



A Study on Linear Shrinkage Behavior of Peat Soil Stabilized with Eco-Processed Pozzolan (EPP)

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Abstract

Peat soil incorporated materials from fragmented organic constituents that originated in submerged wetlands. Peat soil has a particular index property that accounts for more than 75% of its organic content. Due to its low shear strength, high moisture content, high compressibility, low specific gravity, restricted bearing capacity, irregular shrinkage, and instability, peat soil is interpreted as a challenging soil for the building industry. The purpose of this study is to look at the index properties of Klias, Beaufort peat soil, and eco processed pozzolan (EPP), as well as to investigate the strengthening and stiffening effects of EPP stabilization treatment on peat soil and the association between EPP and linear shrinkage effects of peat. The linear shrinkage used to measure the shrinkage behaviour of peat soil consists of untreated samples, namely peat soil, and treated samples, which are peat soil in addition to EPP with a concentration of 20% and 30%, respectively. A scanning electron microscope (SEM) is employed to produce images of a sample by scanning the surface of an untreated peat sample and treated peat samples with EPP. High moisture content with an average of 580% was reported for the KBpt area. EPP can potentially help to reduce the shrinkage by almost 66.66%. Additionally, the results showed that by adding EPP as filler material to the peat soil, shrinkage behaviour decreases significantly for untreated peat soil and treated peat soil with EPP, with 4.29% reduced to 1.43% significantly. Correspondingly, the crystallization process occurred between peat soil and EPP, which contributed to the reduction of shrinkage and tension crack in peat soil and produced Muscovite, which is appeared and identified as mineral that important in rock-forming mineral.

Keywords: Eco-Processed Pozzolan; Peat Soil; Stabilization; Shrinkage.

1. Introduction

Malaysia, which encompasses the regions of Sabah, Sarawak, and Peninsular of Malaysia where various of the largest tropical peatlands in the Ecosphere are founded. It is surmised that Malaysia has about 2.5 million ha of peat soil, according to Tong et al. [1]. Pursuant to the Wetlands International report [2], the second largest peat soil area in Malaysia is found in Sabah, at around 4.76 percent, or 116.965 ha. Nonetheless, regular peatland in Sabah is increasing as opportunities for development are converted into productive use. As reported by the Department of Agriculture (DOA) Sabah, there is an approximate value of 116,965 ha of peat land in Sabah. These soils are classified under the 'Klias' association under the DOA. Most of the available information is limited but adequate to identify the location and extent of the remaining peat swamp forests: in Sabah, on the Klias Peninsula and in the Kinabatangan area, there are two remaining sites [2].

Malaysia's peatlands also include the peat swamp ecosystem, an unsympathetically endangered type of wetland ecosystem, distinguished by deep peat soil layers and waters that are so acidic that few of the plants and animals found inside are found in the other tropical forests of Asia, is also present in Malaysia's peatlands. Generally, peat is classified

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into two groups, namely amorphous peat and fibrous peat. Amorphous peat is different from fibrous peat in several respects. Peat with fiber content of less than 20 percent is amorphous peat. Essentially, it contains particles of colloidal size that are less than 2 microns and are thus absorbed across the particles' surface by the pore water. On the other hand, fibrous peat is peat soil with fiber content of more than 20 percent. Natural biomass material with loose fiber is part of peat. This is evident in the case that peat has a huge specific surface area and a high adsorption capacity due to its porous porosity. As a result, peat offers the advantages of high permeability, hydrophilicity, and reactivity [3]. The peatlands of Malaysia help our eco-system, including the protection of infrastructure, the modification and reduction of flood risk, and the supply of fish, timber, and other resources to local communities.

Peat is composed of combinations of materials from fragmented organic materials produced in submerged wetlands. Relevant topography is derived from chemically altered and fossilized vegetation. Owing to the low shear strength, high compressibility, and high water content, it is often referred to as difficult soil. Johari et al. pointed out that with a range of 0.9 to 1.5 in compressibility, high humidity content, which can be up to 1000 percent, high fiber content, and high organic content, which can be up to more than 75%, which gives a serious problem of settlement [4]. The soil's permeability and bearing capacity are limited, making it unsuitable for large loads. Excessive settlement will occur in the soil, and the settlement will last for a long time [5]. Contrastively, the peat is mainly acidic, and the pH value was always between 4 to 7. Additionally, there are very low pH values that range from 3.0 to 5.5 for West Malaysian peats. Conjointly, pH values may also be below 3.0 in certain cases, particularly where sulphide materials are discovered inside the profile.

For this research, the area of study includes the usage of eco-pozzolanic material for stabilizing purposes and is measured by using the soil shrinkage technique. Pozzolanic materials have been practically used as a substitute for cement. Chindaprasirt et al. [6] have established that the use of pozzolan would reduce the use of cement, and Kusaimi et al. [7] exemplified by their study, support the idea that the use of EPP as a cement substitute in the manufacture of paving blocks can help to lessen the manufacturing industry's reliance on cement. Eco-processed pozzolan (EPP) is derived from the process of degumming and bleaching crude palm oil waste products from refinery plants and is used in blended cement processing [8]. The waste product produced from the processing of edible oil is called spent bleaching earth (SBE). SBE from a refining plant is extensively discarded in Malaysia's landfills, posing a threat to the environment [9]. EPP is predominantly made up of silica, also known as silicon dioxide (SiO_2). The combined value of silica (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3) was higher than 50 percent, thus it is labelled as Class C pozzolan according to ASTM C618 standard. By replacing cement with EPP, it is feasible to minimize wastage and produce cost-effective concrete. Based on the laboratory tests carried out, it is evident that with less than 30 percent of EPP replacement, it showed that it had improved performance characteristics compared to foamed concrete control [10]. Even though EPP material has rarely been used, most implementations have been successful and have proven to be an inexpensive alternative to conventional methods of ground improvement in terms of material being used. It has been used in many types of soil enhancement, the elimination of pollutants, dewatering, and for stabilization. There are various previous studies using this technique for the strengthening of soft soils. The efficacy of EPP has been exemplified in a recent study by Suhaimi & Mohamad [11], which verified that peat soil combined with EPP and cement as a binder will remarkably improve settling demeanor, resulting in minimal settling over time. In support to Suhaimi & Mohamad [11], Kho [12] study has shown that with the help of several superplasticizers, the insertion of recycled pozzolan, Eco Process Pozzolan (EPP), as a partial cement replacement in concrete has been demonstrated to be practical and effective, producing high consistency and strength outcomes.

Soil stabilization is one of the most vital elements to consider while building on soft soil. It is widely accepted that the earth stability can influence the structure stability above it, and there are numerous types of soil to deal with conditional on the area its position, its climate and various other aspects. Andrejko et al. [13] identifies that when peat is subjected to even a small load, it experiences volatility and long-term consolidation settlements. One of the most prevalent methods of soil stabilization is by using admixture. There are diversity of admixtures available. Chemical admixtures ordinarily suplicate the treatment of soil with a chemical substance of some kind, resulting in a chemical reaction if applied on the soil. The chemical reaction either modifies or reinforces the physical and engineering characteristic of a soil, for instance, increase soil strength and stability. The soil mixing method is one of the most common soil stabilization methods in today's world. It is a procedure typically used to reduce ground permeability and regulate the flow of ground water, likewise to reinforce and stiffen the soil [14]. By way of illustration, Shah et al. [15] has conducted a study on characterization and impact of peat fires on stabilization of tropical lowland peats had halted that the most crucial geotechnical features of peat that govern the stabilization process are natural water content, humification grade, ash content and pH value.

The focus of this study for peat stabilization was to enhance the strength of peat and its compressibility. Henceforth, this is the first study which focus on stabilization of peat soil that uses eco-processed pozzolan as the main material. Recent study reported by Kusaimi et al. [7] also indicates that replacement of cement by EPP with the right percentages will enhance the compressive strength up to 32.4 MPa and lower water absorption of 4.78%. The changes in soil volume are usually concurrent with shrinkage or swelling. In consonant with Oleszczuk et al. [16], natural compression causes

volume changes in peat, and volume change was proportional to the total volume of moisture lost in soil. When air reaches the soil, residual shrinkage appears to alter the volume in a much smaller way than usual shrinkage. Knowing how much soil shrinks brings myriad of benefits. One significant benefit is that this predictability removes the element of wonder of the performance of the ground system. However, in Sabah there are limited data available on this matter and this is one of the major highlights that can be taken as an advantage of providing this study.

The methodical purposes of this research are to gain an understanding of peat soil behavior under particular conditions, to investigate the stabilization treatment effects of EPP on peat soil, and to generate the correlation between EPP to the linear shrinkage effects of peat. Aforementioned, the shrinkage or swelling of soil caused a change in volume. As a result, when assessing water storage changes, water obtained or lost due to peat volume changes must be thought about. Peat had a high soil moisture content, but when dried, it lost the moisture, and oxidation of peat causes permanent changes to the material. Peat is also unable to rehydrate to its original state as stated by Kazemian et al. [17]. Fibrous peat has a higher shrinkage potential than other types of peat, allowing it to shrink by up to 50% after air drying [18]. Thereupon, that dried peat can only re-absorb 33 percent to 55 percent of water, it will not swell when re-saturated [19]. Plant structure shrinks more across fiber widths than length, and plant fibers are naturally horizontally oriented in situ, causing shrinkage in vertical and horizontal directions to differ [20]. As thin-walled tissues shrink and the cellular structure collapses, peat's water holding capacity and particle porosity decrease [21].

The amount of shrinkage was found to be allied to different physical properties of peat. The structural water loss phase and shrinkage water loss phase were listed as two phases that occurred during the drying process. There is no shrinkage during the structural water loss process, but there is a linear relationship between water and volume loss during the shrinkage water loss phase. According to Oleszczuk et al. [16], the load applied has a significant impact on the relationship between shrinkage geometry factor and moisture ratio. In contrast to unloaded soil conditions, the results indicate higher values of subsidence and lower values of crack length. The reversible and irreversible shrinkage coefficient values were determined using the "saran resin" process. Hamamoto et al. [22], Mohamad and Zainorabidin [23], and Wu et al. [24] investigates a breakthrough in peat shrinkage that is linked to peat soil heat transport under varying saturation conditions and the impact of volume shrinkage on peat soil thermal properties. Bin Zainorabidin et al. [25] used the bar linear shrinkage approach to examine soil volume shifts and shrinkage at four dimensional stages. The linear shrinkage values for peat soil in Malaysia are shown in Table 1.

Table 1. Shrinkage rate of peat soil in Malaysia

Location	Shrinkage (%)
Rengit, Johor	35.24
Matang, Sarawak	5.35
Parit Nipah, Johor	34.77
Pontian, Johor	33.09

2. Material and Testing Program

The aspiration of this study is to evaluate the linear shrinkage behavior of EPP-stabilized peat soil by examining the physical properties of peat soil, being pH value and moisture content of peat soil, image analysis and chemical analysis seized by FESEM test. All the experiments have been performed at Geotechnics' laboratory, Universiti Malaysia Sabah. This academic research was conducted with a view for refining the design methodology and typically emphasizing parameters. This test was carried out in accordance with British Standards. The disturbed sample used in this analysis to prepare the tests carried out in the Geotechnics Laboratory, including the moisture content, and pH value of soil sample. For shrinkage test of peat soil, BS 1377-2, tests 6.3 and 6.4 (BSI 1990) are referred. All the samples were obtained at a depth of 0.5 m from the topsoil level.

The aim of the laboratory test to be carried out on a peat soil sample is by using EPP on peat soil to inspect the strengthening and stiffening effects of stabilization treatment, to evaluate the index properties of Klias, Beaufort peat soil and EPP, and to develop the reciprocity between EPP and Peat soil shrinkage effects. The research was performed on disturbed samples from Klias, Beaufort. After the collection of disturbed samples, as described in the Von Post classification system, visual observation of the peat soil is carried out.

Index properties tests were done to specify the peat soil moisture content and its pH value. Peat soil is analyzed by using soil shrinkage method with a concentration of 0%, 20% and 30% of EPP. Likewise, shrinkage testing was carried out to produce a stronger correlation between peat soil and EPP as stabilizer. The samples are prepared for one shrinkage observation and were made by following the standard laboratory method (Bar Linear Shrinkage). For shrinkage test, three samples were prepared, the first sample was maintained as 100% of peat soil whereas the second and third samples were stabilized by mixing 20% and 30% of EPP respectively. Then, the soil sample were mixed with approximately 100 ml of distilled water beneficial to achieve 50% of moisture content. The shrinkage bar was filled with peat sample and

placed in the oven for 24 hours at 105 degrees Celsius to complete the drying process. Scanning electron microscopes (SEM) was used in this analysis to capture image samples. One of the key reasons of SEM being included in this study is that this will allow us to visualize the development between the soil and stabilizing material and how it acknowledges with one another. SEM were done for all of the samples after the shrinkage test.

3. Results and Discussion

The drive was to figure out what the index was made of and deem at the shrinkage behavior of peat soils in Beaufort, Sabah. The KBpt pH value obtained from the test is 3.21, indicating that the sample is acidic. Due to its location and activities of decomposition matter, this would have influenced the acidic portion of peat soil itself. When compared to the findings of other researchers, Zainorabidin & Mohamad [26] 4.6 and Shuvaev et al. [27], the pH value of each peat is 4.6 and 3.6, indicating that it is acidic.

3.1. Index Properties of Klias, Beaufort Peat Soil (KBpt)

The moisture content is one of the most essential parameters in this investigation. The ratio of water weight to soil solids weight determines naturally occurring moisture content. The ratio was usually expressed as a percentage. According to Hashim & Islam [28], Sabah has the highest water content in peat, with a water content of about 1000% percent. Physically, it can be seen in the position of the peat soil itself in the peat swamp region, as well as rivers running through the peat valley to the mainstream of the swamp forest. Referring to the Table 2, the average value of moisture content was at 580.5% but Zainorabidin & Mohamad [26] observed that moisture content is from 491.16 to 985.3 percent. From this previous result, it indicated that the moisture content for KBpt is agreed it is between the ranges. Zainorabidin & Mohamad [26] found that differences in moisture content existed and were influenced by a variety of factors, including variations in groundwater level at the location and undrained forest conditions.

These differences in results are attributable to climate change because of changes in temperature, precipitation, and rainfall impacting soil saturation intensity, where the water table forms in a roughly horizontal plane and may rise to a level larger or less than the actual water table [29]. Furthermore, particle size has an impact on moisture content. In comparison to the bigger particle size, the smaller particle size has more void, which indicates that more water may be maintained and held.

Table 2. The index properties of Klias, Beaufort, Sabah peat soil

Description	Rate
Moisture content, %	0.003
pH of peat	3.1
Peat physical colour	Dark brown
Degree of humification	H5

3.2. Linear Shrinkage

In this research we are using the mix design in Table 3 with different concentration of EPP for each sample. The shrinkage result from bar linear shrinkage method for the original sample and stabilized sample are as shown in Table 3. It shows the results for the linear shrinkage of peat soil for different percentage of mixtures. For the original soil sample with 0% EPP, the shrinkage value is at the highest as it is in its natural condition without any stabilize material. The second and the third sample with 20% and 30% EPP respectively content shows a gradual decrease for the linear shrinkage. The maximum shrinkage value for original sample is more than 4%. With the combination of the EPP, the percentage of shrinkage tends to decrease as for the 30% of EPP, the shrinkage reduces to 1.43%. By referring to Figure 1 we can say that by increasing the concentration of EPP the shrinkage of peat soil can be reduced as the R value of the graph is equal to 1 indicating an acceptable and a high accuracy result. The decrease of shrinkage may be caused by the high content of silicon dioxide (SiO₂) as mentioned [8]. This is because silicon dioxide provides water repellence thus lowers the absorption of water and stabilizes the peat soil. According to a previous researcher's study in Table 1, Sarawak's peat has 5.35 percent, according to Huat et al. [30]. Adding to that, Kolay et al. [31] measured a 35.24 percent for Rengit, Johor.

Table 3. Linear shrinkage of Klias, Beaufort, Sabah peat soil

Specimen	Design	Rate (%)
Peat soil	Sample 1	4.29
Peat mixed with EPP 20%	Sample 2	2.14
Peat mixed with EPP 30%	Sample 3	1.43

Whereas Mohidin et al. [32] found that the linear shrinkage was at 34.77 and 33.09 for Parit Nipah and Pontian, Johor respectively. Because the recorded value in this study falls within previously published range for Peat soil in Borneo locations, it is deemed acceptable. Figure 3a shows the shrinkage measurement for untreated peat soil and without EPP. The shrinkage of peat soil observed represented the reduction in void ratio with decrease in water content of peat soil. It shows large differences between treated peat soils with EPP as shown in Figure 3b. The crack tension pattern in specimen treated with EPP has less shrink and void opening. As can be seen in Figure 4a, the SEM image shows darker area for high intensity of pores in peat soil. Uniquely, Figure 4b and Figure 4c shows the treated peat mixed with EPP. Identically, a process called crystallization of mineral in peat soil occurred in stabilized peat with EPP. EPP as a filler, reduced the void in peat and blended well with peat soil.

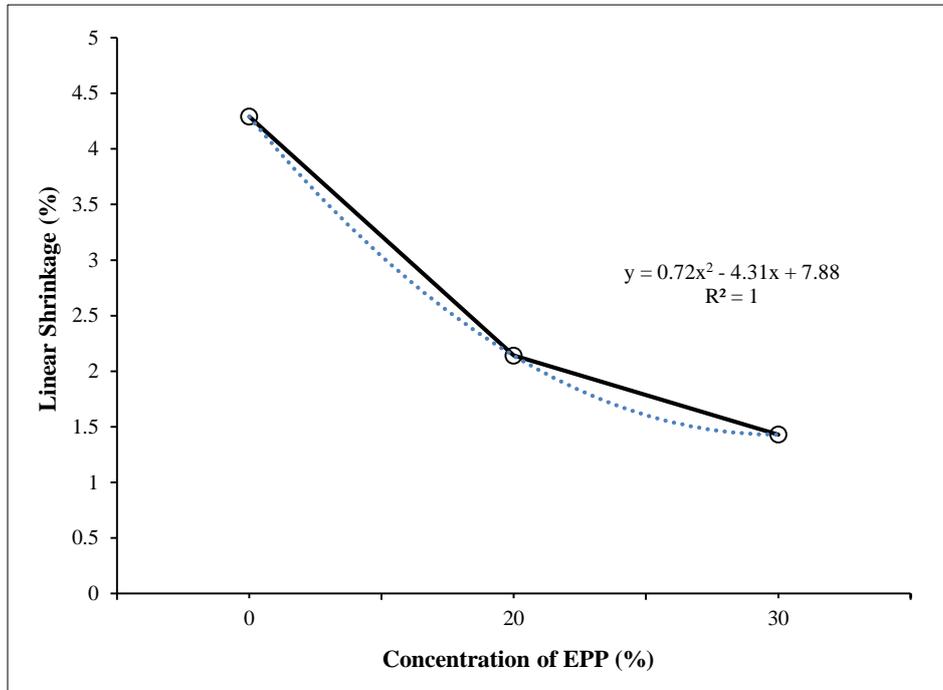


Figure 1. Linear shrinkage improvement with EPP

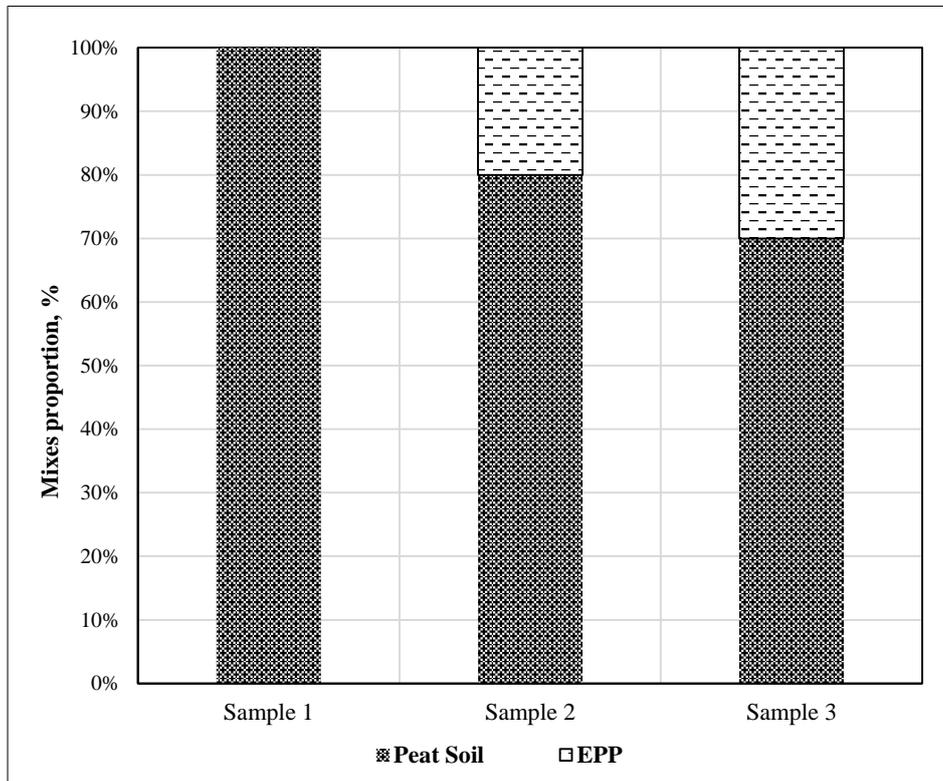


Figure 2. Mixed proportion of peat soil and EPP

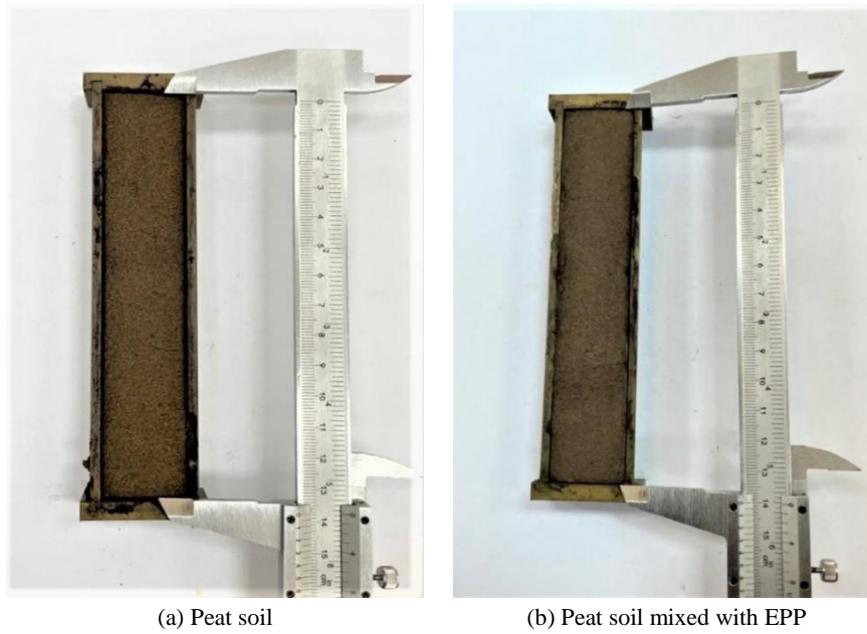


Figure 3. Linear shrinkage measurement for peat soil and mixed with EPP

3.3. Scanning Electron Microscopy (SEM) Analysis

Scanning electron microscopes (SEM) is a general purpose ultra-high-resolution FE-SEM that was used in this analysis to capture image samples based on the special GEMINI technology. In combination with analytical capabilities and excellent imaging properties, SEM field emissions make it ideal for a wide range of applications. The identification of materials based on their diffraction pattern is one of the most common applications of SEM analysis. SEM provides information on how the actual structure differs from the ideal one due to internal tensions and flaws, in addition to phase identification.

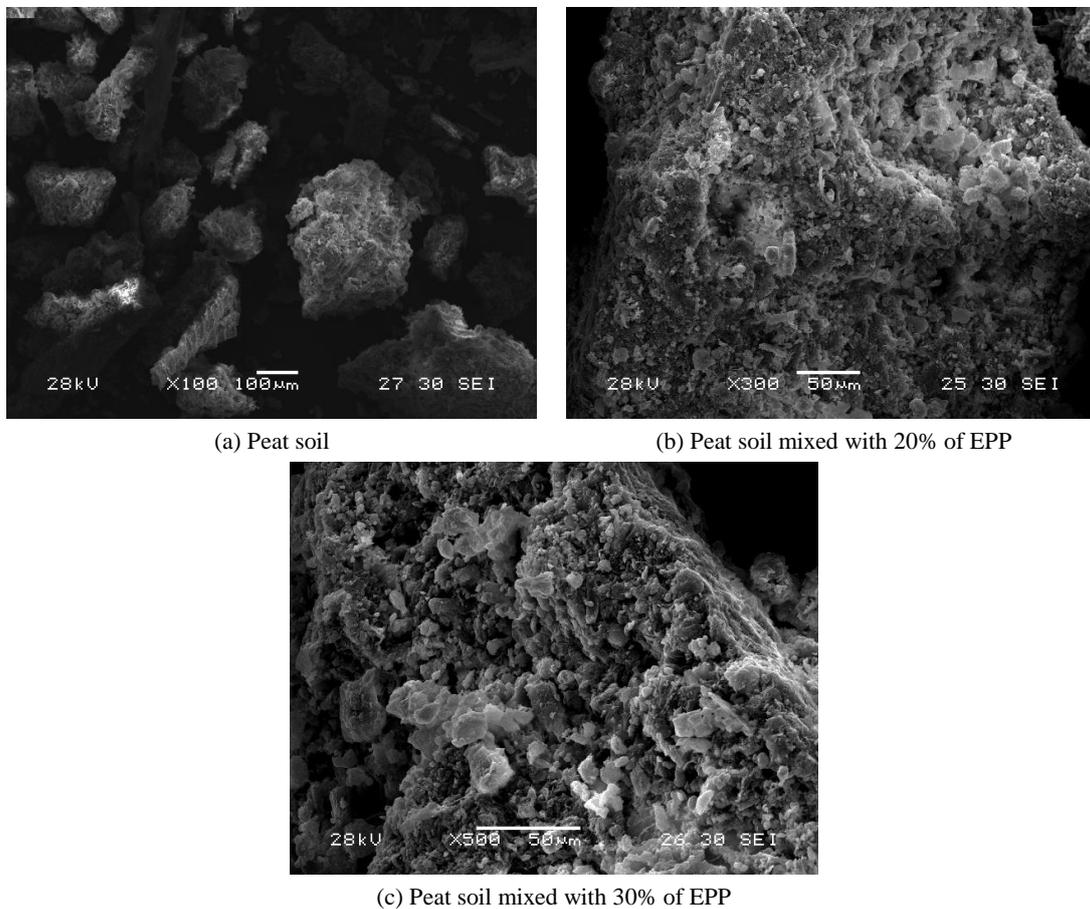


Figure 4. SEM images for stabilized peat soil with EPP

In this study, we used a mixed design with varied EPP concentrations for each sample, with 100 percent peat, 20% EPP, and 30% EPP concentrations. The SEM analysis results for the original sample and stabilized sample are depicted in the figures below. Micrographs taken using a scanning electron microscope at 28kV. Figure 4 indicates that a soil containing 100 percent peat has a considerable amount of void. This is due to the natural condition of peat soil having a high organic content. Figures 4b and 4c, on the other hand, demonstrate a large reduction in void. The decrease in voids was caused by the presence of EPP in the soil mixture. We can deduce that the presence of EPP, with its lower particle size, has filled the previously existent void, hence assisting in the stabilization of the peat soil.

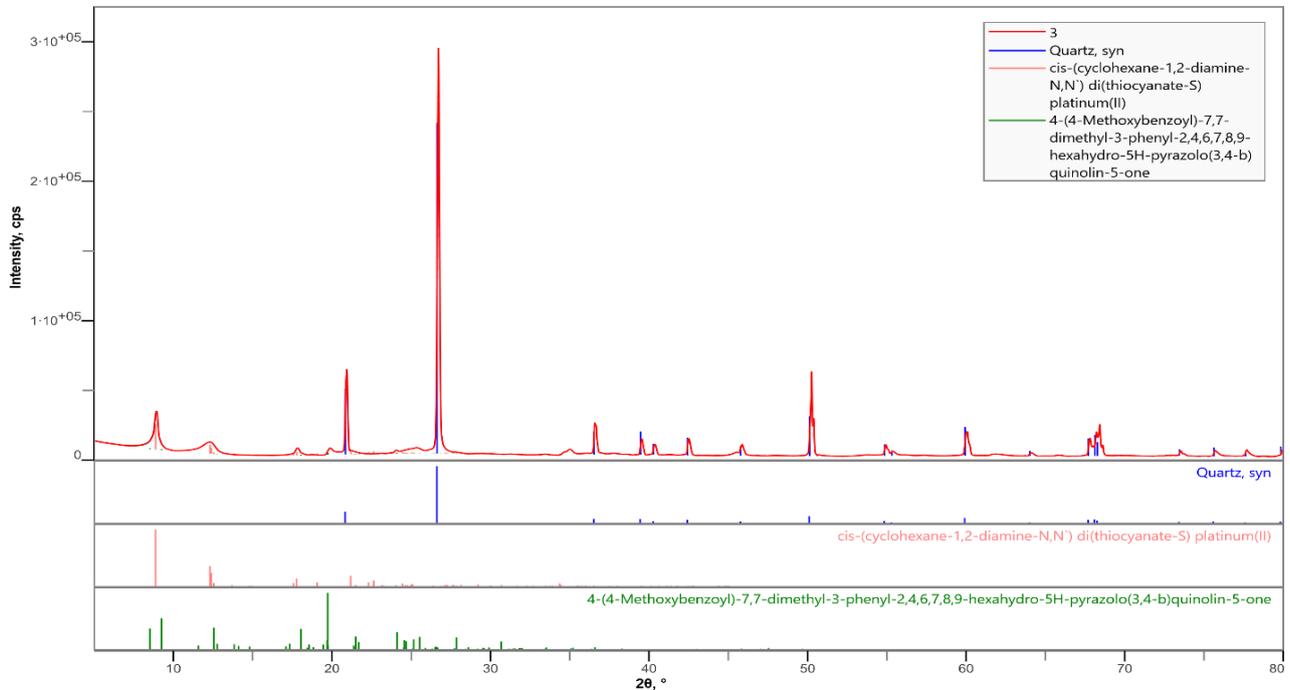


Figure 5. XRD patterns peat soil

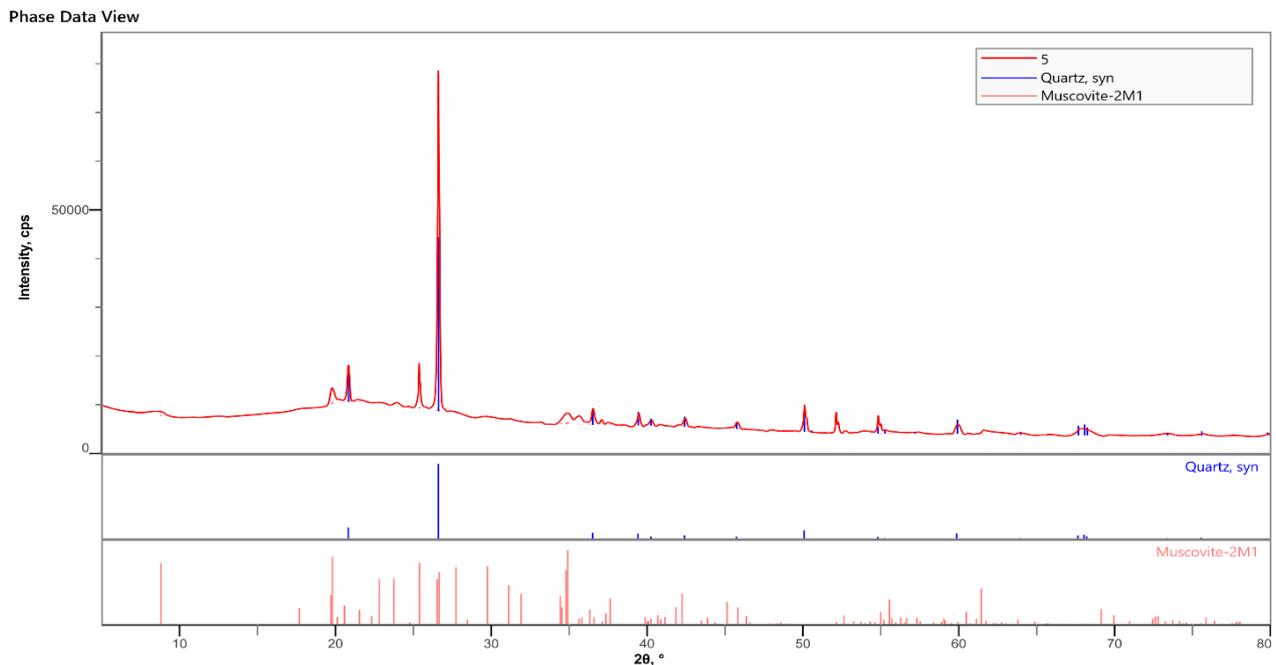


Figure 6. XRD patterns stabilized peat soil with EPP

3.4. Material Crystallization

Shrinkage is represented as reduction in void ratio with decrease in water content of peat soil specimens. The crystallization process occurred between peat soil and EPP seen clearly that contributed to the reduction of shrinkage and tension crack in peat soil. This phenomenon inspected by using X-ray powder diffraction (XRD) by extracting the elements that developed from the mixing of both materials and presented in Figures 5 and 6. The XRD patterns of peat soil alone and stabilized peat soil with EPP described with the parent elements.

In particular, parent material of peat soil alone consists of quartz, syn, cis and platinum (III). The main components of peat binded by 4-Methoxybenzoyl as the synthesis of the organic elements with dimethyl elements as shown in Figure 4. This parent elements slightly seen as main contributor to the crystallization process that developed new elements when mixed with EPP. Under those circumstances, an element was developed from the crystallization process between peat and EPP where Muscovite appeared in the formulation. Muscovite is a hydrated phyllosilicate mineral of aluminium and potassium with formula $KAl_2(F, OH)_2$ and identified as mineral of the mica family. It is an important rock-forming mineral which is appeared less resistant to micro-organism weathering than biotite and the latter less than orthoclase [33-35]. This finding clearly shows that the crystallization process between peat and EPP contributes to the development of compact structure and filled micro spaces or void in peat soil. This phenomenon helps to reduce the shrinkage by almost 66.66%. In essence, this development seen as the present of silicon dioxide content that recognized in the form of quartz provides a water mitigate reaction that lowers water absorption and stabilizes peat soils.

4. Conclusions

The linear shrinkage of peat soil and its reaction to a concentration of 20% and 30% EPP as a soil stabilizing material are investigated in this study using a linear shrinkage test. Based on the research, the following conclusions have been drawn: Moisture content and pH were included in the soil index parameters, and both were found to be appropriate. The average moisture content of the soil sample was 580.5 percent, with pH values of 3.1, 13.02, and 9.00, respectively, for peat soil, eco processed pozzolan, and peat soil with 20% EPP. In terms of KBpt shrinkage and behavior in response to EPP, the results of the tests reveal that applying EPP substantially reduces soil shrinkage, as previously stated. According to the author's observations, EPP was able to reduce soil shrinkage by filling the air void in the soil sample.

After the investigation had been finished, certain improvements were revealed. To improve our understanding of soil behavior and provide a more refined research outcome, recommendations are required. Additional tests, such as fiber content and organic content, are recommended to develop a better correlation between the peat soil index and its responsiveness to EPP. This aids in determining the percentage of organic matter present in peat by mass, as well as classifying the type of peat utilized and determining the proportion of fibers in a peat sample. Another enhancement that can be made is to include more soil samples with EPP concentrations of 50 and 70 percent. This will help researchers better understand the soil sample and EPP's behavior on peat soil. Additional testing, such as soil resistivity on peat soil and EPP, is also advised because it will aid in the understanding of the EPP's role in stabilizing acidic peat. In peat soils, tertiary compression occurs, hence increasing the test period will aid in achieving better tertiary compression.

- Based on the tests that have been done, it shows that by adding EPP as filler material to the peat soil, shrinkage behavior decreases significantly.
- Based on the observation, it was shown that EPP managed to decrease the soil shrinkage as a result that EPP has filled the air void of the soil sample.
- Peat positively reacts to the EPP treatment. In the final analysis, the microstructure of peat reorganized where EPP filled the void spaces in peat EPP. These reactions are believed to reduce the shrinkage behavior of peat soil.
- Muscovite appeared and was identified as a mineral that is important in rock-forming minerals. This development is a new element in peat stabilized with EPP. This mineral is produced from the crystallization process during the peat soil treatment process with EPP. This is a significant finding in this study.

5. Declarations

5.1. Author Contributions

Conceptualization, M.S.S. and H.M.M.; methodology, M.S.S. and H.M.M.; software, M.S.S. and H.M.M.; validation, M.S.S. and H.M.M.; formal analysis, M.S.S. and H.M.M.; resources, M.S.S. and H.M.M.; data curation, M.S.S. and H.M.M.; writing—original draft preparation, M.S.S. and H.M.M.; writing—review and editing, A.A.S.; visualization, M.S.S. and H.M.M.; supervision, H.M.M.; project administration, M.S.S. and H.M.M.; funding acquisition, M.S.S. and H.M.M. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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5.4. Conflicts of Interest

The authors declare no conflict of interest.

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