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SOIL TREATMENT BY BENTONITE AND FLY ASH FOR LINERS OF WASTE LANDFILL: A CASE STUDY IN VIETNAM

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ABSTRACT: Currently, a mixture of bentonite and soil is widely used for the bottom liner of landfill; however, the landfill using this mixture for the liner in Vietnam is limited. Therefore, this paper focuses mainly on investigating the physical and mechanical properties of soil samples from Hanoi, Vietnam; then compared their hydraulic conductivity before and after mixing with bentonite and fly ash in order to assess the efficiency of these mixtures for the landfill in Vietnam. From the hydraulic conductivity results, it was found that a mixture that has 15% or greater than15% of soil replaced by fly ash combined with bentonite (with the ratio between fly ash and bentonite is 4:1) can have the value of hydraulic conductivity (less than $1x10^{-9}$m/s) satisfies Vietnamese standard for bottom liner. Thus, this mixture can be used for landfill in Vietnam. In addition, several X-ray diffraction (XRD) tests along with Energy Dispersive X-ray Spectroscopy (EDX) on Scanning Electronic Microscopy (SEM) were also conducted for better understanding mechanism of reduction in hydraulic conductivity of mixed samples when bentonite combined fly ash added.

Keywords: bentonite, fly ash, landfill; hydraulic conductivity, XRD, SEM, EDX

1. INTRODUCTION

Recently, according to Ministry of Industry and Trade of Vietnam, the total amount of solid waste is approximately 12.8 million tons/year in the whole country with the growth rate of 12% per year, and about 6.4 thousand tons/year in Hanoi [1,2]. This amount of solid waste is mainly treated in urban landfills with approximately 1/3 these landfills in safety level in Hanoi [3]. The largest landfill in Hanoi is Nam Son landfill as shown in Figure 1, which collected and treated around 3800 to 4200 tons of solid waste every day. In this landfill or Xuan Son landfill with Kieu Ky waste treatment plant, solid waste is compacted and burned before being buried deeply, and leachate is gathered in the reservoirs, then treated according to regulations. However, with other landfills (temporary, open, and without the collection of leachate or treatment system), leachate goes directly to the natural lagoon, and leads to a high risk of pollution, particularly in underground water sources [4].

The mixture of soil and bentonite is applied for the bottom liner of sanitary landfills in many countries due to both technical and economic advantages [5,6]. There are many studies were conducted in order to determine the change of hydraulic conductivity according to bentonite content and compacted density in the world [7–11],[15,30].

Cho. et al. reported that with a dry density of 1.6 Mg/m^3 of the mixture, the hydraulic conductivity decreases rapidly with the increasing of bentonite content and is smaller than $1x10^{-9}$ m/s if the bentonite content is higher than 10% by weight [10]. Omer also revealed that hydraulic conductivity decreases when bentonite content increases [11]; besides, Dixon & Gray pointed that adding sand (up to 50%) to bentonite leads to reduce hydraulic conductivity of compacted samples [12]. According to Charles et al. [13], the significant reduction in hydraulic conductivity (k) happens when increase bentonite content in soil samples mixing with bentonite, especially the mixture can have a remarkably low value in hydraulic conductivity ($\leq 1x10^{-10}$ m/s) if bentonite content in the mixture is more than 10%.

Moreover, soil mixing with fly ash or a combination of bentonite and fly ash after compaction also has been used for the bottom liner of waste landfill [14,15]. For the case of a mixture of soil and fly ash, the previous studies showed that plasticity index, hydraulic conductivity, and swelling property of soil samples mixed with fly ash reduced along with the increase of dry density and strength when the fly ash content in mixture increases [14]. In addition, the study of Ollamahmutoğlu and Yilmaz [15] also showed that the mixture soil with bentonite and fly ash can use to improve hydraulic conductivity.

Fig. 1 Solid waste in collection process in Nam Son landfill

In response to sustainable development trend, Hanoi needs to ensure the harmony between economic growth and environmental protection, particularly in strengthening the efficiency of solid waste treatment to meet environmental protection requirements according to Law of environmental protection 38/2015/QH13 and Decree 38/2015/ND-CP on the management of waste and scrap. Hence, research on waterproofing for landfill is essential for Hanoi and is reasonable for orientation towards satellite towns in minimizing effects on the environment. Normally, the waterproofing layers for the landfill are layers of synthetic geotechnical material such as HDPE (High-Density Polyethylene) or GCL (Geosynthetic Clay Liners) [16,17]. According to Vietnamese standard TCXDVN 261:2001 [18], hydraulic conductivity of these liner layers for waste landfill must be less than 10^{-9} m/s with the thickness of compacted clay soil more than 0.6m. However, such materials are quite expensive and difficult in requirements of construction and quality management [16,17]. Therefore, replacement by the compacted clay layer for waterproof can reduce the cost is necessary. Nevertheless, to the best knowledge of authors, there are no studies on hydraulic conductivity using mixtures of soil and bentonite, soil and fly ash, and soil with bentonite combined fly ash for liner layers of the waste landfill in Vietnam. Thus, this research is aiming to evaluate the hydraulic conductivity of this clay layer (a mixture of clay with bentonite and fly ash) poses a huge significance to sustainable development orientation in Vietnam. In this study, we mainly focus on evaluation potential use of mixtures that contained fly ash and bentonite to add in the soil as a replaced waterproofing material for previous materials (HDPE, GCL, etc.) to meet above-mentioned purposes.

2. MATERIALS AND METHODS

2.1 Materials

Four tubes of the sample (i.e. the undisturbed soil samples) were collected from drill holes at the depth of 6 m in Hanoi (in the north of Vietnam) and were coated with a plastic tube in order to keep the moisture content unchanged. Then, they were transported to the laboratory to determine the physical-mechanical properties and microstructure.

In this study, we used the Fly ash class F that obtained from Vung Ang thermal power plant with basic properties and chemical components as described in Table 1. The particle size distribution of fly ash is presented in Fig. 2. Bentonite is manufactured by An Phat Joint Stock Company, Thanh Hoa province, Vietnam that has some basic properties and chemical components as described in Table 2.

Table 1 Properties and composition of Fly ash

Property	Result (%)	Testing method
Amount retained on 45μm	30.60	Sieve analysis
Loss on ignition	6.28	
Chemical composition of fly ash		
SiO_2	53.88	TCVN 7131:2002 [19]
K_2O	3.40	
MKN	6.27	
Fe_2O_3	6.70	
CaO	4.27	
Al_2O_3	21.82	

Table 2 Properties of Bentonite

Property	Result	Testing method
Specific density	2.6 g/cm^3	
Particle size < 0.074mm	85%	Dry sieving method
	95%	Wet sieving method
Loss on ignition	5.32	
Chemical composition		
SiO_2	75.30	TCVN 7131:2002 [19]
K_2O	0.37	
Fe_2O_3	0.50	
CaO	1.87	
Al_2O_3	15.43	
Na_2O	3.51	

Table 3 Testing specifications according to ASTM

Test	Standard specifications
Moisture content	ASTM D2216-2010 [20]
Unit weight	ASTM D7263-2018 [21]
Grain size analysis	ASTM D422-2007 [22]
Atterberg limits	ASTM D4318-2017 [23]
Automatic compaction	ASTM D698-2012 [24]
Hydraulic conductivity	ASTM D5084-2010 [25]

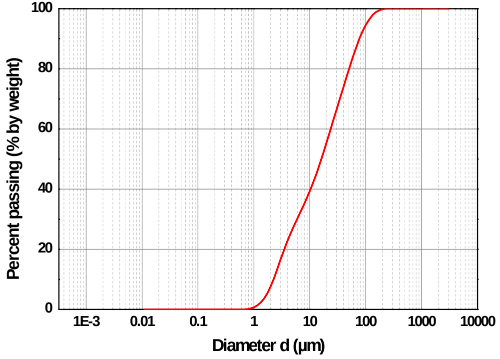

Fig. 2 Particle size distribution of fly ash

2.2 Methods

In this paper, the physical and mechanical properties of soil sample before and after mixing with the combination of fly ash and bentonite were conducted according to ASTM as listed in Table 3. The automatic compaction was applied for compaction test. Soil samples were divided into 3 layers and compacted using automatic rammer with the number of rammer drops of 25 for each soil layer as Standard Proctor [24]. The hydraulic conductivity test was performed in different mixed samples. In this study, we used three types of the mixture, the mixture proportions of three mixtures are listed in Table 4.

Table 4 Mixing proportion of three mixtures

Name of mixture	Soil (%)	Fly ash (%)	Bentonite (%)
Soil-bentontite	97	0	3
	95		5
	93		7
	90		10
	88		12
Soil-fly ash	95	5	0
	90	10	
	85	15	
Soil-fly ash + bentonite	95	5 (80% fly ash + 20% bentonite)	
	90	10 (80% fly ash + 20% bentonite)	
	85	15 (80% fly ash + 20% bentonite)	

In this test, samples were compacted and fully saturated by deairwater pass for approximately one week before conducting hydraulic conductivity test; the samples were. The Falling Head Test Method was performed following ASTM D5084 [25]. The schematic for the hydraulic conductivity test was shown in Fig. 3. The hydraulic conductivity can be calculated based on the formula below:

$$k = \frac{aL}{At}\ln\left(\frac{h_0}{h_1}\right) \quad (1)$$

k = Coefficient of hydraulic conductivity (m/s);
h_o = Initial height of water = 132 cm;
a = Area of the burette = 3.462 cm^2;
h_1 = Final height of water = h_o - Δh (cm);
L = Length of soil sample = 4 cm;
t = Time required to get a head drop of Δh (s);
A = Area of soil sample = 33.166 cm^2.

In addition, this study also applied analysis on the chemical composition of soil samples after mixing with different admixtures in different percentage by weight using X-ray diffraction test (XRD), and observation on the microstructure of these samples by Scanning Electronic Microscopy/ Energy Dispersive X-ray Spectroscopy (SEM/EDX).

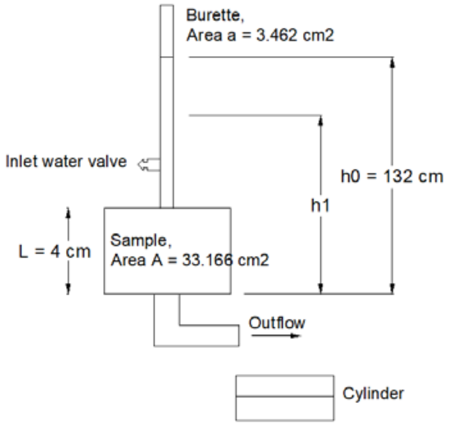

Fig.3 Schematic for the hydraulic conductivity test

3. RESULTS AND DISCUSSION

3.1. Results of soil samples

3.1.1. Physical properties

LA-950 Laser Particle Size Analyzer was used to determine the graduation of soil, and the grain size distribution curve is shown in Fig. 4. It can be observed that there is approximately 95% of soil particle smaller than 100 (μm), thus this soil type is known as fine soil. In addition, physical test results also are shown as below:

- Moisture content (w): 25.16%
- Plastic limit (PL): 19.21%
- Liquid limit (LL): 27.28%

Based on the above results, it can be said that the soil sample in this study for the Hanoi region is low plasticity clay (CL) according to the unified soil classification system (USCS).

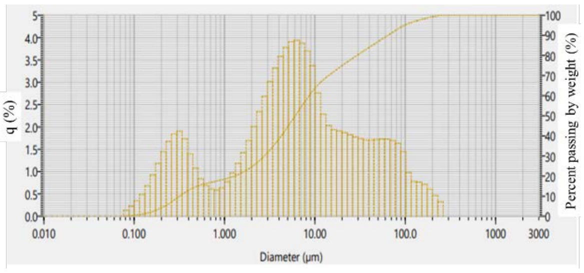

Fig. 4 Grain size distribution curve of soil

3.1.2. Automatic compaction test

The result of the automatic compaction test for undisturbed soil samples (i.e original raw soil) in Hanoi is shown in Fig. 5. According to this figure, it can infer that the optimum moisture content and the maximum dry density are 16.4% and 1.737 g/cm^3, respectively. The results of the compaction test of soil samples mixed using different admixtures with different percentages are compared and depicted in Fig. 6. As can be seen in Fig. 6, the dry density of soil samples mixing with fly ash increases from 0% to 7% and after 7%, it reduces gradually. This is because when fly ash content from 0% - 7%, it can be considered as a filler that can make the soil mixture denser; however, when content of fly ash is more than 7%, it can result in the lower of the dry density of soil mixture due to the lower specific density as well as extra water required for hydration of fly ash. Whereas, the dry densities of the mixture of soil and bentonite along with the mixture of soil with fly ash and bentonite increase when increasing percentage of admixtures.

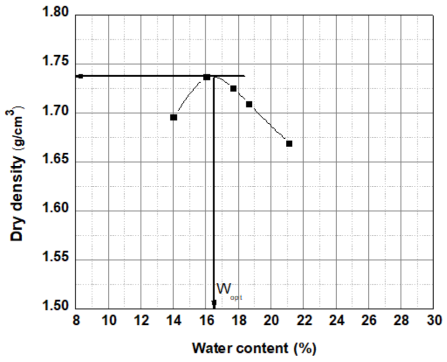

Fig. 5. Standard compaction result of undisturbed soil sample

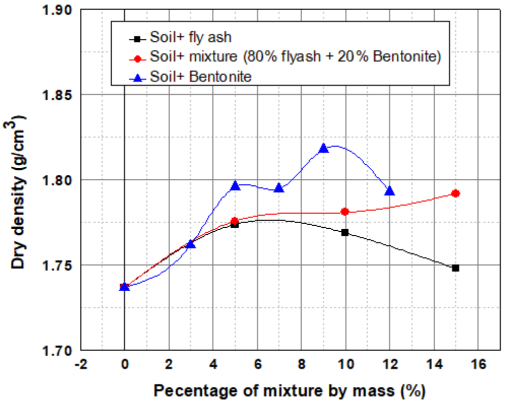

Fig. 6 Standard compaction results of soil samples mixing with admixtures

3.1.3. Hydraulic conductivity test

The average hydraulic conductivity value for the clay sample in Hanoi is about 4.7x10^{-9} m/s and does not satisfy the requirement (be higher than the allowable hydraulic conductivity coefficient for the liner of landfill according to TCXDVN 261:2001 [18]).

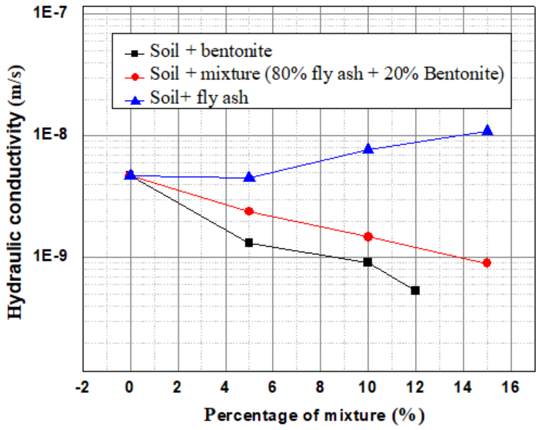

Fig. 7 Hydraulic conductivity results of samples

Hydraulic conductivity coefficient versus addition contents is also compared in Fig. 7. From the figure, it can be seen that the hydraulic conductivity coefficient of soil mixture with fly ash increased when the fly ash content increases, and it is not acceptable for landfill liner when fly ash content increases from 5% to until 15%. In the case of soil samples mixed with bentonite and mixed with a combination of bentonite and fly ash, hydraulic conductivity values gradually reduced when increasing admixture contents. By mixing with 10% bentonite, the hydraulic conductivity coefficient was lower than the required performance for waste landfill liner in Vietnam (corresponds to 1.0×10^{-9} m/s). For the case of mixing with bentonite and fly ash, it can be observed that the hydraulic conductivity gradually decreased, the hydraulic conductivity value reaches acceptable value for landfill liner when a percentage of this mixing is equal or greater than 15% (see Fig.7). Besides, based on the results of Fig. 6 and Fig. 7, the dry density of bentonite-fly ash mixture with 15% replacement was approximately 1.79 g/cm^3 that can yield the required hydraulic conductivity.

3.1.4. X-ray diffraction test results

The result of X-ray diffraction test is shown in Fig.8 (after the obtained schemas are analyzed single line by using MDI Jade software). The intensity (d) values obtained are compared with the ICDD/JCPDS data system to identify minerals). X-ray diffraction analysis was conducted on the untreated sample, soil samples mixed with 5, 12% bentonite; soil samples mixed with 5, 15% fly ash; and soil mixed with 5, 15% combination (including 80% fly ash and 20% bentonite in 100% combination by weight). The diffraction spectrum showed that the main crystal phases existing on such samples are Quartz (SiO_2), Phillipsite ($KCa(Si_5Al_3)O_{16}.6H_2O$), and polycrystalline Potassium Magnesium Silicate Hydroxide $K(Mg, Al)_{2.4}(Si_{3.34}AlO_{66})O_{10}(OH)_2$ (with another name of Phlogopite). The percentage in weight of 3 crystals changed according to each sample; however, these changes are small.

The main diffraction peaks are observed is Quartz (accounted for 75% to 85% by weight), and these peaks have similar wavelengths and reflex angles in all analyzed soil samples. Besides, these samples had low impurity intensity.

3.1.5. Scanning electronic microscopy and Energy Dispersive X-ray test results

In this study, the authors used scanning electronic microscopy (SEM) to discover the shape and microstructure of soil samples mixing for different admixtures. SEM images in Fig. 9 with a magnification of 2500 times showed that the particles had different sizes. Almost particles had the size smaller than 10 µm and connected together to make highly solid property. The observed images in soil samples mixed with fly ash are similar to results reported by Galupino and Dungca [26]. Similarly, the images and spectroscopy of soil samples mixed with bentonite match with the previous study of Lim [27]. When using the images with a magnification of 5000 times and atomic spectrum from Energy Dispersive X-ray *(*EDX) analysis shown in Fig. 10, it is clear that the monocrystalline and polycrystalline bond tightly together to form a membrane connection. Although Feldspar element can be observed from energy dispersive spectroscopy in Fig. 10, it cannot be detected in the XRD spectrum. This can be explained that the percentage of this element is small and unevenly distributed.

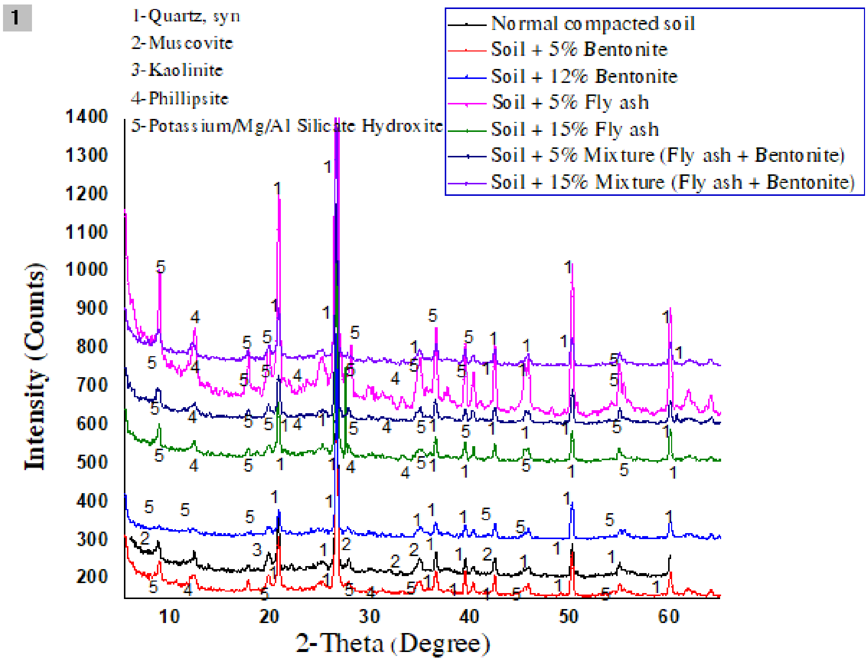

Fig. 8 XRD test results of samples

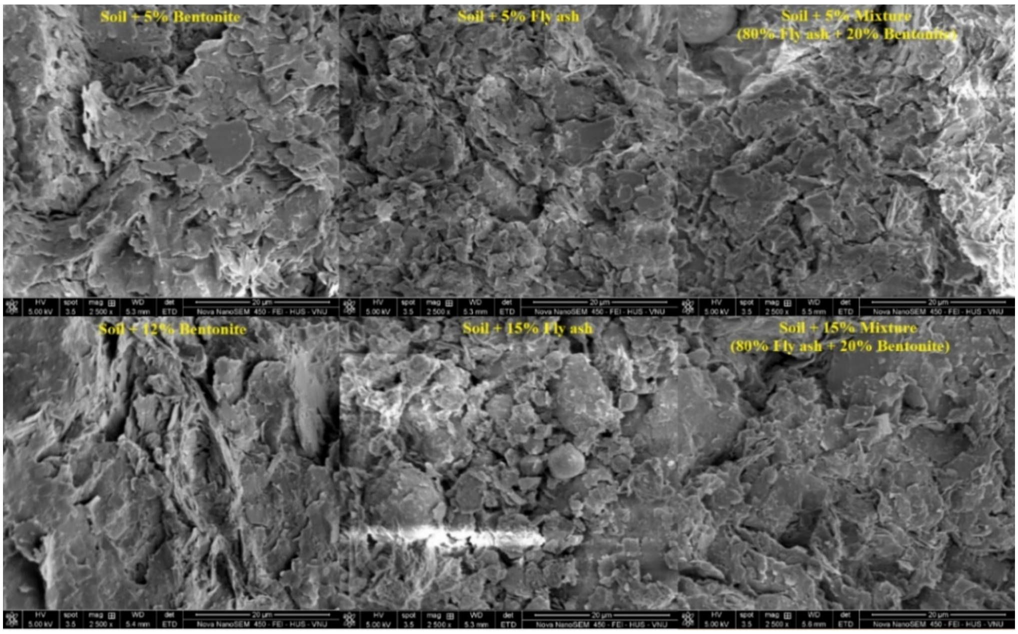

Fig. 9 Images for microstructure observation of samples from SEM with the magnification of 2500 times

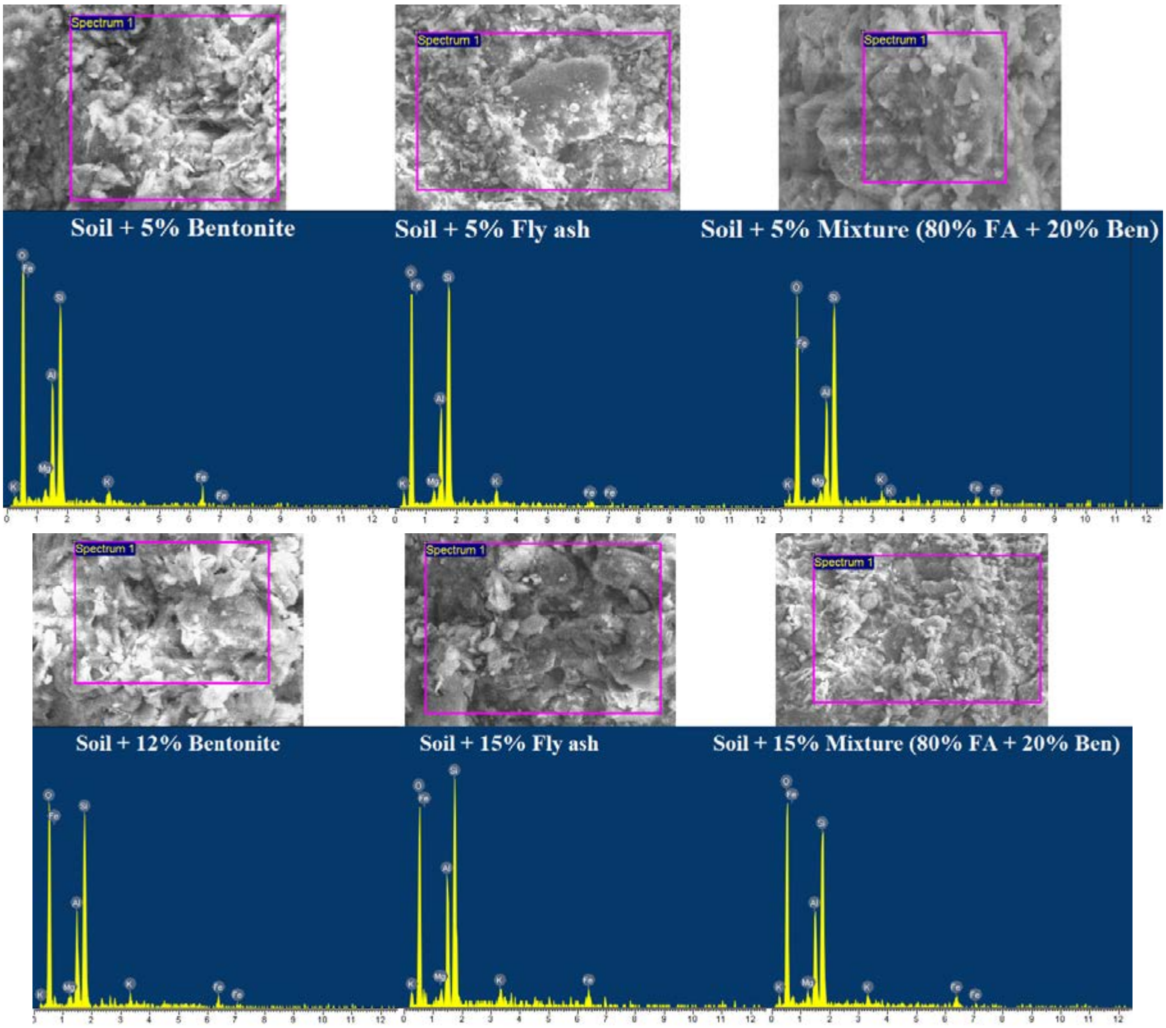

Fig. 10. Results of energy dispersive X-ray spectroscopy

3.2. Discussion

The hydraulic conductivity coefficients of natural soil samples in Hanoi is higher than $1x10^{-9}$ m/s (an allowable value) and is not satisfied the requirement of landfill liner according to Vietnam Specification TCXDVN 261:2001 [18] and guidelines of European Standard 1993/31/EC. Mixing the soil with bentonite and fly ash aims to adjust the hydraulic conductivity coefficient (k) of soil to achieve to required value for landfill liner and utilize fly ash – a by-product material of thermal power plant in response to sustainable development orientation. The results showed that the hydraulic conductivity value (k) increased with an increment in fly ash content, and this result is similar to previous studies [28,29]. Because fly ash generally composes of silt-sized particles that results in high permeability properties [29]. In contrast, the results obtained for the case of mixtures of soil and bentonite and soil mixed with bentonite combined with fly ash indicate that hydraulic conductivity k decreased with the increase in bentonite content. These results are consistent with results published in the literature [10,30]. The reason is that bentonite, with swelling property and small particle size (about 60÷105 µm) [30], possess a primary role in all the mixtures to fill voids, leads to decrease in the hydraulic conductivity and to minimize seepage of liquids (leachates in landfill or pure-phase organic liquid into groundwater). To summarize, these above results show that the optimum mixture content of bentonite and fly ash for adding in clay soil to improve permeability is 15% (with a ratio of bentonite-fly ash of 1:4 by weight).

In addition, from the results of XRD analysis, in the untreated sample, the appearance of monocrystalline Muscovite ($H_2KAl_3(SiO_4)_3$) and Kaolinite ($Al_2Si_2O_5(OH)_4$) are detected with the absence of other polycrystalline. However, these monocrystalline were not detected in the diffraction spectrum of soil sample after mixing with bentonite and fly ash, and this proved that these monocrystalline combined with other doped crystals from fly ash and bentonite to form complex polycrystalline Phlogopite. This polycrystalline is in class silicate, group mica with the hardness of 2.5 – 3, and ability of electrical and thermal resistance as well as waterproofing [31]. According to XRD, Phlogopite percentage increased, this increase can reduce the porosity of the mixture of soil with bentonite and fly ash, resulting in a decrease in hydraulic conductivity of soil samples. Thus, this proved that with the effect of compaction on dry density, Phlogopite also affected the decrease of hydraulic conductivity.

4. CONCLUSIONS

From the above results, it is clear that the changes in hydraulic conductivity depended on bentonite and fly ash proportion. There are some important conclusions can be given as below:

- The hydraulic conductivity of the clay soil-bentonite mixture decreased rapidly with the increase in bentonite content. By mixing 10% bentonite, the hydraulic conductivity is acceptable for the bottom liner in the landfill according to Vietnamese standard.
- The hydraulic conductivity of soil mixing with a combination of bentonite and fly ash decreases rapidly with the increase of admixture contents (with a ratio of bentonite-fly ash of 1:4).
- When the percentage of the mixture of bentonite-fly ash is equal or greater than 15%, the hydraulic conductivity of this mixture satisfied the acceptable value of hydraulic conductivity for the bottom liner system of the landfill in Vietnam. Thus, it can be concluded that this material can be used as potential material for the bottom liner system of the landfill in Vietnam.

The study can give a good recommendation for practical application for the bottom liner system of the landfill by using the mixture of soil in combination with fly ash and bentonite. This study used only for one type of clay, it should be expanded for various type of soils and higher mixing proportion should be tested to achieve universal behavior of mixture in terms of the hydraulic conductivity.

5. ACKNOWLEDGMENTS

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