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Development of Environmentally-Friendly Recycling Building materials from wasted Coal Combustion By-product(Ash)

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Recycling of coal combustion by-product(Ash) are becoming more important in the utilization business as a result of the increased use of NOx reduction technologies at coal-fired power plants. current disposal methods of these by-products create not only a loss of profit for the power industry, but also environmental concerns that breed negative public opinion. Since inherent characteristics make these by-product suitable for building materials, several types of artificial aggregates and construction bricks are manufactured and tested to verify the engineering properties.

Introduction

In this study, artificial lightweight aggregates were manufactured with coal ash to dispose safely and can be adapted to environment. Therefore, a strength characteristic of hardening body dependent on the mix proportion of the used addition, and the quality and stability of artificial lightweight aggregates were investigated by experimental method.
Especially, to invent the artificial lightweight aggregates manufactured by non-heating method, this study was done to raise the stability of coal ash with suitable addition and mix proportion through the understanding physical-chemical characteristics.
In addition, It's supposed to examine closely the application possibility of the concrete manufactured by a little low quality artificial lightweight aggregate through the experiment compared with a natural crushed stone. To verify a concrete application possibility, this study was taken by comparing and analyzing the compressive strength of the concretes manufactured with the artificial lightweight aggregate, existed artificial lightweight aggregate, and the natural stone.

1. Solidification Of Coal Ash
According to the paper written about solidification of coal ash, J. Wastiels and X. Wu[1] said that the reaction between and binding accelerator shows the feldspatoid material which is consisted of an inorganic high molecule composed of the tetrahedral of SiO_4 and AlO_4 connected Oxygen atom jointly. Therefore they announced that this material is much stronger than general Portland cement.
In addition, they investigated the strength of the specimen mixed with coal ash, water glass and sand. After mixing all of this materials in the rotary mixer, this mixture was molded in a mold sized with 20X30X40mm. The specimen was cured under the condition of 60℃ and atmospheric pressure for 24 hour. After that, it was measured the strength in curing with variables as atmosphere, drying of 40℃, and common underwater.
As a result of this experiment, it gained high strength with 631kg/cm^2(40℃ drying curing and 515kg.cm^2 (common underwater curing).
As a result of the experiment for resistance to acid, it showed better resistance to acid than that of common cement.[2]
According to the other papers, the coal ash was solidified with binder. In the papers, the principle of solidification for coal ash is as follows.
Generally, coal ash is composed of amorphous from, which is etched by the binder. To mention it, SiO_2 or Al_2O_3 in pozzolan was attacked by OH- ion, which was attached to Si or net shaped atom. The Oxygen atom was separated by OH- ion, and through this kind of repetitive reaction, hydration reaction is progressed as silicate or other Oxygen negative ion were taken apart from the original structure. Therefore, the binder was used for increasing the reaction between fly ash and $Ca(OH)_2$, and improving the velocity of dissolution of silica in fly ash.
However, it is known that the increasing of the binder's density decreases the density of calcium by dissolving of two steps. Consequently, there is a density of appropriate binder in the coal ash mixture.[3]

Experiment

1. Experiment Material

the coal ash which was used in this experiment was produced manufactured from Boryeong coal fired power plants, which contains CaO less than 6%. It grades F which contains LOI less than 12%.

It was satisfied with KS code and it's each chemical component was applicable to be lightweight aggregates. The normal Portland cement regulated by KS F 5201 was used in this experiment. Finally, a little amount of binder, binding accelerator and metallic oxide were used for solidifying coal ash.

2. Solidification Experiment Of Coal Ash

After drying and mixing coal ash and cement for 2 minutes, the binders, binding accelerator and water were added and mixed for 3 minutes. The mixture were cured in a mold sized with 5X5X5 cm^2 for 24 hours. Its strength and stability dependent the component proportion were analyzed after curing it for 7 days under normal temperature.

In case of coal ash, unlike the normal concrete, there is no standard for curing method. Therefore, after curing it for 7 days the compressive strength was measured with curing variables of Table 2 for checking the characteristic of strength change as curing method. In addition, a specimen added metallic oxide was measured by the above experimental results.

Table 2 shows a mix proportion and curing method used in this experiment.

3. Artificial Lightweight Aggregate And Concrete Experiment

3-1. Production Of Artificial Lightweight Aggregate

Artificial lightweight aggregate in this study was produced by using the way of compressive crush, not using the way the high temperature curing method. Producing method with the compressive crush is as following. First, the materials were mixed as same as in the experiment of non-heating coal ash solidification.

Second, the mixed material was compressed and method in a mold. And after curing the materials for 7 days, the aggregate was manufactured through the way of crushing and sieve analysis.

3-2. Physical properties experiment of artificial lightweight aggregate

Several experiments such as specific gravity (KS F 2503), unit weight (KS F 2505), and solid volume percentage (KS F 2506), were performed to seize the general characteristic of the crushed aggregate.

By performing the experiment for 10% crushing strength (KS F 2541) to seize the resistance against the static load of the artificial lightweight aggregate, the qualities for the natural crushed stone aggregate, the aggregates of inside and outside country were compared.

The eruption experiment based on US. EPA's TCLP(Toxicity Characteristic Leaching Procedure) and KSLT(Korean Standard Leaching Test) of Korean Waste Process Experimental Law for regulation of environmentally harmful materials was performed with aggregates of which diameter was 5mm.

3-3 Concrete Strength Experiment with Artificial Lightweight Aggregate

Several specimen shaped with cylinder(ϕ 10X20cm) were manufactured with the strength of 240kg/cm^2. In this study, they were made from the artificial lightweight aggregate, existing artificial lightweight aggregate of inside and outside countries, and natural crushed stone aggregate. Compressive strength for them was measured with the regulation of KS F 2403 after curing them for 7 days.

The Table 4 shows the mixed proportion for manufacturing the concrete specimen.

RESULTS

1. Solidification of Coal Ash

1.1 Strength Variations Of Strength According To The Content Of Addition

In the case of coal ash, its strength revelation is slow relatively compared with cement because the strength revelation is occurred by Pozzolan reaction.

Therefore, in this study, cement was added for increasing initial strength, and the strength in 10% of cement addition was higher about 5~10kg/cm^2 than that of 5%.

As the result of the experiment, the fact was that the more added cement, the more strength increased.

It is considered that the improving of strength was due to the early hydration reaction according to adding cement. The Figure 2 shows that the strength increased 3~9kg/cm^2 in

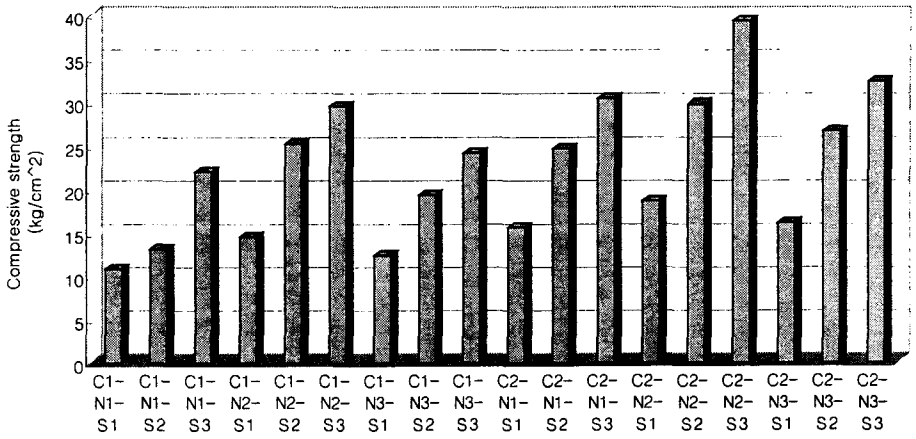

Fig. 1 A Change Of Strength Based On Addition Content

10% of binder content than that of 5%.
However, when the content of binder was 15%, the compressive strength was decreased about 5kg/cm^2. Therefore, the appropriate mix proportion of binders was 10%. In the case of the binding accelerator, the more increased the content of binding accelerator, the stronger a compressive strength.
When the content of coking was increased from 5% to 10%, the strength was increased about 3~20kg/cm^2 (50~200%), and the strength was increased about 5~10kg/cm^2 (20~30%) in increasing the content of coking from 10% to 5%.
Therefore, the appropriate content of the coking is 15%. In addition, the addition that have effect mostly on the increasing strength is binding accelerator by checking that when the mix proportion of the binding accelerator increases from 5% to 10%, its strength effect was 50~200%.

1.2 Strength Variation According To The Curing Method
The compressive strength was measured after curing for 7days by the curing condition of table2 with the mix proportion (C2-N2-S3) that was decided in the compressive strength
The result for the measurement is showed in Fig.3. The compressive strength of the specimen which was cured under water(46℃) and a oven(50℃) was 200 kg/㎠. However, the compressive strength of the specimen which was cured and air was 50kg/㎠. Therefore, from the result of the experiment, the specimen which was cured and water and a oven shows the effect of strength increasing by 150kg/㎠.(300%)

The Fig.4 shows the compressive strength comparison of specimens that were cured under water and constant temperature in a oven.
According to the Fig.4, the specimen which was cured under the constant temperature shows the effect of strength increasing about 70 kg/㎠(35%).
Therefore, the constant temperature curing method can be the most appropriate curing method.

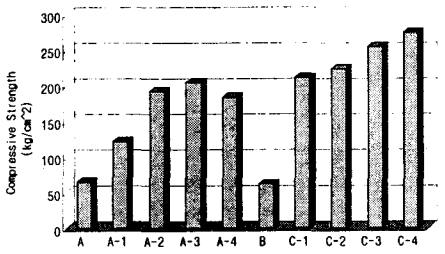

Fig. 2 Strength Variation According To The Curing Method

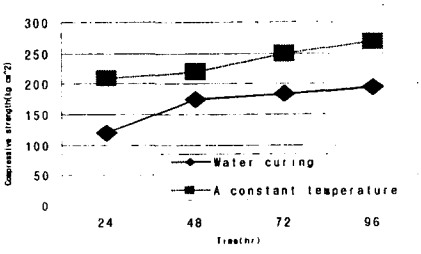

Fig. 3 Compressive Strength Of A Constant Temperature, And Water Curing

1.3 Strength Variation According To The Content Of The Metallic Oxide
After adding the metallic oxide, the strength increased about 70 kg/cm^2 at its maximum.

Table 2 Physical Experiment Result

Aggregate	Specific gravity	Specific gravity(dry)	10% crush strength	Unit weight	Solid volume percentage	The strength for 7 days
JG	1.43	1.32	8.5	0.789	59.8	224
GG	1.25	1.10	8.2	0.678	61.6	236
KG	1.16	1.00	6.1	0.595	59.6	161
FG	1.85	1.66	6.5	0.942	58.3	180
NC	2.71	2.54	23	1.626	58.1	282

The Fig.5 shows the change of the strength according as adding the metallic oxide. From the result of the experiment, when the metallic oxide was added by 5% the strength is higher about 30kg than of 10%. Therefore, the most appropriate content of the metallic oxide is 5%.
In case of the specimen, C2-N2-S3-M1 which has the highest compressive strength shows the strength by 340 kg/cm^2 In addition, the specimen C2-N2-S2-M1 shows the compressive strength by 329 kg/cm^2
In case of the specimen which wasn't added the metallic oxide, the effect of strength was about 20%~30% when the content of binding accelerator was increased from 10% to 15%.
However, as adding the metallic oxide, the effect of strength was around 3%
In case of adding the metallic oxide, the effect of strength increasing according as the increasing of binding accelerator is low.
Therefore, as a result of the experiment for solidification non-heating coal ash, the most appropriate mix proportion was the C2-N2-S2-M1.

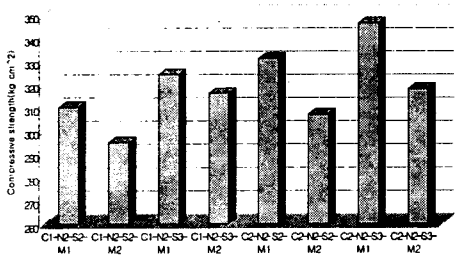

Fig. 4 Strength Variation According To The Content Of The Metallic Oxide

2. Artificial Lightweight Characteristics Of Physical Experiment

2.1 Specific Gravity
As the result of the experiment, the Specific gravity of saturated and the absolute dry Specific gravity for the artificial lightweight aggregate from Japan is 1.43 and 1.32.
In case of the artificial lightweight aggregate from German, the result of the experiment was 1.25 and 1.10.
The result for artificial lightweight aggregate of Korea is rather lower than those of the above aggregates by 1.16 and 1.00.
FG, an abbreviation of aggregate which is manufactured in this research, shows relatively high numeral value than any other aggregates by 1.85 and 1,66 in it's the specific gravity of saturated and the absolute dry specific gravity.
The reasons for that result are verified that the aggregate manufactured by high –temperature heating method has more internal void than that of the non-heating method. All of the artificial lightweight aggregates from inside and outside countries were satisfied with the standard of the lightweight aggregate with the absolute dry specific gravity (1.5)
The FG shows the research is keep going for increasing a internal void with mixing a little expansion agent, the light-weight aggregate that absolute dry specific gravity is lower than 1.5 will be manufactured under common temperature without higher-temperature heating method.

2.2 Unit weight and Solid volume percentage

The unit weight in all of each artificial lightweight aggregate has a similar tension with a specific gravity. The unit weight from Korea is relatively low figure of 0.595 compared with the figure of 0.789 from Japan and 0.678 from Germany. In case of FG, its figure of 0.942 is comparatively higher than others, which is a higher figure than the limit figure, under 0.88 regulated by KSF2534. It'll need a complementary research on it.
The solid volume percentage and percentage of void of the artificial lightweight aggregate for all of the inside and outside of the countries is showing a similar result. The reason for that result is that the grain shape of all aggregates was globe-shaped and big and small particles were mixed so equally that charging effect was similar. In case of FG, because it was.

Table 3 Experimental Results Of Effluent Water Of Heavy Metals

classification	Cd(mg/L)	Cr(mg/L)	Cu(mg/L)	Pb(mg/L)	Zn(mg/L)
KEPT 1st	N.D.	0.017	N.D.	N.D.	0.014
KEPT 2nd	N.D.	0.018	N.D.	N.D.	0.014
KEPT standard	0.2	1.5	3	3	
TCLP 1st	N.D.	0.018	N.D.	N.D.	N.D.
TCLP 2nd	N.D.	0.017	N.D.	N.D.	N.D.
TCLP standard	1	5		5	

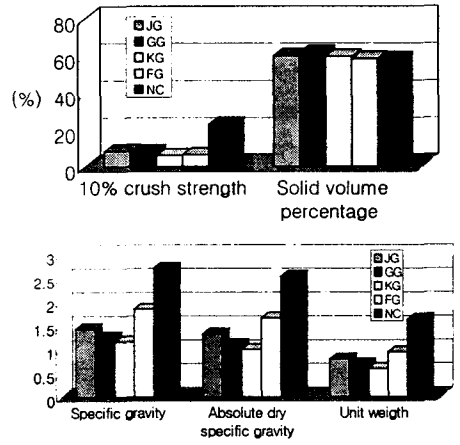

Fig. 5 The Physical Characteristics of Artificial Lightweight Aggregate

manufactured by method of crushing, it was showed lower degree than another artificial lightweight aggregates

2.3 10% Crush Strength

Crush test is a method that indicates a resistance property the against static compressive load of the aggregates; it also indicates the load figure when crush rate is 10% as the load of 40ton is pressed to the aggregate which's put into test cup.

The 10% crush strength of the artificial lightweight aggregates from the inside and outside of the country is 6.1~8.5ton, and 6.5ton in case of FG.

However, it indicates 23ton in case of natural crushed stone aggregate, which's higher numerical value than other artificial lightweight aggregates. This is taken into consideration that it indicates lower than crush strength of natural crushed stone aggregates due to the porous property structure of the artificial lightweight aggregate.

2.4 Heavy metals content and eruption test

The amount of the heavy metals eruption for hardening solid manufactured in coal ash solidity conversion experiment was analyzed by using KSLT (Korean Standard Leaching Test) of Korean waste process test method and TCLP (Toxicity Characteristics Leaching Procedure) test for environmental toxic substance regulation of American environment protection organ, EPA.

According to the table 3, it shows that heavy metals eruption manufactured by hardening solid's satisfied with the inside and outside of the country regulation.

2.5 Compressive strength of specimen manufactured with artificial lightweight aggregates

It is general that the strength of artificial lightweight aggregates with coal ash is lower than that of ordinary aggregates due to the effect of aggregate internal void.

In case of heating lightweight aggregates, its strength can somewhat be increased due to the strong membrane layer of surface, but non-heating lightweight aggregate is known that its strength may be reduced because of not passing through the heating process in hot temperature.

Moreover, in case of specimen used a natural crushed stone aggregate the strength for 7 days is represented into average 282kg/㎠,.but in case of specimen used artificial lightweight aggregate it's represented into 180kg/㎠, in this research. The strength of the artificial lightweight aggregates were decreased by 35% compared with those of the natural crushed stone aggregates. But considering recycling property of coal ash, they were possible to use as a artificial lightweight aggregates.

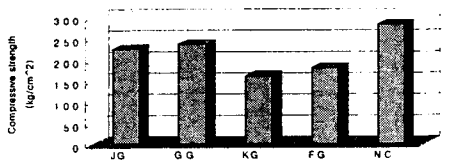

Fig. 6 Compressive strength of specimen manufactured with artificial lightweight aggregates

Fig. 7 Manufactured artificial lightweight aggregate

Conclusion

The result of the experiment for manufacture of artificial lightweight aggregate by non-heating method used coal combustion is as follows.

(1) As the result of the experiment for coal ash solidification by non-heating method, the compressive strength around for 7 days of the specimen mixed with cement (10%), binding accelerator (10%), binder (10%), metallic oxide (5%) which cured under an atmosphere for 3 days after it is cured in drying oven at the temperature of 50 C for 96 hours is the figure of 329kg/㎠.

(2) As the result of progressing characteristic property experiment of aggregates with manufacturing artificial aggregates by using the way of compressive crush with mix proportion gained from the experiment of the coal combustion solidification, it is somewhat higher than specific gravity of artificial lightweight aggregates which was plasticized in hot temperature as specific gravity of saturated surface dry (1.85), absolute dry specific gravity (1.66), but the probability of lightweight-tension was appeared by mixing expansion agent. Also, as the result of 10% crush, although The FG of which weight 6.5ton is much lower than the quality of the natural crushed stone aggregates which weight 23ton, the result was similar with the artificial aggregates of inside and outside countries 6.1~8.8 ton.

(3) Its unit weight is 0.942(g/cm^3), which's lower than that of the natural crushed stone aggregates's 1.625(g/cm^3), but it showed higher in unit weight than the artificial aggregates which was plasticized in hot temperature heating. The result showed that it must be complemented to mix an expansion agent as the specific gravity agent.

Besides, its solid volume percentage is 58.3%, which is lower than that of artificial lightweight aggregate in the inside and outside of the countries, but is similar with the figure of 58.1% from natural crushed stone aggregates which is like crushed stone aggregates.

(4) As the result of being analyzed the heavy metals eruption of the FG by using KSLT (Korean Standard Leaching Test) of Korean waste processing test method and TCLP (Toxicity Characteristics Leaching Procedure) test for environmental toxic substance regulation of American environmental protection organ, EPA, showed to be satisfied with the two regulations.

(5) The compressive strength for 7 days of the curved cylinder manufactured by coarse aggregates with artificial lightweight aggregates used coarse ash is represented by 180kg/㎠. Considering the strength for 7 days The FG will be useful to manufacture concrete that failure compressive strength is below 300kg/㎠ (the strength for 28days), making use of the artificial lightweight aggregates independently will be more effective for the effect of the dead weight decrease

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Table 1 A Mix Proportion Ratio And A Curing Condition Of The Coal Ash's Solidification Experiment

Specimen No.	Cement(%)	binders	Clay binders	a metallic oxide	7days compression strength(kg/cm^2)
C1-N1-S1	5	5	5		10.8
C1-N1-S2			10		13.2
C1-N1-S3			15		22.1
C1-N2-S1		10	5		14.5
C1-N2-S2			10		25.2
C1-N2-S3			15		29.5
C1-N3-S1		15	5		12.5
C1-N3-S2			10		19.4
C1-N3-S3			15		24.1
C2-N1-S1	10	5	5		15.6
C2-N1-S2			10		24.7
C2-N1-S3			15		30.4
C2-N2-S1		10	5		18.6
C2-N2-S2			10		29.8
C2-N2-S3			15		39.4
C2-N3-S1		15	5		16.2
C2-N3-S2			10		26.7
C2-N3-S3			15		32.4
C1-N2-S2-M1	5	10	10	5	310
C1-N2-S2-M2				10	295
C1-N2-S3-M1			15	5	324
C1-N2-S3-M2				10	316
C2-N2-S2-M1	10	10	10	5	331
C2-N2-S2-M2				10	307
C2-N2-S3-M1			15	5	347
C2-N2-S3-M2				10	318

The experimental method of a Curing method (mix proportion ratio: C2-N2-S3)

Specimens	Curing method
A	Curing in the air After a curing during 24hrs under 15°C's water
A-1	Curing in the air After a curing during 24hrs under 46°C's water
A-2	Curing in the air After a curing during 48hrs under 46°C's water
A-3	Curing in the air After a curing during 72hrs under 46°C's water
A-4	Curing in the air After a curing during 96hrs under 46°C's water
B	7days' curing at 18°C's indoor After stripping
C-1	Curing in the air After curing during 24hrs in a drying container keeping on 50°C
C-2	Curing in the air After curing during 48hrs in a drying container keeping on 50°C
C-3	Curing in the air After curing during 72hrs in a drying container keeping on 50°C
C-4	Curing in the air After curing during 96hrs in a drying container keeping on 50°C

A Table of Mix proportion used at manufacturing concrete's conical specimen

Used aggregates	Gmax	Slump	Air	W/C	S/a	Unit quantity(Kg/cm^3)				Admixture(C × %)
						W	C	S	G	
JG	15	8±2.5	4±1.5	44	46	155	352	858	535	0.2
GG	16								468	
KG	19								434	
FG	19								571	
NC	19								988	