Metal industry waste desiccation behavior with the addition of bentonite as a landfill liner

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Abstract. The existence of garbage in the environment can cause pollution. Therefore, it is necessary to carry out waste management, one of which is by building a landfill. Landfill liner should have a permeability coefficient <10^{-6} cm/sec to prevent contamination. Currently, the affordable material used as landfill liner is clay, but it is quite rare. An alternative material we can use is metal industrial waste, which has not been utilized. Metal industrial waste has a permeability coefficient, namely 25.34560 \times 10^{-6} cm/s. In order to reduce the permeability coefficient value, metal industrial waste is added with bentonite material, which has a low permeability value with variations of 0%, 5%, 10%, 15%, 20%, and 25% addition of bentonite. Digital image processing techniques are used to calculate crack intensity factor (CIF) values using the Matlab 2019 software. The results showed that the permeability value that fulfilled was the variation of 20% bentonite addition of 0.8059 \times 10^{-6} cm/s and 25% of 0.5059 \times 10^{-6} cm/s. While the CIF results showed that only the variation of 25% bentonite addition were not eligible because they had a crack area >4%. Thus it can be concluded that the best composite is metal industrial waste with 20% bentonite.

1. Introduction
The improper design of the landfill liner system can open opportunities for leakage that results in groundwater contamination. In order to prevent leakage, a waterproof landfill liner is required. Landfill liner is a layer consisting of materials with low permeability to minimize infiltration occurrence [1]. According to Minister of Public Works Regulation No. 03/PRT/M/2013, landfill liners must have a low permeability, which is less than 1.0 \times 10^{-6} cm/sec [2].

Several studies on composite materials design as landfill liners were considered successful because they resist leachate and can be obtained. Slim et al. (2016) successfully made composite landfill liners using a mixture of fly ash and pulp, increasing the shear strength, cohesion, and friction [3]. The success of Zhang et al. (2017) in making a composite landfill liner using sewage sludge proved that sludge could be a material choice in making composites because of its low permeability and strength to withstand heavy metals[4]. Ehrlich et al. (2019) tried to using clay soil, which strengthened with natural fiber can overcome post-cracking problems so that cracks can be avoided, especially for deeper layers [5]. Herrmann et al. stated that mixed materials could improve the liner's performance to resist leachate to meet the applicable requirements [6].
In this research, the primary material used is metal industrial waste. Metal industrial waste is still underutilized, and there has been no research using metal industrial waste as a landfill liner. Apart from metal industrial sludge, bentonite is chosen as a composite material. Roberts and Shimaoka (2008) stated that bentonite has a low permeability coefficient, so it meets the permeability requirements as a leachate-retaining layer in landfills [7]. Meanwhile, metal industrial waste has high permeability. Thus, metal industrial sludge with bentonite addition is chosen to be used as a mixture for landfill liner composites.

Desiccation behavior is one of the most severe phenomena in the landfill liner. Crack formed from desiccation behavior can cause water to seep in and make the landfill liner to leak [8]. The basis of this research is to examine the desiccation behavior of metal industrial sludge composites with bentonite to obtain a new alternative to water-resistant landfill liner.

2. Methodology
The research was conducted at the Laboratory of Soil Mechanics, Department of Civil Engineering, State University of Semarang, the Laboratory of Environmental Engineering, Diponegoro University, and the Diponegoro University Integrated Laboratory. The test categories carried out are preliminary tests (SEM-EDX test, bentonite swelling test, specific gravity test, proctor test, permeability test, distribution test of grain size of industrial metal waste, and shrinkage limit test). Apart from the preliminary test, the core test for desiccation crack and the vertical crack was also carried out. The crack test is in the form of a moisture content test and CIF value processing, while the vertical crack test is in the crack depth test.

3. Result and discussion
In this study there are 6 variations of composites used, namely:
  a. 100% LL + 0% B (V1)
  b. 95% LL + 5% B (V2)
  c. 90% LL + 10% B (V3)
  d. 85% LL + 15% B (V4)
  e. 80% LL + 20% B (V5)
  f. 75% LL + 25% B (V6)

The six variations use a mixture of industrial metal waste (LL) with bentonite (B). Metal industry wastes are obtained in solid black and have a fine texture like sand. Bentonite is obtained from local miners in Boyolali.

3.1 Characteristics test
The test results of grain size distribution using the sieve system showed that 84.13% of metal industrial waste was classified as sand. The remaining 15.87% is clay and silt. Thus the metal industrial waste has the characteristic of curvature sand. The pure bentonite swelling test showed a free swell index (FSI) of 390%.

| Code | Density (gr/cm³) | Proctor OMC (%) | Permeability (cm/sec) |
|------|-----------------|----------------|-----------------------|
| V1   | 2.30            | 49.0           | 25.346 x 10⁻⁶        |
| V2   | 2.38            | 34.5           | 12.673 x 10⁻⁶        |
| V3   | 2.39            | 34.0           | 7.093 x 10⁻⁶         |
| V4   | 2.46            | 33.5           | 3.086 x 10⁻⁶         |
| V5   | 2.47            | 33.0           | 0.806 x 10⁻⁶         |
| V6   | 2.49            | 32.0           | 0.506 x 10⁻⁶         |
The density test shows that the sample's overall variation has a specific gravity of <2.6 grams/cm$^3$. Besides, the density of the sample continued to increase as the amount of bentonite was added. Based on ASTM D 854, specific gravity <2.6 grams/cm$^3$ is a soil classification with high organic matter content [9]. The proctor test resulted in optimum moisture content (OMC) value, which decreased with the increasing amount of bentonite added.

The permeability test results prove that bentonite affects decreasing the permeability coefficient. The higher the bentonite added, the lower the permeability coefficient. Along with this, of the six variations tested, only the 5th and 6th variations meet the standard permeability coefficient number for the landfill liner. Variations that meet are the addition of 20% bentonite with the permeability of 0.806 x 10$^{-6}$ and 25% bentonite with the permeability of 0.506 x 10$^{-6}$.

The results of the shrinkage limit test decreased with the addition of bentonite. The percentage of shrinkage limit numbers in a row for the addition of bentonite of 0%, 5%, 10%, 15%, 20%, and 25% is 38.42%, 32.03%, 30.18%, 28.28%, 27.50%, and 27.04%. The shrinkage limit number indicates that the sample limit is shrinking. Samples no longer experience shrinkage after falling below the limit of shrinkage.

3.2 SEM-EDX test
SEM-EDX testing is carried out at the Diponegoro University Integrated Laboratory. The sample used was a metal industrial waste composite that passed sieve number 200 with added bentonite.

Figure 1 shows the morphological form of metal industrial waste with bentonite with a magnification of 500x. The surface of waste looks like fibers. And there are cavities or gaps, which are then filled with bentonite. The two particles overlap, the cavities contained in the waste are filled with bentonite. Thus there are no more gaps between particles because the gaps between particles formed from metal industrial waste have been filled with bentonite. When the sample is given water, the bentonite that has filled the metal industrial waste particles' gaps will expand and further seal the particles' cavities.
The metal industry produces production goods in the form of metals, especially steel. Steelmaking uses iron as raw material. Pig iron still contains many elements that are not suitable for construction materials. The elements in question include charcoal/carbon (C) that is too high, sulfur (S), and silicon (Si). The EDX results obtained C is 55.38%, S is 0.10%, and Si is 0.20%. Besides, in steelmaking, it limits dissolved gases such as oxygen, so that there is an O element of 41.62%.

Magnesium is used in the process of making cast iron so that the element Mg is 0.17%. The manufacture of carbon steel uses a combination of iron and carbon with a little added elemental Cu. So, the Cu element is 0.38%. The Cl element is obtained by 0.63% because chloride can accelerate the metal corrosion rate and give an aggressive corrosive effect on the metal. The Cl element is found in waste to improve the quality of steel.

Bentonite has several dominant constituent elements, such as K, Na, and Ca. Then it is found that the K element is 0.95%, the Na element is 0.36%, and the Ca element is 0.22%. That is because the sample is a mixture of metal industrial waste with bentonite. The EDX results found elements derived from steelmaking waste and the constituent elements of bentonite.

### 3.3 Desiccation crack and vertical crack test

The desiccation crack test that was carried out resulted in the moisture content and CIF values carried out for six research days. The following are the research data on the 0th and 6th day.

**Table 2. Desiccation crack test results.**

| Code | WC₀ (%) | CIF₀ (%) | WC₆ (%) | CIF₆ (%) |
|------|---------|----------|---------|----------|
| V1   | 49.0    | 0.0      | 0.0     | 0.6      |
| V2   | 34.5    | 0.0      | 0.0     | 1.3      |
The test results show the percentage of water content (WC) and crack intensity factor (CIF) on day 0 and day 6. The data show that the lower the sample's water content, the bigger the cracks will form on the sample's surface.

| Code | WC_0 (%) | CIF_6 (%) | WC_0 (%) | CIF_6 (%) |
|------|----------|-----------|----------|-----------|
| V3   | 34.0     | 0.0       | 0.0      | 2.1       |
| V4   | 33.5     | 0.0       | 0.0      | 2.5       |
| V5   | 33.0     | 0.0       | 0.0      | 3.3       |
| V6   | 32.0     | 0.0       | 0.0      | 4.9       |

Figure 3. Composite crack results.

Figure 3 shows the results of processing Matlab 2019a for composites on the 6th day. On day 6, all composites were at 0 moisture content, and CIF values were highest. V1 is a composite with 0% bentonite and has a CIF value of 0.6%. In comparison, V2 is a composite with 5% bentonite and has a CIF value higher than V1, which is 1.3%. Then V3 is a composite with 10% bentonite and has an increasing CIF value of 2.1%. V4 is a composite with 15% bentonite, and the CIF value is at 2.5%. V5 is a composite with 20% bentonite and has a higher CIF value of 3.3%. And V6 is a composite with the most top addition of bentonite at 25% and has the highest CIF value with a value of 4.9%. All samples met the requirements for the base layer of landfill except V6 (industrial waste metal + bentonite 25%) because according to the criteria, according to Yamusa et al. stated that the cracks must be <4% to avoid the potential for leachate contamination [10].

The depth of the ground crack (vertical crack) was calculated using bender iron. Then, it was measured using a ruler and then recorded the depth of the resulting crack. The study was conducted by inserting industrial metal waste samples with 25% bentonite into a glass aquarium with dimensions of 30 cm x 30 cm x 20 cm. The sample was put into the aquarium with a sample thickness of 10 cm. Then, observe the cracks formed and measure cracks depth using bender iron, measured using a ruler and recorded every day.

Figure 4. Vertical crack result graph.

The graph presented in figure 4 shows that cracks formed deeper and deeper in the first five days. However, after the first wetting cycle, cracks are formed with unchanged depth from the 7th day to the
10th day when entering the drying cycle. This was also the case after the drying cycle after the second wetting cycle. The depth of the crack did not change from day 12 to day 15. This study's results are appropriate and prove the truth of Ghazizade and Safari's research. Ghazizade and Safari's research said that when samples were wetting-drying cycles, cracks formed, and their depth did not change [11]. Thus the wetting-drying period affects the depth of the crack formed. In addition, the presence of carbon tends to reduce the shear strength of the sand [12].

4. Conclusion
Composite samples that meet the permeability coefficient criteria for the landfill liner (less than $10^{-6}$ cm/s) are V5 (sample of metal industrial waste + 20% bentonite) of $0.8059 \times 10^{-6}$ cm/s and V6 (sample of metal industrial waste + bentonite 25 %) of $0.5059 \times 10^{-6}$ cm/sec. Meanwhile, based on each sample's CIF value, it was found that all samples met the requirements to become the base layer of landfill except V6 because it was >4%. Thus, the best composite is V5 metal industrial waste + 20% bentonite.

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