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New development of triple liner system with polyurethane elastomer between double geomembrane sheets

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ABSTRACT: A new triple liner system for waste disposal sites have been developed and some basic characteristics on the materials used in this system have been investigated. This system consists of double geomembrane sheets with an intermediate protective materials made of cast in place polyurethane elastomer. The polyurethane elastomer intermediate layer essentially has buffer function as a protective layer free from the defect of geomembranes and a high barrier function with its extremely low hydraulic conductivity (less than 10^{-14} m/s). Some geomembranes, geosynthetic clay liner, and composite liner systems have a problem of defects due to cracking by severe accidents during a construction work, at an earthquake, etc. A key feature of the polyurethane elastomer is compatible for large and long-term deformation without any cracking. This system has a reliable barrier function at the joint parts as well and an excellent durability by a high chemical resistance. Consequently, this triple liner system can be applied practically to waste disposal sites as the safety barrier structure.

1 INTRODUCTION

The subjects referring to the waste management such as the increment of waste generation, waste containment system, and illegal waste abandonment are problems of urgency. As the countermeasure of these problems, we must hasten the reduce, reuse and recycling of waste. Although there are many efforts to reuse and recycle the waste, huge volume of waste should be disposed of finally. Because waste materials contain somewhat harmful and toxic substances, safe and reliable structures of waste disposal site must be designed.

The Japanese guideline for the liner systems in waste disposal sites on the land is based on a natural clay more than 5m in thickness and having permeability less than 10^{-7}m/s. Otherwise, it requires one of three following liner systems : (1) two geomembrane (GM)s which sandwich a non-woven fabric or other cushion material, (2) a GM underlain by an asphalt –concrete layer more than 0.05m in thickness with hydraulic conductivity less than 10^{-9}m/s, or (3) a GM underlain by a clay liner more than 0.5m in thickness and having hydraulic conductivity less than 10^{-8}m/s.

In the waste disposal site at the sea, two types of barrier structures are regulated in Japan. First is the vertical barrier wall using sheet piles, and second is the barrier slope laid by two GMs which sandwich a non-woven fabric or other cushion material.

The risk of damage of the liner systems by several accidents cannot avoid in these containment systems (Kamon 1999). Therefore, the careful installation of the liner system is required. In particular, geomembrane has inherently defects itself and at the joints parts. We must try to develop the more safe and stable geosynthetic materials.

The purpose of this study is to develop a new triple liner system (TLS) by use of the ultimate waterproof materials not to leak the leachate from the any waste disposal site.

2 OUTLINE OF TRIPLE LINER SYSTEM (TLS)

Geomembrane liner itself could not be used as the waste disposal site because of having defects originally and during construction (for example, Giroud et al. 1994 and 1998). To improve this problem many efforts have been engaged in the quality of geomembrane, developing the GCL and other liner systems. As mentioned above, double geomembranes (GM)s system with intermediated a non-woven fabric has been often used in the Japanese landfills. This system, however, has been recognized to have a high risk of leaching out the leachates from the landfill. It means that the double membranes have many defects and are impossible to prevent leaching through the GMs. Triple liner system (TLS) has been developed to improve this problem. This new liner system drastically improve the characteristics of intermediate layer introducing the waterproof material with a very low hydraulic conductivity. Figure 1 shows a conceptual cross section of the TLS. Two sheets of geomembranes are set at a certain distance and this space is filled with a polyurethane elastomer (one of the polymer) as an intermediated layer. Each TLS can be connected by the polyurethane elastomer at the joint part. The polyurethane elastomer has a high adhesive strength as mentioned later.

This intermediate layer has a high barrier function and a high flexibility. It shall be 30 mm thickness in the basic design phase, but it is possible to change the thickness due to construction conditions. During the grouting process of the intermediate layer, this polymer could fill all the defects and pores spaces of the GMs. As the results, TLS has three liners, such as two sheets of GMs and one intermediate polymer sheet.

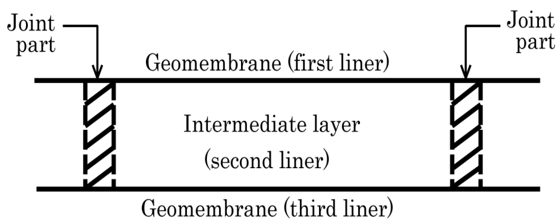

Figure 1. Outline of triple liner system (TLS)

Figure 2 shows the schematic view of TLS. The feature of this system is focused on the characteristics of the intermediate polymer layer between two sheets of GMs. The TLS can be kept a high barrier function due to the intermediate layer, even if GM sheets have some defects. Moreover, it is applicable to various construction sites with suitable characteristics by changing material parameters of polyurethane elastomer as the intermediate layer.

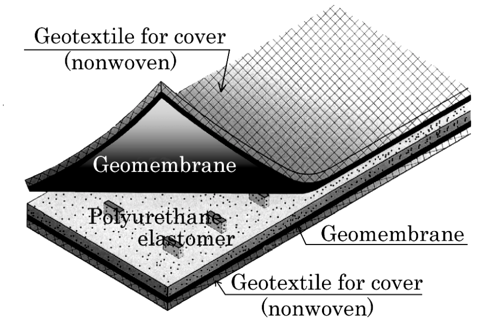

Figure 2. Schematic view of TLS (consisting of a geotextile cover, a GM sheet, an intermediate layer of polyurethane elastomer, a GM sheet, and a geotextile cover)

This system can be applied to waste disposal sites on the land and at the sea. It is also applicable to the vertical wall system. Figure 3 shows some examples of waste containment structures using this system.

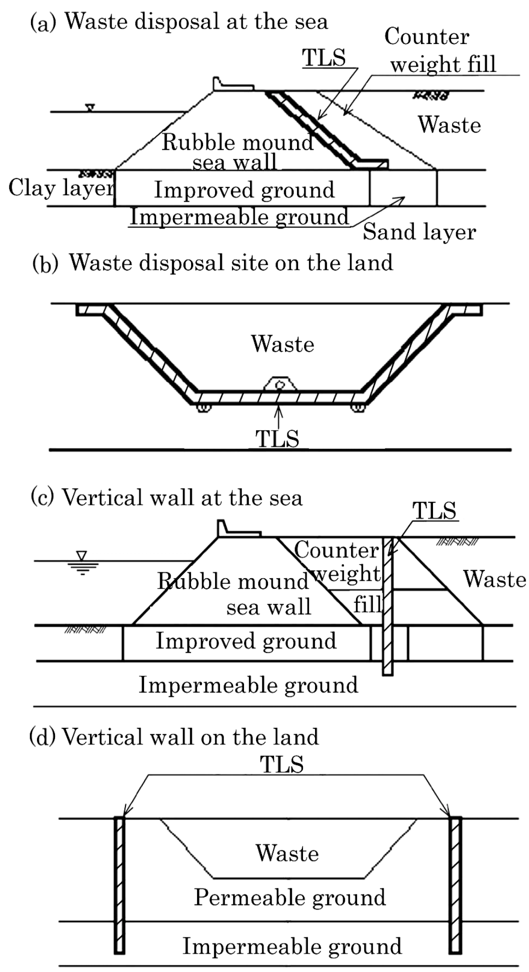

Figure 3. Possible examples of waste disposal sites using TLS

3 BASIC PROPERTIES OF ULTIMATE WATERPROOF MATERIALS

3.1 *Material properties of liquids for intermediate layer*

Polyurethane elastomer was selected as the intermediate material among the many kinds of polymers. It was made from polybutadiene polyol and diphenylmethane diisocyanate as the constituents, and indicates the outstanding hydrolysis resistance. Hydrophobic main chains of the polyurethane elastomer are indicative of excellent water resisting and chemical resistance because it only consists of hydrocarbon.

The polyurethane elastomer was made as follows: liquid A (polybutadiene polyol) and liquid B (polybutadiene diphenylmethane diisocyanate) were mixed with adjusted accelerators and cross-linking agents in order at least for the hardening to obtain the predetermined strength, waterproof, and high flexibility of materials. Table 1 shows material components and properties of polyurethane elastomer.

Table 1. Material properties of two liquids for polyurethane elastomer

	Liquid A	Liquid B
Components	1. polybutadiene polyol 2. plasticizer 3. calcium carbonate	1. polybutadiene diphenylmethane diisocyanate 2. plasticizer
Viscosity(Pa! s)	6.2	0.55
Density(g/ cm^3)	1.59	1.07
Mixing ratio		
by weight	720	100
by volume	480	100

The performance of an intermediate layer required is classified into the characteristics before and after hardening of the mixing. Viscosity and the hardening characteristics of the intermediate layer material is important before hardening. After hardening, hydraulic conductivity, tensile and compressive strength, modification performance, adhesive behavior, and durability are main issues.

3.2 *Properties of intermediate layer material before hardening*

The polyurethane elastomer as the intermediate layer material was grouted into the space of two sheets of GMs. When it is grouted between the double GMs at the construction site, the workability is influenced by the viscosity of materials. For instance, the viscosity of grouting materials is normally required that are kept down to 100 Pa' s (20°C). The most smoothly grouting condition are as follows: the viscosity of grouting materials is down to 50 Pa' s and is kept more than 2 hours.

Figure 4 illustrates the viscosity curves varying the compatible properties of polyurethane elastomer. Viscosity of materials at initial were 3.5 Pa' s with 20°C and increases in about 30 Pa' s after 120 minutes. These values will be considered as limited for grouting on sites.

As for the degree of hardness with increasing the viscosity, it is cleared that the grouted materials changes from a liquid to a plastic state with time elapsing and had a gum-elasticity property less than 24 hours. The degree of hardness was finally 50~60 in the test of JIS K 6301. This level of hardness can be enough to use the intermediate layer materials to apply the waste disposal sites as the liner and waterproof materials.

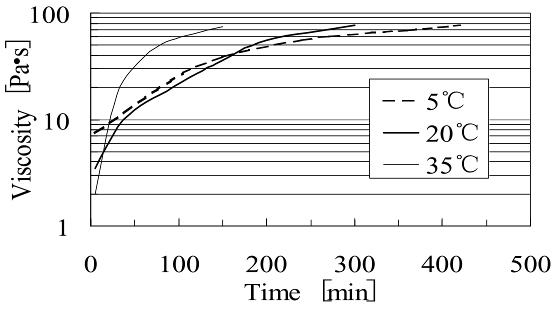

Figure 4. Viscosity curves varying the compatible properties of polyurethane elastomer

3.3 Properties of intermediate layer material after hardening

It is required that the barrier structure for waste disposal sites has enough strength and flexibility against the pressure such as the overburden pressure of wastes.

Figure 5 shows the compressive stress-strain curve of polyurethane elastomer as the intermediate layer. It is recognized that polyurethane elastomer has a strain hardening property. The overburden pressure of the waste layer from 15m to 20m in thickness is about 0.5N/mm^2. This stress is corresponding to almost 10％ strain as shown in Figure 5. Because the thickness of the intermediate layer is 30mm, compressive displacement is only 3mm, and thus, it can be seen that the polyurethane elastomer as the intermediate layer has enough thickness to maintain the barrier function of liner.

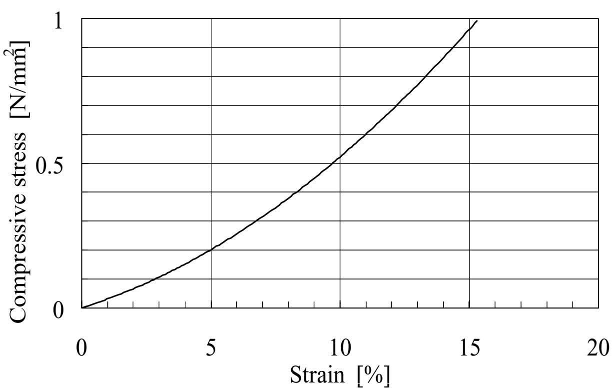

Figure 5. Stress-strain curve of polyurethane elastomer

Barrier structure must have high compatibility of the large earth displacement in the case of during construction work and at an earthquake. The TLS is set up with that the tensile strength of the intermediate layer is more than 60N/mm and the elongation is more than 100％.

Figure 6 shows the tensile strength of two sheets of polyvinyl chloride(PVC) geomembrane and polyurethane elastomer as the intermediate layer. The tensile character of polyurethane elastomer satisfies the set up condition. And the polyurethane elastomer has the same deformation behavior of PVC geomembrane sheets.

The polyurethane elastomer has the contact joints during the construction interval. It is very important to keep the same mechanical property of the polyurethane elastomer as the intermediate layer at the joint parts. The contact joint strength with dumbbell test pieces was tested in laboratory. The size of test pieces was 100mm height, 200mm width, 3mm thickness. First, the polyurethane elastomer was grouted until 50mm height, and next the rest was grouted after some prescribed aging times to get the contact joint samples. To measure the tensile strength of the contact joint, the adhesive property was assessed by the change of tensile strengths. The complete hardening time of the polyurethane elastomer was 120 hours because the hardness of the elastomer was constant after 120 hours of aging. Figure 7 presents the contact joint strength of polyurethane elastomer. Regarding to the ratio of aging time with comparing to the complete hardening time as the abscissa, the rate of contact joint strength against intact strength of polyurethane elastomer was shown in Figure 7. For example, if it was under rate of strength 0.8 that means the joint was contacted after the complete hardening time. It is satisfactory as a contact joint property because maximum intervals of grouting during construction work were 2 or 3 days.

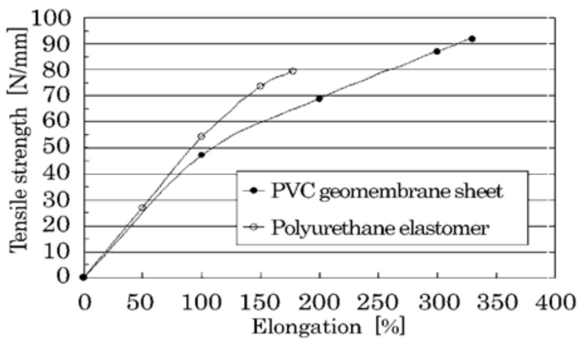

Figure 6. Tensile strength of two sheets of PVC geomembrane and polyurethane elastomer

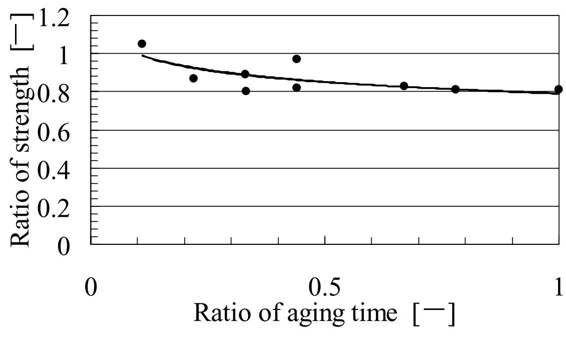

Figure 7. Contact joint strength of polyurethane elastomer

Table 2 summarized the material properties of the polyurethane elastomer. A key distinguishing feature of this material is the excellent hydraulic conductivity. Table 2 shows the intermediate layer made by polyurethane elastomer has a very low hydraulic conductivity under 10^{-14}(m/s), and at the contact joint has same capability. The chemical resistance of the polyurethane elastomer is also excellent as listed in Table 2. The mechanical stability of the elastomer is constant whichever under the soaking in acid or alkaline solutions condition.

*Retention ratio of the tensile strength

Item		Performance	Test method
Hardness(-)		55	JIS K 6301
Density(g/ cm^3)		1.5	JIS K 7112
Tensile strength(N/ mm^2)		2.64	JIS A 6008
Elongation at break(%)		170	JIS A 6008
Tear strength(N/ mm)		8.9	JIS A 6008
Shear strength(N/ mm^2)		1.65	JIS K 7214
Compressive strain(%)	0.2 N/mm^2	4.8	JIS K 7208(sample depth is 10mm)
	0.5 N/mm^2	9.7	
	1.0 N/mm^2	15.3	
Puncture resistance(N)		1240	ASTM D 4833
Chemical resistance(%)	Acid resistance	98.3*	Kept in 0.05%H_2SO_4 solution (pH2) in 60℃ for 240hours
	Alkali resistance	107.6*	Kept in Saturated $Ca(OH)_2$ solution (pH12) in 0℃ for 240hours
Hydraulic conductivity(m/ s)		$<1x10^{-14}$	JIS A 1218

Table 2. Material properties of polyurethane elastomer after hardening

4 MODEL TEST FOR IN SITU FORMING TLS

As to confirm the construction model of this method, a grouting test of intermediate layer was conducted. Figure 8 demonstrates the whole model of TLS tested. The scale of the model was 2m width, 5m length, and 30mm thickness that classifies the minimum parts size of landfill under the pre-casting condition. Figure 9 shows a continuous mixing system flow of the polyurethane elastomer. The system is organized by the snake pump, which quantitatively feeds two materials (liquids A and B) of polyurethane to keep prescribed mixing rate, and by the static mixer, which is continuously grouting between double sheets of GMs with the mixing materials at the same time. As a result, mixture could be filled up equally between double sheets of GMs by means of pumping pressure. In addition, the compound GM sheets with no bubble and in equal thickness could form. The grouting test proved that the execution process of this method could be applied for practical uses.

Figure 8. TLS formed by the model test by grouting of intermediate layer

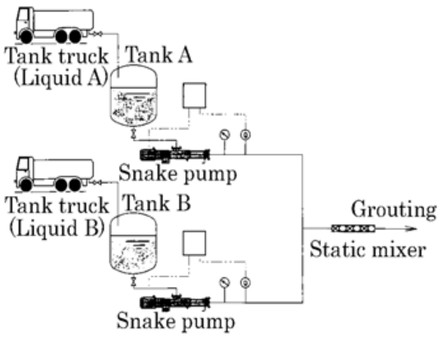

Figure 9. Continuous mixing system of liquids A and B

5 CONCLUSIONS

A new triple liner system (TLS) for waste disposal sites by using high molecule polyurethane elastomer as an intermediate material between double sheets of geomembranes (GMs) has been proposed. Since the system has triple liners consisting of double sheets of GMs and an intermediate layer with barrier capability, it is impossible that the damages and defects of liners occur in the same point of these three liners simultaneously. Furthermore, this system is considered to contribute increasing the capacity of the waste acceptable at the final disposal site, because the complete barrier function can be obtained at the layer even 40mm in thickness. Besides, it is found that intermediate layer material formed by polyurethane elastomer of two liquids mixing in the normal temperature have the following basic characteristics.

(1) It is possible to be grouted into the intermediate layer by pumping pressure. As a result, well filling of materials between double sheets of GMs was confirmed by the model grouting test on site.
(2) The intermediate layer has a high barrier capability (hydraulic conductivity, less than 10^{-14}m/s) and the joint also has same barrier function.
(3) It has enough strength and flexibility against the pressure such as overburden pressure of waste.
(4) As the intermediate layer has high flexibility as same as geomembrane sheets, this system is suitable for deformation of site without crack.
(5) The performance of construction contact joints at the intermediate layer has almost equal strengths to the intact parts.

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