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Assessment of Shear Strength Characteristics and Zinc Adsorption Capacities of Zeolite-Amended Soils for Adsorptive Fill Materials

천연 제올라이트가 혼합된 흡착성 성토재의 전단강도 특성 및 아연 흡착 특성 평가

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Abstract

Assessment of Shear Strength Characteristics and Zinc Adsorption Capacities of Zeolite-amended Soils for Adsorptive Fill Materials

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In industrial complexes, gas stations and railbeds, soil and groundwater contamination have occurred frequently and at a high concentration. Especially, zinc, which is one of the most common contaminants in the industrial areas, is needed to be controlled properly. A concept of fill layer construction using adsorptive soil materials is introduced in this study to minimize spreading of contamination.

The purpose of this study is to evaluate shear strength characteristics and adsorption capacity of candidate materials for adsorptive fill materials. The candidate materials consist of weathered granite soil as a base material and natural zeolite for adsorptive materials. The composition methods were amendment and partial substitution. Amendment was the composition method that zeolite similar to particle size distribution of weathered granite soils was amended to weathered granite soils. Partial substitution was the method that fine parts of weathered granite soils were substituted with fine particles of natural zeolite. Shear stength characteristics and adsorption capacities of zeolite-amended soils and partially substituted materials through compaction

test, direct shear test and sorption isotherm equilibrium test.
In case of amendment, test results showed that internal friction angle was decreased with increasing zeolite content while adsorption capacity was increased linearly. In case of partial substitution, shear strength parameters and adsorption capacities were higher than those of zeolite-amended soils. That is, partially substituted materials could be developed as adsorptive fill materials with maximizing adsorption capacity of materials and maintaining the shear strength of materials at weathered granite soils level.

Keywords: Zeolite, Zinc, Strength, Adsorption capacity, Adsorptive fill materials

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Chapter 1 Introduction

1.1 Background

Industrial complex is factory facilities and/or collection of buildings relating to industrial production. According to the current state data on national industrial complex, the number of industrial complexes in S.Korea increases up to 100 units every year.

In an aspect of construction, soil materials consisting of the the fill layers under industrial complex sites, railroad sites, train stations, and train maintenance depots should have enough bearing capacity for service load. Soil and groundwater contamination, meanwhile, have occurred in such industrial complexes by various types heavy metals which cause serious problems in those areas. Table 1.1 shows that among such heavy metals in industrial areas, zinc is one of the most common contaminants and frequently found in industrial complexes and railbeds at high concentrations (Korea ministry of environment, 2015). Because the contamination in the industrial complexes has potentially threatened our drinking water resources, source control against such contamination can not be too much emphasized.

However, most of the existing research of fill materials have mainly focused on light weight fill materials or recycling wastes (Hong et al., 2010; Lee et al., 2011; Shin et al., 2001). Few research are found to study on the evaluation of adsorption capacity of fill materials considering soil and groundwater contamination, It is necessary to study the adsorption capacity of the fill materail as well as its engineering properties having sufficient bearing capacity as fill material for the industrial complex.

Table 1.1 Detailed soil environmental assessment about industrial area, 2004-2010 (Ministry of Environment, 2015)

Year	***Industrial Area***	***Soil contamination***	
		Num	*Contaminants*
2004	Banwol	7	BTEX, TPH
2005	Onsan	92	**Zn**, Cu, Cd, Pb, As, Ni, TPH
2006	Changwon	36	Cu, **Zn**, Ni, TPH
	Yeosu	26	**Zn**, As, Pb, Ni, TPH, BTEX
2007	Ulsan Mipo	59	Cr^{6+}, F, Ni, As, **Zn**, TPH, BTEX
	Sihwa	30	Cu, **Zn**, Ni, TPH, BTEX
	Cheongju	2	Ni, TPH
	Iksan	4	BTEX
2008	Bupyeong, Juan	39	Cu, TPH
	Jinju Sangpyeong	5	**Zn**
	Seongseo	47	Ni, **Zn**, TPH, BTEX
	W.Daegu	40	Ni, **Zn**, TPH, BTEX
2009	Yangsan	45	**Zn**, TPH, BTEX
	Dalseong	36	**Zn**, TPH, BTEX
	Jeonju	13	**Zn**, TPH
	Gumi	26	As, TPH, PCE
2010	Hanam	41	Pb, TPH, Benzene, Xylene, PCE
	Namdong	13	As, F, TPH, TCE
	Daegu	42	TPH
	Pohang	78	**Zn**, Ni, TPH, BTEX
Total		672	

1.2 Research Concept

For the management of zinc as source control, a concept of fill layer construction using adsorptive soil materials is introduced in this study. To make adsorptive soil materials, weathered granite soil, which has been generally used for construction of fill layers, was used as a base material in this study. In addtion, natural zeolite, which can be used for removal of zinc (ERDEM et al., 2004), was added to weathered granite soil.

In comparison to previous fill, adsorptive fill materials can prevent the spread of contamination, so it can reduce the disposal cost and lower risk to human. For development of this adsorptive fill materials, adsorption ability would be evaluated to measure removal efficiency of zinc. Moreover, shear strength of adsorptive soil materials should be evaluated to have enough bearing capacity, which is similar to shear strength of weathered granite soils. Using the results of these considerations and other requirements for the fill materials, finally, highly adsorptive hybrid-fill materials will be developed.

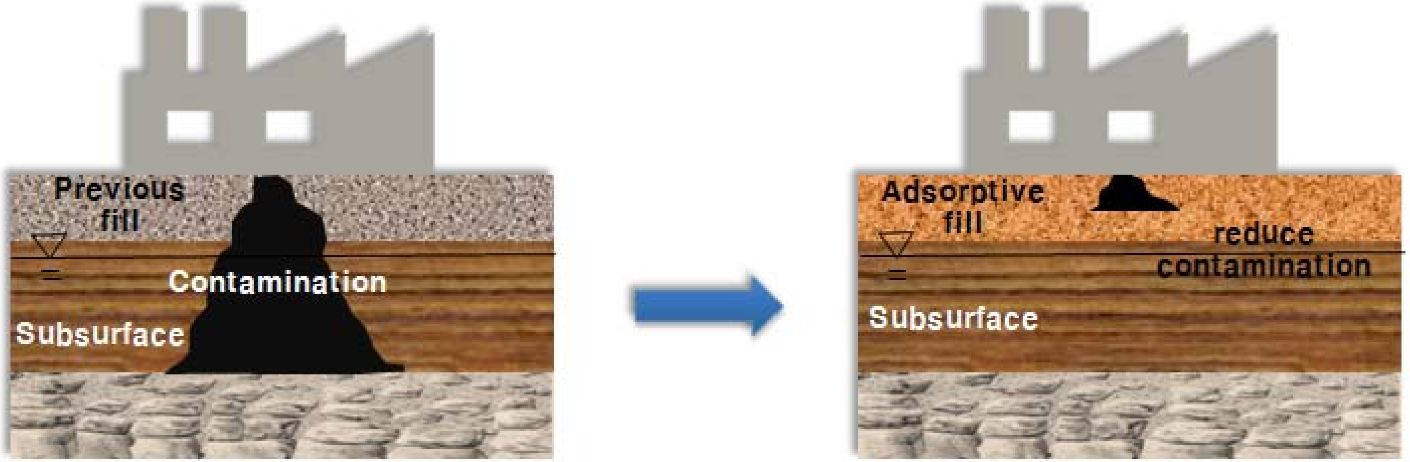

Figure 1.1 Concept of the research

1.3 Objective

The purpose of this study is to evaluate shear strength characteristics and adsorption capacity of zeolite-amended soils. Two composition methods were applied to maintain the strength of zeolite-amended soil and maximize the adsorption capacity. First method is mixing natural zeolite, which is smilar to particle distribution of weathered granite soils, with weathered granite soils in different mixing ratios, 0-100% to find changing tendency in shear strength and zinc adsorption capacity of the materials with increasing zeolite content. Second, weathered granite soils are partially substituted with natural zeolite, which is similar particle distribution of subtituted parts of weathered granite soils.

Shear strength and adsorption capacity of the mixtures including zeolite and Gwanak weathered soils, which were mixed in two different ways, were evaluated through compaction test, direct shear test and equilibrium adsorption isotherm test.

Chapter 2 Literature Review

2.1 Previous Research

This study was motivated by several previous researches on Zn removal efficiency of zeolite, zeolite-amended materials and development of fill materials. The potential of zeolite application on Zn adsorption was found in the research on Zn removal efficiency of zeolite. In addition, geotechnical characteristics of sand-zeolite mixture were investigated in the research on zeolite-amended materials and Cu adsorption capacity of the materials was evaluated with increasing zeolite content. Furthermore, the study on development of fill materials was referred to geotechnical considerations for fill materials.

2.1.1 Zn Removal Efficiency of Zeolite

Several studies indicated that natural zeolite shows high removal efficiency for heavy metals and can be used as economical adsorbents for heavy metals (J. Perić et al., 2004; Erdem et al., 2004; Hong et al., 2011; Shang, 2015). Perić et al.(2004) found that removal efficiency of natural zeolite for Zn, Cu, Pb was high through batch test. Especially, under the low heavy metal concentration condition, natural zeolite could be cost-effective adsorbents for heavy metals. Perić et al.(2004) mentioned that natural zeolite particles are porous, so the adsorption on natural zeolite occurs inner and outer surface of the particles and it is complex process.

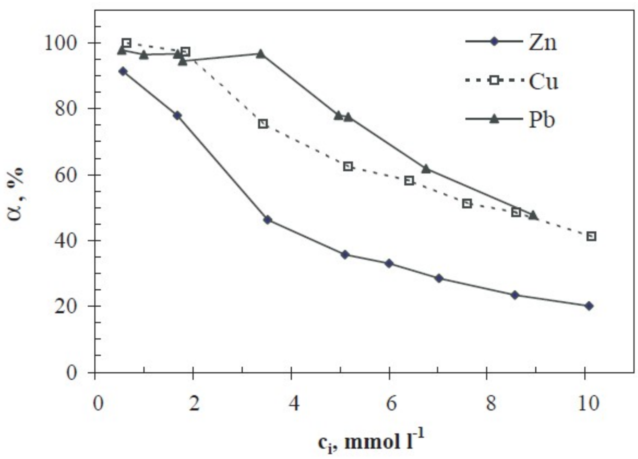

Figure 2.1 The removal efficiency of Zn, Cu and Pb ions in dependence on their C_0 (J. Perić et al., 2004)

2.1.2 Zeolite-amended Materials

Two researches on zeolite-amended materials were motivated by application of the materials as reactive materials (Shang, 2015; Joanna et al., 2013). In Shang's research, sand and zeolite were mixed with 25%, 50%, and 75% of zeolite content. Compaction characteristics of these three groups were compared. As zeolite content increased 25% to 75%, optimum water content was increased and dry unit weight was decreased. The results could be attributed to the lower density of zeolite particles and higher water hold capacity of them (Shang, 2015).

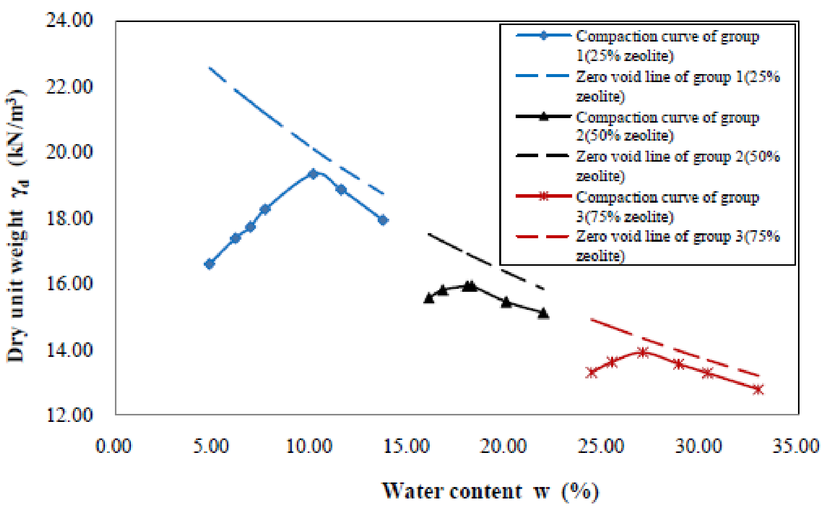

Figure 2.2 Comparisons of three groups compaction curves (Shang, 2015)

In Joanna's research, Cu adsorption capacities of zeolite-sand mixtures were evaluated in batch tests. The results of the tests are shown in Figure 2.3. Adsorption capacity of Cu was increased as the zeolite content increased 20% to 100%. It is due to the increase of specific surface areas. This study mentioned that zeolite-sand mixtures are a promising reactive materials for permeable reactive barriers against groundwater contaminated with Cu because they have high sorbent potentials and cation exchange capacity (Joanna et al., 2013).

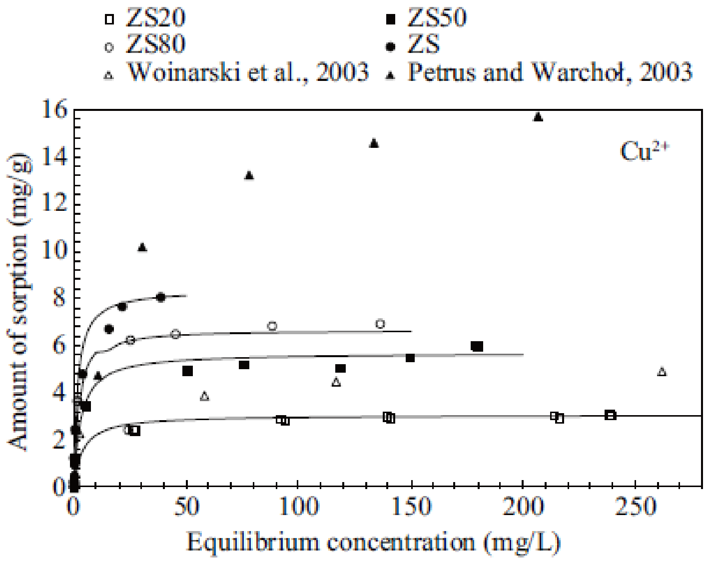

Figure 2.3 Langmuir adsorption isotherms for the zeolite and zeolite-sand mixtures from batch tests (Joanna et al., 2013)

2.1.3 Researches on Development of Fill Materials

The existing researches of fill materials have been mainly focused on light weight fill materials or recycling wastes-amended fill materials (HONG et al., 2010; LEE et al., 2011; SHIN et al., 2001). These studies evaluated geotechnical properties of the materials, such as compaction characteristics, shear strength and permeability, however, the studies didn't evaluate geo-environmental characteristics of the materials, such as adsorption capacity considering an environmental aspect. Because the studies on evaluation of adsorption capacity of fill materials considering soil and groundwater contamination are deficient in Korea, studies on adsorptive fill materials managing soil and groundwater contamination are needed. In Hong's studies, shear strength of recycling wastes-amended materials was lower than that of weathered granite soils.

Table 2.1 Comparison of shear strength between weathered granite soils and waste lime amended soils (Hong et al., 2010)

	Cohesion (kg/cm^2)	Internal friction angle (°)
Weathered granite soils	0.094	33.0
Weathered granite soils + Waste lime	0.104	26.7

2.2 Data Analysis of Adsorption Isotherm Equilibrium Test

2.2.1 Langmuir Adsorption Isotherm Model

The Langmuir model is based on the assumption that a single monolayer of sorbate accumulates at the solid surface. The concentration of the sorbate is increased in the liquid phase, proportionately more of the sorbent surface is covered with the sorbate. At higher concentrations of the material in the solution phase the sorbent is completely saturated (i.e., all adsorption sites are occupied), and above that concentration no more of the material is sorbed. The equation of the Langmuir model is expressed:

$$C_s = \frac{Q_L K_L C_e}{1 + K_L C_e} \tag{2.1}$$

where C_s is contaminant concentration sorbed on the solid (mg/g), C_e is concentration of contaminant remaining in solution at equilibrium (mg/L), Q_L is the maximum adsorption capacity (mg/g) and K_L is the constant related to the affinity.

The Langmuir equation may be transformed to a linear expression by inverting equation (2.1) and separating variables:

$$\frac{C_e}{C_s} = \frac{1}{Q_L K_L} + \frac{C_e}{Q_L} \tag{2.2}$$

The empirical coefficients Q_L and K_L may be obtained by plotting C_e/C_s as a function of C_e. Using linear regression, the slope = 1/Q_L and the y-intercept = 1/($Q_L K_L$).

2.2.2 Freundlich Adsorption Isotherm Model

The Freundlich model is characterized by adsorption that continues as the concentration of sorbate increases in the aqueous phase. The mass of material sorbed is proportional to the aqueous phase concentration at low sorbate concentrations and decreases as the sorbate accumulates on the sorbent surface. Adsorption then continues with increasing aqueous phase sorbate concentrations, but to a diminishing degree. The equation of the Freundlich is expressed:

$$C_s = K_F C_e^{1/n} \tag{2.3}$$

where C_s is contaminant concentration sorbed on the solid (mg/g), C_e is concentration of contaminant remaining in solution at equilibrium (mg/L), K_F is Freundlich adsorption coefficient and n is an indicator of intensity.

The coefficients K_F and n may be determined by plotting experimental data. Alternatively, equation (2.3) can be transformed logarithmically:

$$\ln C_s = \ln K_F + \frac{1}{n} \ln C_e \tag{2.4}$$

Logarithmic transformations of experimental data may then be plotted arithmetically as $\ln C_s$ as a function of $\ln C_e$; through linear regression, $K_F = 10^{y-\mathrm{int}ercept}$ and $1/n$ = slope.

Chapter 3 Materials and Methods

3.1 Materials

In this study, weathered granite soil from Gwanak Mountain (WS) in Seoul was used as a base material for fill materials and its specific gravity was 2.60. Natural zeolite (NZ) from Guryongpo in Pohang, Korea was used for adsorption of zinc and its specific gravity was 2.34.

3.2 Methods

Zeolite, which is commonly used as adsorbents for zinc was amended to weathered granite soil to enhance the adsorption capacity. Two composition methods, amendment and partial substitution, were applied on weathered soil (WS) and natural zeolite (NZ).

3.2.1 Amendment

Zeolite was amended to weathered granite soil with different mixing ratio, of 0 (A0), 25 (A25), 50 (A50), 75 (A75), and 100% (A100). The particle size distribution of zeolite was intentionally adjusted to that of weathered granite soil using purchased zeolite groups of which particle size were under 1mm, 1mm-3mm, 3mm-10mm, respectively. Zeolite was mixed from those different sized group following the mass ratio of particle size distribution of weathered granite soil (under 1mm : 50%, 1-3mm : 30%, 3-10mm : 20%) through wet-sieving. Figure 3.1 is the particle size distribution curves of zeolite and weathered granite soil.

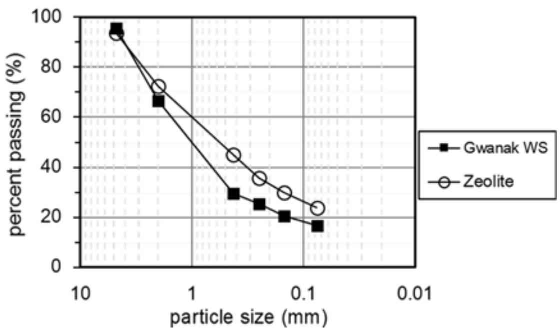

Figure 3.1 Particle size distribution curves of WS and ZL

3.2.2 Adsorption isotherm equilibrium tests in different particle size of zeolite and weathered granite soils

Adsorption capacities of zeolite and weathered granite soils in different particle size were evaluated to investigate an assumption that adsorption capacity would increase as the particle size decreased. Zeolite particles were divided into 5 groups, > 2mm, 0.45-2mm, 0.15-0.45mm, 0.074-0.15mm, < 0.074mm. Weathered granite soils were divided into 5 groups, > 2mm, 0.45-2mm, 0.15-0.45mm, 0.074-0.15mm, < 0.074mm. Initial concentrations of zinc solutions are 80, 240, 500, 640, 850, 1000 mg/L and the final pH of every sample was about 5.5. 45mL of the zinc solution and 2g of soils were put into each vial and shaked for 24 hours with a rotary shaker. The experiments were performed in room temperature and zinc concentration of each sample was measured with AAS (Atomic Absorption Spectroscopy).

3.2.3 Partial Substitution

Two cases of substituted materials were prepared. As shown in Figure 3.2 and 3.3, for the first case, fine parts under #100 sieve of weathered granite soil were substituted with same amount of the zeolite passing #100 sieve (S#100). Another case was prepared using #20 sieve in the same way (S#20). Subtituted samples, S#100 and S#20 contained 20% and 50% of zeolite, respectively. Because it is just susbstitution of fine parts of weathered granite soil with zeolite, particle size distribution of samples were still similar with samples of 3.2.1. This method was based on the assumption that the shear strength would mainly developed by the coarse particles and the adsorption capacity would mainly occur on the surface of fine particles.

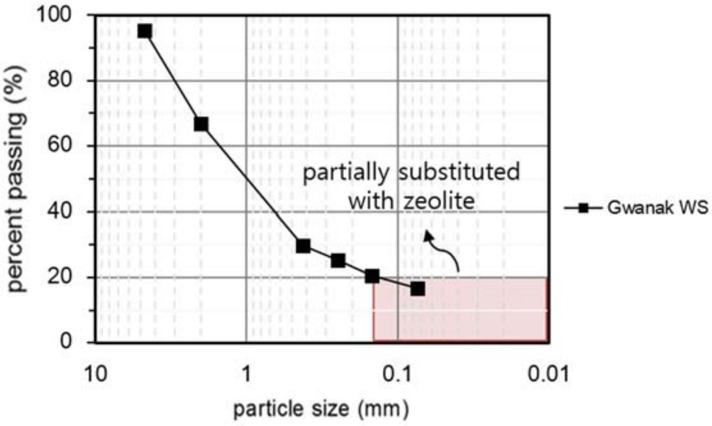

Figure 3.2 Partial substitution with zeolite using #100 sieve

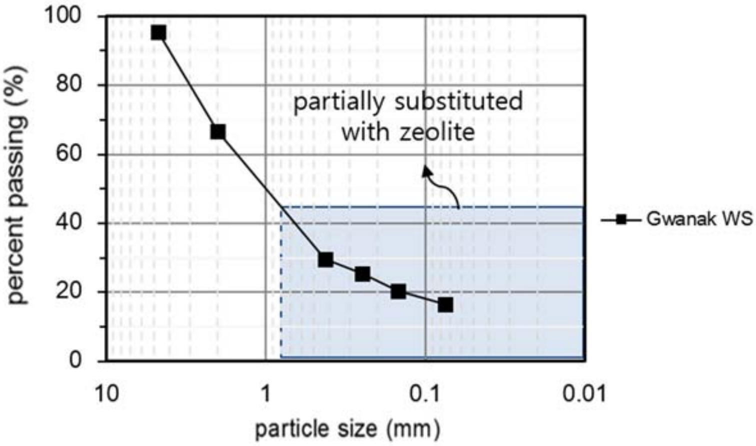

Figure 3.3 Partial substitution with zeolite using #20 sieve

3.2.4 Tests of evaluating properties for adsorptive fill materials

Shear strength and adsorption capacity of mixtures including zeolite and Gwanak weathered soils were evaluated through direct shear test and isothermal adsorption equilibrium test.

To obtain the optimum water content and maximum dry unit weight of each sample, standard proctor tests of samples were performed (ASTM D 698).

To evaluate the strength characteristics of all samples, direct shear tests were performed (ASTM D 3080).

To evaluate the adsorption capacities of all samples, isothermal adsorption equilibrium tests were performed following the procedure in Figure 3.4. Initial concentrations of zinc solutions were 80, 240, 500, 640, 850, 1000 mg/L and the final pH of every sample was about 5.5. 45mL of the zinc solution and 2g of soils were put into each vial and shaked for 24 hours with a rotary shaker. The experiments were performed in room temperature and zinc concentration of each sample was measured with AAS (Atomic Absorption Spectroscopy).

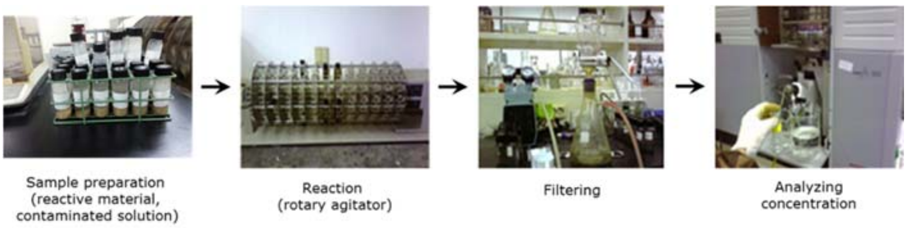

Figure 3.4 Procedure of adsorption isotherm equilibrium test

Chapter 4 Experimental Results and Discussion

4.1 Amendment

4.1.1 Compaction Test

Figure 4.1 shows the optimum water content was increased and the dry unit weight was decreased with increasing zeolite content. Zeolite-amended soils have more compaction characteristics of clayey soils than weathered granite soil as zeolite content of soils was increased. It is due to lower density and higher water holding capacity of natural zeolite particles than weathered granite soil particles.

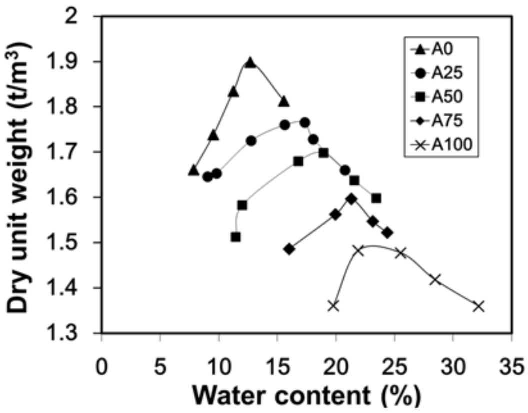

Figure 4.1 Compaction curves of zeolite-amended soils

4.1.2 Direct Shear Test

Table 4.1 is the results of direct shear test with zeolite-amended soils. These soils were cohesionless soils from USCS because passing percentage of #200 sieve is under 50%.

The representative strength parameter of cohesionless soils is effective internal friction angle and the internal friction angle range of cohesionless soils with relatively high density is 30°~45°. The common internal friction angle of fill material is in this range (Kim et al., 2010). The entire samples showed proper internal friction angle for being used as fill materials, but internal friction angle was decreased as the zeolite content was increased. It is because zeolite particles are mesoporous, so they are originally weaker than weathered granite soils. In addition, natural zeolite makes shear strength of the mixture lower than weathered granite soil because natural zeolite is clayey soil.

	A0	A25	A50	A75	A100
Friction angle (°)	47.6	42.0	41.6	40.0	39.8
Cohesion (kPa)	23.6	48.9	49.8	44.1	34.7

Table 4.1 Shear strength parameters of zeolite-amended soils

4.1.3 Adsorption Isotherm Equilibrium Test

Figure 4.2 is the isothermal adsorption curves of zeolite-amended soils. With increasing zeolite content, adsorption capacity was increased. The results of this test were analyzed by Langmuir and Freundlich adsorption isotherm model. Table 4.2 is the adsorption capacity parameters obtained from Langmuir and Freundlich model and it was shown that the adsorption capactiy was increased linearly with increasing zeolite content.

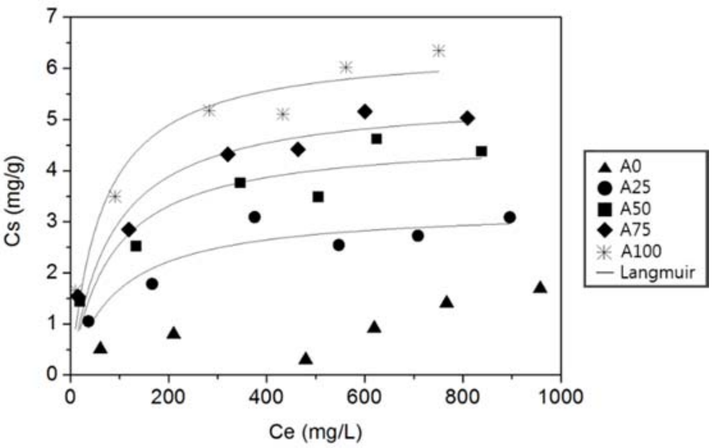

Figure 4.2 Adsorption capacities of zeolite-amended soils

Table 4.2 Langmuir and Freundlich model parameters for zinc by zeolite-amended soils

	Langmuir isotherm			Freundlich isotherm		
	Q_L	K_L (L/g)	R^2	K_F (L/g)	1/n	R^2
A0	1.958	0.016	0.505	0.123	0.383	0.569
A25	3.274	0.109	0.972	0.327	0.336	0.910
A50	4.798	0.249	0.965	0.583	0.306	0.966
A75	5.518	0.383	0.988	0.652	0.315	0.987
A100	6.674	0.623	0.983	0.816	0.314	0.989

This can be discussed by Langmuir isotherm theory, which is based on the assumption that adsorption on solid is surface reaction. That is, adsorption capacity can be considered as the number of adsorption sites of adsorbents. As A is the number of adsorption sites on natural zeolite, B is the number of adsorption sites on weathered granite soils and x is natural zeolite content, the number of total adsorption sites, S is expressed as $S = xA + (1-x)B$. From this equation, it was found that the adsorption capacities of zeolite-amended soils are increased linearly as the natural zeolite content is increased. Therefore, if adsorption capacities of adsorbents and base materials such as weathered granite soils, adsorption capacity of the mixture can be estimated in any mixing ratio.

4.1.4 Comparison with Different Zeolite Content

Figure 4.3 shows the tendencies of internal friction angle and adsorption capacity of the samples with different zeolite content. The shear strength was decreased with increasing zeolite content. However, the adsorption capacity was increased linearly if the zeolite content was increased.

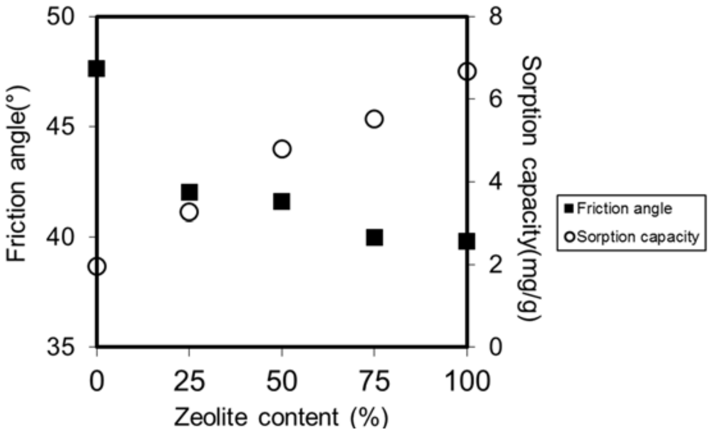

Figure 1.3 Changes in internal friction angle and adsorption capacity

4.2 Adsorption Isotherm Equilibrium Tests in Different Size of Zeolite and Weathered Granite Soils

Table 4.3 shows the results of adsorption equilibrium test in different particle size of zeolite and Table 4.4 shows those of weathered granite soils, which were divided into > 2mm, 0.45-2mm, 0.15-0.45mm, 0.074-0.15mm, < 0.074mm.

Table 4.3 Adsorption isotherm equilibrium test in different particle size of natural zeolite

	Langmuir			Freundlich		
particle size (mm)	**Q_L(mg/g)**	**K_L(L/g)**	**R^2**	**K_F(L/g)**	**1/n**	**R^2**
>2	2.822	0.149	0.923	1.607	0.0003	0.453
0.45-2	2.959	0.122	0.876	1.466	0.0004	0.596
0.15-0.45	3.879	0.184	0.922	1.766	0.0005	0.585
0.074-0.15	4.728	0.356	0.987	1.962	0.0006	0.678
<0.074	6.289	0.737	0.981	2.393	0.0007	0.743

Table 4.4 Adsorption isotherm equilibrium test in different particle size of weathered granite soils

	Langmuir			Freundlich		
particle size (mm)	Q_L(mg/g)	K_L(L/g)	R^2	K_F(L/g)	1/n	R^2
>2	1.457	0.003	0.941	0.064	0.565	0.751
0.45-2	1.630	0.006	0.933	0.018	0.767	0.859
0.15-0.45	1.763	0.011	0.846	0.034	0.679	0.761
0.074-0.15	2.334	0.023	0.867	0.093	0.524	0.838
<0.074	2.920	0.040	0.937	0.067	0.617	0.902

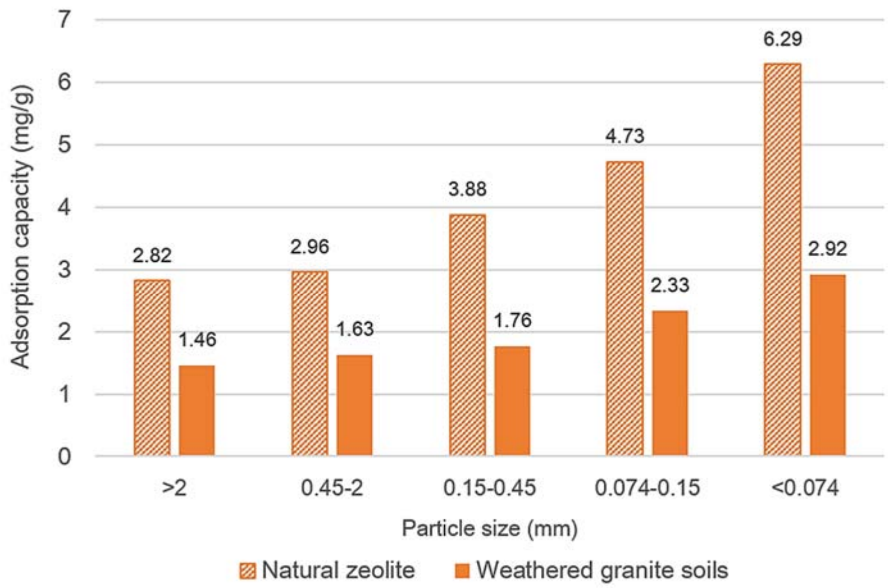

Figure 4.4 Adsorption capacities of NZ and WS in different particle size

As shown in Figure 4.4, in case of natural zeolite and weathered granite soils, both showed that adsorption capacity was increased as the particle size was decreased. This can be explained by increasing specific surface area with decreasing particle size. Based on these results and the assumption that shear strength would mainly developed by the coarse particles, coarse particles of weathered granite soils and fine particles of natural zeolite would be components of a candidate for adsorptive fill materials to maximize the adsorption capacity and maintain the shear strength at weathered granite soils level. Shear strength characteristics and adsorption capacities of the materials were evaluated and the results were compared to zeolite-amended soils in following section.

4.3 Partial Substitution

4.3.1 Compaction Test

The compaction curves of substituted samples are shown in Figure 4.5. Compaction characteristics of S#100 were similar to A25 and those of S#20 were similar to A50. It might be due to similar zeolite content of each other.

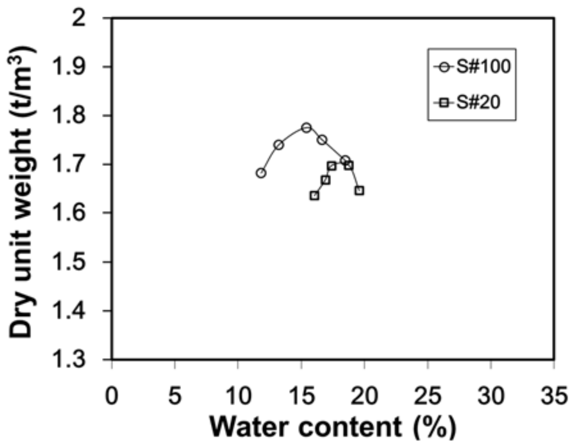

Figure 4.5 Compaction curves of partially substituted samples

4.3.2 Direct Shear Test

Table 4.5 shows strength parameters of zeolite-amended soils and partially substituted samples. Although zeolite content of S#100 is similar to that of A25, internal friction angle of S#100 was higher than that of A25, even similar level to internal friction angle of WS. Likewise, internal friction angle of S#20 was higher than that of A50.

In addition, internal friction angle of S#20 was slightly more decreased than that of S#100. This can be explained by decreasing tendency of internal friction angle in increasing zeolite content, also an assumption in 3.2.3. Because the shear strength is mainly developed by coarse particles and the original strength of weathered granite soil is higher than that of zeolite, there was more decrease in internal friction angle of S#20. In other words, S#100 has more coarse particles of weathered granite soil than S#20, although ratio of entire coarse particles was same, S#100 had higher internal friction angle. These two results can be explained by the assumption that the shear strength would mainly developed by the coarse particles. Still, both decreases in internal friction angles were lower than 10% and their internal friction angles were similar to that of weathered granite soil, so they could be used as fill materials.

Table 4.5 **Shear strength parameters of zeolite-amended soils and partially substituted samples**

	A0	**A25**	**S#100**	**A50**	**S#20**	**A75**	**A100**
Friction angle (°)	47.6	42.0	46.0	41.6	43.0	40.0	39.8
Cohesion (kPa)	23.6	48.9	25.7	49.8	23.2	44.1	34.7

4.3.3 Adsorption Isotherm Equilibrium Test

Figure 4.6 shows the results of adsorption capacity of A25, A50, S#100 and S#20. The sorbed zinc amount of S#100 was increased slightly compared to A25 and adsorption capacity of S#20 was higher than A50. Adsorption capacities of partial substituted samples were higher than zeolite-amended soils. The results can be explained by the assumption that fine particles of zeolite are most effective to express adsorption capacity. These results were also analyzed by Langmuir and Freundlich model and the adsorption capacity parameters are shown in Table 4.6.

In Langmuir isotherm, the adsorption capacity of S#100 was 1.72 times higher than WS and the adsorption capacity of S#20 was 3.79 times higher than WS.

In Freundlich isotherm, the adsorption capacity of S#100 was 2.6 times higher than WS and the adsorption capacity of S#20 was 3.63 times higher than WS.

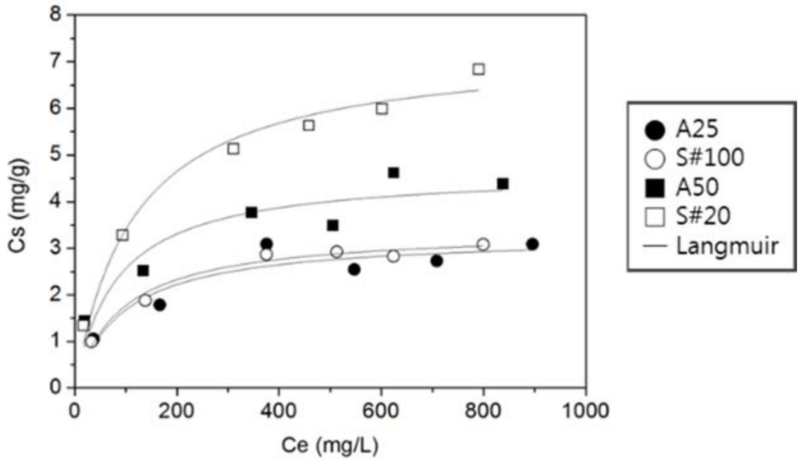

Figure 4.6 Adsorption capacities of zeolite-amended soils and partially substituted samples

Table 1.6 Langmuir and Freundlich model parameters for zinc by substituted samples

	Langmuir isotherm			**Freundlich isotherm**		
	Q_L	K_L (L/g)	R^2	K_F (L/g)	1/n	R^2
A25	3.274	0.109	0.972	0.327	0.336	0.910
S#100	3.370	0.129	0.995	0.320	0.299	0.739
A50	4.798	0.249	0.965	0.583	0.306	0.966
S#20	7.413	0.481	0.987	0.652	0.315	0.986

Chapter 5 Conclusions

In this study, shear strength and adsorption capacity of mixtures including zeolite and Gwanak weathered granite soils, which were mixed in the ways of amendment and partial substitution, were evaluated through compaction test, direct shear test, and adsorption isotherm test to investigate their potentials to be successfully used as fill materials reducing subsurface contamination and maintaining their bearing capacity under service load for industrial complex.

The obtained results can be summarized as follows :

a) In case of amendment, the optimum water content was increased and the dry unit weight and internal friction angle was decreased with increasing zeolite content while adsorption capacity was increased linearly.

b) In case of weathered granite soils and natural zeolite, both showed that adsorption capacity was increased as the particle size was decreased.

c) In case of partial substitution, the friction angles and adsorption capacities of zeolite subsituted materials were higher than zeolite-amended soils.

This study indicates that the composition of coarse particles of weathered granite soils and fine particles of natural zeolite can be developed as adsorptive fill materials. Moreover, the results of 4.1 are expected to be basis for database construction that can forecast the shear strength and adsorption capacity of zeolite-amended soils in any mixing ratio.

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초 록

산업단지, 철도부지 등에서 성토가 이루어지는데, 이 때 건설의 관점에서 거대한 구조물을 지지할 수 있는 충분한 지지력이 필요하다. 한편, 산업 활동으로 인해 다양한 오염물질이 지반 및 지하수로 유입되는 상황이 발생해왔고 특히 아연이 높은 빈도와 농도로 발생하는 오염 물질 중 하나이다. 산업단지에서 발생되는 토양오염은 주로 하부 지반에 발생하는 오염이고, 산업단지의 특성상 다양한 지하 매설물이 존재하기 때문에 정화하기 더욱 어려운 경향을 보인다.

따라서 오염 범위를 축소하기 위해 소스 관리 차원에서 아연의 확산을 방지하는 것이 필요하다. 이는 기존의 성토재와는 달리 산업단지 등과 같은 지반 오염이 우려되는 부지를 조성할 때 흡착성 성토재를 기존 지반 상부에 설치함으로써 오염 확산을 제어할 수 있을 것으로 판단된다.

본 연구에서는 일반적으로 성토재로 이용되는 화강풍화토에 이온교환을 통해 아연 흡착능을 갖는 천연 제올라이트를 두 가지 방법으로 혼합하여 혼합한 물질의 전단 강도 특성과 아연 흡착 특성을 알아보고자 하였다. 화강풍화토의 입도 분포와 유사한 천연 제올라이트를 단순 혼합한 물질과 화강풍화토의 미립분을 천연

제올라이트의 미립분으로 치환한 물질에 대하여 다짐시험, 직접전단시험, 등온흡착평형실험을 수행하였다. 이를 바탕으로 단순 혼합한 물질, 치환한 물질의 전단강도와 아연 흡착능을 평가하여 비교 및 분석을 수행하였다.

주요어 : 아연, 전단강도, 흡착능, 성토재

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