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SIMPLE SHEAR BEHAVIOUR OF PALM BIODIESEL CONTAMINATED SOIL

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ABSTRACT

Palm biodiesel contaminations may bring adverse effect on basic geotechnical properties of foundation soils. This paper presents the results of an experimental study on shear behaviour of palm biodiesel contaminated sandy soil. A comprehensive set of laboratory experiments have been undertaken in a direct simple shear device on samples of palm biodiesel contaminated sandy soil. In the experiments the soil samples were prepared by mixing the sandy soil with B20 palm biodiesel ranging from 0% to 20% by weight. Stress-strain and shear strength response for the samples were monitored continuously during the experiments. The effect of the palm biodiesel content, relative density and normal stress on the shear behaviour of the sandy soil is investigated and discussed.

Keywords: sandy soil, palm biodiesel contamination, simple shear test, shear strength.

INTRODUCTION

Biodiesel is a cleaner burning diesel replacement fuel that is manufactured from vegetable oils, animal fats or recycled cooking oils. It offers advantages as a renewable and energy efficient replacement fuel which has similar properties to petroleum based diesel fuel with less air pollution, biodegradable and environmental friendly. A B20 biodiesel, blend of 20% biodiesel with 80% petroleum diesel can be used as the substitute to petroleum diesel without any changes on current diesel operated engine.

Reviewed literature indicates that research on geotechnical properties of soil contaminated with palm biodiesel is very limited. Several research studies have been carried out to investigate the engineering characteristics of petroleum fuel contaminated soils. Al-Sanad *et al* (1995) and Al-Sanad and Ismail (1997) carried out laboratory tests to investigate the influence of oil contamination and aging effect on geotechnical properties of Kuwaiti sand. The results indicated a small reduction in strength and permeability and an increase in compressibility due to contamination. Aging reduced the oil content due to evaporation of volatile compounds and hence increased the strength and stiffness of the oil contaminated Kuwaiti sand specimens. Evgin and Das (1992) carried out a series of triaxial tests on contaminated and uncontaminated sands and found that the oil contaminated samples significantly decreased the friction angle for both loose and dense samples. The results obtained by Shin *et al* (1999) and Shin and Das (2001) indicated that the bearing capacity of footing decreased drastically with the increase of oil contamination. Khamehchiyan *et al.* (2007) studied the effect of crude oil on geotechnical properties of coastal soils. The results showed that the compactability of soil samples increased with the increasing oil content due to reduction of maximum dry density and optimum water content. Oil contamination induced a reduction in permeability and strength in the soil samples.

This paper presents the results of an experimental investigation using a modified computer-controlled simple shear apparatus on sandy soil contaminated with B20 palm biodiesel. Emphasis is given to the study the shear behaviour of the palm biodiesel contaminated soil. The influence of the palm biodiesel content, relative density and normal stress is also investigated by the simple shear tests.

Basic properties of sandy soil

The sandy soil samples used in this study were collected from a construction site in Perak, Malaysia. Sieve analysis tests were carried out on the sandy soil samples. The grain-size distribution of the sandy soil is shown in Figure-1. It is classified as SP, or poorly graded sand, according to the Unified Soil Classification System. The physical properties of the sand are given in Table-1.

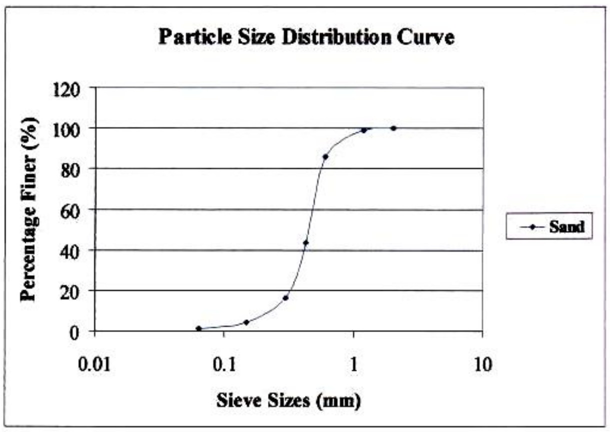

Figure-1. Grain size distribution of sandy soil.

The blender of 20% pure palm oil with 80% petroleum diesel, called B20 palm biodiesel was used in this study as the contaminating material. The palm biodiesel used was produced from palm oil through a chemical process called "Transesterification" and the typical properties of B20 palm biodiesel are listed in Table-2.

Table-1. Physical properties of sandy soil.

Property	Quantity
Effective size, D_{10} (mm)	0.40
Uniformity coefficient, C_u	1.38
Coefficient of gradation, C_z	1.13
Maximum dry unit weight (kg/m^3)	1546
Minimum dry unit weight (kg/m^3)	1314
Specific gravity of soil solids, G_s	2.65

Table-2. Typical properties of B20 palm biodiesel (Choo *et al.* 2007).

Property	Quantity
Density at 15ºC (kg/L) ASTM D4052	0.875
Sulfur content (% wt) IP 242	<0.04
Viscosity @ 40ºC (cSt) ASTM D445	4.5
Pour point (ºC) ASTM D97	+15
Flash point (ºC) ASTM D93	174
Cetane number ASTM D613	62.4
Gross heat of combustion (kJ/kg) ASTM D2332	40,335
Conradson carbon residue (% wt) ASTM D198	0.02

Testing apparatus

A conventional simple shear apparatus has been modified to be a computer-controlled testing system. The simple shear apparatus has three major components namely sample assembly, vertical loading system and horizontal loading system. The sample assembly consists of the upper platen, lower platen, test specimen, membrane and washers. The vertical loading system which consists of an air piston is used to apply the vertical normal load. The vertical load is measured directly from the vertical load cell. The horizontal loading system allows horizontal shear force to be applied by a motor drive with a 25 speed 1.20 mm/min to 0.0005 mm/min gearbox. The horizontal load is measured with a load cell. The vertical and horizontal displacements were measured using linear variable differential transducers (LVDTs). As a part of initial setup of the testing system, all electronic instruments were connected to the designated channels of the data acquisition system with a precise input of their respective calibration coefficients. The entire simple shear testing system for this research study was performed using a modified computer-controlled simple shear apparatus shown in Figure-2.

Figure-2. Modified computer-controlled simple shear apparatus.

Sample preparation

The simple shear tests were performed at relative density of 30, 60% and 80% for both clean and palm biodiesel contaminated soil samples. Palm biodiesel contamination percentage of 0%, 2%, 4%, 6%, 10% and 20% by dry weight were carried out in this study. Contaminated specimens were prepared by mixing the content (dry sand and the desired palm biodiesel percentage) thoroughly.

The prepared specimens were placed and tamped into the 70mm diameter rubber membrane encased by a stack of metal washers in three equal layers. Specimens were compacted by means of tamping each layer to achieve homogeneity and uniformity and the required relative density. A flat bottomed tamper was used for the tamping. Gentle tapping were applied on the external body of the metal washers to minimize voids. The consolidation clamp has to be installed carefully without causing disturbances to the sample prepared earlier. The vertical consolidation pressure can now be applied to the loading yoke by adjusting the pressure regulator. Sufficient time needs to be allowed for the applied vertical consolidation pressure to achieve equilibrium conditions in the sample. All respective clamp screws pertaining to the whole testing system were tightened to avoid any slack that would cause inaccurate experimental results. Any slack in the drive system can be eliminated by disengaging the clutch and hand winding. The applied normal stress in the tests varied from 10 kPa to 30 kPa. The sample was sheared at the rate of 0.24 mm/min up to a maximum horizontal strain of about 10%. The testing procedures and data acquisition were performed by using a computer software and data acquisition system.

RESULTS AND DISCUSSIONS

A series of simple shear tests were performed on reconstituted sandy soil with different content of palm biodiesel under various normal stresses. Figure-3 shows typical shear stress versus shear displacement for soil samples contaminated with different palm biodiesel content. It can be seen that the peak shear stress decreases

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by about 37% when the palm biodiesel content is increased from zero to 20%. This may probably due to the fact that the sand particles will initially become coated with palm biodiesel which results in a reduction in friction when the sand particles slip and slide over other. It also depicts a softer response for the contaminated sand than the clean sand. The reduction of strength and stiffness are similar to the findings of Evgin and Das (1992) and Al-Sanad *et al*. (1995) for crude oil contaminated soils.

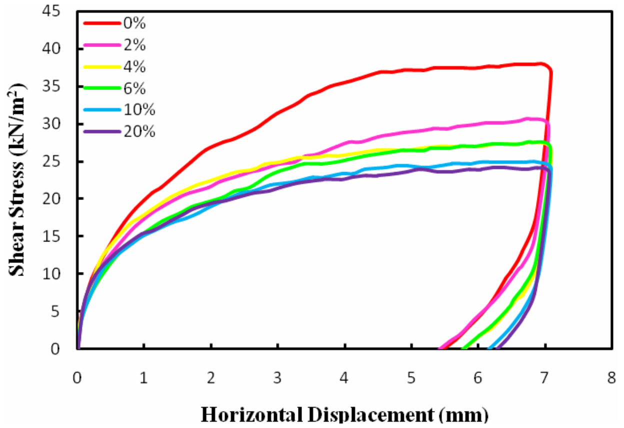

Figure-3. Stress-displacement relationship for 30 KPa normal stress (D_r=30%).

The failure envelopes for both clean and contaminated specimens are plotted in Figure-4. It reveals that the strength parameters decrease with increasing palm biodiesel contamination. The reduction of the strength parameters is mainly due to increase in the inter-particle slippage induced by the present of palm biodiesel acting as a lubricant (Rahman *et al*. 2010).

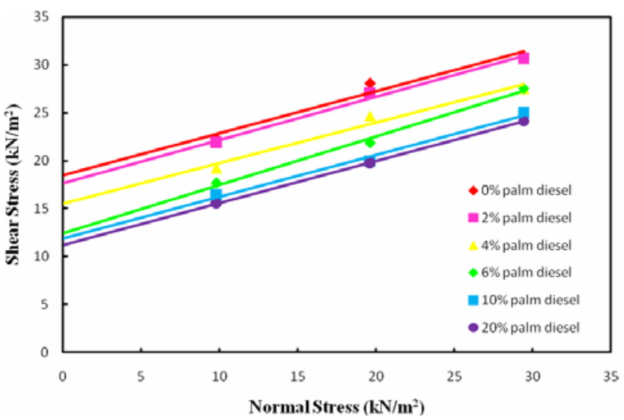

Figure-4. Failure envelopes for clean and contaminated soils (D_r=30%).

The variation of friction angle (Φ) derived from the tests is shown in Figure-5. The friction angle for clean sandy soil was about 28°. It can be seen that the friction angle may be reduced by about 25% when the palm biodiesel content is increased to 20%. This may due to the surface of the sand grains are coated with palm biodiesel which results in a decrease in friction when the sand grains slip and slide over each other.

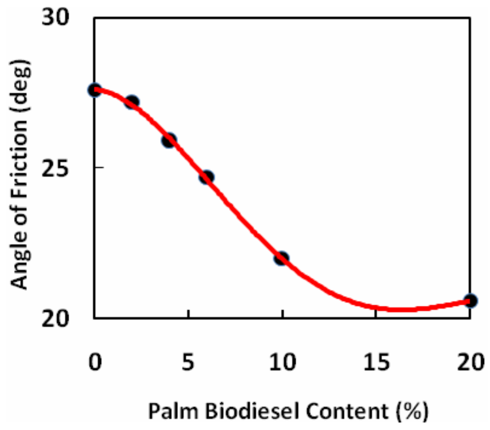

Figure-5. Variation of friction angle with palm biodiesel content (D_r=30%).

Figure-6 shows the variation of soil cohesion with palm biodiesel content. The soil cohesion measured decreases with increasing palm biodiesel content due to the viscosity of palm biodiesel. The cohesion for clean sandy soil is about 18.5 kPa. It is reduced by about 39% when the palm biodiesel content is increased to 20%.

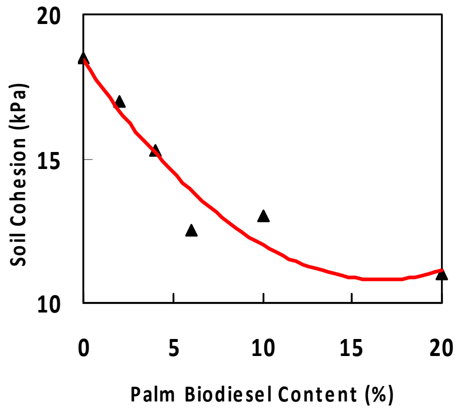

Figure-6. Variation of cohesion with palm biodiesel content (D_r=30%).

Constant head permeability testes were conducted on clean and contaminated sandy soil compacted to a relative density D_r=60%. The coefficient of permeability k= 1.46x10^{-3} m/s for sandy soil may be reduced by about 27% when the palm biodiesel content is increased to 10%. The coefficient of permeability (k) decreases with increasing palm biodiesel content as shown in Figure-7. The reduction may be attributed to the reduction of pore volume contributing to the hydraulic conductivity due to the trapped palm biodiesel. Since the palm biodiesel occupies some pore space, it is expected that the permeability will decrease with increasing the palm biodiesel content (Slattery 1990 and Al-Sanad *et al*. 1995).

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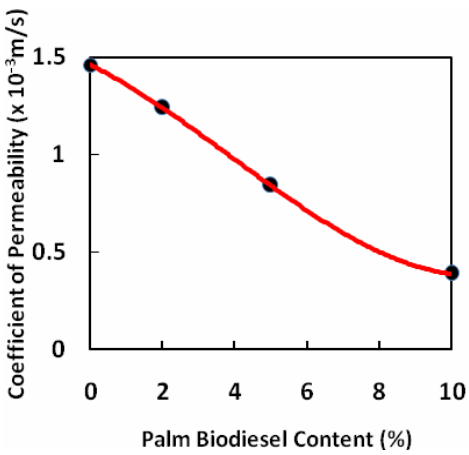

Figure-7. Variation of coefficient of permeability with palm biodiesel content.

Figure-8 shows the relationship between the friction angle and relative density for sandy soil contaminated with different palm biodiesel contents. The friction angle generally decreases with increasing palm biodiesel content with larger reduction occurring in the loose samples.

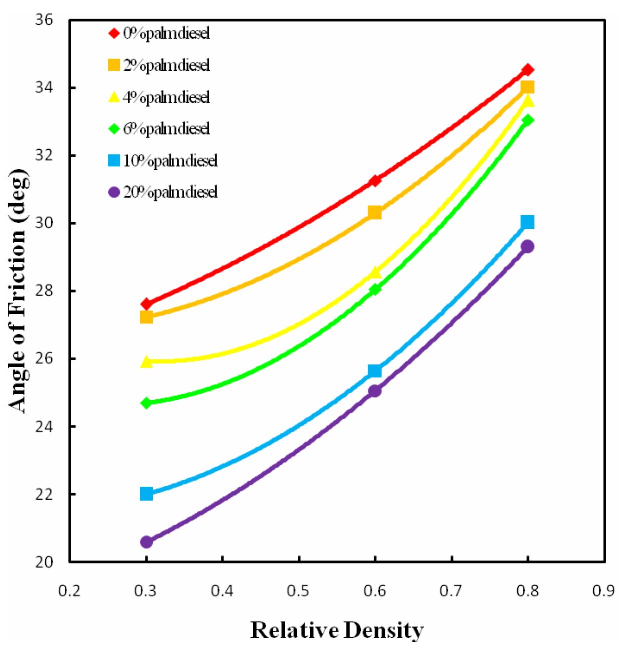

Figure-8. Variation of friction angle with relative density.

CONCLUSIONS

A series of simple shear tests was carried out to study the effects of palm biodiesel contamination on the geotechnical properties of sandy soil. The specimens were prepared by mixing the sandy soil with B20 palm biodiesel ranging from 0% to 20% by weight. The following conclusions may be made based on test results:

a) For a given relative density, the cohesion and friction angle decrease with increasing palm biodiesel content.
b) The peak shear stress may be reduced by about 37% when the sandy soil is contaminated with 20% palm biodiesel.
c) The coefficient of permeability (k) decreases with increasing with palm biodiesel content. The coefficient of permeability of sandy soil may be reduced by about 27% when it is contaminated with 10% of palm biodiesel.
d) The friction angle generally decreases with increasing palm biodiesel content with larger reduction occurring in the loose samples. The cohesion and friction angle of sandy soil may be reduced by about 39% and 25%, respectively when it is contaminated with 20% of palm biodiesel.
e) In general, palm biodiesel contamination causes a reduction in the shear strength of all the sandy soil samples at all relative densities.

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