

# **The Mechanical Properties of Coal-Ash Generated in South Korea for Using Highway Road Material**

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**KEYWORDS:** coal-ash, mechanical property, highway road material.

## **INTRODUCTION**

The mechanical properties of coal-ash for using highway road material, which replaces macadam or sand, was studied due to a shortage of construction aggregates in Korea. The physical/mechanical properties of coal-ash obtained from laboratory tests was compared with the quality standards of sub-base, roadbed, roadbed filled up ground, and backfill material prescribed by Road Construction Guide Specification(2003) and Highway Construction Guide Specification(2005) in order to examine the applicability of coal-ash generated in South Korea.

Also, the variations of mechanical properties of coal-ash due to self-hardening, compaction energy, and freezing / thawing was evaluated by UC tests, proctor tests, and freezing and thawing tests in order to find out durability of coal-ash.

Finally, for the purpose of harmful effects of coal-ash for environment, leaching test for 11 hazardous components stipulated in the Wastes Control Act was performed.

## **THE APPLICABILITY OF COAL-ASH FOR USING HIGHWAY ROAD MATERIAL**

### **Properties of coal-ash**

In this study, laboratory experiments were fulfilled to find out physical/mechanical characteristics of coal-ash collected from Samchunpo(SCP), Dong-hae(DH), Tae-an(TA), and Seocheon(SC) thermoelectric power plants in South Korea. The following Table 1 is a summary of testing conditions and test results.

Table 1. Test conditions and results

Sample	Sand Equivalent Value(%)	Abrasion loss (%)	CBR (%)	Atterberg Limit	
				LL(%)	PI(%)
SCP	78	42%	28.4	NP	NP
DH	85	49%	22.9	NP	NP
TA	92	45%	33.7	NP	NP
SC	87	45%	29.6	NP	NP

Estimation for applicability

Table 2 is result of particle-size distribution test. Uniformity coefficient,  $C_u$  must be larger than 4.0 in case of well-graded gravel and larger than 6.0 in case of well-graded sand, and coefficient of curvature,  $C_g$  must be between 1.0 and 3.0 in both cases of well-graded gravel and sand (Das, 1999). Uniformity coefficients of all coal-ash samples were larger than 6.0, so that they were revealed as well-graded materials. Coefficient of curvature was little smaller than 1.0 for DH, but for the other 3 samples, coefficient of curvature was between 1.0 and 3.0.

Table 2. Result of the particle-size distribution test

Sample	Maximum Particle Diameter (mm)	D <sub>10</sub> (mm)	D <sub>30</sub> (mm)	D <sub>60</sub> (mm)	Uniformity Coefficient $C_u$	Coefficient of Curvature $C_g$	No. 200 Sieve Finer (%)
SCP	20	0.09	0.40	1.7	18.8	1.05	8.4
DH	6	0.17	0.39	1.0	6.0	0.91	2.9
TA	15	0.08	0.32	1.1	13.8	1.08	8.6
SC	20	0.08	0.31	1.0	12.5	1.2	8.7

Table 3 shows the results of particle-size distribution tests with standard particle-size distribution for sub-base prescribed by Road Construction Guide Specification(2003).

Table 3. Comparing particle-size distribution with standard

Samples	% Finer							
	75mm	50mm	40mm	20mm	5mm	2mm	0.425mm	0.075mm
SB-1	100	-	70-100	50-90	30-65	20-55	5-25	2-10
SB-2	-	100	80-100	55-100	30-70	20-55	5-30	2-10
SCP	100.0	100.0	100.0	100.0	83.4	66.2	32.3	8.4
DH	100.0	100.0	100.0	100.0	98.6	85.8	44.2	2.9
TA	100.0	100.0	100.0	100.0	92.5	79.6	33.5	8.6
SC	100.0	100.0	100.0	100.0	93.2	75.5	35.9	8.6

Fig. 1 shows the particle-size distribution curve with standard curve for sub-base(SB-1, SB-2) prescribed by Road Construction Guide Specification(2003). Particle-size distribution curve of all the samples were out of the range between SB-1 and SB-2. Especially, the maximum particle diameter was quite small as 5~20mm, so that it is need to modify particle-size distribution by mixing coarse materials with large diameter for using road material.

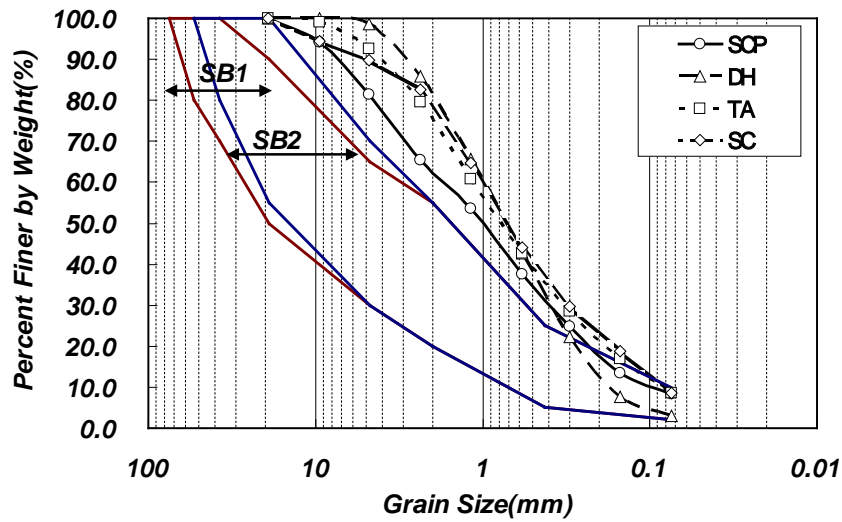


Fig. 1 Particle-size distribution of coal-ash samples

Table 4 shows properties of coal-ash samples and the quality standard of pavement stipulated by Road Construction Guide Specification. All the coal-ash samples were non-plastic. Modified CBR of TA samples were larger than the standard value and those of the other samples were slightly smaller than the standard value of sub-base, but almost same. Sand equivalent value of every sample was highly larger than the standard value, 25%. Abrasion loss of all the samples was also smaller than 50%. Properties of all the coal-ash samples were qualified as a roadbed, roadbed filled up ground, and backfill materials.

Table 4. Comparing properties with quality standard

Layer		Items	Standard	SCP	DH	TA	SC
Sub-base		LL (%)	≤25	N.P	N.P	N.P	N.P
		PI(%)	≤6	N.P	N.P	N.P	N.P
		Abrasion loss(%)	≤50	42	49	45	45
		Modified CBR(%)	≥30	28.4	22.9	33.7	29.6
		Sand equivalent value(%)	≥25	78	85	92	87
Roadbed	Upper	Maximum Diameter(mm)	≤100	≤20	≤6	≤15	≤20
		LL(%)	≤10	N.P	N.P	N.P	N.P
		Modified CBR(%)	≥10	28.4	22.9	33.7	29.6
	Lower	Maximum Diameter (mm)	≤150	≤20	≤6	≤15	≤20
		LL(%)	≤20	N.P	N.P	N.P	N.P
		Modified CBR(%)	≥5	28.4	22.9	33.7	29.6
Roadbed filled up ground		Maximum Diameter (mm)	≤300	≤20	≤6	≤15	≤20
		Modified CBR(%)	≥2.5	28.4	22.9	33.7	29.6
Backfill		Maximum Diameter (mm)	≤100	≤20	≤6	≤15	≤20
		LL(%)	≤10	N.P	N.P	N.P	N.P
		Modified CBR(%)	≥10	28.4	22.9	33.7	29.6

## THE VARIATIONS OF MECHANICAL PROPERTIES

### Test process

#### *Test for effect of self-hardening*

In order to find out strength variation due to self-hardening of coal-ash, UC tests for the specimens, which were made by A compaction with OMC, were performed with curing days. OMC were obtained by laboratory proctor tests.

UC test conditions are shown in Table 5, and Fig. 2 shows the test process.



(a) making specimens



(b) UC test

Fig. 2 UC test process

Table 5. UC test conditions

Samples	Compaction method	OMC (%)	Curing days (days)
SCP	A	35.2	0, 7, 14, 28
DH		20.3	0, 7, 14, 28
TA		28.9	0, 7, 14, 28
SC		19.8	0, 7, 14, 28

#### *Test for effect of compaction energy*

Proctor tests for coal-ash samples were performed by A and D methods, in order to see the variations of coal-ash particle. After proctor test, particle-size distribution test was carried out, and shape of coal-ash particle was shot by SEM.

#### *Test for effect of freezing / thawing*

Because of hollowness of coal-ash particles, particle itself could be damaged if water flow into pore of particle. In this study, freezing and thawing test for coal-ash samples was accomplished and particle-size distribution test and a shot of particle by SEM was executed after freezing and thawing test(Fig. 3). Also, after and before freezing and thawing test, direct shear test and permeability test were carried out in order to examine the variations of mechanical properties.

Freezing and thawing test was performed based on KS F 2456. Each specimen was cured during 14 days and 20 cycles of freezing and thawing, each cycle per 4 hours, was repeated. The temperature inside of test apparatus was  $-18^{\circ}\text{C}$  during freezing, and  $4^{\circ}\text{C}$  during thawing.



(a) test apparatus



(b) coal-ash samples

Fig. 3 Freezing and thawing test

## Test results for variations of mechanical properties

### *Effect of self-hardening*

Table 6 and Fig. 4 show the UC strength of coal-ash samples with curing days. UC strengths of TA samples were larger than any other coal-ash, and those of DH samples were smallest. Metha. P. K.(1984) reported that effect of self-hardening highly take places with coal-ash made from soft coal, but little with coal-ash made from smokeless coal. SCP and TA coal-ash were made from soft coal, so that the UC strength was larger than DH and SC samples.

Table 6. UC test results

Curing days	UC strength (kPa)			
	SCP	DH	TA	SC
7	70.94	35.22	75.49	46.57
14	79.59	40.27	89.36	59.35
28	80.96	41.09	92.29	61.29

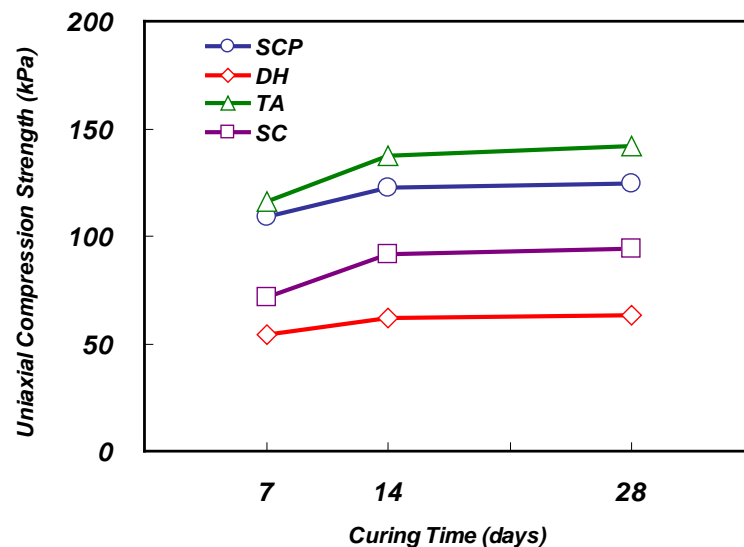
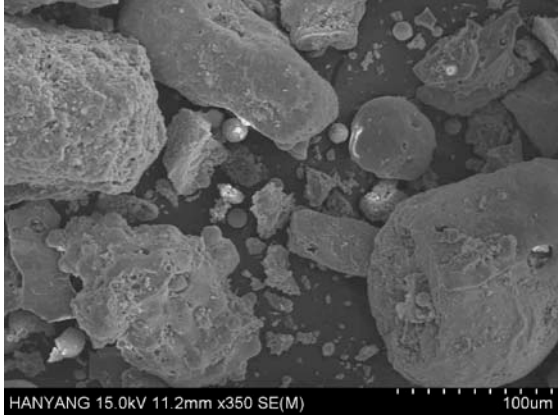


Fig. 4 UC strength of each coal-ash samples with curing days

### *Effect of compaction energy*

Fig. 5 shows the shape of coal-ash particles taken by SEM after proctor test. The coal-ash particles, after proctor test with A method, did not crushed by compaction energy. But, after proctor test with D method, some particles were crushed by compaction. Also it is seen that the fine grains are scattered around the coal-ash particles. Because compaction energy of D method is about four times larger than that of A method, the coal-ash particles, which has lots of pores in itself, could not resist the compaction and crushed.



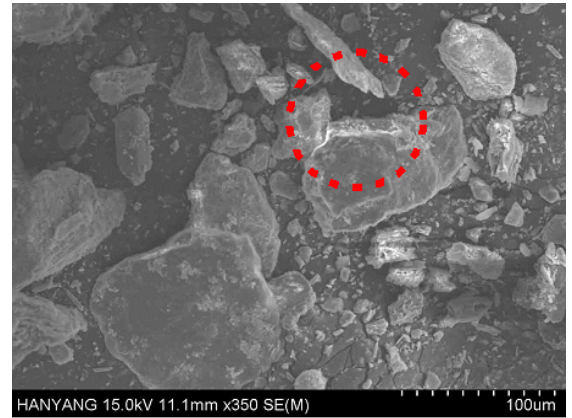
(a) SCP : after A compaction



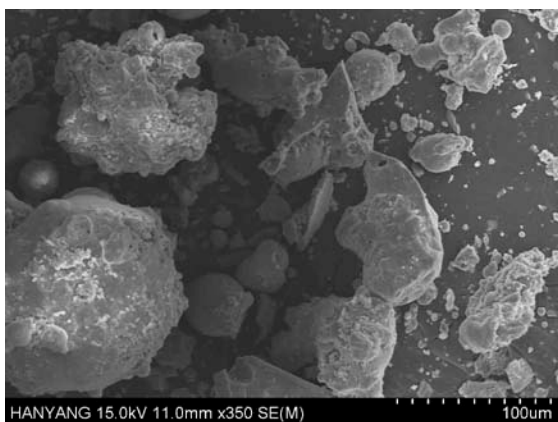
(b) SCP : after D compaction



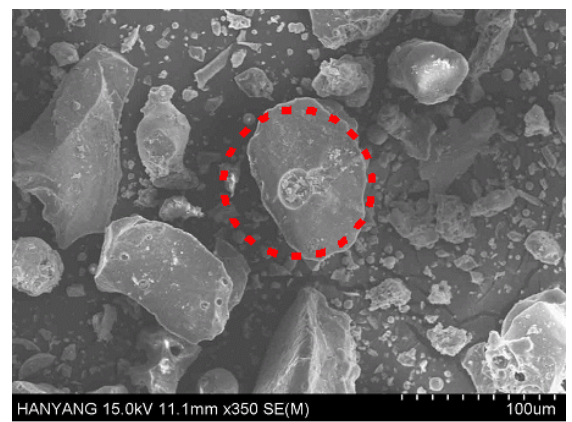
(c) DH : after A compaction



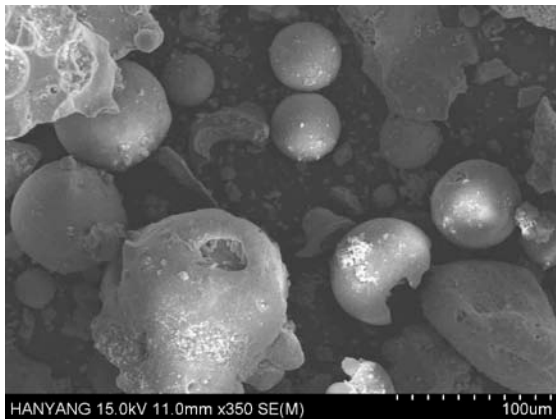
(d) DH : after D compaction



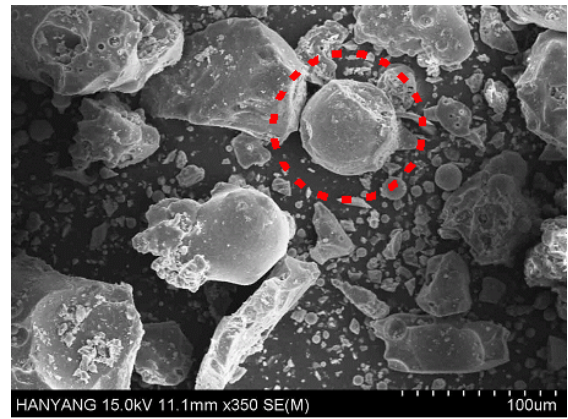
(e) TA : after A compaction



(f) TA : after D compaction



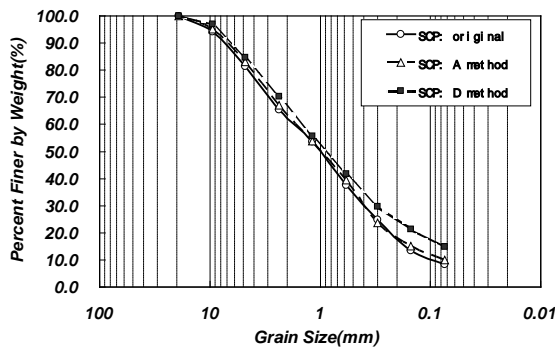
(g) SC : after A compaction



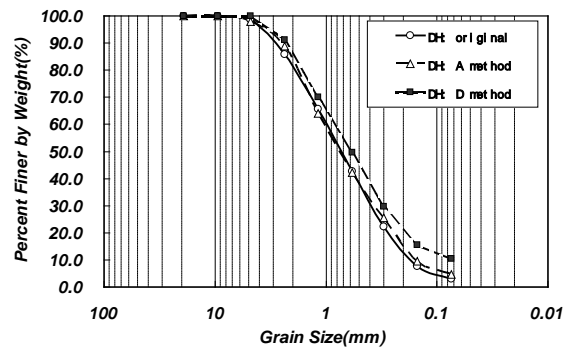
(h) SC : after D compaction

Fig. 5 Shape of coal-ash particles after proctor test (by SEM)

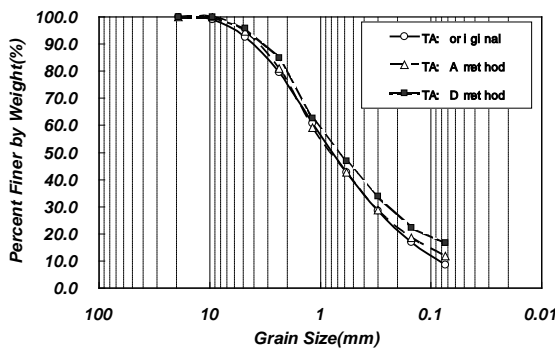
Fig. 6 shows the results of particle-size distribution test performed after proctor test for each coal-ash sample. As the compaction energy increase, distribution curve slightly moved to the right from original distribution curve, because of increase of fine grains by crushing of particles. But it seems that compaction energy does not affect too much to the distribution curve.



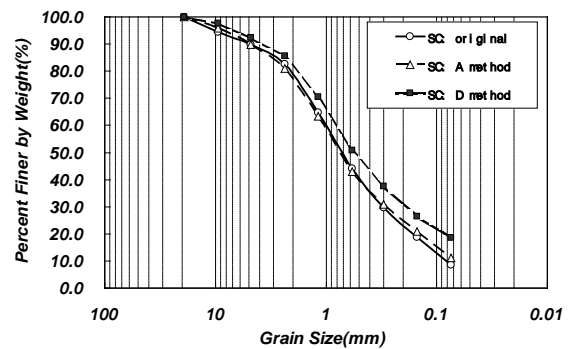
(a) SCP



(b) DH



(c) TA



(d) SC

Fig. 6 Particle-size distribution curves before / after proctor test

### Effect of freezing and thawing

Fig. 7 shows the shape of coal-ash particles taken by SEM after freezing and thawing test. It was observed that some coal-ash particles which have large pores were crushed because of swelling of pore water by freezing.

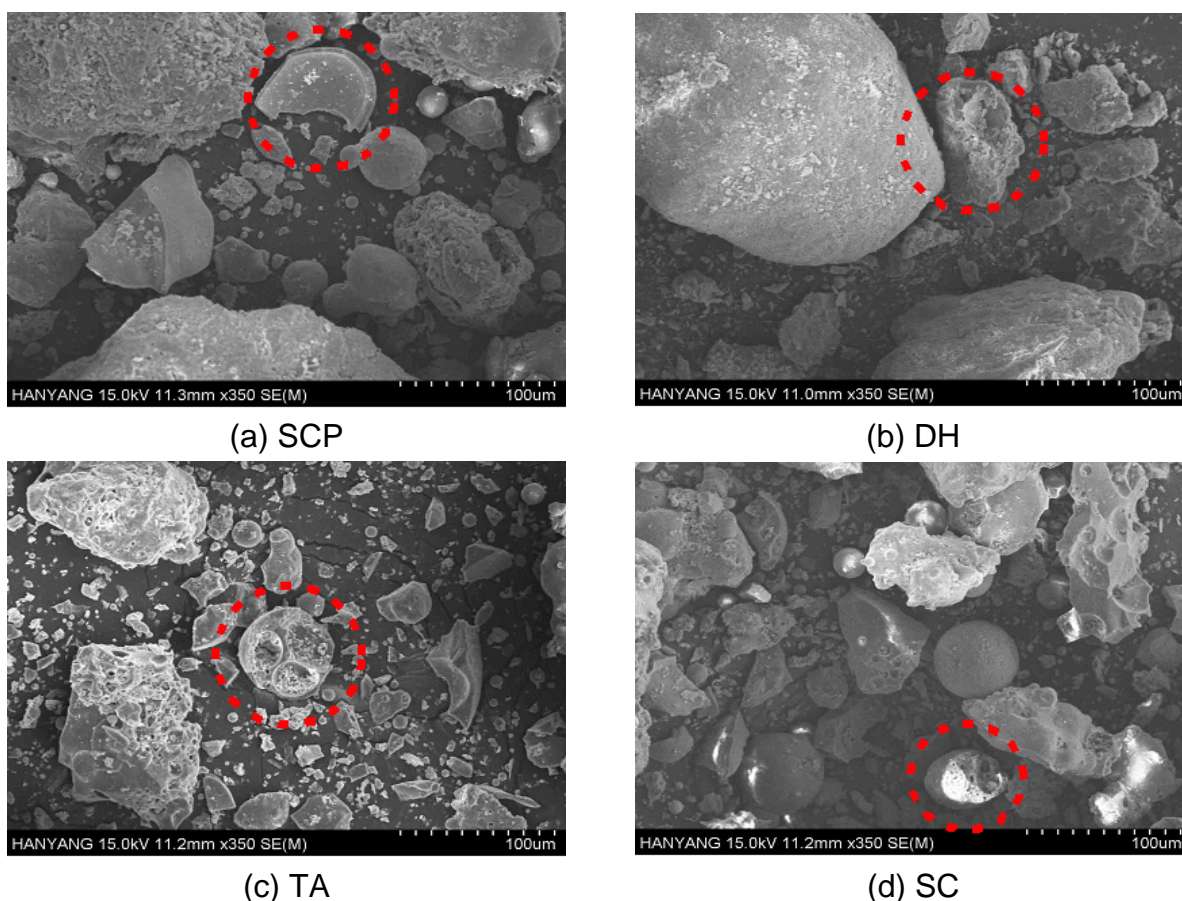


Fig. 7 Shape of coal-ash particles after freezing and thawing test (by SEM)

Table 7 and Fig. 8 show the changed permeability of coal-ash after freezing and thawing test comparing with original permeability. Permeability decreased from 45.2% (SC) to 89% (TA) of original value. It is because of increase of fine grains by crushing of the coal-ash particles induced from freezing of pore water.

Table 7. Results of permeability test for coal-ash samples

Sample	Permeability (cm/sec)	
	Before freezing and thawing	After freezing and thawing
SCP	5.47E-04	2.34E-04
DH	5.78E-04	3.16E-04
TA	4.67E-03	6.61E-04
SC	4.69E-04	2.57E-04

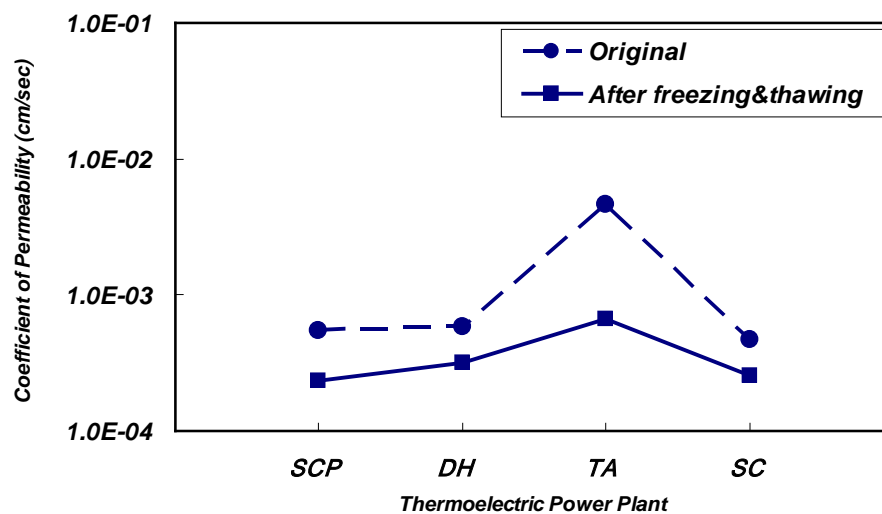


Fig. 8 Variations of permeability after freezing and thawing

Table 8 and Fig. 9 show the results of direct shear test before and after freezing and thawing test. After freezing and thawing, internal friction angle,  $\phi$  was ranging from 32.0° to 36.7°. The internal friction angle was almost same as original value.

Table 8. Results of direct shear test for coal-ash samples

Sample	Internal friction angle, $\phi$ (°)	
	Before freezing and thawing	After freezing and thawing
SCP	32.4	32.0
DH	38.4	36.7
TA	35.7	34.8
SC	36.4	35.0

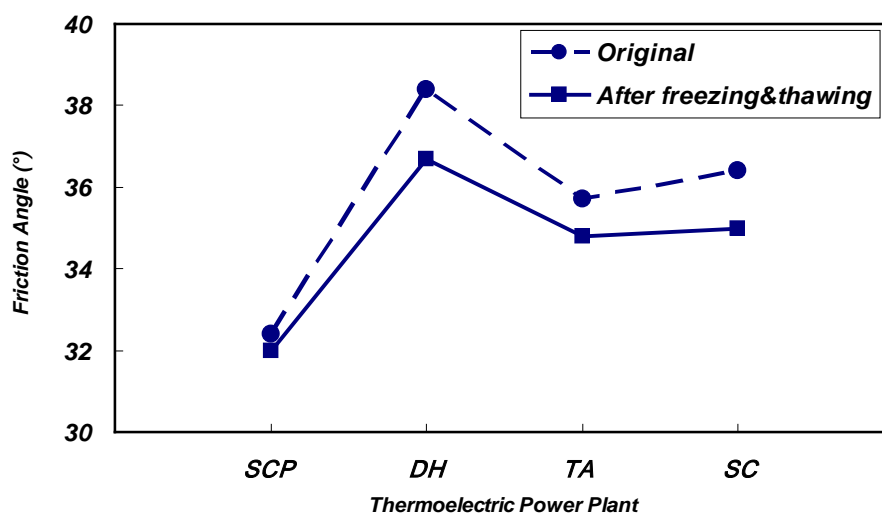


Fig. 9 Variations of internal friction angle after freezing and thawing

## ENVIRONMENTAL IMPACT ASSESSMENT

### Leaching test of hazardous components

Leaching test of hazardous components is generally carried out in order to judge specified wastes or to decide its reclaiming method. In Korea, coal-ash is normally classified as a “industrial waste”, but it can be classified as a “specified waste” if content of hazardous components in leachate exceeds “standard content of specified waste”. Therefore, leaching test of 11 hazardous components stipulated in the Wastes Control Act was performed.

### Test results

The results of leaching test of hazardous components are shown in Table 9. A very small amount of *Pb* and *Cu* leached from SCP and DH sample respectively, but it was quite smaller amount than standard content of specified waste. Except them, the other hazardous components were not detected.

Table 9. Leaching test results

Items	SCP	DH	TA	SC	Standard
Cu(mg/L)	ND	0.011	ND	ND	3
As(mg/L)	ND	ND	ND	ND	1.5
Hg(mg/L)	ND	ND	ND	ND	0.005
Pb(mg/L)	0.042	ND	ND	ND	3
Cd(mg/L)	ND	ND	ND	ND	0.3
Cr <sup>6+</sup> (mg/L)	ND	ND	ND	ND	1.5
CN(mg/L)	ND	ND	ND	ND	1
Organic phosphorus compounds (mg/L)	ND	ND	ND	ND	1
PCB(mg/L)	ND	ND	ND	ND	50
TCP(mg/L)	ND	ND	ND	ND	0.3
PCE(mg/L)	ND	ND	ND	ND	0.1

-ND : non-detected

## CONCLUSIONS

In this study, the applicability of coal-ash for using highway road material, which replaces macadam or sand, was studied. And also, variations of mechanical properties of coal-ash and harmful effects for environment were evaluated.

Based on the above study, the following conclusions can be drawn:

1. By comparing the test results with standards for sub-base, it is founded that it is need to modify particle-size distribution by mixing coarse materials with large diameter for

using road material. Properties of all the coal-ash samples were qualified as a roadbed, roadbed filled up ground, and backfill materials.

2. UC strengths of TA samples were larger than any other coal-ash, and those of DH samples were smallest. SCP and TA coal-ash were made from soft coal, so that the UC strength was larger than DH and SC samples.

3. As the compaction energy increase, distribution curve slightly moved to the right from original distribution curve, because of increase of fine grains by crushing of particles.

4. It was observed that some coal-ash particles which have large pores were crushed because of swelling of pore water by freezing. Permeability decreased from 45.2% (SC) to 89% (TA) of original value. But internal friction angle was almost same as original value.

5. A very small amount of  $Pb$  and  $Cu$  leached from SCP and DH sample respectively in leaching test of hazardous components, but it was quite smaller amount than standard content of specified waste.

## ACKNOWLEDGEMENT

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