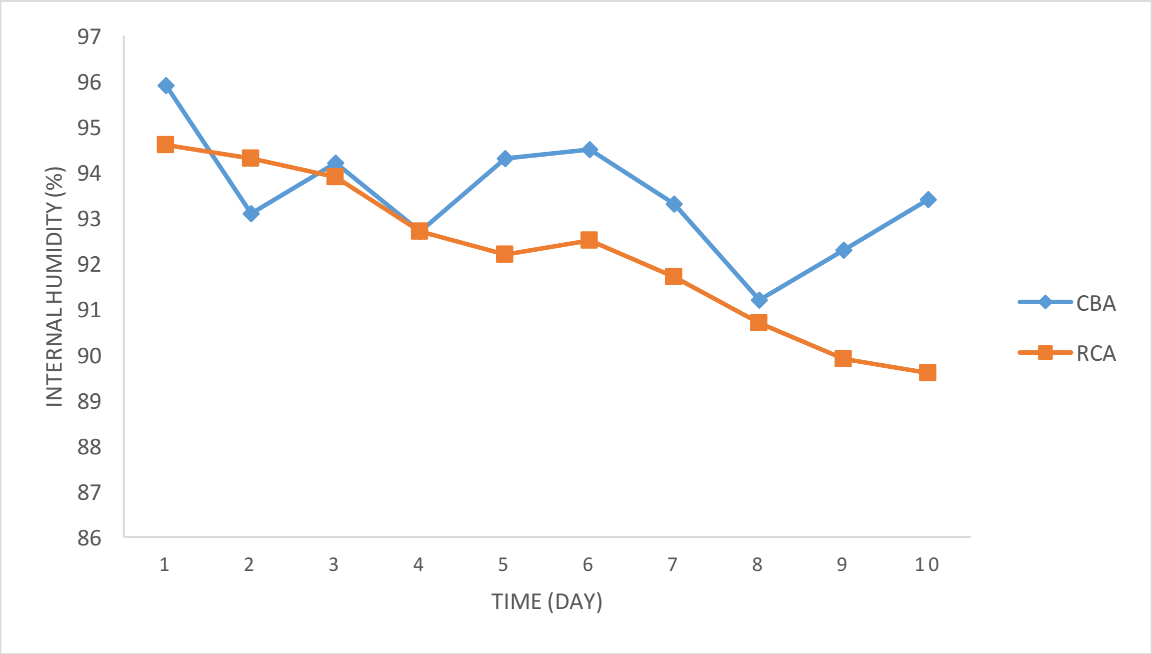

Figure 5.8. Different trends of internal humidity between RCA and CBA

CHAPTER SIX: CONCLUSIONS AND FUTURE RECOMMENDATIONS

6.1. General

This research study was focused on the properties of mortar containing clay brick fine aggregates by testing the effect of prewetting times (0 min., 10 min., and 24 hr), replacement ratios (0%, 30%, 60%, and 100%), and water/cement ratios (0.28, 0.30, and 0.32). A series of experiments were conducted to observe the characteristics and mechanical properties of CBA. Meanwhile, comparisons between RCA and CBA were also stated. The conclusions and future recommendations are summarized in this chapter.

6.2. Conclusion and Benefits

According to the experimental study in chapter three and the discussion in chapter four, some major conclusions are summarized below:

1. Clay brick fine aggregate (from 0.15 mm to 2.36 mm) is a high porosity material, which can achieve high a water absorbing ability, and the result showed an increase in a range of particle size of CBA tends to increase water absorption rate.

2. The water-releasing test showed the lowest humid environment (59.1%, NaBr) created the largest water-releasing rate when compared to the other three humid conditions. Additionally, increasing humidity, led to a decrease in water-releasing ability.

3. For the compressive strength test, the effect of different prewetting times is non-significant in this research; but on the other hand, with the comparison of different replacement percentages of CBA, 30% may be the optimum replacement rate; and 0.28 of water/cement ratio may also indicate the best compressive strength.

4. For flexural strength, prewetting time presented a good effect, especially for the 24 hr presoaking of CBA, it showed the greatest flexural strength under comparison by other prewetting times and the control group; again, 30% of replacement level and 0.28 of water/cement ratio demonstrated the largest flexural strength.

5. Overall, the specimens showed 30% replacement of the weight of sand with CBA has the lowest fluidity loss, in other words, the smaller the replacement rate, the larger the flowability. This result proves the research, which was carried out by Khalaf (2006), indicated to achieve a high workability level, prewetting of the aggregate was useful.

6. Based on characteristics of CBA, especially its high porosity and water absorbing ability, CBA may reach a good condition of internal curing, as the result of internal humidity adequately verified. Longer prewetting times may causes a slow decrease of humidity, meanwhile, internal humidity loss was decreased with the increased replacement rate.

7. Comparing RCA and CBA showed CBA had better performance through the experiments of water absorption, water-releasing, flowability, and internal humidity.

The benefits by using CBA in concrete are summarized below:

1. The pollution of the environment is greatly minimized by disposing of demolition waste of clay brick.

2. Avoiding wastage of the natural resource to produce concrete, and reducing the occupancy of limited land resources.

3. Accelerate the process of recycling demolition waste, especially clay brick waste.

4. Achieving satisfactory workability in concrete: increased permeability, reduced autogenous shrinkage, and improved internal curing.

6.3. Limitations and Future Recommendation

Due to the insufficient time for research and experiment, w/c ratio and replacement rates were limited and the experiment of chemical properties was not studied. Furthermore, only new and clean clay bricks were involved in this research study.

Based on the above mentioned limitations, some recommendations are suggested for future studies:

1. Due to the limited time of this research, micro-hardness test was not finished to observe the effect of the internal curing of clay brick aggregate. It is strongly recommended to conduct the micro-hardness test to observe the effects of different prewetting times, replacement ratios and water/cement ratios of internal curing for the mortars with clay brick aggregate.

2. The tests are designed to evaluate properties of mortar specimens with CBA, and more studies are recommended to investigate the influence of prewetting times, replacement ratios and water/cement ratios in the additional form of concrete.

3. The comparisons between RCA and CBA were limited in this thesis. Thus, further studies of the comparison between RCA and CBA are recommended in the future.

4. This research is focused on the test of 0.28 w/c ratio. Only two mixes were designed for 0.30 and 0.32. The research of the effect of more water/cement ratios will be encouraged to investigate in the future.

5. It is strongly suggested to conduct the experimental work to observe the performance of mortar or concrete specimens, which directly be made with demolition CBA waste.

6. Most studies are suggested to conduct for physical and mechanical properties of CBA. In this thesis, the chemical characteristics are not discussed. Thus, the experimental study of chemical properties is recommended to conduct.

7. Several existing articles stated that the separation of CBA from concrete waste was costly and difficultly to achieve. Thus, the experiment of reusing both concrete and clay brick in new concrete is expected to conduct in future.

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