CHAPTER 3 MATERIALS AND EXPERIMENTAL PROGRAM

This chapter describes the experimental program in details. The main topics in this chapter are equipments, materials, and methodology used in this study. The methodology includes the mix proportion of concretes, recycled aggregate preparation, and tested program. Test program focuses on compressive strength, modulus of elasticity, water permeability, chloride penetration, chloride content, and expansion of concretes due to sulfate attacks. The description of each topic is summarized as follows.

3.1 Equipments

Major equipments used in this study are summarized as follows:

- Ball Mill Machine
- Concrete Mixer
- Compression Machine
- Compressometer
- Scanning Electron Microscopy (SEM)
- X-Ray Fluorescence Spectrometer (XRF)
- Water Permeability Testing Set
- Titration Testing Set
- Exapasion Testing Set

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3.2 Materials

3.2.1 Cement

Ordinary Portland cement type I was used in this investigation.

3.2.2 Fluidized Bed Fly Ash

Fluidized bed fly ash was collected from a power plant in Prachinburi province, Thailand. Fly ash from the fluidized bed combustion is different from that obtained from pulverized coal combustion due to the different combustion processes involved. The irregular shape, rough surface, large and porous particles of fly ash was obtained from a fluidized bed power plant, therefore, this fly ash is not suitable to be used as a pozzolanic material in concrete. To improve the quality, the fly ash was ground until the particles retained on a 45-μm sieve were less than 1% by weight.

3.2.3 Bagasse Ash

Bagasse ash, a by-product obtained from burning bagasse for electricity generation in sugar industry in Lopburi province, Thailand, was collected. The original bagasse ash has particles retaining on a 45-μm sieve of 66.85% by weight and has strength activity indices at 7 and 28 days of 62 and 74%, respectively. These results suggested that the original bagasse ash is not qualified to be used as a pozzolanic material in concrete because the physical requirements of ASTM C 618 (2001) limit the pozzolan particles retained on a 45-μm sieve should not exceed 34% and should have strength activity index at least 75% at 7 or 28 days. Therefore, the original bagasse ash was ground until the particles retained on a 45-μm sieve were less than 1% by weight to improve its reactivity.

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3.2.4 Natural Aggregates

In this study, natural river sand with a fineness modulus of 3.07 and specific gravity of 2.62 was used as a fine aggregate. Crushed limestone with maximum nominal size of 19 mm and specific gravity of 2.73 was used as a coarse aggregate.

3.2.5 Recycled Aggregate

Recycled coarse aggregate (RCA) or recycled aggregate was obtained from 150x300 mm concrete cylinder samples after being tested for compressive strength which had compressive strengths of 25 to 40 MPa. These concrete cylinders were sent to the Department of Civil Engineering, King Mongkut's University of Technology Thonburi to determine the compressive strength of concrete by construction companies in Thailand. The sulfur capping on the top and bottom of tested concretes were removed before crushing. After that, they were crushed by a swing hammer crusher and screened by sieves (retained on a 4.75 mm sieve and passed a 19 mm sieve) to obtain RCA for using in this investigation.

3.2.6 Water

Tap and filtered water were used in concrete mixtures and in water permeability housing cell, respectively. Moreover, distilled water was used in chloride titration process.

3.2.7 Superplasticizer

Polymer type dispersion superplasticizer was employed in some concrete mixtures to adjust and maintain the slump of fresh concrete between 50-100 mm.

3.3 Experimental Program

Both ground fluidized bed fly ash and ground bagasse ash were partially replaced Portland cement Type I in concrete mixtures. The overview of experimental program is shown in Figure 3.1.

3.3.1 Properties of Materials

Physical properties and chemical compositions of ground fly ash, ground bagasse ash, and Portland cement Type I were investigated. After grinding, specific gravity and the amount of particles retained on a 45 μm sieve (sieve No. 325) were determined in accordance with ASTM C 188 (2001) and C 430 (2001), respectively and then the particle size distributions of all materials were also analyzed. Chemical compositions of all materials were analyzed by X-Ray Fluorescence spectrometer. The morphologies of Portland cement Type I, ground fly ash, and ground bagasse ash were studied using scanning electron microscopy (SEM).

3.3.2 Mix Proportions of Concretes

The mix proportions of concretes are shown in Table 3.1. The compressive strengths of conventional concretes at 28 days were designed to be 45, 35, and 30 MPa corresponding to water to binder ratios of 0.45, 0.55, and 0.65, respectively. Recycled aggregate concretes were made with the same mix proportion of conventional concretes, except that the recycled coarse aggregate (RCA) was fully used to replace crushed limestone. In addition, ground fly ash (GFA) and ground bagasse ash (GBA) were used separately to replace Portland cement Type I at 20, 35, and 50% by weight of binder in the recycled aggregate concrete. The slump of fresh concretes was controlled between 50 and 100 mm by varying the amount of superplasticizer.

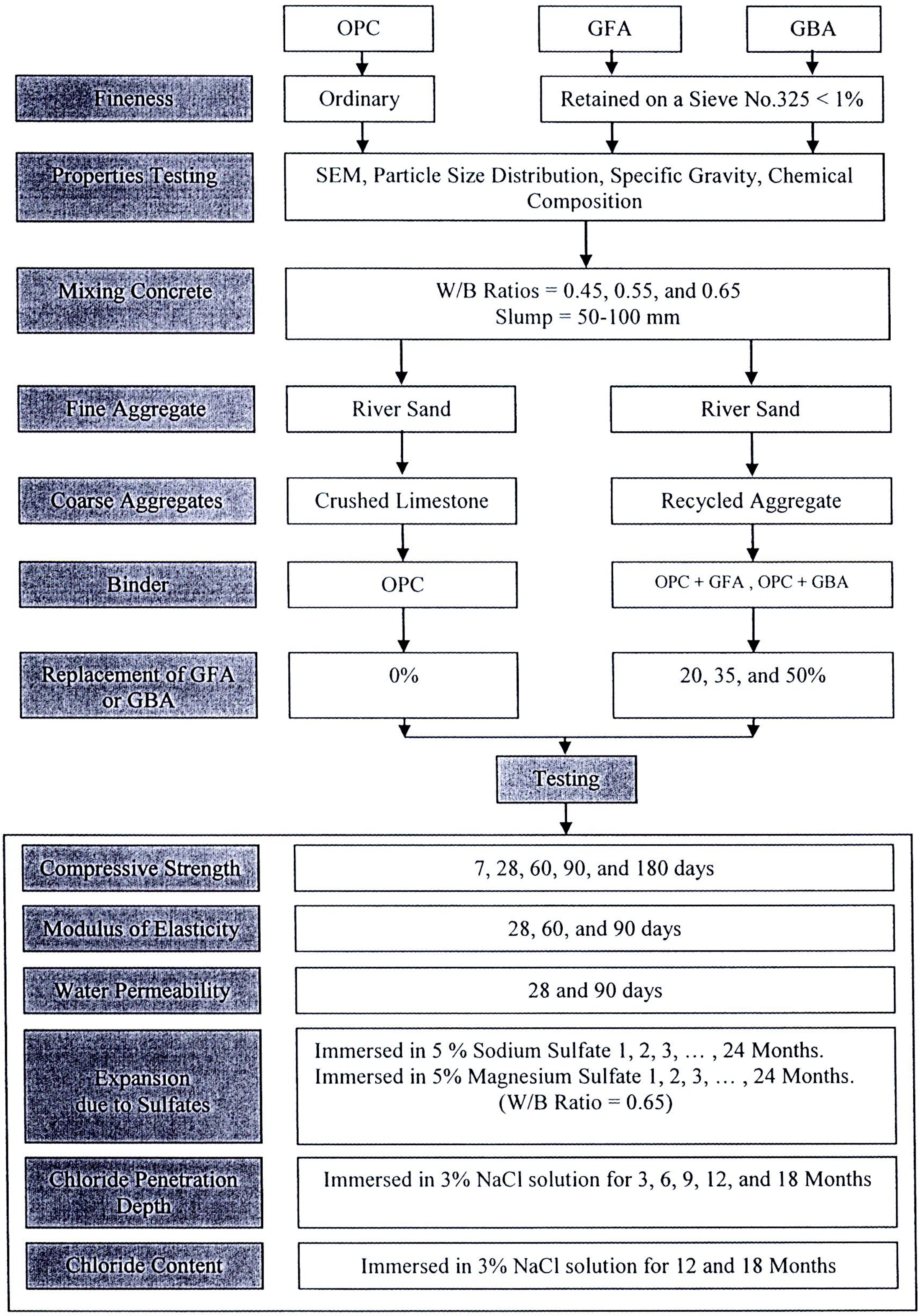


Figure 3.1 Experimental Program

The two-stage mixing approach method was chosen to mix concretes in this study because Tam, et al. (2005) suggested that this method can improve the interfacial zone between old aggregate and attached mortar by forming a thin layer of cement slurry on the surface of recycled aggregate and the cement slurry will permeate into the porous old cement mortar, filling up the old cracks and voids, resulting in denser recycled aggregate. For the two-stage mixing approach method, the mixing process was divided into two stages. In the first stage of mixing, recycled aggregate and sand were mixed together for 60 seconds and half of the mixing water was added into mixer and then mixed for 60 seconds. Then cement was added into the mixer and then mixed for 30 seconds. In the second stage, half of the remained mixing water was added to the mixture and mixed for 120 seconds to obtain fresh concrete. Concrete specimens were cast and removed from the moulds after casting for 24 hours. All concretes were cured in water until the testing date.

Table 3.1 Concrete Mix Proportions

Mix	Mix Proportion (kg/m^3)							W/B[b]	Slump (mm)
	Cement	GFA	GBA	Crushed Limestone	RCA	Sand	SP[a]		
45CON	424	-	-	979	-	767	-	0.45	70
45RC	424	-	-	-	936	733	-	0.45	65
45RCF20	340	84	-	-	922	723	0.9	0.45	60
45RCF35	274	150	-	-	913	716	1.1	0.45	75
45RCF50	212	212	-	-	905	709	2.1	0.45	80
45RCB20	340	-	84	-	922	719	2.5	0.45	80
45RCB35	274	-	150	-	908	708	4.6	0.45	80
45RCB50	212	-	212	-	893	697	8.5	0.45	55
55CON	350	-	-	1015	-	800	-	0.55	75
55RC	350	-	-	-	962	759	-	0.55	70
55RCF20	280	70	-	-	953	752	0.17	0.55	90
55RCF35	227.5	122.5	-	-	946	746	0.52	0.55	90
55RCF50	175	175	-	-	939	740	1.22	0.55	80
55RCB20	280	-	70	-	951	749	0.70	0.55	90
55RCB35	227.5	-	122.5	-	941	742	1.04	0.55	75
55RCB50	175	-	175	-	930	733	4.35	0.55	55
65CON	295	-	-	1039	-	814	-	0.65	80
65RC	295	-	-	-	990	777	-	0.65	80
65RCF20	236	59	-	-	983	770	-	0.65	75
65RCF35	191.8	103.2	-	-	975	767	0.30	0.65	70
65RCF50	147.5	147.5	-	-	971	761	0.59	0.65	90
65RCB20	236	-	59	-	981	768	0.44	0.65	75
65RCB35	191.8	-	103.2	-	973	762	0.88	0.65	75
65RCB50	147.5	-	147.5	-	964	754	1.77	0.65	75

[a] The water in the superplasticizer is assumed to be 50% and used this value for adjusting W/B ratio in the concrete mixture.

[b] Effective water to binder ratio of concrete with recycled coarse aggregate was in the saturated surface dry (SSD) state.

3.3.3 Symbols

The symbols of the samples are the combination of alphabets and numbers as follows.

45CON, 55CON, 65CON - Conventional concretes with the water to binder ratios of 0.45, 0.55, and 0.65, respectively. Conventional concretes used Portland cement and natural aggregates (crushed limestone and river sand) in their mixtures.

45RC, 55RC, 65RC - Recycled aggregate concretes with the water to binder ratios of 0.45, 0.55, and 0.65, respectively. These concretes used recycled coarse aggregate to fully replace crushed limestone in the mixtures.

45RCFxx, 55RCFxx, 65RCFxx - Recycled aggregate concretes with the water to binder ratios of 0.45, 0.55, and 0.65, respectively. These concretes used ground fly ash to replace Portland cement at xx percent by weight of binder and recycled aggregate to fully replace crushed limestone.

45RCBxx, 55RCBxx, 65RCBxx - Recycled aggregate concretes with the water to binder ratios of 0.45, 0.55, and 0.65, respectively. These concretes used ground bagasse ash to replace Portland cement at xx percent by weight of binder and recycled aggregate to fully replace crushed limestone.

3.3.4 Compressive Strength and Modulus of Elasticity

Concrete samples used to determine the compressive strength and modulus of elasticity are cylinder of 100-mm in diameter and 200-mm in height. The compressive strengths of concretes were determined at the ages of 7, 28, 60, 90, and 180 days as followed by ASTM C 39 (2001). At 28, 60, and 90 days, the moduli of elasticity of concretes were also investigated (followed ASTM C 469, 2001). The apparatus and set-up used to determine the modulus of elasticity of concrete is shown in Figure 3.2.

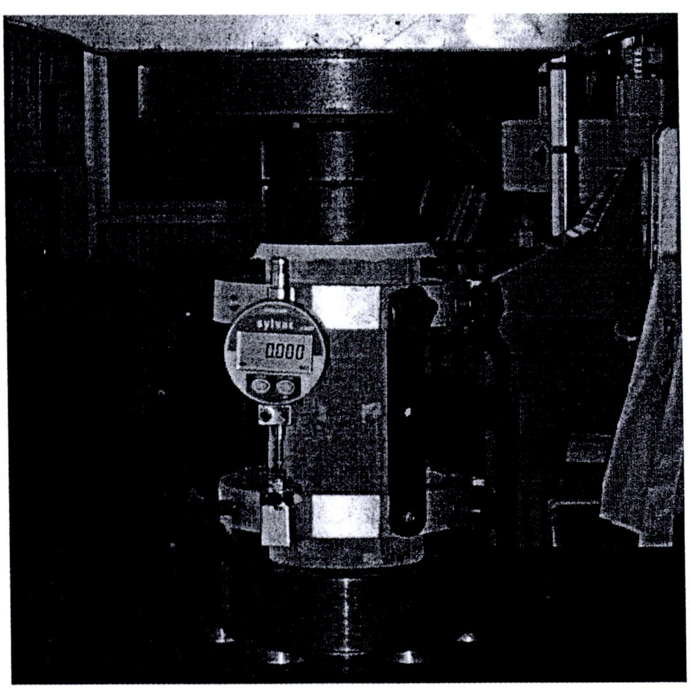


Figure 3.2 Modulus of elasticity testing set-up

3.3.5 Water Permeability

Water permeability coefficients of concretes were determined at the ages of 28 and 90 days. To prepare a concrete specimen, a 100×200 mm cylindrical concrete was cut at the top and bottom of concrete to obtain a 100 mm in diameter and 80 mm in length. The concrete was cut again at mid-height to obtain 2 pieces of concrete having 100 mm in diameter and 40 mm in length. Non-shrinkage epoxy resin with 25 mm thickness was cast around the perimeter of the 100×40 mm cylindrical concrete sample approximately 24 hours before testing to prevent water leakage during testing. After epoxy resin was set about 24 hours, the concrete specimen was installed in a permeability housing cell as shown in Figure 3.3. The steady flow method was selected to determine water permeability of concretes. A water pressure (P) of 0.5 MPa or 5 bars was used in this study because this pressure was recommended by the concrete society (1987). Time and amount of water passing through concrete specimen were monitored until the flow rate was constant and the water permeability was calculated by equation (3.1), which was used by many researchers (Hearn, et al., 1993; Khatri, 1997; Chan and Wu, 2000; Chindaprasirt, et al., 2007; Chusilp, et al., 2009a).

$$K = \frac{\rho L g Q}{PA} \qquad (3.1)$$

where

K	=	Coefficient of water permeability (m/s)
ρ	=	Density of water (kg/m^3)
g	=	Acceleration due to gravity (m/s^2)
Q	=	Flow rate (m^3/s)
L	=	Length of concrete sample (m)
P	=	Absolute water pressure (N/m^2)
A	=	Cross sectional area of concrete sample (m^2)

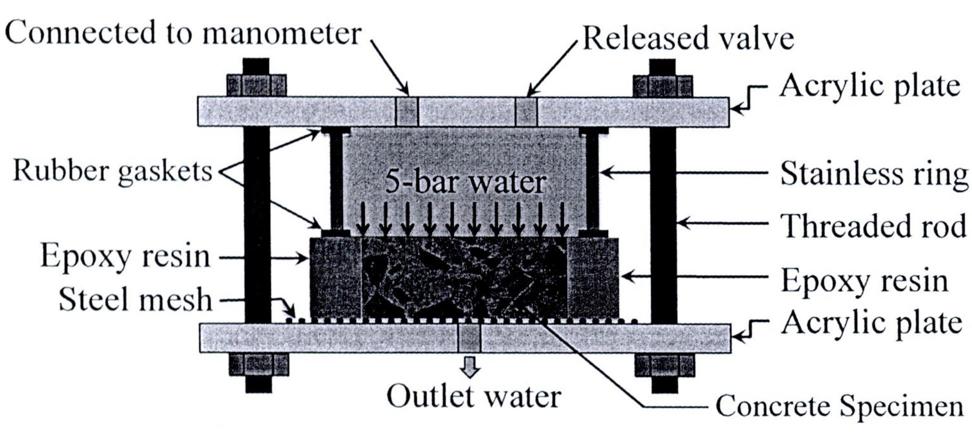


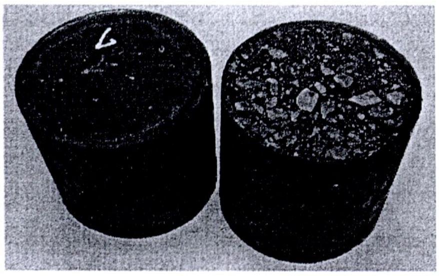
Figure 3.3 Permeability Housing Cell

3.3.6 Chloride Test

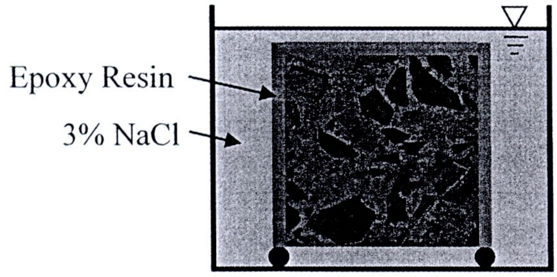
After 28 days of water curing, the concrete sample with 100 mm in diameter and 200 mm in height was cut at the mid-height to obtain two pieces of concrete samples. Non-shrinkage epoxy resin was cast around the surface of the samples prepared for determination of chloride ions diffused into concrete along one dimension as shown in Figure 3.4a. Then, the concrete 240 samples were immersed in 3% sodium chloride solution for investigating the chloride penetration depth and chloride contents as shown in Figure 3.4b.

After immersion in 3% sodium chloride solution for periods of 3, 6, 9, 12, and 18 months, the concrete samples were split (Figure 3.4c) and sprayed with 0.1N silver nitrate ($AgNO_3$) solution on the split surface of concrete as suggested by Otsuki, et al. (1993) who indicated that it was a suitable concentration for measurement of chloride penetration. After spraying with 0.1N $AgNO_3$ solution, the white color of AgCl appeared on the matrix of the sample at the depth at which the free chloride could penetrate into the concrete (Figure 3.4d). The chloride penetration depth was measured at the locations as shown in Figure 3.4e and the average value of chloride penetration depths was obtained from 10 measurements of the two split samples

The chloride contents of the concrete were investigated at 12 and 18 months to measure the chloride ingress into the concrete specimens. The concrete specimens were dried-cut from the surface to obtain 10-mm thick slices (see Figure 3.5a) and then the resin epoxy around concrete was removed (see Figure 3.5b). The concrete specimens in Figure 3.5b were ground into powder (see Figure 3.5c), and then sieved the powder by sieve No. 20 to obtain the powder sample for preparing solution for titration. The solution for determining the acid-soluble chloride content (or total chloride content) was prepared following by ASTM C 1152 (2001), while the solution preparation for investigating the water-soluble chloride content (or free chloride content) was followed by ASTM C 1218 (2001). Finally, the total chloride content and free chloride content were determined by Mohr's method which is one of titration methods.



(a)



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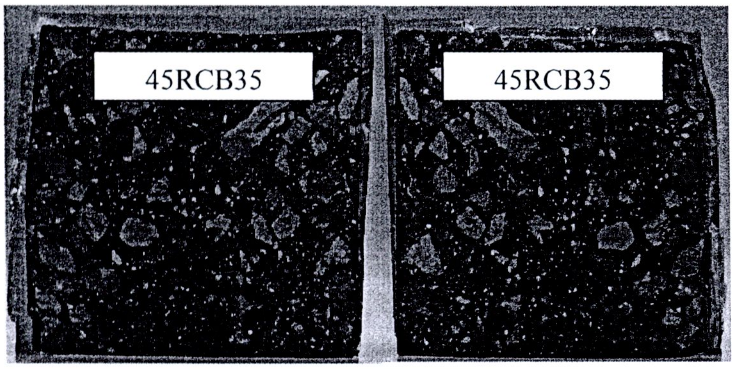

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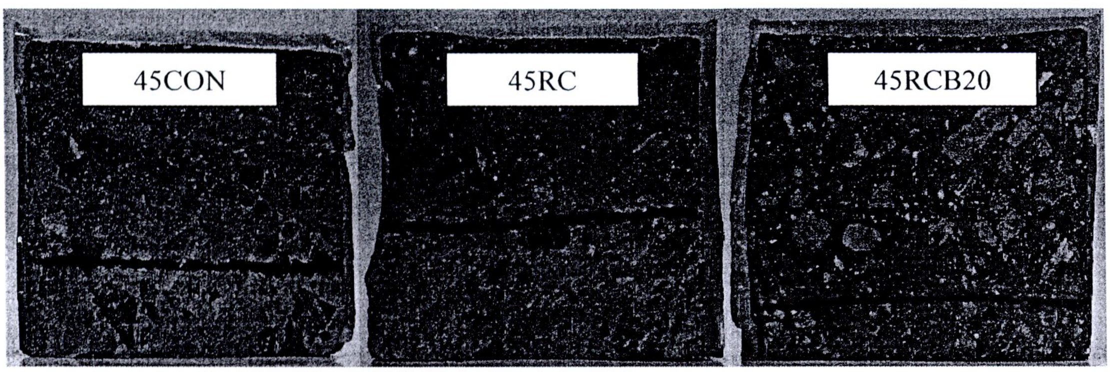

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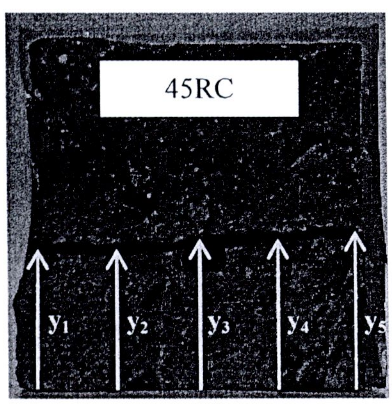
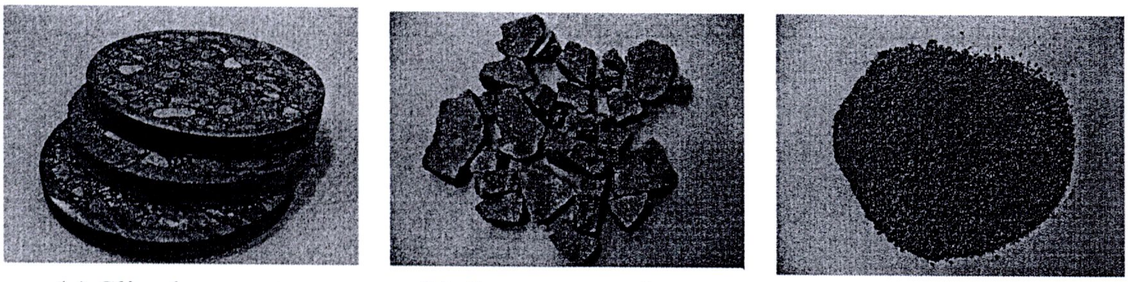


(e)

(a) Concretes were cast around with non-shrinkage epoxy resin
(b) Sample immersed in 3% NaCl solution
(c) Split sample for chloride penetration depth testing
(d) Samples were immersed in 3% NaCl 18 months, being split, and sprayed by 0.1N $AgNO_3$ solution
(e) Chloride penetration depth measurements

Figure 3.4 Concrete samples for chloride penetration depth test



(a) Sliced concretes (b) Concrete specimens (c) Concrete powder

Figure 3.5 Sample preparation for investigating chloride content

3.3.7 Expansion of Concrete in Sulfate Solutions

In this section, the concretes with water to binder ratio of 0.65 were used for testing the expansion due to sulfate attack. Concrete specimens are prism of 75-mm square cross-section and 285 mm in length with stainless stud embedded at both ends. After casting for 24 hours, the concrete specimen was removed from mold and the initial length was measured. The concrete specimens were separated into 2 groups. For the first group, the specimens were immersed in 5% of sodium sulfate solution. The second group, the specimens were immersed in 5% of magnesium sulfate solution. The expansions of concretes were investigated up to 24 months and the average of expansion for each mixture was obtained from two concrete specimens.