International Journal of GEOMATE, May, 2018 Vol.14, Issue 45, pp.170-176
Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2018.45.83839
ISSN: 2186-2982 (Print), 2186-2990 (Online), Japan

EXPERIMENTAL STUDY OF GEOTECHNICAL CHARACTERISTICS OF CRUSHED GLASS MIXED WITH KAOLINITE SOIL

*Shin To Amiri[1], Ramli Nazir[1,] and Ali Dehghanbanadaki[2]

[1]Faculty of Civil Engineering, Universiti Teknologi Malaysia; Johor Bahru, Malaysia

[2] Department of Civil Engineering, Damavand Branch, Islamic Azad University, Damavand, Iran

*Corresponding Author, received: 23 Dec 2017, Revised: 7 Feb. 2018, Accepted: 21 Feb. 2018

ABSTRACT: The Geotechnical properties of adding crushed curbside-collected glass to Kaolinite S300 with various percentages of 10 to 50% were experimentally evaluated. Crushed glass passing the 2.36 mm (#8) sieve, and retaining on 1.18 mm (#16) selected for this study is collected from a different area in Johor Bahru, Malaysia. Measured hydraulic conductivities were on the order of 2.33E-6 and 1.87E-5 for 10% and 50% respectively. The result shows increment in the maximum dry density from $1.615\,mg/m^3$ at 10% to $1.908\,mg/m^3$ at 50% of addition of crushed glass with the optimum moisture content of 18.35% and 7.4% respectively. Friction angles from the direct shear test were evaluated between 12 to 25 degrees at normal stresses of 56.4 to 219.9 kPa. The result shows that the unconfined compression strength of Kaolinite S300 mixed with crushed glass is increased from 5.26 kPa at 10% addition of crushed glass up to 17.52 kPa at 50%. It can be concluded that the crushed glass is environmentally clean, readily available, and relatively low-cost material that can be one of the replacements for traditional aggregate to enhance the geotechnical properties of soft cohesive soils.

Keywords: Crushed Glass, Geotechnical Characteristics, Kaolinite, Soil Improvement, Clean Material

1. INTRODUCTION

One of the most important issues about waste materials around the world is the reuse of waste glass due to the high amount of solid wastes in the landfill and on the other hand non-degradable nature of its disposal [1]. From another point of view, a major component of solid waste is represented by post-consumer [2].

For manufacturing glass containers, recycled glass has been used almost exclusively; However, the recycled glass must go through considerable, important processing before it can be used as feedstock in glass container manufacturing. In The first step, the recycled glass is separated based on its color. This procedure is done manually and is, unfortunately, time-consuming and costly. The second step in this difficult procedure is to remove the debris, such as paper labels, cork, and bottle caps, which are mixed with the recycled glass. This part of the process can be done both manually and mechanically. After being categorized and cleaned, the recycled glass is then taken to a waste glass beneficiation plant where it experiences further cleaning, crushing and screening. At the end, the final product, which is called glass cullet, is then ready to be used in producing of glass containers. Based on the color separation which was mentioned, the glass Cullet with green and amber colors is usually used to make beverage bottles, while the clear glass cullet can be used to make bottles or glass plates.

1.1 Limitation of Using Glass Cullet in The Glass Industry

In the glass container industry, the use of recycled glass is often constrained by the substantial cost brought upon by color sorting, cleaning, and transportation. As mentioned earlier, the cost for color sorting of glass cullet, which is necessary to avoid color contamination in the batch, substantially increases the cost of furnace-ready cullet. Also, so many recycled glasses are broken during the time of handling, and it is impractical to color-sort the many small pieces of broken glass. As a result, there is a large amount of broken glass which cannot be used in glass container manufacturing and must be disposed of at a cost. Furthermore, glass plants are normally placed near the reserves of the basic materials used in glass manufacturing. In a glass cullet recycling process which is taking place in cities, a huge amount of money is needed for transportation cost just to reach the facility. This Transportation costs sometimes become more than the market price of cullet. This new trend in the recycled glass supply will continue in a way that more and more communities everyday participate in recycling programs.

Base on the necessity for this trend, however, the glass container industry has been recently the only available market for glass cullet. Moreover, based on the economic reasons the use of glass cullet by the glass container industry is limited to a low percentage in their batch. Finally, as a result, the supply of cullet continues to be more than necessary because of the single market, and the limitations of using glass cullet in the glass making batch. Therefore, being successful for a long time at glass recycling really depends on the development of new applications and markets for the recycled glass. Use of glass cullet in glass industry has some limitation because of some reasons including the following:

a) Color contamination.
   Glass cullet in this part competes with the virgin batch in the glass container industry. Using cullet to furnace-ready specifications requires costly color separation for sorting to avoid color contamination of the batch.
b) Transportation costs.
   Cullet to transport long distances is expensive because of its high density. Transportation costs often way more than the market price of cullet as a containerized batch. To disposing and carrying a ton of waste material in New Zealand, it costs $NZ 50 to $NZ 80 which is roughly double to quadruple times of crushing and mixing the glass into aggregate [3].

2. THE BACKGROUND OF USING THE CRUSHED GLASS

Using glass cullet as a construction aggregate is one potential solution to the disparity between the supply and demand for recycled glass. Many studies have shown that glass cullet can be used in roadbeds, engineering fills, and drainage fields in combination with other construction materials such as sand and stone. A potentially promising new market for recycled glass might be opened because of the use of glass cullet with other construction aggregates. This construction aggregate market that was mentioned is a very important market, and could easily get used to any recycled glass. Also, a local market for recycled glass could be opened by glass cullet applications in the construction industry, which could make the procedure of transporting of recycled glass unnecessary. Moreover, because in this process, there is no need for color sorting of the glass cullet, the cost to use the cullet to the construction aggregate market will be noticeably lower than the cost incurred for reuse for the container industry as was mentioned in advance.

Total solid waste material generated in 2013 was 254 million tons consist of paper, glass, metals, plastics, wood, and food of 27%, 4.5%, 9.1%, 12.8%, 6.2%, and 14.6% respectively; however, only 27% out of, approximately, more than eleven tons of waste glass entered to waste stream was recycled [4]. The comparison of generated, recovered, and discarded glass material in the waste stream between the years of 2008 to 2012 is shown in Table 1.

The engineering features of soil-crushed glass mixes, as well as unblended crushed glass, has been considered by several researchers. A progression of physical properties, compaction, and strength tests have been conducted by Clean Washington Center [5] to find the impact of crushed glass content on the properties of soil-crushed glass mixes. They concluded that for the most part, the procedure of adding crushed glass had no negative effect on the properties of the two soils used in the study.

Table 1 Waste Glass Materials in The Municipal Waste Stream, 2008 to 2012 (In thousands of tons and percent of total discards)

Items	2008	2010	2011	2012
Generated	12150	11530	11470	11570
Recovered	2810	3130	3170	3200
Discarded	9340	8400	8300	8370

Shin and Sonntag [6] condensed the Dames and Moore research specifying that crushed glass is an awesome supplement and can be swapped for natural aggregates in numerous construction applications. The qualities of the clean laboratory under processed crushed glass were examined by Hagerty [7]; finding the way that profoundly precise materials, for example, crushed glass confront more particle crushing under one-dimensional high-stress loads than comparative, yet less angular materials. On laboratory study reports by Wartman in 2004 [8] of the feasibility of using crushed glass was estimated to enhance the engineering nature of the fine-grained, marginal material like Kaolin and quarry fines, and from another side, they examine the extent to which soil mixing could achieve the cohesive characteristic of crushed glass. As indicated by the outcome the cohesive strength of the crushed glass was expanded by half to 100% by utilizing additionally fine-grained soils; be that as it may, this was joined by a 20% to 45% decrease in frictional strength. Meaning to say that, the frictional strength of the fine-grained material was improved by adding curbside collected crushed glass. They likewise studied in some selected engineering properties of Crushed glass tests were classified as well graded sands with gravel (SW). Their outcomes demonstrate that crushed glass is promptly accessible, freely draining, earth clean, the moderately low-cost material whose engineering performance properties generally equivalent or surpass those of most natural aggregates.

Some other researchers [9], additionally blended 9.5 mm curbside collected crushed glass (CG) with fine-grained soils, for example, ML, CL, MH, OH, and CH (based on USCS), to show the potential utilization of the Crushed Glass-soil mixes in geotechnical construction. The outcomes demonstrated that selected laboratory tests alongside field verification delineated the adaptability of utilizing Crushed Glass to drastically modify the properties of soft-marginal soils. Contrasted with customary mixes of rock/sand with fine-grained soils outline that Crushed Glass can accomplish comparable objectives and performances, and that the utilization of a "reused material" is practically identical to regular totals for geo-mechanical stabilization of soft, fine-grained soils. They have additionally shown that Crushed Glass-soil mixes give huge upgrades in strength to an assortment of fine-grained materials.

3. METHODOLOGY

In this section, the basic properties of Kaolinite soil are presented and the effect of adding Crushed glass on the geotechnical characteristics of Kaolin such as permeability, compaction, direct shear and unconfined compression strength will be discussed. The curbside waste glasses were collected from the different area in Johor Bahru, Malaysia. Before crushing process, the waste glasses washed and de-labeled and hammered to ease the crushing procedure (See Fig. 1).

Fig. 1 Samples of waste glasses

3.1 Used materials and fundamental tests

Crushed glass passing the 2.36 mm (No. 8) sieve, and retaining on 1.18 mm (No. 16) selected for this study as is shown in Fig. 2, since it is closely resembling natural or quarried aggregates and does not keep the remainder shape of the very first container or application shape, although some of the dimensions are smaller than the sieve opening. Moreover, since the shear strength improvement of Kaolinite mixed with crushed glass was examined in this research, the mechanical and geotechnical properties of fine graded crushed glass particles were ignored.

Fig. 2 Sieved Crushed glass

Series of geotechnical properties tests were conducted to study the geotechnical properties improvement in Crushed Glass-Kaolinite mixture soil with various percentages of 10 to 50 percent addition of crushed glass in Kaolinite. In terms of Specific gravity, based on ASTM D854-14 [10] the test result shows that the white kaolinite specific gravity is 2.65. The crushed glass size range from sieve analysis based on ASTM C136 - 06 [11] is 1.18 mm to 2.36 mm. Fig. 3 shows the data obtained from the hydrometer test is determining the size of the Kaolin used in this test. Based on the graph, it shows that the fine grain particle distributed between 0.01 mm to 0.1 mm. Table 2 shows the summary of Atterberg limits results for Kaolinite S300, followed by ASTM D4318 - 17 [12].

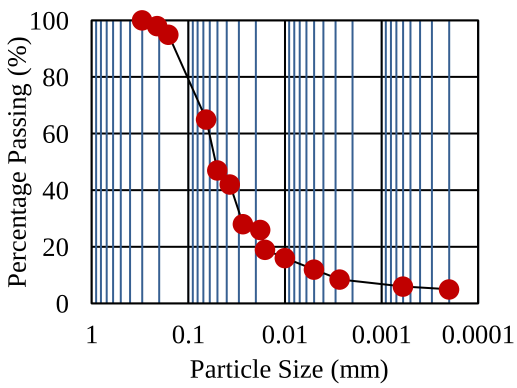

Fig. 3 Sieve Analysis Distribution of Kaolin S300

3.2 Crushed Glass-Kaolinite mixture testing.

In this research, the falling head test method with respect to the particle size distribution results, performed based on ASTM D5084 - 03 [13]while compaction test was carried out to determine the

Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the soil based on ASTM D698-07 [14].

Table 2 Summary of Atterberg limits

Soil	Liquid Limit	Plastic Limit	Plasticity Index
Kaolinite	42	29	19

With respect to direct shear test of soils under Consolidated Undrained Conditions a few textbooks report that undrained strengths can be approximated for saturated specimens using the direct shear test performed at rates on the order of 1.3 mm/min (0.05 in/min) [15]; [16]; [17]; [18]. These investigators recognize the powerlessness to control drainage during the direct shear test but hypothesize that if direct shear tests are run on soils with low hydraulic conductivity at adequately quick shear displacement rates, saturated specimens can be sheared to failure without noteworthy volume change. It ought to be stressed without active or passive control of volume change amid the direct shear test, it does not seem to be conceivable to gain a steady volume condition in the specimen.

A universally undrained condition is not accomplished due to measurable void ratio change amongst the test. Thus, direct shear tests run at fast quick displacement rates can, best case scenario, just give an approximation of undrained strength [19]. To compare the results of shear strength, Unconfined compression tests (UCS) were additionally performed on mixed samples.

4. RESULTS

In this section, the effects of CG on different geotechnical properties of the mixes are presented. Firstly, Fig. 4 indicates the variations of hydraulic conductivity test of different percentages of CG-K mixture. As it can be seen, the more the crushed glass particles percentage, the higher the amount of permeability coefficient in soil was observed. This trend was obviously because of the texture of CG that changes the behavior of soil with increasing the void ratio. Obviously, when the CG increased more than 30%, the coefficient of permeability raised significantly. As it can be seen in Fig. 5, the Optimum Moisture Content (OMC) of the CG-K mixture value was reached to its highest amount of 18.35% with 10% addition of crushed glass with Kaolinite. The more the crushed glass percentages, the less the water need to be added to make the soil saturated.

In addition, in terms of Maximum Dry Density (MDD), it is clear from Fig. 6 that the more the crushed glass percentages, the higher the dry unit weight was achieved. There is an increment in MDD of pure clay with 1.6 Mg/m^3 compared to 1.908 Mg/m^3 with 50% of CG.

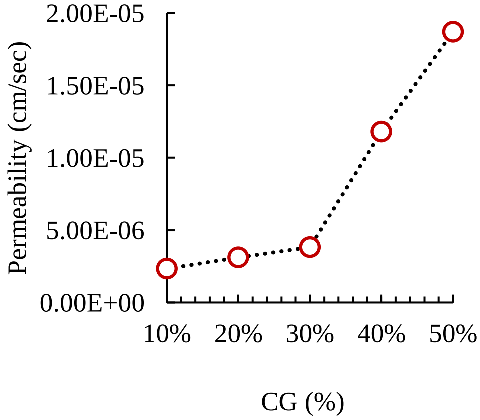

Fig.4 Effect of CG on permeability of the mixtures

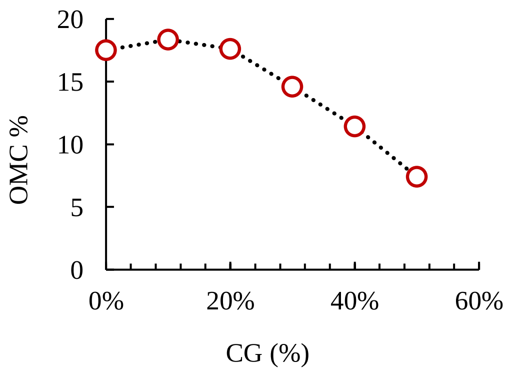

Fig.5 Effect of CG on permeability of the mixtures

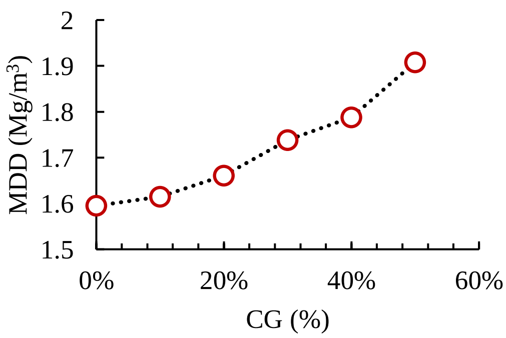

Fig.6 Effect of CG on MDD of the mixtures

Several tests were performed to evaluate the effects of CG on the friction angle. It was estimated that the CG could increase the friction angle of the samples and the behavior of the samples was expected to be changed from cohesion soil to granular soil. For instance, Fig. 7 shows a Direct Shear (DS) test on the mixed samples with CG. As it can be seen in Fig. 8, the changes in internal friction angle and amount of cohesion in the mixture is indicated that the more the percentages of crushed glass, the more the shear strength is in the soil. Moreover, the addition of 50% of CG, make the internal friction angle became doubled by 25° while for the 10% of CG is 12°.

Fig. 7 DS test on the mixed Kaolinite with CG

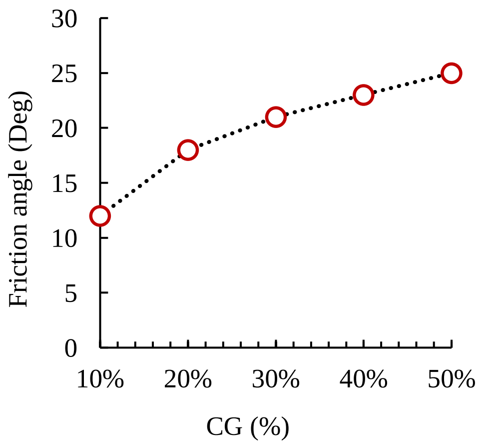

Fig. 8 Effect of CG on friction angle of the mixtures

Furthermore, for the details of DS tests and the relationship between shear stress with the normal stress for various percentages of CG is presented in Fig. 9. To compare the cohesion of the mixed samples, Unconfined compression was conducted and results were presented in Fig. 10. As it clear, both tests resulted in same trends.

4.1 The Relationship Between Stress and Strain.

The axial strain is the vertical change in length based on the total length in terms of percentage. Unconfined compression strength test was conducted in the view of the soil structure will be failed in one direction only. The stress when the soil starts to fail is considered as the maximum compression strength of the soil structure that the soil can sustain before it failed.

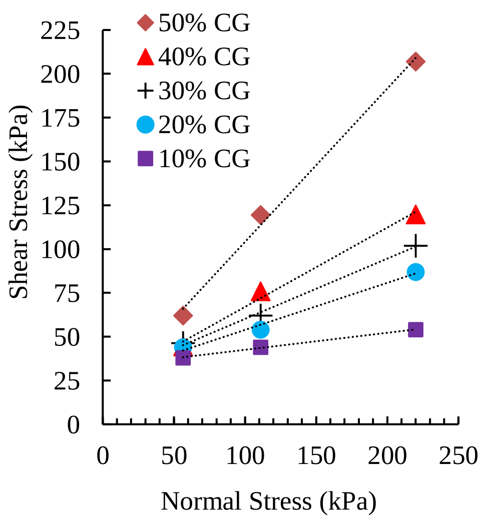

Fig. 9 Shear stress with the normal stress data for various percentages of crushed glass mixed with kaolinite S300

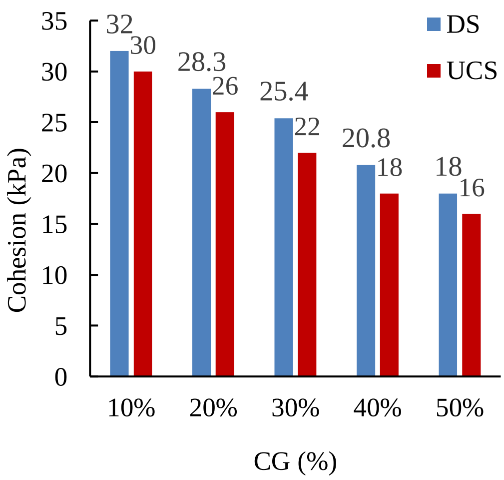

Fig. 10 Comparison of cohesion of mixtures in DS & UCS tests

Unconfined compression strength (UCS) Test is used to determine the soil properties which is as stated in ASTM D2166 - 00 [20], obtain the cohesion, "c", and friction angle, "φ", of the soil. Internal friction angle, "φ", is one of the factor in differentiating the flow characteristics behavior of granular materials [21]. All in all, Fig. 11 illustrates different types of failure modes in UCS tests.

Table 3 shows the data stress and axial strain obtained after the test was conducted. Fig. 12 shows the relationship of axial strain versus stress obtained for the various percentage of crushed glass added. The axial strain is proportional to the stress of the soil for all percentage tested.

Fig. 11 Failure modes samples in UCS tests

Table 3 Stress and Strain obtained at various percentages of Crushed Glass

Item	0% CG	10% CG	20% CG	30% CG	40% CG	50% CG
Strain (%)	0.41	0.24	0.43	0.25	0.25	1.42
Stress (kPa)	6	5	7	5	5	21

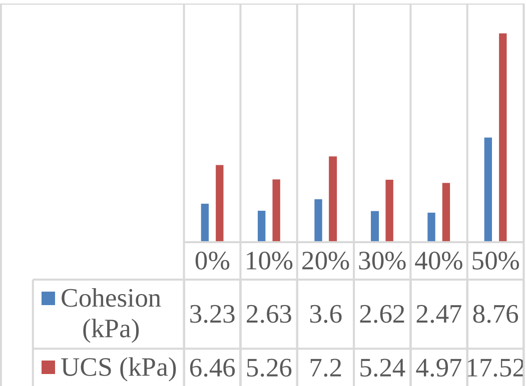

Fig. 12 Strain vs Stress with various percentages of Crushed Glass

There are three soil samples that can sustain 5kPa load applied per unit area which is 10% CG, 30% CG and 40% CG. At 10% CG, the soil sample undergoes 0.24% axial strain before it failed meanwhile at 30% CG and 40% CG, the soils happened to undergo the same deformation which is at 0.25%. Besides, at 50% CG added, the soils happened to give a maximum stress at 21 kPa but happened to have high axial strain percentage at 1.42%. Therefore, the maximum stress that the soil can sustain is 21kPa at 50% CG added compared to 0% CG which is 6kPa. Unfortunately, at 50% CG, the soil happened to undergo high axial strain which is 1.42% meanwhile 0% CG only happened to undergo 0.41% strain.

5. CONCLUSION

This study evaluated the effects of various percentages of crushed curbside-collected glass (CG) on the geotechnical characteristics of Kaolinite soil. The following conclusions can be drawn from the present study:

a) The permeability of Kaolinite-CG samples increased significantly when mixed with different dosages of CG. Therefore, using this material can be useful in the drainage process.
b) Results of compaction tests indicated that the OMC of Kaolinite-CG samples decreased by the presence of CG, while CG raised the MDD.
c) The results of unconfined compression strength (UCS) and direct shear (DS) tests revealed that shear strength parameters of the Kaolinite-CG samples (cohesion and friction angle) increased considerably when different dosages of CG were used. Therefore, the results of this study introduced the presence of CG as a suitable material to increase the bearing capacity of the Kaolinite soil.

6. ACKNOWLEDGEMENTS

The authors would like to express their appreciation to the Faculty of Civil Engineering (FKA), Universiti Teknologi Malaysia (UTM) for their cooperation and facilitation for this research. Also, many thanks to Geotechnical Engineering laboratory staff for their assistance.

7. REFERENCES

[1] Abdallah S. and Fan M., Characteristics of Concrete With Waste Glass as a Fine Aggregate Replacement, Int. J. Eng. Tech. Res., vol. 2, no. 6, 2014, pp. 11–17.

[2] Yunping X., Li Y., Xie Z., and Lee J. S., Utilization of Solid Wastes (Waste Glass and Rubber Particles) as Aggregates in Concrete, Int. Work. Sustain. Dev. Concr. Technol. Beijing, 2004, pp. 45–54.

[3] Fulton B., Hogan F., Use of Recycled Glass in Pavement Aggregate Sustainability, 2008, pp. 1–8.

[4] EPA, Municipal solid waste generation, recycling, and disposal in the United States: facts and figures for 2012, 2014.

[5] Clean Washington Center, Glass Feedstock Evaluation Project Engineering Suitability Evaluation., June 1994.

[6] Shin C. J., and Sonntag V., Using recovered glass as construction aggregate feedstock, Transp. Res. Rec., no. 1437, 1994.
[7] Hagerty M. M., Hite D. R., Ullrich C. R., and Hagerty D. J., One-dimensional high-pressure compression of granular media, J. of Geotech. Eng., vol. 119, no. 1, 1993, pp. 1–18.
[8] Wartman J., Grubb D. G., and Nasim S. M., Select Engineering Characteristics of Crushed Glass, J. of Mater. Civ. Eng., vol. 16, no. 6, 2004, pp. 526–539.
[9] Grubb D. G., Davis A. F., Sands S. C., Carnivale M. III, Wartman J., and Gallagher P. M., Field evaluation of crushed glass-dredged material blends, J. Geotech. geoenvironmental Eng., vol. 132, no. 5, 2006, pp. 577–590.
[10]ASTM D854-14, Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer, ASTM Int. West Conshohocken, PA, 2014.
[11]ASTM C136 / C136M-14, Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates, ASTM Int. West Conshohocken, PA, 2014.
[12]ASTM D4318-17, Standard test methods for Liquid Limit, Plastic Limit, and Plasticity Index of soils, ASTM Int. West Conshohocken, PA, 2017.
[13]ASTM D5084-03, Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter, ASTM Int. West Conshohocken, PA,2003.
[14]ASTM D698-07e1, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft3 (600 kN-m/m3)), ASTM Int. West Conshohocken, PA, 2007.
[15]Bowles J. E., Engineering Properties of Soils and Their measurement, 4th edition, McGraw-Hill, Inc, 1992, No. 187 pp.
[16]Dyvik R., Berre T., Lacasse S., and Raadim B., Comparison of Truly Undrained and Constant Volume Direct Simple Shear Tests, Geotechnique, vol. 37, no. 1,1987 pp. 3–10.
[17]Lambe T. W., Soil Testing for Engineers, John Wiley and Sons, Inc, 1951.
[18]Liu C., Evett J. B., Soil Properties: Testing, Measurement and Evaluation. Prentice-Hall, Inc., 1984.
[19]Bro A., Stewart J., and Pradel D., Estimating Undrained Strength of Clays from Direct Shear Testing at Fast Displacement Rates,2013, pp. 1–14.
[20]ASTM D2166 / D2166M-16, Standard Test Method for the Unconfined Compressive Strength of Cohesive Soil," Annu. B. ASTM Stand. ASTM Int. West Conshohocken, PA, 2016.
[21]Guo Z., Chen X., Xu Y., and Liu H., Effect of Granular Shape on the Angle of Internal Friction of Binary Granular System, Fuel, vol. 150, 2015 pp. 298–304.