Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Applicability of Recycled Soil Mixed with Bentonite and Polymer as a Waste Landfill Liner

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Abstract. Waste landfill liner has been developed with a variety of materials, but the landfill liner and cover material has not been developed in consideration of the local conditions. In order to build a cost effective municipal solid waste (MSW) landfill site, it is necessary to develop technology that utilizes materials suitable for local characteristics as liner. The purpose of this study is to develop an amended compacted clay liner (CCL) by proportionally mixing construction waste soil called “recycled soil” with small amount bentonite powder as well as polymer powder. Permeability and strength characteristics of recycled soil-bentonite mixture were analyzed through laboratory test and then compare this mixture with characteristics of marine clay-bentonite mixture. The characteristics of strength and permeability were analyzed by applying different mixing ratios with adjustment of polymer and bentonite ratios in consideration of its proportion of bentonite’s weight to improve economic efficiency and increase the strength of recycled soil-bentonite mixture. Finally, the proper mixing ratio of recycled soil-4% bentonite-0.28% polymer mixture was determined considering economical efficiency. The mixture was confirmed to be suitable as lining material based on the results of dry shrinkage test, free swelling test, and soil contamination test. In this study, it is proposed the mixing ratio of recycled soil, bentonite, and polymer as a minimum ratio that satisfies the standard of hydraulic conductivity(1×10^{-7}cm/sec) on the waste management law and unconfined compressive strength (500 kPa) on the specification of construction of waste landfill liner.

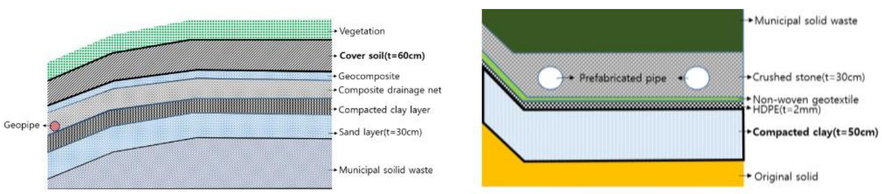
Keywords: Recycled soil, Amended compacted clay liner, Bentonite, Polymer, Permeability, Unconfined compressive strength.

1 Introduction

Recently the use of local available material has been intensively studied for developing the alternative compacted clay liner to substitute of natural clayey soil in the municipal solid waste (MSW) landfill site. Numerous moisture barrier materials are presently available such as natural compacted clay liner (CCL), amended clay liner, geosynthetic clay liners (GCLs), and geomembranes. The natural compacted clay is commonly used at the bottom liners system in the MSW landfill site. However, the natural clayey soil is not sufficient enough where the landfill sites are situated either in the mountain valley area or reclaimed land from the sea.

According to the Korean EPA statistics data [1], recycling of construction waste, the percentages of waste concrete and waste asphalt are 60.8 % and 19.3 %, respectively among total construction waste. The percentage of residual soil called ‘recycled soil’ is 2.8% among total construction waste and its recycling portion is 85.1 %. The usages of recycled soil from construction waste reported by the Korea Construction Recycling Association [2] are categorized into two major applications as the simple embankment soil (50%) and the backfilling soil (50%) in the retaining structures. Therefore, this research was investigated the possibility of use this recycled soil for the amended compacted clay liner at the bottom liners system in the MSW landfill sites. The cover system of MSW landfill site in Korea (1999) is illustrated in Fig.1(a) as including compacted clay liner of 45 cm or high density polyethylene (HDPE) with the thickness of 1.5 mm and gas collection layer with the thickness of 30 cm. The composite drainage layer can be replaced by the gravel layer with the thickness of 30 cm. The most important task in the design and construction of municipal solid waste landfill site is preventing or minimizing the leachate to migrate out to the underground or outside of landfill site through the surrounding multi-staged berms. The environment regulation in Korea (1999) was applied to use HDPE membrane with the thickness of 2mm at the bottom liner system as shown in Fig. 1(b). The compacted clay liner with the thickness of 50 cm is followed HDPE membrane. The thickness of 100 cm CCL is recommended where the HDPE is not used at the bottom liner system. The required permeability of CCL is1×10^{-7}cm/sec.

The non-woven geotextile with the weight of 1000 g/m^2 is placed at the bottom liner system and side slope of MSW landfill site for filtration purpose or protection of the HDPE geomembrane from puncturing by the gravel or rip rock in the landfill site.



(a) Cover system (b) Bottom liner system

Fig. 1. Schematics diagram of covering soil system for solid waste landfill [3]

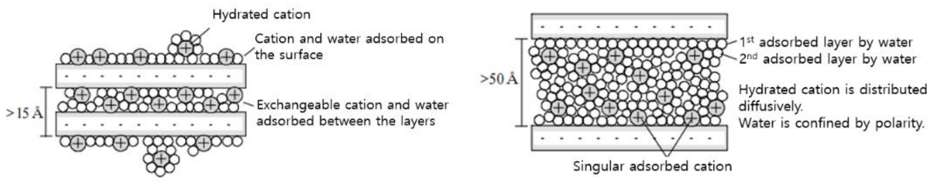
2 Engineering Characteristics of Bentonite and Recycled Soil

2.1 Bentonite

Several combinations of recycled soil specimen mixed with the bentonite powder and polymer powder by the weight were prepared and conducted unconfined compression tests as well as permeability tests in the laboratory. The most cost effective mixing ratio of recycled soil-bentonite-polymer was determined and performed shrinkage and welling tests, and water extraction column test to analyze the applicability of amended recycled soil specimen as a CCL in MSW landfill site.

Bentonite mineral is known as combination of gibbsite sheet sandwiched between two silica sheets forms clay mineral which is called as montmorillonite. The bonding between successive three-layer units of montmorillonite is very weak resulting in an unstable state. The sequential states of changing in double layer from absorbed condition to swelling condition are shown in Fig. 2 [4],[5].

The bentonite can be swell as much as 10-15 times volume of original volume, and absorbed 5 times of its weight [6]. The bentonite has distinctive characteristics such as swelling, hydration, flocculation, dispersion, and strengthening with elapsed times.



(a) absorbed condition (b) swelling condition

Fig. 2. Schematic diagram of double layer for montmorillonite mineral

2.2 Recycled soil

The recycled soil specimens were obtained from 5 different construction waste treatment plants and conducted various soil laboratory tests to determine geotechnical properties including grain-size distribution, CBR value (California Bearing Ratio), Plastic Index, maximum dry density, and organic content as tabulated in Table 1. The grain-size distribution curves of recycled soil specimens A, B, C are drawn in Fig. 3. From the grain-size distribution, the recycled soils are classified as a SP (poorly graded sand) by the USCS (Unified Soil Classification System).

The purpose this study is to create the amended compacted clay liner (CCL) with utilizing recycled soil. The grain-size distribution of recycled soil is similar to poorly graded sandy soil, and thus it should be modified to meet the required permeability, that is1×10^{-7}cm/sec, this criteria is applied for a CCL in MSW landfill site, [7].

Table 2. Geotechnical properties of recycled soil as a product.

Category	Method	Criteria	Result of test				
			A	B	C	D	E
Max. diameter (mm)	KS F 2502 (2014), [8]	Max. 100	10	13	5	13	10
Modified CBR (Compaction spec.)	KS F 2320 (2015)	Min. 10	24.2	22.8	32.8	42.4	28.9
5mm sieve passing rate (%)	KS F 2502 (2014)	25～100	78	65	90	65	89
0.08mm sieve passing rate (%)	KS F 2301 (2015), [9] KS F 2309 (2014), [10]	0～25	8.9	15.9	12.2	8.3	14
Plastic index	KS F 2303 (2015)	Max. 10	N.P	N.P	N.P	N.P	N.P
Dry unit weight (kN/m^3)	KS F 2303 (2015)	Min. 15	17.74	17.82	18.07	18.11	17.57
Organic materi-al (%)	KS F 2576 (2010)	Max. 1.0	0.54	0.71	0.47	0.43	0.65

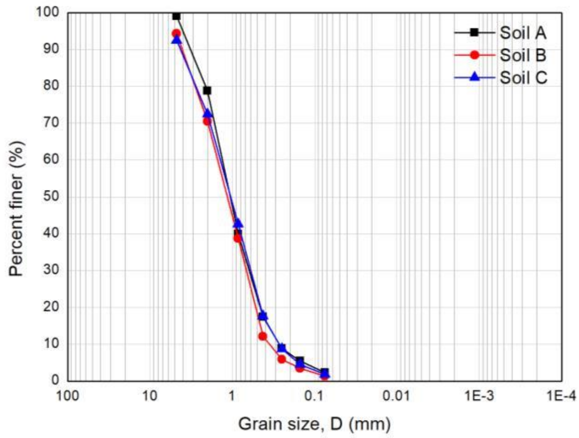


Fig. 3. Grain size distribution of recycled soil (A, B, C)

3 Soil Laboratory Test

3.1 Permeability test and results

The falling head test method was adopted to conduct the permeability test for the amended compacted clay specimens described in Table 2. The diameter of mold is 10 cm with the height of 15 cm. The moisture content of soil specimens for permeability test were prepared at the optimum moisture content with additional 2% to get the lowest permeability for given soil specimen. The preparation of soil specimen for permeability test is shown in Fig. 4. After assembled of mold in Fig. 4(f), the gap between the bottom base part and mold was coated by using the grease to have a completed sealing for prevention of water leakage.

(a) Assemble bottom liner (b) Bottom mesh (c) Bottom porous stone

(d) Top porous stone (e) Rubber ring (f) Assemble top liner

Fig. 4. Test procedures of permeability test for recycled soil specimen

Several series of soil specimens as described in Table 2 were prepared and conducted permeability tests as well as unconfined compression tests with curing days. Basically, recycled soil (RS), weathered granite soil (WS), natural marine clay were prepared as mother soils for amended compacted clay liner. In the 1st Test Series, the bentonite is added to the natural marine clay with the mixing ratios 2, 3, 4 % by the weight. In the 2nd Test Series, the bentonite is added to the recycled soil with the mixing ratios 4, 5, 6, 8% by the weight. In the 3rd Test Series with considering the permeability test of the 2nd Test Series, the bentonite (4 %, 6%) and the small amount of polymer powders (0.16-0.28%) are added to the recycled soil.

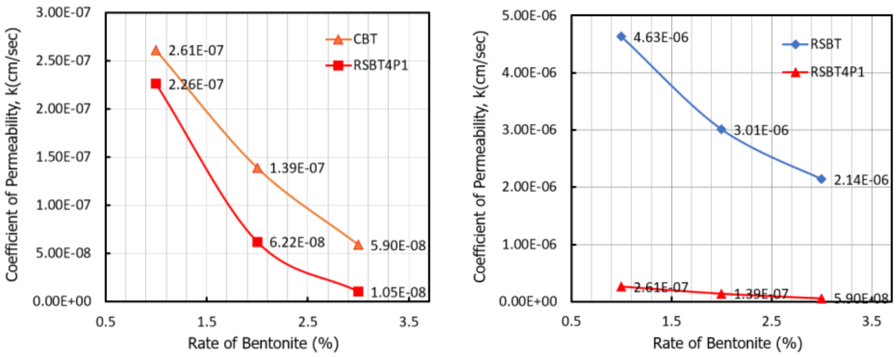
Table 2. Test specimens with mixed material by mixing ratio

Test	Specimen	Recycl-ed soil (%)	Weath-ered Granite soil (%)	Clay (%)	Bento-nite (%)	Polymer (%)	
						(Type 1)	(Type 2)
Soil	RS	100		-	-	-	-
	WS	-	100	-	-	-	-
	C	-		100	-	-	-
Clay soil+Bentonite	CBT2	-	-	-	2	-	-
	CBT3	-	-	-	3	-	-
	CBT4	-	-	-	4	-	-
Recycled soil+Bentonite	RSBT4	-	-	-	4	-	-
	RSBT5	-	-	-	5	-	-
	RSBT6	-	-	-	6	-	-
	RSBT8	-	-	-	8	-	-
Recycled soil+Bentonite+ Polymer	RSBT4(P1)4	-	-	-	4	0.16	-
	RSBT4(P1)6	-	-	-	4	0.24	-
	RSBT4(P1)7	-	-	-	4	0.28	-
	RSBT6(P1)3	-	-	-	6	0.18	-
	RSBT4(P2)7	-	-	-	4	-	0.28
	RSBT4(P2)8	-	-	-	4	-	0.32

*RS: Recycled soil; WS: Weathered granite soil; C: Clay; BT: Bentonite; P1: Polymer1; P2: Polymer2; CBT(N_1): Clay+Bentonite(N_1)%; RSBT(N_1): Recycled soil+Bentonite(N_1)%; RSBT(N_1)(P1)(N_2)：Recycled soil+Bentonite(N)%+Polymer1(N)%

The reclaimed land from the sea is one of favorable sites for MSW landfill site because it has natural clay liner as well as isolated from the residential area. The current Metropolitan Sanitary Landfill Site in Korea is situated on the reclaimed land from the sea. However, the clayey soil is obtained from the coastal line in Incheon is not meet the required permeability by the Korea EPA. The bentonite powder was added to the natural marine clay with the mixing ratios 2%, 3%, 4% by the weight. From the falling head permeability test results for bentonite amended marine clay shown in Fig. 5, clay specimens with more than 3% of bentonite mixture are achieved the desired permeability criteria for CCL in MSW landfill site.

The recycled soil specimens mixed with bentonite are not met the required permeability except the 8 % bentonite soil mixed specimen. Because the grain-size distribution of recycled soil is fallen in the range of sandy soil with high permeability. The high percentage of bentonite mixture in recycled soil can contribute the lowering the bearing capacity of soil ground. Therefore, the additional polymer powder was added to the bentonite-recycled soil mixture to reduce the amount of bentonite and decrease the permeability. The recycled soil ($k=1.35\times10^{-2}$cm/sec) mixed with 4% bentonite gives $k= 4.63\times10^{-7}$cm/sec which is not met the required permeability 1.0×10^{-7}cm/sec. As the results of several trial permeability tests, the recycled soil mixed with 4% bentonite and 0.28% polymer powder by the weight gives $k= 5.90\times10^{-8}$cm/sec which is met the required permeability of CCL in MSW landfill site. These results are shown in Fig. 5.



(a) Comparison of clay and polymer (b) Comparison of bentonite and polymer

Fig. 5. Variation of permeability with combined material

3.2 Unconfined compression test and results

The amended clay specimens were prepared for determination of unconfined compressive strength with the curing times (0, 7, 14, 21, 28 days) as shown in Fig. 6. The inner diameter of mold is 5cm with the height of 10cm. The soil specimen was prepared 90% of the maximum unit weight of soil at the optimum moisture content with additional 2 %.

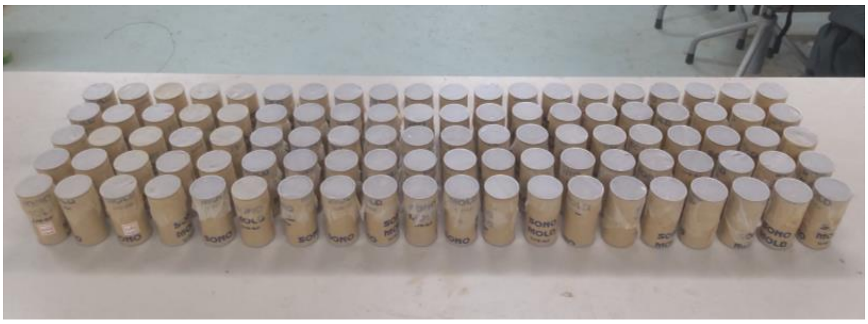


Fig. 6. Preparation of unconfined compressive strength test specimen

The unconfined compressive strength (UCS) with elapsed time and hence curing days is very important for amended compacted clay liners (CCL). Because the CCL in the cover and bottom liner systems in the MSW landfill site is normally located at the bottom part of landfill site. Therefore, it requires a reasonable bearing capacity to support the load given by the municipal solid waste as well as overburden landfill system, and traffic load. The Korean EPA has a policy to maintain the UCS of CCL as 500 kPa. The unconfined compression tests were conducted for 28 days curing RSBT soil specimens for the recycled soil was mixed with bentonite powder with mixing ratios, 0, 4, 6, 8%, respectively. The results of UCS shown in Fig. 7 indicate that the higher mixing content of bentonite powder gives lowering the UCS while the UCS increases steadily with the elapsed curing days.

The 28 days curing all RSBT soil specimens are satisfy the Korean EPA design criteria of 500 kPa [676 kPa (4%); 536 kPa (6%); 516 kPa (8%)].

Based on the laboratory test results of UCS and permeability, and cost of bentonit e powder, the mixing ration between recycled soil and bentonite is fixed as 4 % by the weight. Now, the powder of polymer is added to the RSBT4 soil with the mixi ng ratios 4% (0.0016), 5% (0.002), 6% (0.0024), and 7% (0.0028), respectively.

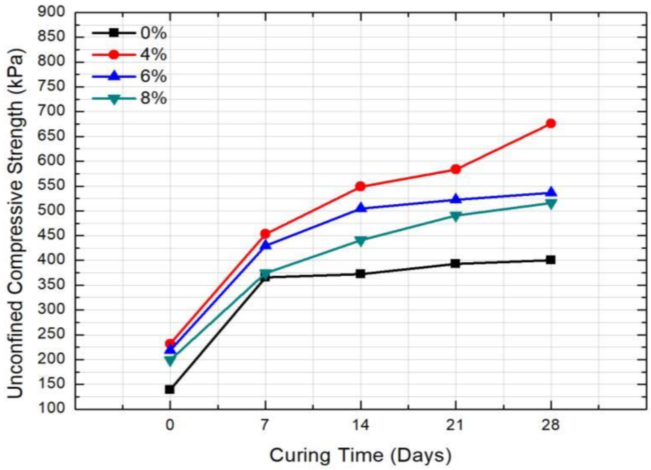


Fig. 7. UC strength for RSBT with elapsed time

Fig. 8 shows the UCS with elapsed time for the amended soil specimen, RSBT4 + polymer (4-7%). From the laboratory test results of UCS for RSBT4, the UCS i ncreases rapidly up to 7 curing days and then the UCS is somewhat increased, but in reality, it is not much improved. However, the additional adding of small amou nt of polymer (4-7% of 4% bentonite weight) is stimulated drastic improvement of UCS. The amended polymer mixed soil specimen with RSBT4 is named as RSB T4P. The RSBT4P is increased rapidly in the first 7 curing days and after then the magnitude of shear strength improvement is not so much. This trend is similar to t he RSBT soil specimen. The magnitude of UCS for RSBT4P soil specimen is in th e order of 6%, 7%, 5%, and 4 % mixed specimen. In general, the amended soil spe cimen, RSBT4 + 4% polymer gives a little bit lower value of UCS and other three amended soil specimens are given similar UCS.

It is indicated that the content of polymer helps the increment of UCS. However, the UCS decreases when the content of polymer in the amended soil specimen whi ch has more than 7 % due to the volume of polymer in the soil specimen.

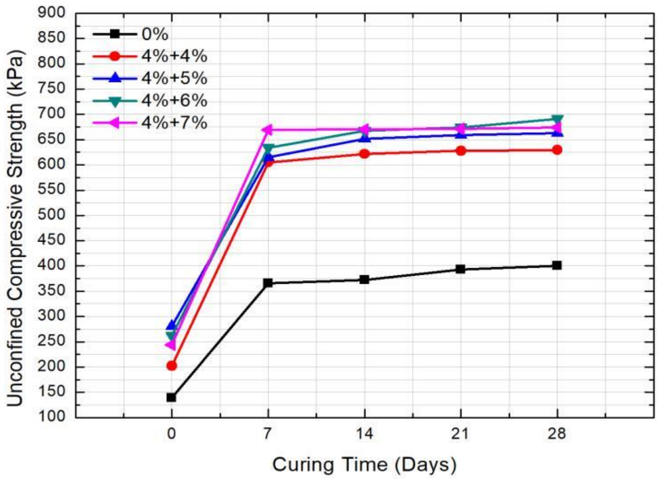


Fig. 8. UC strength with elapsed time on RSBT4P

3.3 Shrinkage test and results

The soil specimen for shrinkage test is prepared by using the mold with the diameter of 11cm and the height of 2.3cm as shown in Fig. 9. The distance of two measuring points on the soil specimen is 4cm. The variation of distance measures after kept the soil specimen in the oven under the temperature of 40°C for 24 hours.

(a) Sampling plate (b) Specimen

Fig. 9. Shrinkage test on RSBT4P

The recycled soil (RS) shows the highest shrinkage rate and then RSBT4 soil specimen is a little bit lower than RS soil specimen. The RSBT4 soil specimen mixed with 7% polymer 1 shows lower shrinkage rate then other two RS soil specimens but still higher than that of decomposed granite weathered and the amended soil specimen, RSBT4+7% polymer 2. The adding polymer powder to RSBT4 reduces the shrinkage potential very much.

Therefore, the use of polymer powder provides beneficial role to reduces the shrinkage crack on the amended compacted clay liner in the MSW sanitary landfill site. The comparison result of shrinkage rate with various soil specimens are shown in Fig. 10.

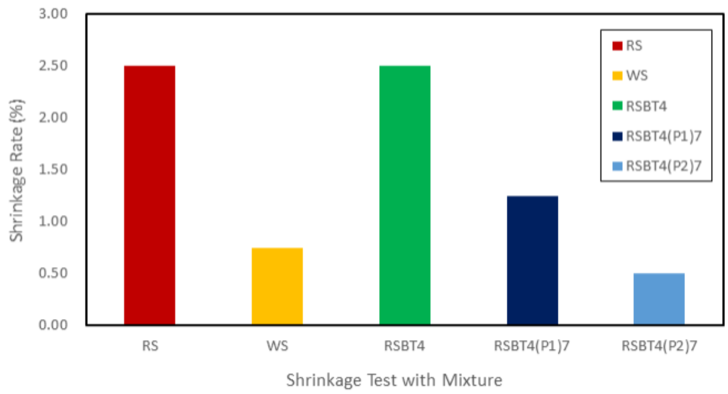


Fig. 10. Comparison of shrinkage rate with various soil specimens

3.4 Swelling test and results

The swelling rate is important in the compacted clay liner because the crack created by desiccation crack or crack due to the differential settlement on the CCL can be self-cured with soaking the water [11]. The swelling tests were conducted with utilizing two types of cylinders 500 mL and 1000 mL. Normally the large size (1000 mL) of cylinder gives a higher percentage of swelling potential for the same given soil.

Fig. 11 shows the view of free swelling tests with utilizing the graduate cylinders with volume 500mL and 1000mL for various amended clay specimens. The degree of soil swelling is influenced on the self-sealing of desiccation crack in the amended clay liner. The soil specimen in the smaller diameter cylinder shows lower swelling potential with comparing soil specimen in the larger diameter cylinder.


(a) Bentonite

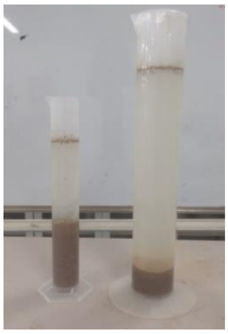

(b) RSBT4

Fig. 11. Free swell test for bentonite and recycled soil specimen free swell test

Because 500 mL cylinder has a large contact area comparing with 1000 mL cylinder. The swelling test results shown in Fig. 12 are based on the experimental work conducted by using 1000 mL cylinder. The 100% bentonite soil specimen swells 283.33 %, but the RSBT4 soil specimen swells only 41.53 % due to a large portion of sandy soil contained. However, with addition of small amount of polymer powder (RSBT4+7% polymer 1) is contributed to the swelling potential as 86.67 %. The permeability and UCS are also improved with the swelling of polymer powder. The decomposed granite weathered soil mixed with 4 % bentonite and 7% polymer 1 gives 75% swelling potential due to the components of bentonite as well as polymer powders**.**

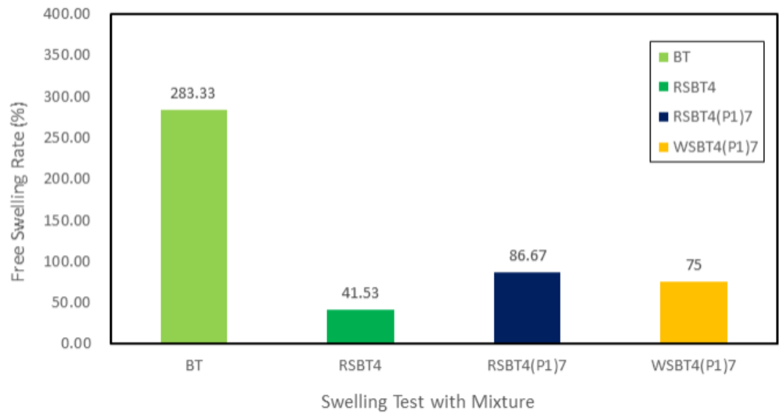


Fig. 12. Comparison of free swelling rate with mixing ratio of mixture

4 Technical Discussion

There is no particular regulation for the criteria of unconfined compressive strength (UCS) for the CCL in the MSW landfill site in Korea. However, it is necessary to carry out the traffic load given by the heavy construction vehicles like Bulldozer and garbage truck and surcharged load by garbage. Therefore, certain degree of bearing capacity and hence the unconfined compressive strength of CCL is required. The UCS of soil specimen which is marine clay mixed with bentonite powder is proportionally increased with increasing the bentonite mixing ratios (0-10%). However, all soil specimens, the bentonite mixed with marine clay, are further increased from 630 kPa to 691 kPa met the required UCS 500 kPa at the 28 curing days. The UCS of RSBT soil specimen at the 28 curing days shows the increasing of UCS except the soil specimen of RSBT7. It would be expected that the UCS could be decreased for the RS soil specimen mixed more than 7% of bentonite powder. The unconfined compressive strengths of soil specimens, RSBT 4%, 6%, 8%, are from 516 kPa to 676 kPa.

With additional adding of polymer powder (4%, 5%, 6%, 7%) to RSBT4, the unconfined compressive strengths are further increased from 630 kPa to 691 kPa as shown in Fig. 13.

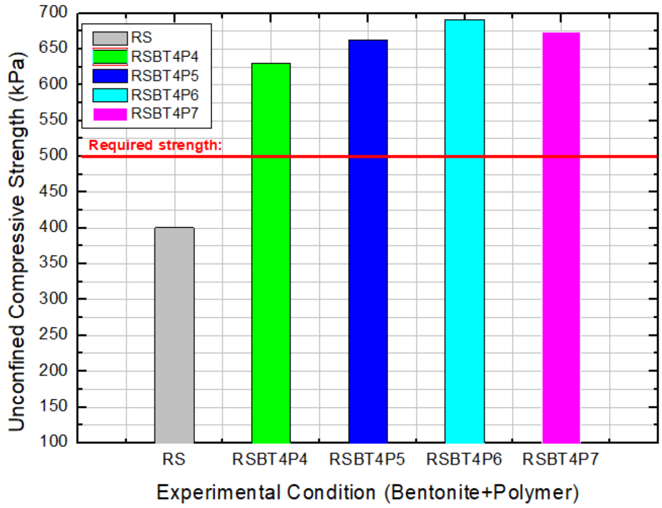


Fig. 13. Variation of UC strength for various soil specimens

5 Conclusions

This study was carried out to develop the environmentally friendly compacted clay liner by utilizing construction waste soil called "recycled soil" as a mother soil which mixed with bentonite and additional polymer powder. Based on the laboratory soil tests, amended compacted clay liner material is proposed with utilizing recycled soil, bentonite powder, and polymer powder. Several conclusions are drawn based on the laboratory test results.

1. The marine clay mixed with more than 3% bentonite powder can achieve the EPA requirement of permeability ($k=1.0\times10^{-7}$cm/sec).

2. However, the recycled soil is needed more than 8% of bentonite powder to meet the permeability of EPA requirement.

3. The amended recycled soil specimen mixed with bentonite 4%, and polymer 0.28% gives the best mixing ratio to meet the requirements of permeability and UCS (500 kPa). The 4 % weight of bentonite powder can be saved by adding the polymer powder (0.28%) for RSBT4 soil specimen.

4. With increasing the polymer mixing ratio for the amended soil specimen, RSBT4, the UCS increment rate is higher than the reduction rate of water content.

5. The addition of polymer to the RSBT4 soil specimen, the shrinkage rate is significantly reduced and shows higher swelling potential due to adsorption of water efficiently.

6. As the results of water quality test for the water extracted from the soil column test, the degree of water pollution is far below the soil pollution category 2 by the EPA criteria. Therefore, the proposed amended CCL from this study can be used in the MSW landfill site.

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