Journal of Hazardous Materials 166 (2009) 348–355

Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Research article

An experimental study on the hazard assessment and mechanical properties of porous concrete utilizing coal bottom ash coarse aggregate in Korea

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ARTICLE INFO

Article history:
Received 18 August 2008
Received in revised form
10 November 2008
Accepted 10 November 2008
Available online 24 November 2008

Keywords:
Aggregate quality
Coal bottom ash
Fracture shape
Hazard
Mechanical property

ABSTRACT

This study evaluates quality properties and toxicity of coal bottom ash coarse aggregate and analyzes mechanical properties of porous concrete depending on mixing rates of coal bottom ash. As a result, soundness and resistance to abrasion of coal bottom ash coarse aggregate were satisfied according to the standard of coarse aggregate for concrete. To satisfy the standard pertaining to chloride content, the coarse aggregates have to be washed more than twice. In regards to the result of leaching test for coal bottom ash coarse aggregate and porous concrete produced with these coarse aggregates, it was satisfied with the environment criteria. As the mixing rate of coal bottom ash increased, influence of void ratio and permeability coefficient was very little, but compressive and flexural strength decreased. When coal bottom ash was mixed over 40%, strength decreased sharply (compressive strength: by 11.7–27.1%, flexural strength: by maximum 26.4%). Also, as the mixing rate of coal bottom ash increased, it was confirmed that test specimens were destroyed by aggregate fracture more than binder fracture and interface fracture. To utilize coal bottom ash in large quantities, it is thought that an improvement method in regards to strength has to be discussed such as incorporation of reinforcing materials and improvement of aggregate hardness.

1. Introduction

Due to the rapid growth and expansion of Korean industries in recent years, industrial wastes have been on the rise [1]. Particularly, with the increase in the demand for power in the public and private sectors due to the expansion of key national projects as well as industrial and transportation facilities, more than 6 million tons of coal ash is being generated from thermal power plants annually in Korea [2]. The fly ash that accounts for approximately 80% of the total generated amount of coal ash is produced in the form of fine powder of 1–100 μm in size, most of which is recycled as raw material for cement or cement admixture. Studies on the recycling of fly ash are performed actively in an ongoing manner [3]. However, the bottom ash that accounts for 10–15% of the total generated amount of coal ash is less effectively recycled compared to the fly ash. Most of the bottom ash is buried or disposed of using facilities that no longer meet its storage capacity [4].

In addition, by the "Instruction for coal ash recycling for enterprises generating coal ash" found under the "Act on the promotion of saving and recycling of resources" for national environmental projects, the goal for the coal ash recycling rate will be increased in Korea (35% up to 2003, 70% from 2008) [5]. It is expected that bottom ash will be used as the recyclable resource that can replace raw material due to the ever increasing size of structures, shortage of good quality construction materials, and natural aggregate resources.

On the other hand, entering the 21st century, as environmental contamination has been recognized seriously and interest has been concentrated on the development of new technology with new concepts that consider the environment, it has been required for the construction industry to perform development that emphasizes harmony between the environment and humankind when implanting various development projects. Paying keen attention to porous concrete with environmentally friendly functionality allowing the habitation of living things including water and air permeability, plantation and water purification by forming a great amount of continuous voids and large specific surface area in the concrete composite, studies are being performed on the recycling of coal ash for various uses. Likewise in the world, attention is being paid to these types of studies [6].

Therefore, in order to effectively recycle the coal bottom ash coarse aggregate, which is one of the industrial by-products, and to develop an environmentally friendly porous concrete utilizing coal ash, this study performed basic quality tests for coal bottom ash aggregate and hazard assessment for nine substances including Cr^{6+}. In addition, this study carried out investigation and analysis on

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doi:10.1016/j.jhazmat.2008.11.054

Table 1
Physical and chemical properties of fly ash.

Physical properties	
Density (g/cm^3)	2.10
Blaine's (cm^2/g)	3124
Particle size (mm)	4.2×10^{-2}
Chemical compositions (%)	
SiO_2	65.3
Al_2O_3	25.5
Fe_2O_3	4.25
CaO	1.20
MgO	0.98
Na_2O	0.21
SO_3	1.03
Ig. loss	3.63

the mechanical property of the porous concrete using coal bottom ash aggregate per mixing ratio.

2. Material and experiment method

2.1. Material used

2.1.1. Cement

The cement used for this study is normal Portland cement whose density is 3.14 g/cm^3 and Blaine fineness is 3200 cm^2/g.

2.1.2. Fly ash

The fly ash used for this study is generated from the thermal power plant of "C" company in Korea. Table 1 shows the physical and chemical properties of the fly ash.

2.1.3. Aggregate

The aggregate used for this study is from crushed granite, and bottom ash which is generated from the thermal power plant (once-through boiler) of "C" company in Korea. Tables 2 and 3 show the physical and chemical properties of the crushed aggregate and bottom ash. In addition, Fig. 1 shows coal bottom ash coarse aggregate, and Fig. 2 shows the XRD diffraction analysis of coal bottom ash.

2.1.4. Admixture

The high-range AE water-reducing agent of the polycarboxylic acid manufactured by "K" company in Japan was used as the admixture to improve the dispersion of cement and fine entraining of the air. Table 4 shows the physical properties of the admixture.

2.2. Mix proportion and mixing

In order to analyze the hazard assessment and mechanical properties of the porous concrete utilizing coal bottom ash, the porous concrete mix was made by changing the grading of aggregate (5–13 and 13–20 mm) and the mixing ratio of the coal bottom ash (0, 20, 40, 60, 80 and 100%) with the w/c being 25% and the design void ratio being 20%. In addition, fly ash was added with mixing ratio of 20% at which optimum performance was obtained through advance testing. Table 5 shows the mix proportion. At this time, the amount of admixture to be added was determined by setting the target flow of the bonding material to 180% through a pretest to secure proper workability when producing porous concrete for paving. The mixing was performed by applying the divided mixing method as follows: the cement, aggregate, and fly ash were put into the omni-mixer, which was used to improve the dispersion of

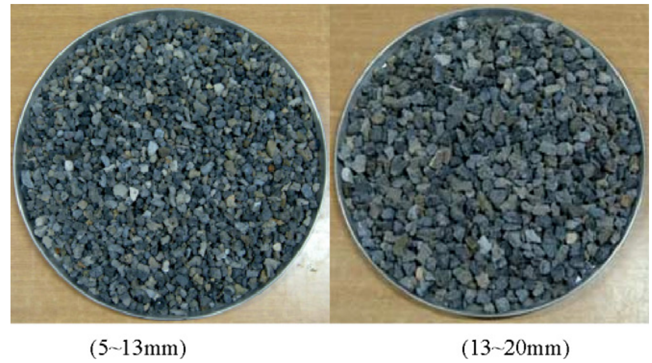

Fig. 1. Coal bottom ash coarse aggregate.

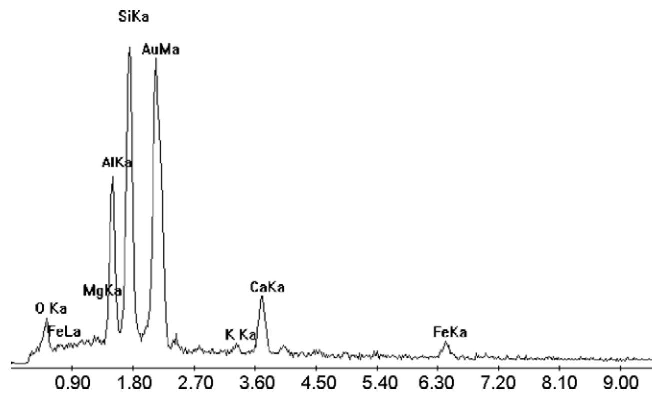

Fig. 2. XRD diffraction analysis of coal bottom ash.

Table 4
Physical properties of admixtures.

Item	High-range water-reducing agent (HWRA)
Appearance	Dark Brown Liquid
Density (g/cm^3)	1.21
pH	7–9
Mass content (%)	41–45

Table 2
Physical properties of crushed aggregate.

Grading (mm)	Density (g/cm^3)	Unit weight (kg/m^3)	Water absorption (%)	Absolute volume (%)
5–13	2.79	1693	0.84	60.6
13–20	2.79	1661	0.74	59.6

Table 3
Physical and chemical properties of coal bottom ash.

Physical properties					Chemical compositions (%)							
Grading (mm)	Density (g/cm^3)	Unit weight (kg/m^3)	Water absorption (%)	Absolute volume (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2
5–13	2.41	1275	2.43	52.86	47.90	25.94	4.76	2.48	1.10	1.38	0.67	0.86
13–20	2.48	1270	2.11	51.11								

Table 5
Mix proportions.

Mix no.	Aggregate condition	W/C (%)	Void ratio (%)	Fly ash contents (%)	Bottom ash contents (%)	Unit weight (kg/m^3)					HWRA (C×%)
						C	FA[a]	W	CA[b]	BA[c]	
Plain (I)	5–13 mm	25	20	0	0	340	0	85	1693	0	2.72
I-1				20	0	261	65	82	1693	0	2.61
I-2					20	281	70	88	1354	254	2.81
I-3					40	301	75	94	1016	508	3.01
I-4					60	322	81	101	677	763	3.22
I-5					80	345	86	108	339	1017	3.45
I-6					100	369	92	115	0	1271	3.69
Plain (II)	13–20 mm	25	20	0	0	360	0	90	1661	0	2.88
II-1				20	0	277	69	87	1661	0	2.77
II-2					20	294	73	92	1329	207	2.94
II-3					40	318	80	100	997	518	3.18
II-4					60	340	85	106	664	777	3.40
II-5					80	367	92	115	266	1036	3.67
II-6					100	387	97	121	0	1295	3.87

[a] FA: fly ash.
[b] CA: crushed aggregate.
[c] BA: bottom ash.

Table 6
Quality test of aggregate.

Items	Test method
Test for soundness	KS F 2507 "Method of test for soundness of aggregate by use of sodium sulfate" ASTM C 88 "Test method for soundness of aggregate by use of sodium sulfate or magnesium sulfate"
Test for resistance to abrasion	KS F 2508 "Method of test for resistance to abrasion of coarse aggregate by use of the Los Angeles machine" ASTM C 535 "Test method for resistance to degradation of large-size coarse aggregate by abrasion and impact in the Los Angeles machine"
Test of chloride content	KS F 2515 "Testing method of chloride content in aggregate"

cement paste, dry mixing was carried out for 90 s and then wet mixing was performed by adding the mixed water (water + admixture) for 120 s to give fluidity.

2.3. Experiment method

2.3.1. Test for properties of aggregate quality

In order to investigate and analyze the possibility of using coal bottom ash as an aggregate for porous concrete, a quality properties test was performed according to relevant KS and ASTM standards as shown in Table 6.

2.3.2. Leaching test of heavy metals

Appendix 1 of the Enforcement Regulation of the Korean Waste Management Law specifies the standard for the content of the deleterious substances in waste [7]. Therefore, before applying the coal bottom ash, an industrial by-product, such as an aggregate for porous concrete to be used as an environmental friendly product. This study performed a leaching test of deleterious substances for the material as well as the concrete in which these materials are used. This test was performed in accordance with the "Waste Process Test Method" of the Ministry of the Environment of Korea to measure the amount of the deleterious substances [8].

2.3.3. Void ratio test

The void ratio was measured in accordance with the "Testing Method for Void Ratio of Porous Concrete (draft)" in the "report of the research committee related to the establishment of design and construction method for porous concrete" of the Japan Concrete Institute [9]. The void ratio was calculated using the following equation (1).

$$A\ (\%) = \left\{1 - \frac{W_2 - W_1}{V}\right\} \times 100 \qquad (1)$$

where A is the total void ratio of the concrete (%); W_1 the weight of the test piece in water (g); W_2 the air dried weight of the test piece after being placed in natural conditions for 24 h (g); and V is the volume of the test piece (cm^3).

2.3.4. Permeability coefficient test

The permeability coefficient was measured in accordance with the "Testing Method for Permeability of Porous Concrete (draft)" in the "report of the research committee related to the establishment of design and construction method for porous concrete" of the Japan Concrete Institute [9]. The coefficient was calculated using the following equation (2) in accordance with Darcy's Law.

$$K = \frac{H}{h} \times \frac{Q}{A(T_2 - T_1)} \qquad (2)$$

where K is the permeability coefficient (cm/s); H the height of test piece (cm); A the cross sectional area of test piece (cm^2); $T_2 - T_1$ the measurement period of time (s); H the difference in level (cm); and Q is the flow quantity during the period from T_1 to T_2 (cm^3).

2.3.5. Compressive strength test

For tests on the compressive strength, specimens of Ø100 mm × 200 mm were made and then cured under water at 23 °C ± 2 °C for 28 days. Measurements were taken in accordance with the KS F 2405 "Test Method for Compressive Strength of Concrete" using the UTM made by "M" company in Japan.

2.3.6. Flexural strength test

For tests on the flexural strength, specimens of 100 mm × 100 mm × 400 mm were made and then cured under water at 23 °C ± 2 °C for 28 days. Measurements were taken in accordance with the KS F 2408 "Test Method for Flexural Strength for Concrete" using the B-Type Autograph made by "S" company in Japan.

Table 7
Quality properties of aggregate.

Items	Standard		Test value			Evaluation
	KS F 2526 "Aggregate for concrete"	ASTM C 33 "Standard specification for concrete aggregate"				
Soundness (%)	≤12	≤18		5–13 mm	9.6	OK
				13–20 mm	8.9	
Resistance to abrasion (%)	≤40	≤50	Crush aggregate	5–13 mm	16.2	OK
				13–20 mm	20.4	
			Coal bottom Ash	5–13 mm	31.7	OK
				13–20 mm	27.2	
Chloride content (%)	≤0.04	–	Washing number	0	0.1812	N.G
				1	0.0611	N.G
				2	0.0238	OK
				3	0.0145	OK

3. Experiment results and discussion

3.1. Quality properties of aggregate

Table 7 shows the results of an aggregate quality test performed to examine the applicability of coal bottom ash as a suitable material for concrete. It was found that the soundness of coal bottom ash aggregate was less than 18%, which is the allowable value of KS F 2526 and ASTM C 33 for all aggregate grading, satisfying the set standards. In addition, when the aggregate grading was 5–13 and 13–20 mm, the soundness of aggregate was approximately 9.6 and 8.9%, respectively, showing little difference. From this it can be seen that there is almost no difference in the soundness of aggregate according to the aggregate grading.

When the aggregate grading was 5–13 and 13–20 mm, the abrasion rate of the coal bottom ash was approximately 31.7 and 27.2%, respectively. Since these values were less than the allowable value of 50% for concrete aggregate, they were found to satisfy KS F 2526 and ASTM C 33. In addition, it was observed that the abrasion rate of the 5–13 mm coal bottom ash aggregate was greater than the 13–20 mm coal bottom ash aggregate. However, the difference was 4.5%, which is not significant. When compared with crushed aggregate, the abrasion rate of the coal bottom ash aggregate with grading of 5–13 and 13–20 mm increased by approximately 15.5 and 6.8%, respectively. It is thought that the abrasion rate was greatly decreased because the surface of the coal bottom aggregate has a porous structure and relatively smaller hardness.

The chloride content of the coal bottom ash aggregate was measured according to the number of times of washing immediately after it was produced. Table 7 shows the measurement results. 5 l of water and 5 kg of aggregate were fed into an omni-mixer and the aggregate was washed for 10 min. From this it was found that following treatment of the coal bottom ash, the chloride content of the coal bottom ash aggregate was 0.1814%, which is greater than the standard chloride content of 0.04%, and that the chloride content was decreased as the number of times of washing increased. When the coal bottom ash aggregate was washed twice, the chloride content was 0.0238%, which indicated that the coal bottom ash aggregate satisfied the standard for concrete aggregate. It is thought that since the coal bottom ash contained many bubbles on the surface, the salt in the aggregate was not removed below standard value by washing it once. Therefore, it is desired to wash the coal bottom ash aggregate at least twice before using it as concrete aggregate.

Table 8
Test method and equipment for detection analysis of harmful materials.

Test items	Test methods and equipments
Cr^{6+}	UV–vis Spectrophotometer
As, Hg	AAS (Atomic Absorption Spectrophotometer)
Pb, Cd, Cu, CN	ICP (Inductive Coupled Plasma Emission Spectrophotometer)
PCE[a], TCE[b], OP[c]	ATD-GC/MS (Automated Thermal Desorption-Gas-chromatography/Mass Spectrophotometry)

[a] PCE: tetrachloroethylene.
[b] TCE: trichloroethylene.
[c] OP: organophosphates.

3.2. Hazard of aggregate

Since the coal bottom ash, an industrial by-product, is classified as waste by the Environmental Act of Korea, this study performed a hazard assessment before applying it as concrete material. Table 8 shows the test methods and equipment for each harmful material according to the Solid Waste Process Test Methods specified by the Ministry of Environment of Korea. In addition, the Waste Management Law provides the environmental criteria concerning the harmful materials and Table 9 presents the criteria specified in the Solid Waste Management Law in Korea.

Table 9 shows the results of assessment on the extent of harmfulness to the natural ecosystem when using the coal bottom ash as concrete aggregate. From this it was found that the initial pH of the coal bottom ash was 7.35 and the coal bottom ash and the porous concrete using the coal bottom ash was below the criteria (nine materials including Cr^{6+}) on the harmful materials specified by the current relevant domestic laws and regulations in Korea, satisfying the environmental criteria [10].

Table 9
Environment criteria and detection amount of harmful materials by solid waste management law.

Sample	Test items (mg/l)									
	Cr^{6+}	As	Cd	Pb	Cu	CN	Hg	PCE	TCE	OP
Environment criteria	1.5	1.5	0.3	3	3	1	0.005	0.1	0.3	1
Coal bottom ash	0.062	0.032	0.004	0.093	0.090	Non-detection	Non-detection	Non-detection	Non-detection	Non-detection
Porous concrete using coal bottom ash	Non-detection	0.012	0.001	0.021	0.005	Non-detection	Non-detection	Non-detection	Non-detection	Non-detection

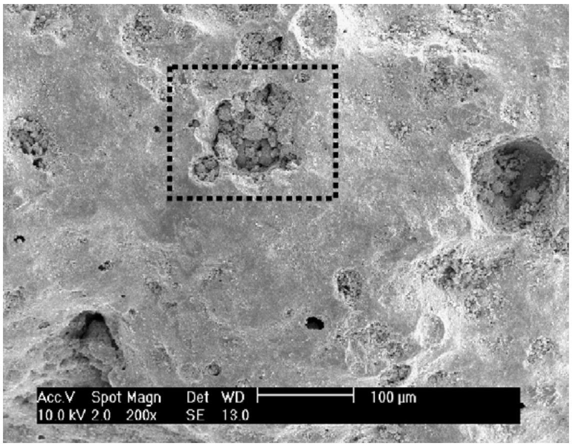

Fig. 3. SEM analysis of coal bottom ash (200×).

3.3. Characteristics of aggregate surface

Figs. 3 and 4 present the SEM images of the coarse bottom ash, an industrial by-product. As shown in the figures, the coal bottom ash had a porous surface with a great many bubbles and the area with voids was not so dense compared to other areas. In addition, it was observed that small particles were tangled and could fall out relatively easily.

3.4. Void ratio

Fig. 5 presents the result of void ratio measurements of the porous concrete using coal bottom ash. From this it was found that as the coal bottom ash mixing ratio increased, the target void ratio was decreased by more or less 20% at all aggregate grading, demonstrating a difference of maximum 1.8%. In addition, it was found that the void ratio according to aggregate grading was 19.7–21.2 and 20.4–22.2% at aggregate grading of 5–13 and 13–20 mm, respectively, and that there was almost no difference according to the aggregate grading. However, as the coal bottom ash mixing ratio increased, the unit mass of the specimen decreased and accordingly the weight of the concrete was decreased.

Therefore, it was found that the mixing ratio of the coal bottom ash and fly ash had no influence on the void ratio. From this it is thought that bubbles were generated during the coal ash cooling process to form voids inside the aggregate. However, since there were lots of smooth surfaced aggregates among various types of

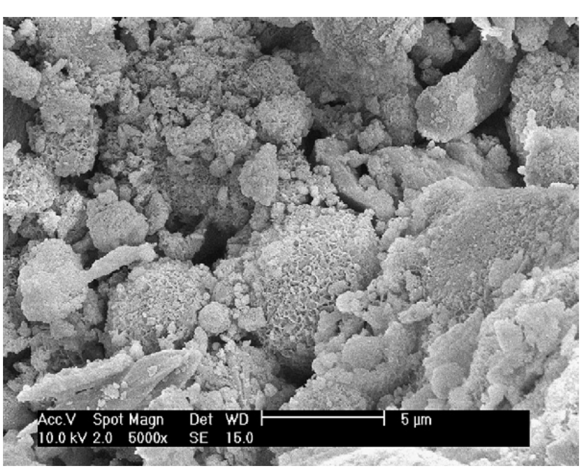

Fig. 4. SEM analysis of coal bottom ash (5000×).

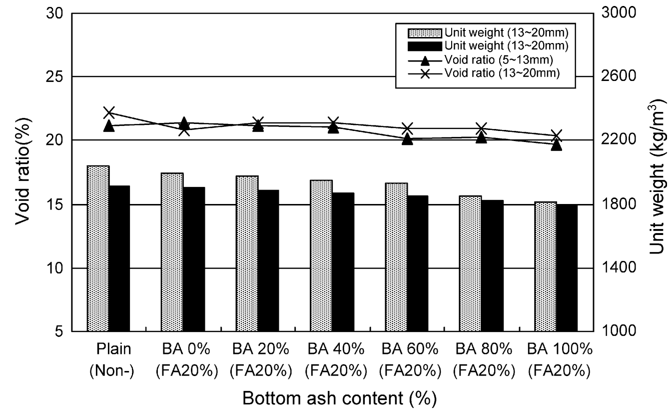

Fig. 5. Void ratio by coal bottom ash contents.

aggregates and the grain shape was mainly round, the void ratio did not show a tendency of significant change.

3.5. Coefficient of permeability

Fig. 6 demonstrates the test result of permeability coefficient of the porous concrete using coal bottom ash by aggregate grading. It was found that as the coal bottom ash mixing ratio increased, the permeability coefficient was decreased at all aggregate grading, showing only a slight difference of 0.028 cm/s. From this it is thought that the grading of the coal bottom ash was the same as the grading of crushed aggregate and the grain shape was mainly round with no angular-shaped grain. Therefore, the influence of the permeability coefficient according to the mixing of the coal bottom ash aggregate was minor.

3.6. Compressive strength

Figs. 7 and 8 present the test result of compressive strength of porous concrete using coal bottom ash. From this it was found that when fly ash was mixed, the compressive strength increase rate of porous concrete at the age of 7 days and 28 days was less than the compressive strength when no fly ash was mixed. However, after the age of 28 days the compressive strength increase rate rose conspicuously, showing approximately 5.6 and 3.0% increase with aggregate grading of 5–13 and 13–20 mm, respectively at the age of 90 days [11]. The reason for this is thought to be that in the aspect of the properties of fly ash, the speed of compressive strength development was decreased, but at old ages the compressive strength increased conspicuously compared to the compressive

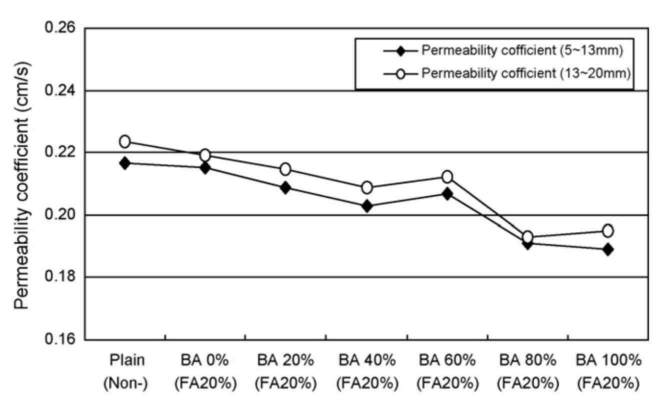

Fig. 6. Permeability coefficient by coal bottom ash contents.

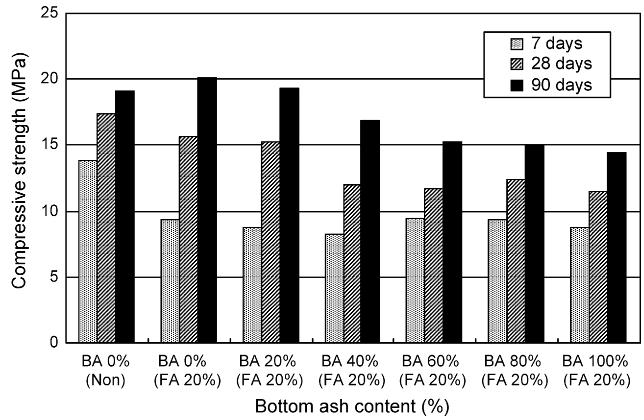

Fig. 7. Compressive strength by coal bottom ash contents (gradation 5–13 mm).

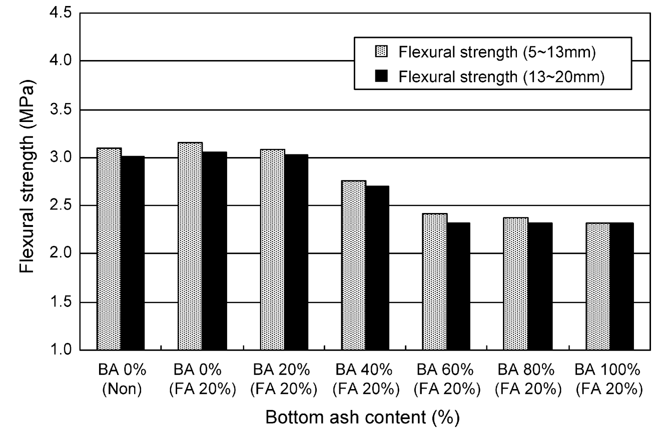

Fig. 9. Flexural strength by coal bottom ash contents.

strength when no fly ash was mixed [12]. When the coal bottom ash was mixed, the compressive strength tended to decrease at all aggregate grading as the mixing ratio increased and the compressive strength with aggregate grading of 5–13 mm was greater than the compressive strength with aggregate grading of 13–20 mm by more than 16.1–26.7%. The reason for this is thought to be that as the aggregate grading became smaller, the number of contact points per unit area between aggregate and paste increased, causing the increase in the strength. In addition, when fly ash and coal bottom ash were mixed together, even though the bottom ash was mixed by up to 20%, the strength increased by approximately 50% at the age of 90 days, but it tended to be decreased conspicuously by more than 11.7–27.1% at the mixing ratio of more than 40%.

3.7. Flexural strength

Fig. 9 presents the test result of the flexural strength of porous concrete using coal bottom ash. From this it was found that in the case of the flexural strength by aggregate grading, it was more or less small with aggregate grading of 13–20 mm showing maximum 3.7% reduction. Similar to the compressive strength, as the mixing ratio of the coal bottom ash increased, the flexural strength tended to be decreased compared to the flexural strength when the coal bottom ash was not mixed, showing a reduction of up to 26.4%. However, it was found that as the coal bottom ash mixing ratio increased, the degree of flexural strength reduction decreased. When fly ash was mixed, the flexural strength was almost identical as that when no fly ash was mixed. It is thought that mixing the fly ash had almost no influence on the flexural strength.

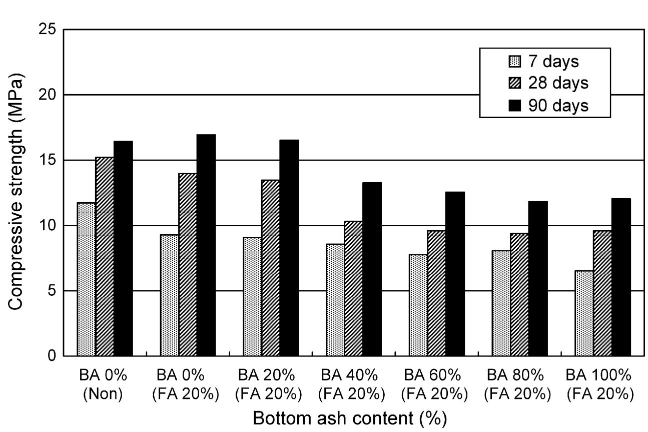

Fig. 8. Compressive strength by coal bottom ash contents (gradation 13–20 mm).

3.8. Analysis on the fracture shape of porous concrete using coarse bottom ash

Shigemitsu defined the fracture characteristics into three types: (1) binder fracture between aggregates; (2) interface fracture at the interface between aggregate and binder; and (3) aggregate fracture that the aggregate itself fractures [13]. Figs. 10–12 present the pictures showing fracture shape.

Figs. 13–18 indicate the fractured zones according to fracture types, which were obtained after taking and visually observing the pictures of fractured cross-sections of the porous concrete using coal bottom ash. From the observation of the fractured cross-section it was found that when no coal bottom ash was mixed the specimen was fractured mostly because of binder fracture and interface fracture between aggregate and binder as shown in Figs. 13 and 16. However, as the coal bottom ash mixing ratio increased, the fracture of the coal bottom ash aggregate itself increased rather than interface fracture and binder fracture and furthermore, when only the coal bottom ash was mixed, the specimen was fractured due to aggregate fracture itself rather than interface fracture as presented in Figs. 15 and 18. It is thought that since the coal bottom ash aggregate integrated with paste more smoothly than the aggregate with smooth surface not only because the abrasion rate of the coal bottom ash aggregate was relatively greater than that of the crushed aggregate but also because the coal bottom ash aggregate had many bubbles on the surface and inside, therefore, fracture occurred at the

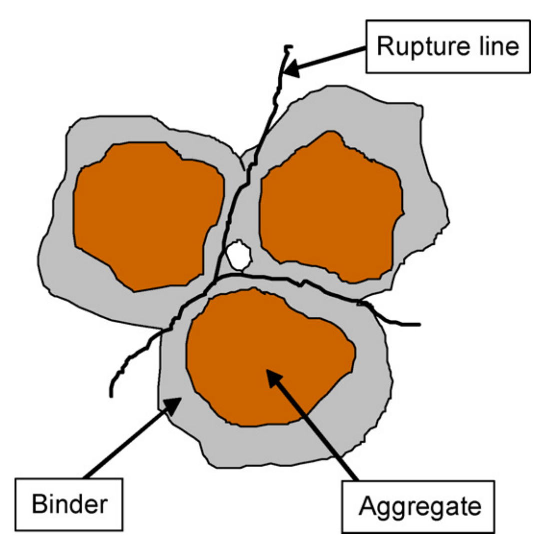

Fig. 10. Binder fracture.

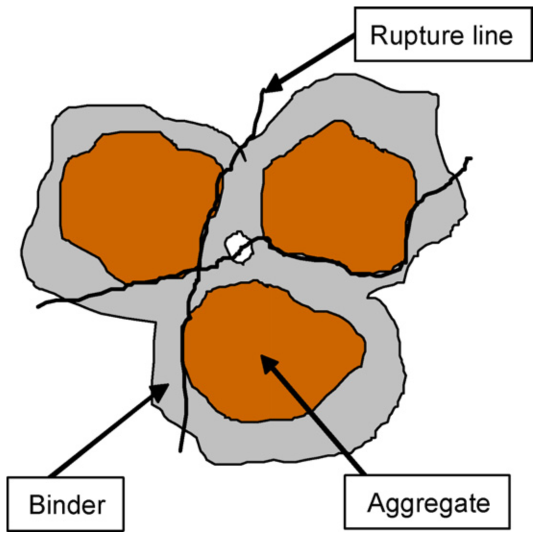

Fig. 11. Interface fracture.

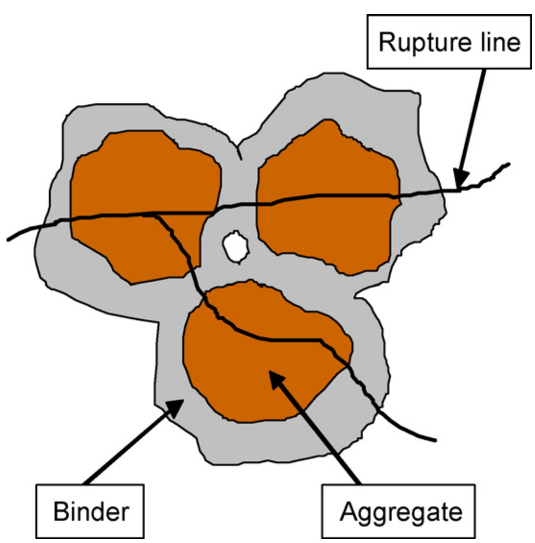

Fig. 12. Aggregate fracture.

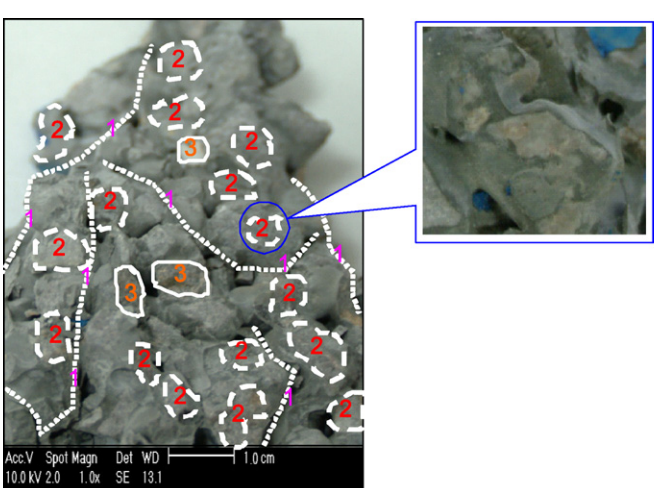

Fig. 13. Coal bottom ash: 0% (1.0×, 5–13 mm).

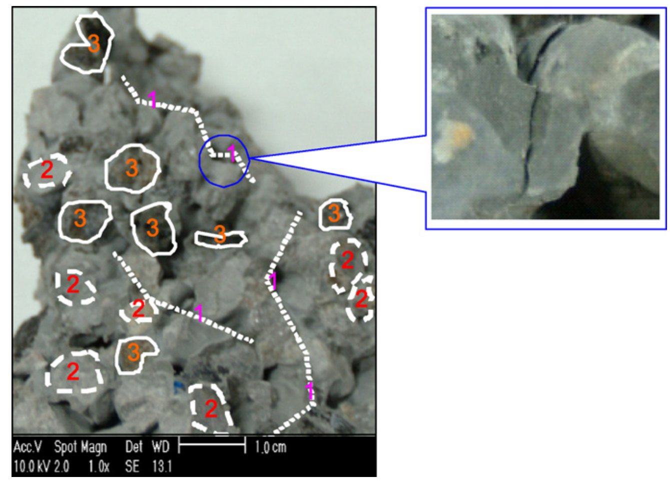

Fig. 14. Coal bottom ash: 40% (1.0×, 5–13 mm).

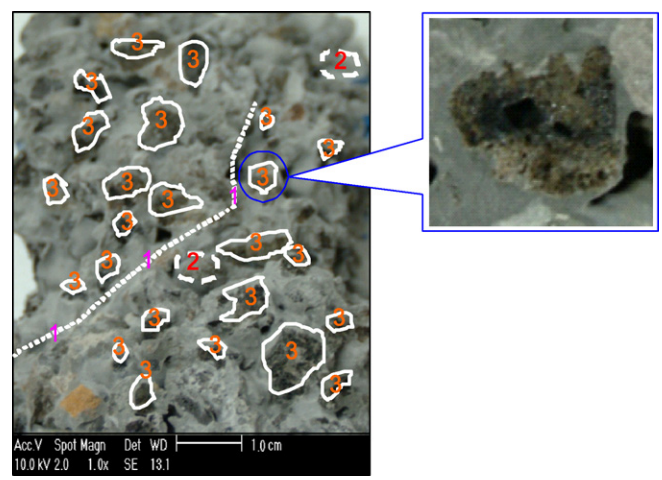

Fig. 15. Coal bottom ash: 100% (1.0×, 5–13 mm).

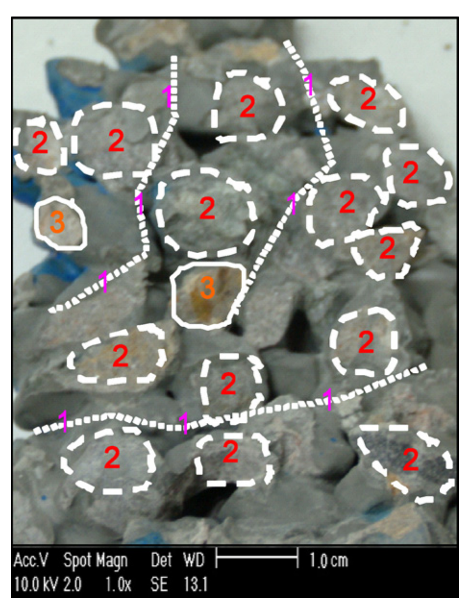

Fig. 16. Coal bottom ash: 0% (1.0×, 13–20 mm).

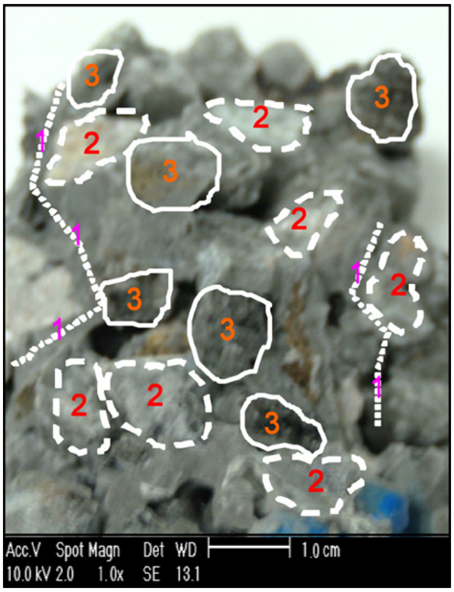

Fig. 17. Coal bottom ash: 40% (1.0×, 13–20 mm).

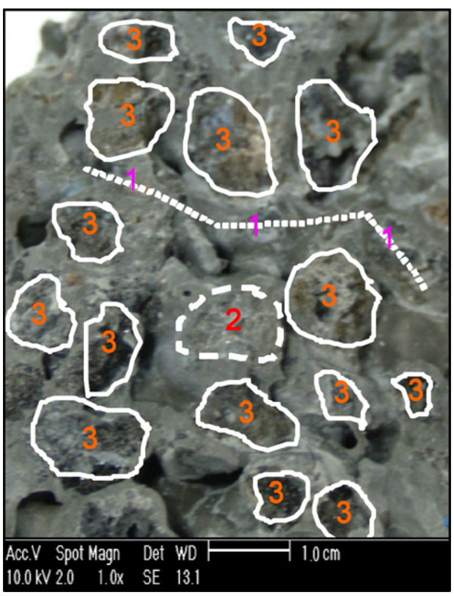

Fig. 18. Coal bottom ash: 100% (1.0×, 13–20 mm).

coal bottom ash aggregate, which had relatively smaller hardness than the crushed aggregate. Consequently, in order to apply porous concrete in large quantity to the secondary products and pavement materials using porous concrete for plantation, sound absorption, artificial fishing reef, etc., it is thought that not only a reinforcing element needs to be mixed to improve strength properties but also the method to increase the hardness of the aggregate itself needs to be considered [14,15].

4. Conclusions

In order to effectively recycle the coal ash waste, an industrial by-product, this study performed hazard assessment and analysis on the mechanical properties of the porous concrete using coal bottom ash. The summary of the analysis results are as follows:

(1) The soundness and abrasion rate of the coal bottom ash aggregate were less than the allowable values in KS F 2526 and ASTM C 33 at all aggregate grading, satisfying the standard values. The chloride content of the coal bottom ash aggregate satisfied the standard allowable values when it was washed more than twice.
(2) The result of the leaching test of heavy metals indicated that the coal bottom ash aggregate and porous concrete using this aggregate satisfied the criteria for the nine substances, including Cr^{6+}, that are classified as deleterious substances in the Solid Waste Management Law in Korea.
(3) The void ratio and permeability coefficient of the porous concrete using the coal bottom ash were decreased more or less as the bottom ash mixing ratio increased. However, the difference was small, being approximately 1.8%, 0.028 cm/s at maximum, respectively.
(4) The compressive and flexural strength tended to be decreased at all aggregate grading as the coal bottom ash mixing ratio increased. When fly ash and coal bottom ash were mixed together and even though the bottom ash mixing ratio was 20%, the compressive strength increased by approximately 0.5% at the age of 90 days. However, it tended to be decreased conspicuously by up to 11.7–27.1% at a mixing ratio of greater than 40%.
(5) When the coal bottom ash was not mixed, the specimen fracture occurred due mostly to aggregate fracture and interface fracture between aggregate and binder. However, as the coal bottom ash mixing ratio increased, the specimen was fractured due to the fracture of the coal bottom ash aggregate itself rather than interface fracture.
(6) Therefore, in order to apply the bottom ash in large quantity to the secondary products and packing materials using porous concrete for plantation, sound absorption, artificial fishing reef, etc., it is needed to mix the reinforcing element to improve the strength properties.

Acknowledgments

This study was performed by the support of the Korea Science and Engineering Foundation (R01-2007-000-10692-0) and we would like to extend deep gratitude to those concerned.

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