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Strength evaluation of air cured, cement treated peat with blast furnace slag

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Abstract. This article describes laboratory research done on strength evaluations for stabilized samples made of tropical fibrous peat. The stabilizing agents used were ordinary Portland cement (OPC) as binding agent and blast furnace slag (BFS) as additive. Stabilized samples were tested for their strength through unconfined compressive strength (UCS) and California bearing ratio (CBR). Different dosage rates of OPC and BFS were used in trial and error experiments for the most effective combination for stabilized peat samples that were at their natural moisture content. Stabilized trial samples were air cured for 90 days. After detecting the most effective dosage rate in the trial samples, their values were used to prepare CBR samples at their optimum moisture content (OMC). CBR samples were then air cured from 1 to 90 days and tested under un-soaked and soaked conditions. The most effective dosage rate for the stabilized peat samples was found to be close to when 75% for OPC and 25% of BFS per total weight of OPC, and BFS. As an example, if 11.25% OPC, and 3.75% BFS are mixed with peat and compacted at their OMC and air cured for 90 days, stabilized peat will have an increase in CBR of 0.8% to 45 % for un-soaked and 20% for soaked conditions.

Keywords: fibrous peat; unconfined compressive strength; California bearing ratio; air curing; ordinary Portland cement; blast furnace slag.

1. Introduction

Peat consists of 50-95% organic substance; they are excessively moist. These features determine their poly-functional nature. Botanists and geo-botanists study the specific features of bog vegetation in peat and the climatic characteristics of the period of the peat accumulation based on the stratigraphy of peat deposits, and they define peat soils as bogs. Geologists explore peat reserves for industrial purposes and consider peat bogs as peat fields (economic deposits). Hydrologists study the hydrological regime of bogs and determine them as water bodies. Foresters study bogs from the point of view of improving the quality class of forest stands and call them forest bogs (Inisheva 2006). Peat deposits, to civil engineers, are referred to as problematic soils due to their high compressibility and low shear strength. Civil engineering projects with these superficial deposits is usually very difficult as the water table will be at, or near the ground surface and therefore the tendency to either avoid construction and building on peat soils, or when that is not possible, to

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simply remove, replace, or displace them, in some instances may lead to possibly uneconomical design and construction alternatives (Huat 2004, 2006, Huat and Faisal 2007, Kalantari *et al*. 2010).

One of the alternative methods for improving the stability and reducing the compressibility of peat deposits is to strengthen it by means of chemical stabilization. According to this technique, a binding agent such as Portland cement or lime is mixed in situ with peat and is stiffened during a curing period. Also, admixtures such as blast furnace slag or fly ash that are common additives for concrete (mixture of gravel, sand, cement and water) mixes may also used to strengthen peat.

Researchers such as Axelsson *et al*. (2002), Hebib and Farrell (2003), Alwi (2007) and Wang *et al*. (2008) have used cement and blast furnace slag (BFS) to improve engineering properties of peat using moist curing technique (the treated samples are kept submerged in water during the curing period); however, the use of cement with blast furnace to stabilize peat using air curing technique does not seem to have been reported.

The organic matter and low *pH* of peat soil tend to interfere with the hydration process if cement is used. This is because the acidity (low *pH*) reacts with the calcium liberated from cement hydrolysis, forming insoluble calcium humic acid. This results in a decrease in the calcium crystallization that leads to an increase in the strength of cement (Chen and Wang 2006). Furthermore, the secondary pozzolanic reaction of the cement stabilised peat is retarded, owing to insufficient silica (SiO_2) and alumina (Al_2O_3) that can react with the calcium hydroxide ($Ca(OH)_2$) generated from cement hydration to form secondary calcium silicates, which are responsible for the long-term strength gain of the stabilised peat soil.

In this laboratory research, the effect of blast furnace slag as an additive to a mixture of stabilized peat with ordinary Portland cement (OPC) as binding agent has been studied. Also control samples of stabilized peat without blast furnace slag that only contained various amounts of OPC have been used in the study as well. The strength tests used for this purpose were unconfined compressive strength (UCS) and California bearing ratio (CBR).

The type of curing used for the stabilized peat samples was an air curing technique that is described by Kalantari and Huat (2008). In this type of curing, the stabilized peat samples are kept at normal air temperature (21 to 25°C) and away from water intrusions (outside sources) during the curing period. UCS tests were conducted on 90 day air cured samples. Also, un-soaked CBR tests were conducted on cured samples that had been cured for periods of 1, 28, and 90 days. Soaked CBR tests were also conducted on stabilized peat samples cured for 90 days as well.

2. Test materials

The basic materials used for this research include:

a) Fibrous peat (FPt)

b) Ordinary Portland cement (OPC)

c) Ground granulated blast-furnace slag or blast furnace slag (BFS)

Peat samples used for the study were collected as disturbed and undisturbed according to ASTM D42069 (Bowles 1978, Department of the Army 1980) from Kampung, Jawa in the western part of Malaysia. Table 1 presents the properties of the *in-situ* (field) peat. Scanning electron microscopy (SEM) and energy dispersing x-ray analyses (EDXA) of the fibrous peat used in the research are shown on Fig. 1.

The stabilizing agent used for the peat soil samples was Ordinary Portland Cement (OPC). Fig. 2

Table 1 Properties of the peat soil used in the research

Properties	Standard specifications*	Values
Depth of sampling		5-100 cm
Moisture content	ASTM D1883	185-417%
In-situ (natural) bulk density		10.23-10.4 kN/m^3
Specific gravity		1.3
Classification (unified)	ASTM D5715	Fibrous
Liquid limit	BS 1377	160%
Plastic index	ASTM D424-59	N.P.
pH	BS 1337	6.40
Organic content	ASTM D2974	80.23 %
W_{opt}	A ASHTO T 180-D	130%
$\gamma_{d(max)}$	A ASHTO T 180-D	4.89 kN/m^3
Hydraulic conductivity, k	ASTM D2434-68	0.42 m/day
e_o (initial void ratio)	BS 1377, ASTM D2435-70	12.55
C_c (compression index)	BS 1377, ASTM D2435-70	4.163
C_r (recompression index)	BS 1377, ASTM D2435-70	0.307
C_u' (effective undrained cohesion)	ASTM D 4767-04	0.10 kPa
φ_u' (effective undrained friction angle)	ASTM D 4767-04	36.64^o
CBR (undisturbed)	ASTM D 1883	0.8%
UCS (undisturbed)	ASTM 2166-6	28.5 kPa
Sensitivity (St)		1.3

shows SEM/EDXA of the OPC used in the study and Table 2 presents the main components of OPC.

Ground granulated blast-furnace slag is the granular pozzolanic material formed when molten iron blast furnace slag is rapidly chilled (quenched) by immersion in water. It is a granular product with very limited crystal formation, is highly cementitious in nature and, ground to cement fineness, and hydrates like Portland cement with a specific surface around 450 m^2/g, specific gravity of 2.9, and bulk density of 1150 kg/m^3 (Fernandez and Puertaz 1997, YTL cement 2008). Ground blast slag used as stabilizer has latent hydraulic properties. This means that, like pozzolanic materials, the slag can form strength-enhancing products with calcium hydroxide (Ca $(OH)_2$) (Axelsson *et al.* 2002). Fig. 3 shows scanning electron microscopy and energy dispersive x-ray analysis for the ground granulated blast furnace slag. Also Table 3 shows the results of chemical components of plain peat, OPC, and BFS obtained from x-ray fluorescence spectrometer (XRF).

Unidentified peaks shown for EDXA of materials used in the study (peat, OPC, and BFS) on Figs. 1, 2 and 3 are Au (gold) elements used during the testing process.

Blast furnace slag is considered to be a latent hydraulic material. Pozzolanic materials are different (e.g. fly ash) and they require external source of CaO in order to undergo hydration and result in C-S-H gel; whereas BFS does not require external source of lime for hydration-instead it requires an alkali activator to initiate hydration (e.g. Portlandite). Its reactivity also depends on the CaO/SiO_2 ratio. As this ratio is increased, the more the hydraulic material will be. CaO/SiO_2 ratio

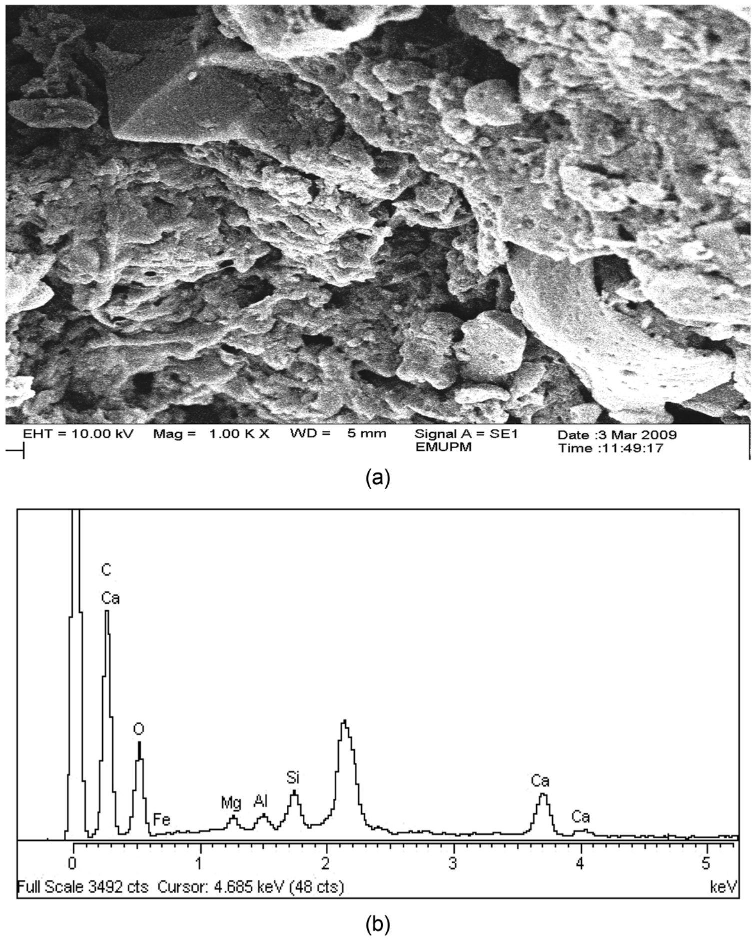


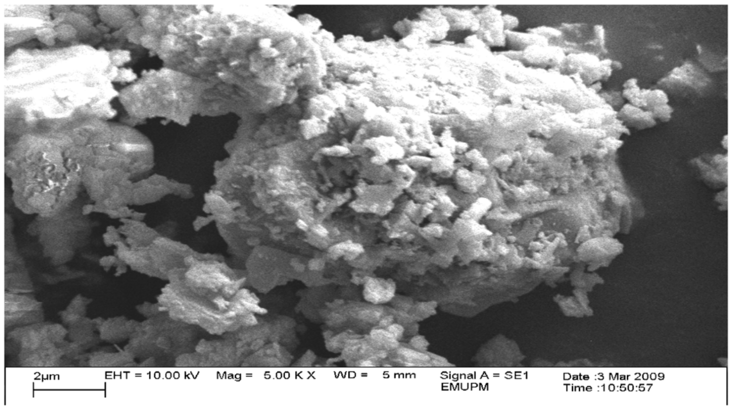
Fig. 1 (a) Scanning electron microscopy and (b) energy dispersing x-ray analyses of the peat used in the study

for blast furnace slag is about 1, while it is up to 3 for ordinary Portland cement. Hydraulic materials such as OPC react spontaneously with water. Since reaction produced by blast furnace slag is slower than OPC, therefore gives a slower strength gain and lower heat evaporation than with cement. However, the long term strength of slag admixture can be higher (Axelsson *et al*. 2002, Janz and Johansson 2002).

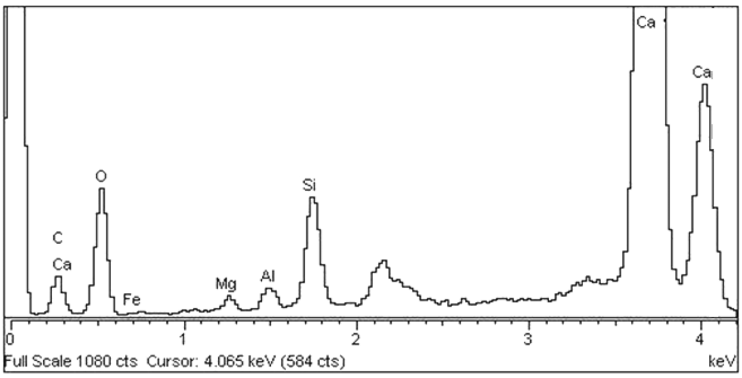
3. Experimental program

In order to examine the effect of blast furnace on the OPC treated samples of fibrous peat, two types of test were used in this study; unconfined compressive strength (UCS) and California bearing ratio (CBR).

UCS tests were conducted on various types of OPC treated peat having different amounts of ordinary Portland cement and also different dosage rates of blast furnace slag. The stabilized



(a)



(b)

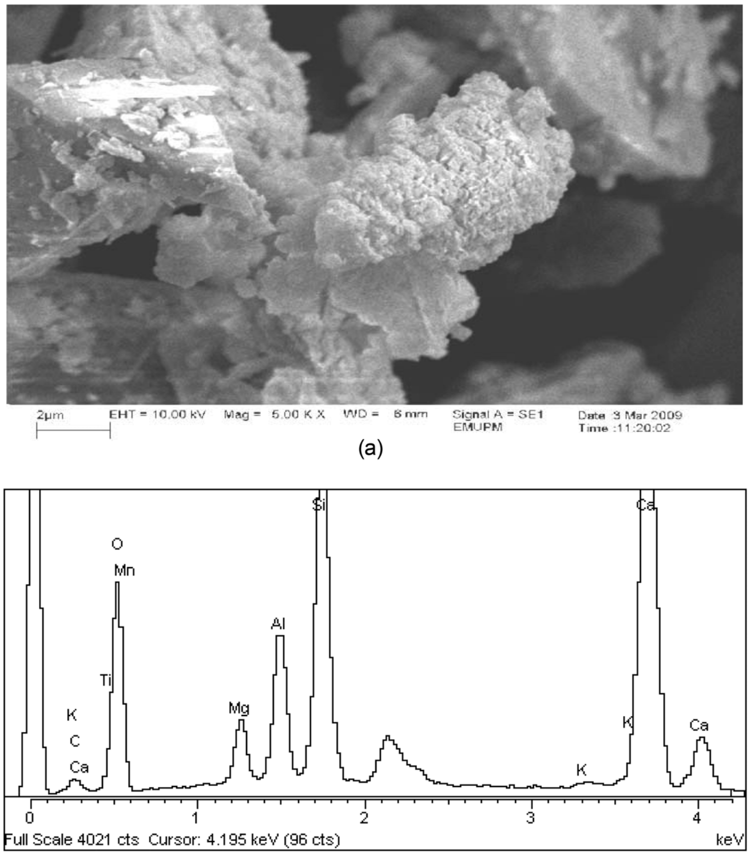
Fig. 2 (a) Scanning electron microscopy and (b) energy dispersing x-ray analyses of the ordinary Portland cement used in the study

Table 2 Main components and chemical compositions of ordinary Portland cement (Neville 1999, Janz and Johanson 2002 and Chen and Fong 2008)

Name of components	Oxide	Abbreviation
Tricalcium silicate	$3CaO\ SiO_2$	C_3S
Dicalcium silicate	$2CaO\ SiO_2$	C_2S
Tricalcium aluminate	$3CaO\ Al_2O_3$	C_3A
Tetracalcium aluminate ferrite	$4CaSO_4\ Al_2O_3\ Fe_2O_3$	C_4AF
Calcium sulphate	$CaSO_4{\cdot}2H_2O$ or $CaSO_4$	Gypsum

samples were then air cured for 90 days. The results obtained from UCS tests were used to examine and detect the most effective dosage rate of blast furnace slag to be used in the OPC treated peat samples.

The results obtained from UCS tests were then used to make CBR samples which were cured and tested at 24 hrs, 28 days, and 90 days. CBR tests were conducted under two conditions; un-soaked



(b)

Fig. 3 (a) Scanning electron microscopy and (b) energy dispersing x-ray analyses of blast furnace slag used in the study

and soaked. Soaked samples were conducted on those samples that were cured for 90 days.

CBR samples when mixed with OPC and blast furnace slag were at their optimum moisture contents found from compaction tests. Compactions as well as CBR test samples were made based on the modified compaction tests specified by ASTM D 1557/ASHTO T 180 D and ASTM D 1883, respectively

3.1 Amounts of ordinary portland cement (OPC) and blast furnace slag (BFS)

In-order to investigate the effect of blast furnace slag on the shear strength values of plain peat, various amounts of ordinary Portland cement from 3.75% to 50% were used. Amounts of OPC used in the study were based on the total wet weight of the peat (e.g. 3.75% OPC means with each 100 g of total wet peat, 3.75 g OPC was added). Also different amounts of blast furnace slag from 1.25% up to 22.5% were used during the testing program either for the UCS or CBR tests. The dosage rates of blast furnace slag used in the research were also based on the total wet weight of the peat at the time of mixing as was explained above (e.g. 1.25% blast furnace slag means with each 100 g of

Table 3 Chemical analysis of peat, ordinary Portland cement, and blast furnace slag used in the study

Chemical compound	Peat	OPC	BFS
SiO_2(%)	0.57	21.60	34.40
Fe_2O_3(%)	0.01	3.70	0.30
Al_2O_3(%)	0.16	6.28	13.80
CaO(%)	0.19	66.23	43.5
MgO(%)	0.11	0.89	5.70
Na_2O(%)	0.47	0.19	0.40
K_2O(%)	< 0.01	0.72	0.00
P_2O_5(%)	0.01	0.09	–
Mg_2O_3	–	–	0.40
Cl	–	–	0.01
LOI(H_2O)(%)	–	–	–
LOI(CO_2)(%)	98.46	–	–

total wet peat, 1.25 g blast furnace slag was added).

3.2 Soaking duration test procedure

According to AASHTO T193-63 and ASTM D1883-73, the soaking period of CBR samples for normal (mineral) soil is 96 hours or four days. For this study, in-order to investigate the CBR values of the soaked stabilized peat samples, CBR samples made with 50% OPC while prepared at its OMC were chosen to be soaked in water, until complete saturation.

The reason that the mentioned sample was soaked in water for a complete saturation test was because the mixture of 50% OPC and peat had shown the maximum strength obtained through a 90 day cure, and assuming sample having highest strength takes longest time to become completely saturated among various types of treated samples. Thus all treated samples followed this obtained time length of complete saturation duration for being soaked before being tested for their soaked CBR values.

The CBR sample for this purpose was cured for 90 days in air, and then submerged in water, for two weeks.

During this two week soaking period, the soaked CBR soil (OPC treated peat) sample was weighed periodically for possible weight increase due to increased saturation. After sometime, this soaked stabilized peat sample was 100% saturated and no weight increased occurred thereafter.

For the first week, the soaked CBR sample weight was recorded every 24 hrs. After the first two weeks, its weight was controlled every two days for a one week duration.

According to the results obtained from this test, the sample reached its constant weight during the first 6 days, after 6 days the recorded weights reached constant until the end of the two week period.

Based on the result obtained in this test, all stabilized peat samples in this study prior to be tested for soaked CBR tests were submerged in water for at least six days.

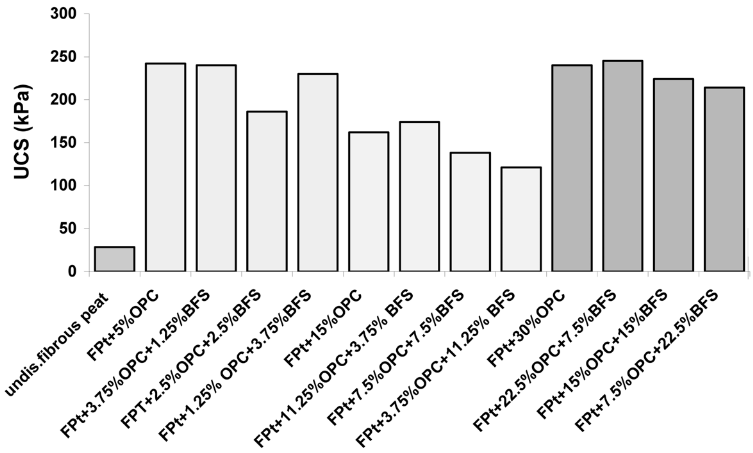


Fig. 4 Unconfined compressive strength for various types of stabilized fibrous samples cured for 90 days, with and without blast furnace slag

3.3 Unconfined compressive strength (UCS) of stabilized fibrous peat

Various trial mixtures of OPC which were treated with and without blast furnace slag were tested for their UCS values. Undisturbed peat as well as peat samples treated with 5, 15, and 30% of OPC without additive (blast furnace slag) were tested as control samples. The stabilized samples were mixed initially at the fibrous peat's natural moisture content (*W* (natural) = 200%) and air cured for three months.

The results of UCS for the stabilized peat samples are shown in Fig. 4. From these results, those samples which provided the highest strength values were chosen to conduct compaction tests on their mixture types.

The four types of mixture chosen from the results of Fig. 4 for compaction tests were fibrous peat with four types of mixtures chosen for compaction test were fibrous peat (FPt) with;

a) 3.75% OPC, and 1.25% BFS
b) 11.25% OPC, and 3.75% BFS
c) 22.5% OPC, and 7.5% BFS
d) 22.5% OPC, and 22.5% BFS

The results of compaction tests to obtain moisture-density relations of the above selected samples are shown in Fig. 5.

3.4 Moisture-density relations (compaction) for stabilized fibrous peat

From different percentage of treated peat samples with a total of 5, 15, and 30% of ordinary Portland cement and blast furnace slag which are shown in Fig. 4, only those dosages (different percentages of OPC and BFS) were selected which provided the highest UCS values in-order to carryout compaction tests on them. For example for various percentages of treated fibrous peat (FPt) with a total amount of 15% of OPC and BFS shown on Fig. 4 (15% OPC + 0% BFS, 11.25% OPC + 3.75% BFS, 7.5% OPC + 7.5% BFS, 3.75% OPC + 11.25% BFS) the dosage rate of treated sample with 11.25% OPC + 3.75% BFS was selected for compaction tests to be conducted on,

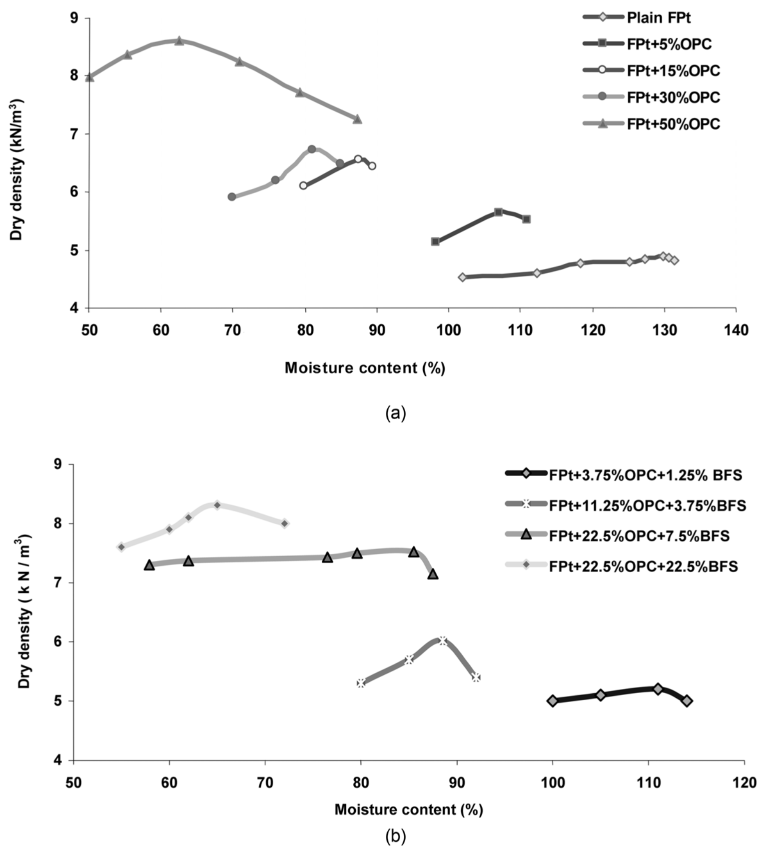


Fig. 5 Dry density-moisture curves, for treated fibrous peat (FPt) with different amount of ordinary Portland cement (OPC), and blast furnace slag (BFS)

because this type of treated sample provided the highest UCS value among four various types of treated peat samples mentioned above and shown on Fig. 4. Also compaction tests were conducted on untreated peat (0% OPC + 0% BFS) as well as treated peat sample with 50% OPC and BFS (22.5% OPC + 22.5% BFS) as control measure samples.

In order to prepare the peat samples for compaction tests, their moisture content was first reduced to around the optimum values. The gradual method of reducing moisture contents procedure described by Kalantari and Huat (2009) that includes leaving the peat samples in oven for several days and at around 70°C until the moisture content reduces to below 90 or 100%.

Tests results for compaction tests that were used based on “modified Proctor test” to mould CBR samples are presented in Figs. 5(a) and 5(b). Water contents used for all treated samples were based on the OMC found from their relevant compaction tests shown on (Figs. 5(a) and 5(b)).

3.5 California bearing ratio (CBR) test values for stabilized fibrous peat

CBR tests were conducted on four selected samples containing OPC and blast furnace slag, as well as on stabilized peat samples made with 5, 15, and 30, and 50% OPC. For the stabilized peat

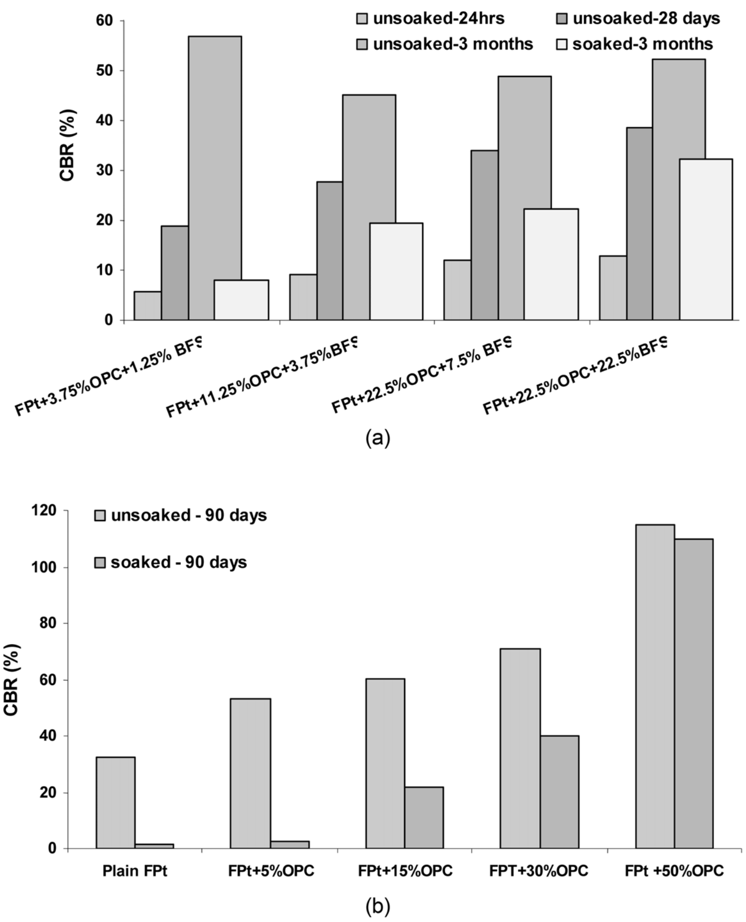


Fig. 6 CBR values of stabilized fibrous peat (FPt) soil samples for (a) treated peat with ordinary Portland cement (OPC), and blast furnace slag (BFS) cured for 1, 28 (un-soaked), and 90 days (un-soaked, and soaked), and (b) Treated peat with OPC, and without blast furnace slag

samples containing blast furnace slag, air curing periods were: 1, 28, and 90 days. All stabilized 90 day air cured samples were tested for CBR under un-soaked and soaked conditions.

CBR test results for various types of stabilized peat samples are shown in Figs. 6(a) and 6(b).

4. Results and evaluations

The results obtained from Fig. 4 indicate that, as the blast furnace slag contents of the stabilized samples is replaced by ordinary Portland cement, the UCS values increase.

Also, test results on various types of stabilized fibrous peat samples shown in Fig. 6(a) show that sample containing least OPC, and BFS gained the highest unsoaked CBR value (56%), and lowest when soaked (8%). The strength gain of low content cement samples (5% treated samples shown on Fig. 4) through air curing are not due to binding produced by calcium silicate hydrate (C-S-H) or the cementitious process that normally takes place as cement and water react during hydration process. Also, their strength does not come from chemical bonds produced through cement, blast furnace slag, and water; rather it is from the drying of the wooden fibres within the peat samples. Thus, as these fibres lose their moisture content, they become more solid, and the samples gain strength.

These samples containing low levels of OPC only gain strength when tested under un-soaked conditions, but they lose most of their gained strength values when tested under soaked conditions. CBR test results on these types of sample are shown in Fig. 6.

CBR test results on various stabilized peat samples air cured from 24 hrs to 3 months are shown in Figs. 6(a) and 6(b) and indicate that, as the cement content of the stabilized peat is increased, the gain in strength is greater and also as ordinary Portland cement and blast furnace slag dosage rates increase, the CBR values for soaked samples increase as well. As the curing period increases from 1 to 90 days, all stabilized samples tend to increase in their un-soaked and soaked CBR values.

Comparison of the results obtained from Figs. 6(a) and 6(b), indicate that samples containing ordinary Portland cement provide more strength than samples containing OPC and blast furnace slag.

According to researchers (Huat 2004 and 2005, Axelsson *et al*. 2002, Hebib and Farrell 2003), organic soils such as peat contain a large amount of humic acid, which reacts with cement and produces insoluble products that make the stabilized peat set at retarded times, on the other hand when blast furnace slag is mixed with cement, the setting becomes slower, therefore when blast furnace slag is added to the mixture of OPC and peat, this makes the mixture even more late setting.

Therefore, when OPC, and blast furnace slag are used to stabilize peat, it is expected to gain strength through time and to be late setting.

Researchers have shown that blast furnace slag when replaced by cement can make concrete (mixture of mineral aggregate, cement, and water) stronger after a longer time, compared with regular concrete using only cement (Axelesson *et al*. 2007, Janz and Johanson 2002).

5. Conclusions

Organic soil such as peat can be stabilized with ordinary Portland cement and blast furnace slag through an air curing procedure. As curing is continued, the stabilized samples gain further strength. Among various types of treated samples used in the study, ranging from 5 to 50% ordinary Portland cement with and without blast furnace slag, the most effective dosage rate of with ordinary Portland cement, to stabilize fibrous peat is in the range of 3 to 1 (75% cement and 25% blast furnace slag). Possibly due to the retarding properties of blast furnace slag, the gain in strength for stabilized samples made from peat and cement give higher CBR values (un-soaked and soaked) than samples made of peat, cement and blast furnace slag. Soaking stabilized peat samples causes CBR values of the stabilized samples to drop. As the cement content of stabilized peat samples increases, this drop becomes smaller.

As an example, if 11.25% of ordinary Portland cement and 3.75% of blast furnace slag are mixed with peat and compacted at their optimum moisture content value after 90 days of curing the soft peat having a field CBR of less than unity will have a CBR of 44% for un-soaked and 18% for soaked conditions respectively.

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