THE INFLUENCE OF SAND's GRADATION AND CLAY CONTENT OF DIRECT SHEART TEST ON CLAYEY SAND

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ABSTRACT
The shear strength of clayey-sand can be affected by several factors, e.g. gradation, density, moisture content, and the percentage of clay and sand fraction. The same percentage of clay and sand fraction in clayey-sand mixtures may have different shear strengths due to those factors. This research aims to study the effect of clay content on sand that cause the change of its shear strength. Samples consisted of different clay and sand fractions were reconstituted at a certain moisture content. Sand fractions varied from well-graded to poorly-graded sand. Shear strength was measured in terms of the direct shear test. Prior to the test, surcharge loads were applied to represent overburden pressures. Shear strength results and their components (i.e. Cohesion and internal angle of friction) were correlated with physical properties of samples (i.e. grading coefficient of curvature, coefficient of uniformity, and density). Results showed that samples classified as well-graded and dense sand had higher shear strength. In the other hand, the shear strengths decreased when the mixtures became poorly-graded and less dense. The inclusion of the clay fraction increased cohesion component and decreased internal angle of friction.

Keywords : Clay, Sand, Density, Gradation, Shear Strength

1. INTRODUCTION

Several places of Indonesia's coastal areas, that are not adjacent to oceans, are dominated by alluvial deposits. The deposits often comprise of soft cohesive soil, which is known to have a low bearing capacity. Road embankments sometimes have to be laid upon this kind of difficult soil. Embankment fill materials that meet standard specifications, are also scarcely available in such areas. The low quality subgrade and fill materials can lead into embankment failures.

In order to ensure fill materials are adequate to withstand loads imposed and become workable, Bina Marga [1] specified properties of materials that can be used as fill. The strength of embankment soil is determined by its mechanical properties, i.e. internal angle of friction angle (ϕ) and cohesion (c). The soil friction is affected by size, shape, and texture of coarse particles, contributed mainly by sand type of soil. Cohesion (c), which is provided by cohesive or fine particle soil, is the force that holds together molecules or like particles within a soil. Soil cohesion is affected by the distance between molecules and particle size distribution, water content, and pore water pressure. The percentage of cohesive (clay) and cohesion-less (sand) soil within soil mass, therefore, governs the strength of the soil. This research attempts to observe the effect of clay content on shear strength of clayey sand mixtures.

2. REVIEW OF LITERATURES

Prihatin & Wahyudi [2] studied a correlation of gradation, density and shear strength of fill materials. The result indicated that the higher ratio of curvature coefficient and uniformity coefficient (Cc/Cu) or the more homogenous the soil particles, the lower γ_{dmax}, cohesion, and internal angle of friction, and vice versa. Kara et al [4] carried out a research related to the effect of sand particle sizes on its shear strength changes using a direct shear test. It showed that the larger the size of particles, the higher the internal angle of friction. The sand, however, has no cohesion and hardly become denser, which results in lower bearing capacity. To solve this problem, some binder materials such as cohesive soil (clay) should be added into the sand. Hakam et al [5] observed the effect of clay additions to the shear strength of beach sand. The result showed that to some extend if the mixture become denser, the internal angle of friction increased, and vice versa. The further addition of clay would increase the mixture cohesion, but decreased the internal angel of friction.

3. RESEARCH METHODOLOGY

This research aims to observe the effect of clayey-sand mixtures gradation and density on their shear strength changes. The procedure of the research is as follows.

3.1. Samples Preparation

The samples were prepared based on the planned variations of sand gradation according to ASHTOO and USCS specifications, and also the variety of clay content in sand mixture. The planned sand gradation can be seen in Figure 1.

Sand can be categorized as well-graded sand if Cc > 6 and Cu between 1 and 3 (1<Cu<3). If only one of them is complied, either Cu or Cc, then the sand can be categorized as poorly-graded sand. Gap grading is a condition where the particle sizes are lacking on one or two numbers of sieves. Gap-graded sand from pure sand soil is a gradation achieved by dispelling the particle size of #20 and #40. Gradation A1-b and A3 are soil classifications based on AASHTO system that are categorized as poorly-graded sand. Uniform fine and coarse-graded sand are the uniform sand with particle size from #40 to #60 and #4 to #40, consecutively. From each gradation of sand above, clay fraction with percentages of 0%, 10%, 20%, and 40%, were then added to the mixtures.

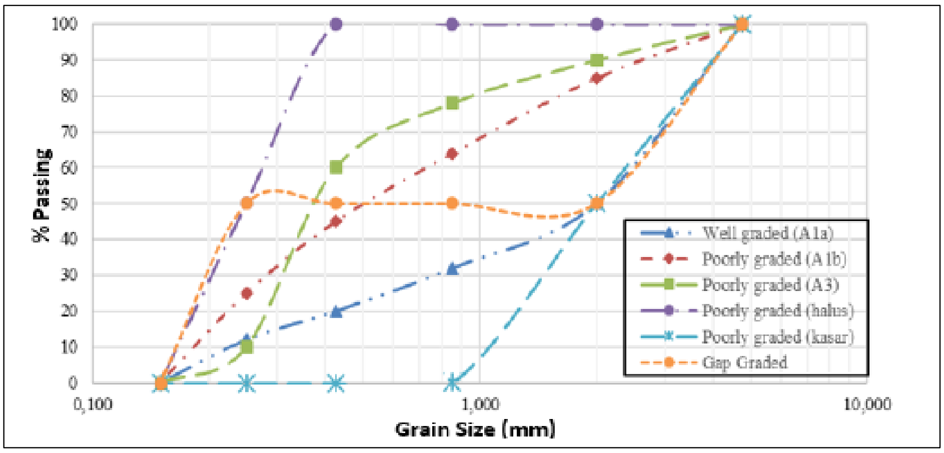

Figure 1. Planned Sand Gradations

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3.2. Samples Densities

The samples were varied into two kinds of densities. The first was 15,24 kN/m^3, which was applied for all sample variances. Secondly, a density that was formed by giving preloading surcharge of 0,16 kN/m^2 for 24 hours on molds. This load resulted in different densities on each variant. A consolidation test was done based on ASTM D-2435. After the desired densities were achieved, shearing test was performed.

3.3. Direct Shear Test

Shearing test was performed using direct shear test according to ASTM D-3080. The purpose of this test was to obtain mixture shear strength parameters, i.e. cohesion (c) and the internal angle of friction (ϕ). The direct shear tests were done on each mixture.

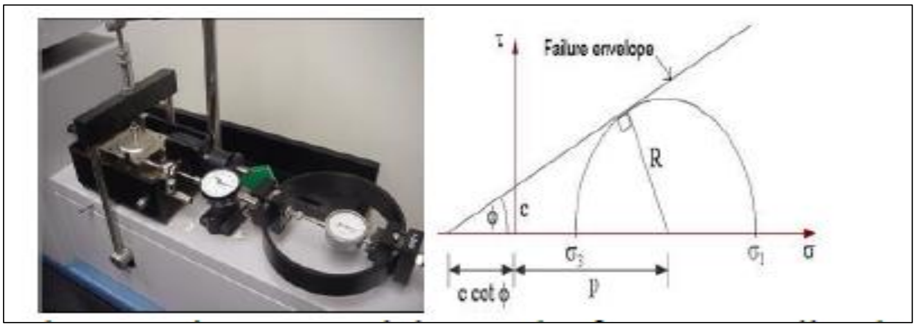

Figure 2. Direct Shear Test Apparatus and Mohr-Coulomb Normal-Shear Stress Chart

4. RESULT AND DISCUSSION

Prior to mixing, the index properties (gradation, specific gravity, and Atterberg limits) of sand and clay used in this research were obtained. The main results of direct shear tests were separated into two parts, with and without preloading.

4.1. Soil Index Properties

The result of soil properties test can be observed in Table 1.

Table 1. The Result of Soil Properties Test

Properties	Unit	Clay	Sand	90%	80%	70%	60%
Specific Gravity (Gs)	-	2.675	2.636	2.637	2.638	2.647	2.651
Atterberg Limits							
-Liquid Limit	%	30.80	-	-	-		
-Plastic Limit	%	20.50	-	-	-		
-Plasticity Index	%	10.30	-	-	-		

It can be seen that specific gravity increased with the increasing of clay content on mixtures. Based on USCS, clay was categorized as low plasticity clay.

4.2 Direct Shear Test Results

Shear strength components, i.e. internal angle of friction and cohesion, were obtained from the tests. In conjunction with other properties tested, i.e. densities and grading, these parameters were then analyzed to discover their relationships.

4.2.1 Correlation between Clay or Sand Content and the Internal Angle of Friction

4.2.1.1 The Internal Angle of Friction without Preloading (Without Consolidation)

The relation between clay content and internal friction angle of samples with the same density of 15,24 kN/m^3 can be seen in Figure 3. Most of internal friction angles showed a trend of improvement as clay fraction increased, except for uniformly fine-graded sand (UF) mixture. This is due to the replenishment of clay content. The internal friction angle of UF mixtures decreased for clay content more than 10%. The further addition of clay fraction caused a reduction in interlocking fine particles. The same trend was also discovered by Arifin and Saputra (2015), where the addition of sand in clay increased the internal angle of friction, peaked at about 50% of sand, and decreased at further inclusion.

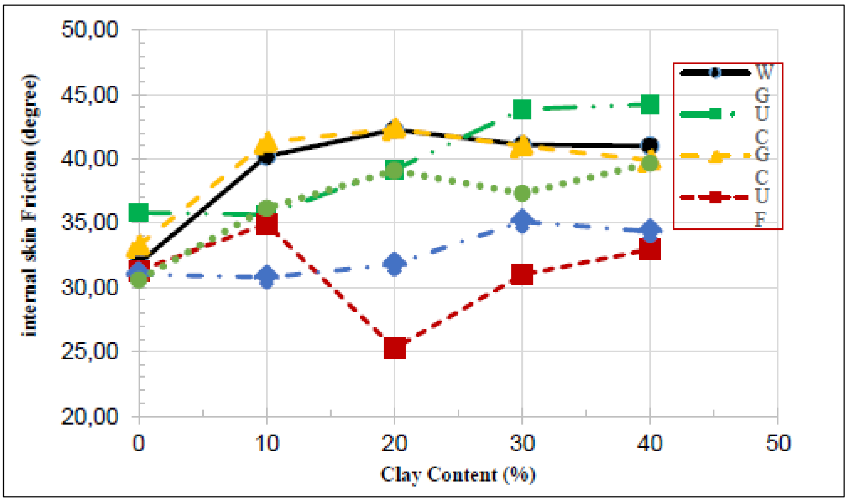

Figure 3. The Correlation between Internal Angle of Friction and Clay Content without Preloading

4.2.1.2 The Internal Angle of Friction with Preloading (Consolidation)

Figure 4 shows fluctuated trends of the internal angle of friction as clay content increased on mixtures with preloading. On mixtures with fine particles less than 12% (i.e. SW, Gap, and UF), the higher the percentage of clay fraction added, the lower the internal angle of friction achieved. On mixtures of A1-b, A3 and UC, however, showed the other way around. Perhaps the addition of clay fraction increase shear plane area due to void fill by fine clay particles. Further addition of clay (more than 12%) made the internal friction angle become higher, except for SG and UF. The clay fraction improved mixtures gradation to become more compact and denser. The addition of clay on SG and UF mixtures, however, decreased the internal angle of friction. This is because the increasing of fine particles, not bigger particles that are needed. Figure 3 and 4 shows that high values of internal friction angle are dominated by coarse sand materials (especially the size of > 0,850 mm) like WG, UC, and SG. For A1-b, A3, and UF, the sand particle sizes were smaller, as a result the internal angle of friction become lower. This corresponds to a previous research conducted by Kara et al. [4], which concluded that the increasing of granular particle size resulted in higher internal friction angle, or vice versa.

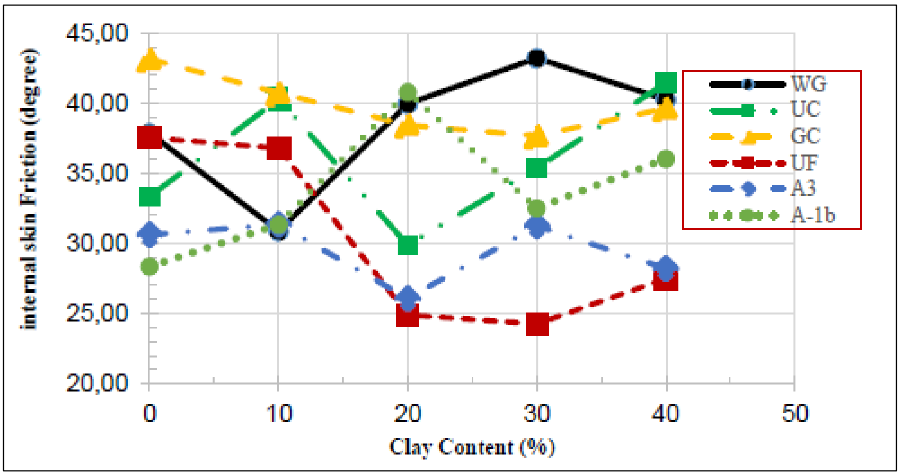

Figure 4. Correlation between Internal Angle of Friction and Clay Content with Preloading

4.2.1.3. The Difference of Shear Strength between Mixtures with and without Preloading

The difference is shown as ratio of the internal angle of friction values between mixtures with and without preloading, as shown in Figure 5. The ratio of higher than 1 means that compression/compaction due to surcharge load (preloading) increases the shear strength component. The ratio of lower than 1 shows the opposite.

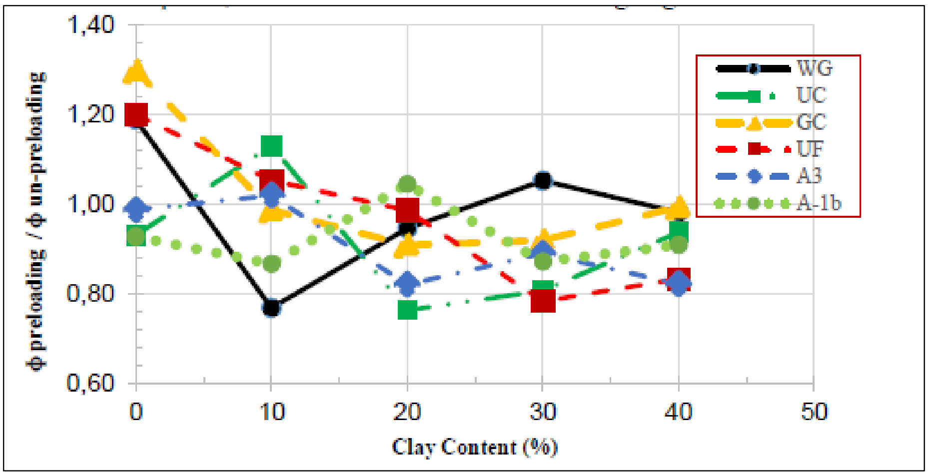

Figure 5. Ratio of the Internal Angle of Friction of Mixtures with and without Preloading

As can be seen from Figure 5, the majority of ratio values is situated below the value of 1, especially at clay content more than 12%. The more compact or denser mixture due to preloading reduced the internal angle of friction. The clay particles reduced the interlocking particles of sand particles.

4.2.2. Correlation between Sand or Clay Content and Cohesion (c)

4.2.2.1. Cohesion of Mixtures without Preloading

The effect of clay fraction inclusion in the mixtures is shown in Figure 6. The cohesions of mixtures with less than 5% clay content are the apparent (untrue) cohesions. As can be seen from the graph, cohesion values were fluctuated as clay content increased. In this test, samples were in relatively less dense condition, therefore the contact between clay particles were still remained low. The shear strength of mixtures were still dominated by friction of sand particles.

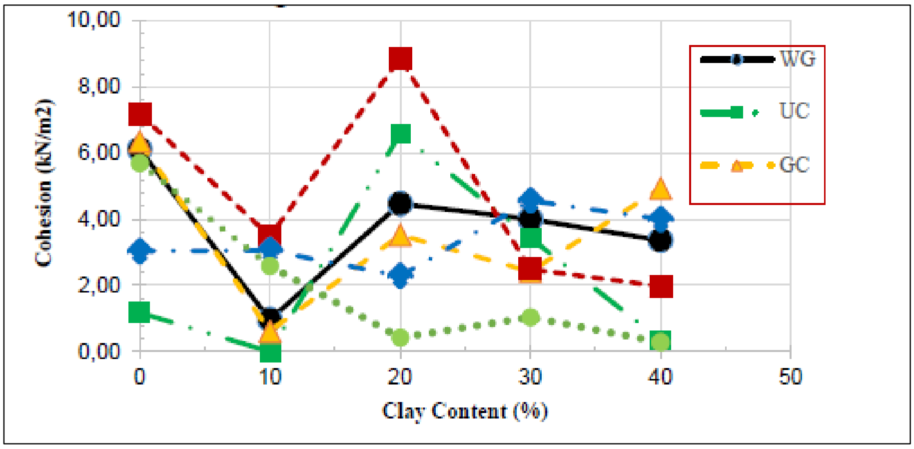

Figure 6. Correlation between Clay Content and Cohesion of Mixtures without Preloading

4.2.2.2. Cohesion of Mixtures with Preloading

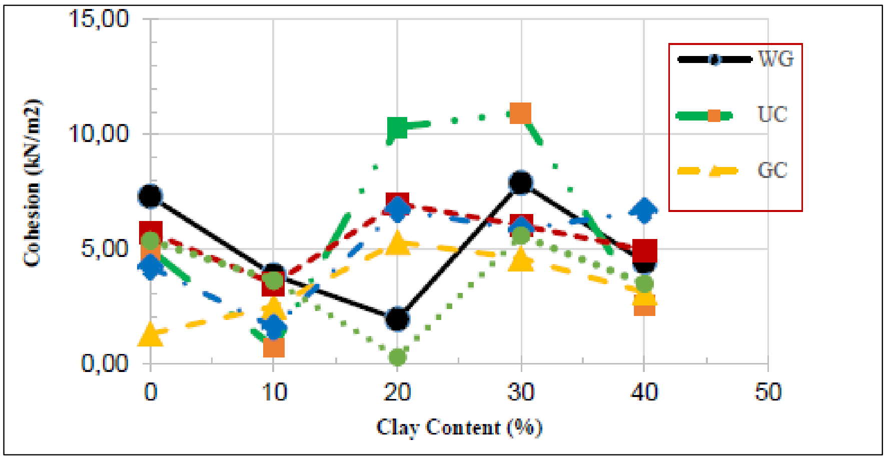

Figure 7. Correlation between Clay Content and Cohesion of Mixtures with Preloading

The effect of clay fraction addition on the change of cohesion values within mixtures with preloading can be seen in Figure 7. In general, the inclusion of clay up to 30% increased the mixtures cohesion component. This indicates that in denser mixtures, fine particles of clay also play an important role in affecting mixture shear strengths. Some coarse particles of sand were covered by fine particles, resulting in lower interlocking particles/friction. In this test, the maximum cohesion occurred when 30% of clay fraction was added to the mixtures.

4.2.2.3. The Difference of Cohesion of Mixture with and without Preloading

Similar to 4.2.1.3, the comparison of cohesion is shown as ratio of cohesion values between mixtures with and without preloading.

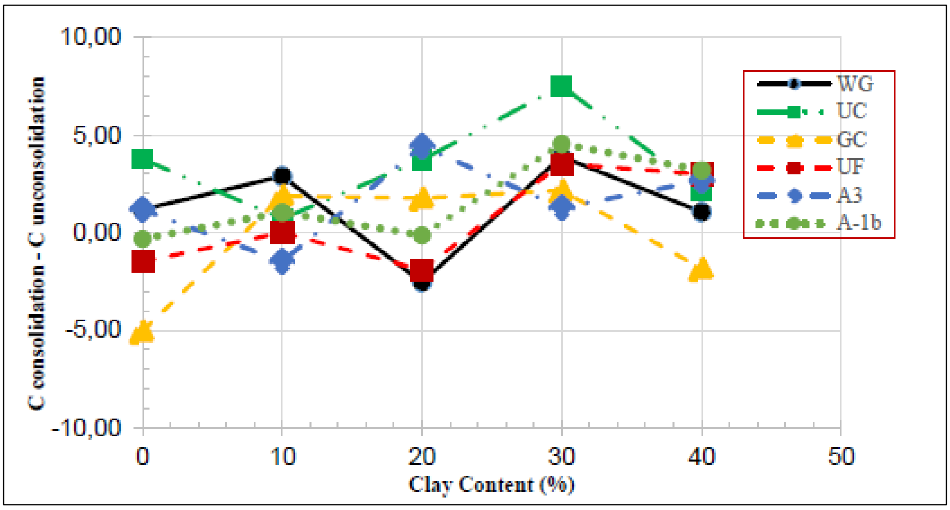

Figure 8. The Cohesion Comparison between Mixtures with and without Preloading

As can be seen in Figure 8, the additional compaction (preloading) on samples enhanced the cohesion component. This improvement occurred significantly for the compressed samples with more than 12% clay content. This also indicated that on that percentage, transition frm sand to clay influence on mixture shear plane was taken place. It also confirmed the previous explanation related to the effect of internal friction angle, where 12% clay fraction addition on compressed mixtures increased the friction component.

4.2.3. Correlation between Gradation Coefficient and Shear Strength

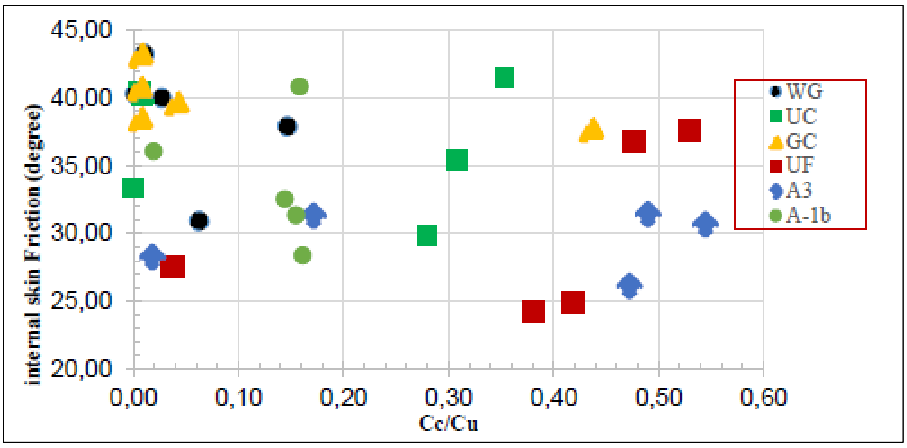

Figure 9. The Effect of Mixture Gradation (Cc/Cu) on the Internal Angle of Friction

According to Prihatin and Wahyudi (2009), if the Cc/Cu become lower, the internal friction angle tends to increase. Figure 9 shows scattered values of gradation coefficient (Cc/Cu) and shear strength of mixtures. The gradation (Cc/Cu) influence on mixtures shear strength cannot be represented only by particles size distribution, but also by other factors i.e. the coherence of fine particles, the void filling of finer materials, and the percentage of coarse sized particles.

Figure 9 shows that mixtures contained coarser sand (i.e. WG and UC) had higher shear strengths, whereas UF and A3, which were dominated by fine sand particles, seemed to have lower shear strength. It demonstrates the influence of particles size on shear strength. The larger the coarse particles, the higher the shear strength.

4.2.4. Correlation between Clay Content and Mixture Dry Density (γ_d)

The mixture densities as seen in Figure 10, are the results of 0,16 kg/m^2 surcharge load.

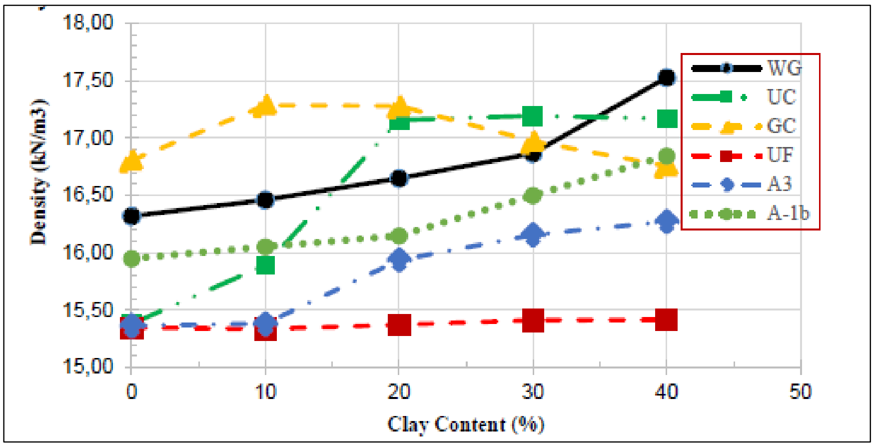

Figure 10. The Correlation between Clay Content and Mixture Dry Density

As can be seen in Figure 10, the addition of clay fraction increased the mixture densities, except for GC. The most significant change occurred on UC mixture, i.e. from 15,38 kN/m^3 to 17,19 kN/m^3 on 30% of clay addition. UC mixture is a uniform-graded sand with coarse sized particles, thus the clay particles could occupy the mixture voids.

On UF mixtures, the addition of clay almost had no impact on the change of mixture density. There was only slightly change from 15,35 kN/m^3 to 15,42 kN/m^3. This was due to lacking of coarse sized particles in the mixtures that could improve the particle gradation.

The clay fraction addition of more than 20% resulted in the decreasing of SG mixture density. This is because SG mixture lacked of medium-sized sand particles, so the addition of clay of more than 20% did not improve the mixture density.

It is found that significant improvement on mixture densities, was achieved at the addition 20% clay fraction. Further addition could no longer effective in increasing densities.

4.2.5. Correlation between Mixture Dry Density (γ_{dry}) and Shear Strength (ϕ and c)

Hakam et al (2010) stated, that on direct shear test, the denser the samples, the higher the internal angle of friction, or vice versa. The higher the clay content, the higher the cohesion (c), and the lower the internal angle of friction (ϕ).

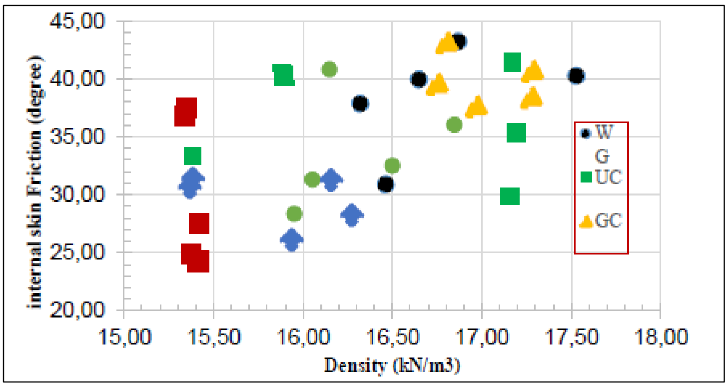

Figure 11. Density (γ_d) and the Internal Angle of Friction (ϕ)

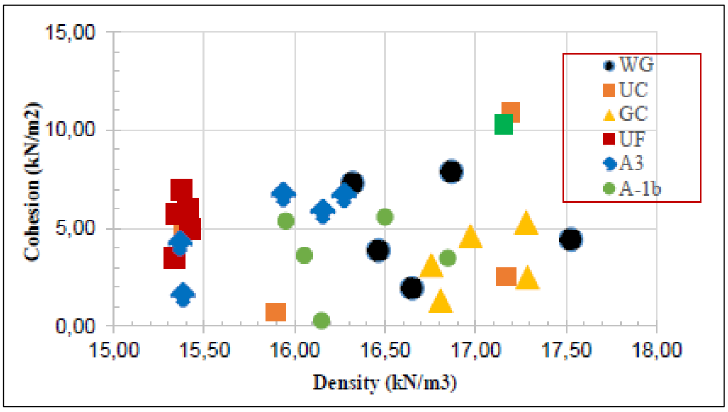

Figure 12. Density (γ_d) and Cohesion(c)

Figure 11 shows that there is an influence of density on mixture internal friction angle (ϕ). The relation of them, however, were fluctuated and inconsistent. The same thing also happen in the correlation of density and cohesion component.

5. CONCLUSION

The test results and discussions illustrate the following conclusions.

1. The addition of clay fraction changes clayey sand mixture gradation.

2. Shear strength components (cohesion and the internal angel of friction) are strongly affected by the particle size distribution of soil mixtures. The larger the sand particles, the higher the friction, and vice versa.

3. Gradation coefficient (Cc and Cu) does not affect the shear strength significantly.

4. The addition of clay fraction in sand mixtures increases the internal angle of friction, and decreases cohesion, at a certain extent where coarse particles still dominates the shear plane. The further of clay addition make coarse particles no longer dominant on the shear plane, resulting in the opposite effects (lower internal friction angle and higher cohesion).

5. Cohesion is more affected by fine materials content rather than coarse particles.

6. The addition of clay up to 40% tends to increase mixture density.

7. The addition of clay in coarse sand mixtures, increases density more than in fine sand mixtures.

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