Reutilization of Organic and Peat Soils by Deep Cement Mixing

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Abstract**—**Limited infrastructure development on peats and organic soils is a serious geotechnical issues common to many countries of the world especially Malaysia which distributed 1.5 mill ha of those problematic soil. These soils have high water content and organic content which exhibit different mechanical properties and may also change chemically and biologically with time. Constructing structures on peaty ground involves the risk of ground failure and extreme settlement. Nowdays, much efforts need to be done in making peatlands usable for construction due to increased landuse. Deep mixing method employing cement as binders, is generally used as measure again peaty/ organic ground failure problem. Where the technique is widely adopted because it can improved ground considerably in a short period of time. An understanding of geotechnical properties as shear strength, stiffness and compressibility behavior of these soils was requires before continues construction on it. Therefore, 1- 1.5 meter peat soil sample from states of Johor and an organic soil from Melaka, Malaysia were investigated. Cement were added to the soil in the pre-mixing stage with water cement ratio at range 3.5,7,14,140 for peats and 5,10,30 for organic soils, essentially to modify the original soil textures and properties. The mixtures which in slurry form will pour to polyvinyl chloride (pvc) tube and cured at room temperature 25^{0}C for 7,14 and 28 days. Laboratory experiments were conducted including unconfined compressive strength and bender element , to monitor the improved strength and stiffness of the 'stabilised mixed soils'. In between, scanning electron miscroscopic (SEM) were observations to investigate changes in microstructures of stabilised soils and to evaluated hardening effect of a peat and organic soils stabilised cement. This preliminary effort indicated that pre-mixing peat and organic soils contributes in gaining soil strength while help the engineers to establish a new method for those problematic ground improvement in further practical and long term applications.

Keywords**—**peat soils, organic soils, cement stabilisation, strength, stiffness.

I. INTRODUCTION

TROPICAL peat lands are form throughout the tropics, however Malaysia is about 1.54 millon hectares, of which about 13% are in peninsular Malaysia, over 80% in Sarawak and about 5% in Sabah [1]. Peat or highly organic soils represent a problematic soils and poor quality of soils due to limited compressible index [2], [3], [4]. Organic soil and peat are most difficult to stabilise due to lower solid content, higher water content, lower pH and its potential to interfere chemically and biologically with time and environmental condition [5], [6].

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Constructing structures on peaty ground involves the risk of ground failure and extreme residual settlement. It is a necessary to adopt a special method for peaty ground to enable quality control including the determination of an appropriate type and quantity of binders to strength the stabilisated soils. Alternatively, deep mixing is generally used as a measurement again these problem. Where there application was started in the late 1970's in Japan and Swedan by adding dry or wet binders in order to reduce settlements, improve the stability and strength of soil [7]. The technique is adopted because it can improve ground considerably in a short period of time [8].

Deep mixing method relies on the introduction of a chemical binder to alter the physical properties of the soil mass. Through this process, the soil will be improved by the reduction of water content, cement hydration harderning, bonding of soil particles and filling of void by pozzolanic reaction [9]. Chemical stabilisation of organic soils and peats with cementitious binders have been proved to be a promising technique which has commercial potential with simple application, low noise,economical and reliable solution [8], [10].

Typical chemical binders include cement, lime were used for stabilised organic soils as peats [4], [11], [12]. As suggestted by Broms (1986), in Southest Asia, it is preferable to use cement instead of lime, because of the low cost of cement compare to lime and the greater strength which can obtained with cement in short period [13]. Chen, 2006 reported that cementitious compounds can change the composition and structure of the calcium liberated gel to form insoluble calcium humid acid, which is responsible for increase of soil strength [14]. Bergado, 1994 noted there are two major chemical reactions in cement stabilisation which is primary hydration reaction of cement and water and secondary pozzolanic reaction between cement and soil mineral [15]. The hydration reaction leads initial gain in strength because of the formation of cementations products by drying up of the water. Futhermore pozzolanic reaction which also termed as solidification where Ca^{2+} ions from binders will react with silicate and alumina in soil to form calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) crystallize compounds which will harded soil skeleton with increase strength by times.

Cement as binder were employing to improve strength and stiffness of soil in this research. The study also takes a practical approach to addressing the effectiveness of using cement as stabilizing agents at peaty ground and to investigate the influence of the amount of binder with various water/cement ratios.

II. MATERIAL AND EXPERIMENTAL PROCEDURE

A.Soils

The disturb organic soils used in this study was retrieved from Bukit Rambai, Melaka (MOS) and peat from MARDI Pontian (PP), Johor at depth of ± 1.5m considerable content fibrous of sedges, root and fragment of decayed wood.

Pontian and Melaka soils was classfied based on organic content, where peat is soils with organic content more than 75% and organic soil is soil with organic content at range 25-75% (ASTM, D4427). PP are in greyish dark brown with moderate smell which have organic content of 95%, moisture content of 659%, unit weight of 12.3kN/m^3, 1.44 specific gravity, pH of 3.66, 180% of liquid limit and no plastic limit. Meanwhile MOS in brownish colour with some fine sand and decayed wood consited of 120% of moisture content, unit weight of 20kN/m^3, 1.57 specific gravity, pH of 4.25, 95% of liquid limit and 34% of plastic limit. U.S Department of Agriculture (USDA) reported that the soil with fiber content over 66% is clasify as fibrous peat while hemic peat is with 33-66% of fiber content. PP were categorize as hemic peat which also know as intermediate degree of decomposition soil while MOS are fibrous peat which is mostly undecomposed soil. The properties of these soils and binders are summarised in Table 1. X-ray fluorescence, (XRF) test was also conducted to reveal the chemical properties of soils and binders as show in Table 2. Figure 1 and 2 show the particle distribution analysis for PP and MOS.

Figure 3 show the infrared spectrosopy, (FTIR) absorption pattern of natural soil with purpose to characterize humid substances of soil matrix. PP was categorize humid acid while MOS as fulvic acid. Where humid acid has a strong absorption band at 2980cm^{-1} cause of C-H vibrations, and a stronger absorption for both carbonyl and carboxyl vibrations in COO^- at 1720cm^{-1} and1650cm^{-1}. There is no absorption bands at 1000cm^{-1}. Fulvic acid has a strong absorption band at 3400cm^{-1}, a weak band at 2980cm^{-1}, a shoulder at 1720cm^{-1}, followed by a medium strong band at 1650cm^{-1}, attributed to vibration of OH, aliphatic C-H, carbonyl (C=O), carboxyl groups in COO^- [16].

As shown in Figure 4 and 5, Scanning Electron Microscopic, (SEM) observations texture of unthreated soil consisted of many sheet – like particles. The soil have flaky shape are likely to have high compressibility and limited strength [17].

B. Binders

The ordinary Portland cement (OPC) with 1.2% of moisture content, 3.13 of specific gravity, pH of 12.32 was used in this study. X-ray Diffraction, (XRD) analysis shown CSH (Calsium Silicate Hydrate), CH (Calcium Hydroxide) and ET (ettringite) were major reaction products in OPC which will influence soil stabilised as in Figure 6.

Figure 7 shown the texture of OPC were it found to be angular with non uniform and corners shapes. Distribution of grain size of cement was within a range of 5- 15µm. There are changes in mineralogical of cement when mixed water at various curing period as Figure 8 where CSH were developed within increased of curing time as fabric structure to gaining in term of strength.

C. Samples perparation and testing

The soil mixture were prepared by remolded soil using hand to form a uniform sample and remove the particle which larger size (> 20mm). Mixes natural soil, binders slurry with various porpotion of water cement ratio which the total water content were controlable (700% for PP and 150% for MOS) using ALCO Bench Mounting Mixer (AL-2000) with 20L capacity, 20V, 750 Watt and 108rpm speed. After 10 minutes of mixing a homogenous mix was formed, which was then poured at 500g into diameter 52mm, height 300mm polyvinyl chloride (pvc) tube. A fabric was taped over the bottom of pvc tube to take up water during cured in box which are filled up with bleach to prevent alga growth at room temperature 25^{0}C. The specimens were trim to 50mm diameter and 100mm height size before testing several tests as bender element, unconfined compressive strength, at ages as 7,14 and 28 days. The percentage constituents of the soil mixes are shown in Table 3 and 4.

TABLE I
INDEX PROPERTIES OF PEAT, ORGANIC SOILS AND BINDERS

Properties		PP	MOS	OPC
Natural water content,%		659	120	1.2
Specific gravity, G_s		1.44	1.57	3.13
Atterberg Limit, %	PL	NA	34	-
	LL	180	95	-
pH		3.66	4.25	12.32
Ash Content,%		1.50	37	-
Organic Content ,% (Loss on ignition)		98.5	63	1.51
Fiber Content,%		49	70	-
Unit Weight, kN/m^3		12.3	20	-
Total Organic Carbon, ppm	TOC	14.78	4.919	-
	TC	14.89	5.015	-

TABLE II
CHEMICAL PROPERTIES OF PEAT, ORGANIC SOILS AND BINDERS

Element		Concentration ,%		
		PP	MOS	OPC
Sulfur trioxide	SO3	26.2	0.67	3.84
Calcium oxide	CaO	24	-	64.9
Feric oxide	Fe2O3	17.7	10.7	3.72
Zink oxide	ZnO	11.3	-	-
Silica dioxide	SiO2	7.16	63.8	17.7
Aluminium oxide	Al2O3	1.5	20.5	6.56

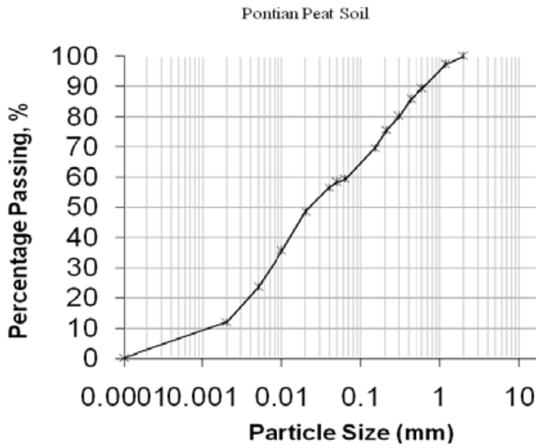

Fig. 1 The particle distribution anlysis of Pontian peat soil

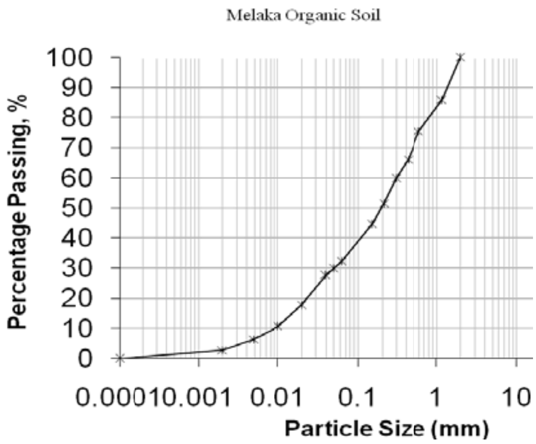

Fig. 2 The particle distribution anlysis of Melaka organic soil

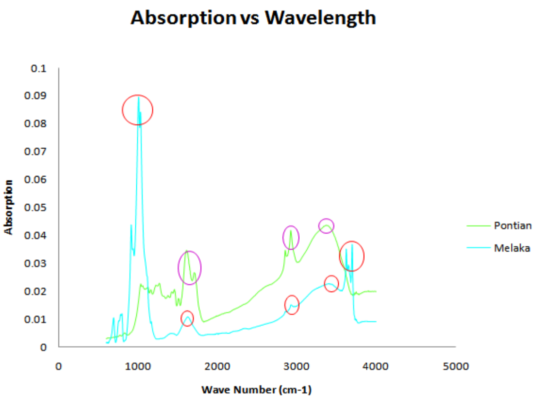

Fig. 3 Absorption vs. wavelength for FTIR Test

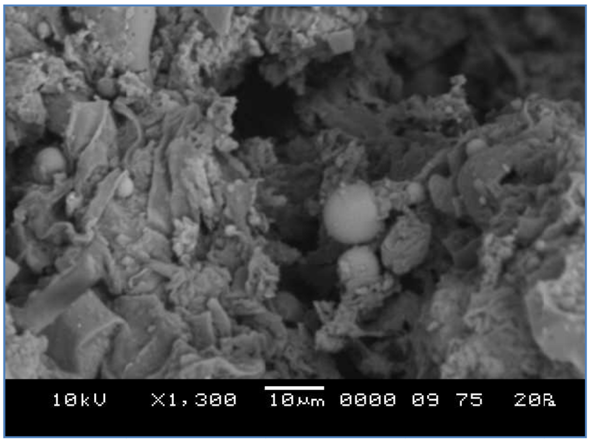

Fig. 4 SEM micrograph of Pontian Untreated Soil

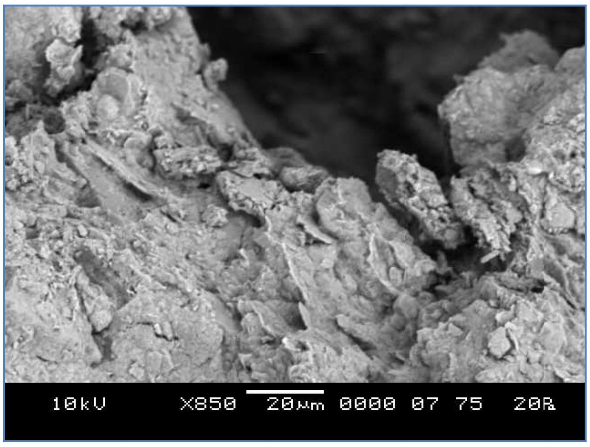

Fig. 5 SEM micrograph of Melaka Untreated Soil

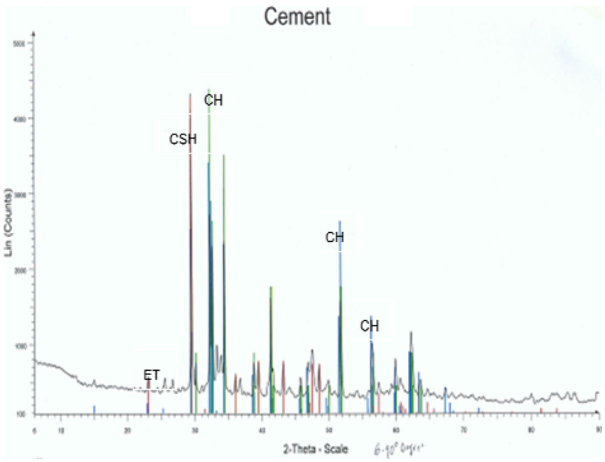

Fig. 6 Typical XRD pattern of cement

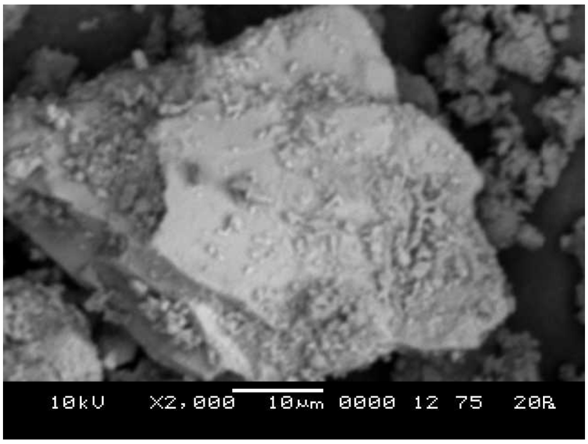

Fig. 7 SEM micrograph of cement powder

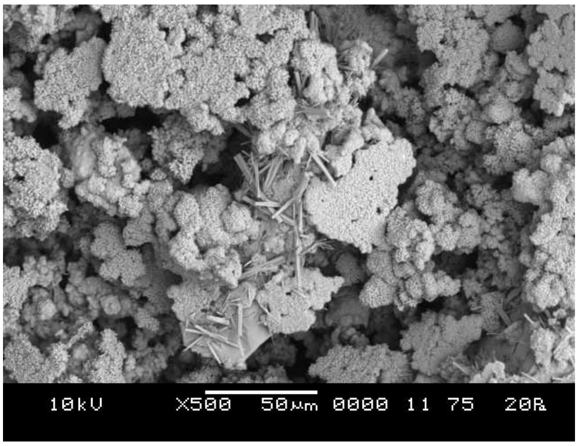

Fig. 8 SEM micrograph of cementt paste at 28 day after added water

TABLE III BINDERS MIXES FOR PONTIAN PEAT

Binder Content, aw (%)	Binder Factor, a (kg/m^3)	Water cement ratio w:c
5	9	140
50	85	14
100	171	7
200	334	3.5

TABLE IV BINDERS MIXES FOR MELAKA ORGANIC SOIL

Binder Content, aw (%)	Binder Factor, a (kg/m^3)	Water cement ratio w:c
5	61	15
15	185	10
30	366	5

III. Result And Discussion

A. Unconfined compressive strength

Figure 9 shows the unconfined compressive strength, qu, of the specimens prepared by different proportion of water cement ratio for stabilized PP at differences age of curing period while Figure 12 show qu for MOS. Due to difference in binders content and soil types, unconfined compressive strength result are in range of 90 kPa for PP and 93 kPa for MOS after 28 days curing.

The effect of cement stabilized peat and organic soil achieved a highest result in UCS have also agreed by [4]-[6], [8]. Filz, 2005 noted mixing with cement for soil with moisture content largest 40%, the estimates shear strength for peat soil are 30-100kPa and organic soil 50 -150kPa meanwhile the UCS of the treated soil with 120-450kg/m^3 cement ranged from 200-400 kPa [18].

The result shown that stabilised behavior of deep mixing PP and MOS is giving lower strength at 90 kPa and this is influence by soil types; binder types; binder dosage rate and proportions; binder- water ratio; curing conditions as reported by [19]; [20]. The binder water ratio is an important factor in considering the improvement effect during curing period [21]; [22]. Dosage rate of binder typically applies for deep mixing methods were 6-12% by dry unit weight of soil or 10% by weight of soil (75-200kg/m^3) [23]. Nevertheless for this study, research has trying the dosage of binder factor at range of 9-334kg/m^3 for PP and range of 61- 366kg/m^3 for MOS, which influence achieved of limited strength.

B. Stiffness

Figure 10 shown the S wave velocity versus curing period of PP while Figure 13 for MOS. The non- destructive bender element test was conducted on the specimens at different ages to monitor the change in stiffness of stabilised soil.

The result reported Vs for the cement stabilised specimens generally increased with time thought aw200 for PP showed negligible increase. Meanwhile for MOS, seemed to similar effect of Vs. For specimens curing at 7 days, Vs data no give much changing within different binder content, where this can be correlated to low qu and high water content in sample. Specimen aw200 seemed to have higher stiffness compared to PP. In prediction, the higher stiffness will be achieved by admixture higher binder factor. Figure 11 and 14 is shown the correlation between qu and S-wave velocity,Vs for PP and MOS at 7,14,28 days curing period.

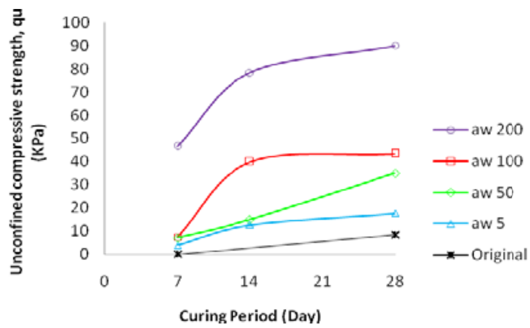

Fig. 9 qu – curing period (Pontian peat)

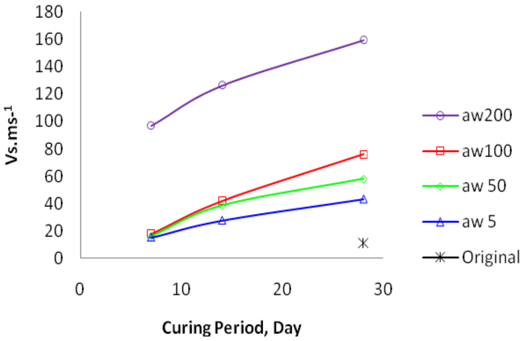

Fig. 10 S-wave velocity – curing period (Pontian peat)

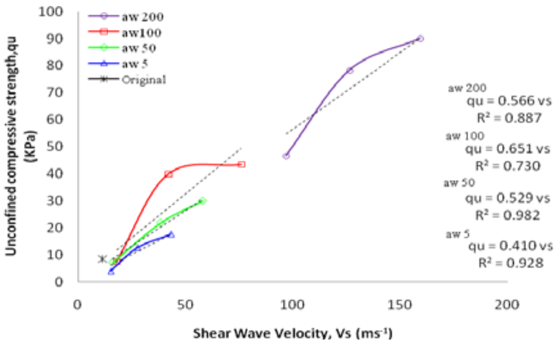

Fig. 11 qu - S-wave velocity at 7,14,28 days curing period (Pontian peat)

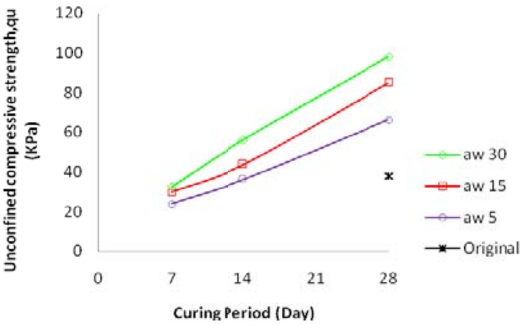

Fig. 12 qu – curing period (Melaka Organic Soil)

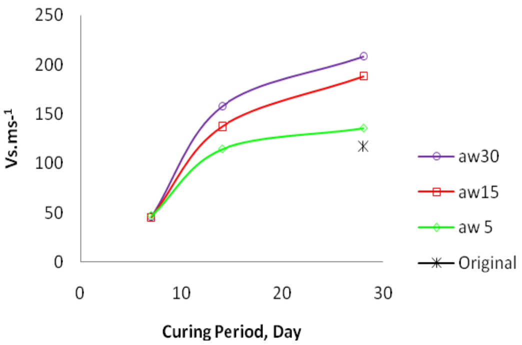

Fig. 13 S-wave velocity – curing period (Melaka Organic Soil)

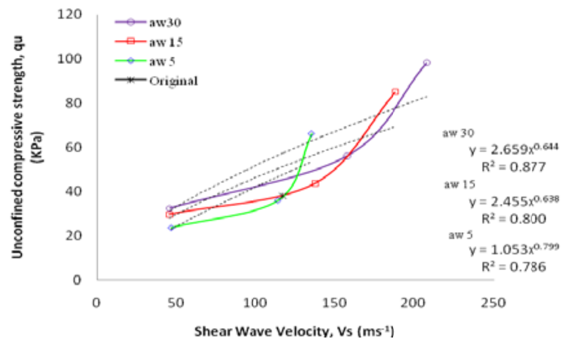

Fig. 14 qu - S-wave velocity at 7,14,28 days curing period (Melaka Organic Soil)

C. Microstructure

The used of SEM to investigate the changes in microstructures and hydration process between cementititous materials with soil of stabilised soils has been useful. Figure 15,16,17 show scanning electron micrograph of stbilised soil at difference day. Figure 15 illustrates a scanning electron micrograph (x 750 magnification) of early stage stabilised soil (7days), where it shown there nothing changing on the soil micrograph compare with untreated soil Figure 4 and 5. The soil consisted of many flaky shape which have highly belive causing of high compressibility and low strength as show in Figure 9.

Figure 16 shown SEM micrograph (x 900 magnification) of soil stabilised at 14 day where cementitious products such as CSH fabrics and ettringite are formed. Ettringite reacted with free gypsum to produces a hexagonal plate. Substantial growth of reaction products can be observed as curing time increased. [18] reported, CSH fabrics and ettringite harded on surface of stabilised soil at 28 day of curing period as shown in Figure 17, where there is no flaky plate occurred, and it is assumed formation and growth of fabrics was made the stabilised soil structures denser and stronger and resulting increased of strength.

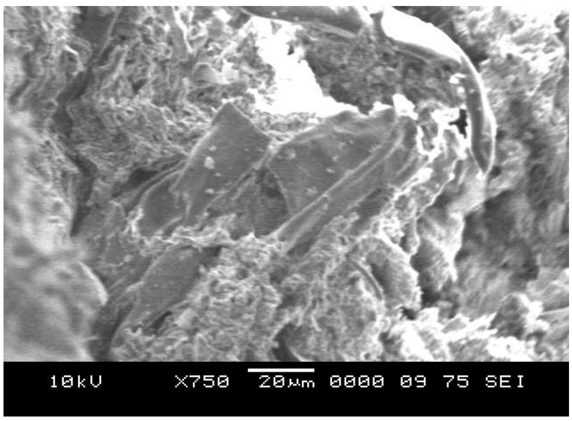

Fig. 15 SEM micrograph of soil stabilised at 7 day

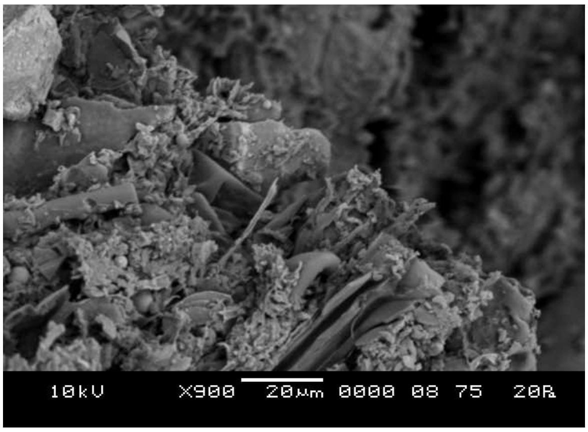

Fig. 16 SEM micrograph of soil stabilised at 14 day

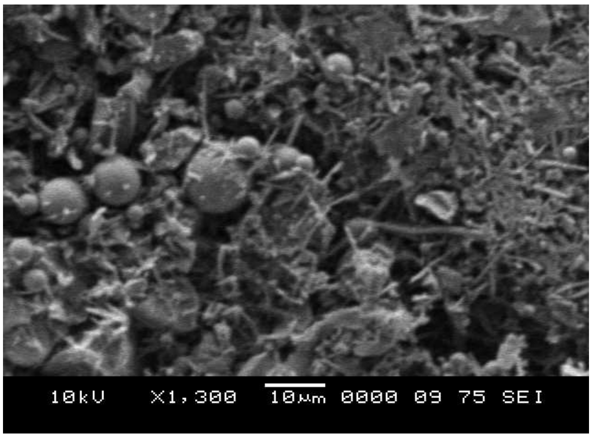

Fig. 17 SEM micrograph of soil stabilised at 28 day

IV. CONCLUSION

The OPC with a suitable mixing content could be effectively used to stabilise peat and organic soil. Geotechnical engineering properties such as unconfined compressive strength and stiffness of stabilised soil markedly improved. It could be conclude that formation of reaction product such as CSH and ettringite from cement made structures denser and contributed strength development in soil stabilised. This can be proved with results of SEM observations.

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