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An Experimental Study on the Properties of Concrete using High Volume of Coal Ash

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Abstract

Recently, the coal-ash production has been increased by increase of consumption of electric power. So it is important to secure a reclaimed land from pollution and develop practical application of coal ash.

This is an experimental study to compare and analyze the properties of concrete using high volume of coal ash (including fly ash and bottom ash) as a part of fine aggregate. For this purpose, the mix proportions of concrete according to replacement ratio of coal ash (10, 20, 35, 50%) were selected. And then air content, slump, setting time, bleeding content, chloride content, compressive strength and carbonation test were performed.

According to test results, it was found that the bleeding content of concrete using the coal ash decreased according to increase of replacement ratio. And the chloride content of concrete using the bottom ash as a part of fine aggregate increased as the replacement ratio of bottom ash increased, but it is satisfied with the total chloride content of concrete recommended by KCI - 0.3kg/m^3 below. Also, the compressive strength of concrete using the bottom ash was similar to that of plain concrete(BA 0) after 28days of curing and the carbonation depth of concrete increased as the replacement ratio increased. However, the carbonation depth of concrete using the fly ash decreased as the replacement ratio of fly ash increased.

Keywords : coal ash, setting time, bleeding, chloride content, compressive strength, carbonation depth

1. INTRODUCTION

Recently, in order to supply electric power to many industries developing fast, a lot of power plants are being constructed and planned. In case of Korea, it is expected that by-product of coal ash will be produced about 6 million tons in 2010.

Generally, coal ash can be divided into fly ash and bottom ash according to occurring place. The fly ash is the most common artificial pozzolana, and the bottom ash is occurred in bottom of combustor and occupies about 10 15% of total coal ash amount. However, because it is difficult to find a reclaimed land and management equipments on the coal ash, it has increased the significance for practical application of coal ash on the side of social and environmental problems.

Also, it is expected that necessity on the development of replacement material supplementing sea sand would be increased due to the restriction of using sea sand and exhaustion of natural aggregate. In case of using the coal ash as a replacement material of fine aggregate, it may be good effected on making up for lost powder washing sea sand and crushed sand.

Especially, it has increased the recycling ratio of fly ash every year but in case of bottom ash, most of it has been threw away. And because of poor physical properties of bottom ash itself - strength, shape, porosity etc.- it is necessary to investigate the properties of concrete using the coal ash as a replacement material of fine aggregate in concrete.

This is an experimental study to compare and analyze the engineering properties of concrete using large amount of coal ash as a part of fine aggregate to develop the efficient application technique of coal ash.

2. EXPERIMENTAL PROGRAM

2.1 Experimental procedure and mix proportions

Table 1 shows the experimental procedure and mix proportions of concrete.

In case of series Ⅰ, it is fixed the water/cement ratio 60%, water content 180kg/m^3 similar to normal strength concrete, and aiming slump is set up 18cm considering fluidity of concrete replacing the fly ash. In case of series Ⅱ, it is selected the aiming slump 8cm considering poor properties of bottom ash. And then it is compared and analyzed the engineering properties of concrete according to replacement ratio of coal ash(10, 20, 35, 50% by volume of fine aggregate).

And tests were performed for air content, slump, bleeding and setting time of fresh concrete by Korean Industrial Standards(KS). Also, in case of seriesⅡ, the total chloride content of fresh concrete was measured because of considering mix of salt in seawater. And in hardened concrete, the compressive strength after 3, 7, 28 and 56 days curing, and the carbonation depth after accelerated test 28 days were measured.

The total chloride content of fresh concrete was measured by means of the CL-203Z of MARUTO Ltd.(Fig. 1). Also, specimens for carbonation test, 100×100×400mm in size, was moist cured for 28 days and left in air for 1 week, and following this the specimens was left in an acceleration test machine at a temperature of about 20±

Table 1. Experimental procedure and mix proportions

Series	Factors[1)]	W/C (%)	Aiming Slump (cm)	Water Content (kg/m^3)	S/a (%)	Absolute volume[2)] (l/m^3)				Unit weight (kg/m^3)				Test items
						C	Ash	S	G	C	Ash	S	G	
Ⅰ	FA 0	60	18±2	180	41	95	0	293	422	300	0	750	1118	- Air content (%) - Slump (cm) - Chloride content[3)] (kg/m^3) - Setting time (hr.) - Bleeding content (cm^3/cm^2) - Compressive strength (kgf/cm^2) - Carbonation depth (mm)
	FA10						29	264			62	674		
	FA20						59	234			125	599		
	FA35						103	191			218	487		
	FA50						147	147			312	374		
Ⅱ	BA 0		8±2			95	0	293	422	300	0	750	1118	
	BA10						29	264			58	675		
	BA20						59	234			116	600		
	BA35						103	191			202	488		
	BA50						147	147			289	375		

Note) 1) FA : Fly Ash, BA : Bottom Ash 2) C : Cement, S : Sand, G : Gravel 3) Test for series Ⅱ

Fig. 1 The CL-203Z

Table 2. Physical property of materials

Materials	Physical property
Cement	Ordinary Portland cement Specific gravity(S.G.) : 3.15 Fineness : 3,265(cm2/g)
Fine aggregate	Sea sand, S.G : 2.56, F.M : 3.04 Maximum size : 5mm
Coarse aggregate	Crushed stone, S.G : 2.65, F.M : 6.5 Gmax : 20mm
Bottom Ash	Maximum size : 5mm, S.G : 1.97 F.M : 2.93, IOL : 20.5% Ratio of absorption : 5.8%
Fly Ash	Fineness : 3,610cm2/g, S.G : 2.13 IOL : 4.0%, SiO2 : 53.2%
Admixture	Superplasticizer (naphthalene-based)

2℃ and a relative humidity of 60±5% and CO_2 concentration 5±0.2%. And after 28 days period, test using 1% phenolphthalein indicator was performed.

2.2 Materials and mixing method

As shown in Table 2, the materials used in this study are ordinary portland cement, 5mm sea sand as fine aggregate,

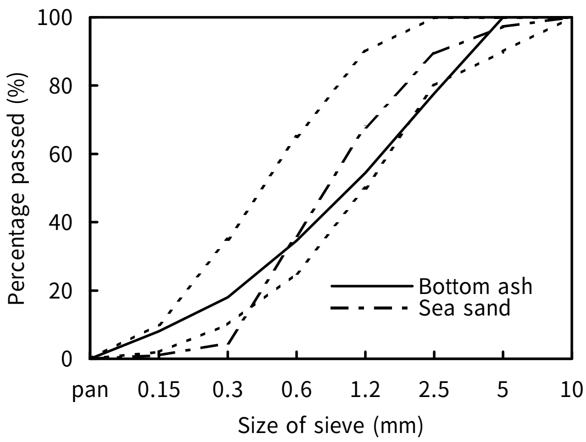
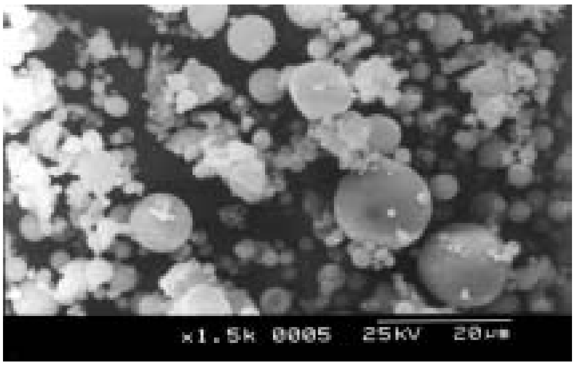


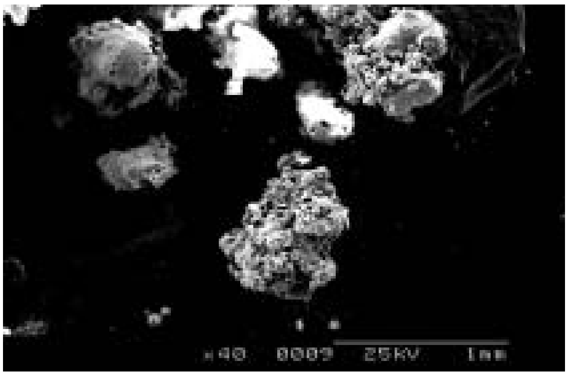
Fig. 3 Grading curve

20mm crushed stone as coarse aggregate and naphthalene-based superplasticizer as chemical admixture. Also, the physical properties of fly ash are S.G 2.13, fineness 3,610cm^2/g, and in case of bottom ash, the physical properties are S.G 1.97, IOL(Ignition on loss) 20.5% and FM 2.93 respectively.

In case of concrete mixing, as shown in Fig. 2, after preparation test mixing, it was mixed with cement, fine aggregate and coal ash about 30 seconds, and then put



(A) Fly ash



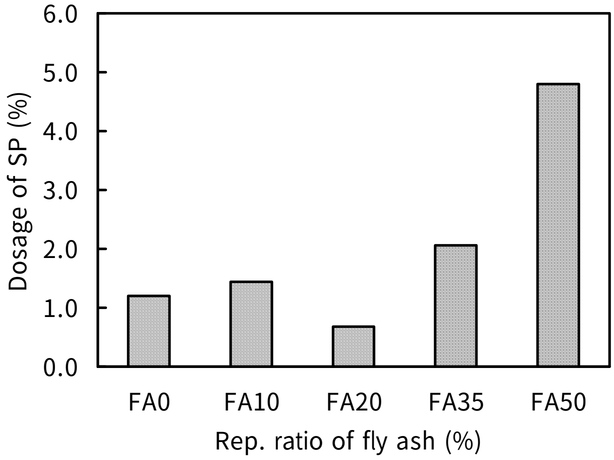
(B) Bottom ash

Fig. 4 SEM of coal ash

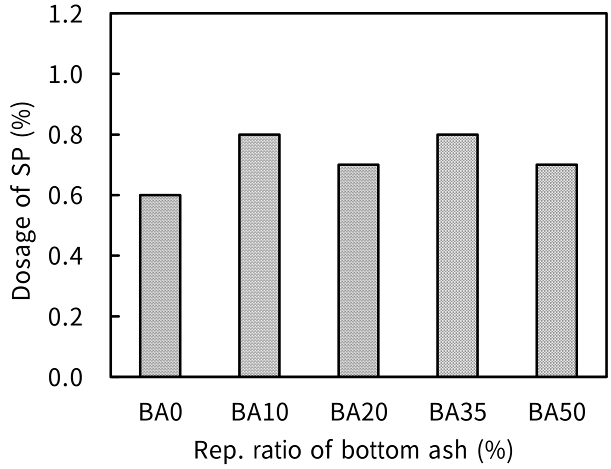
water, coarse aggregate and superplasticizer(SP) in mixer about 2 minutes to be mixed well.

As shown in Fig. 3 presenting grading curve of bottom ash and sea sand, in case of bottom ash it is satisfied with the standard grading curve.

In Fig. 4, the SEM of fly ash and bottom ash are presented. In case of fly ash(A), it is observed the shape of ball, however, the shape of bottom ash(B) is irregular and porous surface



(A) Fly ash



(B) Bottom ash

Fig. 5 Variation of dosage of SP

3. RESULTS AND DISCUSSION

3.1 Fresh concrete

Table 3. Experiment results

Series	Factors	Fresh concrete					Hardened concrete				
		Dosage of SP* (%)	Air content (%)	Slump (cm)	Bleeding content (cm^3/cm^2)	Chloride content (Cl-,kg/m^3)	Compressive strength (Mpa)				Carbonation Depth (mm)
							3days	7days	28days	56days	
Ⅰ	FA 0	1.20	4.5	18.0	0.45	-	17.7	22.2	30.1	32.2	6.9
	FA10	1.44	0.9	19.5	0.32		21.8	27.9	39.5	46.5	6.6
	FA20	0.68	0.9	20.0	0.28		21.6	28.0	45.3	50.4	5.5
	FA35	2.06	1.5	20.0	0.19		24.3	32.0	51.7	54.3	5.3
	FA50	4.80	2.0	20.5	0.12		27.3	32.9	57.7	65.7	4.1
Ⅱ	BA 0	0.60	2.8	10.0	0.50	0.052	13.0	20.1	32.8	35.2	5.7
	BA10	0.80	1.5	7.0	0.45	0.051	19.0	24.3	33.6	36.7	7.0
	BA20	0.70	2.5	7.5	0.38	0.079	17.7	23.0	32.0	34.0	8.3
	BA35	0.80	3.5	10.5	0.39	0.082	16.6	21.2	30.6	34.1	9.1
	BA50	0.70	3.0	7.0	0.08	0.097	14.9	20.5	30.1	32.5	10.3

Note) Series Ⅰ: dosage by binder(cement+FA) content, Series Ⅱ: dosage by cement content

3.1.1 Dosage of SP

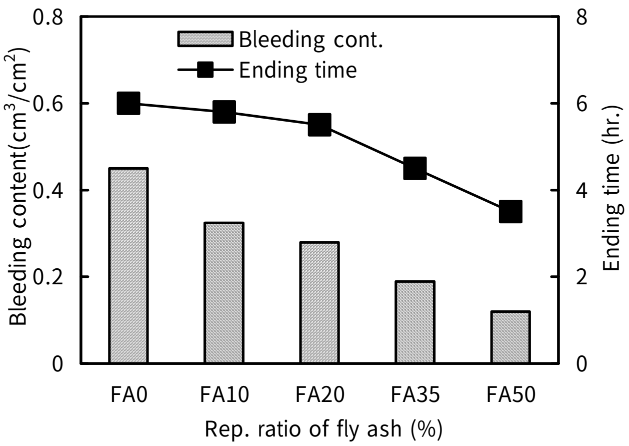
Table 3 shows the experiment results of this study. Fig. 5(A) and (B) shows the variation of SP (superplasticizer) dosage according to replacement ratio of fly ash and bottom ash respectively. In case of fly ash concrete(A), the SP dosage of FA50(replacement ratio of fly ash is 50 %) is larger than any other, in case of bottom ash concrete(B) the SP dosage is similar to each other between 0.6 and 0.8%.

3.1.2 Bleeding and setting time

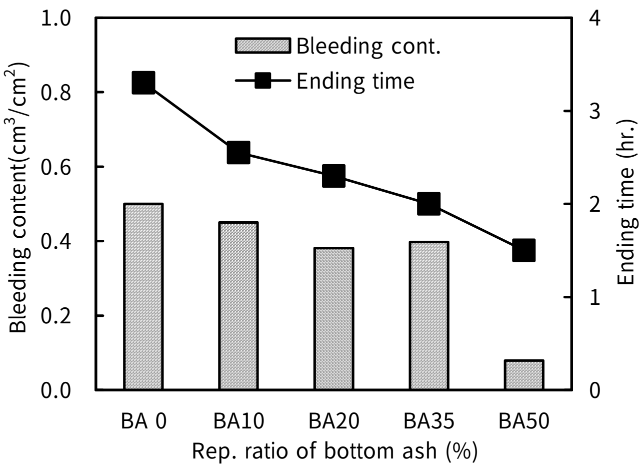
In Fig. 6(A) and 6(B), the variation of bleeding according to replacement ratio of fly ash and bottom ash are presented. As shown in Fig. 6, the incorporation of coal ash reduced the bleeding content and ending time of bleeding. In case of fly ash concrete, the bleeding content ranges from 0.32 to 0.12cm^3/cm^2, and in case of bottom ash concrete, the bleeding content ranges from 0.45 to 0.08cm^3/cm^2.

Fig. 7(A) and 7(B) show the variation of penetration resistance by replacement ratio of coal ash. In case of fly ash concrete, the larger the fly ash was replaced the slower the setting time was. However, comparing to other literature about the setting time of concrete using the large amount of fly ash, it is not much increased the setting time. The setting time of FA50 is much slower than that of others due to large dosage of SP.

The setting time of bottom ash concrete(B) is similar to each other, that is, the initial and final setting time are measured from 7 to 9 hours and from 8 to 11 hours respectively.

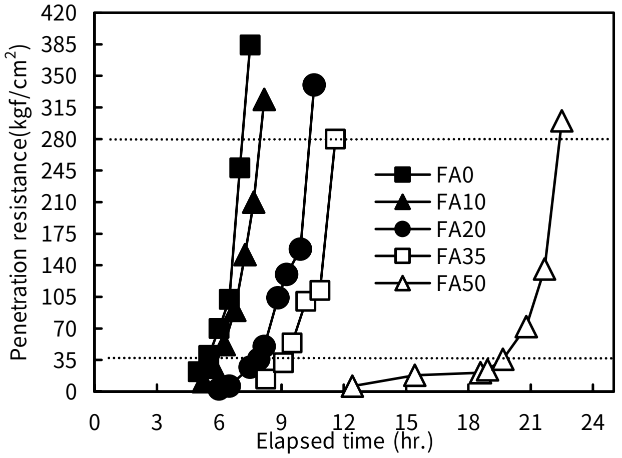


(A) Fly ash

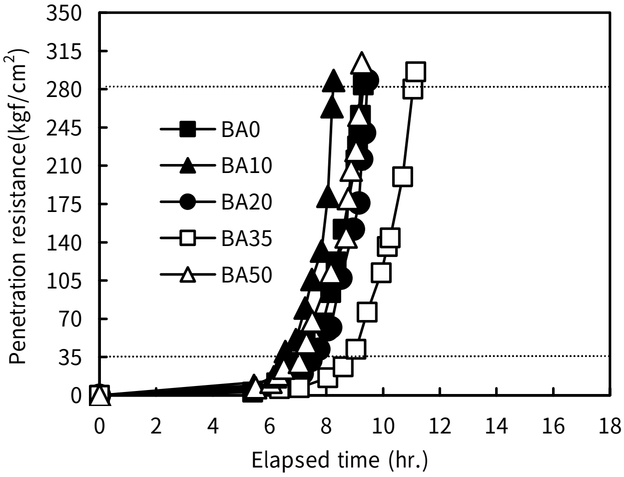


(B) Bottom ash

Fig. 6 Variation of bleeding content and ending time



(A) Fly ash



(B) Bottom ash

Fig. 7 Variation of penetration resistance

3.1.3 Chloride content

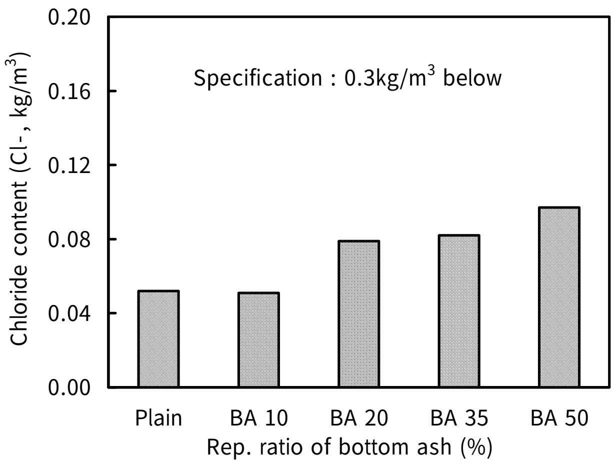


Fig. 8 Variation of chloride content(bottom ash)

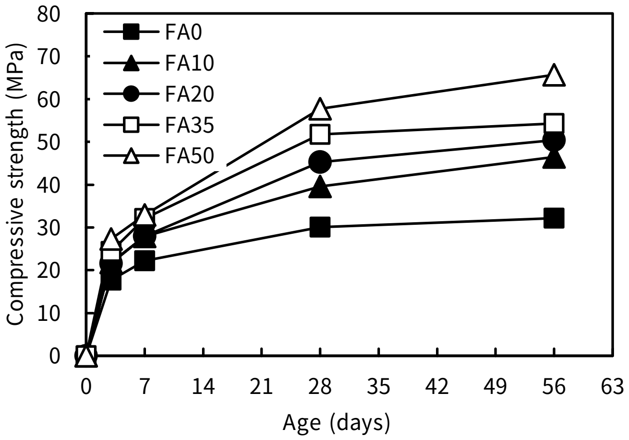
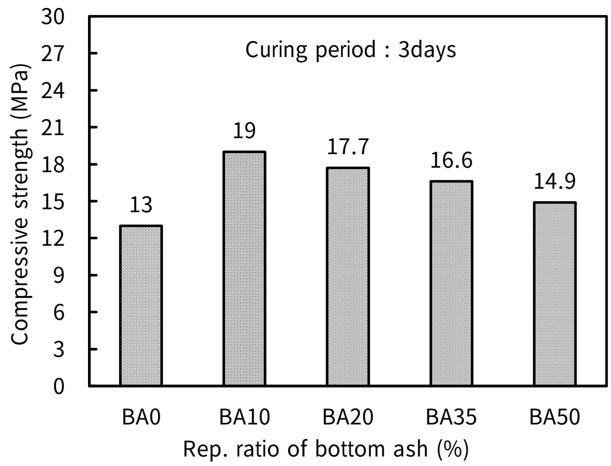
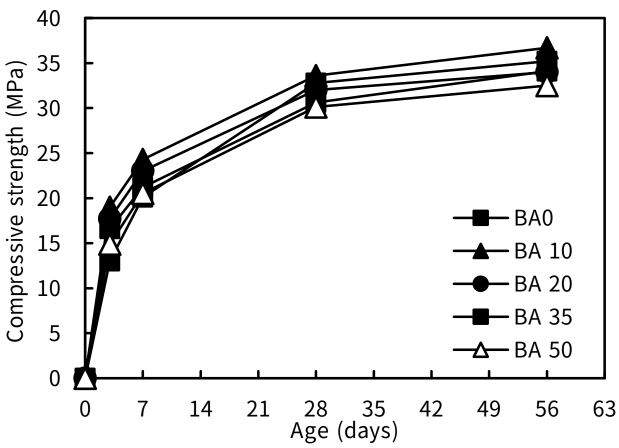


Fig. 9 Variation of compressive strength according to the age (fly ash)



(A) Compressive strength at 3 days



(B) Compressive strength according to the age

Fig. 10 Variation of compressive strength according to the age (bottom ash)

As shown in Fig. 8 presenting the variation of total chloride content according to replacement ratio of bottom ash, the incorporation of bottom ash increased the chloride content of fresh concrete. It is considered that small salt was included in bottom ash of concrete sending to reclaimed land by seawater. However, it is satisfied with the total chloride content of concrete recommended by KCI(Korea Concrete Institute) - 0.3kg/m^3 below.

3.2 Hardened concrete

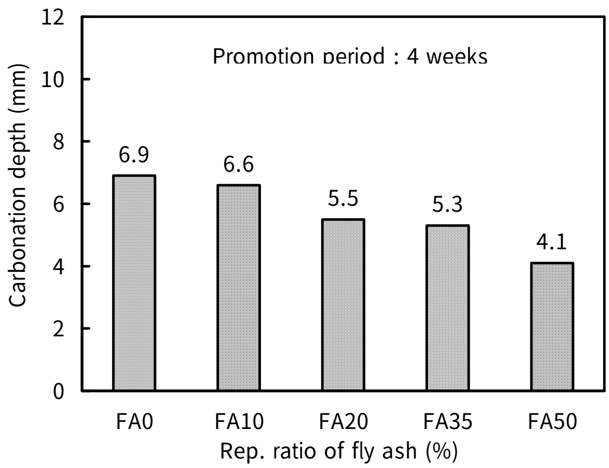
3.2.1 Compressive strength

Fig. 9 shows the variation of compressive strength according to replacement ratio of fly ash. In all the age including early and long term age, the compressive strength increased as the fly ash replacement increased because fly ash particle fill up the pore of concrete and made the cement paste densely. Also it is found that the compressive strength of FA50 is nearly double that of FA0 at 56 days due to the pozzolanic reaction of fly ash.

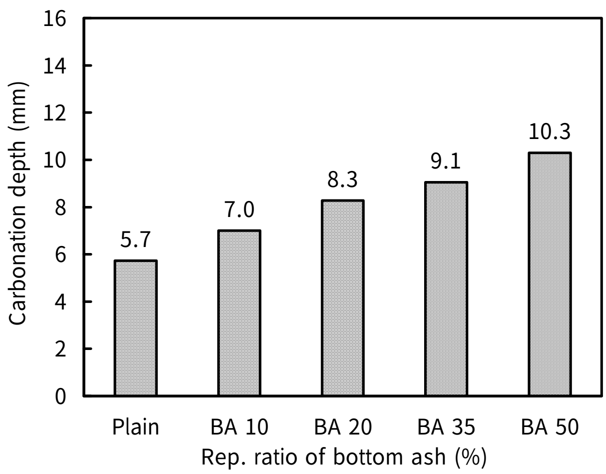
In Fig. 10(A) and 10(B), the variation of compressive strength according to replacement ratio of bottom ash are presented. In case of early age(A), the compressive strength of bottom ash concrete is higher than that of BA0, however the compressive strength are close each other after 28days.

3.2.2 Carbonation depth

In Fig. 11(A) and 11(B), the variation of carbonation depth according to replacement ratio of coal ash after accelerated 28 days are presented. In case of fly ash



(A) Fly ash



(B) Bottom ash

Fig. 11 Variation of carbonation depth

concrete(A), the carbonation depth decreased as the replacement ratio increased, and was smaller than FA0 because the fly ash filled up the pore and pozzolanic reaction made concrete to dense. However, in case of bottom ash concrete(B), it was measured that the carbonation depth increased as the replacement ratio of bottom ash increased due to the porosity of bottom ash.

4. CONCLUSIONS

The following conclusions were obtained based on the results of the experimental study.

1. The incorporation of coal ash reduced the bleeding content and ending time of bleeding. And in case of setting time, the larger the fly ash was replaced the slower the setting time was, however, the setting time of bottom ash concrete is similar to each other.

2. The total chloride content of fresh concrete increased as the replacement ratio of bottom ash increased, but it is satisfied with the total chloride content of fresh concrete recommended by KCI - 0.3kg/m^3 below.

3. The compressive strength of fly ash concrete increased as the replacement ratio increased, however, that of bottom ash concrete similar to each other.

4. When replacing the fly ash to fine aggregate, the carbonation depth decreased as the replacement ratio of fly ash increased, in case of replacing bottom ash, it was measured that the carbonation depth increased as the replacement ratio of bottom ash increased.

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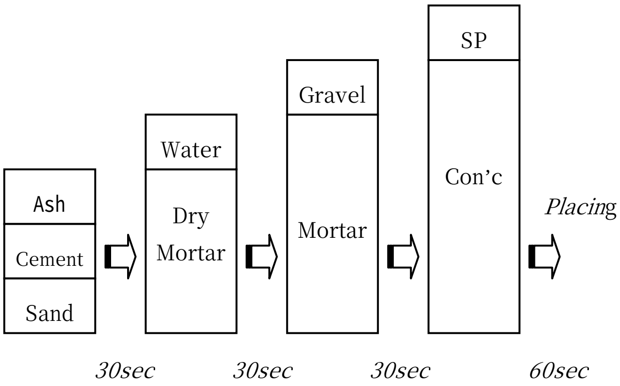

Fig. 2 Mixing method of concrete