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THE CHARACTERISTIC OF SAND-KAOLIN CLAY MIXTURE AS ARTIFICIAL MATERIAL FOR LABORATORY SOIL TESTING

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ABSTRACT

Laboratory soil testing is a routine activity in geotechnical engineering. For the tests, either the characteristic, behaviour of soil or the performance of the laboratory apparatus is studied. One of the most important requirements for laboratory study is that the material should have repeatability property. However, due to the heterogeneity many soil samples do not comply with this requirement. To overcome this situation, articial material might be able to be utilised. The series of laboratory tests using a new material of sand-kaolin clay mixture have been conducted. The low cohesion, no plasticity, and high internal friction possessed by sand mixed with the high cohesion, high plasticity, and low internal friction possessed by kaolin clay produce a new material. The desired new properties are obtained by changing the proportion of sand-kaolin clay mixture. The index properties, compaction characteristic, shear strength properties, and CBR results are presented. It can be concluded that sand-kaolin clay mixture is suitable material for geotechnical laboratory test.

Keywords: Artificial Material, Laboratory Testing, Repeatability Property, Sand-kaolin Clay Mixture

INTRODUCTION

Laboratory soil testing is a routine activity in geotechnical engineering. For the tests, either the characteristic or behaviour of soil or the performance of the laboratory apparatus is studied. However, due to the heterogeneity many soil samples do not comply with this requirement. To overcome this situation, articial material might be able to be utilised. Artificial material is made to resemble the characteristic and the property of original material. One of the geotechnical materials that can be used for producing artificial material is kaolin clay.

Kaolin clay is a versatile material that has a wide range of uses. It has been utilesed in wide range various industries such as : ceramic, cement, fiberglass, paint, paper filling/coating, rubber, plastic, pharmacy, textiles, detergent, and even cosmetics [1]. In geotechnical engineering, kaolin clay has been used for slope stabilization and erosion protection [2] and as a barrier for waste disposal facility. The extensive use of kaolin clay is due to its unique properties.

This paper presents the use of artificial material for laboratory soil testing made from sand-kaolin clay mixture in different proportion. The characteristic of the material is presented in term of physical and engineering properties of the material resulted from the test. A brief of each material characteristic; sand and kaolin clay is firstly described, followed by the description of new artificial material of sand-kaolin clay mixture.

THE PROPERTY OF SAND AND KAOLIN CLAY

The Properties of Sand

The most important physical characteristic of sand is particle size distribution and particle shape. The distribution alse affects the engineering properties. Other influencing factors are density, particle arrangement and isotrophy [3]. Poorly graded sand tends to have a narrower range of density compared to well-graded sand. Particle size distribution can also affect the properties of sand. The increase in the range of particle size (increase in the coefficient of uniformity,*Cu*) causes a decrease in void ratio.

In terms of strength and compressibilty, sand has relatively beneficial engineering properties compared to clay. It has high internal friction, low compressibility, non-plasticity, low swell-shrinkage potential, and in general, the behaviour of sand is rarely affected by water content. A small amount of cohesion may be generated through the capillary tension among the particles, due to the presence of water. The increase in moisture content, to some extent, can cause this increase in cohesion. With the increment of moisture, cohesion also increases significantly. However, when the moisture content reaches a certain value, cohesion will decrease and even disappear when a saturated condition is reached [4].

The shape of the particles also strongly influence the engineering properties of sand. The shape can be angular, sub angular, rounded or semi-rounded. The compaction result of sand containing angular particles tends to be less dense when compared to sand with rounded particles. For ideal uniform-size spherical particles, five different possible packing arrangements are proposed; (a) simple cubic, (b) cubic tetrahedral, (c) tetragonal sphenoidal, (d) pyramidal, and (e) tetrahedral. Simple cubic packing has the loosest stability and highest void ratio of 0.91, whereas tetrahedral packing has the densest arrangement and the lowest void ratio of 0.34.

The Properties of Kaolin Clay

The shape of kaolin clay particle is platy crystal with the length of particle being 0.2 μm to 2 μm with a thickness of 0.05 μm to 0.2 μm. Amongst other clay minerals, kaolin is a mineral with the largest particle size. Kaolin clay is categorized as a silicate mineral. Kaolin clay is one of the minerals in the kaolin group including haloysite, dickite, and nacrite. Theoretically, the main components of kaolin are alumina (Al_2O_3), silica (SiO_2), and water. Kaolin clay consists of alternating layers of one silica tetrahedral sheet and one alumina octahedral (or gibbsite) sheet tied with oxygens and hydroxyls. The common molecule formula for kaolin is $Al_2Si_2O_5(OH_4)$. Table 1 shows the typical results from chemical analyses of different sources of kaolin clay from Georgia, England, and with from Unimin Pty Ltd, Australia.

Table 1 Typical chemical analysis of kaolin clay [1] and [5]

Component (%)	Georgia	England	Unimin Australia
SiO_2	45.3	46.77	49.2
Al_2O_3	38.38	37.79	39.4
Fe_2O_3	0.3	0.56	1.01
TiO_2	1.44	0.02	0.935
MgO	0.25	0.24	0.358
CaO	0.05	0.13	0.51
Na_2O	0.27	0.05	< DL
K_2O	0.04	1.49	0.18

Compared to other clay (montmorillonite and attapulgite), kaolin clay has relatively better properties. It has lowest liquid limit, plastic limit, and activity. Active clay has a high water holding capacity, high compaction under load, high cation exchange capacity, low permeability, and low shear resistance. Therefore, very active soils can be problematic for engineers [6]. The presence of certain types of clay mineral in the soil affects its engineering properties. Soil with a high activity has high swelling when wetted and high shrinkage when dried. Activity can also be used for predicting the amount of clay fraction in the soil and is a very useful indicator for predicting the swelling/shrinkage potential of soil. Conversely, inactive soils may not cause problems for engineers, as it has little cohesion. The strength of inactive soil is mainly caused by internal friction.

PREVIOUS STUDIES ON SAND-KAOLIN CLAY MIXTURE

The effects of kaolin clay content of sand-kaolin clay mixture plus water on the void ratio with the different proportion of the mixtures has been studied [7]. The mixtures were also compacted using a static load. The results indicated that for narrowly graded fine sand, the increase in kaolin clay content led to the decreased in void ratio. However, for coarsed-finesand, the increase in kaolin clay to some extent led to a decrease in void ratio.

In addition to the study, the investigatios has also been conducted to understan the effect of kaolin clay content with different water content on the unconfined compression strength. The results indicated that with a certain water content, the increase in kaolin clay content led to an increase in strength. The results also showed that an increase in water content in the mixture caused a decrease in strength [8].

Sand-kaolin clay mixtures have also been studied by other researchers [9]. They used three different compacted sand-kaolin clay mixtures of 0%, 5%, 10% and 30% to investigate the effects of kaolin clay content on the hydraulic conductivity of the mixtures. They conculed that the increase in kaolin clay content causes the increase in hydraulic conductivity.

Some other studies concerning the engineering properties of sand-kaolin clay mixture have been conducted by several investigators [10]-[15]. However, the information about this mixture is still relatively rare and more studies are required.

TESTING PROGRAM

This study was emphasized on laboratory test for obtaining the physical and engineering properties of sand-kaolin clay mixture in different proportions, starting from index properties (gradation, atterberg limits, classification), continued by compaction characteristic, shear strength, and California Bearing Ration (CBR). To understand the effect of unsaturated condition on the mixture, the measurement of suction was also studied. Note that chemical properties test was not conducted in this study.

RESULTS

The Effect of Kaolin Clay on Index Properties

The mixture of two or more materials with different index properties may produce a material with new properties. The index property analysis on the new material was required to determine its properties. Fig 1 shows the gradation curve of sand, kaolin clay, and sand-kaolin cay mixtures.

Atterberg limits tests were also performed. The results indicated that the increase in kaolin content caused a decrease in the liquid limit and plasticity index respectively. The classification system was the performed on the new materials according to ASTM D 2487. Due to the addition of a proportion of kaolin clay to the sand, the group of specimens altered from poorly-graded sand (SP) for sand and 95:5, poorly graded sand with clay (SC-SM) for 90:10, clayey sand (SC) for 80:20 and 60:40 mixtures, and High plasticity clay (CH) for kaolin clay. Based on plasticity, the sand and 95:5 mixtures were categorized as non-plastic specimens, whereas the rest were low-plastic specimens. The summary of index properties of the mixtures is presented in Table 1.

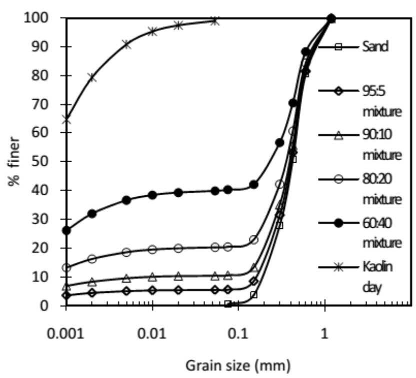

Fig. 1 Gradation curves of different mixtures

Table 2 Index properties of mixtures

Specimen	Gs	LL	PL	PI	Class.
Sand	2.63	N.A	N.A	N.P	SP
95:5 mix	2.63	N.A	N.A	N.P	SP
90:10 mix	2.63	21.3	15.4	5.9	SC-SM
80:20 mix	2.62	26.6	16.7	11.3	SC
60:40 mix	2.60	33	20	13	SC
Kaolin	2.58	58	31	27	CH

Effect of Kaolin Clay on Compaction Result

Standard Proctor test has been conducted on the aforementioned specimens. The result was presented as shown in Fig 2. For the poorly graded sand, the density due to compaction was mainly caused by rearrangement of the particles. During compaction, the particles of sand move to find the best position. The voids become narrower and the specimen becomes denser and more compact. However, due to the lack of smaller particles, the pore spaces in poorly graded sand remain relatively unfilled. Assuming that the particles of poorly graded sand are uniform and round, the packing arrangement of the specimens may be close to one of packing arrangements proposed in [3].

It can be assumed that to some extent (up to 20%), the increase in kaolin clay content would cause the increase in dry density and the decrease in void ratio. However, the void ratio starts to increase when the kaolin clay content of the mixture was > 20 %. This result is in accordance with the results in [7]. It can be concluded that the addition of kaolin clay to sand to some extent could produce a new material with better properties.

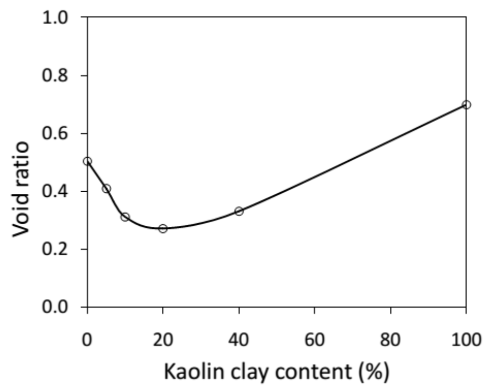

Fig. 2 Curve showing the effect of kaolin clay on void ratio

Effect of Kaolin Clay on Shear Strength

A series of direct shear test on saturated specimens was performed to obtain the effective shear strength parameters (c' and ϕ') for all mixtures. Three different normal forces of 4 kg, 14 kg, and 24 kg were given to each mixture to impose an initial normal stress of 11.2 kPa, 39.2 kPa, and 67.1 kPa. During shear, this normal stress changes due to the change in the shearing area of the sample.

The effect of kaolin clay on shear strength of saturated direct shear test of compacted samples of sand and sand-kaolin clay mixture is shown in Fig 3. A brief description on this figure has been published by authors in [15]. It can be observed that the presence of kaolin clay in the mixture contributes to the increase of cohesion. Note that the test on 60:40 mixture and kaolin clay specimens was not conducted due to the specimen condition. The higher content of kaolin clay would cause to the consistence of the mixture to be softer.

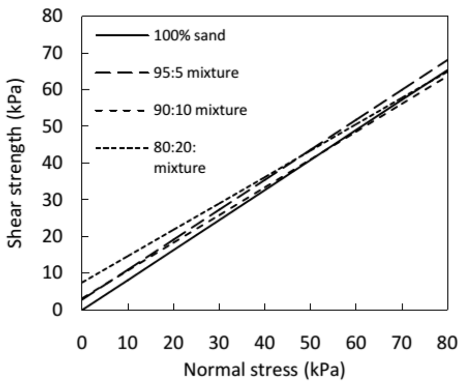

Fig 3 Failure envelopes of sand-kaolin clay mixtures as previously presented by authors in [15]

During direct shear test, sand exhibits hardening behaviour until peak value, followed by softening. The behaviour of cohesionless soil under direct shear testing is dependent on the compactness of the soil. For dense and medium sand, the shear stress increases with shear displacement to a peak value, and then decreases to an approximate constant value. For loose sand, shear stress increases with shear displacement and then remains relatively constant up until ultimate value is reached.

For 95:5 mixture, the strain hardening behaviour was taking place, starting from zero displacement to displacement at peak stress, followed by strain softening behaviour until a residual value was reached. The lowest dilation was experienced by the specimen when the normal stress of 67.1 kPa was applied, whereas the highest was when the normal stress of 11.2 was imposed. In general, the higher the normal stress, the lower the dilation. The similar (strain hardening and dilation) behaviour was also taking place in 90:10 and 80:20 mixture.

The behaviour of the specimen during the test determines the shear strength parameters. Due to limited space in this paper, the stress and strain behaviour during direct shear test is not presented. The parameters resulted from the test are presented in Table 3.

Table 3 Cohesion and internal friction angle of mixtures

Specimen	c' (kPa)	ϕ' (°)	Note
Sand	0	39.3	Saturated
95:5 mix	2.86	39.2	Saturated
90:10 mix	3.21	37.1	Saturated
80:20 mix	7.54	35.7	Saturated
60:40 mix	-	-	Not conducted
Kaolin	-	-	Not conducted

The Effect of Kaolin Clay on the CBR

A series of CBR tests were performed on the sand-kaolin mixture with the same proportions as the specimens in the direct shear test. The tests were carried out on soaked and unsoaked specimens. The procedure for test was conducted in reference to the ASTM D 1883-07. According to this standard, the CBR test can be performed on the specimen either in soaked or unsoaked conditions. The result of CBR test is presented in Table 4.

Table 4 Soaked and unsoaed CBR value of mixtures

Specimen	CBR		Note
	Soaked	Unsoaked	
Sand	13	13	
95:5 mix	11	12	
90:10 mix	19	25	
80:20 mix	20	40	
60:40 mix	-	-	Not conducted
Kaolin	-	-	Not conducted

It can be observed that the values of CBR are typically similar to that the result of compaction. The increase in kaolin clay to some extent (up to 20 % kaolin clay content) contributes to the increase in soaked and unsoaked CBR. Note that due to the same reason as direct shear test, the CBR test for 60:40 mixtures and kaolin clay was not conducted. However it can be easily predicted that their value might **be** relatively low.

CONCLUSION

The use of sand-kaolin clay mixture as artificial material for laboratory soil testing has been described. The behaviour of material was determined by their proportion. The low cohesion, no plasticity, and high internal friction possessed by sand mixed with the high cohesion, high plasticity, and low internal friction possessed by kaolin clay produce a new material. The desired new properties are obtained by changing the proportion of sand-kaolin clay mixture. The index properties, compaction characteristic, shear strength properties, and CBR results were presented. It can be concluded that sand-kaolin clay mixture is suitable material for geotechnical laboratory test.

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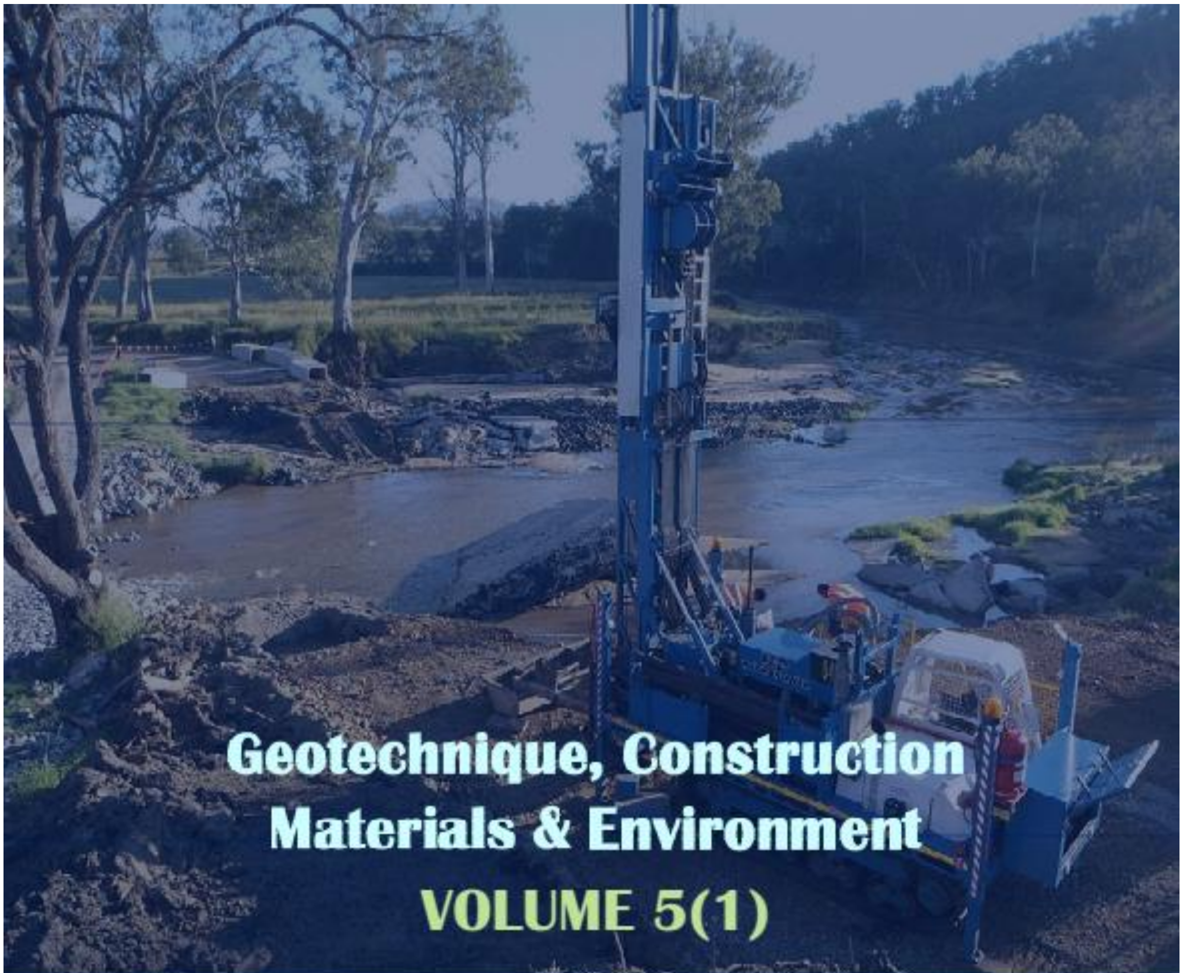

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