International Journal of GEOMATE, July, 2022, Vol.23, Issue 95, pp.10-19
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2022.95.3391
Geotechnique, Construction Materials and Environment

SUSTAINABLE IMPROVEMENT OF BENTONITE CLAY CHARACTERISTICS BY ADDING PULVERIZED WASTE GLASS

Madhat Shakir Al-Soud [1], Sabah Hassan Fartosy [1], Aqeel Raheem Jabur [1,] Muhannd Waleed Majeed[1], Huda M. Madhloom [1] and Nadhir Al-ansari[2*]

[1]College of Engineering, Mustansiriyah University, Baghdad, Iraq;
[2]Lulea University of Technology, Sweden

*Corresponding Author, Received: 31 March. 2022, Revised: 30 April. 2022, Accepted: 28 May 2022

ABSTRACT: Bentonite clay is the soil that undergoes high volume changes (swelling) when its moisture content increases. The soil swelling may cause structural damage leading to damage to structural members like cracking in reinforced foundations and borders, curbs swelling, and eventually produces deformation indoors and on floors. In this study, Bentonite clay with expansive characteristics was used and mixed with various amounts of Pulverized waste glass PWG (0%, 5%, 10%, and 15%). Two types of PWG were prepared: fine glass (passing sieve No. 200) and coarse glass (passing sieve No. 2 mm). Laboratory experiments were performed on Bentonite specimens blended with different amounts of PWG. The results showed that the addition of 15% by Bentonite weight of 2 mm of PWG reduces the Atterberg limits considerably. Moreover, a noticeable reduction was observed in the Bentonite samples' free swell and swelling pressure after being treated with different amounts of PWG. The observed advantages of adding the PWG to Bentonite clay soil by decreasing the volume changes and enhancing the overall properties of Bentonite clay reflect the suitability of using PGW as a good soil stabilizer. Besides reducing the impact of waste glass on the environment due to its non-biodegradable nature.

Keywords: Bentonite clay, Pulverized waste glass, Expansive clay, Swelling pressure

1. INTRODUCTION

Globally, many large civil engineering projects are constructed every year that consume huge quantities of soil. In most situations, the desired soil required to use as a construction material is located far from the site projects and its transportation represents a great challenge. When a site investigation reveals the existence of unpreferable soils such as expansive soils with high-plasticity clay, it is essential to set a suitable scheme to enhance the soil engineering characteristics [1, 2, 3, 4, 5, 6, 7]. For example, Bentonite clay is a common expansive soil that undergoes high volume changes (eight times its original volume) when the moisture content increases which may cause structural damage lead to damage to the structural members like cracking in reinforced foundations and borders, curbs swelling and eventually produces deformation indoors and floors [8, 9, 10]. These deformations can be distinguished into three categories light, moderate, and sed on swelling amounts. The research in expansive soil received more attention over time and was considered a new study field in soil mechanics [11, 12, 13]. The existence of expansive soil to a wide extent around the world, and its potential serious impacts on the structures such as highway-subgrade, highway-fills, buildings footings, canal linings, and other structures enforces the countries to set suitable procedures to reduce the negative impacts of this kind of soils [14, 15].

The choice of selecting the most feasible technique of ground improvement depends principally on soil conditions, type of structure, settlement, and environmental considerations [16]. The creation of long-lasting structures and infrastructures is a major task for civil engineers. Environmentally friendly and cost-effective solutions can be used by geotechnical engineers as part of civil engineering's efforts to promote sustainable growth in the building sector. Cement kiln dust (CKD) [17, 18], fly ash [19, 20], waste tire [1, 3], Granulated Blast Furnace Slag [14, 43], Sawdust ash [21, 22], Rice Husk [23, 24], waste plastic [25, 26] and other alternative materials have been proposed for sustainable ground improvement and soil reinforcement.

In Iraq, large amounts of waste glasses that produced daily with no effective way to recycle or to reduce the great negative impact of this type of waste on the environment [27]. Thus, it is significant to use the produced and accumulated waste glasses for applications that can make a big difference for humans. One of these applications is using waste glasses to improve expansive soils that exist on project sites by enhancing their mechanical properties besides protecting the environment. The high shear strength of recycled glass particles has revealed that they are appropriate materials in different geotechnical projects; for example, embankment fills [28, 29], and earth-retaining structures [30].

2. PAST RELATED STUDIES

Several studies have recently demonstrated the effectiveness of using waste glass in the stabilization of expansive soil. The findings of these studies report an improvement in Atterberg limits, maximum dry density (MDD), optimum-moisture content (OMC), unconfined compressive strength (UCS), California bearing ratio (CBR), characteristics, and consolidation when adding waste glass to use as a stabilizer [31, 32, 33, 34, 35, 36]. Ikara et al. [31] found that the plasticity index of cement-stabilized expansive soil decreased with increasing amounts of waste glass. Canakci et al. [32] used waste soda-lime glass powder to examine the effect on the consistency and strength of clayey soil. The observed results show that the optimum glass content was 12% and no further improvement was achieved. Attom [33] used two cement contents (5% and 10%) with four contents of crushed waste glass CWG (2.5%, 5%, 7.5%, and 10%) to investigate the effect of these mixtures on the swelling pressure of clayey soil. The results showed that CWG and the cement effectively reduced swelling potential. Ibrahim et al. [34] used various percentages of waste glass powder WGP (3%, 6%, 9%, 12%, 15%, 18%, 27%, and 36%) to stabilize the expansive soil. The highest UCS was achieved at a glass powder content of 27% and reduced with further increments. The compression index decreased and the rebound index remained constant with increasing WGP.

Babatunde et. al, [35] studied the influence of WGP content (i.e., 2.0%, 4.0%, 6.0%, and 8.0%) by dry weight of soil on the engineering characteristics of a soil type black cotton. The optimum values for the UCS and CBR tests were achieved at WGP equal to 4%. Blayi et al. [36] used WGP content ranges from (2.5 % - 25 %) of the soil dry-weight. A significant decrease in Atterberg's limits, free swell, and the cohesion of mixtures was observed while the angle of internal friction was increased at a WGP of 25%. The UCS and MDD have reached their maximum values at PWG of 15%.

3. RESEARCH SIGNIFICANCE

This research aims to study the influence of adding PWG (passing from sieves No.200 and No.2) in different percentages (0%, 5%, 10%, and 15%) of soil weight on the Bentonite properties including consistency limits, compaction characteristics, compressibility, shear strength, and swelling. properties. The research findings show the suitability of using the coarse and fine PWG as a good stabilizer by enhancing the overall properties of Bentonite clay soil**.** Besides reducing the impact of waste glass on the environment due to its non-biodegradable nature.

4. MATERIALS AND METHODS

4.1 Soil

The Bentonite clay (98% passing through sieve No.200) utilized in this research is a natural-soil, obtained from Kirkuk province by the State Company of Geological Survey and Mining, which is located in Baghdad city. It is supplied as a powder packed in 25.0 Kg. bags. The summarized results of tested Bentonite specimens are shown in Table 1.

Table 1 Physical properties and test methods of Bentonite clay specimens.

Property.	Value.	Standard-method
Liquid-limit %	163	ASTM: D4318
Plastic-limit %	65	ASTM: D4318
Plasticity-Index %	98	ASTM: D4318
Specific gravity	2.84	ASTM: D854-14
Maximum dry-density (kg/m^3)	15.1	BS:1377:1975,Test 12
Optimum-moisture content %	29.8	BS:1377:1975,Test 12
% Passing sieve No. 200	98	ASTM, D422-63
Soil classification based on Unified Soil Classification System	CH	ASTM D2487-17

The grain-size dispersal test (sieve-analysis) was performed on Bentonite clay according to (ASTM: D422-72) and revealed that 98.0% of the Bentonite particles passed a sieve of 0.075 mm. The chemical compositions of the Bentonite clay are shown in Table 2.

Distilled water was utilized to conduct all tests in this research and to prepare all samples before testing. This is to ensure that the mixed properties will not be influenced by unwanted ingredients that exist in ordinary water.

4.2 Waste Glass material

The waste glass used in this research was obtained from a local provider and pulverized using a grinding machine into two sizes (group A passing from sieve No.200 and group B passing from sieve No. 2) as shown in Fig. 1.

Table 2 Chemical composition of Bentonite clay specimen.

Property	Property value
T.S.S %	7.3
SO_3 %	0.41
Gypsum %	0.98
pH	8
Montmorillonite %	70
CEC meq/100 gm	65
CaO %	5.5
SiO_2 %	57
Al_2O_3 %	13.5
Fe_2O_3 %	5.5

Table 3 shows the chemical properties of the PWG used in this study. The tests were conducted using laboratories that belong to the State Company of Geological Survey and Mining. The chemical test results reveal that the PWG contains a higher amount of silica which is needed to reduce the swelling characteristics of Bentonite soil.

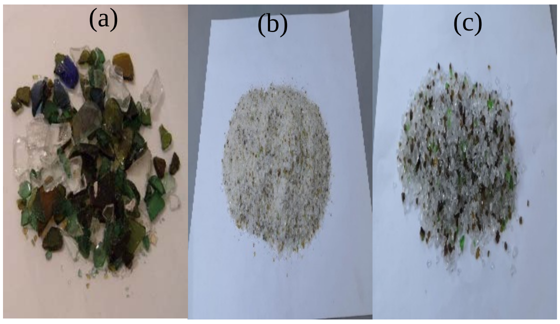

Fig. 1 Waste glass preparations; a) raw waste glass, b) fine PWG (group A) passing sieve No. 200, c) coarse PWG (group B) passing sieve No. 2.

Table 3 Chemical compositions of the pulverized waste glass PWG*

Silica Oxide	75%
Aluminum Oxide	2%
Calcium Oxide	6%
Magnesium Oxide	2%
Sodium Oxide	15%

* Supplied by the State Company of Geological Survey and Mining.

4.3 Test Devices

Some of the experiments were implemented on Bentonite soil without adding any PWG (intact sample 0%), whereas the remaining tests were carried out on Bentonite blended with different amounts of PWG (5%, 10%, and 15%) by weight of the PWG that passed through two types of sieves: No. 2 and No.200. Before the mixing process, the soil was dried using an oven over (105 C^o) for a while one day. To investigate the properties of the Bentonite specimens that blended with PWG groups, different test devices were used to conduct the Atterberg limits test, shear tests, swelling tests, and compaction tests. Furthermore, a scanning electron microscope (SEM) was used in this study to obtain 2-dimensional high-resolution images and to measure the particle size for Bentonite clay mixed with PWG groups. Figure 2 shows a photograph of the SEM device used in this research, which is available in the department of applied science, University of Technology.

Fig. 2 Photograph of the scanning electron microscope (SEM) Inspects S50.

5. RESULTS AND DISCUSSION:

5.1 Effect of Pulverized Waste Glass PWG on Consistency Characteristics

Representative electronic images with two scales (50 μm and 500 μm) of Bentonite clay specimens that were treated with three fine percentages of PWG are shown in Fig. 3. The treated specimen with a higher PWG percentage of 15%, shows a smooth surface with a dense packing. As can be seen in Fig. 3 (a3 and b3), the voids between Bentonite clay particles are filled with the PWG, which enhances significantly the engineering properties of Bentonite. Finally, the potential swelling behavior of Bentonite clay is reduced because adding PWG reduces the amount of water that can infiltrate to fill the gaps between clay particles to fill, causing less volume for water to fill and producing swelling.

On the other hand, the PL and LL of the stabilized Bentonite clay using different percentages of two groups of PWG (0%, 5%, 10%, and 15%) were obtained per the standard ASTM D4318, using the cone penetration method. Figure 4 shows the relations between the percentages of the PWG passing sieves No. 200 and No. 2 (groups A and B) that mixed with the Bentonite clay and their influence on PL, LL, and PI. Examining the figure reveals that LL, PL, and PI for the two groups decrease as the percentages of PWG increase. This can be attributed to the significant amount of silica existing in the PWG that behaves as a material with no cohesion, which substitutes an amount of plastic soil for Bentonite clay and impacts the reduction in water absorption. Consequently, the LL, PL, and PI are decreased [37].

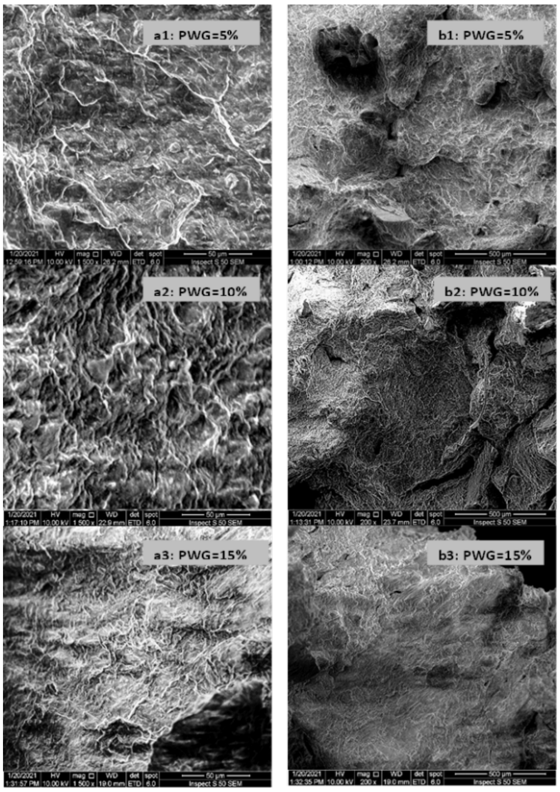

Fig. 3 Scanning electron microscopy images of the Bentonite clay specimens treated with PWG passing N.200; a1-a3) scale 50 µm, b1-b3) scale 500 µm.

Group A of PWG that passed sieve No. 2 (coarse appearance) reduces LL, PL, and PI more than group B (fine appearance). Roy [38] made a direct relation between MDD of expansive soil and the size of sand grains used as a stabilizer. Figure 4 also shows that LL., PL., and PI. are nearly stable when mixed with 15% of the PWG for both groups, which can be considered the optimum percentage of waste glass required to stabilize Bentonite clay.

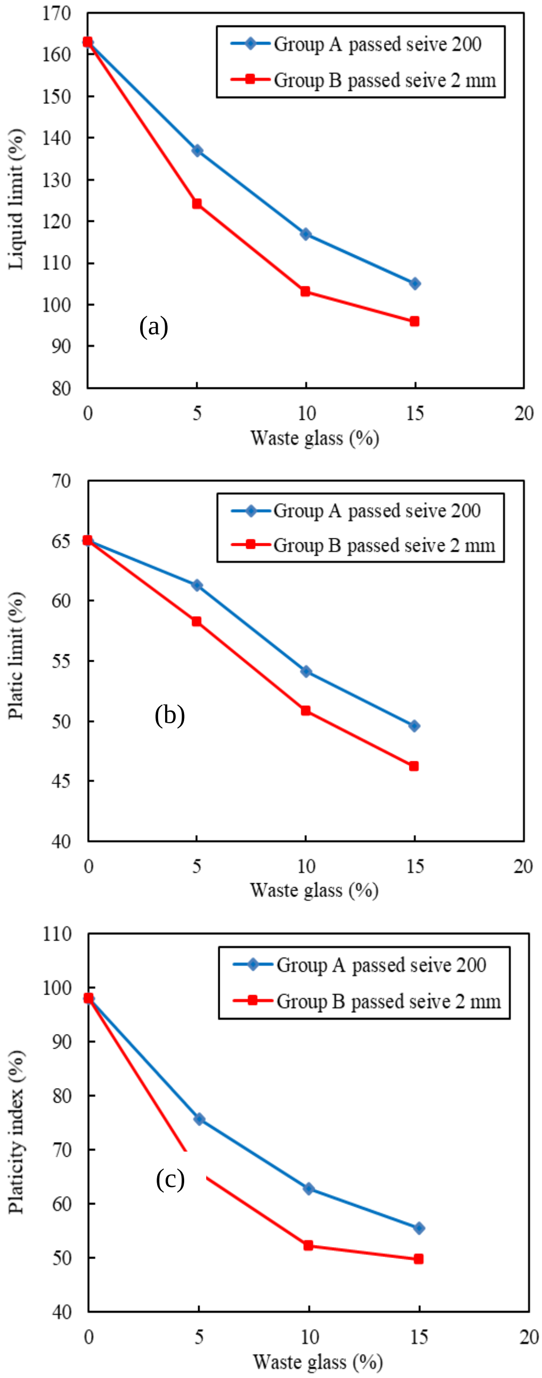

Fig. 4 Effect of PWG on the Atterberg-limits of treated Bentonite.

Furthermore, the observed reduction percentages in LL, PL, and PI after adding 15% percentage of PWG for group A were 35%, 24%, and 43%, while for group B were 41%, 29%, and 49%, respectively, as shown in Table 4. The gradual reduction in Atterberg limits can be attributed to the larger content of non-reactive silica and smaller content of calcium oxide [39].

5.2 Effect of Pulverized Waste Glass PWG on Specific Gravity (Gs)

The specific gravity of the PWG used in this research was found to be (G_s= 2.54). Figure 5 illustrates the variation in specific gravity to Bentonite soil that blended with various amounts of PWG. The observed values for both groups of the PWG show a gradual decrease as the PWG percentage increases. In addition, Group B (coarse PWG) shows lower values of specific gravity than group A (fine PWG). The average values were found to be 2.73 (group A) and 2.67 (group B), respectively.

Table 4 Values of L.L., P.L., and P.I. of Bentonite clay and PWG mixes.

Sieve No.	PWG (%)	Liquid-limit LL. (%)	Plastic-limit P.L. (%)	Plasticity-index PI. (%)
Group A (N0. 200)	0.0	163	65	98
	5	137	61.29	75.71
	10	117	54.13	62.85
	15	105	49.58	55.42
Group B (No. 2)	0.0	163	65	98
	5	124	58.3	65.7
	10	103	50.81	52.19
	15	96	46.21	49.79

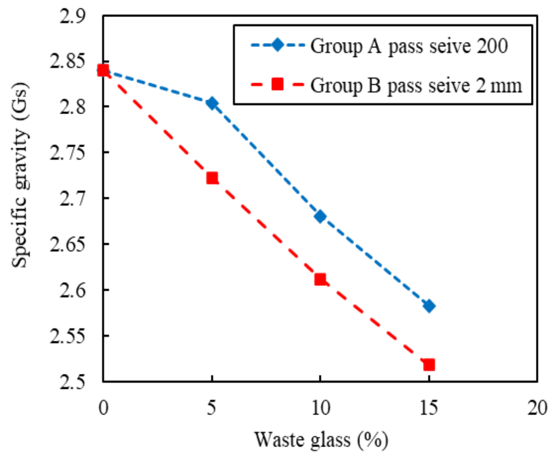

Fig. 5 Specific gravity versus percentage PWG of treated Bentonite.

5.2 Effect of Pulverized Waste Glass PWG on Specific Gravity (Gs)

The specific gravity of the PWG used in this research was found to be (G_s= 2.54). Figure 5 illustrates the variation in specific gravity to Bentonite soil that blended with various amounts of PWG. The observed values for both groups of the PWG show a gradual decrease as the PWG percentage increases. In addition, Group B (coarse PWG) shows lower values of specific gravity than group A (fine PWG). The average values were found to be 2.73 (group A) and 2.67 (group B), respectively.

5.3 Effect of Pulverized Waste Glass PWG on the Dry Density- Moisture Relationships

Figure 6 shows the relations between dry density and water contents of groups A and B with different percentages of PWG obtained using standard Procter tests. A considerable improvement in compaction properties of Bentonite soil with adding gradually more PWG irrespective of glass size particles.

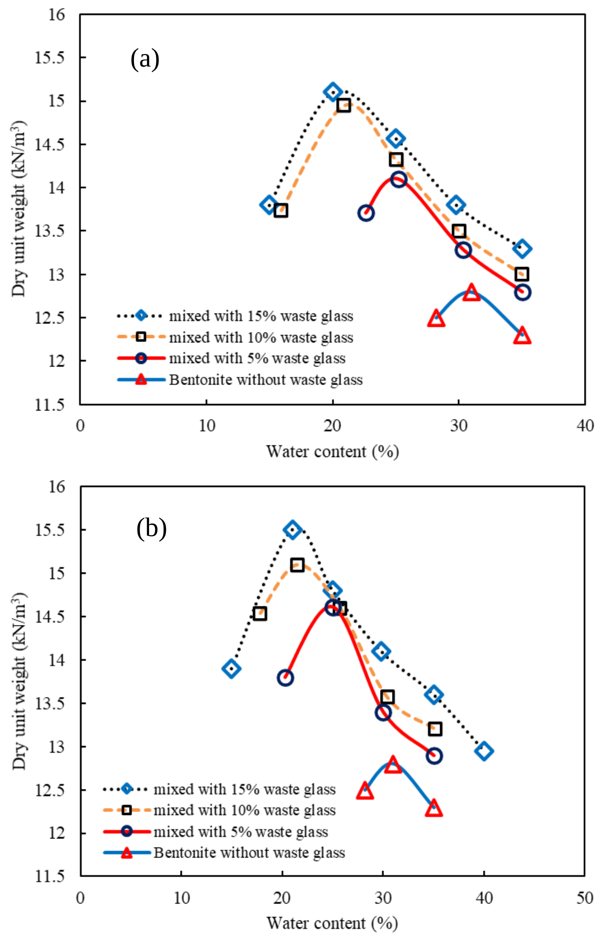

Fig. 6 Effect of adding PWG on moisture-dry density relationships a) group A, fine PWG b) group B, coarse PWG.

For group A, Fig. (6-a) which represents Bentonite clay mixed with fine PWG; the values of dry density increase and water contents decrease as the percentage of PWG increases. A similar trend was observed with the results of group B, which represents Bentonite clay mixed with coarse PWG (Fig. 6-b). The increase in the values of MDD. This is because of the replacement of clay particles with silica, which represents the major component of the PWG. Moreover, the added PWG reduces the specific surface of the Bentonite clay mixture, which leads to a decrease in the OMC, [8, 37]. Table 5 summarizes the values of the maximum dry density (MDD) and optimum moisture contents (OMC) for all specimens tested in this study, as well as, the reduction ratios.

These obtained results are in good match with [32, 40]. Figures 7 and 8 show the MDD and OMC versus the percentage of PWG in groups A and B. The gradual addition of PWG to the bentonite increases the MDD from 12.5 kg/m^3 to 15.1 kg/m^3 (group A) and 15.5 kg/m^3 (group B). Also, the OMC for both groups reduces roughly from 32% to around 20% as the PWG reaches 15%.

5.4 Effect of Pulverized Waste Glass PWG on Free Swell Characteristics

The test was carried out on Bentonite clay mixed with different percentages of PWG (0%, 5%, 10%, and 15%) and passed through two sieves (No. 200 and No 2).

Table 5: Variations in maximum dry unit weight and optimum moisture contents of Bentonite clay mixed with PWG mixes.

Sieve No.	PWG (%)	MDD (kN/m^3)	O.M.C (%)
Group A (No. 200)	0.0	12.8	31
	5	14.10	25.2
	10	14.95	20.9
	15	15.1	20
Group B (No. 2)	0.0	12.8	31
	5	14.61	25
	10	15.1	21.5
	15	15.5	21

Each Bentonite clay specimen was statically compacted inside a consolidation ring with an internal diameter of 75.0 mm and depth of 19.0 mm using compression equipment. The height of the extracted sample was set to be 7.0 mm smaller than the ring consolidation height to confirm that the sample specimen would not move laterally and remain stable during the swelling. The inside of the ring was coated with oil to reduce the influence of friction. After that, the specimen was kept submerged underwater and allowed to swell normally.

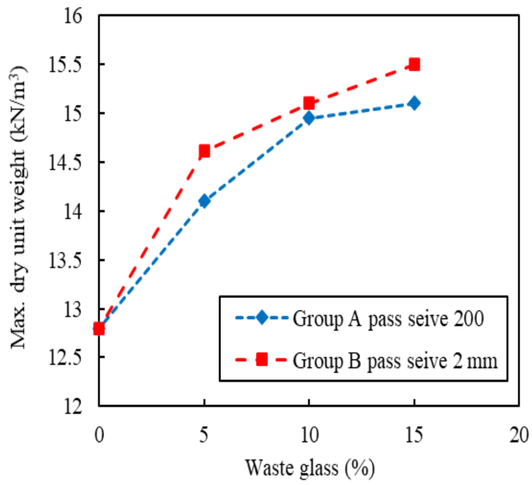

Fig. 7 Maximum dry-unit weight (MDD) versus the percentages of PWG treated Bentonite specimens).

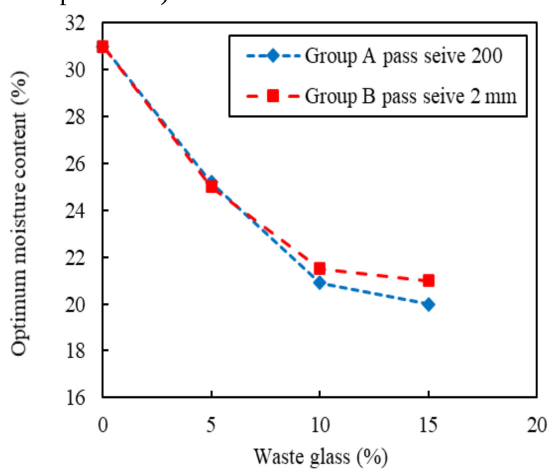

Fig. 8 Optimum-moisture content (OMC) versus percentage of PWG (treated Bentonite specimens).

Then, the change in specimen thickness was recorded by using a dial-gauge of 0.0010 mm/div. The standard ASTM: D4546 was followed to conduct this test. Figure 9 shows values of measured free swelling versus percentage of PWG.

The maximum value of free swell belongs to the untreated bentonite. The gradual replacement of bentonite clay with a non-swelling material such as PWG leads to a decrease in the free swell values of the treated clay. Furthermore, the results reveal that coarse PWG causes a greater reduction in swelling than fine PWG. The free swell of untreated bentonite is 7 and reaches 5.62 for groups A and 4.31 for group B at a PWG of 15%. These findings are compatible with [39] and [42].

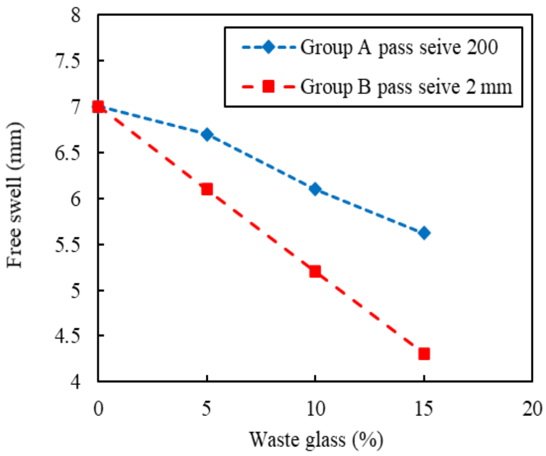

Fig. 9 Free swell versus percentage of PWG of treated Bentonite.

5.5 Effect of Pulverized Waste Glass (PWG) on Swelling Pressure

Figure 10 shows the effect of adding different percentages of PWG on the swelling pressure of Bentonite clay. It is clear that PWG significantly decreases swelling pressure, which can minimize the risk of using such problematic soil under the building. The swelling pressure of untreated bentonite was 362 kN/m^2 and started to decrease until reaching 162 kN/m^2 at PWG equal to 15%. Mixing the bentonite with a non-swelling material such as PWG leads to a decrease in the free swell and therefore, the swelling pressure is decreased [43]. This figure also shows that group B is more efficient than group A; i.e., the coarser the PWG particles are the more effective on swelling pressure.

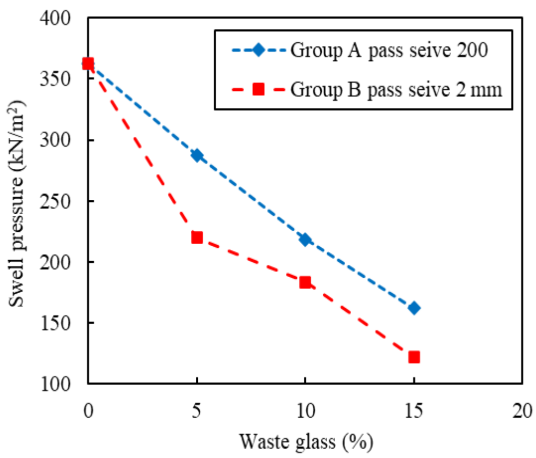

Fig 10 Swelling pressure versus percentage of PWG of treated Bentonite.

Thus, mixing the bentonite clay with 15% of PWG causes a reduction in swelling pressure from 362 kN/m^2 to 122 kN/m^2. Bahia [41] mentioned that using coarse sand decreases the swelling potential and swelling pressure due to large voids within the expansive clay.

5.6 Effect of Pulverized Waste Glass PWG on Bentonite Strength Properties

Direct shear tests were conducted on Bentonite clay treated with several percentages of PWG at the predetermined values of MDD and OMC. Figures 11 and 12 show the relationship between the parameters of shear strength (cohesion (c) and internal friction angle (ϕ)) versus percentages of PWG. In Fig. 11, the observed results of both groups show that cohesion decreases as the percentage of PWG increases. While Fig. 12 shows a gradual increase in internal friction angle as the PWG amount increases.

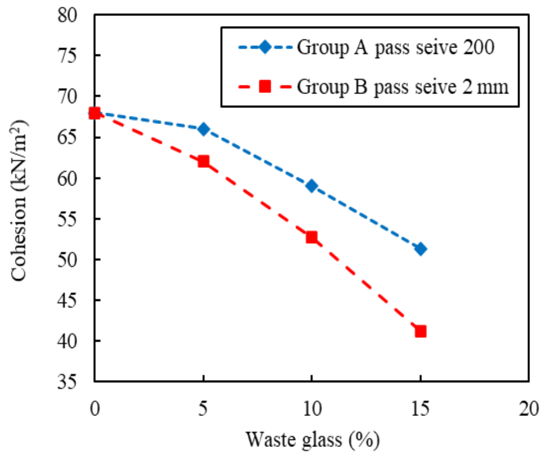

Fig. 11 Cohesion (c) versus percentage of PWG of treated Bentonite.

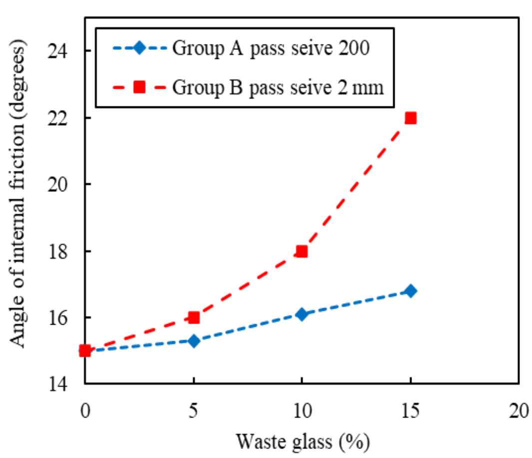

Fig. 12 Angle of internal friction (ϕ) versus percentage of PWG of treated Bentonite.

One can notice that the coarse PWG is mostly more efficient in reducing cohesion and increasing the angle of internal friction of bentonite clay than the fine PWG. The increase in friction angle values ranged from (15^o to 16.8^o) for group A and (15^o to 22^o) for group B at 15% of PWG. This may be related to the reduction in voids between clay particles due to the increase in MDD of the Bentonite mixtures [8]. On the other hand, the reduction in the cohesion of Bentonite mixtures after adding PWG is because of the higher amount of silica that causes PWG to behave as cohesionless waste material. A coarser fraction of PWG was found to be more efficient in reducing cohesion.

6 CONCLUSIONS

Two groups of pulverized waste glass PWG (group A passing through sieve No. 200 and group B passing through sieve No. 2) of different percentages (0%, 5%, 10%, and 15%) were mixed with Bentonite clay to study the influence of adding waste glass on the engineering properties of Bentonite clay. Several tests were performed on Bentonite soil without adding any waste glass (intact sample 0%), while the other experiments were performed on Bentonite soil with various amounts of PWG that passed through two types of sieves: No. 2 and No. 200.

The following are concluded based on the obtained results in this study:

1- The addition of fine and coarse PWG increases the plastic limit and decreases the liquid limit and plasticity index of Bentonite clay.
2- The values of observed specific gravity for both groups of the PWG show a gradual decrease as the waste glass percentage increases.
3- The gradual addition of both PWG groups to Bentonite clay causes the maximum dry density to increase and reduces the optimum moisture content.
4- The addition of PWG decreases the free-swelling and swelling-pressure of Bentonite; the reduction in free-swelling after adding 15% of fine and coarse PWG were 20% and 38%, respectively. While the reduction in swelling-pressure was 55% and 66%, respectively.
5- A significant increase in the shear strength parameters appeared after treating Bentonite with PWG. The friction angle (ϕ) rises from (15^o to 16.8^o) for group A and from (15^o to 22^o) for group B at 15% of PWG.
6- Generally, the coarse PWG is more efficient in enhancing Bentonite clay properties than fine PWG.
7- The research findings show the suitability of using PWG as a good soil stabilizer besides the advantages of reducing the impact of waste glass on the environment due to its non-biodegradable nature.

7 ACKNOWLEDGMENTS

The authors would like to appreciate the great support they received from Mustansiriyah University during the present work. (www.uomustansiriyah.edu.iq), Baghdad - Iraq.

8 REFERENCES

[1]. Benny J. R., Jolly J., Sebastian J. M., and Thomas M., Effect of glass powder on engineering properties of clayey soil. International Journal of Engineering Research & Technology, Vol.6, Issue 5, 2017, pp. 228-231.

[2]. Bhuvaneshwari S., Robinson R., and Gandhi S., Micro-fabric and mineralogical studies on the stabilization of expansive soil using inorganic additives. International Journal of Geotechnical Engineering, Vol.4, Issue 3, 2010, pp. 395-405.

[3]. Chowdhury R. H., Swell–Shrink–Consolidation Behavior of Compacted Expansive Clays AU - Azam, Shahid. International Journal of Geotechnical Engineering, Vol. 7, Issue 4, 2013, pp.424–430.

[4]. Rogers J. D., Olshansky R., and Rogers R. B., Damage to foundations from expansive soils. Claims People, Vol 3, Issue 4, 1993, pp. 1-4.

[5]. Seco A., Ramírez F., Miqueleiz L., and García B., Stabilization of expansive soils for use in construction. Applied Clay Science, Vol. 51, Issue 3, 2011, pp. 348-52.

[6]. Thyagaraj T., and Suresh P., In-situ stabilization of expansive soil in a desiccated state. International Journal of Geotechnical Engineering, Vol. 6, Issue 3, 2012, pp. 287-96.

[7]. Thyagaraj T., Samuel Z., and Kumar K.S., Relative efficiencies of electrolytes in the stabilization of expansive soil. International Journal of Geotechnical Engineering, Vol. 10, Issue 2, 2016, pp. 107-113.

[8]. Bilgen G., Utilization of powdered glass as an additive in clayey soils. Geotechnical and geological engineering, Vol. 38, Issue 3, 2020, pp. 3163-73.

[9]. Khademi F., and Budiman J., Expansive soil: causes and treatments, i-Manager's Journal on Civil Engineering, Vol. 6, Issue 3, 2016, pp. 1-14.

[10]. Lucian C., Geotechnical aspects of buildings on expansive soils in Kibaha. Tanzania: a preliminary study (Doctoral dissertation, KTH), 2006.

[11]. Al-Rawas A.A., and Goosen M.F.A., Expansive Soils: Recent Advances in Characterization and Treatment (1st ed.), CRC Press, 2006.

[12]. Chen F. H., Foundations on expansive soils,

Elsevier, 1975.
[13]. Rai A. K., Singh G., and Tiwari A. K., Comparative study of soil stabilization with glass powder, plastic and e-waste: A review. Materials Today: Proceedings, Vol. 32, Issue 3, 2020, pp. 771-776.
[14]. Mahdi Z., and Al-Hassnawi N., Assessment of subgrade soil improvement by waste glass powder. International Journal of Civil Engineering and Technology, Vol. 9, Issue 10, 2018, pp. 12-21.
[15]. Nelson J. D., Chao K. C., Overton D. D., and Nelson E. J., Foundation engineering for expansive soils, John Wiley & Sons, 2015.
[16]. Dalaly N.K., Al-Soud M.S., and Abdul Jabar S.S., A new technique of strengthening soft soil under a strip footing by a granular trench reinforced with geogrid micro mesh. Australian Journal of Civil Engineering, Vol 13, Issue 1, 2015, pp. 11–21.
[17]. Salahudeen A. B., Eberemu A. O., & Osinubi K. J., Assessment of Cement Kiln Dust-Treated Expansive Soil for the Construction of Flexible Pavements. Geotechnical and Geological Engineering, Vol. 32, Issue 4, 2014, pp. 923–931.
[18]. Mosa A. M., Taher A. H., and Al-Jaberi L. A., Improvement of poor subgrade soils using cement kiln dust, Case Studies in Construction Materials. Vol. 7, 2017, pp. 138-143.
[19]. Sharma A. K., and Sivapullaiah P. V., Swelling behaviour of expansive soil treated with fly ash–GGBS based binder. Geomechanics and Geoengineering, Vol. 12, Issue 3, 2017, pp. 191-200.
[20]. Tastan E. O., Edil T. B., Benson C. H., and Aydilek A. H., Stabilization of organic soils with fly ash. Journal of geotechnical and Geoenvironmental Engineering, Vol. 137, Issue 9, 2011, pp. 819-833.
[21]. Abbaspour M., Narani S. S., Aflaki E., Moghadas Nejad F., and Mir Mohammad Hosseini S. M., Strength and swelling properties of a waste tire textile fiber-reinforced expansive soil. Geosynthetics International, Vol.27, Issue 5, 2020, pp. 476-489.
[22]. Al-Bared M. A., Marto A., and Latifi N., Utilization of recycled tiles and tires in the stabilization of soils and production of construction materials–A state-of-the-art review. KSCE Journal of Civil Engineering, Vol.22, Issue 10, 2018, pp. 3860-3874.
[23]. Jain A., Choudhary A. K., and Jha J. N., Influence of rice husk ash on the swelling and strength characteristics of expansive soil. Geotechnical and Geological Engineering, Vol. 38, Issue 2, 2020, pp. 2293-2302.
[24]. Sakr M. A., Omar A. E., Ene A., and Hanfi M. Y., Effect of Various Proportions of Rice Husk Powder on Swelling Soil from New Cairo City, Egypt. Applied Sciences, Vol. 12, Issue 3, 2022, pp. 1616.
[25]. Fadhil S. H., Al-Soud M. S., and Kudadad R. M. Enhancing the Strength of Clay-Sand Mixture by Discrete Waste Plastic Strips. Journal of Applied Science and Engineering, Vol. 24, Issue 3, 2021, pp. 381-391.
[26]. Salimi K., and Ghazavi M., Soil reinforcement and slope stabilization using recycled waste plastic sheets. Geomechanics and Geoengineering, Vol. 16, Issue 6, 2021, pp. 497-508.
[27]. Pascual A. B., Tognonvi M. T., and Tagnit-Hamou, A., Waste glass powder-based alkali-activated mortar. Int. J. Res. Eng. Technol, Vol. 3, Issue 13, 2014, pp. 32-36.
[28]. Disfani M. M., Arulrajah A., Bo M. W., and Hankour R. J. W. M. Recycled crushed glass in road work applications. Waste Management, Vol 31, Issue 11, 2011, pp. 2341-2351.
[29]. Disfani M. M., Arulrajah A., Bo M. W., and Sivakugan N., Environmental risks of using recycled crushed glass in road applications. Journal of Cleaner Production, Vol. 20, Issue 1, 2012, pp. 170-179.
[30]. Grubb D. G., Liu W., Cadden A. W., and Humphrey D. N., Bulkhead design using recycled materials as backfill. In Ports 2007, pp.1-11.
[31]. Ikara I. A., Kundiri A. M., and Mohammed A., Effects of waste glass (WG) on the strength characteristics of cement stabilized expansive soil. American Journal of Engineering Research (AJER), Vol. 4, Issue 11, 2015, pp. 33-41.
[32]. Canakci H., Aram AL., and Celik F., Stabilization of clay with waste soda-lime glass powder. Procedia Engineering, Vol. 161 2016, pp. 600-605.
[33]. Attom M., The use of waste glass material to control soil swelling pressure, Proceedings of International Conference on Technological Challenges for Better World, 2018.
[34]. Ibrahim H. H., Mawlood Y. I., and Alshkane Y. M. Using waste glass powder for stabilizing high-plasticity clay in Erbil city-Iraq. International Journal of Geotechnical Engineering, Vol. 15, Issue 4, 2019, pp. 496-503.
[35]. Babatunde O. A., Sani J. E., and Sambo A. H., Black Cotton Soil Stabilization using Glass Powder. International Journal of Innovative Research in Science Engineering and Technology, 2019, pp. 5208-5214.
[36]. Blayi R. A., Sherwani A. F., Ibrahim H. H., Faraj R. H., and Daraei A., Strength

improvement of expansive soil by utilizing waste glass powder. Case Studies in Construction Materials, Vol.13:e00427, 2020,pp.1-12.

[37]. Nuruzzaman M., and Hossain MA., Effect of soda-lime glass dust on the properties of clayey soil. Global Journal of Research in Engineering, Vol.14, Issue 5, 2014, pp.1-7.

[38]. Roy T.K., Influence of sand on strength characteristics of cohesive soil for using as subgrade of road. Procedia-Social and Behavioral Sciences. Vol. 104, 2013, pp. 218–224.

[39]. Parihar N. S., Garlapati V. K., and Ganguly R., Stabilization of black cotton soil using waste glass. Handbook of Environmental Materials Management, 2018, pp. 1-6.

[40]. Khan M. S., Tufail M., and Mateeullah M., Effects of waste glass powder on the geotechnical properties of loose subsoils. Civil Engineering Journal, Vol. 4, Issue 9, 2018, pp. 2044-2051.

[41]. Bahia L., and Ramdane B., Sand: an additive for stabilization of swelling clay soils. International Journal of Geosciences, Vol.3, Issue 4, 2012, pp.719-725.

[42]. Elsawy M.B.D., Performance of Sand Dunes in Stabilizing Highly Expansive Soil. Journal of GeoEngineering, Vol. 16, Issue 1, 2021, pp. 023-034.

[43]. Phanikumar B.R., Dembla S., and Yatindra A., (2021) Swelling Behaviour of an Expansive Clay Blended with Fine Sand and Fly Ash Geotechnical and Geological Engineering, Vol. 39, Issue 1, 2021, pp. 583–591.

[44]. Alrammahi F., Khassaf S., Abbas S., Madhloom H., Aljaradin M., and Al-Ansari N., Study the Slope Stability of Earthen Dam using Dimensional Analysis Technique, International Journal of GEOMATE, Vol. 21, Issue 83, 2021, pp.125-131.

[45]. Sulaiman, S.O., Al-Ansari, N., Shahadha, A. et al. Evaluation of sediment transport empirical equations: a case study of the Euphrates River West Iraq. Arab J Geosci 14, 825 (2021). https://doi.org/10.1007/s12517-021-07177-1