Assessment on the Effect of Fine Content and Moisture Content Towards Shear Strength

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ABSTRACT: The shear strength τ, shear modulus G, friction angle ∅, and cohesion c are remarkable design parameters in the geotechnical and civil projects. These design parameters were affected by several factors. In this paper, the fine content and moisture content factors were evaluated. Numerous compacted sand-kaolin samples were test through the direct shear box test (by using shear rate equals to 1 mm/min, the samples dimension equals to 100 × 100 mm) to assess the effect of these factors. The results showed interface between both effects of fine content and moisture content towards the shear strength parameters. According to the results; (1) there is no significant effect on shear strength parameters at low portions of fine content FC and moisture content w, (2) at higher portion of FC and w, both FC and w showed different relationships with shear strength parameters, (3) both relative high shear rate and low applied stress lead to present high value of friction angle (4) compact the soil mixtures with same compaction effort and different fine and moisture content lead to change the soil structure and void ratio thus produce regressive relationship between the friction angle toward density.

KEYWORDS: Fine content, Moisture content, Shear strength, Friction angle, Cohesion, Fines and water bonds

1. INTRODUCTION

The shear strength is one of the most important physical properties of the soil. Evaluation of the soil strength is requiring in the engineering design to assess the suitability of soil usage for engineering purpose. However, several methods can be used to measure the shear strength parameters such as; direct shear box, triaxial, unconfined compression test UCT (Amšiejus, et al., 2014; Omar & Sadrekarimi, 2014). However, in this paper, the direct shear box test was adopted.

In the direct shear box test, there are many factors effect on the shear strength, cohesion and friction angle (e.g. applied normal stress, shear box dimensions, particle size and shape, coarse and fine content, shear ratio and moisture content). Even Li et al. (2013a) indicated that shearing process causes soil disturbance in the shear zone (shear surface) greater than the other un-sheared zone (the parts of soil mass which is not located in the shear zone). However, in this paper, effects of fine content and moisture content towards the shear strength parameters (i.e. shear strength, friction angle and cohesion) were studied through the whole soil sample mass rather than the shear zone.

1.1 Effect of Fine content

Stark and Eid (1994) declared that the percentage of the clay particles control the drained residual strength magnitude. In addition, Ueda et al. (2011) declared that even a small amount of fine content has significant contribution in value of shear strength. Thus, because of fine particle has reduced the friction surface between the coarse particles. According to previous researchers, the shear strength decreased with the increment of the fine content (FC) (Alshameri, et al., 2017; 2016; Simpson & Evans, 2015; Omar & Sadrekarimi, 2014; Li, et al., 2013b). Simpson and Evans (2015) hypothesized this behaviour is due to the presence of fine material which caused relief the shear force upon the skeleton of coarse particles only, thus, caused faster breakdown of the coarse particle. In addition, Cubrinovski and Rees (2008) indicated that the increment the fine content (FC) caused decrement the density thus decreased the shear strength. Moreover, Bensoula et al. (2015) and Belkhatir et al. (2014) and expressed this issue through the equivalent inter-granular void ratio. The increasing of the fine content caused increment the equivalent inter-granular void ratio, thus decreased the critical undrained shear strength (Monkul & Yamamuro, 2011). However, Belkhatir et al. (2010) expressed the decrement in the shear strength with the increment of the fine content as the followings; when the fine content increased, the voids were filled by the fine materials which caused increment the inter-granular void ratio then decrement in the friction surface between the coarse particle thus the shear strength decreased. However, the reduction percentage of the shear strength was subjected to change when all the voids were totally filled. In addition, Belkhatir et al. (2014) declared that the increasing of the fine content caused increment pore water pressure, thus decreased the shear strength. Meanwhile, Zlatović (1995) (by using sand silt mixture) indicated that the increasing of the fine content (i.e. silt content) caused decrement the shear strength until silt content equals to 30%, then the shear strength increased with the increment of the silt content when silt content is above 30%. Similar to Naeini and Baziar (2004), where the results showed decrement in the shear strength by the increment of the fine content to 35%. Then with further increment on the fine content, the shear strength increased.

The inter-granular void ratio (e_s) term in the previous paragraph is referred to the void ratio corresponding to the coarse content only as in equation 1:

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

Where V_v, V_f and V_s are the volume of voids, fine content and coarse content respectively. Meanwhile, the inter-granular void ratio (e_s) can be expressed through the void ratio (e) by using equation 2 (Monkul & Yamamuro, 2011):

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

Where 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, FC is the fine content.

Liu et al. (2006) declared that the presence of low amount of coarse content (i.e. when coarse content is less than 10%) has negligible effect on the shear strength while the higher effect of coarse material occurred when both of size and content of coarse material increased. However, these researchers declared that the cohesion has significant contribution on the shear strength when the amount of the coarse content is higher than 25%. On the other hand, according to the results from Prakasha and Chandrasekaran (2005), the increasing of the fine content caused decrement undrained shear strength to the lower value at fine content equals to 50%. Then with further increment of the fine content above 50%, the undrained shear strength increment. In contrary, Naeini (2006) indicated (by using gravel sand mixture) that the increment of the coarse content (i.e. decreasing on the fine content) caused decrement the undrained shear strength.

The presence of fine materials caused reduction of the friction surface between the coarse materials which led to the reduction of the friction angle. According to the previous researchers' results, it can be indicted that decrement the friction angle with the increment of the fine content for different soil mixtures (Okonta, 2015; Shin & Santamarina, 2012; Ueda, et al., 2011; Vithana, et al., 2012). Meanwhile, Vithana et al. (2012) indicated that the increment of the fine content caused decrement the cohesion.

1.2 Effect of Moisture content

Generally, the presence of water caused lubrication of sliding surface (i.e. surface between the particles) (Omidvar, et al., 2012; Mitchell & Soga, 2005). Omidvar et al. (2012) declared that water acts as a lubricate agent for the soil particles (sand particles); consequently, reducing the friction between the sand particles. Previous researchers indicated that the increment of the moisture content caused decrement the shear strength (Bai, et al., 2012; Mohamad, et al., 2011). Moreover, several researchers indicated that the presence of the moisture content caused decrement in the amount of the friction angle (Farooq, et al., 2015; Mohamad, et al., 2011). In addition, Bai et al. (2012); Matsushi and Matsukura (2006) indicated that the increment of the moisture content caused decrement the friction angle and cohesion. While Mouazen et al. (2002) declared that the increment of the moisture content caused decrement in the cohesion and Young's modulus (i.e. decreasing the cohesion and shear strength) of sandy loam soil. Mohamad et al. (2011) results showed decrement in the cohesion with the increment of the moisture by using older alluvium (i.e. natural mixture of gravel, sand, silt and clay). While Farooq et al. (2015) proposed a curve relationship between the moisture content and cohesion. Where the cohesion increased to the highest value with the increment of the moisture content, then when the moisture content became higher than 40%, the cohesion tends to decrease with the increment of the moisture content.

1.3 Effect of Other parameters

Many researchers indicated increment of the shear strength with the increment of the applied normal stress (Vithana, et al., 2012; Okonta, 2015; Bai, et al., 2012). In contrary, the friction angle decreased with the increment of the applied normal stress (Toufigh, et al., 2015; Li, et al., 2013a; Liu, et al., 2006). In addition, Toufigh et al. (2015) Gratchev and Sassa (2015), Okada et al. (2004) indicated decrement the shear strength with the increment of the shear rate. Moreover, Gratchev and Sassa (2015) and Perret et al. (1996) indicated that the increment of the shear rate caused acceleration of the bonds were broken between the clay particles greater than the ability of clay particles to the restoration of their bonds. On the other side, Miao et al. (2014) expressed the variation in the residual shear resistance to the behaviour of pore water pressure. When the shear rate became higher, the pore water pressure built faster than the process of water dissipation. Thus the increment of the pore water pressure caused increment the total shear stress and decrement the effective shear stress. While Wang et al. (2010) declared increment of the share strength with the increment of the shear rate has no relation to the pore water pressure because the tests were applied on dry clay samples. However, Li et al. (2013a) indicated tow patterns related to the relationship between the friction angle and shear rate. In the material with high coarse content, the friction angle increased with the increment of the shear rate, while in the material with high fine content, the friction angle decreased with the increment of the shear rate. On the other hand, Suzuki et al. (2004) indicated increment of the friction angle with the increment of shear displacement rate in the kaolin samples.

2. MATERIALS AND TEST PROCEDURE

2.1 Materials properties

In this research, a series of direct shear box test was conducted to assess the effect of fine content and moisture content on the shear strength, shear modulus, friction angle and cohesion. The materials were divided into six sand-kaolin mixtures with different fine and moisture content. Figure 1 showed the graduation curve for the sand at different fine content. The fine material is kaolin which has the following properties: Industry name (AKIMA 45), minimum 40% of particle size less than 2 μm, maximum 0.05% of 325 mesh residue and packed in FIBC/ paper bags while the coarse material is sand with maximum particle size less than 3.35 mm. Table 1 showed the specific gravity (G_s) values for the soil mixtures. Where the highest value of G_s equals to 2.61 at FC equals to 20% and the lowest value of G_s equals to 2.553 at FC equals to 70%.

Table 1 Specific gravity for sand kaolin mixtures

Fine content	Specific gravity Gs
20	2.61
30	2.597
40	2.585
50	2.576
60	2.563
70	2.553

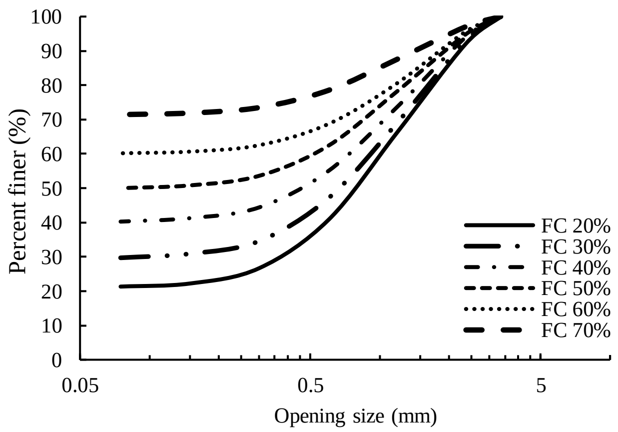


Figure 1 The particle size distribution of sand at the different FC

2.2 Test procedures

All the samples were compacted by using standard compaction effort, method C and mold 6" at ASTM D 698 (D698, 2012). 141 samples were divided between the six soil mixtures and used in this research to evaluate the effect of fine content FC and moisture content w toward the shear strength τ, shear modulus G, friction angle ∅ and cohesion c. The samples were subjected to shear under direct shear box according to the methodology in ASTM D 3080 (2011). The shear box has 100 × 100 mm interior dimension. Figure 2 showed photos for the direct shear box apparatus and one sample during the preparation and after has been sheared. Meanwhile, all the sand-kaolin mixtures were tested under different moisture content and three applied normal stresses σ equal to 10.5, 21 and 31.5 kPa and with using fix shearing rate equals to 1 mm/min. Moreover, all the shear strength parameters were calculated according to the following equations (D3080, 2011; D6528, 2007):

$$\sigma = F/A \quad (3)$$

$$\tau = c + \sigma \tan\emptyset \quad (4)$$

$$G = [(\tau100 - \tau50) / \{(\varepsilon100 - \varepsilon50) / (t100 - t50)\}] \times 100 \quad (5)$$

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.

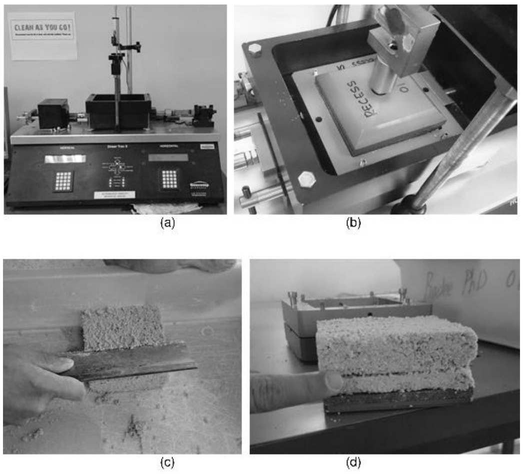


Figure 2 Components and samples of direct shear box, where (a) is the direct shear box apparatus, (b) the shear box, (c) the sample during the preparation, (d) the sample after shearing

3. RESULTS AND DISCUSSIONS

Figure 3 and Table 2 showed summary of the results of the compaction and direct shear box tests. It can indicate the followings:

1- The maximum dry density for FC 20, 30, 40, 50, 60 and 70% were 1.93, 1.89, 1.81, 1.71, 1.64 and 1.58 g/cm^3 respectively.
2- At σ = 10.5 kPa: The highest value of shear strength (τ = 70.4 kPa) located at moisture content w = 12%, saturation = 55% and FC = 50%. While the highest value of shear modulus (G = 6.2 MPa) was at w = 12%, saturation = 55% and FC = 50%.
3- At σ = 21 kPa: The highest value of shear strength (τ = 102 kPa) located at w =12%, saturation = 55% and FC = 50%. While the highest value of shear modulus (G 9 MPa) was at w = 12% saturation = 55% and FC = 50%.
4- At σ = 31.5 kPa: The highest value of shear strength (τ = 118 kPa) loacted at w = 16%, saturation = 68% and FC = 60%. While the highest value of shear modulus (G = 10.6 MPa) was at w = 12%, saturation = 55% and FC = 50%.

Meanwhile, the highest value of cohesion (c = 53.70) at FC = 40 and w = 12% and the highest value of friction angle (∅ = 716 kPa) at FC = 60% and w = 16%.

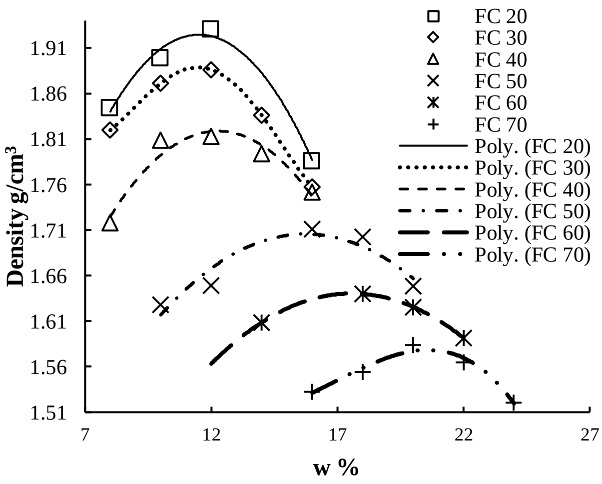


Figure 3 Compaction curves

3.1 Effect of moisture content on friction angle and cohesion

The results of cohesion versus moisture content for different fine content were shown at figures 4. According to figures 4a (where FC 20%), there are regressive relationship between the cohesion and moisture content where the cohesion decrease with the increment of the moisture content. While figures 4b 4c, 4d, and 4e (where FC equals to 30% 40%, 50%, and 60%) showed curve relationship between the cohesion and moisture content where the cohesion increased with the increment of the moisture content to the maximum value then with further increment of w, the cohesion decrease. Meanwhile, figures 4f (where FC equals to 70) showed reverse pattern where the relation between c and w can be considered as progressive relationship.

Table 2 Results of direct shear test for different soil mixtures

FC (%)	w (%)	S (%)	ρ_{wet} (g/cm^3)	τ σ =10.5 (kPa)	τ σ =21 kPa (kPa)	τ σ =31.5 (kPa)	c kPa	∅ (^{0})	G σ =10.5 (Mpa)	G σ =21 (Mpa)	G σ =31.5 (Mpa)
20	8	50	1.99	44.2	53.5	65.3	32.8	45.1	3.6	4.6	5.5
20	10	70	2.09	33.7	44.1	48.9	26.7	37.2	2.8	3.6	3.9
20	12	89	2.16	35.5	45.3	57.0	23.9	45.8	3.0	3.8	4.8
20	14	88	2.11	26.7	36.3	42.3	19.1	36.7	2.1	2.8	3.5
20	16	90	2.07	19.3	29.9	39.7	8.9	44.3	1.6	2.4	3.2
30	8	49	1.97	38.2	55.8	61.7	28.0	48.2	3.3	4.0	4.5
30	10	67	2.06	49.2	56.3	69.4	37.6	43.9	4.0	4.0	5.8
30	12	83	2.11	53.2	61.4	80.5	36.9	52.6	4.4	5.1	6.8
30	14	88	2.09	35.4	43.3	58.8	21.9	48.2	3.0	3.7	5.1
30	16	87	2.04	26.9	37.7	41.5	20.6	34.9	2.1	2.7	2.8
40	8	41	1.86	45.2	50.8	68.2	31.2	47.7	3.7	4.1	5.7
40	10	60	1.99	32.6	69.2	72.2	17.8	62.0	2.8	5.4	5.9
40	12	73	2.03	63.2	81.2	85.5	53.7	46.7	5.4	6.7	7.0
40	14	82	2.05	41.6	68.6	72.4	29.2	55.7	3.4	5.6	6.2
40	16	87	2.03	42.0	59.2	72.0	27.2	54.9	3.6	4.8	5.9
50	10	44	1.79	42.6	63.9	93.7	15.0	67.6	3.4	5.3	7.6
50	12	55	1.85	70.4	102.0	117.0	48.7	65.8	6.2	9.0	10.6
50	14	65	1.89	55.9	71.2	73.9	48.7	40.6	4.8	5.9	6.2
50	16	81	1.99	68.3	77.9	108.0	44.1	62.1	5.8	6.6	9.0
50	18	90	2.01	43.5	74.6	80.9	28.1	60.8	3.6	6.1	6.7
50	20	92	1.98	25.6	37.6	43.6	17.6	40.5	2.3	2.6	3.5
60	14	60	1.83	47.5	68.2	106.0	14.3	70.3	3.9	5.6	8.6
60	16	68	1.86	54.7	77.6	118.0	18.9	71.6	4.5	6.6	10.1
60	18	82	1.94	53.4	65.0	81.8	37.8	53.5	4.6	5.5	7.2
60	20	89	1.95	51.4	63.3	64.2	46.5	31.5	4.4	5.5	5.5
60	22	92	1.94	30.1	54.4	68.3	12.1	61.4	2.5	4.1	4.9
70	16	61	1.78	43.1	65.3	94.1	15.4	67.7	3.6	5.6	8.1
70	18	71	1.83	36.7	60.3	65.8	24.8	54.1	3.0	5.1	5.3
70	20	83	1.90	50.2	57.1	102.0	16.3	68.3	4.2	4.8	8.6
70	22	89	1.91	60.3	70.9	86.0	46.0	50.9	5.2	6.1	7.2
70	24	90	1.89	47.1	63.4	67.6	38.7	44.3	3.9	5.4	5.7

∅: friction angle, c: cohesion, FC: Fine content, G: shear modulus under different applied normal stress, w: Moisture content, ρ_{wet}: Bulk density in (g/cm^3), S: Degree of saturation ratio, σ: applied normal stress in kPa, τ: shear strength under different applied normal stress

By referring to results in table 2 and figures 4, it can indicate that in general, the effect of the moisture content on the cohesion depends on the fine content. In low fine content, the cohesion decreases with the increment of the moisture content. While in high fine content, the cohesion increased with the increment of the moisture content. The author hypothesized this phenomenon due to the interface between the fine content and the moisture content. At low fine content, the increase of the moisture lead to separate the kaolin particle and decrease the attraction force between the particle thus decrease the cohesion force (Mitchell & Soga, 2005). Meanwhile, in high fine content, the effect of the moisture content was reduced as the fact of that the ability of the fine content to absorb higher amount of moisture. Consequently, at the begin the increase of the moisture content added adhesion force (water molecular attraction) without increasing the distance between the kaolin particles. Thus, in total there are two cohesion forces; (1) fine content cohesion, and (2) water molecular attraction force. However, with further increment on the moisture content the water molecular attraction force was reduced and distance between the kaolin increased thus decreased the adhesion between the kaolin (Bai, et al., 2012; Mohamad, et al., 2011; Matsushi & Matsukura, 2006; Mitchell & Soga, 2005)

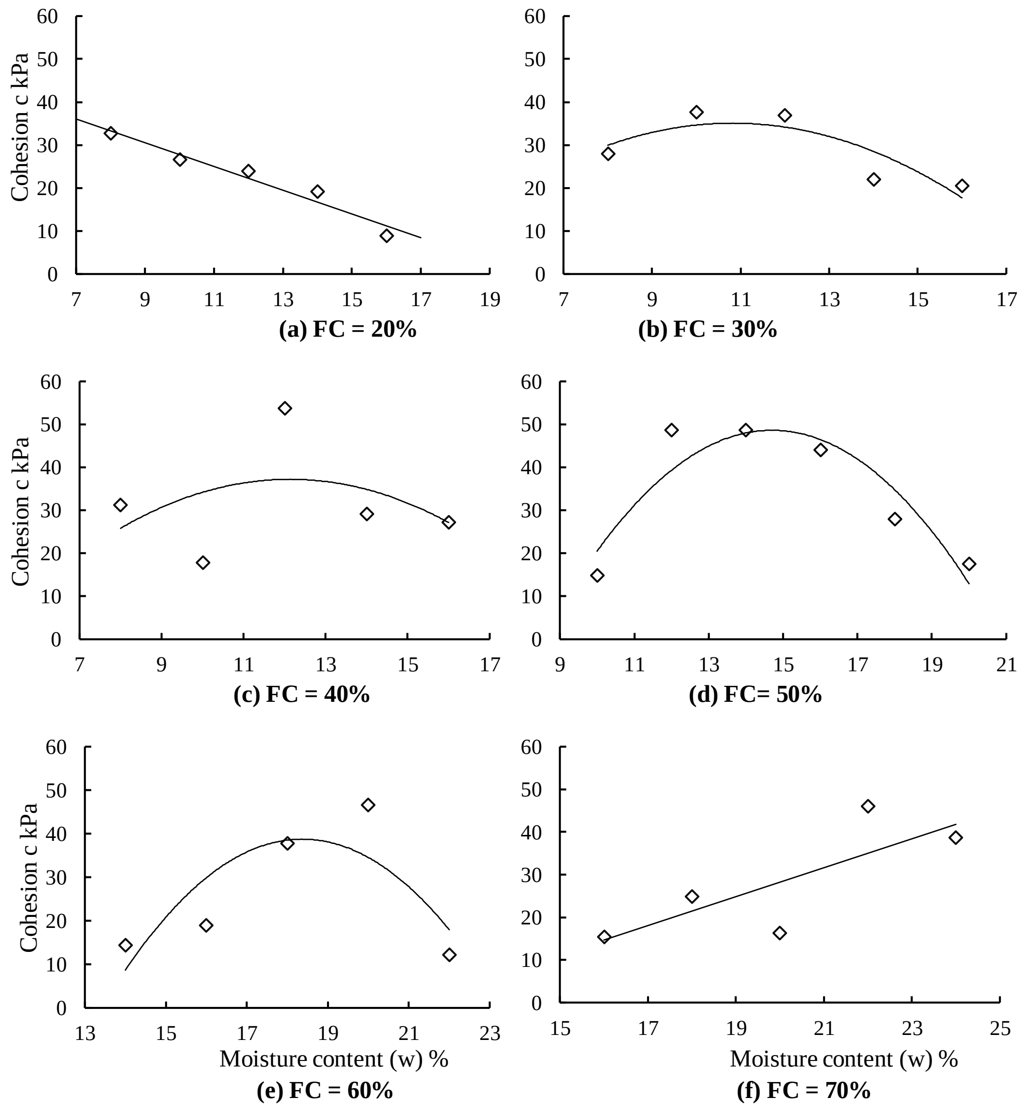


Figure 4 Cohesion versus moisture content at different fine content

Figure 5 showed the results of friction angle versus moisture content for different FC. Generally, the results showed regressive relationship between the friction angle and moisture content. However, from the results it can indicate that, at low fine content (FC less than 50%), the moisture content has less effect on the cohesion, while this effect became a significant at high fine content where the friction angle decreases with the increment of the moisture content. Where increased both FC and w% lead to increase the lubrication effect of the moisture and fine content toward the coarse particles thus, decreased the friction angle (Okonta, 2015; Bai, et al., 2012; Omidvar, et al., 2012; Mitchell & Soga, 2005).

3.2 Effect of moisture content on the shear modulus and shear strength

A comparison between the shear modulus and moisture content for different fine content were shown at figures 6 where applied normal stress equal to 10.5, 21 and 31.5 kPa. In figures 6a and 6e (where FC equals to 20% and 60%) there is regressive relationship between the shear modulus and moisture content where the shear modulus decrease with increment of the moisture content. While figures 6b, 6c, and 6d (where FC equals to 30%, 40%, and 50% respectively) showed curve relationship between the shear modulus and moisture content where the shear modulus increased to the highest values with increment of the moisture then the shear modulus decrease with further increment on the moisture content. Meanwhile, for figure 6f (where FC = 70%), showed different relationships between shear modulus and moisture content for the same amount of the fine content and different applied stress.

The comparison between the shear strength and moisture content for different fine content at figure 7 and by using applied normal stresses equal to 10.5, 21 and 31.5 kPa showed similarity to the results of shear modulus. There are three patterns between the shear strength and moisture content:

(1) In figure 7a and 7e (where FC equals to 20% and 60%), there is regressive relationship between the shear strength and moisture content.

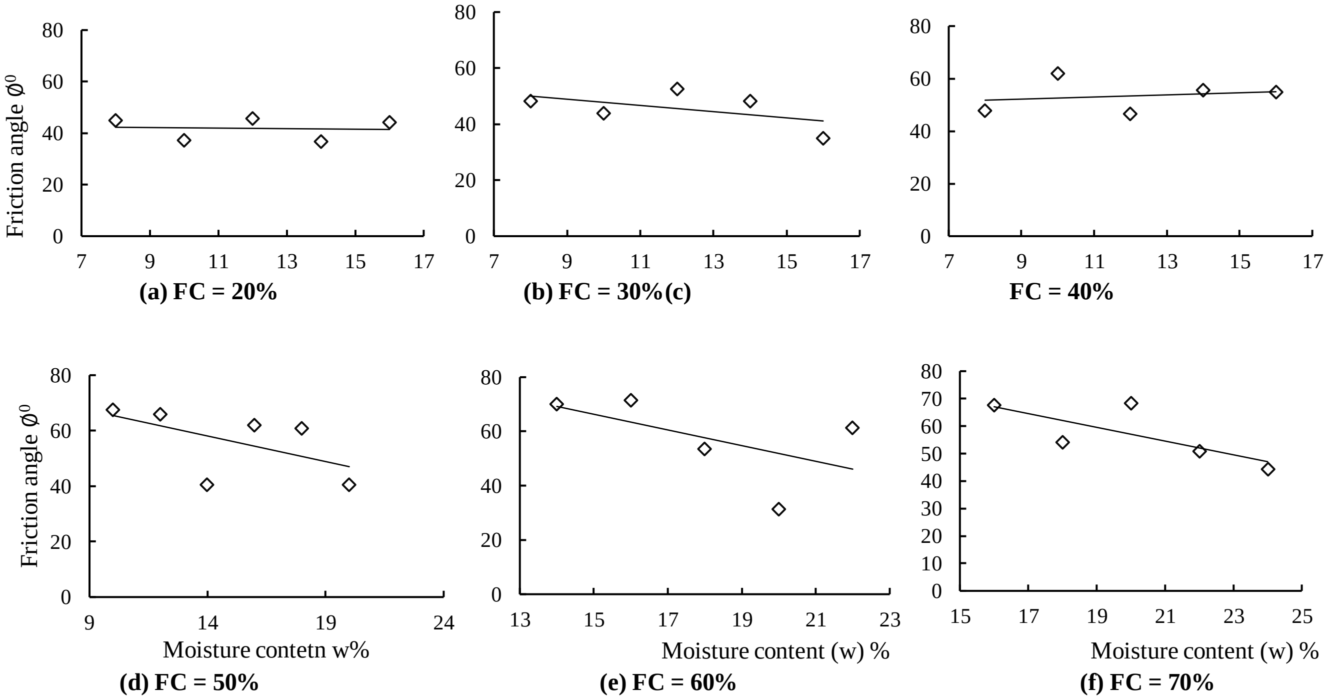
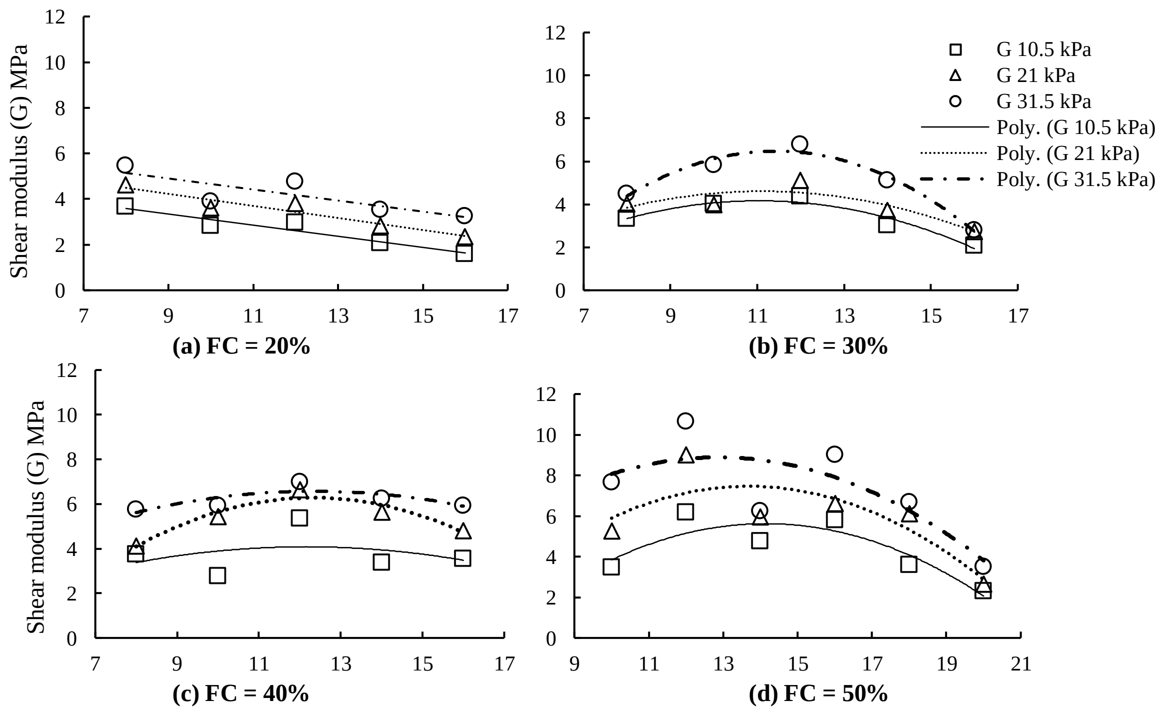
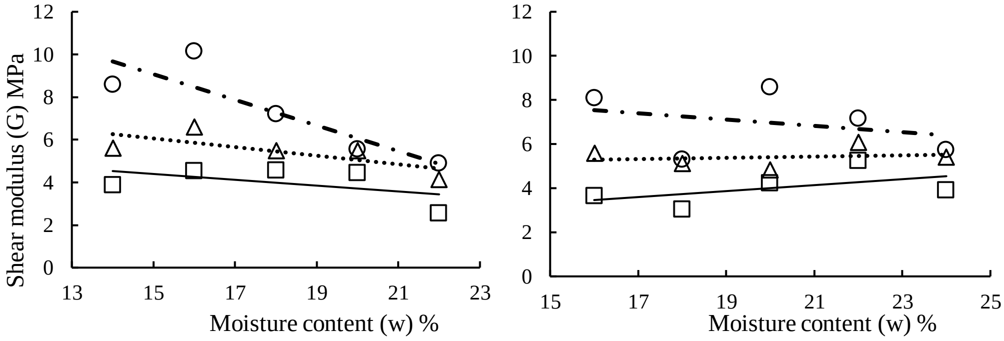


Figure 5 Friction angle versus moisture content at different fine content





(e) FC = 60% **(f) FC = 70%**

Figure 6 Shear modulus versus moisture content at different fine content

(2) At figures 7b, 7c, and 7d (where FC equals to 30%, 40%, and 50% respectively) there are curve relationships between the shear strength and moisture content where the shear strength increased to the highest values with increment of the moisture. Then the shear modulus decreases with further increment on the moisture content.

(3) For figures 7f (where FC = 70%) there different relationship between shear strength and moisture content with different applied stress.

(4) In addition, figure 7a showed the highest value of shear strength (τ equals to 44.2, 53.5 and 65.3 kPa for σ equals to 10.5, 21 and 31.5 kPa respectively) at lowest value of moisture content (w equals to 8%). While the lowest value of shear strength (τ equals to 19.3, 29.9 and 39.7 kPa for σ equals to 10.5, 21 and 31.5 kPa respectively) at the highest value of moisture content.

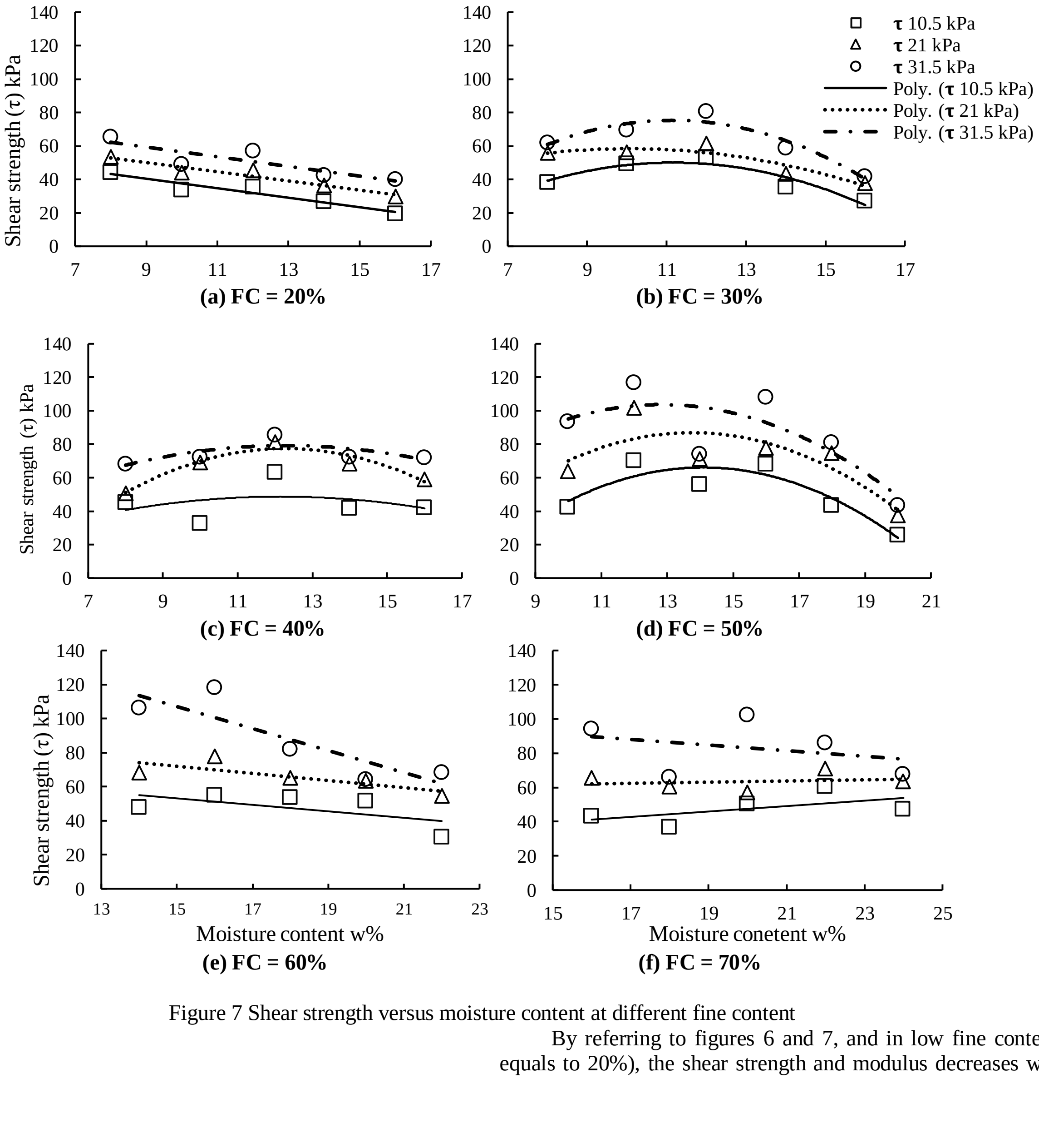


Figure 7 Shear strength versus moisture content at different fine content

By referring to figures 6 and 7, and in low fine content (FC equals to 20%), the shear strength and modulus decreases with the increment of the moisture content. This behaviour can be expressed by the lubrication effect of the moisture content between the coarse material which caused decrement in the friction angle and shear strength (Mohamad, et al., 2011; Bai, et al., 2012). However, with further increment on the fine content, the relationship between the shear strength and modulus towards moisture content converted to curve relationship. Both of shear strength and modulus increased to the highest value with the increment of the moisture content and then both decreased with further increment of the moisture content. This behaviour can be expressed through the following fact: At low moisture content, the water molecules strengthen the electrical bond between the kaolin particles (i.e. increased the whole sand-kaolin mixture strength) by dipole attraction, thus by additional moisture content, the water started to increase the distance between the kaolin particle; consequently, decreased the bonds between the kaolin particles thus decreased the sand-kaolin mixture strength (Das, 2014; Mitchell & Soga, 2005).

3.3 Effect of fine content on the friction angle and cohesion

The comparison between the results of cohesion versus fine content for different moisture content indicate the following (see Figure 8); (1) Figure 8 a and b (where w equals to 8% and 10 respectively) showed no significant effect for variation the cohesion by variation of the fine content, (2) meanwhile, from Figure 8 b to g (where FC from 12% to 20%) indicate curve relationship between friction angle and fine content where the cohesion increased to the highest value (c ≈ 50 kPa) with the increment of the fine content then the cohesion decreases with further increment of fine content.

By referring to Figure 8, it can indicate that at low moisture content (w% equal to 8 and 10%), cohesion showed no significant effect by variation the fine content. At the range of moisture content from 12 to 20%, there is curve relationship between the cohesion and the fine content where the cohesion increases to the highest value with the increment of the fine content (i.e. c ≈ 50 kPa and FC ≈ 50 to 60%). Then the cohesion decreases with further increment of fine content. This behaviour can be expressed through the void-fine interaction and intergranular void ratio. With the increment of the fine content, the voids were filled by fine material which added bonds to the particle beside the water molecular attractive bond (i.e. add two cohesion forces). However, with further moisture content, the distance between the kaolin particles increased the effective zone (the zone where the cohesion between the particle work) thus neutralizing the effect of water attraction; consequently, decrease the cohesion forces force (Das, 2014; Mitchell & Soga, 2005).

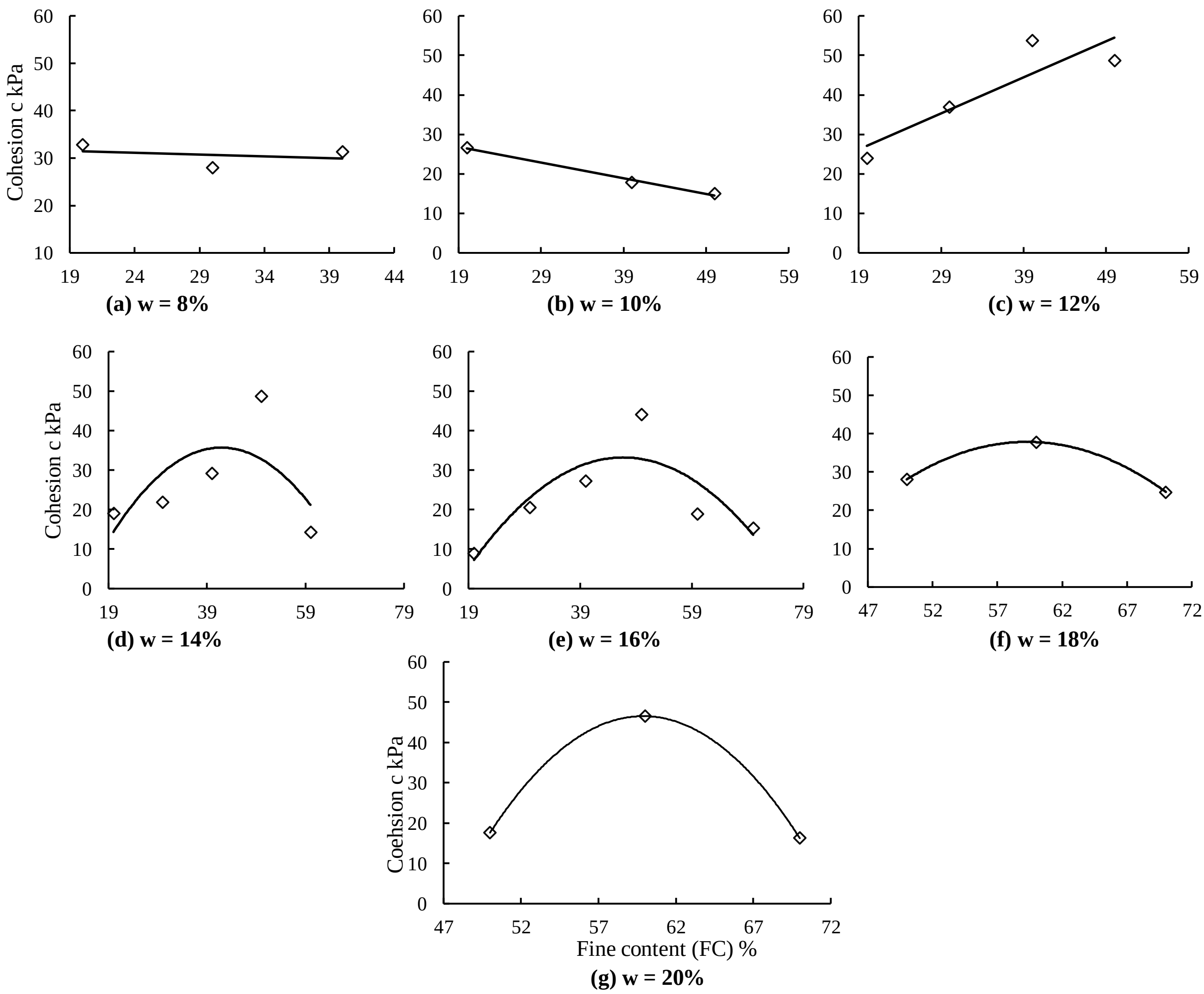


Figure 8 cohesion versus fine content at different moisture content

Figure 9 showed the results of friction angle versus fine content for different moisture content. Figure 9 a (where w equals to 8%) showed no significant variation on the friction angle values with the increment of the fine content. However, Figure 9 b, c, d, e, and g (where w equals to 10%, 12%, 14%, 16%, and 20% respectively) showed progressive relationship between the friction angle and fine content where the shear strength increased with the increment of the fine content. Generally, the effect of fine content in the friction angle has progressive relationship when the moisture content is between 10 to 16%. Thus, due to use the same compaction effort and different fine and moisture content on the mixtures which lead to change the soil particles structure (strength the soil particles structure) which has higher significant effect on the shear strength parameters (including the friction angle) more than the density (i.e. the fine content) effect (Bensoula et al., 2015; Belkhatir et al., 2014). Thus, produce progressive relationship between the friction angle and fine content. However, the author hypotheses this increment due to high value of τ at σ equal to 31.5 kPa which produce the highest value of friction angle. In general, the high value of friction can be related to the high shear rate and low applied stress (Toufigh, et al., 2015; Li, et al., 2013b; Liu, et al., 2006).

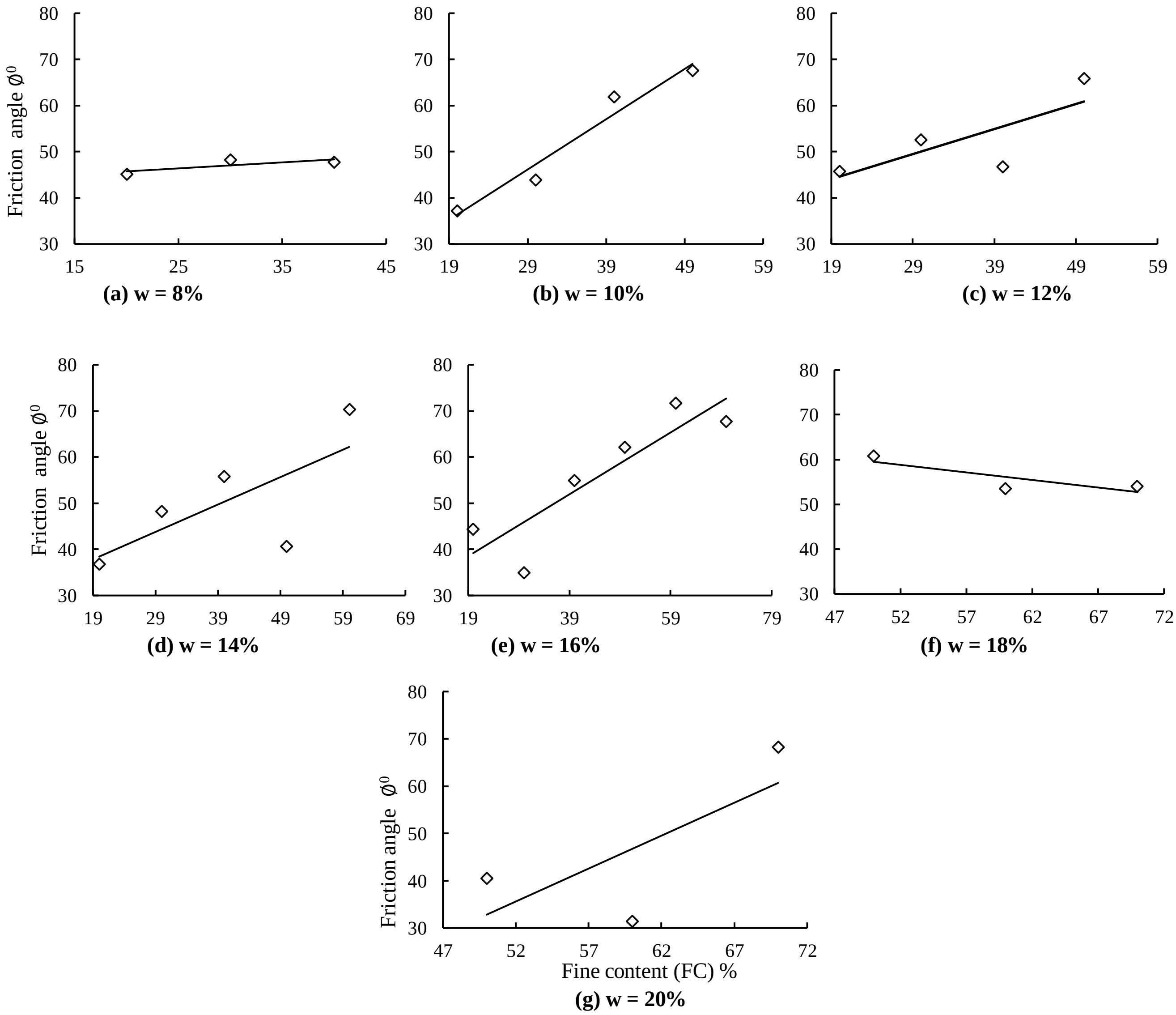


Figure 9 Friction angle versus fine content at different moisture content

3.4 Effect of fine content on the shear strength

The results on figures 10 showed the results of shear strength versus fine content for different moisture content under three applied normal stresses (σ = 10.5, 21 and 31.5 kPa) indicate the following; (1) figures 10a and 10f (where w equals to 8 and 18% respectively) showed no significant pattern between the shear strength and fine content, (2) meanwhile, figures 10b, 10c, 10d, 10e, and 10g (where w equals to 10%, 12%, 14%, 16%, and 20%) showed progressive relationship between the shear strength and fine content where the shear strength increased with the increment of the fine content.

In figure 10a and 10f, the shear strength is less affected by the variation of the fine content at moisture content equals to 8% and 18% respectively. This insignificant effect can be connected to the same behaviour of cohesion and friction angle at the same amount of the moisture content. The shear strength tends to increase with the increment of the fine content when the moisture content equals to 10%, 12%, 14%, 16%, and 20%. This result is in an agreement with Naeini (2006), but it disagrees with others previous researcher such as Zlatović (1995), Naeini and Baziar (Naeini & Baziar, 2004), Prakasha and Chandrasekaran (2005). The differential in results can be expressed through the effect of the shear rate. In this research, a relative high shear rate (i.e. equals to 1 mm/min) was used which caused acceleration in the bonds to be broken between the kaolin particles greater than the ability of kaolin particles to restore their bonds (Toufigh, et al., 2015; Gratchev & Sassa, 2015).

3.5 Interface of moisture and fine content

According to the previous two sections, it is clear that there is interface between the effect of moisture content and fine content towards the shear strength parameters. The fine content has less effect on the shear strength parameters when the moisture content is low and vice versa. On the other side, the presence of high level of fine content caused no significant effect for the variation of moisture content on the shear strength and modulus. At the same high level of fine content, the moisture content has complex effects. While the increment of the moisture content caused increment the cohesion, the increment of the moisture content caused decrement the friction angle at high level of fine content.

4. CONCLUSION

The effect of fine and moisture content towards the shear strength, shear modulus, friction angle and cohesion were tested in this paper and the results indicate the followings:

- Both fine and moisture contents showed interface effect in the shear strength parameters.
- At low fine content and moisture content, there are no significant effect on the shear strength, modulus, friction angle and cohesion. With the increment of both fine and moisture contents, the values of shear strength, modulus, friction angle and cohesion varied.

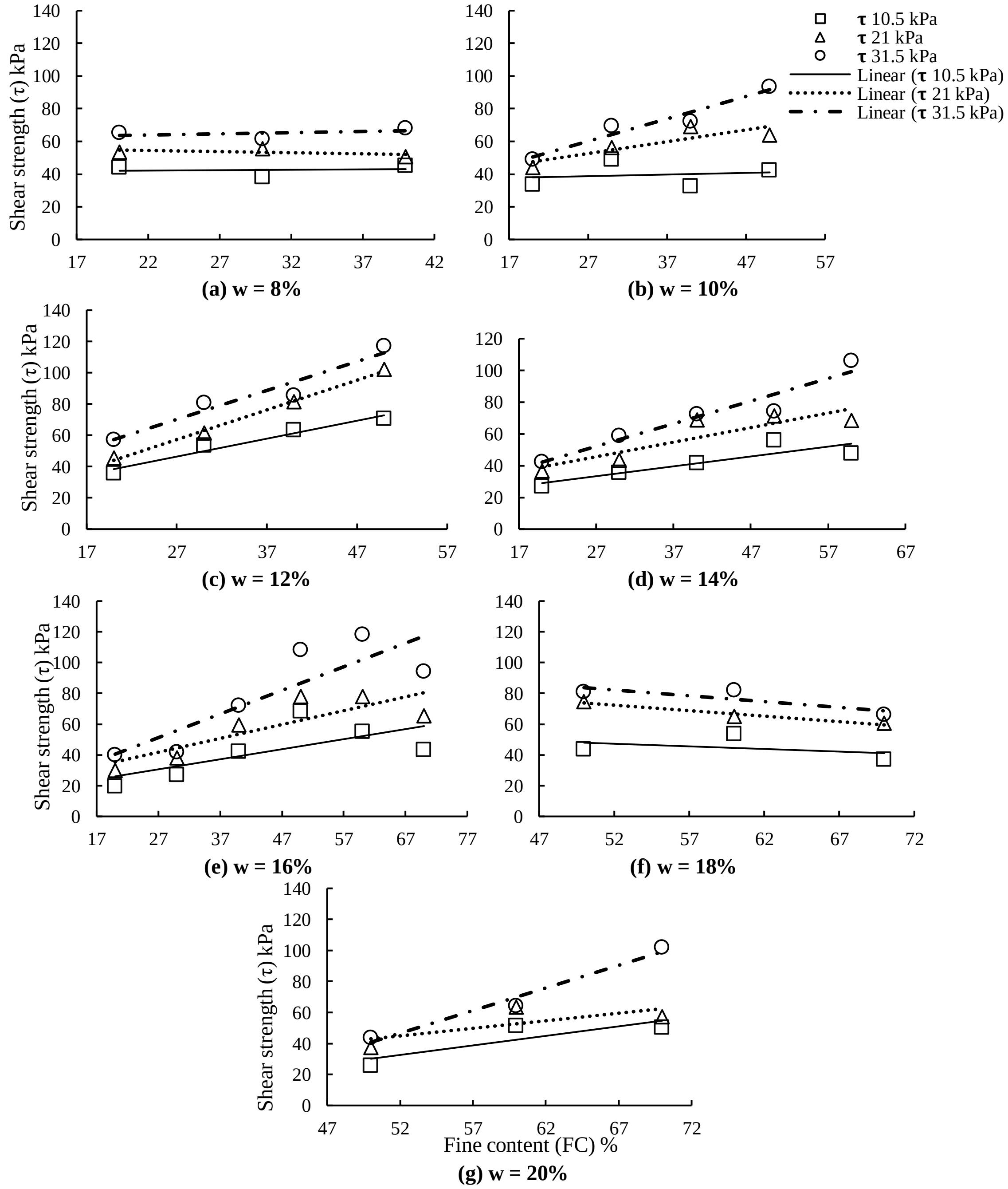


Figure 10 Shear strength versus fine content at different moisture content

- Both high shear rate the low applied stress lead to produce high value of friction angle and inverse the results compared with the previous researchers.
- Compact the soil mixtures with same compaction effort and different fine and moisture content lead to change the soil structure and void ratio thus produce regressive relationship between the friction angle toward density.
- The bond between the fine particles and water molecules has effect in the values of the shear strength, modulus, friction angle and cohesion.

- The inter-granular void ratio expresses curve relationship between the fine content and shear strength parameters.

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