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STRENGTH ENHANCEMENT OF PEAT STABILIZED WITH RUBBER CHIPS

NUR RASFINA MAHYAN[1]*, SITI NOOR LINDA TAIB[2], NORAZZLINA M. SA'DON[2], LIYANA TRUNA[1], VENESSA AJON[2], CARRIE CLARE MIDOL[2]

[1]Centre for Pre-University Studies, Universiti Malaysia Sarawak,
94300, Kota Samarahan, Sarawak, Malaysia
[2]Faculty of Engineering, Universiti Malaysia Sarawak,
94300, Kota Samarahan, Sarawak, Malaysia
*Corresponding Author: mnrasfina@unimas.my

Abstract

Peat is often considered a problematic deposit with poor geotechnical characteristics, and which regularly requires stabilization to withstand any building or infrastructure constructed on it. Since structural damages due to peat deposits such as ground settlement, slope failure, and poor stability occurs, it is important to investigate the characteristics of peat and methods to improve its strength properties. This study proposes the use of various percentages of cement in a suitable water-additive (W/A) ratio, with rubber chips as a stabiliser and sand as a filler. The optimum W/A ratio needed to attain the maximum unconfined compressive strength (q_u) and to achieve the greatest reductions in the permeability coefficient (k) was investigated. The peat was treated with admixtures that included peat with its natural moisture content, 15% sand, and 10% rubber chips at three different W/A ratios of 2.0, 2.5, and 3.0. The W/A ratio of 2.0 was indicated to be the optimum ratio of stabilized peat as it achieved the highest maximum strength, 106.75kPa, and attained the highest reduction in permeability coefficient, -49.42%, compared to the other W/A ratios. Peat stabilization with other additives, such as lime and gypsum, at W/A ratios over 3.0 for curing periods of over 28 days should be conducted to produce the best strength variation that treated peat can achieve.

Keywords: Cement, Rubber chips, Peat soil stabilization, Permeability coefficient, Unconfined compressive strength.

1. Introduction

Peat is a soft soil with high organic and water content that is comprised of disintegrated plant remains. It is black to dark brown in colour, spongy in texture, and has an organic odour. Peat is often considered a problematic deposit with poor geotechnical characteristics, and which regularly requires stabilization to withstand any structures or infrastructures built on it [1]. Peat soil is characterised as being high in compressibility, porosity ratio, permeability, and consolidation settlement. Meanwhile, it has a low pH value, shear strength, bearing capacity and bulk density [2]. It poses a major problem in most construction projects and the development of infrastructures due to its very low shear strength and high compressibility behaviours [3].

Since much structural damage occurs when structures or roadways are built on weak compressible soils [4], it is important to investigate the characteristics of peat and methods to improve its strength properties. Previous studies reported that various construction methods, such as replacement, pile-supported embankment, thermal precompression, chemical stabilization, surface reinforcement and stage loading were costly but technically effective, while others experienced settlement and failure issues [5]. In practice, the removal, replacement, and displacement of peat soil with alternative good materials is the solution commonly adopted to address the presence of this problematic soil. However, difficulties have been identified when dealing with deep peat exceeding five metres, as stated by Sa'don et al. [6]. Many soil improvement methods, either chemical or mechanical, can enhance certain desired peat characteristics, but not all can be expected to be efficient and inexpensive.

Sarawak has the most peatland in Malaysia, covering over 16,500 km^2 (13% of the state), with about 90% of it is peat over one metre deep [7]. Infrastructure development in Sarawak has experienced major challenges due to the large peatland areas. With the rapid industrialisation and population growth in the state, it has become essential to build infrastructure facilities on peatland [8]. In this study, the soil stabilization method is proposed to enhance the strength performance of peat soil. This is crucial when stabilising peaty soils as one of the construction methods that support structures and infrastructures on it [9]. Stabilising the peat soil is expected to increase the soil stability and improve its bearing capacity, as well as decrease lateral deformation and settlement [10]. Recent soil stabilization innovations include developing methods of using waste materials such as scrap tyres, which are cheap, accessible, and not detrimental to soil [2]. Rahgozar and Saberian [2] also noted that the excessive amount of waste tyres has resulted in worldwide environmental problems. Recycling waste materials and developing civil engineering projects offer solutions to these environmental issues [11]. Extending the use of waste tyre products to stabilise peat soil is practical, as Hambirao and Rakaraddi [12] reported that soft clay soil samples, when mixed with rubber waste, increase the ductility, unconfined compressive strength, and durability of the soil.

Numerous experimental studies such as Huat et al. [3], Hambirao and Rakaraddi [12] and Rahgozar and Saberian [2] have been reported on the geotechnical properties of peat, peat stabilization and peat enhancement techniques. However, limited data is available on the strength effect of stabilising peat soil with various percentages of water-additive (W/A) ratios and adding rubber chips as a peat soil stabiliser.

Moreover, the effect the curing period has on stabilising peat soil prior to testing needs further investigation. Thus, the use of waste tyre materials to stabilise problematic peat soil is expected to be an efficient solution as it addresses environmental concerns and reduces construction costs. This study proposes to use various percentages of cement in suitable W/A ratios, rubber chips as a stabiliser and sand as a filler. To examine the performance of the stabilized peat soil, it was essential to identify the optimum W/A ratio of stabilized peat needed to attain the maximum unconfined compressive strength (q_u) and achieve the greatest decrement in permeability coefficient (k). This study was expected to be able to recommend the best mix design to stabilise peat soil with rubber chips and sand at the optimum W/A ratio for the subgrade of road embankment.

2. Methods

2.1. Collection of peat samples

The peat soil samples were collected from Kampung Meranek, Sarawak, Malaysia on a hot sunny day at the coordinates 1°26'31.1" N, 110° 28'54.3" E, as shown in Fig. 1. The sampling area is considered to have less development, which may be due to the existence of peat soil. A peat auger equipment was used to collect peat samples and determine the depth of the peat layer. The peat layer ranged in depth from 0.1 to 1.50 m below the ground surface and is a potential source of risk for proposed building or roadway construction projects.

Fig. 1. Location of peat sampling.

2.2. Peat identification

A field vane shear test was conducted on-site based on ASTM D 2573, as shown in Fig. 2, to determine the in-situ undrained strength of peat according to the standard test method used for a field vane shear test in cohesive soil. This was performed directly on the ground by pushing a four-bladed vane, 2 mm thick and with sharpened ends, into the undisturbed peat. The blade penetrated until it reached 2 m deep into the peat soil. Torque readings were taken every 0.5 m.

The Von Post classification test was also conducted on-site by squeezing the peat by hand, as shown in Fig. 3. The colour and fluid between the fingers were observed while the remaining sample content was observed in the squeezed hand to determine the Von Post scale of the peat samples. The field assessment of classifying the peat

included observing the botanic composition, wetness, fibres, and woodiness of the peat. Table 1 lists the laboratory tests conducted to determine the physical properties of the untreated peat collected from Kampung Meranek, Sarawak.

Fig. 2. Field vane shear test.

(a) Squeezing of peat **(b) Remaining content after squeezed hand**

Fig. 3. Von post classification test.

Table 1. Physical properties tests of Kg. Meranek untreated peat.

Physical Properties	Symbol (Unit)	Method
Von Post Classification	-	Von Post 1922 Classification
Moisture Content	w (%)	BS 1377: Part 2: 1990
Organic Content	OC (%)	BS 1377: Part 3: 1990
Fibre Content	FC (%)	ASTM D 1997-91
Specific Gravity	G_s	BS 1377: Part 2: 1990
Liquid Limit	LL (%)	BS 1377: Part 2: 1990
Linear Shrinkage	W_s (%)	BS 1377: Part 2: 1990
pH	-	BS 1377: Part 3: 1990

2.3. Preparation of samples

A recognised procedure for preparing the admixtures of stabilized soil and test samples were based on the Design Guide of Soft Soil Stabilization [13]. The admixtures consisted of peat with its natural moisture content, cement, sand, and rubber chips, as shown in Table 2. The mass of cement as an additive used was 496.71g, 262.20g, and 110.61g based on the W/A ratios of 2.0, 2.5 and 3.0 respectively. The proportion of sand and rubber chips used in this study was 15% and 10% of the total weight of peat and cement calculated by the W/A ratio method, respectively. The cement used was the Portland Cement (PC) produced by CMS Cement Division which follows the quality requirements specified in the Malaysian Standard MS EN 197-1 which is equivalent to ASTM C150. The sand used was the river sand from Saraoil (M) Sdn. Bhd., which consists of 5-20% of silt content. The size of the rubber chips, sourced from ZHA Environmental Sdn. Bhd., were 0.5-3.0 mm in diameter, as shown in Fig. 4. All the peat test samples underwent an air curing process for curing periods of 7, 14 and 28 days.

Table 2. Mix design for stabilized peat.

No.	W/A Ratio	Mixing Sample	Curing Period
1.	2.0		
2.	2.5	Peat + 15% Sand + 10% Rubber Chips	7, 14 & 28 days
3.	3.0		

Fig. 4. Rubber chips.

2.4. Geotechnical tests

Unconfined compression and falling head permeability tests were conducted to measure the mechanical properties of the test samples. The test samples were prepared according to the mould size of the tests, as shown in Table 3. The moulds used for the unconfined compression test were plastic tubes (38 mm internal diameter, 73 mm long), as shown in Fig. 5. For the falling head permeability tests, the moulds (lower chamber sections for the permeameter) were cylindrical (107 mm internal diameter × 150 mm tall), as shown in Fig. 6. The test material was packed into the moulds in layers and compacted using a tamping device. All the laboratory testing methods used were in accordance with British Standard 1377: Methods of testing soils for civil engineering purposes. Each test was replicated three times and the average result was calculated.

Table 3. Sizes of soil samples for unconfined compression and falling head permeability tests.

Geotechnical Test	Method	Dimensions of soil specimen
Unconfined Compression	BS1377: Part 7: 1990	38 mm ⌀ × 73 mm height
Falling Head Permeability	BS1377: Part 5: 1990	107 mm ⌀ × 150 mm height

Fig. 5. Unconfined compressive strength test sample moulds.

Fig. 6. Falling head permeability test sample moulds.

Unconfined compressive strength (UCS) tests were performed to determine the unconfined compressive strength (q_u) of the samples. The tests were conducted by applying a load onto the compression device containing the soil samples, which produced axial strain at a rate of 1.25 mm/min, as shown in Fig. 7. Then, the load and deformation dial readings were observed and recorded at every 20 divisions. The test was continued until each sample reached a maximum value, at which point the force gauge reading dropped.

The falling head permeability test involved a flow of water through a soil sample that is connected to a standpipe. This provided the water head and allowed the volume of water passing through the sample to be measured, as shown in Fig. 8. The tests were performed by recording the time taken for the water to flow through the sample. Then, the permeability coefficient (k) was calculated using a formula.

Fig. 7. Unconfined compressive strength apparatus.

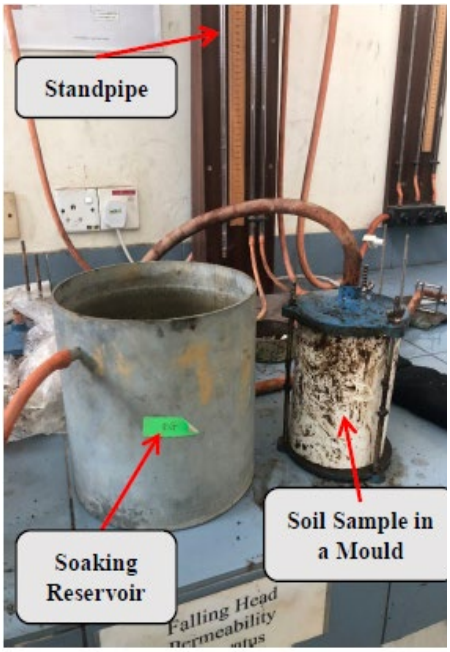


Fig. 8. Falling head permeability apparatus.

3. Results and Discussion

3.1. Physical properties

The physical properties of the untreated peat from Kampung Meranek, Sarawak is tabulated in Table 4.

The Von Post classification test was performed on-site to determine the Von Post scale of the peat samples by squeezing the peat with the fingers. It was observed that the peat had a dark brown colour, and a small quantity of pasty water was released when the peat was squeezed between the fingers. Sediments from woody remains such as roots and small branches were also found and could be

observed on the hand; hence, the peat was identified as H8 on the Von Post scale. According to Jarret [14], peat classified in the range of H7-H10 is known as amorphous peat.

Table 4. Physical properties of Kg. Meranek untreated peat.

Physical Properties	Values
Von Post Classification	H8
Moisture Content, *w*	1118.19%
Organic Content, *OC*	75.88%
Fibre Content, *FC*	22.19%
Specific Gravity, G_s	1.28
Liquid Limit, *LL*	628.13%
Linear Shrinkage, W_s	13.33%
pH	4.25

The natural moisture content of the peat recorded a value of 1118.19%, which was within the 200-2207% range which was found to exist in East Malaysian peat in a study by Huat [15]. The value of moisture content differed compared to previous studies due to the variations in groundwater levels between the site location and undrained forested conditions [16]. Peat has high natural moisture content due to its natural water-holding capacity, which makes it very soft and sensitive. Moreover, it was impossible to identify the plastic limit of the peat since its plasticity gave little indication of its character, while the presence of fibres made determining the Atterberg limits difficult [17]. The organic content of the peat sample was determined from its loss of ignition at 450°C as a percentage of oven-dried mass at 105°C, which produced a value of 75.88%. Since the peat had a high-water content value, the organic content also had a higher value.

Furthermore, the fibre content of the peat was determined from the dry weight of fibres that had been retained on a 0.15 mm sieve; the fibre content of the peat was recorded as 22.19%. According to the fibre content classification by Huat et al. [18], peat soil is divided into three groups, mainly fibric (more than 67% fibre content), hemic (intermediate decomposition) and sapric (less than 33% fibre content). In this case, the peat soil obtained was classified as sapric, which is peat containing highly decomposed materials, as well as having the highest organic content and bulk density among the three types of peat. The specific gravity of the peat soil was obtained using the specific gravity bottle method. It produced a value of 1.28, which was in the 1.25- 2.97 range found to exist in East Malaysian peat in a study by Huat [15].

The liquid limit represents an index property of soil that is widely used in the geotechnical engineering field. The liquid limit of peat was determined by using the cone penetrometer method, which obtained a value of 628.13% at a penetration of 20 mm. The liquid limit of peat increased when the natural water content and organic content increased. The shrinkage limit value was 13.33%, which indicated that below this limit, the soil-water mixture was no longer saturated, and no further volume decrease occurred in the drying process [19]. However, above the liquid limit phase, the soil-water mixture behaved like a fluid. Lastly, the peat soil sample was classified as acidic because its pH value was 4.25. In the tropics, peat soil is usually acidic, with a pH value ranging from 3 to 4.5.

3.2. Geotechnical properties

3.2.1. Unconfined compressive strength

Unconfined compressive strength tests were conducted on the stabilized peat samples to determine their maximum soil unconfined strength. The maximum unconfined compressive stress for peat treated at W/A ratios of 2.0, 2.5 and 3.0 is tabulated in Table 5.

The strength of peat increased when the curing period was longer, based on the observation that when the curing period was 28 days, the highest UCS value was achieved, as shown in Fig. 9. Figure 9 also shows that for all W/A ratios, the average maximum unconfined compressive stress for the 28-day curing period had a higher standard deviation than for the 7-day and 14-day curing periods. For all W/A ratios, the UCS value was lower at the curing period of 7 days compared to that of 28 days. It can be said that when the curing period was lengthened, the treated peat soil could achieve greater strength. This was proven in a previously mentioned study by Rahman et al. [20] in which a UCS value of 98.2 kPa was obtained at 28 days for peat treated with cement, followed by a UCS value of 61.4 kPa measured at 3 days.

Kalantari and Huat [21] also conducted a study with curing periods of 28 days and 90 days, obtaining UCS values of 60 kPa and 230 kPa, respectively, for peat treated with cement. Most samples in this study showed an increase in UCS value during the curing period process. Among all the curing periods, W/A ratio of 2.0 showed a major strength increase at 28 days, while the UCS values were almost the same observed for the 2.5 and 3.0 W/A ratios.

It was also identified that an increase in W/A ratio caused the strength of the stabilized peat samples to decrease. The peat strength had decreased at a W/A ratio of 3.0 when compared to a W/A ratio of 2.0. The W/A ratio of 2.0 was indicated as the optimum ratio of stabilized peat as it achieved the highest maximum strength, 106.75 kPa, compared to the other W/A ratios. In a study conducted by Tajuddin et al. [22], at 28 days, peat treated with cement and fly ash started to show a decrease in strength starting from W/A ratios of 3.0 and above. At a high ratio, the strength of treated peat also reduced due to the initial cracks on the specimen after removal from the mould [23].

Table 5. Unconfined compressive stress of untreated peat and stabilized peat.

W/A Ratio	Curing Period (days)	Average maximum unconfined compressive stress (kPa)
Untreated Peat	0	0
2.0	7	53.81
	14	51.37
	28	106.75
2.5	7	38.16
	14	57.00
	28	46.89
3.0	7	36.11
	14	28.60
	28	54.86

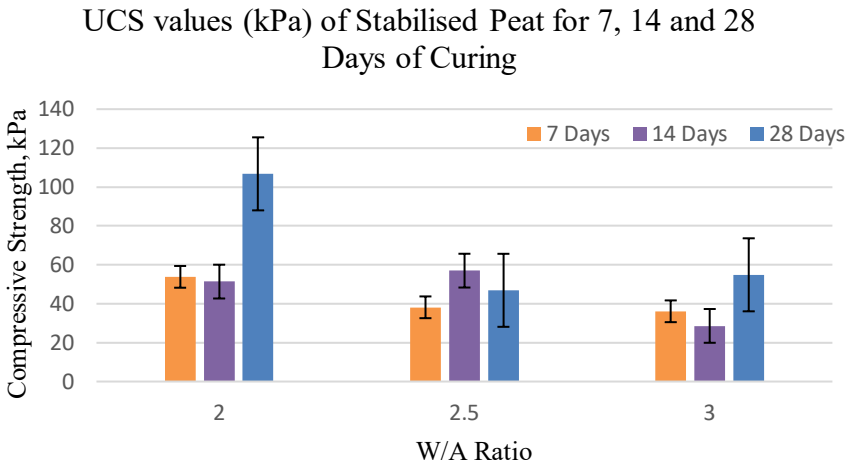


Fig. 9. Average maximum unconfined compressive stress (kPa) of stabilized peat at W/A ratios of 2.0, 2.5 and 3.0.

The UCS value of stabilized peat soil can be enhanced by increasing the cement dose; however, the UCS value may decrease if the cement is added at a ratio greater than the optimum. In this study, the cement values at the W/A ratios of 2.5 and 3.0 at the 14-day curing period were 128.49 g and 214.15 g, respectively, and based on Table 5, the UCS value at the W/A ratio of 2.5 was higher than at the 3.0 W/A ratio. A study conducted by Ismail [24] showed that peat strength decreased when the cement was added at a greater ratio than the optimum, whereby a value of 30.87 kPa was achieved for peat treated with cement at a W/A ratio of 3.0, while 9.92 kPa was achieved at a W/A ratio of 5.0, with both samples having undergone a 28-day curing process.

The UCS values for W/A ratios of 2.5 and 3.0 showed almost the same value although each contained different amounts of cement, which revealed that an inadequate amount of cement could not neutralise the humic acid and thus hindered the cement-hydration process. To neutralise the humic acid, the quantity of cement would need to exceed a required threshold quantity [25]. Furthermore, the application of the W/A ratio in peat stabilization is based on its moisture content. For instance, at a W/A ratio of 2.0 (at 14 days), the moisture content was 1146%, which resulted in almost the same strength value as with the W/A ratio of 2.5 (at 14 days), whose moisture content was 829%. Therefore, for different moisture content levels, the findings indicated that optimal additive designs according to W/A ratio for peat stabilization may differ slightly.

Sand has often been used in previous trials of various possible stabilization additives for peat soils, either as a filler or as a link to other ingredients such as cement or lime. In this study, 15% of sand was added into the peat samples from the overall design mix proportion. The inclusion of sand in peat stabilization increases its strength since the void spaces within the stabilized soil reduce to a minimum when well packed with coarse-grained sand. The use of sand as a filler does not cause a chemical reaction, but it increases the strength of the binder's stabilized peat by increasing the number of soil particles available for the binder to join with, thus creating a permanent, stabilized soil structure [26]. In addition, this

method may be economical as it reduces soil stabilization costs by replacing a certain part of the binder with a filler.

The inclusion of a filler in the design mix proportion of peat stabilization may affect the UCS results. According to Ismail [24], peat treated with cement at a W/A ratio of 3.0 but without the addition of a filler achieved the highest UCS value of 21.02 kPa at a 28-day curing period, compared to the highest UCS value obtained in the current study at the same W/A ratio and curing period, which was 54.86 kPa. Similar observations were made in a study by Rahmi et al. [25] on peat treated with cement but without the addition of a filler, for a 28-day curing period. The stabilized peat samples achieved the highest UCS values of 44 kPa, 26.72 kPa and 12.92 kPa at W/A ratios of 2.0, 2.5 and 3.0, respectively. Meanwhile, the highest UCS values obtained in the current study were 106.75 kPa, 46.89 kPa and 54.86 kPa for the same W/A ratios [25]. The UCS values obtained in this study were higher than those identified by Ismail [24] and Rahmi et al. [25]. Peat stabilized with the addition of fillers, such as sand and rubber chips, has higher UCS values compared to peat treated only with cement.

In this study, a percentage of 10% of rubber chips was used as a soil stabiliser, since this is the optimum value needed for peat to achieve its maximum strength. According to Rahgozar and Saberian [2], the stabilization of peat samples with 10% of shredded tyre chips showed the highest unconfined compressive strength compared to the other percentages used (0%, 5%, 15% and 20%). In stabilized soil admixtures, rubber chips play an equally important role as fibres in enhanced concrete, minimising crack growth and restricting the extension of any forming cracks.

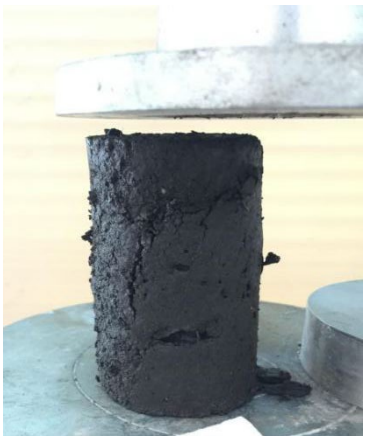
This study indicates that UCS tests could not be conducted for the untreated peat sample because the peat was too soft and watery, making it impossible to obtain any values from the UCS scale. The untreated peat sample could not stand upright and slanted slightly to the right, as shown in Fig. 10. It could be stated that the untreated peat had zero strength (0 kPa). The vane shear test also could not be obtained as the peat was very soft and watery, possibly due to the high degree of humification of peat on-site. The higher water content meant the peat had a low shear strength and as the degree of humification increased, the shear strength of the peat decreased [18].

Fig 10. Untreated peat sample at 0 days.

Figure 11 shows the failure condition for each stabilized peat test sample and the failure regions that appeared at different locations for each sample. A narrow crack in Sample 1 was observed during the failure process; the crack propagated from the bottom to the top of the sample. There was also a narrow crack in Sample 2 during the failure process and a slight shear at the top left of the sample. For Sample 3, some cracks were observed at the bottom of the sample. For sample 4, a crack appeared on the surface which propagated from the bottom to the top of the sample. A long crack formed on the left side of the surface of Sample 5. The left side of Sample 6 was sheared during the failure process and a few pieces of the sample had fallen from other parts of the surface due to shearing. As for Sample 7, a small crack appeared on its surface which propagated from the bottom to the top and there was a slight shear on the left side of the sample. Sample 8 underwent a Y-shaped failure with no presence of shearing during the failure process. Cracks were present in Sample 9, which propagated from the bottom to the top of the sample.

(a) Sample 1. Stabilized Peat of W/A 2.0 at 7 days.

(b) Sample 2. Stabilized Peat of W/A 2.0 at 14 days.



(c) Sample 3. Stabilized Peat of W/A 2.0 at 28 days

(d) Sample 4. Stabilized Peat of W/A 2.5 at 7 days

(e) Sample 5. Stabilized Peat of W/A 2.5 at 14 days

(f) Sample 6. Stabilized Peat of W/A 2.5 at 28 days

(g) Sample 7. Stabilized Peat of W/A 3.0 at 7 days

(h) Sample 8. Stabilized Peat of W/A 3.0 at 14 days

Sample 9. Stabilized Peat of W/A 3.0 at 28 days

Fig. 11. Failure condition of test samples of stabilized peat.

3.2.2. Permeability falling head test

Permeability Falling Head tests were conducted on the stabilized peat samples to determine their coefficient of permeability. There are limited data on permeability studies in stabilized peat soil. It is hoped that the data obtained in this study could be significant for future references. The permeability coefficients of the treated peat samples at W/A ratios of 2.0, 2.5 and 3.0, which underwent air curing for 7 and 14 days, are tabulated in Table 6.

Table 6. Result of permeability falling head test.

W/A Ratio	Coefficient of permeability, k(m/s)		Percentages of reduction (%)
	7 days	14 days	
2.0	2.224×10^{-8}	1.125×10^{-8}	- 49.42
2.5	3.617×10^{-8}	1.590×10^{-8}	-56.04
3.0	3.953×10^{-8}	1.306×10^{-8}	-66.96

Figure 12 illustrates that the permeability coefficient of each peat sample decreased at the curing period of 14 days for all W/A ratios. The W/A ratio of 2.0 at the 14-day curing period days had the lowest coefficient of permeability, $1.125 \times 10\text{^}(-8)\ m\ s\text{^}(-1)$, compared to the other W/A ratios, as it had the highest cement dosage. A similar result can be seen in the study by Paul and Hussain [27], who stated that the curing effect leads to a decrease in the permeability coefficient, k. Rahman et al. [20] also pointed that the pozzolanic activity in the stabilized peat samples can contribute to the reduction of permeability coefficient, k and increase the strength of stabilized peat soil if the curing period is extended.

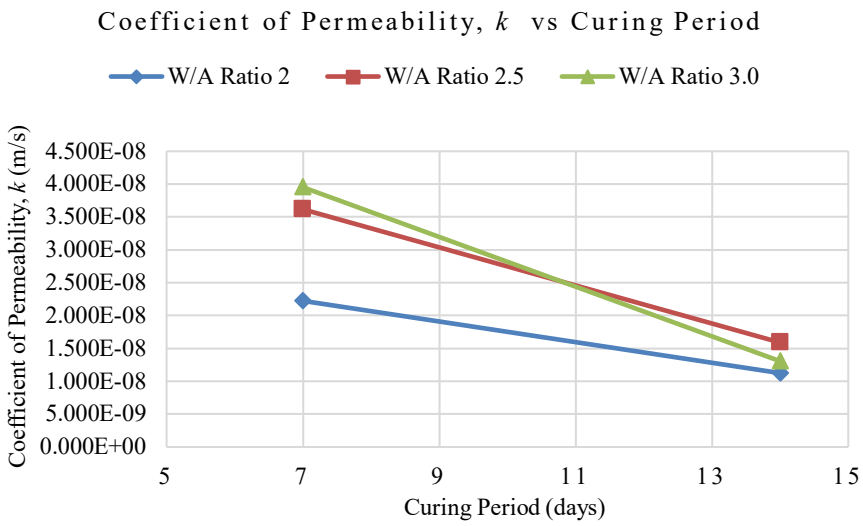


Fig. 12. k vs curing period.

The reductions in percentages of the permeability coefficients, k at all W/A ratios were calculated and are recorded in Table 6. The results show that the W/A ratio of 2.0 produced the highest reduction in permeability coefficient, compared

to the other W/A ratios, due to the higher cement volume used in the W/A ratio of 2.0. The use of a higher amount of cement induced more pozzolanic activity, which helps in binding the peat soil.

Relating to the porosity factor, the lower the W/A ratio is, the lower the porosity. The effect of decreasing porosity also affects the permeability of the peat samples. Less pore in the peat samples lead to a lower flow of water when conducting the Permeability Falling Head test results in the reduction of the permeability coefficient, *k*. Chen and Wu [28] agreed that a higher W/A ratio increases the porosity of the treated soil. They also stated that an increased curing period and lower W/A ratio result in lower porosity. Water flow through soil is highly dependent on porosity and the reduction in the permeability coefficient, *k* of the treated soil was due to the bonding of individual soil particles [29].

In this study, the amount of sand used in the peat stabilization mix design was sufficient to reduce the coefficient of permeability, *k*. The amount of sand used was 15% of the overall weight, which also contained peat, cement, and rubber chips. The reductions in permeability coefficient, *k* show that the amount of sand used assists in reducing the porosity of the stabilized peat samples. Ali et al. [30] found that treated peat soils containing 75% cement, 25% slag and 950 kg/m^3 siliceous sand help to decrease permeability to 2.339×10^{-8} m/s. The siliceous sand used by Ali et al. [30] contributed by filling the void spaces within the soil, which led to reduced porosity. Therefore, this current study has shown that the use of sand as a filler is a potential factor in reducing the permeability coefficient, *k*. However, as this study only used river sand, which contains 5-20% silt, future research should be able to distinguish between river sand and siliceous sand as fillers since the type of sand used could influence on the treated peat.

The amount of rubber chips used in this study also helped in reducing the porosity of the stabilized peat samples. The amount of rubber chips used was 10% of the overall weight, which also contained peat, cement, and sand. The effect of rubber chips bonded with cement and sand demonstrated the ability of rubber chips to fulfil the porosity of the peat samples, making the peat more impervious. This effect enhanced the peat soil strength and reduced the water flow in the soil. According to Rahgozar and Saberian [2], the UCS value of peat treated with sand and rubber chips shows that the fillers achieved the maximum strength. Hence, this current study has shown that the effect of adding rubber chips is greatly beneficial in filling soil pores, which subsequently reduces the permeability coefficient, *k*. However, the size of rubber chips can play a role in reducing the permeability. The rubber chips used in this study were considered as very light and small in size. Hence, using varied sizes of rubber chips were recommended in future studies to examine the effect of rubber chips sizes in peat soil stabilization.

4. Conclusions

Based on the experimental study, the following conclusions were made:

- The peat was classified as H8 according to the Von Post scale, with an original moisture content of 1118.19%, organic content of 75.88%, fibre content of 22.19%, a liquid limit of 628.13%, linear shrinkage of 1333.33%, a specific gravity of 1.28 and a pH of 4.25.

- The unconfined compressive strength of the stabilized peat soil increased with the inclusion of cement, rubber chips and sand. The results showed an improvement in strength from the original peat, which at first recorded a strength value of 0 kPa with no added stabilisers. After the addition of stabilisers, the peat strength increased throughout the curing periods of 7, 14 and 28 days. At a high cement dosage and at the W/A ratio of 2.0, the peat achieved its highest maximum strength of 106.75 kPa at 28 days.
- The permeability coefficient, k of the peat samples at the W/A ratios of 2.0, 2.5 and 3.0 reduced continually throughout the curing periods of 7 and 14 days after the addition of different dosages of cement according to its W/A ratio, 10% of sand and 15% of rubber chips. The W/A ratio of 2.0 at the 14-day curing period produced the highest reduction in permeability coefficient, -49.42%, and the lowest coefficient of permeability, $1.125 \times 10\text{^}(-8)\ m\ s\text{^}(-1)$, compared to the other W/A ratios since it contained the highest cement dosage.
- Peat stabilization with the addition of rubber chips and sand at the W/A ratio of 2.0 was indicated as the best mix design in this study as it achieved the highest unconfined compressive strength and the highest reduction in permeability coefficient, compared to the other W/A ratios.

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Nomenclatures

FC	Fibre Content, %
G_s	Specific Gravity
k	Permeability Coefficient, m/s
LL	Liquid Limit, %
OC	Organic Content, %
q_u	Unconfined Compressive Strength, kPa
W_s	Linear Shrinkage, %
w	Moisture Content, %
$\varnothing$	Diameter, mm

Abbreviations

ASTM	American Society for Testing and Materials
BS	British Standard
CMS	Cahya Mata Sarawak
MS	Malaysian Standard
UCS	Unconfined Compressive Strength
W/A	Water-additive

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