Comparison of the Effect of Fine Content and Density towards the Shear Strength Parameters

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ABSTRACT: The improvement of soil strength is very important in the engineering design for the civil and geotechnical projects. However, this improvement can be achieved by improving the shear strength parameters of soil (i.e. shear strength, friction angle and cohesion) by using different techniques (e.g. densify the soil and change the soil composition). This paper will compare between the effects of density and fine content towards the shear strength parameters. Numerous soil samples from six soil mixtures of sand-kaolin mixtures were compacted and subjected to direct shear box test to evaluate the effect of density and fine content. The results showed some discordant effects between the density and fine content. While the cohesion increased by the increment of the fine content, it decreased by the increment of the density. However, both of shear strength and friction angle increased to the highest value with the increment of the fine content and density then by further increment in the fine content and density, the shear strength and friction decreased where this behaviour can be explained through the inter-granular void ratio issue. On the other side, even the results showed interface between the effect of density and fine content, but the fine content has more significant effect in the shear strength parameters and also in the soil density value itself.

KEYWORDS: Shear strength parameters; Sand-kaolin mixture; Fine content, Density; Inter-granular void ratio

1. INTRODUCTION

The improvement of the soil strength is very important in the engineering design for the civil and geotechnical projects (Das, 2016) where this improvement can be achieved through different technique. However, the soil compaction is widely known as one of most important mechanical method to improve the soil strength. The basic concept of the soil compaction depends upon densify the soil to improve soil strength (Das and Sobhan, 2014). This densification can be achieved by replacing the air voids with water or solid particles (Das and Sobhan, 2014). However, while the compaction is a mechanical method to strengthen the soil, the direct shear box is one of the methods which used to evaluate the soil strength. The shear strength, friction angle and cohesion are the main parameters to evaluate the soil strength (Das and Sobhan, 2014; Wang et al., 2015). The direct shear test concept depends upon the consolidation of the soil sample and then share it under specific applied normal stress and shear rate (ASTM D3080, 2012; ASTM D6528, 2007).

The measured shear strength parameters (i.e. shear strength, friction angle and cohesion) depends on several factors which can be related to soil properties (e.g. fine content, moisture content, particle size and shape) (Chen et al., 2015; Li, 2013) or the shear mechanism (e.g. shear ring or box size, shear rate and applied normal stress) (Wang et al., 2015; Gratchev and Sassa, 2015; Li et al., 2013a). This paper will implement the comparison between the effect of equivalent moist density ρwet (i.e. the moist density for the maximum dry density) and fine content towards the shear strength parameters.

1.1 Effect of density

In general, the density influences the soil strength parameters (Chenari et al., 2015) where the increment in the soil density can lead to strengthen the soil (Garg and Ng, 2015; Tang et al., 2014). According to the results from Sadek et al. (2011), the denser soil means the higher shear strength parameters values (i.e. higher friction angle and cohesion). In addition, the results from Tabibnejad et al. (2015); Chenari et al. (2015) showed increment the friction angle with the increment of the density. Moreover, Farooq et al. (2015); Dadkhah et al. (2010) results showed that both of friction angle and cohesion increased with the increment of the density. Hamidi et al. (2009) indicated that the friction angle increased with the increment of the relative density. Meanwhile, Bensoula et al. (2015) indicated increment in the critical undrained shear strength with the increment of the equivalent relative density.

1.2 Effect of fine content and particle size and shape

Many studies present the effect of the fine content FC in the shear strength τ, friction angle $\emptyset$ and cohesion c. Even the presence of a small amount of fine content influences the shear strength (Ueda et al. 2011). While Zlatović (1995) mentioned to the high sensitive of soil strength value to the presence of fine content. The results from Alshameri et al. (2016); Chenari et al. (2015); Li et al. (2013b) showed increment in the friction angle with the increment of the coarse content CC (i.e. decreasing the FC). Omar and Sadrekarimi (2014) indicated that the increment in the mean particle size caused increment in peak shear strength and the mobilized friction angle for the same sandy soil density. In addition, Islam et al. (2011) indicated increment in the shear strength and friction angle with the increment of the particle size. Moreover, Mostefa Kara et al. (2013) declared that the increment in the particle size led to the increment in the peak friction angle. While the results from Tabibnejad et al. (2015) showed two patterns: (a) In saturated condition, the friction angle decreased with the increment of the fine content. (b) In dry condition, the friction angle showed curve relationship with fine content. Where at fine content range from 2 to 8%, the friction angle increased to the maximum value with the increment of the fine content. Then, when the fine content ranged from 8 to 16%, the friction angle decreased with the increment of FC the fine content. In addition, Pitman et al. (1994) declared that the increment of the fine content to specific value (i.e. to fine content equals to 40%) led to the reduction or elimination of any contact between the coarse particles; consequently, reduced the friction angle.

Furthermore, the effect of fine content can be explained more effectively through the inter-granular void ratio issue. The inter-granular void ratio plays significant effect on the soil shear strength (Belkhatir et al., 2010; Rahman et al., 2010; Mitchell and Soga, 2005). The inter-granular void ratio explains the relationship between the fine content, coarse content and voids ratio *e*. When the fine materials filled the voids between the coarse materials, this will lead to add more bonds between the soils particles without touching the friction surface between the coarse particles. However, with further increment of fine content, the fine particles will occupy the space between the coarse particles. Consequently, it decreases the friction surface between the coarse particles, thus decreased the friction angel and shear strength. Equations 1 and 2 show the calculation for the inter-granular void ratio (e_s):

$$e_s = (V_v + V_f)/ V_s \quad (1)$$

$$e_s = [e + (G_s/G_{sf}) (FC/100)] / [1-(G_s/G_{sf}) (FC/100)] \quad (2)$$

Where V_v, V_f and V_s are the volume of voids, fine content and coarse content respectively, G_s is the specific gravity for whole material (i.e. voids, fine and coarse content), G_{sf} is the specific gravity for fine material.

1.3 Density or fine content, which one has more effect!

Even many previous studies showed increment in the soil strength with the increment of the density; however, high density does not always lead to high soil strength. According to Horn et al. (1994) (by using soil aggregation of sand, silt and clay) the density has less effect on the physical soil properties (i.e. soil strength) compared with the soil structural. Moreover, results by Güllü (2015) (by using mixture of clay, ash and lime) showed different effect on the density towards the soil strength in three groups of soil mixtures as the followings:

- Even the density of group 1 < density of group 2 < density of group 3,
- But the strength of group 1 < strength of group 2 > strength of group 3.

Moreover, Omar and Sadrekarimi (2014) (by using sand) indicated variation in the values of peak shear strength and the mobilized friction angle for the same sandy soil density. In addition, Shahnazari et al. (2015) (by using granular soil) declared that at first stage (i.e. low loading), the increment in the soil strength is correlated with the increment of the soil density while the microstructural of the soil remained un-touch. However, at second stage (i.e. further increment in the loading) the soil microstructural played an advance effect on the increment of the soil strength. Meanwhile, at the third stage (when the soil was subjected to load lower than the previous stage), the results showed decrement in the soil strength although relative soil density showed increment. Tabibnejad et al. (2015) (by using natural soil with particle size up to 19 mm and fine content less than 18%) indicated that with the same density, the elastic modulus exhibited different values by changing the fine content and vice versa.

However, this paper will try to answer the question of: which one has more significant effect on shear strength parameters, is it the density or the fine content? By using soil mixture of sand kaolin where the sand has maximum particle size less than 3.35 mm and the fine content range from 20% to 70%.

2. MATERIALS AND TEST PROCEDURE

2.1 Materials properties

Soil mixtures were divided into six groups that have six different fine contents (FC from 20% to 70%). While the sand represents the coarse material, the kaolin represents the fine material. The sand was sieved through the 3.35 mm aperture and the kaolin has industrial name called AKIMA 45 and has the following properties, (1) brightness equals to 76% minimum. (2) more than 40% has particle size less than 2 μm, (3) lower than 0.05% has particle size higher than 45 μm. Figure 1 shows the particle size distribution curve for CC at the six sand kaolin mixtures. Table 1 and Figure 2 show the d_{50} for the six groups where the highest value of d_{50} (d_{50} = 0.79 mm) at FC = 20% while the lowest value of d_{50} (d_{50} = 0.019 mm) at FC = 70%.

2.2 Test procedures

Several soil mixtures samples were compacted to achieve the maximum dry density MDD and optimum moisture content OMC. Method C with mold 6" was used to implement the compaction by using standard compaction effort in ASTM D 698 (2012) (Figure 3). The dry density was calculated according to equations 3 and 4:

$$\rho_m = (M_t - M_{md}) / V \quad (3)$$

$$\rho_d = \rho_m / [1 +(w/100)] \quad (4)$$

Where ρ_m is moist density, M_t is the mass of moist soil in mold and mold, M_{md} is the mass of compaction mold, V is the volume of compaction mold. ρ_d is the dry density of compaction point and w is the molding water content of compaction point.

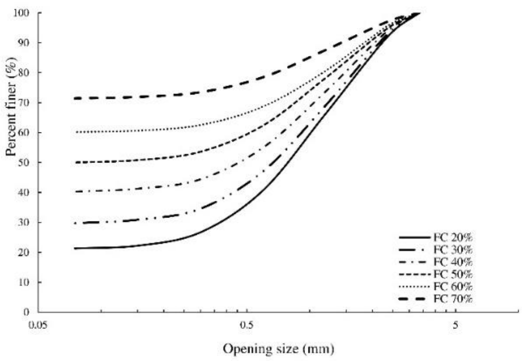

Figure 1 The particle size distribution of sand at the different FC

Table 1 d_{50} for different groups of sand-kaolin mixtures

Group no.	Fine content (FC) (%)	d_{50} (mm)
1	20	0.79
2	30	0.66
3	40	0.46
4	50	0.075
5	60	0.035
6	70	0.019

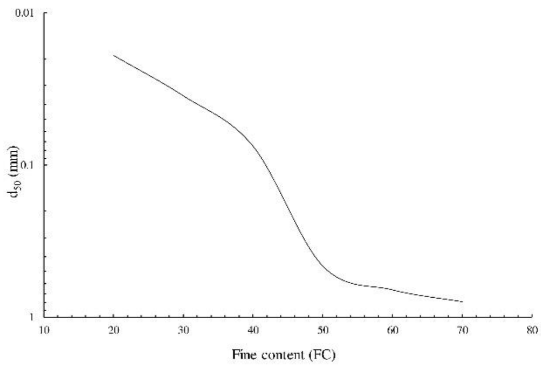

Figure 2 d_{50} versus FC

However, ρwet were tested by using direct shear box test. The interior dimension shearing box is 100×100 mm and all samples were tested by using shear rate equals to 1 mm/min. In addition, three applied normal stresses σ were used to measure the shear strength for each mixture (i.e. σ = 10.5, 21 and 31.5 kPa). The shear strength calculations were according to equations 5, 6 and 7(ASTM D3080, 2011; ASTM D6528, 2007).

$$\sigma = F/A \quad (5)$$

$$\tau = c + \sigma \tan\emptyset \quad (6)$$

$$G = [(\tau_{100} - \tau_{50}) / \{(\varepsilon_{100} - \varepsilon_{50}) / (\tau_{100} - \tau_{50})\}] \times 10^2 \quad (7)$$

Where F is applied force, A is the area of sheared sample (in this case is 100× 100 mm), ε_{50} is shear strain at 50 % of the peak shear stress, ε_{100} is the shear strain at the peak shear stress, t_{50} is the time at 50 %

of the peak shear stress and t_{100} is the time at the peak shear stress, G is the shear modulus.

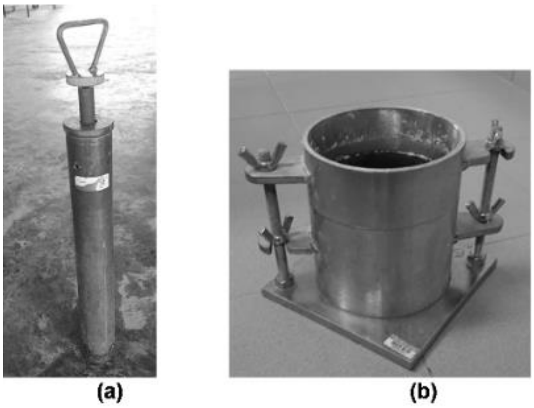

Figure 3 Tools of compaction (a) Standard hammer (b) 6” mold

3. RESULTS

3.1 MDD and OMC results

Table 2 and Figure 4 show the results of the compaction tests. The results can be concluded as follows:

1- At FC = 20% and OMC = 12%, all wet and dry densities and unit weight have the highest values. The moist density and dry density equal to 2.16 and 1.93 g/cm^3 respectively. Furthermore, the unit weight and dry unit weight equal to 21.2 and 18.93 kN/m^3 respectively.

2- At FC = 70% and OMC = 20%, all wet and dry densities and unit weight have the lowest values. The moist density and dry density equal to 1.9 and 1.58 g/cm^3 respectively. The unit weight and dry unit weight equal to 18.64 and 15.53 kN/m^3 respectively.

Table 2 Results of soil mixtures compaction

FC (%)	ρ_{wet} (g/cm^3)	Unit weight (kN/m^3)	OMC (%)	MDD (g/cm^3)	Dry unit weight (kN/m^3)
20	2.16	21.20	12	1.93	18.93
30	2.11	20.71	12	1.89	18.50
40	2.03	19.91	12	1.81	17.78
50	1.99	19.47	16	1.71	16.78
60	1.94	18.98	18	1.64	16.08
70	1.90	18.64	20	1.58	15.53

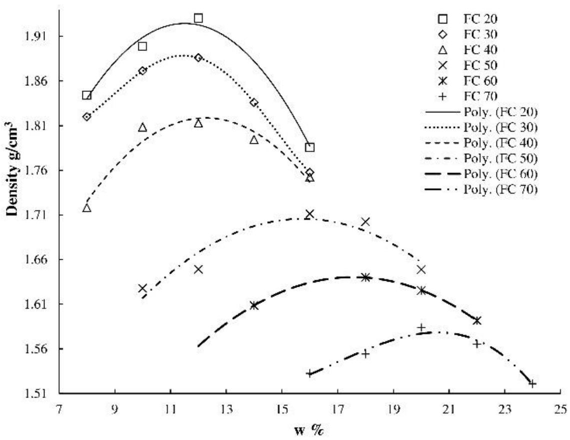

Figure 4 Compaction curves

3.2 Effect of ρ_{wet} and MDD towards τ, ∅, c, G

Table 3 shows results of shear strength, friction angle and cohesion at different ρ_{wet}. According to Table 3, it can be concluded as follows:

1- At σ = 10.5 kPa, the highest value of shear strength (τ = 68.3 kPa) and shear modulus (G = 5.8 MPa) at FC = 50% and w equals to 16%.

2- At σ = 21 kPa, the highest value of shear strength (τ = 81.2 kPa) and shear modulus (G = 6.7 MPa) at FC = 40% and w = 12%.

3- At σ = 31.5 kPa, the highest value of shear strength (τ = 108 kPa) and shear modulus (G = 9 MPa) at FC = 50% and w = 16%.

4- The highest value of cohesion (c = 53.7 kPa) at FC = 40 and w = 12%.

5- The highest value of friction angle (∅ = 68.3 kPa) at FC = 70 and w = 20%.

Table 3 Results of direct shear test for different soil mixtures at MDD

FC (%)	w% (%)	ρ_{wet} (g/cm^3)	MDD (g/cm^3)	τ at σ =10.5 (kPa)	τ at σ =21 kPa (kPa)	τ at σ =31.5 (kPa)	c kPa	∅ (^{0})	G at σ =10.5 (Mpa)	G at σ =21 (Mpa)	G at σ =31.5 (Mpa)
20	12	2.16	1.93	35.5	45.3	57	23.9	45.8	3.0	3.8	4.8
30	12	2.11	1.89	53.2	61.4	80.5	36.9	52.6	4.4	5.1	6.8
40	12	2.03	1.81	63.2	81.2	85.5	53.7	46.7	5.4	6.7	7.0
50	16	1.99	1.71	68.3	77.9	108	44.1	62.1	5.8	6.6	9.0
60	18	1.94	1.64	53.4	65.0	81.8	37.8	53.5	4.6	5.5	7.2
70	20	1.90	1.58	50.2	57.1	102	16.3	68.3	4.2	4.8	8.6

Figure 5 shows a curve relationship between cohesion and both densities (i.e. ρ_{wet} and MDD). The cohesion increased to the maximum value (∅ = 53.7^0) with the increment of both densities then with further increment in densities, the cohesion decrease. On the other hand, Figure 6 shows the relationship between the friction angle and both of ρ_{wet} and MDD. The results show that the friction angle tends to decrease with the increment of both of ρ_{wet} and MDD. Equations 8 and 9 express the regressive relationship between the friction angle and density.

$$\emptyset = 188.61 - 66.17\ \rho_{wet} \quad (8)$$

$$\emptyset = 188.61 - 66.17\ MDD \quad (9)$$

Where c in kPa, ρ_{wet} in g/cm^3 and MDD in g/cm^3.

Figures 7 and 8 show the result of shear strength in different densities. While Figures 9 and 10 show the result of shear modulus in different densities. According to Figures from 7 to 10, it can conclude the follows:

1- At σ = 10.5 and 21 kPa:
  a) There are curve relationships between τ and G towards ρ_{wet} and MDD.
  b) τ increased to the maximum values (τ = 68.3 and 81.2 kPa at σ = 10.5 and 21 kPa respectively) with the increment of ρ_{wet} and MDD. Then, with further increment in ρ_{wet} and MDD, τ decreased.
  c) G increased to the maximum values (G equals to 5.8 and 6.7 MPa at σ = 10.5 and 21 kPa respectively) with the increment of ρ_{wet} and MDD. Then with further increment in ρ_{wet} and MDD, G decreased.

2- At σ = 31.5 kPa, the relationship between τ and G towards ρ_{wet} and MDD became more scatter compared with the one at σ =10.5 and 12 kPa.

3- The lowest values of τ and G are at highest values of ρ_{wet} and MDD (when densities equal to 2.16 and 1.93 for ρ_{wet} and MDD respectively).

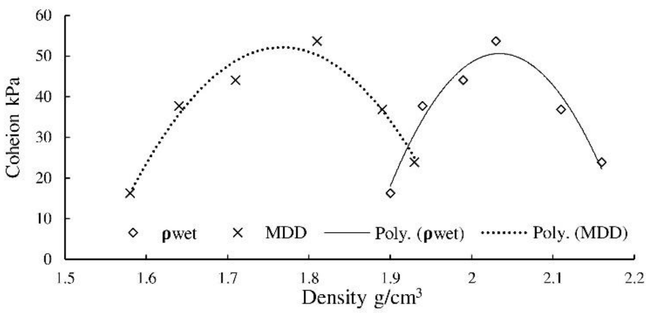

Figure 5 c versus ρ_{wet} and MDD

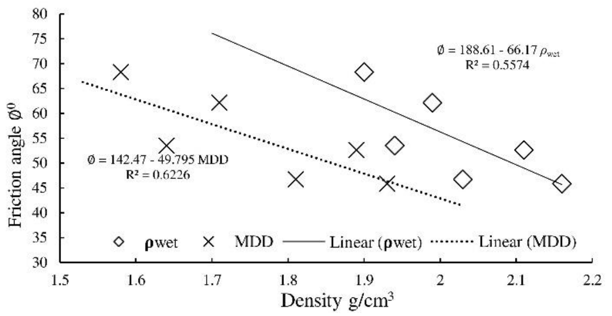

Figure 6 Ø versus ρ_{wet} and MDD

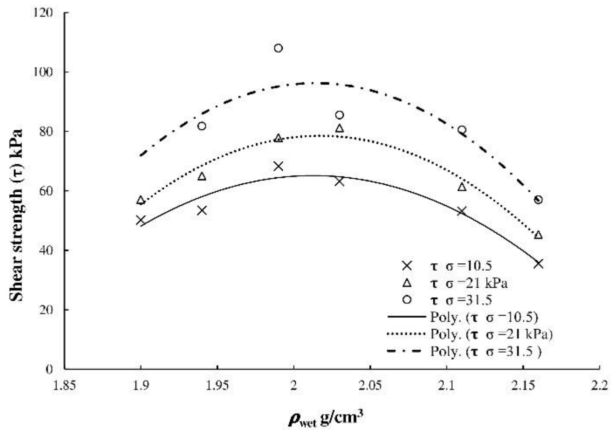

Figure 7 τ versus ρ_{wet}

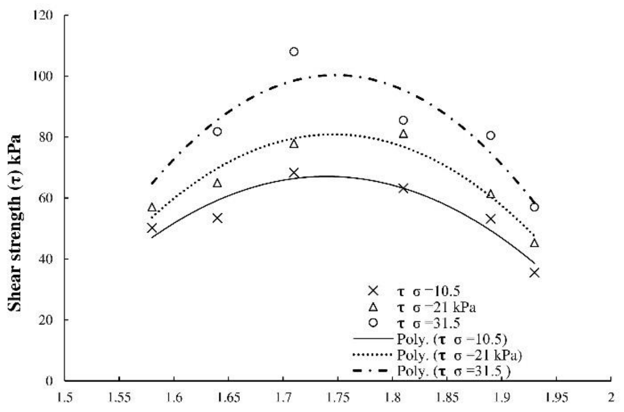

Figure 8 τ versus MDD

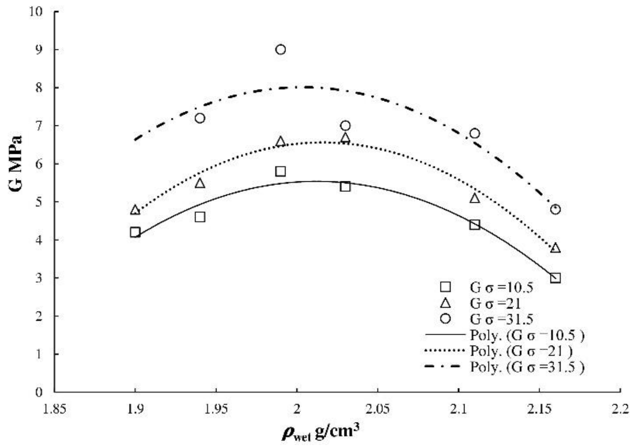

Figure 9 G versus ρ_{wet}

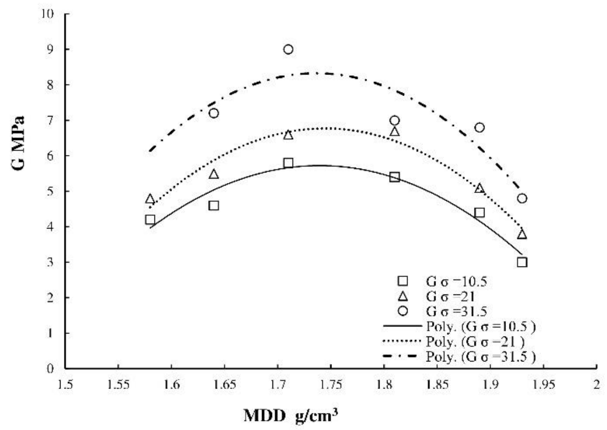

Figure 10 G versus MDD

3.3 Effect of FC on Ø, c, τ and G

The results at Figure 11 show a curve relationship between the c and fine content corresponding to MDD (FC_{MDD}). The cohesion increased to the highest value ($c = 53.7^0$) with the increment of FC_{MDD}. Then, with further increment in the FC_{MDD} above 40%, the cohesion decreased. Meanwhile, Figure 12 shows progressive relationship between the friction angle and FC_{MDD}. Equation 10 shows this progressive relationship where R^2 equals to 0.6269.

$$\emptyset = 0.3731\ FC_{MDD} + 38.042 \quad (10)$$

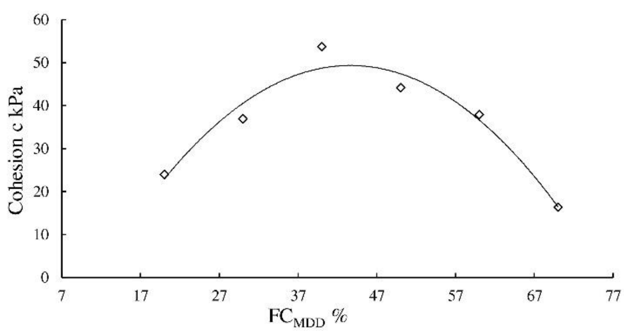

Figure 11 c versus FC_{MDD}

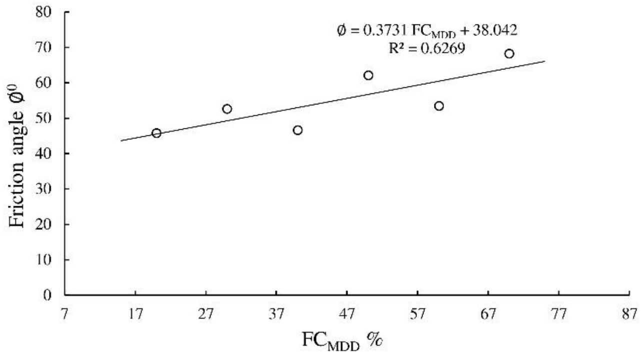

Figure 12 c versus FC_{MDD}

On the other hand, Figures 13 and 14 show the relationships between the shear strength and shear modulus towards FC_{MDD} respectively. The Figures show curve relationships between τ and G towards FC_{MDD}. The results concluded as the followings:

- At σ = 10.5 and 21 kPa, both of τ and G increased to highest value with the increment of the FC_{MDD}. Then, with further increment in FC_{MDD} above the range of 40-50%, both of τ and G decreased.
- At σ = 31.5 kPa, there is more scattered in the data between τ and G towards the FC_{MDD}, but both of shear strength and modulus show the same pattern in as in σ = 10.5 and 21 kPa.

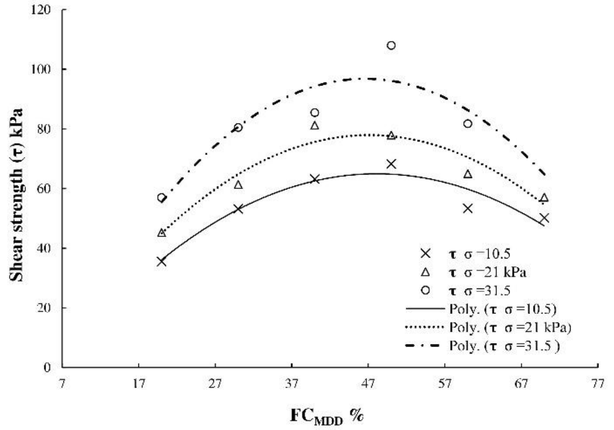

Figure 13 τ versus FC_{MDD}

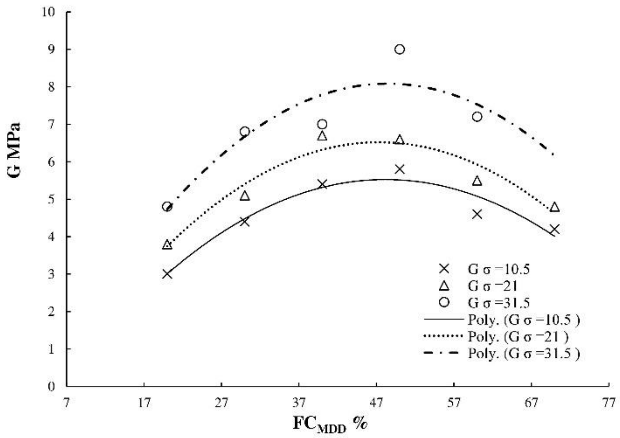

Figure 14 G versus FC_{MDD}

3.4 Comparison on the effect of density and fine content

Figures 6 and 12 show inverse behaviour of cohesion at variation of density and fine content. While the cohesion tends to decrease with the increment of the density, the cohesion tends to increase with the increment of the fine content. Otherwise, at different σ values, there is a curve relationship between τ and G towards ρ_{wet}, MDD and FC_{MDD}. Both of τ and G increased to highest values with the increment of ρ_{wet}, MDD and FC_{MDD}. Then, with further increment in ρ_{wet}, MDD and FC_{MDD}, both of τ and G decreased.

On the other side, Table 4 shows the comparison between the location of the highest and lowest values of shear strength parameters. While the lowest values of τ and G were located at the highest values of both densities (i.e. ρ_{wet} and MDD), in contrast, the lowest values of τ and G were located at the lowest value of FC_{MDD}. And the highest value of the cohesion was at highest value of FC_{MDD}. Moreover, Table 4 shows no significant effect of OMC in shear strength parameters.

Table 4 Comparison of the location of highest and lowest values of shear strength parameters

Parameter	Status	Location of the maximum and minimum values			
		ρ_{wet} (g/cm^3)	MDD (g/cm^3)	FC (%)	OMC (%)
c	highest	2.03	1.81	40	12
	lowest	1.90	1.58	70	20
Ø	highest	1.90	1.58	70	20
	lowest	2.16	1.93	20	12
τ and G at σ =10.5 kPa	highest	1.99	1.71	50	16
	lowest	2.16	1.93	20	12
τ and G at σ =21 kPa	highest	2.03	1.81	40	12
	lowest	2.16	1.93	20	12
τ and G at σ =31.5 kPa	highest	1.99	1.71	50	16
	lowest	2.16	1.93	20	12

4. Discussion

4.1 The interface between density and fine content

By referring to results from Tables 2 to 4 and from Figures 2 to 14, it concludes the followings:

- While the increment in the density caused decrement in the friction angle, the increment in the fine content caused increment in the friction angle. This can be related to the high differential values of τ between σ 31 kPa and 10.5 kPa at high level of fine content (i.e. at FC = 70 and 50%) which lead to produce high value of fiction angle compare with low differential of τ value between σ 31 kPa and 10.5 kPa and low fine content. Generally, the high value of friction angle can be related to; (1) the high value of shear rate, (2) low value of applied stress (Toufigh et al., 2015; Wang et al., 2013; Li et al., 2013b).
- The curve relationship between the cohesion can be explained through the following; (1) at the range of FC from 20 to 40, the fine content increase with constant moisture content which lead to increment the cohesion force, then (2) beyond FC > 40 the moisture increase with increment the FC which lead to decrease the cohesion force (Ekwue and Seepersad, 2015; Das and Sobhan, 2014)
- At different values of σ, both of τ and G at different FC_{MDD} and densities have curve relationship. This behaviour can be explained through the friction angle relationship which also show curve relationship with fine content and density. This issue is related to the inter-granular void ratio which plays significant effect through the presence of the fine content (Monkul and Yamamuro, 2011; Mitchell and Soga, 2005; Thevanayagam, 1998). The presence of fine material caused filling the voids between the coarse particles (i.e. sand particles) thus add more cohesive bond without touching the surface of the friction

between the sand particles. However, with further increment on the fine content, the kaolin started to separate between the sand particles thus the kaolin acted as lubricate agent (Zeng and Feng, 2014; Tang et al., 2013; Thevanayagam et al., 1997). Consequently, the friction angle decreased when more fine content was added, thus decreased the shear strength (Li et al., 2013b).

- At σ = 31.5 kPa, the scatter in the results indicate the effect of increasing the applied normal stress in the soil strength behavior. The authors hypothesis this phenomenon through three issues; (1) The effect of σ on the friction angle (where the ∅ decreased with the increment of σ). (2) The effect of FC_{MDD} on the cohesion (where c increase with the increment of FC). (3) The multi-effect of relative high shearing rate (where the effect of increasing the shear rate depends on the FC value). Thus, the values of ∅, τ and G will be subjected to scatter with the increment of σ and applied the relative high shearing rate (Toufigh et al., 2015; Li et al., 2013a; Liu et al., 2006).

4.2 Fine content versus the density, which one has significant influence?

According to the results, there was interface between the effect of the density and fine content towards the shear strength parameters. However, the effect of fine content is more significant than the density where the changing in the fine content caused change in both of density and soil shear strength parameters (Ekwue and Seepersad, 2015; Cubrinovski and Rees, 2008). This issue agreed with the finding from Tabibnejad et al. (2015); Güllü (2015) Thevanayagam et al. (1997).

5. CONCLUSION

Numerous soil samples from six soil mixtures of sand-kaolin with different fine content were tested to investigate the effect of both fine content and density towards the shear strength parameters. The results are as follows:

- There is discordant relationship between the effect of the fine content and density towards the cohesion. While the cohesion increased with the increment of the fine content, the cohesion decreased with the increment of the density.
- The presence of fine materials has multi-effect in the sand-kaolin mixture properties. The increment in the fine content caused; (a) decrement in the density, (b) changed the area of friction surface and (c) changing the shear strength values. The inter-granular void ratio explains to the effect of fine materials where the present a relative small amount of fine content (i.e. kaolin) in the sand-kaolin mixtures lead to fill the voids by the kaolin particles which caused an increment in the bond between the particles without touching the surface friction area. However, with the increment of the fine content above 50%, the fine materials started to occupy the space between the coarse particles (i.e. sand particles) and acted as lubricate agent between the sand particles and decreased the friction surface area. Consequently, decreased the friction angle and shear strength.
- Even there is interface between the effect of fine content and density towards shear strength parameters, but the effect of fine content is more significant than the density effect. The changing in the fine material caused change in the density and shear strength parameters at the same time.

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