The effect of demolition waste composition on the landfill liner physical characteristic

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Abstract. This study analyses the physical characteristics of demolition waste on the composite landfill liner. In this study, three characteristic composite landfill liner tests consist of swelling/specific gravity, OMC standard proctor determination, and atterberg limit test. Composite landfill liner consists of demolition material, bentonite, and lime with eight variable samples. Based on this research, specific gravity ranges from 1.8 - 2.1 g/cm³, OMC's highest is V7, and MDD's lowest is 1.81 g/cm³. Demolition waste content is below 80% can be carried out atterberg limit test. It is related to the particle size distribution test, which states that the size of demolition waste is a type of sand.

1. Introduction

Pollutants in leachate are hazardous for human health and the environment around the landfill. Leachate may contain many hazardous refractory organic compounds and inorganic materials [1]. Landfill liner serves to prevent leachate from entering and mixing with groundwater [2]. Some composite materials used as landfill liners include natural, waste, and stabilization [3]. Waste materials often used are fly ash, red mud, mining waste, and what is rarely used is demolition waste. The demolition waste can also be called construction waste, the residual material from building/construction materials. The material can be a mixture of cement and sand, crushed gravel, crushed bricks, gypsum, and other small aggregates [4]. So, these materials can be used as landfill liners because they have high compressive strength and high stability, such as cement. Research by Mishra et al. that mixed fly ash and cement showed the results of 5% wet OMC (optimum moisture content)-MDD (Maximum dry density) and could be used as a landfill liner material [5].

The addition of bentonite in this research reduces the conductivity of the liquid limit and a good plasticity index. Based on the research Budihardjo et al. using bentonite with a mixture of fly ash, bentonite can improve performance in making landfill liners with plasticity (liquid limit ≥ 20%, plasticity index ≥ 7%) and the hydraulic conductivity criteria (k ≤ 1 x 10⁻⁷ cm/sec) [6]. The addition of bentonite causes OMC and MDD to decrease because bentonite has swelling properties in contact with water [7,8]. This study used lime to reduce the conductivity value and prevent excessive swelling from the effects of bentonite [9]. On the other hand, a decrease in the internal friction angle may occur as the water content in the mixture increases. Meanwhile, cohesion increases with the addition of bentonite content until it reaches the optimum and decreases with a further increase in bentonite content [10].

Therefore, this study examines the characteristics of variations in the mixture of demolition waste, bentonite, and lime as landfill liners. The composite characteristics to be tested are OMC, MDD, and...
atterberg limit. The physical characteristic test results concluded which composite would be used as a composite landfill liner because all components met the standard landfill liner.

2. Methodology
The materials used in this study consisted of demolition waste from construction projects in Semarang, bentonite obtained from a chemical shop in Semarang, and lime from a chemical shop in Tangerang. Abundant availability and ease in getting is the reason for choosing these materials. The composite variation consisted of 8 mixtures, the details of which can be seen in Table 1.

Table 1. Variation of composition.

| Variable | Composition                  |
|----------|-----------------------------|
| 1        | DW 100%                     |
| 2        | DW 85% + B 15%              |
| 3        | DW 80% + B 20%              |
| 4        | DW 75% + B 25%              |
| 5        | DW 84% + B 15% + L 1%       |
| 6        | DW 79% + B 20% + L 1%       |
| 7        | DW 74% + B 25% + L 1%       |
| 8        | DW 99% + L 1%               |

Notes: DW = Demolition Waste; B = Bentonite; L = Lime

The characteristic test consists of swelling and specific gravity/density test, OMC standard proctor determination, and atterberg limit test of construction waste sample with bentonite and lime.

2.1. Swelling and specific gravity test
Soil swelling testing aims to measure the free swell, percent swell, and swelling pressure. Two 10g of soil specimens are taken in a 100ml glass cylinder filled with water and kerosene. Then it was left to stand for 24 hours, and the final result was observed, the volume of soil in the cylinder was taken, and the free swelling index was calculated. The calculation is done using the formula;

\[
\text{FSI} \, (\%) = \frac{V_w - V_k}{V_k} \times 100
\]  

where \( V_w \) is the volume of soil containing water, while \( V_k \) is the volume of soil containing kerosene. Soil swelling occurs due to capillary events or changes in water content in the soil, usually owned by soil with lots of clay, and experience volume changes when the water content changes. Adding water content will cause the development of the soiled object being tested [11]. Density testing was carried out on composite materials with a particle size that passed the sieve number 40 or smaller than 0.425 mm. The test was carried out using a small pycnometer with a capacity of 250 ml, each filled with ± 30 grams. At the time of testing, the standard air temperature was 31°C. Tests are carried out in each of its variations. The test results for each variation are averaged while still paying attention to the relationship with other composite variations.

2.2. OMC standard proctor determination
Preliminary testing in the form of proctor standards is carried out before the permeability and shear strength tests. The test aims to obtain the value of optimum moisture content, OMC (Optimum Moisture Content), and Maximum Dry Density (MDD). The standard proctor test was carried out by compacting, and the steps follow the ASTM D698 method. Standard Proctor testing for a variety of pure construction waste and combination material bentonite and lime.

2.3. Atterberg limit test
This test was carried out based on ASTM D4318 and aimed to show the mixture's level of consistency and plasticity when added with water. The plastic limit value must be higher than the shrinkage limit, while the liquid limit value must be higher than the plastic limit. The nature of plasticity is indicated by the plasticity index value and can be obtained by the formula:
Plasticity Index  = Liquid limit - plastic limit  

\[ (1) \]

3. Results and discussion

3.1. Swelling and density/specific gravity test

Soil swelling tests are used to measure the free swell, percent swell, and swelling pressure. The tests are carried out according to the provisions of IS 2720 (Part 40): 1977. This swelling test was carried out for bentonite samples. 10 grams of the bentonite sample were put into a 100ml test tube with water, and kerosene was added, then let stand for 24 hours and wait for the results. The volume of soil in the tube is taken, and the free swelling index is calculated. The calculation is done using the formula:

\[
\text{FSI (\%)} = \frac{V_w - V_k}{V_k} \times 100\%  
\]

FSI (\%) = 5\%.05 - 1\%.1 x 100\%
FSI (\%) = 359\%

Bentonite is the essential component of composites by water retention and swelling potential. The swelling of bentonite induced by the hydration should be limited when the composite reaches low suction values \[12\]. Another factor that influences the swelling of bentonite is the degree of acidity or pH. According to Tang et al. state, the swelling of bentonite will be maximized in an alkaline state \[13\]. The binding with OH ions causes floc formation, which causes the space between particles to be narrowed to reduce permeability. Therefore, the increase in bentonite content in the composite will be inversely proportional to the permeability value. The permeability value will also decrease along with the ability to expand the bentonite itself. The addition of bentonite generally causes an increase in specific gravity.

Meanwhile, the addition of lime causes a decrease in density. Data of density is the initial data from subsequent tests such as standard proctor testing. The key is to compare dry particle weight with the volume of the particles in the solid. The results of the density test can be seen in Table 2.

| Composition | Density gr/cm³ | Density kN/m³ |
|-------------|----------------|---------------|
| DW 100 %    | 2.01           | 19.71         |
| DW 85 % + B 15% | 2.09       | 20.49         |
| DW 80 % + B 20% | 2.00       | 19.61         |
| DW 75 % + B 25% | 1.92       | 18.82         |
| DW 84 % + B 15% + L 1% | 1.86      | 18.24         |
| DW 79% + B 20% + L 1% | 1.85      | 18.14         |
| DW 74% + B 25% + L 1% | 2.02      | 19.80         |
| DW 99% + L 1%    | 2.09           | 20.49         |

Notes : DW = Demolition Waste; B = Bentonite; L = Lime

Based on the specific gravity test results, which range from 1.8-2.1 g/cm³. Al-Taie et al. state that the density that ranges between these values is classified a low, namely the humus and peat soil categories \[14\]. The amount of specific gravity is inversely proportional to the number of pores between the particles. A small density indicates that a specific volume of the solid particles that exist only has such a weight that there may be pores between the particles. It is supported by Seiphoori et al., which stated that particle modification in the hydration pathway increases the appearance of new pores in the structure of composites \[12\]. According to Akcanca et al., the increased density due to the addition of bentonite can be caused by the expansive nature of bentonite \[9\]. The swelling process in bentonite causes it to act as a filler in the particle pores \[15\]. The addition of water to the test process will cause the bentonite to expand and fill the cavities in the composite. Thus, the weight ratio of the composite to the volume of the composite without pores is more excellent. In the V3 composite, there was a significant decrease
in density. It is due to mixed demolition waste that is different from the time of collection with other composites.

The composite density will decrease when lime is added. According to Akcanca et al., the added lime can increase the porosity of the composite [16]. It is due to the pore formations during the hydration process due to the reaction of lime with water. The pores formed will cause an increase in volume due to the presence of air in the composite. Tiny pores will still affect the density of the composite. The added lime can reduce the density of the composite when compared to the density of the composite containing bentonite. From Table 2, it can be concluded that the added bentonite can increase the density. In contrast, the added lime reduces the density of the composite.

3.2. OMC standard proctor determination
Proctor test is also called the compaction test, where compaction on the soil minimizes pore space by using dynamic loads influenced by the movement mechanism of the solid particles. The optimum moisture content (OMC) will be obtained for each compaction standard, resulting in the maximum density (maximum dry volume weight). In other moisture content, either dry or wet areas, the optimum moisture content will result in a density more minor than the maximum density. The farther from the optimum water content, the smaller the density that will be obtained. Water content mixes water with each variation of demolition waste and bentonite used for liner manufacturing.

Table 3. OMC and MDD data for each sample.

| Composition | OMC % | MDD gr/cm^3 |
|-------------|-------|-------------|
| DW 100 %    | 6.75  | 2.13        |
| DW 85 % + B 15% | 10    | 1.94        |
| DW 80 % + B 20% | 10.5  | 1.95        |
| DW 75 % + B 25% | 14.5  | 1.86        |
| DW 84 % + B 15% + L 1% | 10.5  | 1.92        |
| DW 79% + B 20% + L 1% | 10.75 | 1.95        |
| DW 74% + B 25% + L 1% | 14.6  | 1.81        |
| DW 99% + L 1% | 8.5   | 2.09        |

Notes: DW = Demolition Waste; B = Bentonite; L = Lime

From these data, it can be concluded that OMC has increased and MDD has decreased, and the addition of material [17]. The effect of compaction includes particle size, soil density, and stabilizer additives, so bentonite is reactive with water. High-quality aggregate is indicated in the mixture. It is characterized by the density results obtained. It contributes to an increase in density for the coarse aggregate [18]. The space in the bentonite layer can expand and be filled by water molecules and other cations [19]. The addition of lime also affects the OMC-MDD value. The OMC value increases with lime, and the MDD value decreases. Following previous research, lime added to the mixture will increase the optimum moisture content, strength, and shrinkage limit. Plasticity index, liquid limit, and maximum dry density of the soil obtained the opposite result [20]. However, several studies have shown that the addition of lime causes a reduction in the potential for expansion of expansive soils [21]. Therefore, an essential factor in determining the swelling and shrinkage properties of the mixture stabilized using lime to produce an impermeable layer for the landfill retaining layer.

3.3. Atterberg limit test
Atterberg Limits test is a limit that shows the level of plasticity and consistency of the aggregate when mixed with water. This test consists of 3 stages, including shrinkage limits, plastic limits, and liquid limits—results of atterberg limit from each composite in Table 4.
Processes, and al properties of the test material. Soils with high on, rates that the possibility of presence of bentonite in the as and permeability value. This characteristic can also lower. Pores between the particles is also slight so that the possibility of water escaping through the pores is small particle size categories, namely clay, and silt. Small particle size indic

Permeability according to the particle size of the material. Materials generally own high plasticity with first, such as adding cement fr

Low stability bearing capacity, high compression, significant volume changes, complex compaction processes, and low stability [23]. Therefore, materials with high plasticity generally undergo a stabilization process first, such as adding cement from demolition waste. However, materials with high plasticity have low permeability according to the particle size of the material. Materials generally own high plasticity with small particle size categories, namely clay, and silt. Small particle size indicates that the possibility of pores between the particles is also slight so that the possibility of water escaping through the pores is also lower.

4. Conclusion
Bentonite has a high value of swelling potential. This phenomenon is related to the degree of acidity and permeability value. This characteristic can positively impact the composite with a low density, such as construction waste. The addition of lime can decrease the density but increase the porosity. The presence of bentonite in the construction waste composite can increase the optimum moisture content,

Table 4. Result of Atterberg Limit.

| Composition | Liquid Limit (%) | Plastic Limit (%) | Plasticity Index (%) | Category |
|-------------|------------------|-------------------|----------------------|----------|
| DW 100 %    | Not valid        | Not valid         | -                    | Non Plastic |
| DW 85 % + B 15% | 68.76        | 69.11             | -0.35                | Non Plastic |
| DW 80 % + B 20% | 71.04         | 50.68             | 20.18                | -         |
| DW 75 % + B 25% | 73.40         | 32.61             | 40.78                | -         |
| DW 84 % + B 15% + L 1% | 56.23        | 51.30             | 4.93                 | Non Plastic |
| DW 79% + B 20% + L 1% | 60.94         | 51.84             | 9.09                 | Non Plastic |
| DW 74% + B 25% + L 1% | 66.05         | 52.39             | 13.66                | -         |
| DW 99% + L 1% | Not valid      | Not valid         | -                    | Non-Plastic |

Notes: DW = Demolitation Waste; B = Bentonite; L = Lime

Table 4 shows that there are composites that do not have an element of plasticity. It can happen if the results of the liquid limit test are lower than the plastic and liquid limits, or the shrinkage limit test fails because the composite crumbles after heating with an oven. Test results show that demolition waste content is below 80%, which can be carried out atterberg limits test because it has plasticity, which means that bentonite content that forms the composite’s plastic characteristics must be more significant than 20%. V1 composite variation with 100% demolition waste content does not have plastic properties. It is related to the particle size distribution test, which states that construction waste is a type of sand. Minerals dominated by quartz sand or other sand will not have plastic properties even though the particle size is fine and the amount of water is added a lot [22]. Thus, the addition of bentonite, a type of clay, will affect the values of the atterberg limits. The plasticity index value with bentonite variations of 20% and 25% ranged from 13% to -40%. According to Guney et al., the plasticity index value is between 7% -17%, as in the V6 variation, which is classified as soil with moderate and cohesive plastic properties [21]. A plasticity index above 17% belongs to the high plastic properties category. At the same time, the plasticity index value is around 0% as that of the variations of the composites V1, V2, V5, and V8, indicating non-plastic and non-cohesive properties. Bentonite content is higher, liquid limit value, plastic limit, and shrinkage limit can be detected easily. Bentonite of 20% content can cause plasticity in the test material. At the same time, levels in bentonite below 15% in the composite have not produced plastic properties. Even so, results of liquid limit, plastic limit, and plasticity index show fluctuating data. It can occur due to the nature of demolition waste that does not absorb water, so the absorption capacity of bentonite is the primary key in testing. The difference in speed and water absorption capacity of bentonite allows value fluctuation of both values of each limit and plasticity index. The addition of lime also changes the values of these limits.

The addition of lime causes an increase in the liquid limit and plastic limit, decreasing the plasticity index. Addition of lime causes changes in the technical properties of the test material. Soils with high plasticity and ability to expand and shrink generally show poor material properties as soil, including low bearing capacity, high compression, significant volume changes, complex compaction processes, and low stability [23]. Therefore, materials with high plasticity generally undergo a stabilization process first, such as adding cement from demolition waste. However, materials with high plasticity have low permeability according to the particle size of the material. Materials generally own high plasticity with small particle size categories, namely clay, and silt. Small particle size indicates that the possibility of pores between the particles is also slight so that the possibility of water escaping through the pores is also lower.
preventing the composite from early fracturing / cracking and reducing the possibility of soil expansion. The addition of bentonite can affect the plasticity of soil properties. The higher the addition of bentonite in the composite, the more plastic the composite will be. This paper presents a different mixture that will affect the physical characteristic of the liner system.

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