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A Study on Engineering Characteristics of Geotechnical Material Using By-Product Lime and Pieces of Waste EPS Beads

석회부산물 및 폐 EPS beads를 활용한 지반재료의 공학적 특성에 관한 연구

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요 지

본 연구에서는 석회부산물의 재활용 방안으로 경량성토재, 뒤채움재 및 경량블록의 활용방안을 종합적인 실험 연구를 통해 수행하였다. 이를 위하여 본 연구에서는, 석회부산물, 성토용 토사 및 폐 EPS 조각을 혼합한 새로운 형태의 경량성토재 및 이에 시멘트 고화제를 첨가한 경량블록을 고안하였고, 다양한 배합비로 제작된 경량혼합토 및 경량블록에 대한 시료에 대하여 종합적인 시험을 실시하여 물리적, 지반공학적 및 환경적 특성을 분석하였다. 또한 경량블록에 대하여 국내 용출시험법(KMS Method)을 실시하여 화학성분의 농도변화에 대하여 평가하였다. 본 연구는 석회부산물 처분의 문제에 대하여 해결을 기대할 수 있으며 뿐만 아니라 성토재 및 블록에 대하여 석회부산물의 재활용 방안을 기대할 수 있다.

Abstract

The purpose of this study is to provide the ways of recycling of by-product limes as lightweight fill, backfill materials, and lightweight blocks by performing experimental study. New lightweight fill materials and blocks were devised by mixing by-product lime, weathered granite soil, small pieces of waste EPS, and Portland cement. Physical, geotechnical, and environmental properties of the lightweight mixed soils and blocks were analysed by laboratory experiments for mixed samples manufactured with various mixing ratios. KMS tests were also performed to evaluate the concentration variation of the chemical components of the light weight blocks leachates. It is expected that this study will contribute to resolving the problem of by-product lime disposal as well as to recycling the by-product limes as fill materials and blocks.

Keywords : By-Product lime, Expanded polystyrene, Lightweight fill material

1. Introduction

Recently, various types of waste materials were rapidly increasing and become wasted resources due to fast industrialization in modern society. To prevent pollution problem costs much amount of social expense and the demand for effective methods to recycle wasted resources is on the rise for decontamination. For example, the by-product lime which is produced from chemical factory in Incheon reaches about 3.2 million

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tons and generation of the annual amount of 120,000 tons. Most by-product limes nowadays are disposed in the pond and seawater, therefore, the development of the techniques and the areas of utilizing by-product limes are necessary in order to provide the spaces for the disposal. A study related to recycling of by-product lime, Shin et al. (1999), has conducted a research concerning physical and mechanical properties of by-product lime and assessment of the appropriateness of using by-product limes as fill materials. He proposed the ways of utilizing soil / by-product lime mixed soil as landfill materials with a mixed ratio of 25% by weights. DongYang Chemical Co., Ltd. (1996) performed chemical analysis of by-product lime and examined environmental effect.

The purpose of this study is to provide the ways of utilizing by-product limes as lightweight fill, backfill materials and lightweight blocks by performing synthetic experimental study.

New lightweight fill materials and blocks were devised by mixing by-product lime, weathered granite soil, small pieces of waste EPS and Portland cement. Physical, geotechnical and environmental properties of the light weight mixed soils and blocks were analysed by laboratory experiments for mixed samples manufactured with various mixed ratios. KMS tests were also performed to evaluate the concentration variation of the chemical components of the light weight blocks leachates. It is expected that this study will contribute to resolving the problem of by-product lime disposal as well as to recycling the by-product limes as fill materials and blocks.

2. The Basic Properties of Used Material

In this study, weathered granite soil samples were gathered from Ansanshi area. Physical and mechanical tests for the soil samples were performed: atterberg limit tests, specific gravity tests and compaction tests, shear tests etc. The tests results are summarized in Fig. 1, Table 1 and Table 2. By-product lime samples were gathered randomly at the lime pond in Incheonshi. The characteristics of by-product lime were referred to from existing research results (refer as Shin, 1999). Portland cement which is used as cementation materials for manufacturing lightweight concrete blocks is the ordinary one that is generally used in construction and public works. Jumunjin sand is used as fine aggregates in lightweight concrete blocks. EPS beads used in this study are usually made while the block of closed EPS is crushed into one having a diameter of 0.6 to 5mm. The density of EPS beads is about $0.02g/cm^3$, its shape is not constant but usually close to an irregular globe. Grain size distribution curve for the

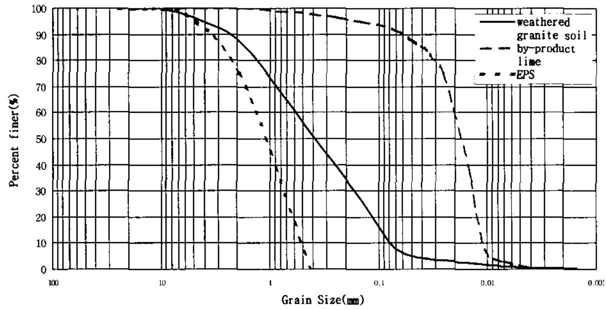

Fig. 1. Grain size distribution curve

Table 1. Physical · Mechanical properties of weathered granite soil

Test items	Values
Specific gravity	2.60
Water content (%)	10.02
Plasticity index	NP
USCS	SM
Uniformity coefficient	8.57
Coefficient of curvature	0.77
Maximum dry density (t/m^3)	1.85
Optimum moisture content (%)	14.02
Internal friction angle (°)	29.17
Cohesion (t/m^2)	2.87

Table 2. Physical · Mechanical properties of by-product lime

Test items	Values
Specific gravity	2.50
Water content (%)	48
Plasticity index	12
USCS	MH
Uniformity coefficient	1.35
Coefficient of curvature	0.96
Maximum dry density (t/m^3)	1.21
Optimum moisture content (%)	37.80
Internal friction angle (°)	29.5
Cohesion (t/m^2)	8.5

pieces of waste EPS is shown in Fig. 1.

3. Laboratory Tests

3.1 Lightweight Fill Material

In this study, physical and mechanical properties of the light weight mixed soils were analysed by laboratory tests for mixed samples manufactured with various mixed ratios. For the laboratory experiments, weathered soil samples were mixed with various mixed ratios after oven dried status. Mixed ratio of 4 : 1 (weathered soil : by-product lime) was applicated based on the research result of Incheon University Engineering Institute (1999). Kim et al. (1996), 森範行 他 (1993) and 峯岸邦夫 他 (1994) have conducted a research concerning lightweight fills mixed with weathered soil and EPS beads. In this study, based on the study of Kim and Bang (1996) and many preliminary tests results, EPS beads were mixed with ratios of 0.1, 0.3, 0.5% respectively. Direct shear tests, falling head permeability tests and laboratory CBR test were performed for the mixed sample which was compacted as 95% of maximum dry density. Environmental effect was also evaluated through pH tests. Table 3. shows the test results.

Table 3. Lightweight fill material test by mixing ratio

Mixing ratio (weathered granite soil : by-product lime)	Pieces of waste EPS	Test
1 : 0	-	Compaction test Permeability test Shear test CBR test pH test
4 : 1	-	
	0.1%	
	0.3%	
	0.5%	

3.2 Lightweight Block

To examine the possibility for the alternate application of blocks as existing lightweight block, several laboratory tests were performed for the mixed block samples. Block samples were manufactured with different mixed ratios of by-product lime, small pieces of waste EPS, fine aggregate and portland cement. Uniaxial compressive strength is most important factor for the quality criterion of the lightweight blocks (KS F 4004). In this study, uniaxial compressive strength tests were performed for the lightweight block samples with different mixed ratios and curing days of 7, 28, 60 and 90, respectively. Environmental characteristics were also evaluated through Leaching Tests (KMS Method). In Table 4, mixed ratios are based on the weight. W/C of blocks are 60%, specimen size is 3.5cm in diameter, 7cm in height. Mixed ratios of pieces of waste EPS and W/C (%) were decided from the preliminary test results.

Table 4. Mixing ratio of lightweight block specimen

Mixing ratio	By-product lime	Sand	Cement	W/C (%)	waste EPS
Case A	10%	70%	20%	60%	0.1% of total weight
Case B	15%	65%	20%		
Case C	10%	65%	25%		
Case D	15%	60%	25%		
Case E	15%	55%	30%		
Case F	20%	55%	25%		
Case G	10%	60%	30%		
Case H	20%	50%	30%		
Case I	30%	40%	30%		

4. Result of Laboratory Tests and Consideration

4.1 Lightweight Fill Material Characteristics

4.1.1 Compaction Characteristics

Compaction test results are summarized in Fig. 2 and Table 5. Maximum dry density and optimum moisture content variation with different mixed ratios are shown in Fig. 3 and Fig. 4. As shown in Table 5, the maximum dry density of lightweight fill material appeared 1.38～1.57t/m^3 and optimum moisture content appeared 21.80～23.92%. It is thus found that with an increase of the EPS beads mixed ratios, the higher the optimum moisture content, the lower the maximum dry density.

In the case of 0.5% of EPS beads mixed ratios, the maximum dry density decreases by about 25.4% and the optimum moisture content increase by 70.6%. Also

Table 5. Compaction characteristics by mixing ratio

Mixing ratio (weathered granite soil : by-product lime)	Pieces of waste EPS	Maximum dry density γ_{dmax} (t/m^3)	Optimum moisture content (%)
1 : 0	-	1.85	14.02
4 : 1	-	1.64	20.91
	0.1%	1.57	21.80
	0.3%	1.44	23.54
	0.5%	1.38	23.92

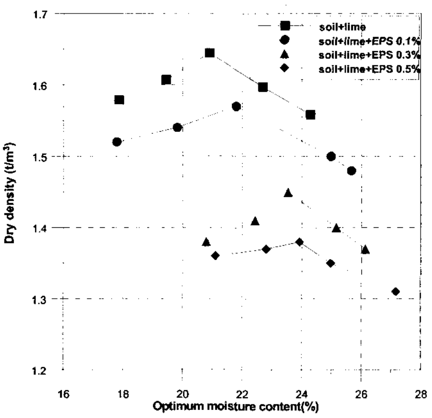

Fig. 2. Compaction curve by mixing ratio

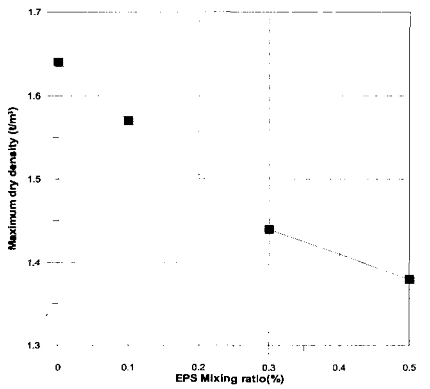

Fig. 3. Maximum dry density by mixing ratio

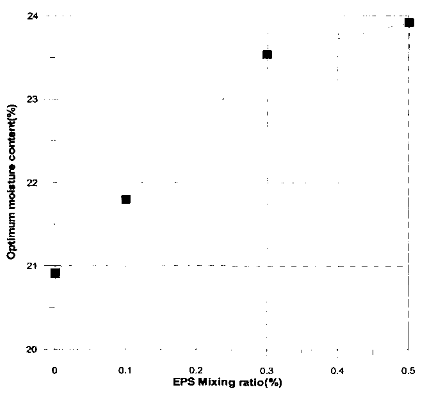

Fig. 4. Optimum moisture content by mixing ratio

in the case of 0.0% of EPS beads mixed ratios, the maximum dry density decreases by about 15.9% and the optimum moisture content increases by about 14.4% compared with purely weathered granite soil. This indicates the distinct decrease effect in the maximum dry density in the case of EPS beads mixtured soil, compared with the case of by-product lime mixtured soil except EPS beads. For instance, 15.9~25.4% of unit weight reduction effect can be expected compared with the soil / by-product lime mixed soil in the case of the mixed ratio of 25%. From Figs. 2, 3 and Fig. 4, the maximum dry density and the optimum moisture contents appeared varying with mixed ratios in the comparatively consistent tendency.

4.1.2 Shear Strength Characteristics

The results of direct shear tests are summarized in Table 6 and tendency of internal friction angle and cohesion variations are shown in Fig. 5 and Fig. 6. As shown in Table 6, in the case of weathered granite soil mixed by-product lime, cohesion increases and internal friction angle decreases compared with the purely weathered granite soil. As shown in Fig. 1, these results are because by-product lime has fine-grained. In the case of light weight soil mixed EPS beads, as mixed ratio increases, cohesion decreases. For instance, the mixed ratio of 0.5%, compared with the purely weathered granite soil, cohesion and internal friction angle decrease by 0.5t/m^2 and 5.8, respectively.

Lightweight fill material mixed pieces of waste EPS, cohesion and internal friction angle are shown in 2.4~3.4t/m^2 and 23.4~26.0°, respectively. As shown in Fig. 5 and Fig. 6, as EPS beads, increase, cohesion and internal friction angle show the tendency suggested in the study of Kim and Bang (1996).

Table 6. Shear characteristics by mixing ratio

Mixing ratio (weathered granite soil : by-product lime)	Pieces of waste EPS	Cohesion (t/m^2)	Internal friction angle (°)
1 : 0	–	2.9	29.2
4 : 1	–	3.6	26.3
	0.1%	3.4	26.0
	0.3%	2.7	24.8
	0.5%	2.4	23.4

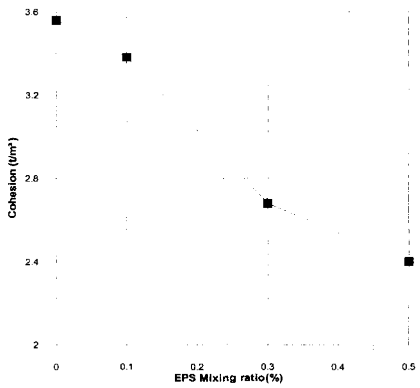

Fig. 5. Cohesion by mixing ratio

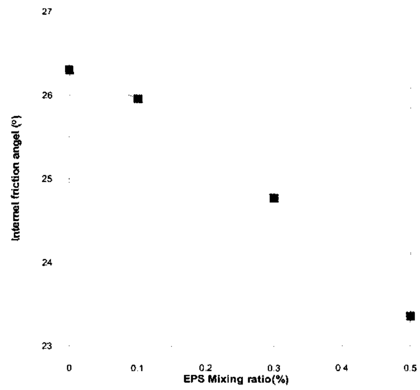

Fig. 6. Internal friction angel by mixing ratio

4.1.3 Permeability Characteristics

The Results of the falling head permeability tests are summarized in Table 7. And tendency of permeability variations with respect to mixed ratios is shown in Fig. 7. The permeability coefficient of lightweight fill material mixed with pieces of waste EPS varies from 3.56×10^{-4} to 2.88×10^{-4}cm/sec in the state of optimum moisture content. It can be found that the more the EPS beads mixed ratios decrease, the better the permeability gets. But the value of the coefficient of permeability is not much different. It can be further found from the results of Fig. 7 that as the EPS beads mixed ratios decrease, permeability coefficient converged very gently. It is thus found that the permeability coefficient of lightweight fill material is not influenced greatly by mixed ratios of EPS beads.

4.1.4 CBR Characteristics

The Results of CBR tests are summarized in Table 8. The change of the CBR valus according to the mixed ratios of EPS beads is also shown in Fig. 8. From the results of Table 8, the CBR values of lightweight fill material ranges between 5.3～11.8%. It is found that as the EPS beads mixed ratios increase, the CBR value decreases. As shown in Fig. 8, decrease tendency of the CBR values appeared very gently when the mixed ratios

Table 7. Permeability characteristics by mixing ratio

Mixing ratio (weathered granite soil : by-product lime)	Pieces of waste EPS	Permeability k (cm/sec)
1 : 0	–	4.58×10^{-4}
4 : 1	–	5.72×10^{-4}
	0.1%	3.56×10^{-4}
	0.3%	3.25×10^{-4}
	0.5%	2.88×10^{-4}

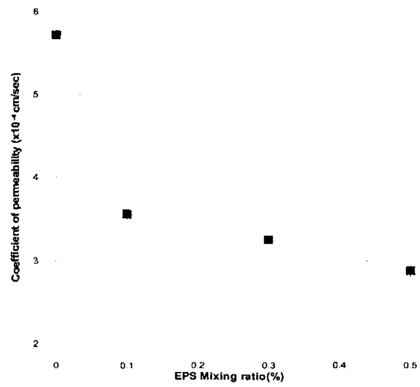

Fig. 7. Permeability by mixing ratio

Table 8. The CBR value by mixing ratio

Mixing ratio (weathered granite soil : by-product lime)	Pieces of waste EPS	CBR (%)
1 : 0	–	14.6
4 : 1	–	12.7
	0.1%	11.8
	0.3%	10.2
	0.5%	5.3

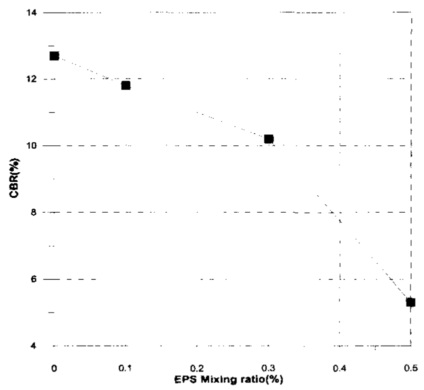

Fig. 8. The CBR value by mixing ratio

of pieces of waste EPS are 0.1～0.3%. But the decrease tendency of the CBR value appeared very quickly when mixed ratios of pieces of waste EPS are 0.5%. According to domestic standards (Korea Highway Corporation, 2001), in the case of base of embankment the CBR value is more than 2.5%, in the case of the lower and upper subgrade, CBR values are more than 5.0% and 10%, respectively. Also in the case of backfill, values of lower and upper backfills are more than 5.0% and 10%, respectively. Therefore, lightweight fill materials in this study can be used as the base of embankment, subgrade and backfill except when the mixed ratio of waste EPS is 0.5%. Also lightweight fill material mixed with pieces of waste EPS 0.5% can be used as the base of embankment, lower subgrade and lower backfills.

4.1.5 pH Characteristics

The pH tests were conducted with weathered granite soil, by-product lime and mixed soil (weathered granite soil:by-product lime) in order to evaluate the environmental effect of lightweight fill materials. The pH values of the weathered granite soil and by-product lime were 6.4 and 10.4, respectively. The lightweight fill materials with pH values of 8.3～8.4, which is classified into weak alkali, were not influenced with mixed ratios of EPS beads.

4.2 Lightweight Block Characteristics

4.2.1 Compressive strength Characteristics

In this study, mechanical properties of lightweight block were investigated in order that lightweight block can be used in concrete block (lightweight block), construction and public works.

Lightweight block was manufactured with various mixing ratios (refer to Table 4) and Lightweight block was given uniaxial compression strength test and air-dry density test. Results of uniaxial compression strength test are summarized in Table 9 and Fig. 9. Specimen of lightweight block was given uniaxial compression strength test for about 7, 28, 60, and 90 days in order to examine whether specimens satisfy quality standard. Specimen of

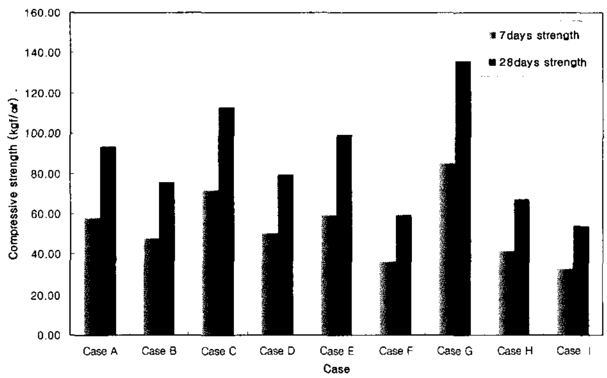

Fig. 9. Compressive strength by curing duration

Table 9. Compressive strength of lightweight block

Curing duration \ Mixing ratio	Case A	Case B	Case C	Case D	Case E	Case F	Case G	Case H	Case I
7days strength (kg/cm^2)	57.62	47.57	71.34	50.31	59.40	36.07	84.96	41.37	32.33
28days strength (kg/cm^2)	93.14	75.54	112.65	79.45	99.26	59.18	135.69	67.01	53.74

Table 10. Later-age compressive strength of lightweight block

Mixing ratio / Curing duration	Case A	Case C	Case E	Case G
7days strength (kg/cm^2)	57.62	71.34	59.40	84.96
28days strength (kg/cm^2)	93.14	112.65	99.26	135.69
60days strength (kg/cm^2)	94.25	113.45	100.80	137.87
90days strength (kg/cm^2)	96.18	115.15	102.22	138.67

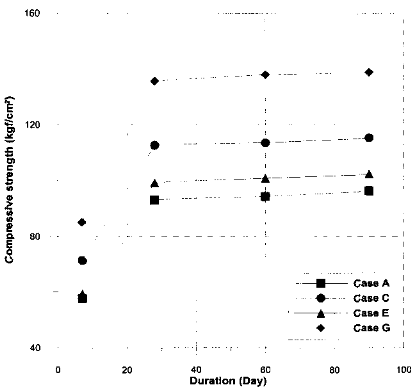

Fig. 10. Compressive strength by later-age curing

lightweight block performed water curing. From Table 10, 7 days compressive strength of lightweight block appeared 63% of 28 days strength regardless of mixing ratio. In the case of Case G (refer to Table 4, By-product 10%, Sand 60%, Cement 30% and EPS 0.1% of total weight), both 7 days and 28 days compressive strength had the highest values. With the same cement amount, Case H of by-product lime 20% content was compared with Case I of by-product lime 30% content. As the content of by-product lime increases, compressive strength decreases. These phenomena also appeared in the case of cement content 20% (Cases A and B) and cement content 25% (Cases C, D and F). Also, these phenomena appeared regardless of cement mixing ratio. A more various experiment and analysis research are required for the effect that by-product lime mixing ratio gets in compressive strength of lightweight block. 「KS F 4004 Concrete Brick (1997)」 of lightweight block is regulated below. B type of Concrete Brick satisfies the standard that compressive strength is more than 122kg/cm^2 and air-dry density is less than 1.9t/m^3. Also, A type of Concrete Brick satisfies the standard that compressive strength is more than 82kg/cm^2 and air-dry density is less than 1.7t/m^3. At present, B type is used in most construction works. In the case of lightweight block proposed in this study, compressive strength of Case G satisfies the standard of B type and Compressive strength of Cases A, C and E satisfies the standard of A type. Air-dry density was about 1.9t/m^3 regardless of any Cases.

In this study, selected specimens of Cases A, C, E, and G, suitable for Standard of 「KS F 4004 Concrete Brick (1997)」, were given long-term compressive strength tests. Results of long-term compressive strength are summarized in Table 10 and Fig. 10. Fig. 10 shows that compressive strength remains unchanged according to passage of time.

4.2.2 Leaching Characteristics

Leaching tests were performed to evaluate environmental effect of lightweight block and results of Leaching tests are summarized in Table 11. In this study, heavy metals content including Cr, Cd etc are measured in order to examine whether heavy metals content satisfied pollutants emission standards of water quality pollutants according to the water quality environ-

Table 11. Leaching results of lightweight block unit : mg/ℓ

KMS Method		Cr	Mn	Fe	Zn	Cd	Pb	Cu	As
The water quality environment preservation law standard		0.5~2.0	2.0~10.0	2.0~10.0	1.0~5.0	0.01~0.02	0.2~1.0	0.5~3.0	0.1~0.5
90 days	Case A	0.056	0.001	0.009	0.012	0.004	0.023	0.001	0.004
	Case C	0.085	0.001	0.008	0.011	0.004	0.018	0.002	0.002
	Case E	0.065	0.001	0.004	0.018	0.003	0.014	0.002	0.008
	Case G	0.04	0.001	0.009	0.014	0.003	0.029	0.004	0.006

ment preservation law (2000). In this study, selected specimens of Cases A, C, E, and G, suitable for Standard of 「KS F 4004 Concrete Brick (1997)」, were given leaching tests. Table 11 shows that results of leaching tests (KMS Method) satisfied pollutants emission standards of water quality environment preservation law (2000).

4.2.3 Freezing and Thawing Characteristics

Freezing-thawing tests are performed for the durability of lightweight block using by-product and results of freezing-thawing tests are summarized in Table 12 and Fig. 11. The basic data obtained from the test can be accumulated for the utilization of lightweight block. Freezing-thawing tests are performed for specimens cured for 7 days. Freezing-thawing cycle of specimen is to drop temperature from 4℃ to -20℃ and raise temperature from -20℃ to 4℃, repeatedly. Compressive strength decreases a little with increasing freezing-thawing cycle, but resistance tests of freezing-thawing show favorable results.

5. Conclusions

In this study, new lightweight fill material and block were mixed with by-product lime, soil, small pieces of waste EPS and cement. Mixed material and lightweight block were examined to investigate their physical and mechanical properties. Based on the laboratory test results, the following conclusions can be drawn:

Table 12. Freezing-thawing strength of lightweight block

Mixing ratio / cycle	Case A	Case C	Case E	Case G
28 days strength (kg/cm^2)	93.14	112.65	99.26	135.69
21 cycle strength (kg/cm^2)	85.69	104.76	90.33	126.19

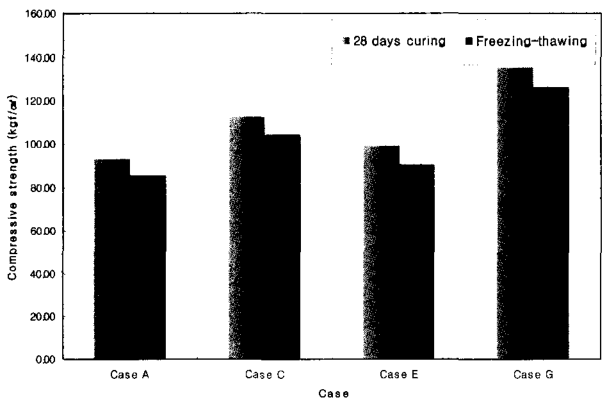

Fig. 11. Compressive strength by freezing-thawing cycle

(1) Maximum dry density of lightweight fill material appeared between the range of 1.38～1.57t/m^3, dry density of lightweight fill material decrease by 15.9～25.4% of weathered granite soil and mixed soil (weathered granite soil : by-product lime = 4 : 1). As a result, it is expected that lightweight fill material produced load reduction effect when it is used as fill material, backfill and landfill.
(2) Cohesion and internal friction angle of lightweight fill material, are shown to be in 2.4～3.4t/m^2 and 23.4～26.0°, respectively. In the case of lightweight fill material mixed pieces of waste EPS by 0.5%, cohesion and internal friction angle decrease by 0.5t/m^2 and 5.8°, respectively.
(3) Permeability coefficient of lightweight fill material mixed with pieces of waste EPS ranges between 3.56×10^{-4}～2.88×10^{-4} (cm/sec). Permeability coefficient of lightweight fill material is not greatly influenced by mixing ratio of pieces of waste EPS.
(4) The CBR value of lightweight fill material ranges between of 5.3～11.8%. Lightweight fill material can be use for base of embankment, subgrade and backfill except when mixing ratio pieces of waste EPS is 0.5%. Also lightweight fill material mixed pieces of waste EPS 0.5% can be used for base of embankment, lower subgrade and lower backfill.
(5) In Case G (refer to Table 4, By-product 10%, Sand 60%, Cement 30% and EPS 0.1% of total weight), both 7 days and 28 days compressive strength showed the highest values. In the case of lightweight block proposed in this study, compressive strength of Case G satisfies the standard of B type and compressive strength of Cases A, C and E satisfy the standard of A type. In long-term compressive strength tests, compressive strength remains unchanged according to the passage of time.

(6) Leaching tests were performed to evaluate environmental effect of lightweight block. Results of leaching tests (KMS Method) satisfied the pollutants emission standards of water quality environment preservation law (2000).

(7) In freezing-thawing tests, compressive strength decreases a little with increasing freezing- thawing cycle, but resistance tests of freezing-thawing show favorable results.

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