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Experimental study of strength of cement solidified peat at ultrahigh moisture content

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Abstract. Peat soil has the characteristics of high moisture content, large void ratio and low shear strength. In this study, unconfined compressive strength and SEM tests are conducted to investigate the effects of ultrahigh moisture content, cement content, organic content and pH value on the strength of solidified peat. As an increase in the cement content and curing period, the failure mode of solidified peat soil changes from ductile failure to brittle failure. The influence of moisture content on the strength of solidified peat is greater than the cement content. As cement content increases from 10% to 30%, strength of solidified peat at a curing age of 28 days increases by 161%~485%. By increasing water content by 100%, decreases of solidified peat at a curing age of 28 days is 42%~79%. Compared with the strength of solidified peat with a pH value of 5.5, the strength of peat with a pH value of 3.5 reduces by 10% ~ 46%, while the strength of peat with a pH value of 7.0 increases by 8% ~ 38%. It is recommended to use filler materials for stabilizing peat soil with moisture content greater than 200%. Because of small size of clay particles, clay added in the cement solidified peat can improve much higher strength that that of sand.

Keywords: cement content; moisture content; peat; pH value; unconfined compressive strength

1. Introduction

Peat is well known for its inherent high moisture content, low strength and high compressibility (Hobbs 1986). Peat can be classified into one of three categories, namely, fibrous, hemic and sapric peat, based on its degree of humification. Peat soil spreads all over the world and covers about 5~8% of overall land area on earth. Construction on peat soils is challenging as this soil is highly compressive. Chemical solidification is considered an effective solution to deal with insufficient bearing capacity and excessive settlement induced by peat soils (De Guzman and Alfaro 2018, Paul and Hussain 2020, Cheng *et al.* 2021, Kalantari *et al.* 2010). The mechanical properties of solidified peat have great impacts on nearby infrastructures (Shi *et al.* 2019a, b, 2020, 2022, Meng *et al.* 2020).

Mechanical properties of solidified peat can be affected by binder, curing period, initial moisture content, organic content and pH media. Kolay *et al.* (2011) found that cement is the most effective binder and the optimal cement content is 150~250kg/m^3 for peat soil. The range of acidity level in peat varies wildly and pH of most peats is 4~7 depending on the organic content (Kalantari and Rezazade 2015). Acidic peat nature is harmful to the cementation and pozzolanic activity of solidified peat mixture, leading to a substantial decrease in the shear strength of cement treated peat (Huat *et al.* 2011, Kazemian *et al.* 2011, Cao *et al.* 2021). On the other hand, natural peat often has high organic content, which is known to impede the cementing process for cement treated peat. The addition of solid particle filler such as fine sand and clay (e.g., red clay and kaolinite) can increase the strength of peat soil stabilized by cement (Jorat *et al.* 2013, Kalantari and Rezazade 2015, Dehghanbanadaki *et al.* 2020, Wang *et al.* 2020). For example, the addition of quartz sand filler can reduce the void ratio of peat and acts as stiffener to the weak skeleton of peat (Timoney *et al.* 2012, Canakci *et al.* 2019, Wang *et al.* 2020). Other factors such as cement grade and int-situ mixing techniques can also have a significant impact on the strength of solidified peat (Dehghanbanadaki *et al.* 2016, Yu *et al.* 2019).

Although the addition of excessive cement can significantly improve strength of solidified peat, this practice can consume a large amount of cement. Many scholars have proposed to replace cement partially with different fillers (e.g., fly ash and blast furnace slag). For example, Kolay *et al.* (2011) found that fly ash can improve strength of peat soil but the measured UCS is only about 50% that of cement solidified peat. In addition, research carried out by Hernandez-Martinez (2006) revealed that the combination of fly ash and cement does not effectively solidify peat soils. Apart from fly ash, other fillers such as quartz sand, biochar (Lau 2018), rock wool (Cheng *et al.* 2011) and recycled glass (Taha and Nounu 2009) are also proven to be effective in solidifying peat soil. For example, Timoney *et al.* (2012) found that quartz sand can fill the pores between peat particles, and cemented quartz can form at the contact points of quartz grains, thus improve density and strength of peat.

Although extensive studies have been carried out to

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Fig.1 Peat used in the test

investigate geochemical mechanisms of peat stabilized using different binders and fillers, those studies mainly focus on peat soil with initial moisture content of less than 250% (Li *et al.* 2017, Wang *et al.* 2019, Zhang *et al.* 2020, Cao *et al.* 2021). The solidification behavior of peat soil with ultrahigh moisture content (>250%) is missing.

In this study, a series of laboratory tests were conducted to systematically investigate effects of initial moisture content, organic content, pH, cement content and curing time on the strength of solidified peat. Cement and quartz, as binder and filler, were adopted to solidify peat. In addition, the microstructure of solidified peat was observed by scanning electron microscopy (SEM).

2. Soil type and sample preparation

In this study, strength of cement solidified peat at the second trunk road project in Sarawak, Malaysia is studied. This project is located in the southwest of Sarawak, Malaysia. The design speed of second trunk road is 100 km/h, and post-settlement after construction shall not exceed 25 cm. The site mainly includes peat, peat soil, silt and silty fine sand. The thickness of peat is generally in a range of 15 to 25 m. The moisture and organic matter contents of peat in this site are in ranges of 400% to 1000% and 40% to 95%, respectively.

As shown in Fig. 1, the material used in this study was moss peat, which has good water holding capacity. Measured organic content and pH value were 94.3% and 5.56, respectively. According to von Post Classification System (Landva et al. 1983), the peat can be classified as $H_{2\sim3}B_2F_3R_0W_0$, which represents low humification level ($H_{2\sim3}$), moisture content (B_2), crude fiber (R_0) and woody residual (W_0). The major mineral components of the peat are quartz and illite. In order to prepare peat samples of different organic contents (e.g., 40%, 60% and 80%), water washed kaolin, an inorganic soil, was selected as additive.

Compared with mixed clay, the composition of kaolin is clearer, which can reduce the influence of clay mineral on the test results. The kaolin used in study had plastic and liquid limits of 34% and 62%, respectively. Moreover, the specific gravity and pH value of the kaolin were 2.57 and 6.65, respectively. Table 1 lists chemical components of Kaolin.

Based on previous studies (Axelsson *et al.* 2002, Hernandez-Martinez 2006, Cortellazzo and Cola 1999), cement was found to be the most effective binder for stabilising peat soil. Thus, Portland cement is chosen as the curing agent for the peat with high water content. Table 2 tabulates basic physical properties of the cement.

Table 1 Chemical components of Kaolin

Oxide	SiO_2	Al_2O_3	K_2O	Fe_2O_3	MgO	TiO_2	Na_2O
Content (%)	55.17	38.06	4.24	1.41	0.53	0.25	0.07

Table 2 Basic physical properties of cement

Initial setting time (min)	Final setting time (min)	Bending strength (MPa)		Compression strength (MPa)	
		3d	28d	3d	28d
172	234	5.5	7.4	27.2	45.1

Table 3 Physical and mechanical properties of standard sand

D_{50} (mm)	e_{max}	e_{min}	G_s	φ(°)
0.85	0.73	0.38	2.65	30.7

Around the second trunk road project, there are tremendous silicon sand. Moreover, silicon sand in this site with small particles can effectively fill voids of the peat, which can improve soil stiffness and strength. By adding filler materials such as fine sand, Axelsson *et al.* (2002) found that the usage of binder required for stabilisation of peat can be reduced. At a given amount of silicon sand, the smaller diameter the greater number of particles. Thus, the diameter of sand particle is the control parameter. Other wastes, such as rock wool waste, recycled glass sand and synthetic fibers, can be used to replace quartz sand. Quartz sand of different diameters was selected as fuller to solidify peat. Table 3 summaries the physical and mechanical properties of adopted sand. The sand was further sieved into three groups (i.e., <0.5 mm, 0.5~1.0 mm and >1.0 mm) based on particle diameter. By conducting direct shear tests, the internal frictional angle of silicon sand at the critical state is 30.7°.

3. Test program and procedures

A series of tests were performed to investigate effects of moisture content, organic content, pH, cement proportion and curing time on strength of solidified peat. Table 4 shows the experimental program. Essentially, the moisture content ranged between 200% and 800%. Three organic contents (i.e., 40%, 60% and 90%) and three pH media (i.e., pH=3.5, 5.5 and 7) were designed. In addition, cement of 10%, 20% and 30% were adopted as binding agent. Three curing periods of 7, 14 and 28d were proposed to solidify peat mixture.

When the respective water and organic contents are 600% and 60%, effects of quartz sand proportion are investigated. The designed quartz sand proportions are10%, 15%, 20%, 25% and 30% and the diameters of quartz sand are <0.5 mm, 0.5~1.0 mm and > 1 mm.

Table 4 Test program of solidified peat

Moisture content (%)	Organic content (%)	pH	OPC Proportions (%)	Curing time (d)
200	40	3.5, 5.5, 7	10, 20, 30	7, 14, 28
300		5.5		
400		3.5, 5.5, 7		
300	60	3.5, 5.5, 7	10, 20, 30	7, 14, 28
400		5.5		
500		5.5		
600		3.5, 5.5, 7		
400	80	3.5, 5.5, 7	10, 20, 30	7, 14, 28
600		5.5		
800		3.5, 5.5, 7		

Key steps for preparing the peat samples in Table 1are summarized as follows.

1) Moss peat, kaolin and water with designed quantities in Table 4 were uniformly mixed, and different pH media were prepared by mixing appropriate amounts of NaOH and HNO_3 in distilled water. The well mixed peat was sealed for 3 days in order to ensure that the mixture was homogeneous in moisture content.

2) In order to obtain a relatively uniform soil sample, peat-water-cement mixture was placed into a mould (i.e., 50 mm in inside diameter and 50 mm in height) in five layers. To ensure the prepared samples were as homogeneous as possible, a 40 mm diameter cylindrical aluminium rod was used to tamp peat-water-cement mixture.

3) The prepared samples were curved in an oven under constant temperature (20±2℃) and constant humidity (95±2%).

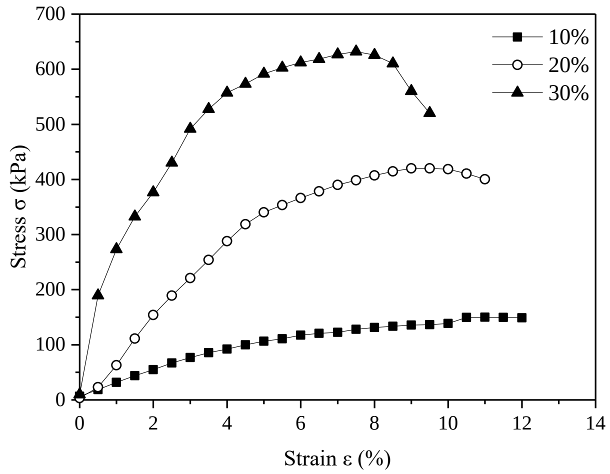


Fig. 2 Stress-strain curve of solidified peat under different cement contents

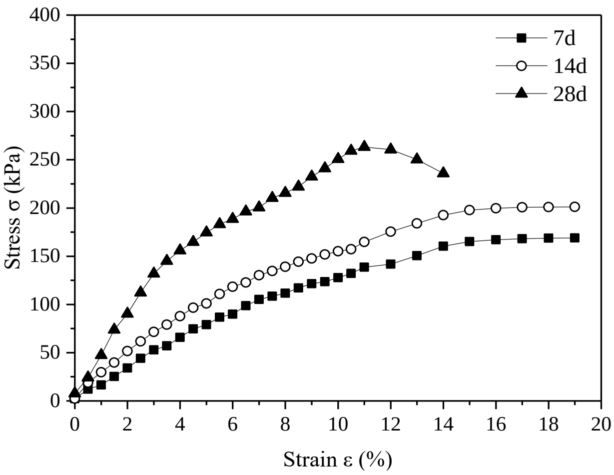


Fig. 3 Stress-strain curve of solidified peat under different curing time

4. Interpretations of experimental results

4.1 Stress-strain relationships of solidified peat

The following stress-strain relationships were measured by unconfined compression tests. Fig. 2 shows the stress-strain curve of solidified peat under different cement contents. The moisture content, organic content and curing time for the solidified peat samples were 400%, 40% and 7d, respectively. It is observed that the solidified peat with 10% cement exhibits strain hardening behavior before brittle failure. With an increase in cement content, the stress level upon failure increases and the axial strain corresponding to peak strength gradually reduces. In other words, solidified peat switches from ductile failure mode to brittle failure mode when cement content increases from 10% to 30%. Correspondingly, there is a transition in stress-strain relationship from strain-hardening behavior to strain-softening behavior. This is attributed to the fact that mechanical behaviors of solidified peat are mainly governed by original peat soil at low cement content and resembles cement at high cement content.

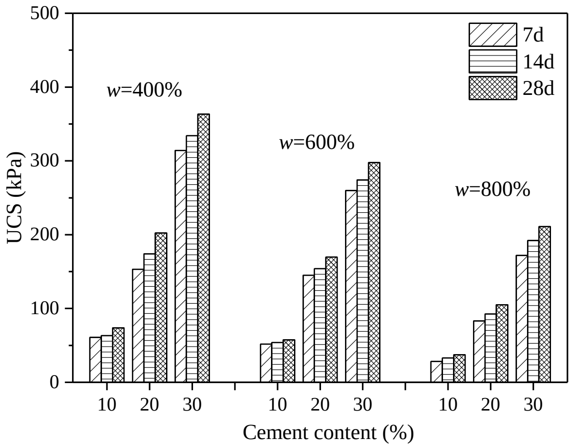
Fig. 3 shows the stress-strain curve of solidified peat under different curing time. The solidified peat samples had moisture content, organic content and cement content of 400%, 80% and 20%, respectively. The peak strength upon failure continues to increase when the curing time increases from 7d to 28d. The solidified peat exhibits strain-hardening behavior when the curing time is less than 14d, and the peak strength is not reached even though the axial strain is 19%.

When strength softening stress-strain curve is obtained, the UCS is the peak strength. For strength hardening stress-strain curve, the UCS is the strength corresponding to axial strain of 15%.

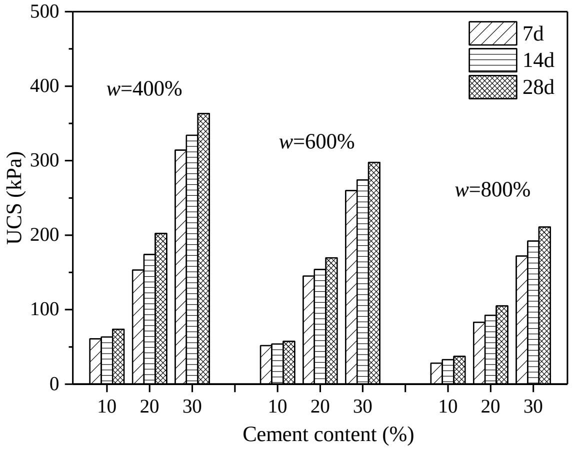
4.2 Unconfined compression strength (UCS) of solidified peat

4.2.1 Effects of curing time, cement content and moisture content on UCS of solidified peat

Unconfined compression strength (UCS) can be determined based on the type of stress-strain curve. Fig. 4 shows variation of UCS with cement content under different given moisture contents and curing time. Clearly, the



(a) Organic content 40%



(b) Organic content 80%

Fig. 4 UCS of solidified peat under different curing time

variations of UCS with curing time are similar for solidified peat irrespective of the organic content (e.g., 40%, 60% and 80%). In general, there is a rapid increase in UCS in the first 7d and the trend continues at a reduced rate thereafter.

For solidified peat with initial moisture content of 200%, UCS values at 7d are 196.4, 436.9 and 640.7 kPa when cement contents are 10%, 20% and 30%, respectively. Corresponding 14d UCS values increase to 254.7, 486.1and 733.8 kPa. Accordingly, measured UCS values at 28d further increase to 322.2, 563.6 and 867.2 kPa. Clearly, increments of 9%~29% and 29%~64% in UCS are obtained for solidified peat cured at 14d and 28d, respectively, in comparison with that cured at 7d.

For solidified peat with organic content and moisture content of 40% and 300%, respectively, UCS values measured at 14d and 28d are 11%~12% and 17%~36% larger than that at 7 days. When the moisture content increases to 400%, UCS values measured at 14d and 28d are found to increase by 8%~15% and 23%~26%, respectively. Clearly, the curing time is highly correlated with the strength of solidified peat. The longer the curing time, the larger the measured UCS. Irrespective of moisture content and cement content, UCS values of solidified increase by 9%~36% and 15%~69% when the curing time increases from 7d to 14d and 28d, respectively.

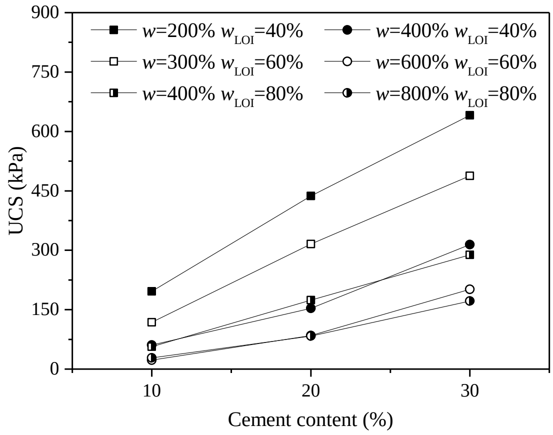
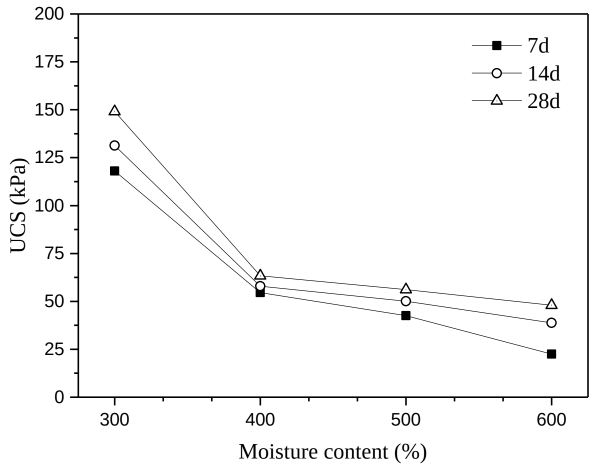


Fig. 5 UCS of solidified peat under different cement contents after curing for 7 days

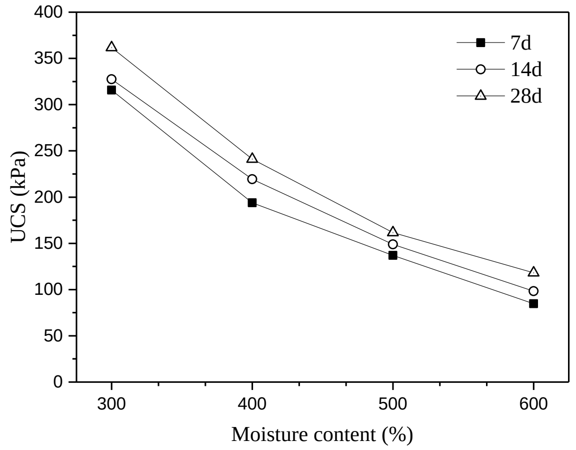
Fig. 5 shows the variation of UCS for solidified peat with different cement contents after curing for 7d. It is observed that measured UCS of solidified peat increases linearly with cement content. At low moisture content, UCS of solidified peat is more sensitive to cement content and exhibits a rapid increase in UCS with added cement. For example, when the organic content and moisture content are 40% and 200%, respectively, UCS of solidified peat is 196.4 kPa after adding cement (i.e., cement content = 10%). In comparison, UCS is only 150 kPa if moisture and cement contents simultaneously double, namely, moisture content = 400% and cement content = 20%. Clearly, by increasing the cement content by 100%, the strengthening effects cannot offset the strength loss after increasing the moisture content by 100%.

Fig. 6 shows variation of UCS for solidified peat with different moisture contents. The UCS of solidified peat reduces with an increase in moisture content. There is a dramatic reduction in UCS when initial moisture content increases from 300% to 400%. The decreasing rate of UCS reduces when moisture content increases beyond 400%.

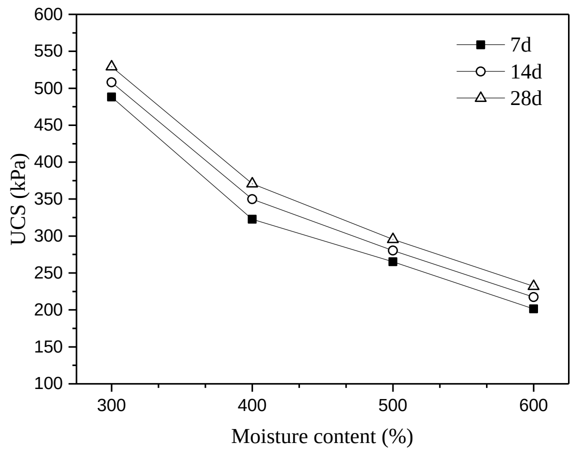
For pavement design, the required UCS at 7d and 28d should be larger than 200kPa and 300kPa, respectively. If 200kPa is taken as the design criterion, solidified peat with organic content = 60% and cement content = 10% fails to meet the strength requirement when the initial moisture content ranges between 300% and 600%. On the other hand, if the initial moisture contents equal to 400% and 600%, corresponding cement contents should be more than 20% and 30%, respectively, for UCS of solidified peat meeting the strength requirement. In comparison, peat with initial moisture content = 200% and organic content = 40%, UCS of solidified peat can reach 200kPa after adding cement content of 10% and curing for 7d (see Fig. 4). Clearly, the initial moisture content of peat has an overwhelming effect on the final strength of solidified peat after solidification. Therefore, for cost-effective engineering design, it is recommended to directly solidify peat with cement if the initial moisture content is less than 200%. On the other hand, peat with moisture content more than 200% may possibly be solidified by replacing cement partially with appropriate fillers.



(a) Cement content 10%

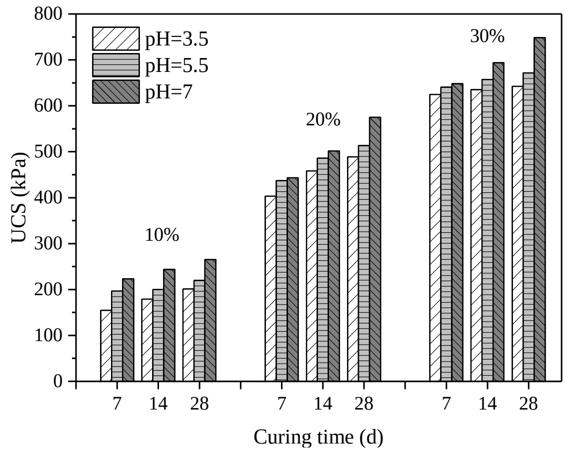


(b) Cement content 20%

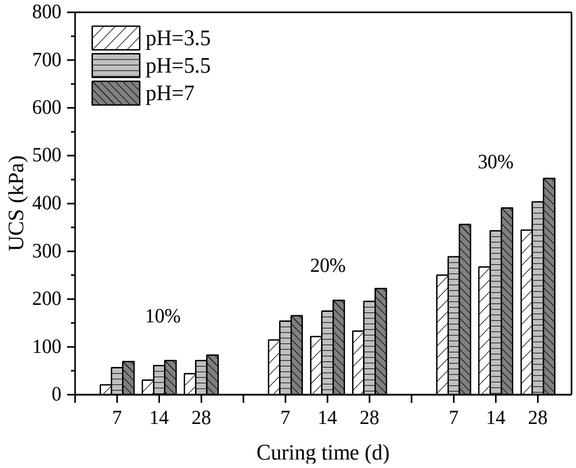


(c) Cement content 30%

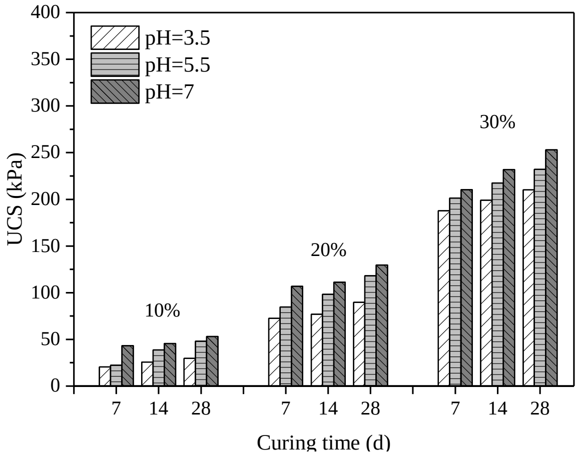
Fig. 6 UCS of solidified peat under different water contents (organic content is 60%)



(a) Moisture content 200% organic content 40%



(b) Moisture content 400% organic content 40%



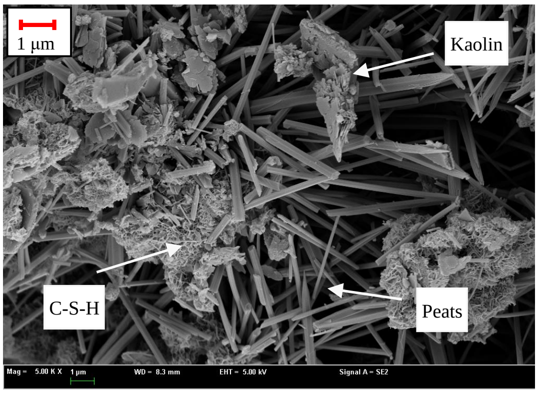
(c) Moisture content 600% organic content 60%

Fig. 7 UCS of solidified peat under different pH values

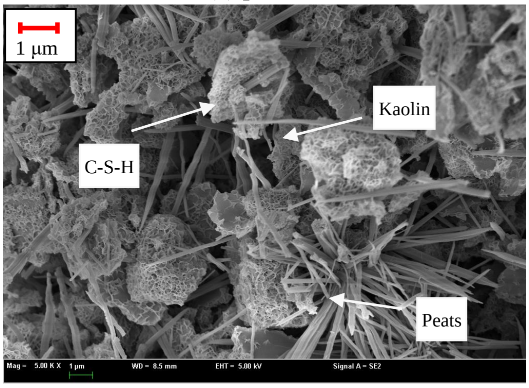
4.2.2 Effects of pH on UCS of solidified peat

Fig. 7 shows the variation of UCS for solidified peat with different pH values. For peat with initial moisture content = 200%, organic content = 40% and treated by cement (i.e., cent content = 10%), UCS values of solidified peat are 154.8, 196.4 and 223.3 kPa after curing for 7d in media having pH equal to 3.5, 5.5 and 7, respectively.

It is evident that the lower the pH value, the smaller the UCS of solidified peat. For example, UCS values of solidified peat in acidic media (pH = 3.5 and 5.5) are 30% and 12% less than that in distilled water (i.e., pH = 7), respectively. Based on results from solidified samples prepared for this study, measured UCS in media with pH=3.5 is about 10%~46% less than that with pH=5.5. In comparison, measured UCS in distilled water (i.e., pH=7.0) is 8%~38% larger than that in media with pH=5.5.



(a) pH=3.5



(b) pH=7

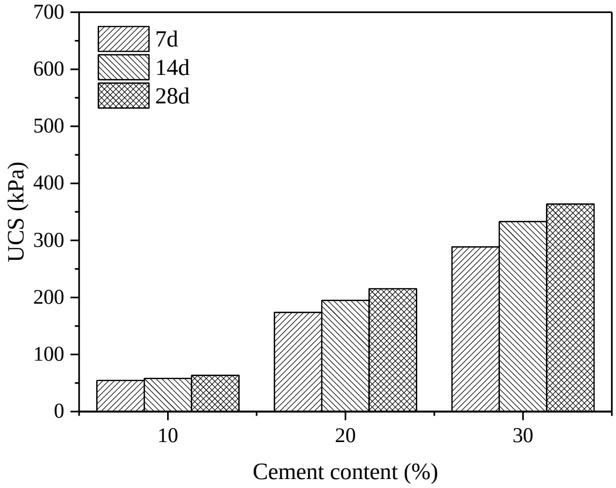
Fig. 8 Microstructure of solidified peat under different pH

Effects of pH on strength of solidified peat can be better explained via microstructural analysis. Fig. 8 shows SEM images of solidified peat cured in different media. The solidified peat sample used in this study was a mixture of moss peat, kaolin and cement. Kaolin particles are mainly of platy, worm-like, accordion-like shape with large pores between soil grains. C-S-H gel generated during cement hydration can help improve strength and stiffness of soil skeleton. At the early stage of cement hydration, C-S-H gels grow rapidly and attach to surface of soil particles, forming a mesh. At the same time, the pores between soil skeletons get filled with spherical C-S-H particles. Note that the higher the pH, the more C-S-H gels are attached to kaolin and fibrous peat, leading to a larger UCS value.

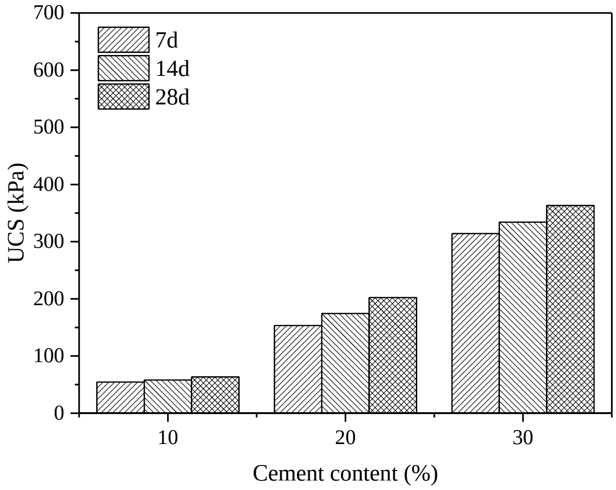
When the pH value reduces from 7 to 3.5, the concentration of H^+ gradually increases, which neutralizes OH^- generated during cement hydration. The reduction in OH^- is accompanied with the formation of $Ca(OH)_2$. Therefore, $Ca(OH)_2$ solution cannot reach saturated state, which on the contrary prevents the generation of C-S-H gels. The reduction in C-S-H gels explains the fact that cement treated peat cured in acidic media has a larger UCS value than that in alkaline media.

4.2.3 Effects of organic content on UCS of solidified peat

Fig. 9 shows the variation of UCS with organic content in solidified peat. For simplicity, only the results from initial moisture content = 400% are reported. Similar results were obtained for solidified peat with moisture content



(a) Organic content 40%



(b) Organic content 80%

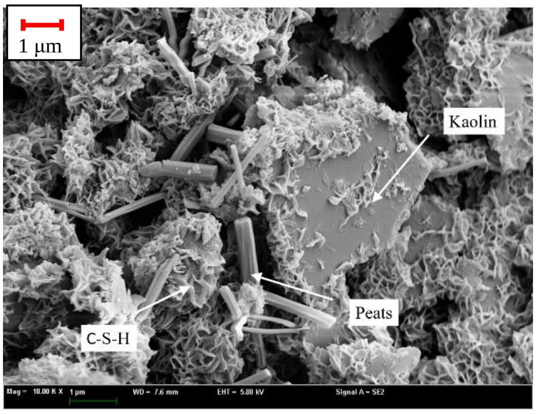
Fig. 9 UCS of solidified peat under different organic content (water content is 60%)

larger than 200%. It can be seen that there is a mild reduction in UCS with an increase in organic content. For example, when the organic content doubles from 40% to 80%, corresponding UCS measured at 28d reduces by 15%. Similarly, the reduction in UCS with organic content can be explained by microstructural change.

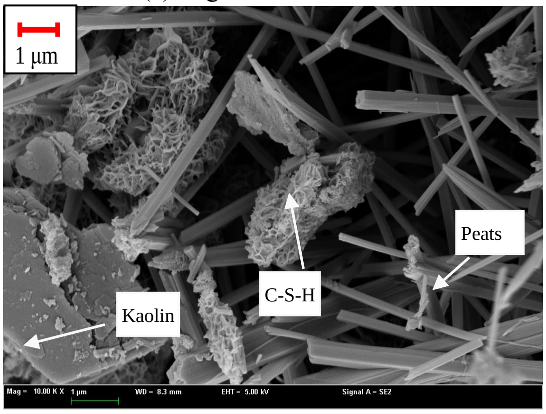
Fig. 10 shows SEM images of solidified peat with different organic contents. When the organic content is low, there are many platy kaolin particles accompanied by few fibrous peat particles. C-S-H gels generated by cement hydration mainly grow on the fibrous peat particles. With an increase in curing time, the individual C-S-H gel connects and forms new skeleton. The fibrous peat is more prone to suffer compression when subject to external forces. This explains the fact that peat of high organic content has low strength.

4.2.4 Effects of filler on UCS of solidified peat

Fig. 11 shows the SEM images of peat solidified using cement and filler of different diameters (i.e., <0.5 mm, 0.5~1mm and >1mm). The initial moisture content, organic content, cement content and quartz sand content of the peat



(a) Organic content 40%

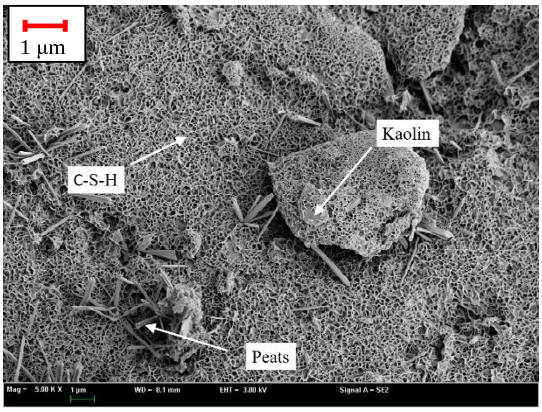


(b) Organic content 80%

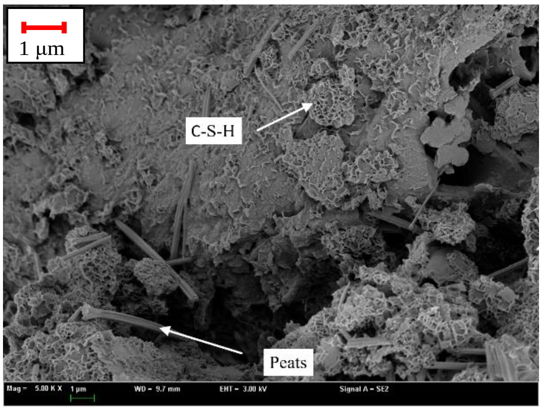
Fig. 10 Microstructure of solidified peat under different organic content

were 600%, 60%, 30% and 20%, respectively. Three different curing periods (i.e., 7d, 14d and 28d) were designed. Due to page limit, only results of the solidified peat cured for 28d are reported and shown in Fig. 11. Effects of filler with different diameter are indirectly analyzed based on the amount of C-S-H gels coating with peat particle. It can be seen that the added filler provides additional contact points, which is beneficial for growing C-S-H gels. When the diameter of filler is less than 0.5mm, the amount of filler particles is sufficient to fill pores between peat particles. In addition, C-S-H gels can grow rapidly on filler particles, forming solid skeletons. In comparison, when the diameter of filler increases to 0.5~1.0mm, which is larger than the pore size of fibrous peat, C-S-H gels can only aggregate locally. If the diameter of filler further increases beyond 1mm, the large filler particle cannot effectively bind peat particles. C-S-H gels can only coat around individual filler particle and cannot form continuous skeleton, which results in low UCS of solidified peat samples.

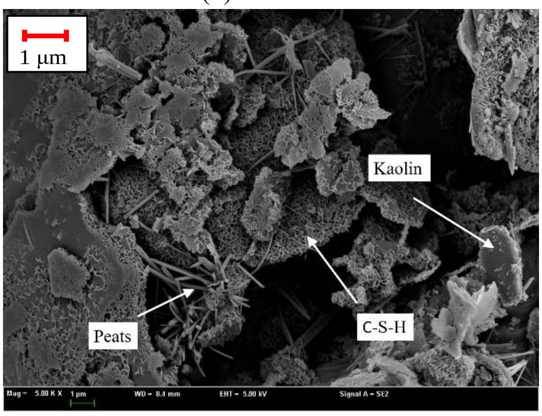
Fig. 12 shows the optimal content of sand filler for different curing periods. The solidified peat samples had moisture content, organic content and cement content of 500%, 94.3% and 30%, respectively. The diameter of sand filler was less than 1mm. The strength of solidified peat increases with sand filler when sand filler content increases



(a) <0.5 mm



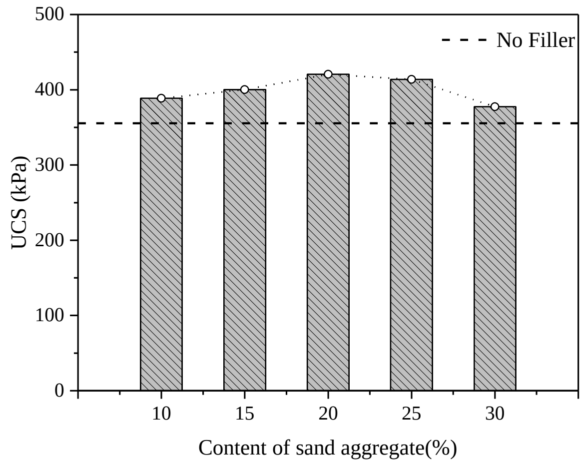
(b) 0.5-1 mm



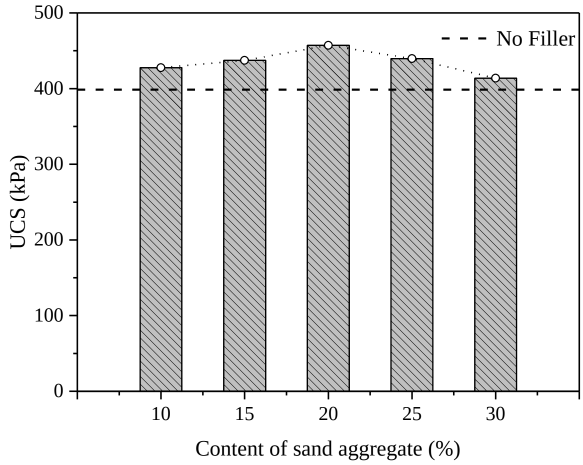
(c) >1 mm

Fig. 11 Effects of particle size on microstructures of solidified peat under 28 d curing time

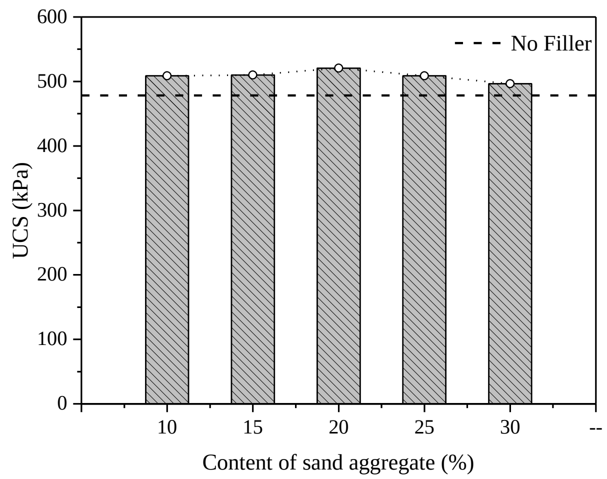
from 10% to 20%. Any further increase in sand filler content causes a reduction in the strength. For example, the solidified peat sample with sand filler content of 30% exhibits an increase of 18% in strength in comparison with the sample without sand filler. This can be explained by the fact that filler of small diameter can better fill pores between peat particles. In addition, more C-S-H gels can form, thus improve strength of peat. However, when excessive sand filler is added, new pores can form between newly added sand particles, which can deteriorate overall strength of solidified peat. In addition, the stiffening effects of sand filler weaken as the curing period increases from 7d to 28d. This is because cement hydration has not completed



(a) 7d



(b) 14d



(c) 28d

Fig. 12 Optimal content of sand aggregate

at a short curing period (e.g., less than 7d) and the direct addition of sand filler can immediately increase strength of solidified peat. As the curing period increases, cement hydration products dominate. Therefore, the desired strength of peat can be obtained by partially replacing cement with sand filler for cost-effective design of solidification.

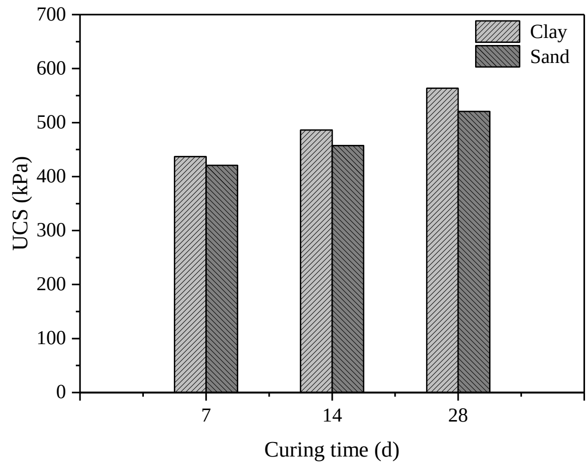


Fig. 13 Effects of filler type on strength of solidified peat

As shown in Fig. 11, sand particles with small size can form much more C-S-H gels. Thus, a larger unconfined compression strength (UCS) is observed at the peat solidified by sand with smaller particles. Obviously, clay particles have much smaller size than that of sand particles. Thus, effects of different fillers on UCS are explored. Fig. 13 compares UCS of peat solidified using two fillers (i.e., kaolin and quartz sand). The peat samples have the same initial moisture content of 500% and organic content of 94.3%. The UCS for the peat solidified using 20% quartz sand and 30% cement is smaller than that using 20% kaolin and 25% cement irrespective of curing time. As shown in Fig. 5, the UCS of solidified peat increases almost linearly with an increase in the cement content. Although the cement content used in clay is 5% smaller than that used in sand, the UCS solidified by kaolin is about 3.9%~8.2% smaller than that solidified by quartz sand. It is clearly demonstrated that the solidification effects of clay admixture are better than that of sand admixture. This can be explained by the fact that kaolin particle has a large specific surface area and water retention capacity. At a given amount of fillers, the specific surface area of kaolin is much larger than that of silicon sand. Thus, the kaolin has much more ability to absorb water inside the peat, causing a significant reduction of moisture content of peat. In addition, kaolin particle is very small with a nominal size of 1250 mesh and can effectively fill pores between peat skeletons. It is also worthwhile to analyze the phenomenon from microstructural scale. It is anticipated that the smaller the diameter of filler, the better the solidification of peat is.

5. Mix proportion design of cement solidified peat at high moisture content

Based on code for design of highway embankment on soft ground (DB33/T, 2013) for Zhejiang province in China, the 7d and 28d UCS for laboratory cured cement solidified peat should be more than 200kPa and 300kPa, respectively. Table 5 summaries the required cement amount for fulfilling the 7d strength requirement of 200kPa for peat with different moisture contents. When the initial moisture

Table 5 Cement content of unconfined compressive strength of 200 kPa at curing age of 7 days

Moisture content (%)	pH	Organic content (%)	OPC proportions (%)	Notes
200	3.5	40	12.3	Solidification
	5.5	40	10.2	
	7.0	40	9.0	
300	3.5	60	17.7	Solidification with fillers
	5.5	40/60	18.6/14.1	
	7.0	60	13.7	
400	3.5	40/80	26.7/22.9	
	5.5	40/60/80	22.3/20.5/22.1	
	7.0	40/80	20.4/19.1	
600	3.5	60	31.1	
	5.5	60/80	29.9/24.8	
	7.0	60	29.0	
800	3.5	80	35.5	
	5.5	80	34.7	
	7.0	80	33.2	

Table 6 Cement content of unconfined compressive strength of 300 kPa at curing age of 28 days

Moisture content (%)	pH	Organic content (%)	OPC proportions (%)	Notes
200	3.5	40	11.7	Solidification
	5.5	40	9.0	
	7.0	40	8.4	
300	3.5	60	19.9	Solidification with fillers
	5.5	40/60	21.3/17.1	
	7.0	60	16.3	
400	3.5	40/80	29.1/26.1	
	5.5	40/60/80	25.7/24.5/23.8	
	7.0	40/80	23.8/23.0	
600	3.5	60	37.5	
	5.5	60/80	36.0	
	7.0	60	33.8	
800	3.5	80	37.4	
	5.5	80	37.0	
	7.0	80	31.7	

content of peat is 200%, cement contents of 9%~12.3% are required. In comparison, Table 6 summaries the required cement amount for fulfilling the 28d strength requirement of 300kPa for peat with different moisture contents. In order to meet the strength requirement, the desired cement content should be between 8.4% and 11.7%. Clearly, the required cement content varies between 8.4% and 12.3% for peat with initial moisture content of 200%. However, once the initial moisture content of peat is more than 300%, the required cement content rises significantly to between 13.7% and 37.5%, particularly, cured in media having a low pH value. Therefore, it is recommended to add solid particle fillers such as fine sand, fly ash or clay to solidify peat with moisture content over 300%.

Obviously, soil sample mixed in the lab is much more uniform than that in-situ. Thus, strength of cement solidified peat from the lab is likely to be higher than that in-situ. It is suggested to conduct a field trial test to correlate the relationship of soil strengths in the lab and field.

6. Conclusions

In this study, a series of UCS and SEM tests were conducted to systematically investigate effects of moisture content, cement content, organic content, filler type and pH value on strength of solidified peat. Based on results of this study, the following conclusions may be drawn.

(1) The stress-strain curve of solidified peat changes from strain-hardening behavior to strain-softening behavior with an increase in cement content and curing period. Corresponding failure mode switches from ductile failure to brittle failure.

(2) The strength of solidified peat increases with curing period, and the primary strength gain occurs within the first 7d. The strength values at 14d and 28d are about 9~36% and 15~69% larger than that at 7d, respectively.

(3) There is a linear trend between UCS of solidified peat with cement content. The strength gain originated from 100% increase in cement content cannot offset the strength reduction caused by 100% increase in moisture content. Moisture content of peat has a larger impact on the final strength of solidified peat than cement content.

(4) Strength of solidified peat reduces rapidly with an increase in moisture content. It is recommended to directly solidify peat with moisture content less than 200% using cement binder. However, a large amount of cement is required for solidifying peat with moisture content more than 300%. Therefore, it is considered appropriate to replace cement binder partially with filler materials such as quartz sand.

(5) Strength gain of solidified peat mainly originates from cement hydration generated C-S-H gel. C-S-H gels are more prone to attach to fibrous peat with higher organic content, leading to an overall reduction in strength of peat. More specifically, the strength at 28d reduces by 15% when the organic content increases from 40% to 80%.

(6) Surfaces of soil particles are coated with more C-S-H gels if peat is cured in media with a higher pH value, leading to improvement in overall strength of solidified peat. More specifically, the strength of solidified peat in media having pH = 3.5 reduces by 10%~46% in comparison with that in media having pH = 5.5.

(7) Peat soil can be solidified directly when its moisture content is lower than 200%, and it is recommended to use filler materials for stabilizing peat soil with moisture content greater than 200%. Because of small size of clay particles, clay added in the cement solidified peat can increase much large strength that that of sand. For peat with ultrahigh water content, it is suggested to add clays to

improve the unconfined compression strength of cement solidified peat.

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