Applicability of Calcium Carbide Residues for the improvement of Soft Peaty Clay

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***Abstract*— Most of the constructions in Sri Lanka is to be carried out on soft peaty clay. The problems with the soft peaty clay are its high-water content, being extremely compressible and having very low shear capacity. Therefore, from an engineering point of view it is very important to improve the geotechnical properties of this weak soil. Among the methods of chemical stabilization, the most common method used in world is stabilization using cement. However, using cement in such large-scale projects is unbearable for a developing country like Sri Lanka. This study is to evaluate the suitability of Calcium carbide residues (CCR) as a binder to improve soft peaty clay. Number of samples were prepared by mixing CCR with different proportions having maximum of 20% binder in soil. Improvements achieved in strength of treated peat for short term and long term were assessed by conducting unconsolidated undrained triaxial tests at 28 days and 90 days respectively. The results have shown that when the CCR content is increased, shear strength is gradually decreased in both short-term and long-term curing. However, strength improvement due to CCR is higher in long-term curing. That will be economically beneficial in projects where stabilization of soil is done in larger scale.**

Keywords—calcium carbide residues, microstructure, shear strength, soft peaty clay, soil stabilization

I. INTRODUCTION

Rapid development in the construction industry leads the geo technical engineers to emphasize on the improvement of weak soil. Since the demand for the land is getting high, the industry has to look for the lands even with the presence of underlaying peaty clay for the constructions although the required soil conditions are not present.

The peaty clays which is frequently encountered in the highway embankments in Sri Lanka are with a water content of nearly or more than 300% and have a shear strength as low as $2kN/m^2$ [1]. Peat consists of organic and fiber matter and the classification of peat is based on degree of humification (von post scale). Presence of the organic matter in peat clay is a critical issue since further decomposition of this organic matter due to the environmental changes leads to the failures of the structures made on peaty lands. Peat has a comparatively higher pore volume (high void ratio) and therefore it has a low bulk density and a low bearing capacity. Further, lowering the ground water table may cause the shrinkage of peaty clay with the removal of higher water contents in peat [1].

Although the shear strength of peaty clay is very low it can be made high by several methods. Preloading is one such technique where soil undergoes primary and secondary consolidation. Primary consolidation is due to the dissipation of excess pore water pressure caused by the increase in effective stress followed by the secondary consolidation where the compression of fibrous peat occurs under constant effective stress. Permeability plays a major role in consolidation since it speeds up the process. Previous studies reveal that the peat is averagely porous and therefore has a medium state of permeability [2]. The embankments are preloaded with a surcharge greater than the load expected on the embankment during the operational stage. Construction of the embankment is done in stages and much time is allocated for the consolidation in each stage which is not time and cost effective for a project.

Replacing the weak soil with granular soil is another practice that can be adopted however absence of a proper way of disposal of the peaty clay to the environment is a problem.

II. CHEMICAL STABILIZATION OF SOFT SOIL

A. Cement as a Stabilizer

Deep mixing method is currently being practiced in the world as a ground improvement technique. The soft soil is mixed in-situ with different binders which will give early strength compared to preloading method. The hydration reaction occurs when cement is used as the binder is shown in Eq. (1).

$$\text{Cement} + \text{water} \rightarrow CSH + CAH + CASH + Ca(OH)_2 \qquad (1)$$

In the cement hydration process hydrated calcium silicates (CSH), hydrated calcium aluminates (CAH), hydrated calcium aluminum silicates (CASH), hydrated lime [$Ca(OH)_2$] are the main products (formation of primary cementitious materials). There is an increase in pH value of the medium due to the dissociation of $Ca(OH)_2$ which let the silica and alumina from the soil to be dissolved as an acid in a strong base. The hydrous silica and hydrous alumina then gradually react with Ca^{2+} ions to form secondary cementitious materials. Formation of cementitious materials get hardened with time and dissipation of pore water for the hydration process make the peaty clay to be stabilized quickly [3].

Madhusanka and Kulathilaka [4] reveals that the ratio of 20-25% of cement is generally used with soil in order to have a considerable improvement in peaty clay soil. It is about 250 kg to stabilize 1 m^3 of embankment which is both economically and environmentally (CO_2 emission due to cement manufacturing) unfeasible. This emphasis the need of an ecofriendly and economical additives for soil stabilization. Previous studies show that attempts are taken to check whether the amount of cement can be reduced or replaced by using $Ca(OH)_2$ rich materials along with or without materials rich with pozzolans. Calcium Carbide Residues is one such material.

B. *Calcium Carbide Residue (CCR)*

Calcium Carbide Residue (CCR) is a byproduct of the acetylene gas production process in sludge form at large scale. The production of CCR is described in Eq. (2).

$$CaC_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2 \quad (2)$$

Eq. (2) shows that 64 g of calcium carbide (CaC_2) provides 26 g of acetylene gas (C_2H_2) and 74 g of CCR. The CCR is generated as an aqueous slurry and is composed essentially of calcium hydroxide $Ca(OH)_2$ with minor parts of calcium carbonate ($CaCO_3$), unreacted carbon, and silicates [5]. There is an increasing demand for a way of disposal of CCR since it is very difficult to dispose to the nature being a highly basic material (one acetylene gas factory produces around 32000 kg of CCR per month in Sri Lanka). Hence, it is economically and environmentally feasible to use CCR as a soft soil stabilizing agent.

There are three basic reactions of CCR stabilized soil namely, Cation exchange, Flocculation and Aggregation and Pozzolanic reaction [6]. When Ca^{2+} is present due to $Ca(OH)_2$, the cation exchange takes place by replacing dissimilar cation of the soil complex by Ca^{2+} ions. The negative charge of clayey soil gets neutralized and makes the soil particles to clump in to large sized particles which is flocculation and aggregation. Then silica and alumina get removed from the soil mineral lattice and reacts with Ca^{2+}. With the pozzolanic reaction, shear strength is gradually increased and ultimately there is a change in plasticity and shrinkage.

There are several studies on the improvement of silty clay and marginal lateritic clay of Thailand using CCR [3,6]. According to those studies, the strength development in CCR stabilized soil can be categorized under three zones. They are;

- *Active Zone* – Strength is clearly increased with the input of CCR and all the input CCR is reacted with natural pozzolanic materials in the soil.
- *Inert Zone* - Strength development with the CCR content gradually slow down since the amount of pozzolanic materials in the soil gets depleted.
- *Deterioration Zone* - Strength is decreased since no pozzolanic materials left and due to the unsoundness caused by free $Ca(OH)_2$.

Further, a research conducted on soft clayey soil showcased that the average value of the CBR sharply increased from 44.9% to 117% for the CCR stabilized soil. Further, the bearing capacity of the stabilized soil increases with curing time [7].

However, up to date, no study has been conducted on the ability of CCR to improve the soil properties of soft peaty clays (organic soil). Hence, the main aim of this research is to investigate the suitability of CCR as an additive to improve the soft peaty clays during the chemical stabilization of soil.

III. EXPERIMENTAL METHODOLOGY

A. *Sample Preperation*

Peaty clay was obtained from the Southern Expressway extension at Beliaththa, Sri Lanka. Debris were removed and a homogeneous peat sample was remolded to avoid the complications arise due to the heterogeneity of the peaty clay. Next the basic properties of the peaty clay were determined and are shown in Table 1. CCR was taken from Ovin Gases Pvt (ltd), a leading acetylene manufacture in Sri Lanka. The Particle Size Distribution is showed in Fig. 1. The specific gravity of CCR was 1.875. Initial Moisture content of the CCR sample was 42.14%. Hence, the CCR was air dried before mixing with the soil samples to remove the moisture. The air-dried CCR consisted of 85.7% of $Ca(OH)_2$, 5.17% of SiO_2, 2.34% of Al_2O_3 and 5.48% of Calcite.

Then samples were prepared by mixing the peat soil with cement and air dried CCR under five different mix proportions (refer to Table 2) using a mechanical mixture to stimulate the dry mixing method in deep mixing of soil. Here, 20% of total cement content (ordinary Portland cement) was selected according to literature [1] and was replaced by CCR as 5% additions (Table 2). Similar mixing speed and durations were ensured for the uniformity of all the samples.

TABLE I. BASIC PROPERTIES OF PEATY CLAY

Basic Property	Value
Moisture Content (%)	277.88
Dry Density (kg/m^3)	343.3
Specific Gravity	1.915
pH Value	3.8
Organic Content (%)	26.22

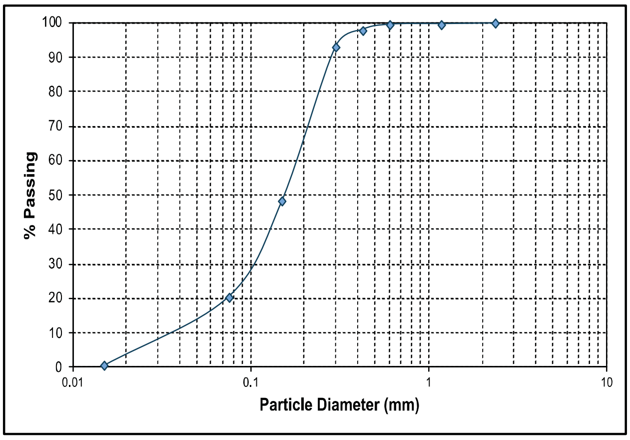


Fig. 1. Particle Size Distribution of CCR Samples

Adequate amount of soil mixes was then placed in buckets and kept fully saturated to achieve actual field conditions. Each bucket was applied with 10 kN/m^2 surcharge after laying a geotextile and thin sand layer on top of the mixed soil samples to facilitate the hardening of peaty clay due to self-weight in the field. Buckets were then kept for 28 days and 90 days curing periods separately for short-term and long-term stabilization respectively. Fig. 2 shows the loading arrangement of the sample. Since, the moisture in the peat is dissipated for the hydration process, water was put in to the buckets at regular time periods.

B. *Testing Soil Specimens*

Undisturbed samples were extruded upon the completion of curing period using a sampler. Unconsolidated undrained tri axial test according to ASTM D2850 was carried out for three samples of each mix proportion having three different cell pressures of 50 kN/m^2, 100 kN/m^2 and 150 kN/m^2. Continuous increment of the axial stress was given until the failure of the sample occurred. Average failure deviator stress and the shear strength parameter (C_u) were determined for each treated sample.

Further, basic properties of the samples of each mix proportion were also determined for short-term and long-term to observe the variations of the peaty clay properties due to the addition of cement and CCR.

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

A. *Variation of Basic Properties of the Soil*

Table 3 and 4 shows the basic properties determined after curing the samples for the different cement and CCR mixtures. According to the Table 3 and 4, moisture content has been considerably reduced compared to the peaty clay sample since moisture is dissipated for the hydration process. Further, this reduction is higher when the CCR amount is increased (mind that water was added to the buckets with samples to facilitate the hydration process). Furthermore, the dry density values have also been increased for both 28 days and 90 days curing periods with cement percentage.

In addition, acidic nature of the peaty clay (pH = 3.8) has been converted to a more basic environment due to the addition of both CCR and Cement. This basic environment facilitates the formation of secondary cementitious materials by stabilizing the peaty clay rapidly.

B. *Unconsolidated Undrained Shear Strength*

Fig. 3 shows the stress-strain and Mohr-circle plots after conducting unconsolidated undrained shear triaxial testing for peaty clay mixed with 20% cement (P+20C) and peaty clay mixed with 10% cement and 10% CCR (P+10C+10CCR) respectively for both 28 days and 90 days curing. Table 5 presents the shear strength (C_u) values obtained for all the tested samples after 28 days and 90 days curing period.

C. *Short-term Improvement of Shear Strength*

The addition of 20% CCR only take that value to 10.3 kPa. With the increment of Cement amount in the mixture, the C_u value increases gradually. Highest C_u value of 53.76 kPa is achieved by the Peat + Cement 20% sample.

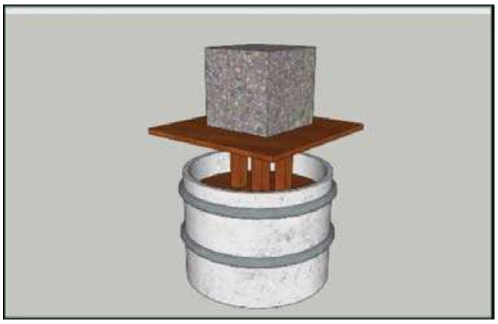


Fig. 2. Loading arrangement used for curing stabilized peaty clay samples

TABLE II. MIX PROPORTIONS

Notation	Peat (%)	Cement (%)[a]	CCR (%)[a]
P	100	0	0
P+20C	100	20	0
P+15C+5CCR	100	15	5
P+10C+10CCR	100	10	10
P+5C+15CCR	100	5	15
P+20CCR	100	0	20

[a.] Additive percentage is calculated from the total weight of peaty clay used for each combination

TABLE III. BASIC PROPERTIES AFTER 28 DAYS OF CURING

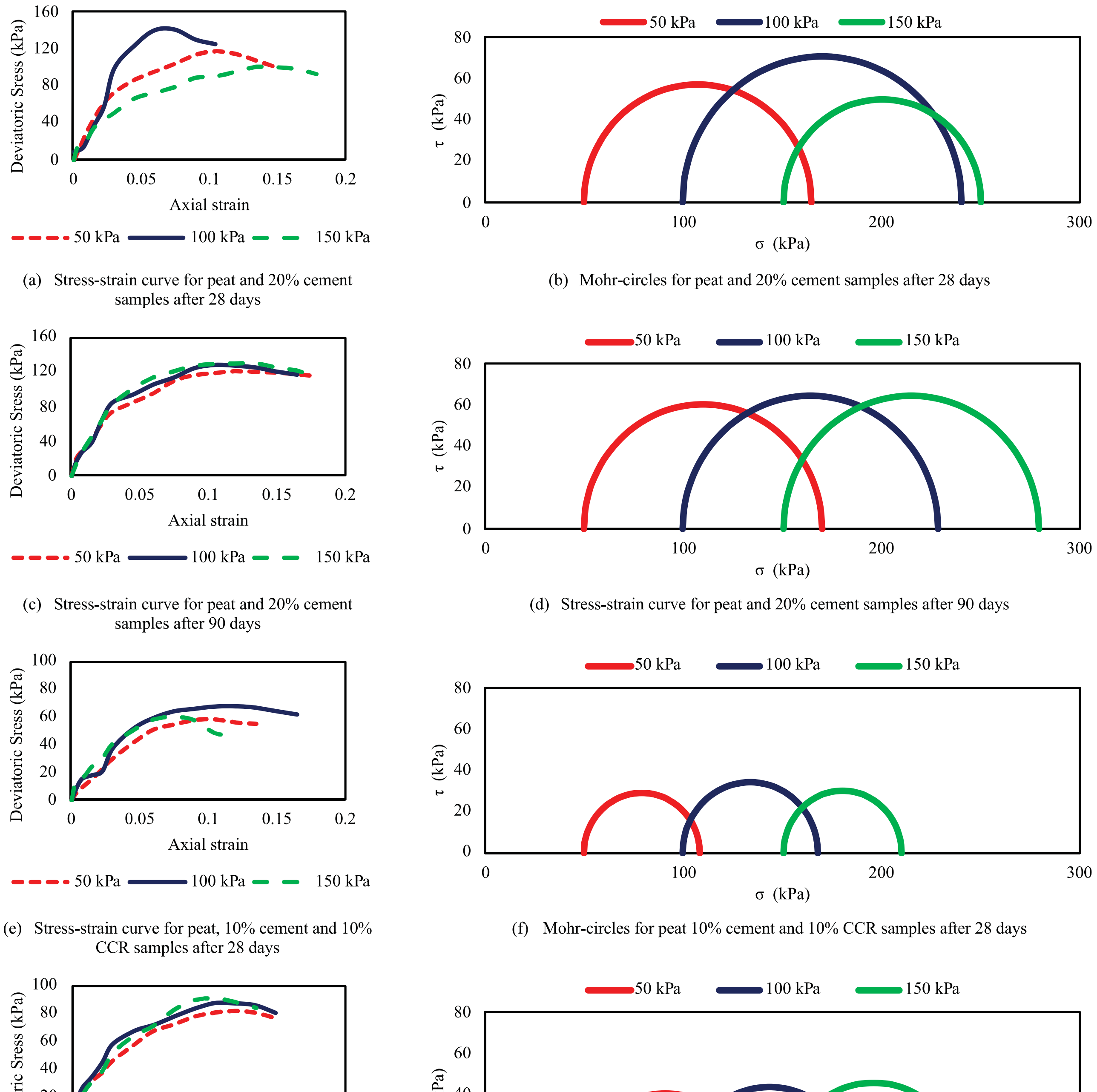
Sample	Moisture Content (%)	Specific Gravity	Organic Content (%)	pH	Dry Density (kg/m^3)
P	253.47	1.915	26.22	3.8	343.30
P+20C	192.14	1.985	20.58	9.3	571.48
P+15C+5CCR	179.93	1.997	18.34	10.5	527.06
P+10C+10CCR	171.68	2.037	19.15	11.2	489.71
P+5C+15CCR	150.19	2.108	18.05	9.4	471.21
P+20CCR	140.35	2.150	17.37	11.1	448.38

TABLE IV. BASIC PROPERTIES AFTER 90 DAYS OF CURING

Sample	Moisture Content (%)	pH	Dry Density (kg/m^3)
P	240.85	3.8	416.05
P+20C	121.65	9.5	587.14
P+15C+5CCR	155.95	10.8	541.50
P+10C+10CCR	148.80	11.3	503.13
P+5C+15CCR	130.18	9.7	484.12
P+20CCR	129.35	11.8	460.67

TABLE V. C_U VALUES OF THE TESTED PEATY CLAY SAMPLES

C_u (kPa)	Samples					
	P	*P+ 20C*	*P+15C+ 5CCR*	*P+10C+ 10CCR*	*P+5C+ 15CCR*	*P+ 20CCR*
28 days	7.39	53.76	49.74	31.09	22.22	10.30
90 days	10.39	63.15	54.37	43.44	30.34	19.29



(a) Stress-strain curve for peat and 20% cement samples after 28 days

(b) Mohr-circles for peat and 20% cement samples after 28 days

(c) Stress-strain curve for peat and 20% cement samples after 90 days

(d) Stress-strain curve for peat and 20% cement samples after 90 days

(e) Stress-strain curve for peat, 10% cement and 10% CCR samples after 28 days

(f) Mohr-circles for peat 10% cement and 10% CCR samples after 28 days

(g) Stress-strain curve for peat, 10% cement and 10% CCR samples after 90 days

(h) Mohr-circles for peat 10% cement and 10% CCR samples after 90 days

Fig. 3. Stress-strain and Mohr-circle plots of P+20C and P+10C+10CCR samples after 28 and 90 days

Fig. 4 shows the percentage increment of shear strength compared to the untreated peaty clay specimen. Untreated peat soils show an average C_u value of 7.39 kPa. When we consider the percentage increment with respect to the untreated sample more than 200% increment can be seen in every sample when cement is involved. Significant improvement can be seen in the 5th sample where 15% CCR and 5% Cement is mixed. However, in the last two samples, a huge variation cannot be seen although cement is increased by 5%. Highest strength increment for a 5% increment of cement is seen in the Peat + 10% Cement + 10% CCR sample to Peat +15% Cement +5 % CCR sample.

D. Long-term Improvement of Shear Strength

According to Table 5, untreated peat sample has around 41% increment in shear strength after 90 days compared to 28 days samples showing the effect of preloading. Fig. 5 shows the percentage increment of shear strength compared to the untreated peaty clay specimen. Same trend that was observed in the 28 days results can be seen in the 90 days results as well, where Peat + 20% CCR sample gives the minimum C_u value after the untreated sample and expectedly Peat + 20% Cement gives the highest C_u value. The long-term curing provides higher strength to the peaty clay for all mix combinations (refer to Table 5). Because in longer durations, much time is available for Ca^{2+} ions to get attached with soil particles and to occur flocculation and thereafter the pozzolanic reaction. This indicates the availability of pozzolanic material to further continue the pozzolanic reaction.

E. Effect of CCR on the Strength Improvement

Fig. 6 shows the C_u variation with CCR percentage added to the peaty clay samples for both short-term and long-term curing. According to Fig. 6, addition of CCR by replacing cement has reduced the strength of the peaty clay sample gradually. This might be due to the lack of silica and alumina to form a better pozzolanic reaction compared to cement. For example, the CCR used for the present study has around 5.17% of SiO_2, 2.34% of Al_2O_3. However, OPC has around 20% of SiO_2 and 5% of Al_2O_3 [8]. Hence, more the cement content, more the silica and alumina on mixture providing better pozzolanic reaction.

When comparing the curing time, CCR addition provides higher strength during long-term curing than for short-term curing (refer to Fig. 6). This gives the idea of the capacity of the peaty clay to absorb Ca^{2+} ions which comes from $Ca(OH)_2$. Hence, CCR addition is more beneficial in strength improvement with time.

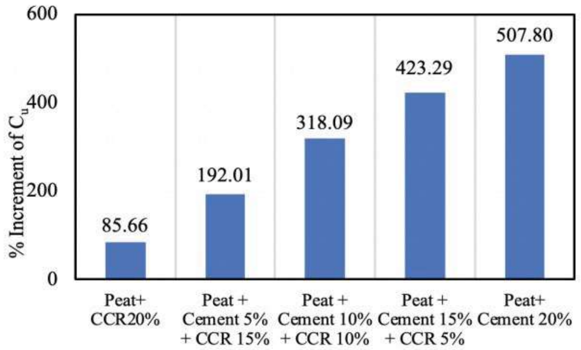


Fig. 4. Percentage increment of C_u for treated peaty clay comapred to untreated peaty clay after 28 days

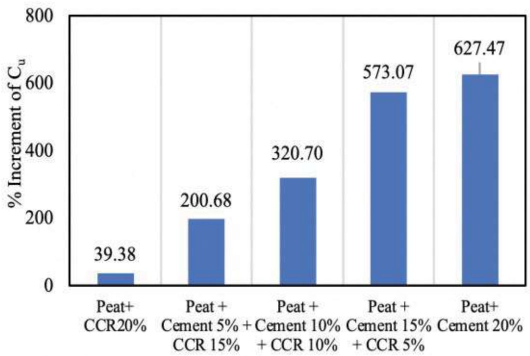


Fig. 5. Percentage increment of C_u for treated peaty clay comapred to untreated peaty clay after 90 days

F. Analysis of Microstructure

Microstructure of CCR, peaty clay and the mixed samples were investigated through scanning electron microscope (SEM) which shows how the particles attribute to the properties. Fig.7(a) shows some irregular shapes of the peaty clay particles in which the voids among the particles are clearly depicted.

CCR particles are plates like structures also with pointed shapes that can be seen in Fig. 7(b). Fig. 7(c) shows that the nature of the peat has been changed in to a more aggregated bonded nature when it is mixed with cement. Irregular shapes of the peaty clay change in to bar shapes resulting the formation of cementitious materials after pozzolanic reaction.

Rod shaped structures can also be seen in the Fig. 7(d), the combination of peat and CCR. In between the rods CCR structures can be seen where pozzolanic reaction has not occurred yet or due to the absence of natural pozzolanic materials. This further explains the observation of Fig. 6 of increased C_u with time. The void nature that present in peat cannot be seen in the Fig. 7(c) and (d) after treatment which provides higher density to the structure as observed in Table 3 and 4.

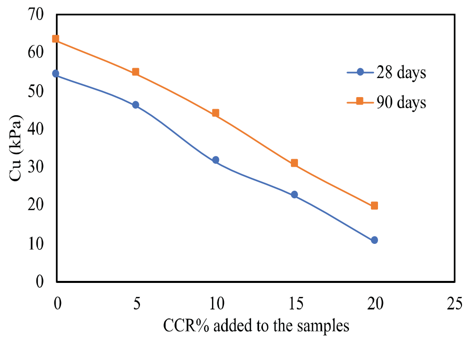


Fig. 6. Effect of CCR% in the treated peaty clay samples during short-term and long-term curing

(a) (b) (c) (d)

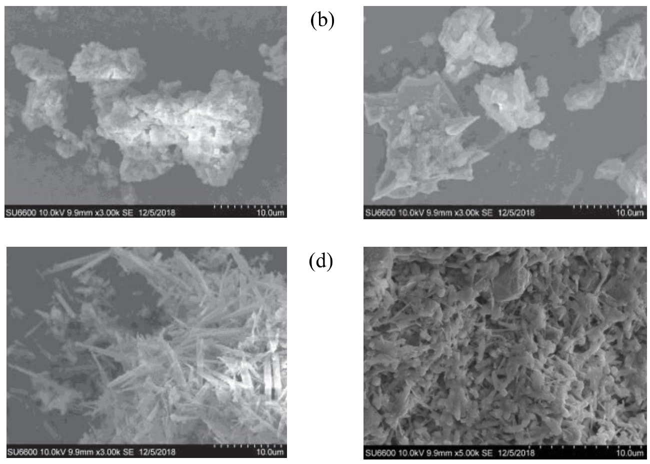


Fig. 7 SEM images of (a) untreated peaty clay, (b) CCR, (c) Peat + 20% Cement and (d) Peat + 20% CCR

G. *Comparison with Peaty Clay Improved by Paddy Husk Ash*

Table 6 shows a comparison of C_u values obtained after treating with Paddy Husk Ash (PHA) using a similar testing procedure [9]. According Table 6, both the soil types has somewhat similar type basic properties. When comparing the percentage increase of both studies shows a higher improvement with PHA compared to CCR at a glance. However, it should be noted that the combinations used here are different. For example, by adding 30% PHA has improved strength by 105% while a 39% of strength improvement is provided by only 20% CCR. Because, PHA has higher pozzolanic materials than CCR and facilitates better formation of secondary cementitious materials. For example, PHA has around 84% of SiO_2 and 4% of Al_2O_3 [10] which are quite higher than CCR.

However, addition of cement with CCR provides much higher strength than with PHA. According to Table 6, by adding 10% of PHA with 20% cement gave only 248% strength improvement while 10% of CCR with only 10% of cement provides 320% improvement. Hence, CCR should be added with cement or any other material rich with silica and alumina (such as Fly ash) to obtain satisfactory strength improvement which warrants future studies.

V. CONCLUSIONS

Following major conclusions can be drawn from the present study.

- When the CCR content is increased, C_u is gradually decreased in both short-term and long-term curing. However, strength improvement due to CCR is higher in long-term curing.
- Compared to PHA, application of CCR alone provides lesser strength increase. However, addition of cement to CCR provides better improvements than for PHA with cement. Hence, CCR should be used with cement or pozzolans rich material to obtain satisfactory results.
- For the peaty clay used for this study, 216 kg of cement is needed to stabilize 1 m^3 of peaty clay (20% cement). In the case of CCR, the optimum results can be obatined when 113 kg from each cement and CCR will be mixed with 1 m^3 of peaty clay (10% CCR + 10% cement).
- Further, to obtain a better understanding of the applicability of CCR for soft soil stabilization, improvement in compressibility characteristics are also need to be studied in the future.

VI. COMPARISON BETWEEN CCR AND PHA TREATED PEAT

Study		Madhuransi [9]		Present Study	
Moisture content (%)		290		277.88	
Organic content (%)		22		26.22	
Specific Gravity		1.98		1.915	
pH		2.1		3.8	
C_u (kPa)	***Peat only***	5.36 (by vane shear test)		7.39	
	Cement only	47	↑777%	53.76	↑627%
		(30% cement)		(20% cement)	
	Alternative only	11	↑105%	10.30	↑39%
		(30% PHA)		(20% CCR)	
	Cement + Alternative	18.67	↑248%	31.09	↑320%
		(10% PHA+ 20%cement)		(10% CCR+ 10%cement)	

The shaded areas show the percentage increase in C_u compared to the respective untreated peaty clay

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