Stabilization of Peat Soil Using Fly Ash, Bottom Ash and Portland Cement: Soil Improvement and Coal Ash Waste Reduction Approach

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Abstract. Peat soil is very compressible, which leads to an excessive settlement. Stabilization of peat soil is the way to improve the engineering properties of peat soil through mixing peat with supplementary cementation materials. Therefore, this study aims to investigate the stabilization of peat soil using fly ash, bottom ash and ordinary Portland cement (OPC) to improve the engineering properties of peat soil. Also to examine the possibility of fly ash and bottom ash waste reduction through using them as a binder of the mixture in soil improvement application. In this study, fly ash and bottom ash were collected from generation wastes at coal-fired electric power and stabilization of peat soil was done by mixing peat soil with fly ash, bottom ash and OPC. Unconfined compressive strength (UCS) and Fourier transform scanning electron microscope (FESEM) was conducted before and after the stabilization of peat soil. Also, some essential physicochemical properties of a mixture have identified before the mixing process. The findings of the compressive strength of peat soil were equal to 5 kPa at its natural state and after stabilization strength of peat soil was equal to 47 kPa. FESEM micrographs have shown ultrastructure of peat stabilization appears as inherent and coherent while the ultrastructure of original peat appears as incoherent and sporadic. The findings have revealed the effectiveness of fly ash and bottom ash to improve the strength of peat and the applicability of the utilization of coal ash waste as binder materials.

1. Introduction
The total world coverage of peat soil is approximately 30 million hectares [1]. Peat soil is very compressible and low shear strength which leads to an excessive settlement [2]. Also, peat soil is a highly organic soil, which partially or fully decomposed plant fragments with virtually no measurable strength [3-4]. Thus, tropical peats are considered extremely soft, wet and unconsolidated deposits with high compressibility and low shear strength.

Construction in the peat soil site is a challenging task for civil engineers due to the high moisture content and an accumulation of organic matter of peat soil [5]. This challenge is the settlement when peat soil has affected by loading leads to ground failure [4-6]. Duraisamy et al. [7] state that peat soil is considered unsuitable for supporting foundations in its natural state. Nonetheless, stabilization of soil is a significant technique to improve the stability of peat soil through mixing soil with supplementary cementations materials that have lower permeability and lower compressibility more than soil [8-9].
On the other hand, the burning of coal ash produced annually millions of tons by coal-burning power plants over the world, which is considered a challenge for the environment [10]. In the United States, the coal ash produced yearly by coal-burning power plants amounts to more than 100 million tons [11]. Coal ash generates by coal-burning electric utilities and they are disposed of together as waste in utility disposal sites with a typical distribution rate of 80 % fly ash and 20 % bottom ash [11]. According to the Council of the European Union, fly ash and bottom ash have been classified as hazardous waste [12].

Although, the utilization of coal ash waste to use as binder materials in soil improvements is the way to minimize the amounts of coal ash waste to be disposed to the environment that causes pollution to the environment [11, 13-14]. Furthermore, coal ash is an economical alternative to the use of traditional materials. Therefore, this study aims to investigate the stabilization of peat soil by mixing peat soil with fly ash, bottom ash, and OPC to improve the engineering properties of peat soil as well as to examine the possibility of coal ash waste reduction through its use as a binder of the admixture.

2. Materials and methods

This section explains the materials, mixing process, tests and experiments of this study as follows:

2.1. Materials

Peat soil was collected from Kampung Medan Sari, Johor, Malaysia. Peat soil was tested on-site sampling according to Von post scale to determine which type of this soil is considered. It was observed as hemic peat soil; thus, hemic peat soil was used in this study. The fibers in the soil, which more than 2 cm were taken out. Then, peat soil was collected in bins and covered with plastic at a chamber with a temperature of 25°C. Whereas fly ash and bottom ash were collected from a waste of coal-fired electric power generation at Tanjung Bin, power plant, Johor, Malaysia, and OPC were available at the laboratory. Fly ash, bottom ash, and OPC also were oven-dried to ensure moisture free then kept in a tight container. After that, peat soil, fly ash, bottom ash and OPC are ready for mixing.

2.2. Mixing

Fly ash, bottom ash and OPC were mixed with peat soil. This mixing was done by using a mixer machine for 10 minutes until all admixtures have thoroughly mixed. The admixture consists of 60 % of peat soil, 18 % of fly ash, 14 % bottom ash and 8 % OPC. Then stabilized peat samples were cured for 14 days and 28 days in a dry place.

2.3. Testing and experiments

Loss on ignition, fiber content, specific gravity and moisture content were carried out for peat soil to identify the physicochemical properties of a peat soil sample that was used in this study. Also, loss on ignition and specific gravity were done for fly ash, bottom ash, and OPC. Besides, UCS and FESEM were carried before and after the stabilization of peat soil. The imaging of particle surface shape and fiber was performed by using FESEM and analysis of chemical compositions of fly ash and bottom ash was done by using X-Ray Fluorescence (XRF).

3. Results and discussion

This section represents the results and discussion in four subsections which they are: the physicochemical properties results, the chemical composition of fly ash and bottom ash, compressive strength test results and FESEM results.

3.1. Physicochemical properties results

Table 1 illustrates some physicochemical properties of materials that were used in this study. Moisture content of peat soil was 678 %. Thus, peat soil is considering as soil with high moisture content compared to other types of soil due to the high contents of the organic contents which increase the space between the particles of peat soil that ease for water absorption a peat soil. The moisture content of west Malaysian peat soil differs between 200 to 700 % and east Malaysia peat varies from 200 to 2207 % [10, 15]. Fiber content of peat in the present study was 32.5 %, and the organic content of peat soil was 89.9 %. While, organic content in OPC, fly ash and bottom ash were equal 0.33 %, 0.48 % and 0.46 %,
respectively. Organic content is an important parameter to identify organic content in a peat soil; it was determined from loss on ignition test as a percentage of oven-dried mass.

Specific gravity is the ratio of the soil density to the water density. Specific gravity of peat was found as 1.63 %. The specific gravity of peat soil has affected by the organic constituents of cellulose and lignin due to that peat soil has lower specific gravity values [10]. Whereas, the specific gravity of OPC, fly ash and bottom ash were equal to 2.41, 2.67 and 1.61 respectively. Fly ash and bottom ash containing a large ratio of hollow particles would have a lower apparent specific gravity because different amounts of hollow particles present in fly ash also cause a variation in apparent specific gravity [11].

### Table 1. Physicochemical properties of the admixture

| Properties           | Peat soil | OPC    | Fly Ash | Bottom Ash |
|----------------------|-----------|--------|---------|------------|
| Loss on ignition (%) | 89.970    | 0.33   | 0.48    | 0.46       |
| Moisture content (%) | 678       | NS     | NS      | NS         |
| Specific gravity     | 1.63      | 2.41   | 2.67    | 1.61       |
| Fiber content (%)    | 32.5      | NS     | NS      | NS         |

*NS means "Not Stated"

3.2. Chemical composition of fly ash and bottom ash

Table 2 shows the chemical composition of fly ash and bottom ash. Fly ash and bottom ash consist of SiO$_2$ with a value of 44.40 % and 48.00 % respectively, thus SiO$_2$ is the highest chemical composition content in fly ash and bottom ash. A study of fly ash and bottom ash from power plant sources by Kim et al [11] found out that fly ash was consisting 51.1 % of SiO$_2$ whereas the fly ash was consisting of 39.6 % of SiO$_2$. The percentage content of the chemical composition of fly ash and bottom ash depends on the type of source that produces fly ash and bottom ash, the chemical content of the coal used by the power plants may have changed [11].

Thus, fly ash and bottom ash contains compounds of chemical which includes silicon and calcium, which makes fly ash and bottom ash have the cementations features. Thus there is a possibility for utilization of coal ash in construction activities. However, Hauashdh et al. [4] pointed out that if fly ash and bottom ash were used excessively in the admixture of soil stabilization in a wetland, leachate from stabilized soil could affect the elements’ concentration of the groundwater and land properties.

### Table 2. Chemical composition of fly ash and bottom ash

| Chemical composition | Fly Ash | Bottom ash |
|----------------------|---------|------------|
| SiO$_2$              | 44.40   | 48.00      |
| Al$_2$O$_3$          | 27.50   | 26.60      |
| CaO                  | 11.50   | 8.73       |
| Fe$_2$O$_3$          | 6.21    | 8.51       |
| TiO                  | 1.79    | 1.95       |
| MgO                  | 2.36    | 1.76       |
| K$_2$O               | 0.99    | 1.05       |
| P$_2$O$_5$           | 1.37    | 0.45       |
| SO$_3$               | 1.01    | 0.25       |
| Na$_2$O              | 1.38    | 0.84       |
| BaO                  | 0.42    | 0.28       |

3.3. Unconfined Compressive strength test results

Figure 1 shows the result of the compressive strength for non-stabilized peat (peat in its natural state) and stabilized peat with curing of 14 days and 28 days. The compressive strength values of the non-stabilized was equal to 5 kPa. Whereas, the compressive strength of stabilized peat soil with curing 14 days and 28 days was equal to 32 kPa and 47 kPa respectively. In the comparison between the compressive strength of non-stabilized peat and stabilized peat with 28 days of curing, it clears after the
stabilization of peat soil, the compressive strength of peat increased to 42 with 28 days of curing. The compressive strength of stabilized peat is directly proportional to curing period. Therefore, the stabilized peat revealed a significant increment in the compressive strength for the stabilized peat as compared to non-stabilized peat.

Figure 1. Unconfined compressive strength results

3.4. FESEM results
Figure 2 shows the arrangement of fiber and void size in the natural peat soil can be observed clearly that natural peat has lots of void space between particles. Figure 3 shows the voids between particles of stabilized peat became smaller as a result of mixing peat with fly ash and bottom ash where fly ash and bottom ash contain compounds of the chemical that have the cementations feature such as silicon and calcium. The internal mineralogical formation in stabilized peat was improved when compared with the natural peat [10]. Also, it can be observed that stabilized peat soil particles are strongly bonded, as shown in Figure 3. The voids between particles of stabilized peat became smaller as a result of mixing peat with fly ash and bottom ash where fly ash and bottom ash contain compounds of the chemical that have the cementations feature such as silicon and calcium. Therefore, FESEM micrographs display the ultrastructure of peat stabilization appears as inherent and coherent while ultrastructure of the original peat appears as incoherent and sporadic.

Figure 2. FESEM micrographs of natural peat (Non-stabilized peat)  
Figure 3. FESEM micrographs of stabilized peat after curing 28 days
4. Conclusion
Construction activities on peat soil is a challenging task since peat soil has high moisture content and organic matter. Nevertheless, stabilization of soil has been proven as an excellent approach to improve soil engineering properties as well as to reduce coal ash waste through its utilization to be used as materials of a binder. Thus, fly ash and bottom ash are highly recommending to be utilized in the soil improvements and roads filling. Based on the obtained results, it appears that fly ash and bottom ash mixtures have cementations features. Compressive strength of stabilized peat soil with curing of 14 days and 28 days has increased from 27 kPa to 42 kPa respectively. The compressive strength of stabilized peat increases with the increment of the curing period. FESEM micrographs have shown ultrastructure of peat stabilization appears as inherent and coherent while the ultrastructure of original peat appears as incoherent and sporadic. Therefore, stabilized peat showed a significant increment in the compressive strength after the stabilization of peat soil also confirmed the possibility of the utilization of coal ash waste as binder materials.

5. References

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