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STRENGTH ENHANCEMENT OF REINFORCED PEAT WITH RUBBER WASTE AND MELAMINE UREA FORMALDEHYDE (MUF) RESIN

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Abstract

Peat is classified as a problematic soil due to its low shear strength, low bearing capacity and high compressibility characteristics, which has become a crucial problem in the construction development. The presence of this peaty soil caused difficulties due to its instability and high settlement rate. This paper presents the stabilization of local peat from Kota Samarahan, Sarawak, Malaysia by using two types of processed tire-waste disposal, namely shredded rubber powder (RP) and rubber crumb (RC) at a controlled percentage of 10% of the weight of peat. In this study, liquid Melamine Urea Formaldehyde (MUF) resin was used in different percentages (i.e., 10%, 20%, and 40%) and mixed along with 5% cement to act as a binder. All of the additives were added into the peat at its optimum moisture content. The samples were cured for 7 and 28 days at room temperature e and the Unconfined Compressive Strength (UCS) test and California Bearing Ratio (CBR) test are performed on the reinforced peat stabilized with MUF. Based on the findings, the results show that shredded rubber crumb, rubber powder and MUF polymer resin gradually improved the strength of the reinforced peat samples by increasing the effective contact area between the peat and the additive. The highest UCS strength recorded is 438 kPa with a composition of 10% rubber powder, 40% of MUF polymer resin and 5% cement. According to the CBR test findings, the peat increased strength as a result of the addition of 10% rubber crumb, 40% MUF and 5% cement which is 20.3%for soaked condition. Furthermore, the results show that peat soil may be used as a subgrade. The findings of this study indicate that the use of shredded rubber crumb and rubber powder with addition of MUF can improve the engineering properties of peat soil. Thus, these findings may be applied in the construction of subgrade layer.

Keywords: California bearing ratio (CBR) test, Melamine urea formaldehyde (MUF) resin, Rubber crumb, Rubber powder, Soil stabilization, Unconfined compressive strength (UCS) test.

1. Introduction

Peat is known as a soft soil that is prone to instability due to its high percentages of organic matter and high-water content. In Malaysia, peat covers a major area that is approximately 25,000-30,000 km^2 that roughly occupying 8% of the country total land area [1-3]. Zainorabidin and Wijeyesekera [4] and Melling [5] in their study has stated that Sarawak has the largest peat area in Malaysia that constituting about 13% of the state covering around 16,500 km^2 of the Sarawak land. According to Sa'don et al. [6], about 90% of peat in Sarawak is classified as deep peat which means the depth of the peat layer is more than 1.5 meters and it is increasing from the coastal area towards the inland. However, with population increase and growing urbanization, infrastructure facilities in soft and unstable soil areas, such as peat, are becoming increasingly required.

Most of the reduction in peat land is due to deforestation includes conversion of forestland to farms, ranches, or urban use, especially in Pahang and Sarawak including development for residential purposes in Malaysia. In general, Sarawak peat soil is black to dark brown in colour. The depth of the peat layers in Malaysia ranges from less than 1m to 25m depending on the region. Huat, [1] observed that the depths for peat deposits in Malaysia were varying from 1 m to 20 m. Unfortunately, in Sarawak, about 90% of the peat is classified as deep peat which the depth is more than 1.5 m [6, 7]. Studies by Sa'don et al. [8] stated that in some areas in Sarawak, the peat is exceeding 10 m in depth, and it is mainly in low-lying areas. The hot temperatures of the tropics that up to 32℃ are one of the key reasons for the rapid decomposition in peat soil.

Moayedi and Nazir [3], in their study shows that Sarawak peat can be found in a swampy area, coastal area and steeply undulating inland hills. Deep peat and muck soils form the coastal plains, and some distance inland from the coastline occurs at different points along the coast. Peat occurs mostly between the low stretches of the main riverbeds (basin peat) and the poorly drained inner valleys (valley peat). Most of the Sarawak peat land is located in the central region of the state, which contributes about 70% of the division [9]. Samarahan division is also one of the biggest peat areas for deep peat in Sarawak as reported by Davies et al. [10] in Wetland International-Malaysia.

To strengthen the peat soil, soil stabilization is vital. Therefore, it is very important to stabilize the underlying soils to provide an optimum performance of the soil foundation for a better engineering property. Peat soil can be improved through a variety of methods. Several researchers has done researches on stabilizing soft soil [4, 8-10]. According to previous study by Sa'don et al. [6], mechanical improvement and chemical treatment are the two primary methods usually used to develop engineered soil. However, all of these procedures require the use of certain specialised equipment and a skilled worker in order to ensure that the project outcomes are sufficiently satisfactory. Mechanical improvement is a process of enhancing soil resistance by physical processes such as compaction, consolidation, external loading by surcharge, drainage or any other means. Chemical treatment implies inside-soil chemical reactions such as hydration or pozzolanic reactions to produce artificial binding between soil particles [11]. Chemical reactions between soil particles and additives can bind the particles of soil together to form a strong network, resulting in higher-quality soil compared to mechanical and physical methods thus increasing soil strength and durability [11, 12]. Saberian and Rahzogar [13] mentioned in their study that the hydration reaction initiates initial improvements in strength as a result of the development of cementation products has resulted of water drying out. The pozzolanic reaction, which occurs under alkaline conditions from a chemical reaction between calcium and silicates or aluminates, results in the formation of cementing agents such as calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) [3, 14]. The most typical method of soft or peat soil treatment is by excavation method and replacing it with quality granular or sandy soil. Nevertheless, this method is discouraged due to its costly design [15-17].

Therefore, one of the alternatives to enhance the soft soil characteristics is by soil stabilization. Recent soil stabilization techniques have highlighted the need to completely or partially replace traditional binders with more sustainable, resilient, and environmentally friendly materials. These materials are expected to give a comparable or better durability and strength performance in stabilizing the soft soil than traditional binders. Therefore, it is more cost effective by using these waste materials to strengthen the soil's strength and stiffness so that any engineering structure can be built on top of it apart from being able to contribute towards environmental sustainability. Hence, scrap tire waste in the form of shredded rubber crumb and rubber powder could be an excellent alternative for soil stabilization when combined with a small quantity of cement. This by-product waste material can be utilized as a filler and reinforcing material with an addition of traditional and/ or non-traditional stabilizer to form a durable and sustainable soil foundation. Several researchers have done researches on the use of rubber waste product on soft soil stabilization [6, 14, 18, 19]. From the studies, they have found that scrap tires could be used as an effective reinforcement material underneath retaining walls, foundations, embankments and subgrade layers. Studies show that specimens with scrap tire as a reinforcing agent can increase the percentage of axial strain at failure compared to specimens without scrap tire. Furthermore, by utilizing this waste product in the soft soil treatment will mitigate the environmental problems and resulting in the new products that contribute to protecting the environment.

Soil stabilization through chemical admixtures involves the modification of the soil's fabric and structures. As a result of the chemical reaction, changes will occur in the soil structure such as pH, moisture content, shear strength, and other physical, chemical and engineering properties. The addition of chemical stabilizer will accelerate the bonding in the soil thus will improve the strength and stiffness of the soil, but it is depending on the type of stabilizer used. Polymer soil stabilization, as defined by Chang et al. [20], is the process to improve the physical properties of the soils by adding polymers such as synthetic polymer and biopolymer. Various types of polymers have been reported to stimulate soil water retention, improves the soil shear strength and act as a support system to the peat soil structure [15-17, 21]. The soil aggregation and strength are mainly affected by the polymer substances. It is by increasing the steric stabilization that related to the spatial arrangement of the atoms in soil molecule that preventing soil particles from contacting each other when interact with the fine particles. Steric stabilization as described by Tadros [22], says that it is a process by which the adsorption of surfactants or non-ionic polymers induces a significant repulsion between particles and droplets in a dispersion. When non-ionic surfactants or polymers are adsorbed on the surface of particles or droplets, an adsorbed layer of thickness is formed.

This layer can be substantially solvated or hydrated by the molecules of the good solvent for the surfactant or polymer layer.

The most well-known chemicals used in soil stabilization are lime, fly ash and Portland cement. Chemical stabilization with the use of calcium-based binders such as cement and lime are a common approach for improving soil performance in civil engineering applications, particularly for soft soils, due to its cost-effectiveness, adaptability, and durability [7, 23]. These additives change the physical and mechanical properties of the soil, enhancing its strength, stiffness, and shrinkage. Cement may be mixed into a variety of soils and is considered one of the most practical and convenient techniques of soil stabilization. The stability of the pavement foundation and sub-grade, on the other hand, need a larger cement dosage. Unfortunately, while these calcium-based binders can enhance a range of soil engineering features, they have a number of drawbacks, particularly in terms of environmental impact. A large use of cement, for example, produces a significant amount of carbon dioxide, which is a greenhouse gas and hence is not an environmentally friendly substance [24, 25]. It is critical to discover an alternative to cement stabilization that has a low environmental impact while maintaining the material's strength, stiffness, and long-term performance. According to Mohd Daud et al. [26], one tonne of cement produces one tonne of CO_2, whereas one tonne of lime produces about 0.86 tonnes of CO_2. CO_2 emissions have a negative influence on the environment, resulting in climate change and global warming. Another issue that affects the environment is the emission of particulate matter into the atmosphere in the form of cement dust.

In peat soil, critical research on chemical admixtures such as formaldehyde resin is currently uncommon and rare [27]. A recent study by Mohd Daud and Nik Daud [26] on the strength enhancement of peat soil treated with MUF found that employing the liquid form of MUF resin for air curing applications at the lower moisture content yielded encouraging results. However, limited study was conducted with a non-traditional stabilizer [28, 29]; and in Sarawak research concerning the improvement of peat soil stabilization by using scrap tire as a reinforcing agent with different types of non-traditional admixtures tends to be limited. Hence, this study was conducted by using different percentages of liquid Melamine Urea Formaldehyde (MUF) in order to investigate the strength changes in peat after the stabilization process.

Numerous experimental studies have been published on the geotechnical properties, chemical stabilization, and reinforcing technique of peat. However, there is a scarcity of data on the strength effect of processed tyre waste disposal using shredded rubber crumb and rubber powder as reinforcement materials for reinforced peat as a sub-grade [6]. Therefore, it is reasonable to expand the use of waste tire materials to the stabilization of peat soils, especially because it may not be possible to stabilize peat soil using conventional methods in all circumstances due to its high organic content and high pH.

Various research studies on the use of shredded tyre waste as reinforcement for civil engineering projects, particularly road and embankment building, have been published. According to Bai et al. [30] and Hambirao and Rakaraddi [19], shredded tyre chips were classified as ideally extensible inclusions of soil reinforcement (based on their stiffness), alongside natural and synthetic fibres with low modulus, plant roots, and polymer fabric. Rahzogar and Saberian, [31] also stated that the effect of shredded tyre chips in stabilized soil admixtures is similar to that of fibres in reinforced concrete, in that they effectively prevent the formation of cracks and limit the expansion of existing fissures.

Studies conducted by Akbulut et al. [18] and Hambirao and Rakaraddi [19] observed an increase in the unconfined compressive strength, ductility, and toughness when soft and weak clayey soil samples were mixed with waste rubber. M. Sa'don [32] also investigated the effect of stabilizing soft clay and peat using scrap tyre reinforcement and cement as a stabilizing agent, and the results indicate that the strength was significantly improved after curing. Study conducted by Md Zain et al. [33] recently used recycled waste tyre granules as reinforcing material with and without the addition of sand as a filler to stabilize peat soil in Klang, Selangor, Malaysia. Her findings show that adding recycled waste tyre granules improved the compressibility behaviour of natural peat soil. As reported by Otoko and Pedro [34], scrap tyre material can also be used as reinforcement to replace deep or raft foundations. Additionally, Mohajerani et al. [35] noted that scrap tyres can be used in the form of tyre chips and crumb rubber as a substitute or replacement for aggregates used in construction projects or as reinforcing material in ground or soil improvement. The possibility for strengthening clayey soils by the use of fibre materials such as scrap tyres also has been investigated by Akbulut et al. [18]. They discovered that these materials are effective reinforcement materials for clayey soils, increasing their strength and dynamic behaviour.

As a result of the presented published studies, the authors are inspired to examine the strength of the fibre reinforced technique on Sarawak peat by utilizing scrap tyre. The objective of this study is to give a comparative investigation of the unconfined compressive strength (UCS) and California bearing ratio (CBR) values of fibre reinforced peat mix with shredded rubber-crumb and rubber powder. The study aims for a UCS value of at least 345 kPa, as defined by ASTM D4609 and with a minimum threshold of 5% to 12% CBR value, respectively. The authors are also examining the performance of the designated mixture utilizing scrap tyres with a minimum cement content of 5% that act as a bonding agent.

The results on geotechnical characteristics and strength improvements of the design mixture with shredded rubber crumb, rubber powder and MUF resin for reinforced peat are presented in this study. A series of laboratory testing of physical and mechanical investigation have been conducted in Geotechnical Laboratory, Faculty of Engineering, UNIMAS, Sarawak. All the tests, namely Proctor compaction tests, unconfined compressive strength (UCS) tests and California bearing ratio (CBR) tests were conducted in accordance with BS1377: Part 2:1990 [36] unless stated otherwise.

2. Materials

The materials used in this study consists of Sarawak peat, Ordinary Portland Cement (OPC) as a binder, reinforcing materials (i.e., shredded rubber crumb and rubber powder) and Melamine Urea Formaldehyde (MUF) resin that acted as an additive.

2.1. Peat

The peat samples for this study were collected from Kampung Meranek-Langsat, Kota Samarahan. The majority of the surrounding location is mostly dominated with pineapple plantation. This location can be found in Fig. 1 and is categorized under moderately to severely degraded of peat [10]. Preliminary, top vegetation was cleared to remove unwanted grass and roots from the upper soil layer. To obtain the samples for this study, a disturbed soil samples was collected by excavation of trial pits and taken from a depth of 0.3 to 1 m below the ground surface. To avoid further possible oxidation, all samples were immediately placed and sealed in a black plastic storage.

The Von Post classification system was carried out during the peat sampling, and it releases very muddy dark water together with a little amount of granular peat escaped from the fingers as the peat was squeezed. The visual classification of the test conducted is shown in Fig. 2. Thus, the peat is classified as hemic peat which is categorized as H5; moderately decomposed peat with very pasty residue and dark brown in colour. The organic content (OC) of peat is determined through the loss of ignition test and the value obtained is 96 %. Based on the test, it can be seen that the moisture content of the peat is very high, which is 566.7 % which related to the high percentage of organic matter. The summary of the geotechnical properties of the studied Sarawak peat is presented in Table 1.

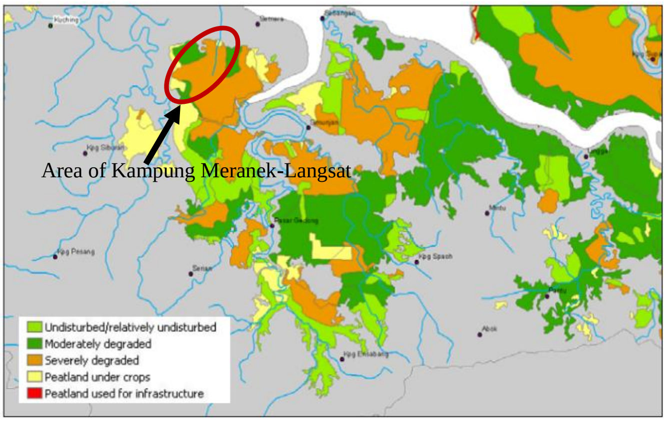

Fig. 1. Distribution and status of peat swamp forest in Samarahan Division.

Fig. 2. Von post scale classification (Hemic peat, H5).

Table 1. Engineering properties of studied Sarawak Peat in Kota Samarahan, Sarawak.

Basic properties	Result
Degree of decomposition	H5 (Hemic)
Natural Moisture Content, w_N (%)	566.7
Undrained Shear Strength, c_u (kPa)	11-19
Organic Content, *OC* (%)	96
Specific gravity, G_s	1.31
Liquid limit, *LL* (%)	107.5
Shrinkage limit, *SL* (%)	5.36

2.2. Ordinary Portland cement (OPC)

Ordinary Portland Cement (OPC) was used in this study as a binding agent to stabilize the peat soil at a controlled percentage of 5% from the dry weight of peat. The utilization of OPC will enhance the hydration process in the soil mixture due to the presence of the organic matter and low pH of peat that tends to interfere with the hydration process. Furthermore, with its low pH value, the acidic nature of the peat soil will interact with the calcium released during cement hydrolysis that will form an insoluble calcium humic acid. This causes a decrease in calcium crystallization that resulting in an increase in the peat-cement mixture strength. OPC that used in this study is manufactured by Cahaya Mata Sarawak Cement Sdn Bhd (CMS), Sarawak. Table 2 represent its physical and chemical characteristics.

Table 2. Physical properties and chemical composition of OPC (Adapted from Balang et al. [37]).

Ordinary Portland Cement (OPC) ASTM Type 1		
Physical Properties	Bulk Density	1.2 - 1.4 kg/L
	Specific gravity	3.15
Chemical Composition (%)	Silicon dioxide, SiO_2	19.34
	Aluminum oxide, Al_2O_3	5.20
	Ferric oxide, Fe_2O_3	3.41
	Sulphur trioxide, SO_3	2.85
	Magnesium oxide, MgO	1.44
	Potassium oxide, K_2O	0.47
	Calcium oxide, CaO	64.75
	Sodium oxide, Na_2O	0.10
	Loss on ignition, LOI	3.42
	Free Cao	1.39
	Total Alkali	0.41

2.3. Processed scrap tire: shredded rubber crumb (RC) and Rubber powder (RP)

The processed scrap tire that acts as fibre reinforcement material in this study is shown in Fig. 3. This material was supplied by ZHA Environmental Sdn Bhd, a local company located in Matang, Sarawak. A mechanical grinding machine is used to process the scrap tire, which has been classified according to the required size. The reinforcing wire of the scrap tire was removed first before being converted into rubber crumbs, rubber powder and fibre polyester. The size of shredded rubber crumb used in this study is ranging from 1-5 mm and rubber powder is in the range of 0.08-1.6 mm which is classified as a fine material. The amount of the reinforcing materials was controlled at 10% of dry weight of peat.

Rahgozar and Saberian [31], investigated the effects of adding sand as a filler at a constant dosage of 400 kg m^{-3} and varying dosages of tire chips (5-20% by weight) to stabilized peat soils. According to the study's findings, a mixture containing 10% shredded tyre chips had the highest unconfined compressive strength with a value of 405.4 kPa, which was approximately 64 times that of untreated peat. The inclusion of 10% tyre chips in the sample resulted in the highest stiffness and significantly enhanced ductility. Besides, Saberian and Rahzogar [13] investigated the performance of waste tyre chips (10% by weight) and sand (400 kg m^{-3}) supplemented with a pozzolanic binder (gypsum, lime, or cement) at a range of dosages of 5%, 10%, and 15% by weight as a peat stabilizing agent, and all samples with additives showed increased values in the unconfined compressive strength. Therefore, the authors chose to control the value of tyre chips at 10% based on the findings of previous studies.

(a) Shredded rubber crumb. **(b) Rubber powder**

Fig. 3. Processed scrap tire.

2.4. Melamine urea formaldehyde (MUF) resin

Generally, material stabilization can be achieved by adding a chemical substance to the material that interacts quickly with the particles of the material, then gluing them together to form a stronger material. This includes the use of resin like Melamine Urea Formaldehyde (MUF). Polymer such as Melamine Urea Formaldehyde (MUF) is often available as an industrial mass product in liquid and solid powder forms and commonly used in the wood and plastic industries. It is a type of polymer with extremely high compressive, tensile and bond strength. The percentage of MUF to be mixed with peat samples in this study is varies at 10%, 20% and 40%, respectively with the total weight of dry peat. The MUF resin used for this study in the form of a transparent liquid as shown in Fig. 4. The details and specification of MUF polymer resin provided by Hexzachem Sarawak Sdn. Bhd are listed in following Table 3.

Fig. 4. Liquid melamine urea formaldehyde (MUF) polymer resin.

Table 3. The properties of liquid MUF polymer resin (provided by Hexzachem Sarawak Sdn Bhd).

Properties	MUF-Liquid
Appearance	Clear and colourless liquid
Viscosity Brookfield @ 30 ° C	55 - 110 MPa.s
Solid content @ 3 hrs./105 ° C	51 - 53%
Specific gravity @ 30 ° C	1.205 - 1.235
pH @ 30 ° C	8.5 - 9.0
Free formaldehyde	0.8 % max
Gel time	55 - 65 sec
Water tolerance	40% - 70%
Chemical formula	$HO(CH_2\text{-}NH\text{-}CO\text{-}NH)_nCH_2O$

3. Sample Preparations and Methods

The collected peat soil samples are first dried under sunlight for about 1 week and crushed by a mechanical machine. Then it is sieve to a size finer than 2mm. In this study, the treated reinforced peat was tested using the unconfined compressive strength machine at designated mixture and curing methods. The design mix consists of peat (Pt), cement (C), shredded rubber crumb (RC), rubber powder (RP) and melamine urea formaldehyde (MUF) polymer resin. The dry peat sample at its optimum moisture content (OMC) of 43% and maximum dry density (MDD) of 0.782 Mg/m^3 was treated by liquid MUF to represent relatively dry moisture condition of the peat. Compaction test by standard proctor (accordance to BS 1377: Part 4: 1990) was used to prepare relatively dry peat specimens in order to provide optimum moisture content that were specifically intended to be mixed with liquid MUF resin.

The samples then cured under air dried curing method, in Geotechnical Laboratory, UNIMAS for 7- and 28-days. On the other hand, the high-water content of natural peat soil was also treated with MUF as a control sample for comparison with the reinforced peat samples. The measured parameters of the stabilised soil must be compared with those of (a) untreated peat, (b) peat with cement, and (c) peat with MUF (alone) as an additive to determine the degree of improvement in the mechanical properties of the test specimens and to ascribe it to the different additives as suggested by Saberian and Rahzogar [13].

RC and RP, were added as non-active additive agents, acting as fillers in the mix design. Fibre reinforcement is added to promote the soil particle cohesion and to act as a structural mesh that bonds the soil together in order to increase soil structural stability. Cement is also added to act as the bonding agent. Both additive agents and cement was added at controlled proportion of 10% and 5% respectively.

The amount of cement used for stabilization was chosen based on previous study on the stabilization of peat using cement conducted by different researchers [32, 38, 39]. This selection is supported further by Paul and Hussain [40] statement, which states that, regardless of the organic composition of the soil, 5% of cement is adequate to meet the minimum strength criteria after 28-days of curing. Besides, the rationale for the percentages of the rubber content is based on the recommendation of prior published work done by Rahzogar and Saberian [31].

The procedures for preparing the stabilised soil admixtures and test specimens were as described in [6]. The mixture of Pt, C, RC or RP at different percentages of MUF resin is homogenously mixed using the mixer for at least 3-5 minutes after water addition to ensure all the added materials were evenly distributed. The mixed samples were then moulded into a 38 mm diameter cylinder at 3 compacted equivalent layers. The samples then wrapped using a plastic film and stored at 7- and 28-days of curing period at ambient temperature including control samples. In this study, the air curing method is used to improve sample stability by allowing moisture content to gradually decrease [41]. By enabling peat to progressively lose moisture content over time and grow drier and harder, no additional water is required throughout the curing process by means no submerging the samples in water. Tables 4 and 5 shows the design mix for reinforced peat performed in this study.

Table 4. Design mixture for UCS test.

Sample	Design Mix	No. of samples		
	Curing period (days)	**0**	**7**	**28**
Control sample	Pt only	3		
	Pt + 5% C		3	3
	Pt + 10% MUF		3	3
	Pt + 20% MUF		3	3
	Pt + 40% MUF		3	3
Reinforced samples	Pt + 5%C + 10% RC + 10% MUF		3	3
	Pt + 5%C + 10% RC + 20% MUF		3	3
	Pt + 5%C + 10% RC + 40% MUF		3	3
	Pt + 5%C + 10% RP + 10% MUF		3	3
	Pt + 5%C + 10% RP + 20% MUF		3	3
	Pt + 5%C + 10% RP + 40% MUF		3	3

Note: Pt-Peat; C-Cement; MUF-Melamine Urea Formaldehyde;
RC-Shredded Rubber Crumb; RP-rubber powder

Table 5. Design mixture for CBR test.

Sample	Design Mix	No. of samples	
	Curing period (days)	**0**	**7**
Control sample	Pt only	2	
	Pt + 40% MUF		2
Reinforced samples	Pt + 5%C+ 40% MUF		2
	Pt + 5%C + 10% RC + 40% MUF		2
	Pt + 5%C + 10% RP + 40% MUF		2

Note: Pt-Peat; C-Cement; MUF-Melamine Urea Formaldehyde;
RC-Shredded Rubber Crumb; RP-Rubber Powder

4. Results and Discussion

This section presents the results of the proctor compaction test, unconfined compression strength tests, and California bearing ratio testing on the effect of reinforced peat reinforced with shredded rubber crumb (RC) and rubber powder (RP) along with melamine urea formaldehyde (MUF).

4.1. Unconfined compressive strength (UCS) effect of reinforced peat

All of the reinforced peat samples were compacted using a Harvard Miniature Compacter with a diameter of 38 mm and a height of 76 mm and prepared at their optimum moisture content. The internal part of cylindrical tube was applied with a thin layer of grease to reduce friction during the sample extraction. The specimens were then extruded using a jack, wrapped and sealed with plastic wrap then cured for 7- and 28-days prior testing. BS 1377: Part 7 (1990) was used to conduct the unconfined compressive strength test and it was carried out by applying axial compression load per unit area to the soil specimens until it failed. In this study, three samples had been prepared and tested, and the average value was taken into consideration and analysed. The summary of the unconfined compression test values is tabulated in Table 6 and the strength performance of the cemented reinforced peat is illustrated in the Figs. 5 and 6, respectively.

Table 6. Summary of UCS results.

Sample	**Design Mix**	**Unconfined Compressive strength (kPa)**		
	Curing period (days)	**0**	**7**	**28**
Control sample	Pt only	57.29	-	-
	Pt + 5% C	-	78.00	145.53
	Pt + 10% MUF	-	124.58	65.708
	Pt + 20% MUF	-	136.08	87.09
	Pt + 40% MUF	-	418.25	382.47
Reinforced samples	Pt + 5%C + 10% RC + 10% MUF	-	55.44	31.37
	Pt + 5%C + 10% RC + 20% MUF	-	232.95	217.16
	Pt + 5%C + 10% RC + 40% MUF	-	170.96	173.10
	Pt + 5%C + 10% RP + 10% MUF	-	118.00	66.99
	Pt + 5%C + 10% RP + 20% MUF	-	182.77	195.43
	Pt + 5%C + 10% RP + 40% MUF	-	437.66	321.71

From the figures show that the addition of RC and RP of 10% in the cemented reinforced peat increased the UCS value for both 7- and 28-days, respectively. One can be seen that the highest unconfined compressive strength (UCS) is recorded with the design mix of cemented peat with 10% RC and 40% of MUF which is 437.7 kPa for 7-days curing period (Fig. 5). The strength increment was high comparing to the natural peat strength value that only possessed 3.334 kPa. However, the strength decreased about 26.5% with the curing time of 28-days of the same design mixture. The positive sign of incremental by curing period in reinforced peat with RP shown in the design mix of cemented reinforced peat with the addition of 10% rubber powder and 20% MUF. The value slightly increased about 7% from 7-days to 28-days of curing period. The mixture of peat and 40% of MUF also shows higher strength achieved in 7-days curing period which is 396.5 kPa but decreased by 18.9% when reach 28-days. From the result, it can be concluded that the use of 40% MUF was able to create an improvement in strength of the peat with or without the addition of cement and RP, as can be seen throughout the strength of two peat samples. Besides, it can be observed that the strength achieved by peat with 5% cement at 28-days is higher compared to the 7-days curing time although 5 out of 7 design mixture shows a decremental value for 28 days of curing. This shows that the strength of the design mix of peat and cement is better in-28 days and is increasing by times.

From the results shown, it is indicated that the strength improves with increasing percentages of MUF but declines with time, with the exception of cemented specimens with 10% RP and 20% MUF addition. As a matter of fact, it can be concluded that the reinforced sample mix design with 10% and 40% MUF produces better results at 7-days, whereas the reinforced sample mix design with 20% MUF performs better at 28-days.

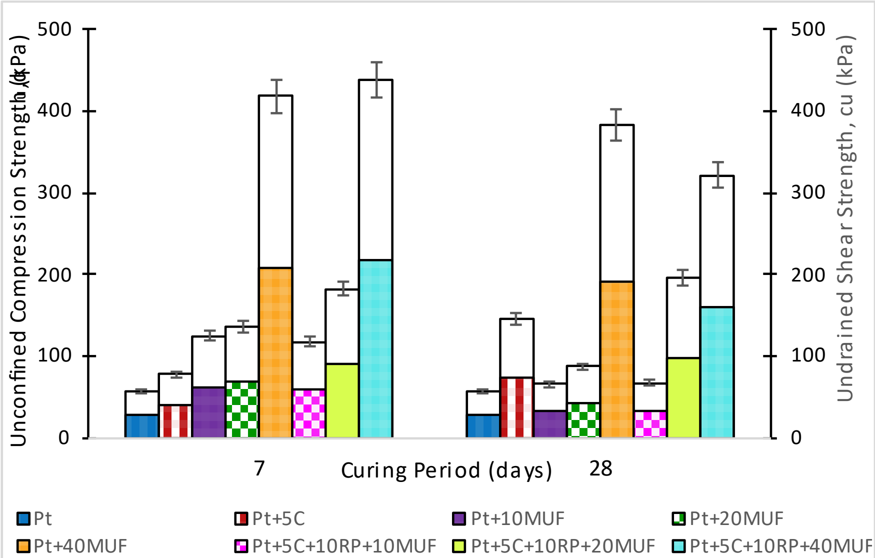

Fig. 5. Reinforced peat with rubber powder.

Based on the findings from the UCS test, the strength decreases over time as indicated in Fig. 5 for reinforced peat with RP. The behaviour of the resin with combination with peat is the reason for this behaviour. Resin behaves like a glue, binding the soil particles thus hardening the sample. As the number of curing days increases, the sample becomes harder and more brittle. This explains why some of the design mix strength deteriorates with time.

Figure 6 shows the reinforced peat with RC and various percentage of MUF polymer resin. When compared to natural peat, which has a strength of only 3.334 kPa, the strength increase for the treated peat was significant. By referring to Fig. 6, design mix of peat with 40% MUF shows the highest UCS value which is 418.3 kPa. Furthermore, design mix of cemented peat with 10% shredded RC and 20% MUF had the maximum unconfined compressive strength (UCS) at 7-days with 232.9 kPa. However, the strength decreased to 217.2% at 28-days of curing, which means about 6.7% decrement. From the graph, it shows that the cemented peat reinforced with RC and addition of 10% and 20% of MUF has a strength decrease from 7-days to 28 days. The strength of peat and 10% MUF drop the most at 57.27% when compared to other mixtures. However, the strength of reinforced peat with RC, C and 40% MUF resin show a slightly increase in the strength at 28-days of curing period from 170.96 kPa to 173.1 kPa.

This rapid strength growth throughout the 7-day curing period is considered to be connected to the MUF resin's initial rapid hydration. The decrease in the UCS value following the addition of 40% MUF resin could be a result of the excess resin being added to the soil, forming weak connections between the soil particle and the cementitious compound formed. Kolay and Pui [15], confirmed a similar trend in their study, stating that increasing the number of additives results in a decrease in the UCS value. Increasing hardener (MUF) addition can result in brittleness of the cured resin and a high level of acid residue in the bond line.

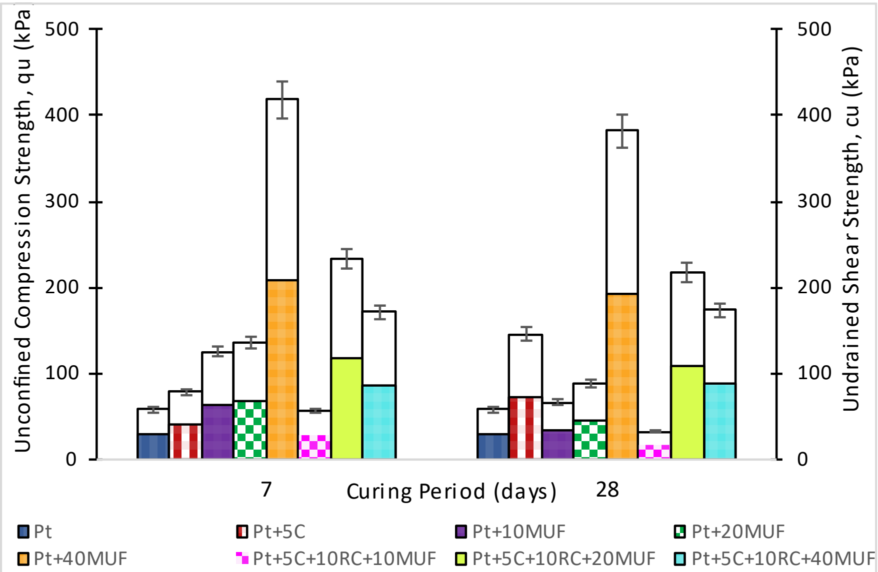

Fig. 6. Reinforced peat with shredded rubber crumb.

According to Dunky and Pizzi [42], deterioration of a bond line can occur as a result of resin failure, resulting in decreased hydrolysis resistance and a loss of bonding strength due to resin degradation. Failure of the interface between resin and the soil surface can also occur as a result of water or other non-resin substances displacing secondary forces between resin and reactive soil surface locations. Additionally, the dissolution of bonds caused by mechanical forces and stresses results in swelling and thus movement of the structural components in the sample that are affected by water. Moreover, liquid resin hardens significantly faster than Portland cement, with resin reaching its ultimate strength in hours depending on the type and concentration, whereas cement hardening might take months or even years due to pozzolanic reaction [43, 44].

Thus, at an early age of 7-days, rapid hardening of liquid resin increases the efficiency of soil strength improvement; but, as curing time increases, cement stiffness increases due to the stability of resin stiffness, resulting in an apparent decrease in liquid polymer efficiency [45]. By reinforcing samples with resin, the strength of 28-day samples decreased, despite the possibilities of resin polymerization and cement pozzolanic reactions during the time period. Therefore, it is probable that the pozzolanic reaction of cement was inhibited as a result of the soil and cement solidifying because of the resin's polymerization reactions. Given the increase in strength of stabilized samples using only cement, it is possible that polymerization processes prevent the pozzolanic reaction from being completed [46].

ASTM D4609-Standard Guide for Evaluating Effectiveness of Admixtures for Soil Stabilization [47] indicates that an effective soil stabilisation treatment must result in an unconfined compressive strength of 345 kPa (50 psi) or above. As illustrated in Fig. 7, the observed UCS value for 7-days was greater than 345 kPa for the admixture of 40% MUF which is 418.2 kPa and the admixture of 5% cement, 10% RC and 40% MUF which is 437.7 kPa. The UCS value was the highest with the addition of 5% cement, 10% RP and 40% MUF, while the highest ductility was achieved with 40% MUF at 7-days of curing period, as indicated in Fig. 7.

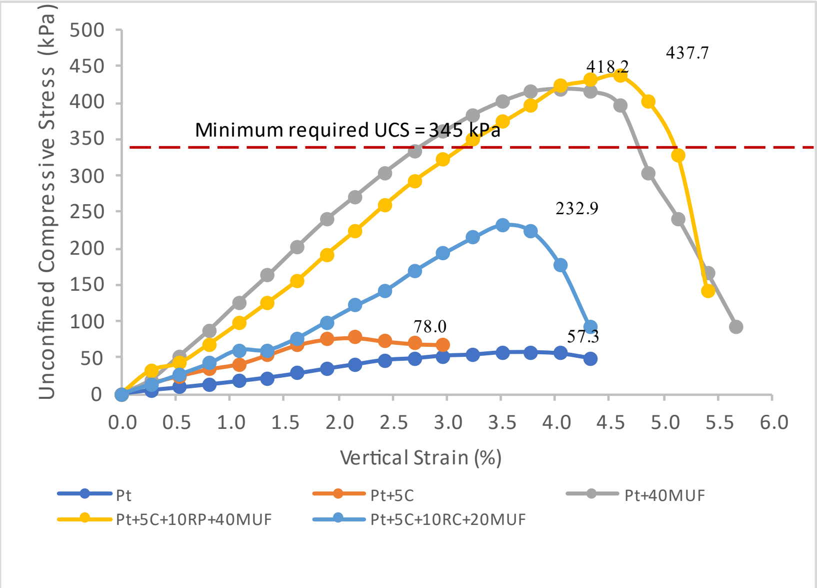

Fig. 7. UCS results on selected specimen at 7 days of curing period.

Despite the fact that the strength of the peat with 5% cement, 10% RC and 40% MUF mix design was the highest for 7-days of curing, it is essential to specify that the treated peat is indicating a ductile behaviour along with the specimens of 40% MUF. This improved strength and ductility may help prevent cracking and/or failure of the soil under load [31]. From the results, it is undeniable that adding shredded rubber crumb and MUF to the peat increases its strength when compared to the natural peat, although the strength specimens cured for 7-days are higher than the 28-days.

After 28-days of curing, the admixture containing 40% MUF had a UCS of 382.5 kPa at a vertical strain of 3.5%, as shown in Fig. 8. This is the highest UCS, and stiffness values achieved, and the value was above the minimum requirement of 345 kPa. However, the cemented peat mixture exhibited quite brittle behaviour, with maximum strength being reached at relatively small elastic strains. Additionally, the UCS values for three other admixtures were below than the ASTM D4609 minimum strength requirement. Overall, the results of this study indicate that the efficiency of adding MUF and rubber waste to peat stabilization leads in an increase in the strength and the stiffness of the peat.

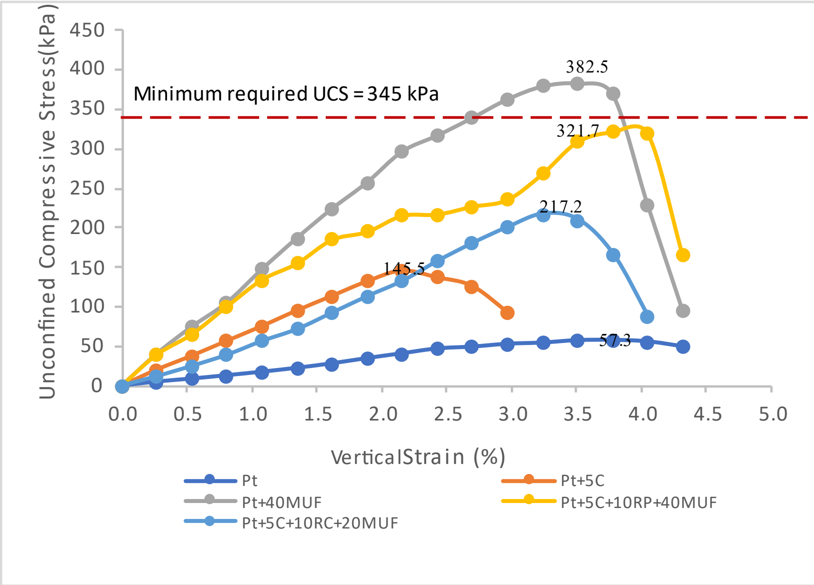

Fig. 8. UCS results on selected specimen at 28 days of curing period.

According to Rahgozar and Saberian [31], the function of tyre waste in stabilised soil admixtures is similar to that of fibres in reinforced concrete in prevent crack formation and limit the widening of any cracks that do form. The decrease in strength and stiffness at tyre chip addition is due to a reduction in bonding between chips and soil caused by a decrease in peat homogeneity and consistency. This behaviour is caused by an increase in the content of reinforced materials such as RC and RP in the mixture, which increases the bonding between the reinforced materials and the soil particles. As a result, the friction is increased, making it more difficult for the soil particles around the reinforced materials to move position from one point to another, increasing the cohesion of the treated reinforced samples [32]. The findings also support Kumar and Gupta [48], who said that when soil exhibits local cracks, the reinforced materials used will cross the cracks and absorb the tension in the treated samples. Thus, effectively inhibits further crack propagation and increases the soil's frictional resistance to the applied load.

4.2. CBR strength effect of reinforced peat

California Bearing Ratio (CBR) test was conducted to investigate the strength effect and measure the improvement of cemented reinforced peat for subgrade embankment applications. To maintain consistency of the test, the reinforced peat is prepared in a rigid metal cylindrical mould with an internal diameter of 152 mm and 178 mm height. The specimens were prepared at the same MDD and OMC as the UCS test in soaked condition for 7-days of curing period. Figure 9 presents the results of reinforced peat using RC and RP for soaked condition. Based on the figure, the addition of reinforcing agent significantly improved the CBR value when compared to untreated specimens and specimens treated with MUF resin only. The addition of 10% RC contributes to the highest CBR soaked value which is 20.31%. It was also observed that the addition of 10% RP also shows an increment in CBR soaked value of 18.88%.

According to the Public Works Department (PWD) Malaysia Design Manuals (ATJ 5/85, JKR Malaysia, (1985)) [49], the subgrade embankment must have a minimum CBR value ranging from 5% to 12% for T1-T5 types of roads. As a result of this study, the reinforced peat employing RC and RP shown a considerable improvement in strength development by exceeding the minimum intended CBR value of 5%. This suggests that the increased bearing capacity of stabilized soil is not just related to the cement hydration process over time, but also to the rubber and resin content in the soil mixture. A significant reduction in the total thickness of the pavement can be achieved by increase in the CBR value.

Rubber powder and rubber crumb are non -striped rubber products with small particle size that can be used to reduce the impact of soil after mixing. In addition, it can reduce the load on the foundation to increase the shear strength of the soil and other mechanical properties [50]. The increase in cohesiveness is primarily due to the increase in strength of rubber reinforced soil.

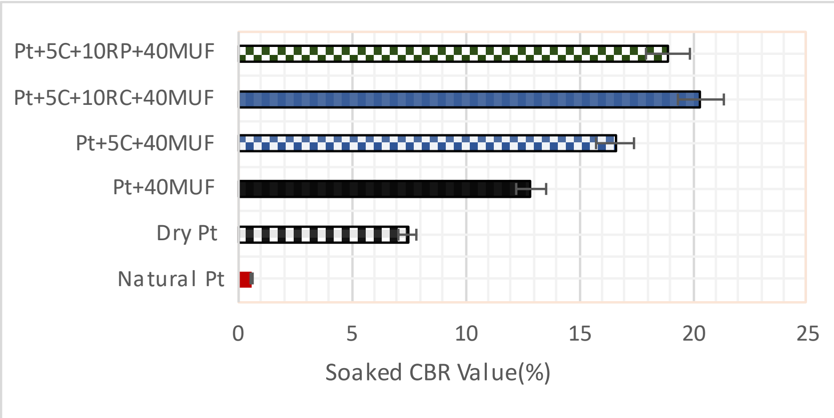

Fig. 9. Soaked CBR for fiber reinforced peat.

Figure 9 shows that mixture with RC has the maximum strength due to the higher tensile strength of the mixture due to reinforcement. Nonetheless, the mixture containing RP has a lesser strength due to the mixture's impaired cohesiveness. According to Akbarimehr and Fakharian [49], granular rubber in the form of longitudinal components results in more effective reinforcement, increasing strength and volumetric strain. The reinforcing property increases the resistance of the rubber crumb mixture.

Furthermore, the higher strength of granular rubber (RC) specimens compared to fine rubber (RP) specimens can be attributed to grain size. Because the RC particles are larger than the RP particles, the reinforcing is more effective, increasing the strength and volumetric strain of the RC soil mixture. The RP particles are predominantly spherical, making them prone to dislocation and slip, whereas the RC particles are larger and mostly fragmented, which can better occlude and have a better shear effect [51]. Granular rubber reinforces the soil by promoting strong adhesion between rubber and soil particles. Because coarse rubber particles share a larger surface area with the soil in the mixture, it provides more reinforcement, increasing the mixture's strength.

According to Akbarimehr and Fakharian [51], as the rubber grain size decreases, the rubber grains become more evenly distributed between the soil particles and a more homogeneous mixture forms, resulting in a more effective transfer of the rubber's elastic properties to the soil. Furthermore, Saberian et al. [52] discovered that the addition of either RP or RC increased the soil's shear modulus, damping ratio, and unconfined compression strength. Rubber crumb, on the other hand, proposed a more effective improvement than rubber powder.

5. Conclusions

The study was conducted on reinforced peat soil samples using shredded rubber crumb and rubber powder that act as a lightweight waste material with the addition of MUF resin as an additive. A series of unconfined compression test and California bearing ratio test was conducted to investigate the strength improvement for both cemented and uncemented reinforced peat.

From the UCS tests, it shows an increment with the addition of 10%, 20% and 40% of MUF resin. The highest strength gain is 437.7 kPa for the inclusion of rubber powder with 40% of MUF resin while 232.9 kPa for the inclusion of shredded rubber crumb with 20% MUF resin. However, the strength recorded a decremental value over curing time for both mix design except for the addition of peat with 10% rubber powder and 20% MUF and also the design mix of peat with 10% shredded rubber crumb and 40% MUF that shows incremental strength value from 7 days to 28 days of curing time.

When compared to natural peat, the CBR value of reinforced peat was improved for all tested design mix. The maximum CBR value recorded was the design mix of cemented peat reinforced with 10% shredded rubber crumb and 40% MUF resin with the value of 20.31%. The value exceeded the requirement for minimum CBR value of 5% for subgrade embankment from Public Works Department (PWD) Malaysia Design Manuals.

From the results of this study, it can be concluded that the use of shredded rubber crumb and rubber powder with the addition of MUF as an additive can improve the engineering properties of peat soil.

Thus, these finding can be useful in the construction field in determining the optimum percentage of design mix for the construction purposes. However, further research can be conducted with a longer curing period to investigate the strength performance of the reinforced peat soil over extended length of time.

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