Crack formation behavior of composite fly ash – bentonite (FAB) in landfill liner system

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Abstract. This study aims to investigate the influence of different mixtures on the phenomenon of desiccation cracking in bentonite-fly ash mixtures as a landfill liner system. Fly ash is quite potential to be used as a landfill liner mixture because it has a low hydraulic permeability or conductivity value. This study uses class F fly ash from the Paiton power plant production process, Indonesia, which has been distributed commercially. Desiccation test was conducted in this study. The composition of fly ash and bentonite which is used are pure fly ash (FAB0), fly ash and bentonite 15% (FAB15), fly ash and bentonite 20% (FAB20) and fly ash and bentonite 25% (FAB25). The smallest CIF value is found in the pure fly ash layer. However, the pure fly ash cannot be used as landfill liner because the high permeability value. Therefore, the addition of bentonite will increase the possibility of crack formation. This study reveals that the addition bentonite in the fly ash composite will increase the crack. However, determining appropriate mixture composition is critical when working on the landfill liner system.

1. Introduction
Landfill liner system as a layer of retaining leachate contamination from waste on the surface of the soil is one of the important components in landfills that withstand the load of landfill and prevent leachate from leaking into the environment [1]. Liners used as base coatings in landfill systems generally have low hydraulic conductivity and are rich in clay material [2]. Clay consists of various soil minerals where bentonite is the mineral most often used both as a landfill liner and cover [3]. Bentonite is quite desirable to be used as a constituent of landfill liners because it has a low hydraulic conductivity value and is easily installed as a mixture of other materials. Montmorillonite in bentonite can bind enough water molecules during the hydration process. The ability of bentonite to bind water molecules is able to prevent bulk water from entering, causing the bentonite hydraulic conductivity to decrease. However, cracking or desiccation and leakage which can lead to failure of the containment system can occur at any time depending on the environment in which the material is placed and operational conditions such as chemical exposure, dry-wet cycle and increase in gradient temperature [4].

Optimization of the performance of the liner system is done in various ways one of them by using a mixture of waste material with binding material [5]. Fly ash is quite potential to be used as a landfill liner mixture because it has a low hydraulic permeability or conductivity value. The permeability value of pure fly ash is in the range of 10^-4 to 10^-7 cm/s [6]. Pozzolanic fly ash has a low shrinkage potential and is not susceptible to cracking [7]. The effectiveness of liner performance is influenced by several
factors, such as initial water content and particle size distribution of the soil above and/or below the geosynthetic clay liner (GCL), the level of exposure to thermal cycles, sustained thermal gradients, and the stress on the GCL [8]. The increase in temperature due to the degradation process of the waste pile in the landfill can bring moisture downward which tends to reduce the temperature of the liner system. If the temperature increase gradient is higher than the possibility of desiccation in the liner layer will be even greater. Desiccation causes an increase in the value of hydraulic conductivity, compressibility and consolidation rate which causes a decrease in soil strength and affects self-healing capacity [9].

Nevertheless, studies that analyze the influence of bentonite mixtures to the phenomenon of desiccation cracking in the mixture of bentonite-fly ash landfill liner materials of the composite layer is lacking. In this study, the influence of the mixtures on the phenomenon of desiccation cracking in bentonite-fly ash mixtures as a landfill liner system was further investigated to overcome gaps in studies of landfill liner cracking. This research is expected to be able to contribute knowledge to the use of alternative composite materials for better landfill liner systems.

2. Methodology

This study uses class F fly ash from the Paiton power plant production process, Indonesia, which has been distributed commercially. The results of the XRF test show that fly ash is composed of mineral quartz (SiO₂), ferrous oxide (Fe₂O₃), periclase (MgO), alumina (Al) and titanium oxide (TiO₂). The permeability value of pure fly ash is 1.653 x 10⁻⁸ m/s. As a result of the high permeability value, it is necessary to add other materials that can reduce the permeability value of composite soils. Bentonite clay is taken from mineral and rock mining in Giriwoyo District, Wonogiri Regency, Central Java. To distinguish the effect of salinity on desiccation crack, NH₄Cl 1 N was used as a substitute for aquadest in one of the treatments [10].

This research was conducted at the Environmental Laboratory, Environmental Engineering and Soil Mechanics Laboratory, Civil Engineering, Diponegoro University in March - June 2019. The research was carried out by making a mixture of bentonite-fly ash [2]. The study was conducted with the same mixture and obtained optimal results of bentonite levels of 20%. Thus, in this study the variation in bentonite levels was 15%, 20% and 25%. In addition, researchers also made a mixture of 25% bentonite composite - fly ash and NH₄Cl 1 N solution with a concentration of 7.1 ppm following the salinity concentration at Jatibarang Landfill, Semarang. Bentonite-fly ash composites are put into a 2-inch hubcap and are loaded on them.

The desiccation test is carried out by placing a load on the bentonite-fly ash composite. Determination of the amount of pressure/load is based on the assumption that the area of the landfill is 1 m², the waste density is 800 kg/m³ and the height of the landfill is 4 meters. The amount of load faced by the simulated landfill liner system is calculated using equation (1).

\[
P = \frac{W}{A} = \frac{\rho \times V \times g}{A}
\]

\[
P = \frac{800 \text{ kg/m}^3 \times 1 \text{ m}^2 \times 4 \text{ m}}{1 \text{ m}^2} = \frac{31,392 \text{ kgms}^{-2}}{1 \text{ m}^2} = 31,392 \text{ kgms}^{-2} \text{S}^{-2}
\]

The lab-scale liner that will be used in the study has a diameter of 0.06 m² so that according to equation (1), the load used (W) on a fly ash-bentonite composite dish is 9.043 kg or estimated to be ± 9 kg.

Crack observations on bentonite-fly ash composites were carried out by analyzing composite fracture photographs. Image pixel methods are used to measure the dimensions of cracks that occur [11]. Photo acquisition was carried out using a cellphone with a 13 megapixel camera specification. Image sizes vary from 3.077 x 2.304 pixels to 1.632 x 1.224 pixels which are converted into black and white images. The ratio of crack area to total surface area will describe the crack intensity factor (CIF). Crack intensity factor is defined as the ratio of crack area (Ac) to total surface area (At) of the mass of the soil experiencing drought [12]. The CIF value is determined using the 2018a Matlab® software. Analysis is carried out based on the contrast of the cracked soil which is characterized by darker colored segmentation of the gap compared to the area that has not experienced cracking or in other words, Matlab® will calculate the ratio of black and white in the image the liner layer [13]. Researchers analyzed
the results of the software by comparing data taken every day for 39 days on a composite layer and pure fly ash.

3. Results and discussion

Water content testing was carried out on all samples of bentonite-fly ash, bentonite-fly ash with 7.100 ppm salinity solution and pure fly ash. The results of observations on changes in water content in the composite showed that during the 39 days of the study as a whole all mixes experiencing a decrease in water content until the end of the study time (See Figures 1). Likewise, the lowest moisture content values on the composite were observed in the pure fly ash layer. Fly ash + 25% bentonite composite have the highest water content compared to other mixtures and pure fly ash. The moisture content in the fly ash + 25% bentonite composite had increased on the 18th day and continued to decline until the last day of the study.

![Figure 1. Fly Ash bentonite composite moisture with loading.](image)

Researchers also observed cracks that occur in the fly ash bentonite composite layer and analyzed the crack intensity factor (CIF) value. The results obtained indicate that the CIF value is higher along with a decrease in water content. Based on the data presented in Table 1 it is known that the lowest CIF value was obtained on pure fly ash dish. Whereas the highest CIF value was found in dishes with a composite fly ash + 20% bentonite on the last day of the study of 2.439. The second highest value was found on the composite fly ash + 25% bentonite on the last day of the study amounting to 2.250. The results obtained are quite different in composite fly ash bentonite without loading. The lower the water content, the higher the CIF value. However, the CIF value at the end of the study time on the fly ash composite + 15% bentonite with a moisture content of 15,660 lower than the composite layer of fly ash + 20% bentonite with a moisture content of 20,219. Similarly, the pure fly ash composite layer with the lowest CIF value has a lower moisture content value compared to the fly ash composite + 15% bentonite at the end of the study.

| Day | Pure Fly Ash | Fly Ash + 15% Bentonite | Fly Ash + 20% Bentonite | Fly Ash + 25% Bentonite |
|-----|--------------|-------------------------|-------------------------|-------------------------|
|     | W (%)        | CIF                     | W (%)                   | CIF                     | W (%)                   | CIF                     |
| 0   | 19.300       | 0                       | 29.428                  | 0                       | 47.481                  | 0                       |
| 5   | 15.700       | 1                       | 25.518                  | 1                       | 42.541                  | 1                       |
| 10  | 12.800       | 2                       | 21.728                  | 2                       | 38.681                  | 2                       |
| 15  | 10.800       | 3                       | 17.938                  | 3                       | 34.821                  | 3                       |
| 20  | 8.800        | 4                       | 14.148                  | 4                       | 30.961                  | 4                       |
| 25  | 6.800        | 5                       | 10.358                  | 5                       | 27.101                  | 5                       |
| 30  | 4.800        | 6                       | 6.568                   | 6                       | 23.241                  | 6                       |
| 35  | 2.800        | 7                       | 2.778                   | 7                       | 19.381                  | 7                       |
| 40  | 0.800        | 8                       | -                       | 8                       | 15.521                  | 8                       |
| 45  | -            | 9                       | -                       | 9                       | 11.661                  | 9                       |
| 50  | -            | 10                      | -                       | 10                      | 7.801                   | 10                      |

Table 1. CIF value and moisture content in each composite coating cup by loading.
It is known that a decrease in water content and an increase in CIF values from day 1 to day 39 are illustrated by the appearance of cracks or desiccation cracks in the composite layer. The lowest CIF value in the pure fly ash layer can be observed in the absence of cracks which are represented by the presence of black in image analysis with MATLAB version 2018a. If these results are compared with studies conducted by Safari et al., the geotextile layer covering compacted clay soils was considered capable of reducing CIF by an average of 52% [14]. The burden on the composite layer is assumed to act like a geotextile layer that covers the layer of compacted clay soil so that the composite layer is protected from atmospheric conditions [15]. The reduced water content followed by cracks in the composite layer will certainly affect the permeability of the layer.

Fly ash can be used as a reactive liner material because some researchers say that fly ash is classified as pozzolanic material, a material that can do self-cementing due to the high content of silica or silica alumina so that it forms a chemical reaction with water to form an adhesive at room temperature [16]. On the other hand, bentonite clay soils are expansive when going through a wet-dry cycle, giving rise to the potential for cracking during the dry season. Bentonite is always negatively charged and isomorphic substitution of ions such as Al$^{3+}$, Mg$^{2+}$, and Fe$^{2+}$ occurs. The gap between the bentonite layers can expand and be filled with water molecules and other cations [17]. The mixture of bentonite-fly ash is considered to be able to minimize the potential for crack desiccation because the liquid limit of the bentonite increases and the cation exchange capacity increases [18]. Both bentonite and fly ash have their advantages and disadvantages in their function as a leachate barrier. Therefore, determining the right mix composition is a critical factor in the decision to use this mixture.

4. Conclusion
Based on research that has been done, it is known that the phenomenon of desiccation which is marked by the value of CIF (crack intensity factor) appears along with the decreasing value of the water content. The smallest CIF value is found in the pure fly ash layer, but the permeability coefficient of pure fly ash exceeds the limits in force in Indonesia. So that the addition of bentonite to fly ash can reduce the value of the permeability coefficient of the composite landfill liner so that it complies with applicable regulations for use on pilot-scale. Loading on the composite can increase the value of the optimum moisture content thereby increasing the value of CIF.

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