Stability performance of demolition waste composite as landfill liner

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Abstract. Landfill liner is one of the essential components that prevent leachate infiltration of the soil from causing pollution. A liner has specific design criteria to function optimally. This study analyses the permeability and stability value of the mixture of composite materials consisting of demolition waste, bentonite, and lime materials. This study using some methods include falling head method for permeability test and direct shear strength for stability test. Based on the results of this research, it can be seen that the mixture of demolition waste and bentonite to composite can reduce the internal shear angle and increase the cohesion. While lime provides a fluctuating value for cohesiveness, it can increase the internal shear angle. The best mixture to be used as an alternative composite liner is the V6 composite which has a demolition waste composition of 79%, 20% bentonite, and 1% lime with a permeability coefficient value of $8.526 \times 10^{-7}$ cm/s.

1. Introduction

The ground layer of the landfill must have adequate stability so that it can keep away subsidence or cracks. Several studies have been conducted to overcome the problem of desiccation crack and stability landfill liner. Soil improvement methods for landfill liner, for example, stabilization with chemical additives, adding waste product as a liner, preventing an increase in water content, have generally been applied to overcome the problem of swelling and cracking [1]. Among them is the addition of material such as waste material for example, demolition material, cement, sand, and lime, to intensify the stability value and increase the strength of the soil due to cracking [2]. Another research still rare uses waste products in the form of demolition waste to increase the slope of the clay layer that is retaining landfill leach and increase the shear stress [3]. Soil shear strength can be defined as the maximum ability of the soil to withstand changes in shape under certain pressure and humidity conditions [4]. Demolition waste is mainly in crushed bricks, waste rocks, reclaimed asphalt, a mixture of sand and cement, and concrete aggregates, usually only dumped in one place or used as a landfill. Besides, it also increases the soil permeability coefficient but is not significant and still meets the landfill liner's permeability, according to the EPA. A liner made by adding lime can maintain its impermeability for longer [1]. Thus, lime is considered capable of providing optimal conditions for landfill liners in reducing cracks. Chaduvula et al. confirm using materials that can reduce moisture above the soil surface layer, namely lime, sand, and cement [5].
The addition of lime can increase the value of hydraulic conductivity and control the swelling pressures [6]. However, gradually the hydraulic conductivity value tends to decrease during drying conditions. In mixed waste products and bentonite, it is known that the advance in bentonite content in the composition causes the maximum dry density (MDD) and optimum water content (OMC) to decrease. Bentonite has colloidal solid properties and expands upon contact with water [8] and low permeability value, making it suitable for use as a leachate barrier [9]. Based on these considerations by referring to previous studies, this study presents an investigation related to the use of demolition materials with the addition of other materials, namely lime and bentonite is a proven strategy to get higher strength and impermeable landfill liner.

The primary materials used for the landfill liner design in this study are bentonite and lime. Previous research has shown that building waste is proven to work up the quality of the landfill layer [6]. However, there are no studies that mix these three materials as a coating for landfills. Accordingly, this work aims to analyze the composition of demolition waste, lime, and bentonite as a landfill coating in terms of its permeability and stability. The remaining techniques are organized as follows: sampling techniques, testing techniques, and processing and data analysis. The sample taken includes demolition waste, bentonite, and lime. The second stage is sample testing and other tests, including the permeability and material stability tests. The test results were analyzed and concluded which composites are suitable to be used as landfill coatings.

2. Methodology
This study used demolition waste, lime, and bentonite. Demolition waste is obtained. Bentonite is obtained from demolition waste located in Semarang, lime is available from one of the chemical shops in Tangerang, and bentonite is available from one of the chemical shops in Semarang. The reason for choosing this material is because it is a material that is readily available. There are eight variables used in this study, with the composition listed in Table 1.

| Variable | Composition                                      |
|----------|--------------------------------------------------|
| V1       | 100% demolition waste                            |
| V2       | 85% demolition waste + 15% bentonite             |
| V3       | 80% demolition waste + 20% bentonite             |
| V4       | 75% demolition waste + 25% bentonite             |
| V5       | 84% demolition waste + 15% bentonite + 1% lime  |
| V6       | 79% demolition waste + 20% bentonite + 1% lime  |
| V7       | 74% demolition waste + 25% bentonite + 1% lime  |
| V8       | 99% demolition waste + 1% lime                  |

The method used in testing soil permeability is the Falling Head method. This test is carried out in a laboratory by applying a predetermined procedure. This method obtains the K coefficient value, which states the convenient water flow through fine-grained soil samples. The method used in the permeability test refers to the falling head method of AS 1289.6.7.2-2001. The falling head permeability test is conducted by flowing water through a soil sample connected to a standpipe filled with water. The vertical pipe is equipped with a height unit to calculate the water flowing through the sample. Before taking measurements, the soil sample is first saturated, and the standpipe is filled with water to a certain height. The test begins by passing water through the soil sample until the water level in the standpipe drops. This test is done several times to get the average value.

Composite stability indicated by the safety factor’s value can be determined by direct shear test and then analyzed using GeoSlope / W software. The direct shear test aims to set the cohesion soil shear strength (c) and soil shear angle (Ø), where ASTM D3080 guides the work steps. Direct shear testing is carried out for demolition waste mixed with 0%, 15%, 20%, 25% bentonite, which is cured with distilled water for 24 hours, also a mixture of 0%, 15%, 20%, 25% bentonite mixed with lime in curing with
distilled water for 24 hours and 0%, 25% cured for 24 hours with leachate water. The purpose of curing is to determine how leachate affects the composite stability of each variation. Meanwhile, GeoSlope/W is an analysis software that uses balance limits to calculate soil and slope safety factors. The data inputted in the application are specific gravity, inner sliding angle, and cohesion values.

3. Result and discussion

3.1. Permeability

The composite variable owns the lowest permeability coefficient value with the composition of demolition waste, 25% bentonite, 1% lime. In contrast, the composite variable owns the highest permeability coefficient value with the composition of pure demolition waste. Based on Appendix III of the Regulation of the Minister of Public Works No.03/PRT/M/2013 concerning the implementation of infrastructure and facilities for solid waste, it states that the permeability coefficient of the bottom layer of the landfill must be less than $10^{-6}$ cm/s, the permeability coefficient at V1 (pure demolition waste), V2 (demolition waste + 15% bentonite), V6 (demolition waste + 15% bentonite + 1% lime) and V8 (demolition waste + 1% lime) do not meet these requirements [10]. Based on the permeability testing of composite materials using the falling head method, it was found that the addition of bentonite and lime affected the permeability of demolition waste.

Table 2. Permeability test results.

| Variable | Composition | Permeability (cm/s) |
|----------|-------------|---------------------|
| V1       | 100% demolition waste | 9.6976 x $10^{-6}$ |
| V2       | 85% demolition waste + 15% bentonite | 8.0191 x $10^{-6}$ |
| V3       | 80% demolition waste + 20% bentonite | 9.155 x $10^{-7}$ |
| V4       | 75% demolition waste + 25% bentonite | 4.8696 x $10^{-7}$ |
| V5       | 84% demolition waste + 15% bentonite + 1% lime | 6.9731 x $10^{-6}$ |
| V6       | 79% demolition waste + 20% bentonite + 1% lime | 8.5263 x $10^{-7}$ |
| V7       | 74% demolition waste + 25% bentonite + 1% lime | 4.278 x $10^{-7}$ |
| V8       | 99% demolition waste + 1% lime | 8.168 x $10^{-6}$ |

Table 2 was shown that demolition/construction waste has a significant enough effect on the increase in permeability value. It can be seen from the V3 and V6 composites that the permeability value is low, with a percentage of approximately 80% construction waste. It is because the composition of demolition waste supports the decrease in permeability. Demolition waste is obtained from ex-demolished demolitions consisting of cement, concrete aggregate, road base demolition, excavated soil, crushed bricks, and gypsum [11]. These contents are included in the material category landfill liner [12]. Construction and demolition waste consisting of concrete aggregates also affect the value of hydraulic conductivity. The hydraulic conductivity of recycled concrete is higher than the pure aggregate [13]. Rubinos and Spagnoli state in their review paper that the construction and demolition waste has a low permeability value of $10^{-9}$ cm/s with added physical and chemical treatments to maximize its function as an absorbent of hazardous waste in layers. When there is an increase in the content of demolition waste, including cement, excavated soil, gypsum. When it comes to water, it will keep bentonite and lime particles in the superficies and be covered—blocking the flow path, thereby reducing hydraulic conductivity Rate or permeability. This study strengthens these results that the V3 and V6 composites also obtained a low permeability value approximately $7x10^{-9}$ cm/s.

Permeability value will also decrease along with the ability to expand bentonite itself. A decrease in the permeability coefficient in composite variation consisting of demolition waste and bentonite was caused by the swelling bentonite process, which caused the pores between particles to become narrow. This narrowing of the pores will cause the flow of water in the composite to be obstructed. Increasing bentonite levels will generally decrease the permeability value. An increase in the plasticity index is also in line with a decrease in the permeability value. The plasticity index shows the possibility of water
permeating the composite and making it plastic. So that if the plasticity index value increases, the permeability value will also decrease [14].

Generally, the permeability value will increase significantly when the percentage of sand is above 40% compared to when the sand is in the range of 20-40%. More bentonite content shows a slightly higher permeability value because the increase in permeability is the fracture process of the bentonite in all directions outside the pores of the dry mud particles, allowing new pores to appear. The addition of lime will also reduce the permeability value. Lime has properties as a binding material, such as plastic, hardens quickly, and has good binding capacity. The higher lime content can cause lime and clay clumping, which causes enlarged pores [1].

3.2. Stability
Material construction and demolition waste consisting of several types of materials mixed in this study significantly contribute to the stability of composites for landfill liners. Crushed bricks, waste rocks, cement, and concrete aggregates have good shear strength in the form of coarser aggregates. Besides that, it also has a small shear angle value similar to sand and a high cohesion value [15]. The level of bentonite composition is one of the factors that advance the shear stress. The addition of the bentonite will load the gaps between the aggregates so that the friction will not be too large. The other reason is the role of the bentonite as a binder, the cohesion/adhesion value increases as the content of bentonite increases. The fluctuating results were obtained due to differences in the test materials' homogeneity, differences in the rotation of the test equipment lever, which was less stable, and differences in the characteristics of demolition waste. It can be seen in Table 3, shown by V2-V4.

The addition of lime in the composites caused changes in the inner shear angle and cohesion values. The reaction of lime with aggregate (demolition waste and bentonite) causes contact between clay minerals and lime. This contact results in ion exchange, which results in the calcium silica gel that does not decompose by water resulting in clotting, which causes aggregate pores to be closed, thereby increasing aggregate stability. Therefore, the cohesion value will increase compared with the demolition waste and bentonite mixture without the lime test variable. The increase in lime composition also affects the value of the inner shear angle. The value of the material's cohesion mixed with lime has a smaller decrease compared to demolition waste materials and bentonite without lime. The internal shear angle parameter will increase if more than 1% lime composition is added. The factor that causes an increase in the internal shear angle is lime's function as an increase in the binding power between particles in the composite. In comparison, the factors that cause a decrease in the internal shear angle can be the size and shape of the demolition waste and the composite's homogeneity. Composites' stability due to the addition of lime can be seen in Table 3 for V5-V7.

| Variable | C (kN/m²) | Ø (°) |
|----------|------------|-------|
| V1       | 7.9        | 35.31 |
| V2       | 12.1       | 35.04 |
| V3       | 22.9       | 26.39 |
| V4       | 35.9       | 25.2  |
| V5       | 3.9        | 38.66 |
| V6       | 7.9        | 38.06 |
| V7       | 12.5       | 39.6  |
| V8       | 13.67      | 37.4  |

Curing the composite with landfill leachate also provides significant changes in the inner shear angle and cohesion for each of the mixed variations of demolition waste, bentonite, and lime. There was an increase in the internal shear angle and the cohesion value when curing with leachate for 24 hours from
each test material. This time was chosen because the maximum bentonite development process occurred during the first 4 hours of mixing.

An increase in the internal shear angle and the materials' cohesion value indicate an increased instability. It shows the feasibility of the test material as a leachate-retaining layer or liner for landfills. Material mixed with leachate still has good stability. The stability of the leachate infiltration into the liner will be maintained. The reason for this increased stability is the viscosity of the leachate itself. Black liquor at 28°C has a viscosity value of 1.4565 Ns/m². Meanwhile, the viscosity of pure water is 0.82 mPa.s or equivalent to 0.00082 Ns/m².

The higher viscosity value of leachate than water has an effect on its adhesion to the test material.

3.3. Safety factors

Table 4. Results of analysis of safety factors using geoslope/w software.

| Variable | Composition | Safety Factor |
|----------|-------------|--------------|
| V1       | 100% demolition waste | 4.683 |
| V2       | 85% demolition waste + 15% bentonite | 5.867 |
| V3       | 80% demolition waste + 20% bentonite | 8.782 |
| V4       | 75% demolition waste + 25% bentonite | 12.200 |
| V5       | 84% demolition waste + 15% bentonite + 1% lime | 3.755 |
| V6       | 79% demolition waste + 20% bentonite + 1% lime | 5.134 |
| V7       | 74% demolition waste + 25% bentonite + 1% lime | 6.169 |
| V8       | 99% demolition waste + 1% lime | 8.822 |
| V1 Currying | demolition Waste + curing leachate | 14.303 |
| V4 Currying | demolition Waste + bentonite 25%+ curing leachate | 14.303 |
| V7 Currying | demolition Waste + bentonite 25%+ lime 1%+ curing leachate | 9.149 |
| V8 Currying | demolition Waste + lime 1%+ curing leachate | 8.251 |

Based on Table 4, it is known that the greater the bentonite composition, the greater the level of safety that the shear strength of the material, the bond between particles, and the bearing capacity will also increase. However, all-composite variables in the study have good stability because they have a safety factor value. Factors that hinder the occurrence of motion include the internal shear angle and cohesion. Meanwhile, the factors that cause movement can come from outside or inside. External factors can be in the form of loading, while internal factors can be material density.

4. Conclusion

Demolition waste mixture bentonite and lime can affect decreasing the current permeability value. This decrease can occur when the addition of bentonite material ≥20% and 1% lime percentage can degrade the permeability value more than simply adding bentonite material. The permeability coefficient value for pure construction waste is 9.6976 x 10⁻⁶ cm/s. The permeability coefficient of the landfill base layer must be less than 10⁻⁶ cm/s, so the permeability coefficient for pure construction waste, construction waste + bentonite 15%, construction waste + lime 1%, and construction + bentonite 15% + lime 1% does not meet these requirements.
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