

Peat soils stabilization using Effective Microorganisms (EM)

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Abstract. Peat soil is known as geotechnical problematic soil since it is the softest soil having highly organic and moisture content which led to high compressibility, low shear strength and long-term settlement. The aim of this study was to obtain the stabilized peat soils using the Effective Microorganisms (EM). The volume of EM added and mixed with peat soils varied with 2%, 4%, 6%, 8% and 10% and then were cured for 7, 14 and 21 days. The experiment was done for uncontrolled and controlled moisture content. Prior conducting the main experiments, the physical properties such as moisture content, liquid limit, specific gravity, and plastic limit etc. were measure for raw peat samples. The Unconfined Compressive Strength (UCS) test was performed followed by regression analysis to check the effect of EM on the soil strength. Obtained results have shown that the mix design for controlled moisture contents showed the promising improvement in their compressive strength. The peat soil samples with 10% of EM shows the highest increment in UCS value and the percentage of increments are in the range of 44% to 65% after curing for 21 days. The regression analysis of the EM with the soil compressive strength showed that in controlled moisture conditions, EM significantly improved the soil stability as the value of R^2 ranged between 0.97 – 0.78. The results have indicated that the addition of EM in peat soils provides significant improving in the strength of the soil as well as the other engineering properties.

1. Introduction

Peat soils composed of fibrous organic matters which are the partly decomposed plants such as the roots, leaves, and stems. These types of soil can be easily found in all part of the world except the arctic and desert regions. It is estimated that about 1 billion acres of peatland existed in the world which contribute to about 4.5% of total land areas. Due to its high compressibility and low shear strength, this soil is considered as geotechnical problematic soil making it unsuitable to be the base soil for any building construction. The main reason for being high compressibility and low shear strength is due to the present of 80 to 90 % of water content in fresh peat soil. The organic residues present in peat are derived mainly from vegetative matter, and to a lesser extent from microbial sources. Peat soils contain an enormous number of organic compounds that makes its composition complex. In addition, the composition of the peat can vary considerably from bog to bog, and even within the same bog, the chemical composition can change with depth [1].

Several researchers have conducted laboratory experiments to study the effect of binders on the shear strength of peat. A group of scientists conducted an experiment that aimed to increase the compressibility and stability of the peat soil by adding the cement as a binder. It was observed during laboratory testing that the Unconfined Compression Strength (UCS) of stabilized peat increased remarkably already after 7 days of curing in the water container. The results showed stabilization in peat soils with ordinary Portland cement 20 times more than the natural peat soils. They reported an



improvement in the engineering properties (UCS) of cement stabilized peat. Generally, the more cement that is added to the peat, the greater the strength [2]. Most of the researcher study on the effect of binders and fillers on the strength of stabilized peat using pozzolanic effects [3], [4], [5, 6].

However, the use of pozzolan material such as cement can cause the disturbance to the soil ecology and caused global warming issue due to the release of CO₂ and heat. To resolve this issue, a research found that the use of Effective Microorganisms (EM) for concrete can be used in the construction industry to increase the sustainability [7]. Stabilization using microbes is a relatively new ground improvement method for the soft soils to increase the peat strength, improve the deformation properties and save costs. Use of Effective Micro-organisms (EM) is still at an early stage in the construction field, hence detailed research needed to determine the actual effects on concrete. Therefore, the main objective of this research was to investigate the effectiveness of the EM for the stabilization of peat soils. More specifically it was desired i) to Optimize the Effective Microorganism (EM) concentration and curing time for the peat soil stabilization for the samples of uncontrolled moisture content and the samples of controlled moisture contents and to test their compressive strength after curing period.

2. Study Area

The research was conducted on the soil samples collected from the oil palm plantation area in Seri Iskandar, Perak. Perak is the second largest state in the peninsular Malaysia with the geographical area of 21,000 km². The lithological composition of Perak consists of igneous rocks (44 %), quaternary deposits (24 %) and sedimentary deposits (32 %) [8, 9]. The climate of Perak is tropical where the daily temperature fluctuates from 21 °C to 34 °C with an annual rainfall of 2,400 mm [10].

3. Materials and Methods

A total 87 undisturbed soil samples were collected from the oil palm plantation area at Seri Iskandar, Perak. Half of the samples then dried in the oven at 105 °C for 24 hours and rest of the soil samples were contained in a container with care to preserve the moisture content along the experimentation. The effective microorganisms (EM-1®) in form of liquid (molasses as main medium) were obtained locally from MG Ecotech at Selangor. The EM consists of a wide variety of effective, beneficial and non-pathogenic microorganism such as yeast, photosynthetic bacteria, and lactic acid bacteria. It was kept in the closed plastic container and the container's cap was opened time to time to release the gasses produced inside the container.

3.1 Physical Properties of Peat soil

In this study, the moisture content of peat soil samples was determined using the oven-dried method and the specific gravity (ρ_s) of the highly organic or peat soil is determined based on procedure stated by British Standard BS 1377: Part 2 [11] by using small pycnometer. The liquid limit (*LL*) of the soil samples was investigated by cone penetrometer method. The test was repeated several times to have four sets of values of penetration in the range of 14 to 28 mm. The exact moisture content of each trial was determined. A graph representing water content on Y – axis and the cone penetration on X – axis was prepared and a best fitting straight line was then drawn. The plastic limit and plasticity of the peat soil samples were tested according to the British Standards BS 1337: Part 2: 4.3/4.4. From the data of liquid limit and plastic limit, the plasticity index (PI) of the sample was obtained using by subtraction of liquid limit with plastic limit.

3.2 Uncontrolled and Controlled Moisture Content Mix Designs

The experiments were divided into two main categories: uncontrolled moisture content mix designs and control moisture content mixture designs. As for the uncontrolled moisture content, the study used the peat soil samples with its original moisture content and the EM was added according to 2%, 4%, 6%, 8% and 10% (v/w).

As for the controlled moisture content, the peat soil samples were dried at the first place at 105°C in the oven for 24 hours. This mix design was maintained on the specific moisture content which was 50%

including the percentage of EM added. The concentration of the EM was used in the experiments were 2%, 4%, 6%, 8% and 10% (v/w). The moisture content in each of the sample was the same with one another and gave more promising data.

Air curing is a technique in which the mixture of peat and stabilizer is exposed to the air for curing, without any external water intruding into the stabilized samples. The air curing technique was adopted as the natural water content of the peat was very high. The samples were prepared in a mold, taken out after compaction and then wrapped in a thin plastic sheet and kept in the air at a room temperature of 30 ± 2 °C during the curing period. The samples were cured for 7, 14 and 21 days. The samples from both designs were then tested using the UCS.

4. Results and Discussion

4.1 Physical Properties of Peat soil

The average value of the moisture content of the soil samples was 141.5%. The moisture content in peat soil depends on the origin of the soil, the chemical composition of the soil itself and the degree of decomposition. Generally, the water content of the peat soil may range from 200 to 2000 % which is very rare for clay and silt deposits which seldom exceed 200 % [12]. In West Malaysia, the water content of the peat soil was reported ranges from 200 to 700 % [13]. The water content of the peat soil at Seri Iskandar does not exceed 200 % which means that the decomposition's degree of the soil is quite low compared to the peat soil at the other location that is why it cannot store a high percentage of water [14].

The average value of the specific gravity obtained for the soil samples was 1.45 Mg/m^3 and the average moisture content obtained was 47.8%. The value also represents the plastic limit of the peat soil and it was further used to calculate the plasticity index of peat. The results for the liquid limit using the peat soil samples are shown in Table 1.

Table 1. Liquid limit data

Parameters	Samples		
	1	2	3
Average penetration(mm)	7.25	16.8	21.95
Moisture content (%)	66.67	73.47	89.87

From the Table 1 above, the moisture content of the peat to obtain 7.25mm penetration is 66.67%. As the moisture content is at 73.47%, the penetration of the peat soil is 16.8mm while moisture content at 89.87%, the penetration goes to 21.95mm. A graph was plotted using moisture content data against the penetration data.

From figure 1, it can be observed that the penetration of the soil at 20 mm, following the standard procedure, give a moisture content of approximately 82 % which also acts as the liquid limit for the peat soil sample. This data was further used to calculate the Plasticity Index (PI) of the peat soil.

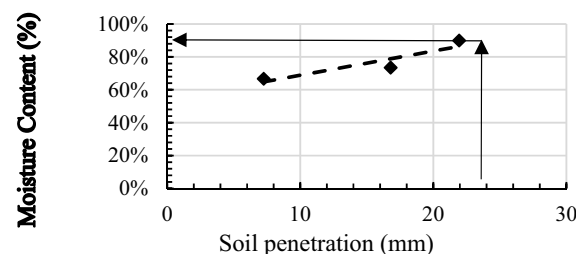


Figure 1. Moisture content against soil penetration for the determination of liquid limit

The value for the plasticity index obtained from the values of plastic limit (*PL*) and liquid limit (*LL*). The calculated value for plasticity index (*PI*) obtained for this experiment was 22.2%. The increase in plasticity index increases the strength of the samples since the plasticity index of the peat soil was medium therefore the strength was also in the medium ranges.

4.2 Testing of Uncontrolled Moisture Content Mix Design Samples

The UCS test was applied to the samples with uncontrolled moisture content after being cured for 7, 14, and 21 days at room temperature. The results of UCS for peat samples cured for 7, 14, and 21 days in kiloPascal (kPa) have been presented in Table 2.

Table 2 provides the results of UCS for the peat soil samples mixed with different EM concentrations on different curing time scale. In general, it is evident that the compressive strength of the soil samples under different curing period remains same. Slight increase in the UCS values for peat soil with 2 % of EM from 11.349 kPa to 12.043 kPa after 7 days and 21 days curing were observed. The results were more obvious in the soil samples with the EM concentration of 4 % and 6 % as the compressive strength showed increment by 100 % and 80 % respectively after the curing of 21 days. The results of UCS for same compressive strength showed the improvement of compressive strength with the increase in curing time. As if the samples remained for a more curing period, the EM will enhance the soil stability.

Table 2. UCS of soil for 7 days, 14 days and 21 days for mix design of uncontrolled moisture content

EM Concentrations	Unconfined Compressive Strength (kPa)		
	7 – Days	14 – Days	21 – Days
Raw	33.986	30.997	34.819
2%	11.349	10.979	12.043
4%	3.197	5.799	6.410
6%	3.090	3.957	5.555
8%	3.904	3.726	4.396
10%	2.572	2.603	2.857

Figure 2 presents the breakdown of individual behavior of each EM concentration on different curing periods. In the figure, active data points are represented by the blue dots whereas, the modeled fit points are shown by the black line on 95 % confidence interval. Figure 2-a presents the regression analysis of compressive strength with EM concentration in soil samples for 7 days curing time. As for uncontrolled moisture content mix design, the moisture contents were not controlled, therefore it is obvious from the figure that with the increase in MC, the compressive strength of the soil decrease. The lowest values of the UCS were observed for the sample with the EM concentration of 10 %. Figure 2-b illustrates the results of regression analysis of UCS test for soil samples with different EM concentrations after cured for 14 days. The same trend like UCS for 7 days was observed. The compressive strength of raw peat soil was much higher than the compressive strength of soil sample with 10 % EM. Figure 2-c depicts the regression analysis of UCS with EM concentrations on the soil samples cured for 21 days. Again, the trends observed were similar to previous experiments. The UCS showed the decrease in its values with the increase in EM concentration and moisture contents. The drop in the value of the compressive strength from the raw and the other mix design is due to uncontrolled moisture content. Each of the mix design has different moisture content compared to others. The moisture content can affect the compressive strength of the samples. Research into the subject matter has explained that increase in moisture content can significantly decrease the compressive strength of the soil samples [15]. As the mix design with 10 %, EM concentration has the most amount of MC resulted in reduced compressive strength. Even though, the compressive strength of soil sample with

EM concentration of 10 % was 2.57 kPa after 7 days curing showed increment after 21 days curing and the compressive strength was recorded as 2.85 kPa. It is evident that microbial reactions took place during the curing period if the moisture content to be ignored. Generally, the mix design of uncontrolled moisture content shows a reduction in UCS values if it were compared to the raw sample.

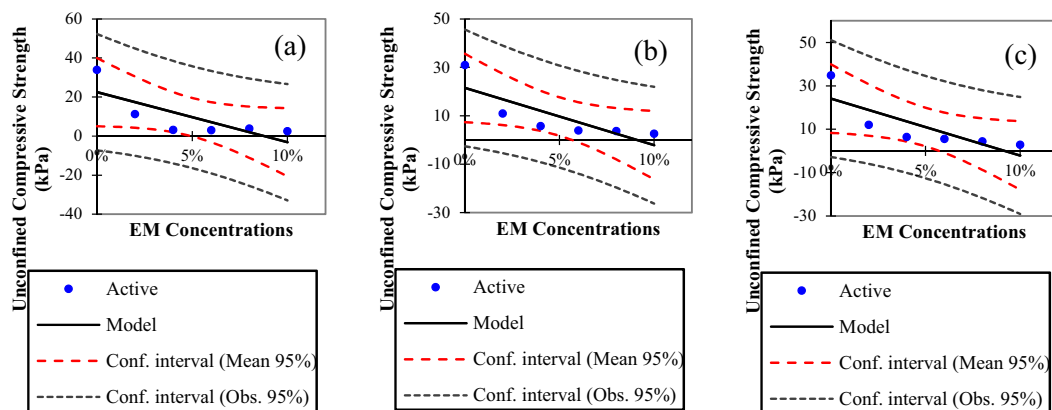


Figure 2. Regression analysis of the compressive strength of peat soil samples with different EM concentration on (a) 7, (b) 14, and (c) 21 days curing period for mix design of uncontrolled moisture contents.

4.3 Testing of Controlled Moisture Content Mix Design Samples

From Table 3, it can be observed that the compressive strength for each of the different concentration increased significantly from 7 days to 21 days. The mix design with controlled moisture content is having the specific moisture content of 50% including the volume of EM added. The highest increment of the peat soil was observed occurring in the peat soil with 10% EM with values increasing from 12.672 kPa to 20.913 kPa. The other formulations are also showing impressive increment in the UCS within the range of 44.14% to 64.57%.

Table 3. UCS of soil for 7 days, 14 days and 21 days for mix design of controlled moisture content

EM Concentrations	Unconfined Compressive Strength (kPa)		
	7 – Days	14 – Days	21 – Days
Raw	11.815	11.824	11.731
2%	11.961	13.150	17.240
4%	11.976	13.618	18.004
6%	12.020	14.247	18.805
8%	12.387	15.880	19.013
10%	12.672	16.365	20.913

Figure 3 represents the regression analysis of the compressive strength of peat soil samples with different EM concentration on 7, 14, and 21 days curing period. The actual data represented by blue dots whereas the black line represented the modeled data set on 95 % confidence interval. Figure 3-a represents the effect of EM on the stability of the peat soil after 7-days curing. It was observed that with the increase in EM concentration, the stability of peat soil increased. The same trends were observed for the samples cured for 14 and 21 days (Figure 3-b and 4-c). As the highest compressive strength of 20.91 kPa were observed for the sample with EM of 10 % cured for 21 days. From the result obtained, it can

be concluded that the higher the percentage of EM added to the sample, the higher the compressive strength of the soil. It was observed that the compressive strength was increasing after curing. The values might increase if the samples are cured for a longer time. The increment of the compressive strength is due to the biocementation process which is the generation of particle-binding materials through microbial processes in situ so that the shear strength of soil can be increased. The precipitation of material in between the spaces of the soil particles and the binding of the particle takes place in the process of improving the strength of peat soil [16].

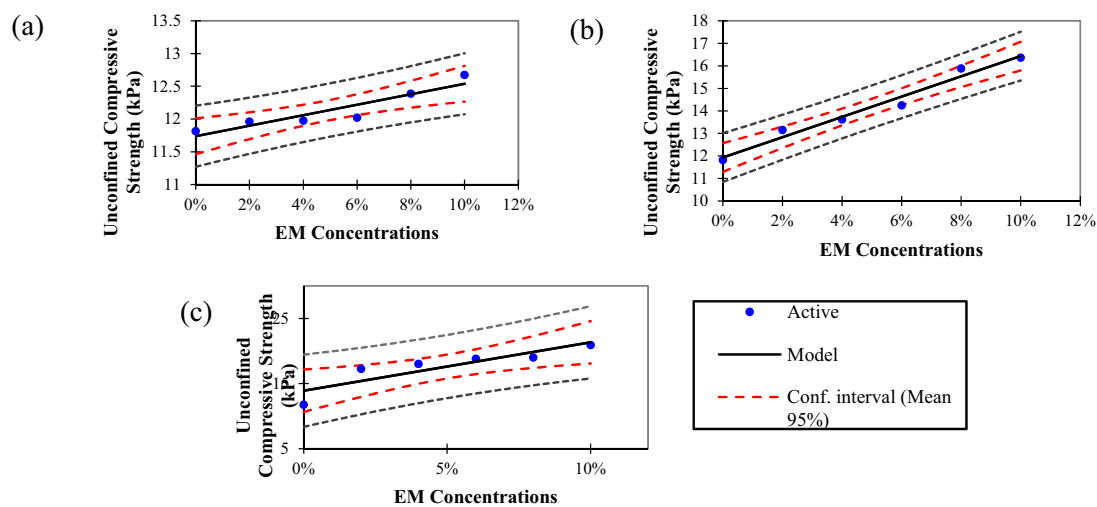


Figure 3. Regression analysis of the compressive strength of peat soil samples with different EM concentration on (a) 7, (b) 14, and (c) 21 days curing period for mix design of controlled moisture contents

The experimented results of UCS of peat soil samples and EM concentrations were then correlated by the linear regression model by using above equation.

$$UCS (kPa) = A_0 + A_1(EM) \quad (3)$$

Where A_0 and A_1 represents the correlation parameters. For both uncontrolled and controlled designs the values of R^2 and standard deviation values were calculated. The values of R^2 and SD for both designs have been presented in Table 4. The values of R^2 for uncontrolled experiments were acceptable and ranged between 0.60 – 0.66. The lower values of R^2 suggest that inclusion of other parameters such as moisture content that can explain the rest of the model. The R^2 values for the controlled design showed the good agreement as the values of R^2 ranged between 0.78 – 0.97.

Table 4. Equation parameters for linear regression between peat soil compressive strength and EM concentration

Curing Period	A_0	A_1	R^2	SD
<i>Uncontrolled Moisture Content Mix design</i>				
7-Days	22.50	256.45	0.60	7.10
14-Days	21.50	236.53	0.66	5.74
21-Days	24.12	262.29	0.66	6.42
<i>Controlled Moisture Content Mix design</i>				
7-Days	11.74	8.01	0.85	0.11
14-Days	11.92	45.03	0.97	0.25

21-Days	13.90	74.33	0.78	1.32
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The effect of a microorganism to stabilize the peat soils were assessed by calculating the unconfined compressive strengths of both designs viz controlled and uncontrolled moisture contents under different curing periods. Figure 4 provides the scatter plot of UCS for experimental and predicted models according to uncontrolled and controlled moisture content designs. It has been observed that the soil strength keeps improving with the increase in a number of curing days. The R^2 values for 21 days curing period are better than 7 days curing period for uncontrolled moisture content design. The values of R^2 for 7, 14 and 21 days were observed as 0.60, 0.66 and 0.66 respectively (Figure 4a, 5c & 5e). While for the controlled moisture content design, the best USC results were observed after 14 days curing period. The values of R^2 for controlled moisture content 0.85, 0.97 and 0.78 for 7, 14 and 21 days curing period respectively (Figure 4b, 4d & 4f).

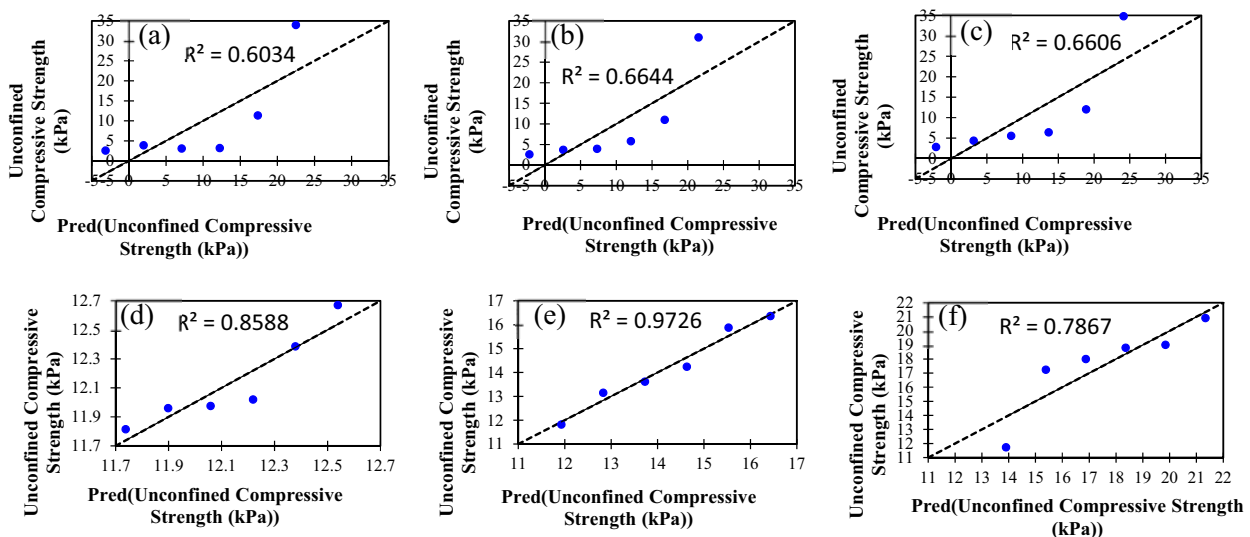


Figure 4. Predictive UCS (kPa) vs Experimental UCS (kPa) for Uncontrolled moisture content mix design (a) 7-days curing, (b) 14-days curing, (c) 21-days curing, and Controlled moisture content mix design (d) 7-days curing, (e) 14-days curing, (f) 21-days curing.

5. Conclusions

Utilization of the EM as the additive to stabilize the peat soil has been investigated. The strength of the stabilized peat soil does not improve compared to the raw samples for the uncontrolled moisture content. However, if it were to be compared by itself, it showed small increments. The moisture content is affecting the strength of the peat soil samples. As for the mix design of controlled moisture content, the result shows increment on the compressive strength of the soil samples compared to the samples with 78% increment after curing which means that the EM are reacting and in the process of stabilizing the soil sample. The project will sure give significant impact to the construction industry because it can save the cost of the replacement of the peat soil the site if ever the engineer encounters the peat soil at the site.

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