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Research Article

Study of Desiccation Crack Behavior of Fly Ash - Bentonite (FAB) Composite in Landfill Liner System

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Abstract
The addition of bentonite to fly ash can lower the permeability coefficient of the composite landfill liner. Also, the montmorillonite bentonite can bind quite a lot of water molecules during the hydration process. In this study, the effect of mixture, water content, and salinity on the desiccation cracking phenomenon in the bentonite - fly ash mixture as a landfill liner system was investigated by conducting tests such as desiccation test, water content test, and standard proctor and permeability test. The variation in bentonite levels: 0%, 15%, 20%,25% and 25% + 1 N NH_4Cl solution. The result shows that the appropriate mixture is fly ash + 15% bentonite with permeability of 4,065 x 10^{-7}. The mixture complies with local regulations where the permeability coefficient of the bottom layer of the landfill should be less than 10^{-6} cm/s and have a low cracking value (CIF). Furthermore, the addition of saline solution to the composite can rise the value of the optimum moisture content. However, saline conditions can decrease the value of CIF drastically.

Keywords: Bentonite; fly ash; permeability; water content

1. Introduction
Many studies have discussed the phenomenon of desiccation in this landfill liner over the last few decades to find the right formula to improve the effectiveness of liner performance (Azad et al., 2011; Qiang et al., 2014; He et al., 2015; Ehrlich et al., 2019; Yu and El-Zein, 2019). Based on the study conducted by Safari et al (2014), it is known that the atmospheric cycle and the geotextile layer that covers the compacted clay liner (CCL) can influence desiccation and crack intensity factor (CIF) values. Geotextile covers that cover compacted soil can significantly reduce the intensity of desiccation. Some studies use CIF as one method to quantify the intensity and classify the phenomenon of cracking in clayey soil used as a landfill liner (Qiang et al., 2014; Safari et al., 2014; Chaduvula et al., 2017). A lower CIF value indicates that clayey soil does not need more external moisture to avoid desiccation so that the soil is considered more stable and has higher integrity (Safari et al., 2014; Chaduvula et al., 2017).

Based on the study conducted by (Chaduvula et al., 2017), (Qiang et al., 2014) and (Ehrlich et al., 2019), The clay soil used is strengthened by using natural fiber which is considered to be able to overcome the post-cracking problem so that cracks in deeper layers can be avoided. In addition to using natural fiber, efforts to strengthen landfill liners have also been carried out with a mixture of bentonite-tropical soils (Morandini and Leite, 2015), dune sand-bentonite (Gueddouda et al., 2016), bentonite-sand (Soumya M Das and Sudha A R, 2016), fly ash, phospogypsum, red mud (Çoruh and Ergun, 2010), fly ash-sewage sludge (Herrmann et al., 2009), fly ash-cement (Mishra and Ravindra, 2015), coal gangue (Wu et al., 2017), shale–clay (L. Li et al., 2017), zeolite-sand (Joanna and Kazimierz, 2013), rubber-bentonite-fly ash (Cokca and Yilmaz, 2004), additive substance (Mukri et al., 2018) and waste material stabilization (Kalkan, 2006; Karimpour-Fard et al., 2011; Akcanca and Aytekin, 2012; Budihardjo, 2016). The use of a mixture can improve the performance of the liner in holding the leachate so that it meets the applicable requirements (Herrmann et al., 2009).

Moisture content in the soil layer or liner can also be one of the causes of desiccation crack. Malizia and Shakoor (2018) and Wan et al. (2019) conducted a study of the effect of water content and evaporation on the desiccation cracking phenomenon in the soil layer. Desiccation causes cracking due to loss of moisture content. Bentonite can be used as a coating for landfills because it has a low hydraulic conductivity value and is easy to install as a mixture of other materials. The montmorillonite bentonite can bind quite a lot of water molecules during the hydration process. The ability of bentonite to bind water molecules can prevent the entry of bulk water so that the hydraulic conductivity of bentonite decreases.

Furthermore, optimization of liner system performance is carried out in vary ways, one of which is using a mixture of waste materials and binders (Cheriyan and Chandrakaran, 2018). Fly ash can be utilized as a landfill liner mixture because it has a fairly low value of hydraulic conductivity or permeability. The permeability value of pure fly ash is in the range of 10-4 to 10^{-7} cm/s (Bhatt et al., 2019). Pozzalonic fly ash has low shrinkage potential and is not prone to cracking (Yao et al., 2015). However, studies analyzing the effect of moisture content, curing with salinity, bentonite mixture on the phenomenon of desiccation cracking in bentonite - fly ash landfill liner mixture of the composite layer have not been found. In this study, the effect of water content and salinity on the phenomenon of desiccation cracking in a mixture of bentonite - fly ash as a landfill liner system was investigated further to overcome the gap in the study of landfill liner cracking. The results of this study are expected to contribute to knowledge about alternative uses of landfill liner composite materials

2. Methodology

2.1 Materials

In this study fly ash (class F) was chosen from the production process of PLTU Paiton Indonesia which has been distributed commercially. X-Ray Fluorescence (XRF) test results show that fly ash is composed of minerals quartz (SiO_2), ferrous oxide (Fe_2O_3), periclase (MgO), alumina (Al), and titanium oxide (TiO_2). The permeability value of pure fly ash is 1.653 x 10^{-8} m/s. The high value of pure fly ash permeability causes the need for the addition of other materials that can reduce the permeability value of composite soil. 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 (Abd El-Salam and Abu-Zuid, 2015), then 1 N NH_4Cl was used as a substitute of aquadest in one of the treatments.

2.2 Experimental Setup

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. Pandey and Jain (2017) investigated a study with the same mixture and obtained the optimal bentonite content of 20%. Thus, the variation in bentonite levels was 0%, 15%, 20%, and 25% in this study. In addition, this study also made a mixture of 25% bentonite composite - fly ash and 1 N NH_4Cl solution (replacement distilled water) with a concentration of 7,100 ppm following the salinity concentration at Jatibarang Landfill, Semarang. Bentonite composite – fly ash is inserted into the 3.5-inch petri dish and is given a load on it. The experimental setup is shown in Figure 1.

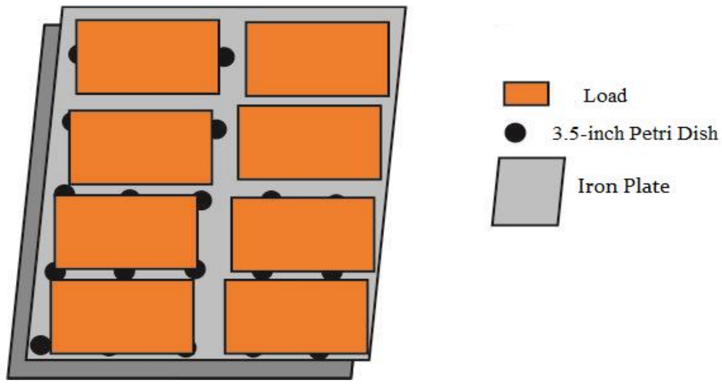

Figure 1. Experimental setup

2.3 Dessication Test

The desiccation test was carried out on the bentonite – fly ash composite. Bentonite - fly ash composite is made by mixing bentonite - fly ash with aquadest / NH_4Cl solution until it looks homogeneous, marked by an even color. The mixture of bentonite - fly ash which has been homogeneous is then put into a cup. Observation of cracks in bentonite – fly ash composites was carried out by analyzing composite crack photos. Image pixel methods are used to measure the dimensions of the cracks that occur (Harianto et al., 2008). Photo acquisition is done using a cellphone with a 13 megapixel camera specification. The image size varies from 3,077 x 2,304 pixels to 1,632 x 1,224 pixels which is converted into a black and white image. The ratio of the crack area to the total surface area will describe the crack intensity factor (CIF). Crack intensity factor is defined as the ratio of the cracked area (Ac) to the total surface area (At) of the dry soil mass (Chaduvula et al., 2017). The CIF value was determined using the Matlab® software version 2018 A. The analysis was carried out based on the contrast of soil cracks which were marked by segmentation of gaps that were darker in color compared to areas that had not experienced cracks, in other words, Matlab® will calculate the ratio of black and white in the image of the liner layer (Mukunoki et al., 2014). This study analyzes the results of the software by comparing the data taken every day for 39 days on a composite layer and pure fly ash.

2.4 Water Content Test

Water content testing in this study was carried out using the gravimetric method in accordance with Indonesian National Standard number 1965: 2008 which is conducted every three days for 39 days by weighing the composite bentonite - fly ash to determine the weight before and after being put into the oven. After being heated in the oven for 24 hours at 105 ° C, the composite was weighed again. Differences in initial weight and final weight will indicate composite water content.

2.5 Standard Proctor and Permeability Test

Environmental The standard proctor test is carried out with the standard compaction test of the proctor on pure fly ash. This test is carried out to obtain the optimum value of moisture content (OMC) and maximum dry density (MDD) in making test samples. OMC values vary from 4-22% and MDD 1.48-1.93 g/cm3. The falling head permeability test was conducted in this study because it is very suitable to be used to test the permeability of fine-grained soils. Water in a vertical pipe is installed above the test sample so that it can flow through the sample. The water level at the beginning of the test is given the value of h1 at the time of t1 = 0. Then, water is passed through the sample and measured the difference in the height of water at t2 with the value of h2. Equation (1) is used to find the permeability coefficient value using falling head methods (Sivapullaiah and Baig, 2011).

$$k = 2.303 \left(\frac{aL}{At}\right) \log \left(\frac{h_2}{h_1}\right) \quad (1)$$

Where k is the permeability value at the laboratory scale (cm /s), a is the cross-sectional area of the measuring pipe (vertical pipe), A is the sample cross-sectional area of the sample (m^2 or cm^2), L is the length of the sample (m or cm), t is travel time for fluid along L (s), h1 is the initial height (m or cm) and h2 is the final height (m or cm).

3. Result

3.1 Water Content and Desiccation

Water content testing was carried out on composite samples such as pure fly ash, bentonite fly ash, and bentonite fly ash with a salinity solution of 7,100 ppm. As shown in Figure 2, all samples significantly decreased in moisture content on the 36th day test. The most significant water content decrease was observed in the fly ash + 25% bentonite sample, the percentage decreased by 45.7 points. In contrast, the percentage of pure fly ash samples fell 19.6 points. The percentage of water content decreases with increasing bentonite content. In addition, the effect of salinity desiccation in fly ash + 25% bentonite + NH_4Cl solution sample decreases in the percentage of water content by 42.9 points. This drop is 2.73 points less than the fly ash + 25% bentonite sample. So that the effect of saline condition can resist a reduce in water content.

The desiccation results in table 1 show that CIF value raise with rose bentonite content in the mixture. The result found the highest CIF value in Fly ash + 25% bentonite composite of 3.999. In contrast, the lowest CIF value in pure Fly ash of 0.007. Moreover, saline condition in fly ash + 25% bentonite + NH_4Cl solution resulted in CIF value decreases by 30 percent. Thus, CIF value decrease with increased water content. A lower CIF value indicates that clayey soil does not need more external moisture to avoid desiccation so that the soil is considered more stable and has higher.

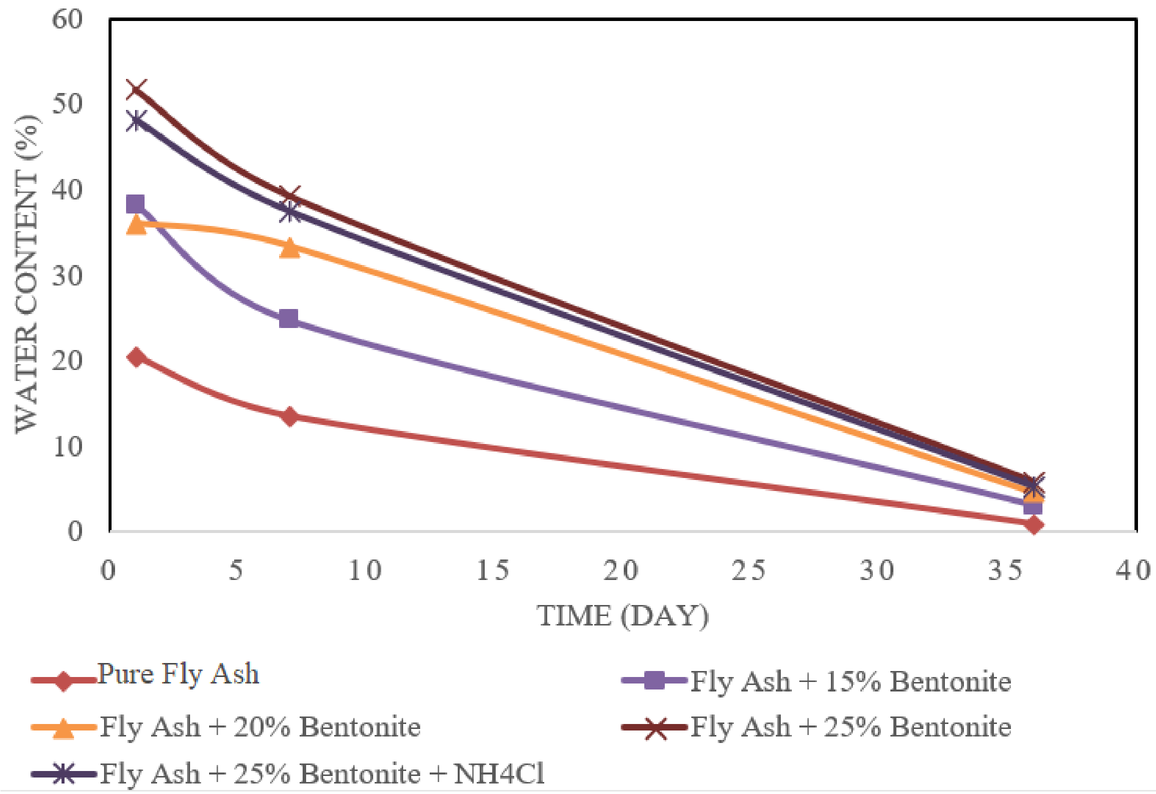

Figure 2. Fly ash bentonite composite moisture

Table 1. CIF value and water content in each cup composite layer

Day-	Pure Fly Ash		Fly Ash + 15% Bentonite		Fly Ash + 20% Bentonite		Fly Ash + 25% Bentonite		Fly Ash + 25% Bentonite + NH_4Cl Solution	
	W (%)	CIF	W (%)	CIF	W (%)	CIF	W (%)	CIF	W (%)	CIF
1	20.45	0	38.289	0	36.017	0.037	51.655	0.026	48.251	0.004
7	13.48	0.014	24.666	0.242	33.350	1.077	39.252	1.584	37.526	2.340
36	0.878	0.077	3.064	1.840	4.579	3.398	5.921	3.999	5.252	2.799

3.2 Standard Proctor and Permeability Test

The standard compaction test of the proctor is carried out on pure fly ash to get the optimum moisture content (OMC) and maximum dry density (MDD) values. Based on the proctor test the results are as shown in Table 2. The data is then analyzed using a standard proctor graph (Figure 3) so that the dry weight content of pure fly ash is 1,940 gr / cm^3 and the optimum moisture content is 11.25%. In addition, permeability tests were carried out on pure fly ash composites, fly ash + 15% bentonite, fly ash + 20% bentonite, and fly ash + 25% bentonite. From the research that has been done, it is also known that the permeability coefficient value decreases with increasing content of bentonite in the composite. The greatest value of the permeability coefficient measured on pure fly ash with a coefficient of 1.653×10^{-6} cm /s and followed by 4.065×10^{-7}, 2.567×10^{-7}, and 1.584×10^{-7} for fly ash with a mixture of bentonite 15%, 20% and 25%.

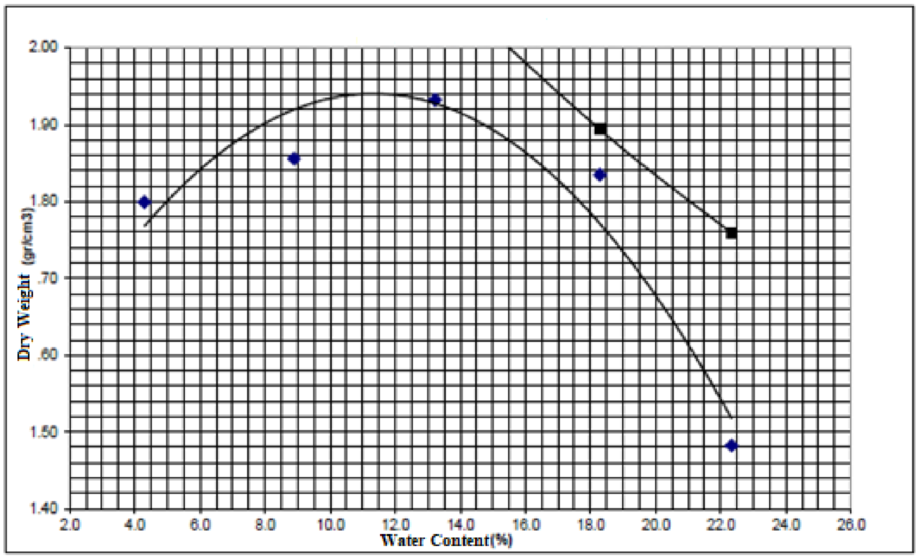

Figure 3. Proctor standard on fly ash composites

Tabel 2. Standard proctor test results on pure fly ash

Test No.	1	2	3	4	5
Additional Water (cc)	100	200	300	400	500
Weight of proctor + compacted soil (gr)	6144	6274	6425	6409	6087
Solid soil weight (gr)	4450	4450	4450	4450	4450
Volume proctor (cm³)	1694	1824	1975	1959	1637
Wet weight (gr/cm³)	902.75	902.75	902.75	902.75	902.75
Dry weight (gr/cm³)	1.88	2.02	2.19	2.17	1.81
Pore number (e)	1.80	1.86	1.93	1.83	1.48
Porosity (n)	0.61	0.56	0.50	0.58	0.95
No. Cup	1	3	5	7	9
Weight of cup + wet soil (gr)	62.47	61.69	53.07	63.40	69.15
Weight of cup + dry soil (gr)	2.25	2.30	3.99	4.80	8.04
Water weight (g)	9.35	8.81	8.83	8.55	8.87
Cup Weight (gr)	53.12	52.88	44.24	54.85	60.28
Dry soil weight (gr)	62.47	61.69	53.07	63.40	69.15

4. Discussion

Proctor and permeability test results produce data in the form of dry weight content of fly ash material, optimum moisture content of fly ash and the permeability coefficient of each composite liner. The results of the optimum moisture content in each composite showed that the addition of bentonite to the fly ash had an effect on increasing the optimum moisture content of the composite. The largest optimum moisture content measured on the composite fly ash + 25% bentonite + NH_4Cl 1 N is equal to 32,276%. The addition of saline solution to the composite affects the increase in the optimum measured water content. Decreased water content can occur due to drying in the composite layer as a result of rising temperatures and atmospheric phenomena (Aldaeef and Rayhani, 2015). Based on the research conducted by (Budihardjo,

2016) addition of salt solution (NaCl) can increase the hydraulic performance of GCL. Moreover, addition of salt solution (NaCl) can lower CIF value indicates that the soil is considered more stable and higher.

Bentonite is considered to have a self-healing capacity to return to its original state so that it can affect its hydraulic ability (Budihardjo et al., 2012). The smaller the permeability coefficient with the addition of bentonite can illustrate the effect of the addition of bentonite to the fly ash on the permeability coefficient. The smallest permeability coefficient is measured in the composite fly ash layer + 25% bentonite. If the measured permeability coefficient value is compared with the standard used in Indonesia (Indonesian Minister of Public Works, 2013) then the pure fly ash permeability coefficient value does not meet the standard.

The desiccation behavior has actually been studied by various researchers. Harianto et al. (2008), for example, tried to analyze the effect of levels of polypropylene fiber on the reduction of cracks in shrinkage and soils. Mixing of shrinkage soil and fibers turns out to be able to reduce the possibility of cracking because the more fiber, the greater the possibility of fiber filling the soil cavity and forming a lump and reducing volumetric shrinkage (Harianto et al., 2008). Shrinkage is the change in the total volume of the soil as a whole (Mukherjee and Mishra, 2017b). The reduction in shrinkage may occur because the total area of contact of soil particles with fiber increases with increasing fiber concentration. The increase in the crack area is the result of the amount of water in the soil during the drying process (Harianto et al., 2008). When the drying process has exceeded the soil's endurance limit, cracking will occur. Fiber (fly ash – bentonite) is able to increase the soil's resistance to volumetric shrinkage because it strengthens the bond between soil surfaces, increasing the interlocking force and considerable friction (Chaduvula et al., 2017). The surface of the fiber is attached by many particles so that the strength of the ground bond is greater. Composite with a low chance of shrinkage is very suitable to withstand rainfall infiltration and leachate when used as a landfill liner system (Li et al., 2017).

Table 4. Optimum moisture content of each composite liner

A	**Pure Fly ash**	**30.343**
B	fly ash + 15% bentonite	11.602
C	fly ash + 20% bentonite	22.006
D	fly ash + 25% bentonite	24.649
E	Fly ash + 25% bentonite + NH_4Cl 1 N	32.276

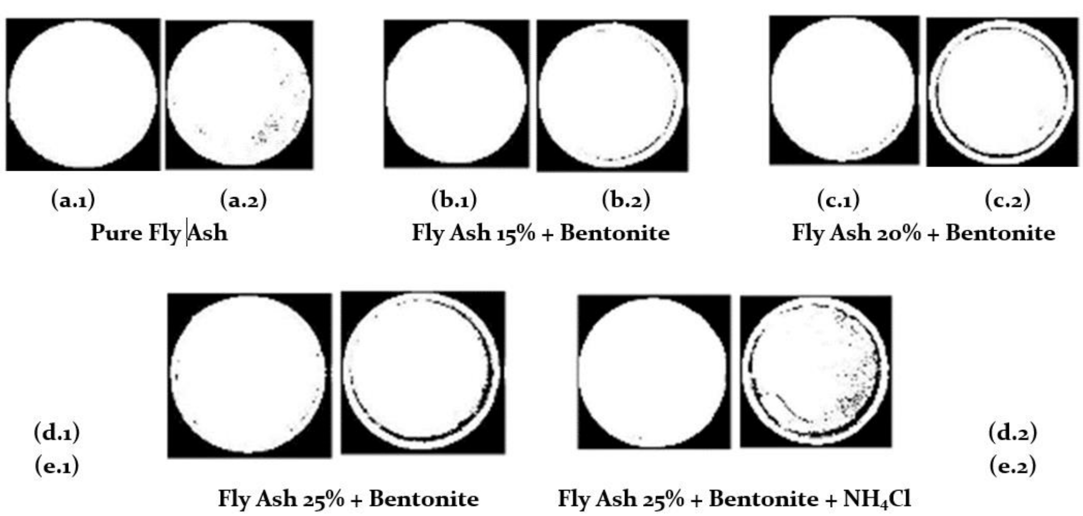

Figure 4. Crack images on the composite layer on the first day (a.1; b.1; c.1; d.1) and 39th day (a.2; b.2; c.2; d.2)

5. Conclusion

Based on the study results, it is known that the desiccation phenomenon characterized by the value of CIF (crack intensity factor) appears along with the decrease in the 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 applicable in Indonesia. So that the addition of bentonite to fly ash is able to reduce the permeability coefficient value of the landfill liner composite so that it is in accordance with applicable regulations for use at pilot-scale. The increasing bentonite content can decrease water content, decrease CIF value and decrease permeability coefficient. To meet local regulations where the permeability coefficient of the bottom layer of the landfill must be less than 10^{-6} cm/s and have a low cracking value, the appropriate mixture is fly ash + 15% bentonite. Furthermore, addition of saline solution to the composite can increase the value of the optimum moisture content. However, saline conditions can reduce the value of CIF drastically. This condition shows the opportunity for further research related to different saline concentrations given the considerable amount of landfills built in high salinity environmental conditions.

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