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MODIFICATION OF KAOLIN MINERALOGY AND MORPHOLOGY BY HEAT TREATMENT AND POSSIBILITY OF USE IN GEOTECHNICAL ENGINEERING

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ABSTRACT: This paper presents an experimental work on the effect of heat treatment on the mineralogy and morphology of kaolin. Kaolin, which is moderately expansive, was preheated at temperatures ranging from 200°C to 800°C by increment of 200°C and cooled at room temperature before it was mixed with peat. Peat represents a compressible soil and has low bearing value. The main aim of the work is to study the effect of heat treatment on shear strength parameters of peat-kaolin mixture. The mixtures are prepared at different proportions, and at each proportion triaxial samples were prepared and tested in the undrained condition to study the shear strength parameters. Untreated kaolin-soil mix was also prepared to provide a comparison between the treated and untreated soil mix in terms of the shear strength behaviour. XRD and FESEM were also carried out to investigate the change in soil micro-structure due to heat treatment. The tests showed that there was a slight improvement in the strength of peat-kaolin mixture when kaolin was preheated to a temperature of up to 400°C. Finally results were discussed and conclusions were made for the preheated kaolin-peat mixture.

Keywords: Kaolin, Peat, Heat treatment, Triaxial, Shear strength

1. INTRODUCTION

Kaolin is a subgroup of the clay family of mineral which contains polytypes such as kaolinite, dickite, nacrite and halloysite [1]. Mineral compositions of the tropical residual soils in Malaysia are mostly dominated by kaolinite which occurs from weathering or hydrothermal processes. Kaolinite is the principal mineral element in Kaolin which is used in various industries and has a natural moisture content between 16 to 49% [2],[3].

Kaolinite crystals are usually 0.2–2 micrometers in size. Kaolinite ($A1_2Si_2O_5(OH)_4$) is a 1:1 type clay mineral composed of stacked layers of SiO4 tetrahedral (silica) sheets and $AlO_2(OH)_4$ octahedral (alumina) sheets. The ideal chemical composition is Al_2O_3 39.53%, SiO_2 46.51% and H_2O 13.96% [4]. The particles tend to agglomerate more strongly at a higher temperature and produce higher amount of coarse particles. Yilmaz [5] had mentioned that the thermal treatment affects the behaviour of clays through the influence of absorbed water. It may cause dispersion of flocculation effects depending on kaolinite mineral and the type of ion exchange. The disintegration of soil particles is completed when the water around the particles is removed. This situation may lead to particle growing to larger sizes. The XRD pattern study shows that only a small part of kaolinite mineral remains when kaolin is heated at 500°C. Some changes are observed in mineral composition like the transformation from kaolinite to metakoalinite when kaolin is heated to between 650°C and 850°C [6].

A number of researchers recently studied the replacement of the synthetics products for ground improvement by more natural additive such as fly ash, coal ash, lime slurry, bentonite, recycled gypsum and waste plastic trays [7]. In fact, naturally occurring weak soils are the types of soil that need more attention to improve their engineering properties. The term ‘weak soil’ mentioned in this study refers to an organic soil that has high compressibility but low permeability, bearing capacity and shear strength.

In engineering projects, weak soils have unacceptable physical and mechanical properties. For example peat is a problematic soil. In Malaysia peat is found mainly in low-lying poorly drained depressions or basins in the coastal areas that occupies over a total of 2.7 million hectares, which represents about 8% of the total land area of the country [8]; hence, the need to find solutions to strengthen this problematic soil before any projects is built on it.

In a comparative study by other researchers had found that the amendment of peat with 10% kaolin could increase the compressive strength [9]. Ref Kalantari et al [10] also found a solution for increasing compressive strength of peat by mixing it with cement and fibers. However, another study has shown that by increasing the amount of kaolinite may increase shear strength of soil treated but cause shrinkage of cement grout in grouting method [11].

Construction industries in the United States use soil mixing technique, a low-cost method in a ratio of one to five compared with other solutions; and this technique is used to treat contaminated soft soil [12].

Soil mixing can be used to treat contaminated sand as well [13]. Deep mixing method is an option to use for mixing the binding agents such as lime or/and cement because it may improve the permeability, strength and deformation properties of weak soil [14]. But, when the depth of peat layer is less than 4m, the mixing method is not effective enough.

The present work analyzes the effect of heat treatment on the shear strength parameters of the peat-kaolin mixture. We applied the soil mix design method of peat-kaolin mixtures in laboratory conditions to assess the improvement of engineering properties.

2. MATERIALS AND TECHNIQUE OF CHARACTERIZATION

2.1 Materials

In the field, the predominant soil types based on texture are identified by inspection. Generally, the identification and description methods of soils have already been clarified in BS 5930 Section 6. Since the texture and colour of peat soil is different than other soils it is easier to notice. Peat soil contains sediments from woody remains such as roots, branches and tree trunks. Typically the colours of peat are from dark brown to black. The samples for this study were taken at Jalan Kuantan-Pekan, Pahang, Malaysia in the coordinate of longitude E 103.301239 and latitude N 3.650854. The area has soils that have organic content.

The commercial kaolin mineral as shown in Figure 3.4 was imported from Kaolin (Malaysia) Sdn. Bhd. This is one of the main mineral suppliers in Malaysia that extracts and process kaolin in their own factory in Tapah, Perak. Type of kaolin powdered that has been used in this study is C type. The moisture content of C type is less than 7.0% in natural condition. Average particle size of this powdered kaolin in between 2.5 μ – 4.5μ and the pH of 30% solid mineral are between 3.0 – 5.0. The chemical composition of kaolin as provided by the manufacturer is summarized in Table 1.

2.2 Experimental methods

In order to investigate the changes in engineering properties of our soil samples mixed with thermally treated kaolin, tests were conducted for mixtures with raw kaolin and with kaolin thermally treated at 200°C, 400°C, 600°C and 800°C. The specimens were prepared by laboratory soil mixing method at mass ratio of peat soil mix at 90:10, 80:20, 70:30. 60:40 and 50:50%.

Table 1 Chemical composition of kaolin

Type of properties	Kaolin (Manufacturer data)
• Aluminium (Al_2O_3)	• B32.0 – 38.0 %
• Silica (SiO_2)	• 47.0 53,0 %
• Iron (Fe_2O_3)	• Below 1.3 %
• Potassium (K_2O)	• Below 2.5 %
• Magnesium (MgO)	• Below 0.5 %
• Loss on Ignition @ 1025°C	• 11.0 – 14.0 %

Laboratory furnace has been used to burn kaolin with different temperatures for 1 hour. In order to investigate the effect of peat and kaolin mix on shear strength, soil compaction tests were conducted by using automatic compactor with 1 L mould. These tests are needed to determine the optimum moisture content. After mixing thoroughly, the soil samples again were compacted with the same compacter machine and then they were extruded using an extruder to a sample cylinder with the size of 38 mm diameter and 76 mm high. All re-compacted samples were left to mature in a clear plastic tube container for at least 24 hours. The unconsolidated-undrained (UU) Triaxial test has been used in order to determine the shear strength parameters. The values of the shear strength parameters reported here were the average values. The UU tests were performed according to BS 1377:1990 Part 7. In the second part of this study, the XRD and FESEM were also carried out to investigate the change in soil micro-structure due to heat treatment to gain better understanding of improvement of soil mixing properties.

3. RESULT AND DISCUSSION

The weak soil properties have been analyzed based on BS1377:1990 as shown in Table 2. Before the untreated soil was tested in laboratory condition, the observation was done by visual classification according to ASTM D2487. The visualization result obtained was ML (silt content with low plasticity), but the laboratory test result refined the classification as sandy silt with organic matter. The influence of different proportions of soil mixture with different levels of temperatures has been investigated and the results are presented in tables and figures.

3.1 Influence of soil mixing on optimum moisture content

Figure 1 shows the graph of optimum moisture content for soil mixture samples with different ratios of kaolin-peat mixtures at various temperatures.

Table 2 The properties of untreated weak soil

Properties	Organic soil
• Moisture content (%)	• 23.15
• Organic content (%)	• 10.5
• Ash Content (%)	• 89.5
• Specific gravity, Gs	• 2.58
• Liquid Limit (%)	• 38.93
• Plastic Limit (%)	• 27.65
• Plasticity Index (%)	• 11.28
• Bulk Density (kg/m^3)	• 1986.98
• Soil Type (USCS)	• SM
• Description	• Sandy Silt with Organic Matter

When the organic soil has been mixed with increasing proportions thermally heated kaolin, the optimum moisture content gradually increased. Theoretically, when the soils are subjected to heat, dewatering process will take over after all the moisture is trapped in voids it evaporated in. Due to this dewatering process, the natural mineral soil subjected to thermal high temperatures will go through this process. Hence, the optimum moisture content of thermally heated kaolin will be much higher than the raw kaolin.

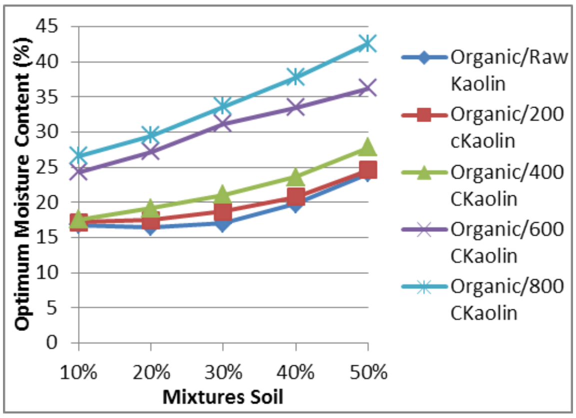

Fig. 1. Graph of optimum moisture content against soil mixture samples

Moreover, one of the factors that can also be discussed due to high OMC with low MDD are the particle rearrangement and orientation. While the preferred orientation increased as the moisture content increases, the particles, pores and other elements tend to become parallel with each other. As expected, the long platey particles seemed to be rearrange and reorientate themselves into a new more stable position [15] but when the thermal treatment took place, the bulk density gradually decreased with temperature due to particle size distribution [16]. Eventually, when kaolin is subjected to heating process, particles are found to agglomerate more strongly and lead to have a coarser fraction. Hence, the treatment tends to reduce the density of the mixture soil samples.

3.2 Influence of soil mixing on shear strength

Shear strength was developed from both 50KPa cell pressure and deviator stress with maximum values of 182.0KPa for peat and unheated kaolin mixture at about 10% mix ratio. Figure 2 shows the pattern of the different shear strength values in term of percentage mixture. As we can see, when the proportion of mixture was increased, the shear strength value decreases.

At higher temperatures, shear strength of peat mixed with thermally treated kaolin decreases. The soil mixture at 400°C shows kaolin has lesser values in shear strength than the unheated and 200°C of heated kaolin. The main concern in shear strength development is related cohesion and the angle of friction.

The correlation coefficient (R square) by regression shows a relationship between cohesion and internal angle of friction with effects of gradient of temperature. By referring to Fig.3, the cohesion of mixture soils is found to gradually decreasing with the increasing of soil mixture temperature with R square being 0.998. In addition, the internal angle of friction (Fig.4) was increased steadily with increasing temperature of mixture and the R square is 0.997. When the soil is mixed with heated kaolin, the optimum moisture content increased but the cohesion was found to decrease steadily.

Without stabilization the untreated peat specimen has very low cohesion and internal angle of friction. This is because organic soil such peat has poor mechanical properties. Strong correlations were found between the internal angle of friction and thermal treatment of kaolin as determine by Yilmaz [5]. The internal angle of friction depends on the grain size distribution of thermal treated kaolin. The experimental results show gradually decreasing shear strength values. If we continue the experiment the results might show lower value of shear strength as the temperature increases. Hence, the investigation was stopped at 400°C.

3.3 Influence of mineralogy and morphology on optimal design of mixing soil

Figure 5 shows the energy dispersive X-ray characterization for optimum design of mixed soil sample that was 90% peat with 10% unheated kaolin soil. It can be observed from this figure that other elements such as S, K and Ca are present. Table 3 lists the components identified in the 10% natural mixed soil. It has been observed that, the bonding of silica and alumina has shown major distribution effect among the elements. But the presence of some elements is detrimental to good bonding and forming strong compound of stabilizing weak soil. In their analysis of unconfined compression tests, Wong et al have shown the presence of high peaks of Ca, Si and O after curing the test specimens. These three elements would form calcium silicate hydrate as a main cementation product in stabilized soil [9].

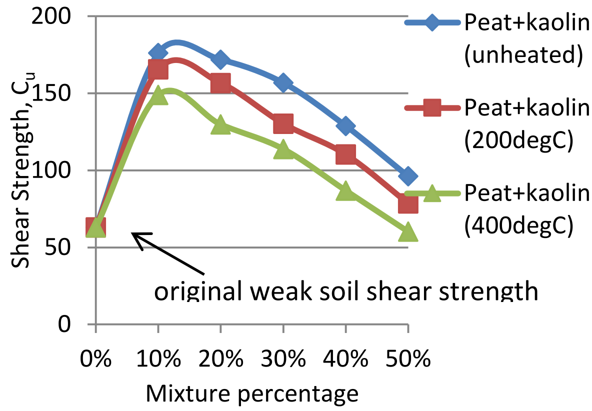

Fig. 2. Graph of shear strength against percentage of soil mixture samples

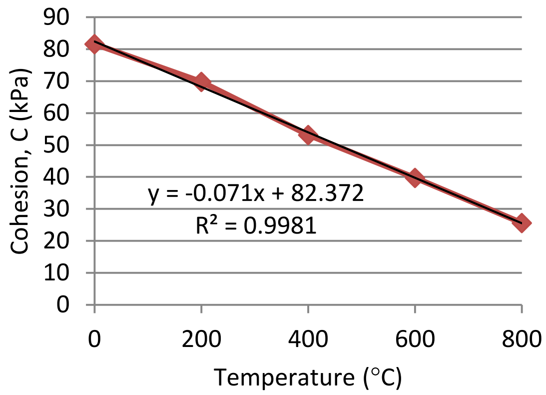

Fig. 3. Graph of cohesion against kaolin temperature of soil mixture samples

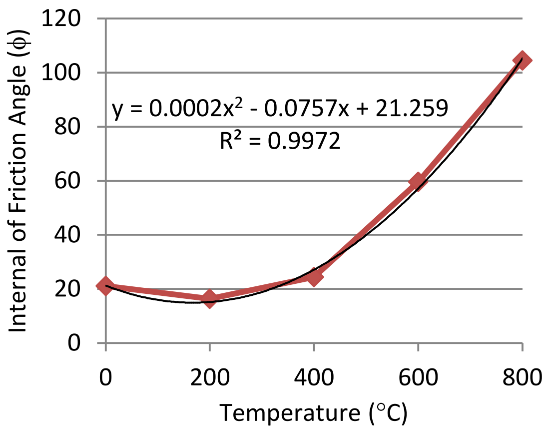

Fig. 4. Graph of internal of friction angle against kaolin temperature of soil mixture samples

Even though this EDAX analysis did not show a high percentage of Ca, yet this element plays an important role as a bonding agent to form an optimized mixture soil in this study. This can be clearly observed from the particle morphology of 10% mixture in Fig.6. The platy structures are closely packed together and reducing voids between the particles. Such association development is likely because the kaolin particle surface charge is compensated and hydrogen bonds can dominate instead of stronger ion-dipole interactions [17].

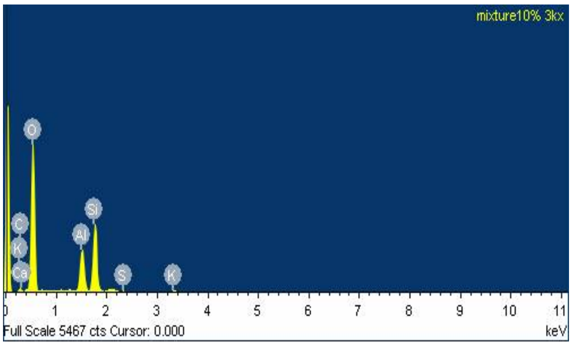

Fig. 5. The EDAX result for optimum design of mixed soil sample

Table 3. The component obtained for optimum design of mixed soil samples

Element	Weight	Formula	Compound (%)
C	7.04	CO_2	25.80
Al	11.37	Al_2O_3	21.47
Si	23.66	SiO_2	50.62
S	0.25	SO_3	0.63
K	0.87	K_2O	1.05
Ca	0.31	CaO	0.43
O	56.50		

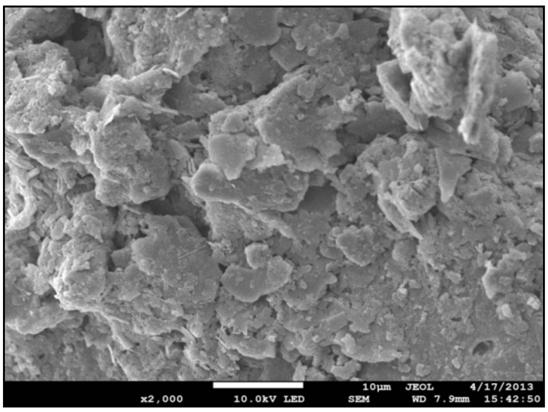

Fig. 6. The morphology photo of optimum soil mixing design by FESEM

4. CONCLUSION

This study was carried out to investigate the effects on shear strength of peat soil treated with unheated and thermally heated kaolin, added in different proportions. It was observed that, when cohesion increases, the internal angle of friction decreases. This phenomenon can be observed based on the effect of soil mineralogy on internal angle of friction in soil mass. When kaolin is subjected to 400°C we can see a substantial decrease of soil cohesion, and in the same time, the internal angle of friction is increased. It can be indicated that bonding sheets of silica and alumina in clay indirectly controls the internal angle of friction. The best result has been observed in the combination of 10% of unheated kaolin to the peat. This research work was limited to the specimen in the laboratory. For more investigation the subsoil or earth structure can be modelled using materials used in this research work for more application of produced materials.

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