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Evaluation of Sand Glass Powder to Enhance Some Geotechnical Properties of Expansive Clay Soils

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ABSTRACT

Expansive soil is mostly considered a problematic soil due to its potential for changes in geotechnical characteristics such as heave, differential settlement, expansion and shrinkage. This soil has a low bearing capacity and it is very sensitive to moisturizing, drying and other factors. Consequently, these soils need suitable improvement before any construction. The waste glass (WG) has been used to improve and stabilize the weak soils. In this study, an investigation into the influence of sand glass powder (SGP) addition to the expansive soil is conducted. SGP is a natural material abundantly available in western Iraq. It is characterized by a high content of silicate minerals, aluminum, iron and other elements that are effective in reducing the risks of the expansive soils. Although, WG has similar properties, it is present to a lesser extent. Moreover, recycling waste glass requires labor, as well as crushing and grinding processes, making it significantly more expensive compared to raw materials such as SGP. The expansive clay soil and natural sand glass are taken from the western Iraq. SGP was mixed with the dry expansive clay soil by different intensities (0%, 5%, 10%, 15%, and 20%). The result showed an enhancement in the expansive clay soil, where the geotechnical properties such as liquid limit, plastic limit, and plastic index (L.L., P.L. and P.I) were declined at about 14.5%, 24.1% and 35.8% by increasing SGP at 20%. Also, the free swelling and swelling pressure were reduced by 18.7% and 32.9% with an increase of SGP at 20%. Moreover, the unconfined tests showed that the treated samples increased the value from 90.12 kPa to 151.8 kPa after the addition of 20% of SGP. This improvement is particularly important because of the availability of the SGP as a natural material with a very low cost. The study is sustainable and environment friendly because of the high reduction for swelling potential.

1. INTRODUCTION

A large cause of failure in soil under structures is due to environmental factors such as rainfall, water evaporation, leakages of water pipe and flooding [1, 2]. According to the Environmental Protection Agency (EPA) in 2005, waste glass accounted for about 12.5 million tons from the USA, but 18.8% was recycled into raw material [3, 4]. In 2006, 22% of the waste glass was recycled. In 2018, 12.3 million tons of waste glass was made in the USA which contained 4.2% of waste glass as a solid, where 3.1 million tons were recycled. Though, according to National Waste Report in 2020, Australia's production of waste glass was equal to 1.16 million tons from 2018 to 2019, but only 57% to 59% was recycled [5, 6]. Glass materials including container glass and flat glass cover about 90% of the world manufactures. While about 20% of glass materials have been recycled, about 70% of the manufactured glass materials are disposed of as waste materials in landfills [7]. Waste glass (WG) is one of the most important materials that is widely used in the world. WG is a non-biodegradable material that does not decompose in landfills, which leads to continuous accumulation in the amounts and represents serious risks that may impact the environment and ecosystems [8]. In Iraq, there are no specialized facilities for glass recycling, most glass ends up in landfills, and if any recycling does take place, it is at a very minimal level.

In Iraq, the expansive soil is widespread in the middle and west, its causing damages to the buildings including schools, houses and pavement. Furthermore, similar soils are often found in Al-Anbar governorate such as Akshat, Rahhaliya and Qaim city [9, 10]. The study area was selected due to its investment and construction of various (personally and publicly) projects. Although, this location is distant from the center of Al-Anbar Governorate, it is essential to make a strategic decision: to enhance the soil using locally available and natural alternative resources.

2. LITERATURE REVIEW

The influence of swelling soil is limited near the soil surface. Usually, it occurs at depth of not more than 3 m from the surface, itis affected by the state of environment. Some factors such as initial void ratio, stress state, particle's structure and water content have a significant influence on the potential of expansive soils [11]. The characteristics of problematic soils might be treated by increasing strength and decreasing plasticity. To enhance the soil stability, chemical solutions or some materials could be added [12]. Mechanical stabilization of this soil is done by adding other types of soils such as: crash of stones, lime, flay ash and sand, this method is used to treat the potential swelling [13]. The clay soils can have low strength when the soil gains moisture content from many resources. Consequently, the soil needs to improve some properties before and during building, so to stabilize this soil different materials and solutions are used [14-19]. It is believed that the improvement in this soil is due to the presence of silica, which increases the bonds between the soil particles [20]. The shrinkages and swellings of clay soil cause settlements and heaves on the footing of buildings, slopes, pavements, dams and other constructions. The high pressure and free swelling were measured in the study, these values were 30-150 ton/m^2 and 100-300 mm [21]. The influence of glass materials such as glass fibers, foamed glass, glass powder, aggregates glass and geopolymers was obvious on some properties of highway engineering for different soils. In different study, a group of researchers investigated the unconfined compressive strength, CBR California, dry density, water content and shrinkage - swelling for soils by utilizing the triaxial and direct shear strength and then comparing them [22]. The using of waste materials (eco-friendly) to improve geotechnical applications and decrease their environmental influence is now generally recognized. Some materials such as lime, fly ash, blast and waste plastic can be utilized to increase the bearing capacity and stabilization of the soil [23, 24]. Many studies have tried to use waste materials to stabilize expensive clay soil, and some studies suggested using them as construction materials [25, 26]. More experiments were achieved by adding waste glass as a powder to stabilize expansive soil, the ratios were 3, 5, 7 and 9% of dry weight to clay soil. The results showed that the addition of waste glass as powder can improve the strata subgrade in highway field. The change in volume decreases with the increase of waste glass. The maximum compressive strength was recorded when the ratio was at 7% of dry weight to clay soil. It is concluded that by stabilizing the expansive soil, there is an improvement in some properties [27]. In their study, many researchers utilized waste glass powder was used for improve some properties of expansive soil, this soil was collected from the district of Karak, Pakistan. The addition of waste glass powder in soil was with different magnitudes 0, 4, 8, 12, 16, and 20%. A maximum decrease in potential swelling as dry unit weight, plasticity, free swelling, specific gravity and CBR California were detected at 20% [28]. Some studies used waste glass with different magnitudes that include 2.5, 5, 10, 15 and 25% to enhance the expansive soil properties. When the waste glass is increased by up to 25% the plasticity index is reduced by approximately 50% [29]. Future, different contents of waste glass 0, 6, 12, 18, 27 and 36% were utilized to investigate its influence on the clayey soil properties. The plastic limit decreases from 0 to 18% with the increase of waste glass from 0 to 36%. The unconfined compressive strength was improved after adding waste glass powder by 3, 5 and 7% for high plasticity soil, to be equal to 303, 371 and 329 kPa respectively. The reduction values observed due to the increase of the glass powder concentration in the interparticle of clay (flat plate) soil [30]. In another study, recycled glass as powder was used to treat silty clay and displayed that they improved the strength and durability properties [31]. Some studies used mix from glass powder and lime to improve swelling soil, The unconfined test showed an improvement in the clayey soil properties after adding the waste glass and lime mixture, the optimal content for glass powder and lime was found to be equal to 7.5 + 5%, this increases the strength up to 166% for clayey soil [32]. In a new work, glass fibers were employed to reinforce the expansive soil. The content fiber made up 0.25 to 1% of the dry soil's weight. Many tests such as the free swell, CBR California, and unconfined compressive strength were achieved on reinforced and unreinforced samples. The CBR value was improved from 1.6% to 9.6% after adding 0.25 to 1% of glass fiber to the soil. The peak value in the unconfined test was 150 kPa at 1% of the dry soil's weight. The free swelling value decreases with increasing of glass fiber [33, 34].

Regarding the earlier studies, several researchers have utilized glass powder to enhance various clay soil, but the technique of utilizing glass powder requires a lot of resources for recycling including crash machines, labor, money and energy. Generally, the concept of sustainability is based on reducing energy, machines and costs. The current study aims to improve the problematic soil with natural materials at a low cost. Moreover, sand glass powder was used for improving some properties of swelling soil in the west of Iraq as a case study.

3. METHODS

3.1 Expansive clay soil

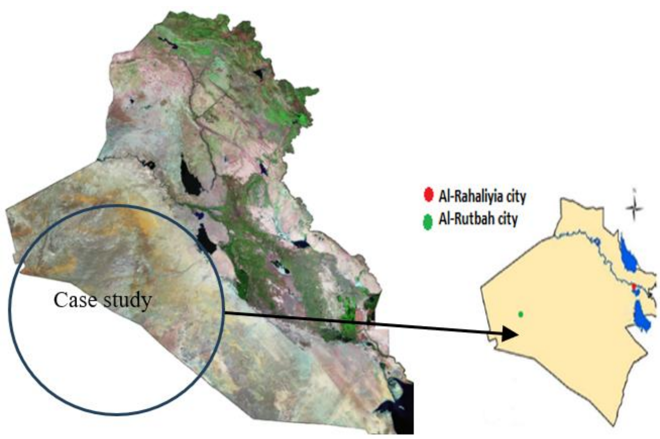

Figure 1. Study area

In this investigation, the expansive clay from the western region of Iraq was collected at a depth of around 50-100 cm. Based on ASTM standards, classification examinations of the soil were collected from Al-Rahaliyia city in Al-Anbar province. It is located at west of Al-Razzaza Lake and south of Al-Ramadi City [14]. Figure 1 shows the study area. It is located between 42-43 degrees east longitude and 33- 34 degrees north latitude. The topographical description of the region demonstrates the geotechnical and geographical features. This benefits the scientific research to develop the exploitation sustainably. The grain distribution curve of expansive clay samples is shown in Figure 2. The specific gravity of the clay samples is equal to 2.78. Some geotechnical properties of the expansive clay soil were recorded as shown in Table 1.

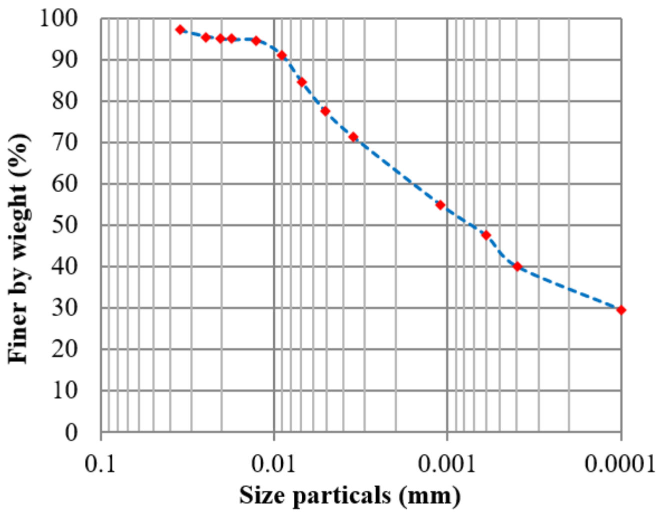

Figure 2. Gradation curve of the expansive clay soil

Table 1. The properties of expansive clay soils

Property	Value	Specification
Optimum moisture content (%)	22.5	ASTM D-1557
Maximum dry density (g/cm^3)	1.38	ASTM D-1557
Specific gravity	2.78	ASTM D-854
Void ratio	1.02	ASTM D-1557
L.L (%)	87	ASTM D-4318
P.L (%)	48	ASTM D-4318
P.I (%)	39	ASTM D-4318

3.2 Sand glass powder

The sand glass powder (SGP) was collected from Al-Rutbah city (27QP+4G7) as natural sand. The sand glass quantities were estimated to be about 330.000.000 m^3 by the Iraq Geological Survey. SGP was carefully crushed into homogeneous particles by an electricity apparatus (mixer). In the study, the particle size of SGP was less than 0.1 mm. The specifications of SGP data are characterized in Table 2 and Figure 3.

Table 2. Properties of SGP

Chemical Compounds	Property	Value
Silicon dioxide	SiO%	98
Iron (III) oxide	Fe_2O_3%	0.08
Aluminium oxide	Al_2O_3%	1
Potassium oxide	K_2O%	0.12
Calcium oxide	CaO%	0.2
Magnesium oxide	MgO%	0.2
Sulphur trioxide	SO_3%	0.1
Sodium oxide	Na_2O%	0.3
Chlorine	Cl%	0.12

The grain distributions of the SGP were D10 equal 120 µm, D50 equal 315 µm and D90 720 µm respectively. Silicon dioxide in SGP is greater than that of WG, this value is up 90% in SGP but in WG is less than 70%. Silicates are a chemical compound widely created in quartz, sand and other resource. These chemical composites are not reactive due to the polarity of the molecule is zero. This component is highly useful in soil because it acts as cementation in particles of soil. Sulphur trioxides in SGP is less than that of WG, this value is 0.1% in SGP while in WG it is up to 0.25%. Sulfates compounds are considered the most harmful on foundations, they cracked the binding material in concrete.

Figure 3. SGP

3.3 Sample preparation and methods

SGP was gradually added to dry weight expansive clay soil specimen (after the oven-dried) in proportions as 5, 10, 15, and 20%. In each test mentioned in the study, five samples were used, the first sample was untreated, while the other four samples were treated with SGP proportions as 5, 10, 15, and 20%. To confirm the consistent composition, all elements were mixed manually and all steps were closely observed. The Standard Proctor (TSP) tests were used for measuring the compaction property of the specimen of the expansive clay soil. The specimens had been compacted into the molds and removed from them. Plastic bags were used for placing the molds to get uniform moisture content distribution, the duration of this process was 24 hrs. The unconfined compressive strength test was achieved on cylindrical specimen by height of 100 mm and diameter of 50 mm based on all samples [35]. The moisture content was taken at 22.5 ± 0.05% in both treated and untreated clay specimens. Lastly, the specimens were remolded using a moist tamping system with a dry density of 1.38 ±0.05 g/cm^3. The free swelling test was scaled by using two samples of clay soil, each one weighing 10g passing through sieve No. 4. They were placed in two separate glass cylinders with a size of 1 liter or 100 mm^3 and then adding water in one cylinder while adding kerosene to the other. After 24 hours, the free swelling is recorded and compared between the two cylinders [36]. Also, the pressure swelling and the unconfined strength were achieved on the clay by the same moisture content and the dry density. Many researchers adopted this technique in their studies [14, 15, 37]. To understand the interaction between flat plates in expansive soil after adding SGP, X-ray diffraction (XRD) was tested on the specimens to explain the results.

4. RESULTS AND DISCUSSION

4.1 SGP effect of on plasticity

The addition of SGP has an impact on plasticity LL, PL and PI% for treated and untreated clay soil specimens with 5,10, 15, and 20%. The figure displays the improved LL, PL and PI values by increasing SGP quantities. Both plastic and liquid limit were reduced from 2% to 14.5% and from 5.7% to 24.1% by using SGP intensity from 5% to 20%, respectively. The plastic index for expansive clay soil decreased from 10.2% to 35.8% by adding SGP as shown in Figure 4. The concentration of silicate, components, salts and some metals in SGP can cause decreasing in distance between the flat plate clay. In addition, the construction of SGP reduces the available surface that affects the exchange between water and soil particles. Reducing in the plasticity index leads to enhancement in the workability [38]. These improvements are vital as little compaction (density) efforts are required to achieve higher soil densities, therefore saving money and time.

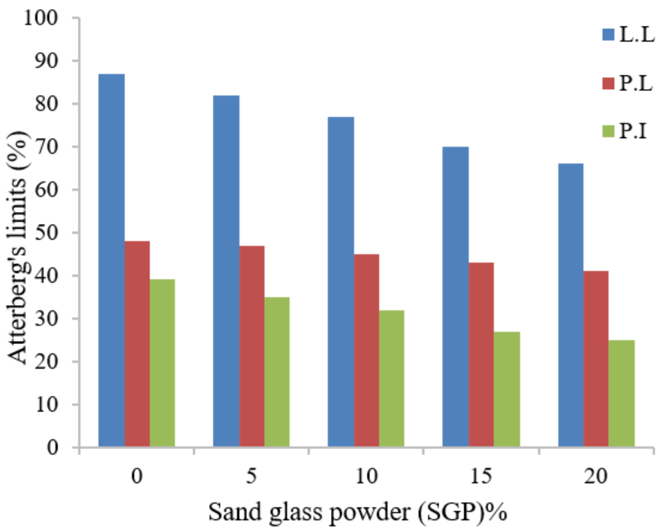

Figure 4. Relationship between SGP and Atterberg's limits

4.2 SGP effect on free and pressure swelling test

The influence of SGP on the result of swelling was clear and positive, as shown in Figure 5 and Figure 6. It is found that SGP improved the soil by decreasing the free swelling. In fact, free swelling was reduced from 3.5 to 18.7% for an expansive clay that was treated by SGP intensities of 5-20%, respectively. In test pressure swelling, it reduced with the increasing of the intensities of SGP as presented in Figure 7. The decline in the result of pressure test was from 9% to 32.9% for an expansive clay that was treated by SGP intensities of 5-20%.

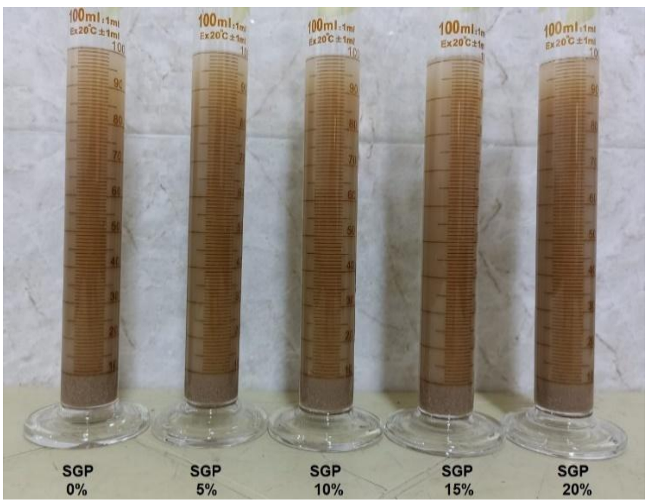

Figure 5. The test of swelling clay soil

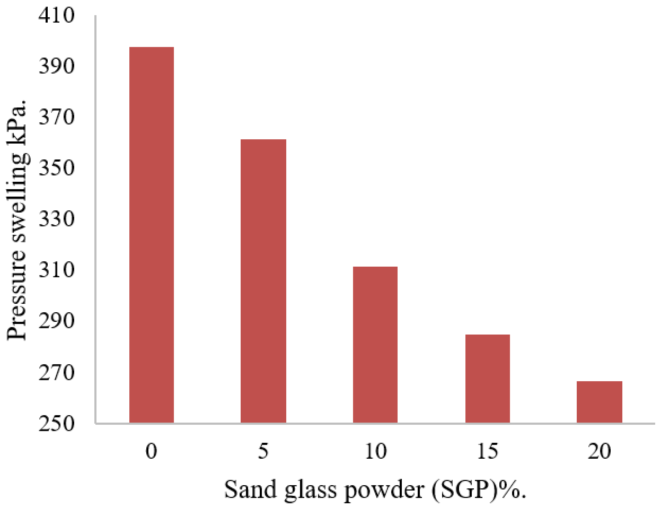

Figure 6. Relationship between SGP and pressure swelling

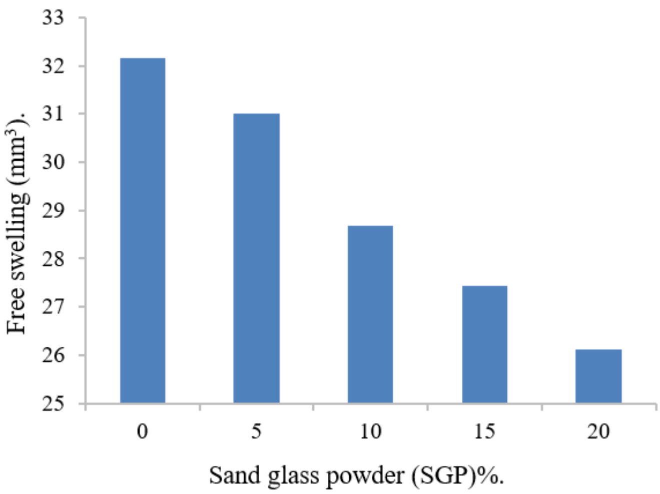

Figure 7. Relationship between SGP and free swelling

These drop of free and pressure are probably due to the filling up of the voids in soil by SGP or by replacing the clayey friction from the mixture. In this case, sand glass powder can contribute to bonds between flat plates or soil particles which have small distances between them. This is because of dissolving silicate, some minerals, salts and other components in voids.

4.3 SGP effect on unconfined compressive strength test

From the results of the unconfined test, SGP impacted the unconfined test values for expansive clay. It increased from 90.12 kPa to 151.8 kPa after addition of 20% of SGP, as illustrated in Figure 8. This increase displays a significant development in the strength of expansive soil. The intensification in unconfined test denotes an increase in the clay soil strength.

These increases are credited to the reactions of the pozzolanic which occurs between stabilizers and any clay soil. Moreover, the stabilizers improved the clay gradation, which are essential features in strength progress [38, 39]. The increases of internal confine pressure inside the soil sample and rises the shear strength for the treated clay soil due to the added of the SGP. Since more links are required to be overcome in shearing, the unconfined test will in return to increase value [34].

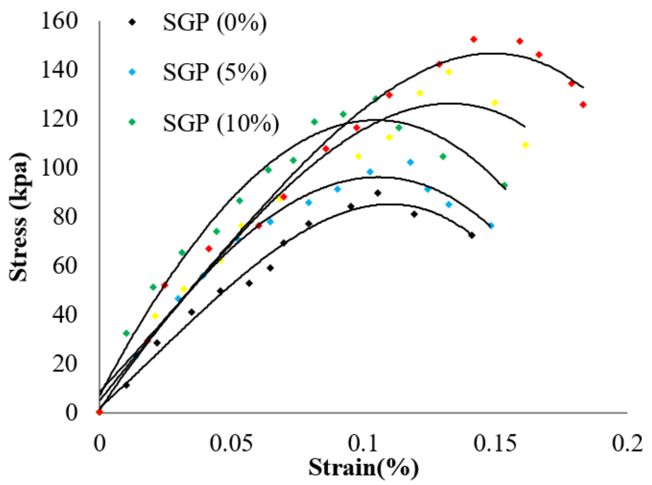

Figure 8. Relationship between SGP and unconfined strength

4.4 SGP effect on specific gravity value

The specific gravity variations of different SGP percentage are shown in Figure 9. It was obvious that specific gravity for expansive clay soil changed from 2.78 to 2.41 with the increasing of SGP. This behavior of swelling clay soil at specific value was close to the behavior of sand soil because of the increasing of material concentrations and components that have sand glass powder. This high specific gravity is due to the smallest particle size. So due to the high specific gravity of SGP, the overall weight of the system decreased.

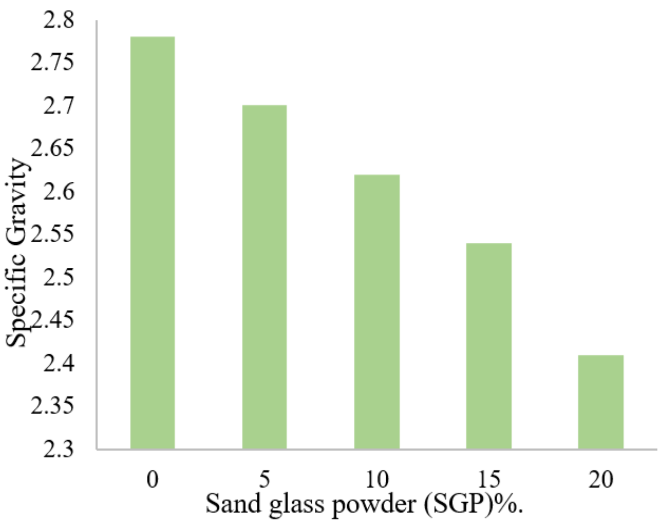

Figure 9. Relationship between specific gravity and SGP

4.5 XRF analyses for treated and untreated clay

The results of XRF analysis for expansive clay specimen treated by SGP are given in Table 3. The expansive clay after SGP treatment, air-dried and was later crushed into fine particles. The values of the tests explained that the concentration of some components such as SiO_2, AL_2O_3 Fe_2O_3, CaO and K_2O increased when raising the intensity of SGP. These components connect the flat plates or the particles of soil to reduce the space among them and link these sheets by bridges such as cementation. At the end, some of the elements and components such as Cl, SO_3 and Na_2O decreased in clay specimens that were treated with SGP. This decreasing is due to the sand glass powder that contains the silica and the alumina (high values). The soil with high concentrations of Cl, SO_3 and Na_2O elements are very dangerous under structures' foundations because of creating the acid solutions and salts. All tests were achieved on apparatus (Thermo Fisher Scientific, Type Spectrometer, Model ARL 9900) in the Factory of cement Al-Qaim as shown in Figure 10. During the microstructural analysis, it discovered denser material for the treated specimens, which decreased voids between the flat plate clay, these materials arise into closer connection and make stronger impacts when is additional to the clay soil as concept (stabilizations) [40].

Figure 10. XRF

Table 3. Some chemical compounds collected from (X-ray analysis) for natural the expansive clay and adding of sand glass powder (SGP)%

Chemical Compounds	Minerals	Adding of SGP (%)				
		0	5	10	15	20
Silicon dioxide	SiO_2	39.57	39.88	40.06	42.78	43.32
Aluminium oxide	AL_2O_3	12.42	12.58	12.88	13.42	13.8
Iron (III) oxide	Fe_2O_3	4.74	4.79	5.08	5.21	5.63
Calcium oxide	CaO	17.01	17.1	17.68	18.55	18.83
Magnesium oxide	MgO	3.09	3.22	4.23	4.92	4.98
Sulphur trioxide	SO_3	0.66	0.65	0.53	0.43	0.41
Sodium oxide	Na_2O	0.16	0.16	0.15	0.13	0.12
Potassium oxide	K_2O	3.68	3.71	3.82	3.9	3.94
Chlorine	Cl	0.8	0.8	0.71	0. 67	0.64

5. CONCLUSION

1) In this study, the treatment of expansive clay with SGP leads to a significant decline in its plasticity properties, free swelling and swelling pressure.
2) The unconfined test of expansive soil explained that sand glass powder SGP significantly improved the properties of unconfined samples. This technique would be suitable in dropping the costs of constructions such as high ways, dams, foundations and other buildings.
3) SGP is a suitable material because of its availability with high quantities as raw materials and very cheap.
4) The SGP has a high silica, which is a non-polar solid that causes a reduction of water adsorption in the soil, since silica would rather attach to mud rather than water.
5) From the results XRF tests, the contents of some

components such as SiO_2, AL_2O_3, Fe_2O_3, CaO and K_2O increased and the other elements and component such as Cl, SO_3 and Na_2O decreased with increasing of the SGP.

6) Sand glass powder may be used as treatment of expansive clay soil without any problem.

However, many gaps in knowledge are still needed to be addressed, such as, sand glass powder-soil interaction and stabilization mechanisms. Additionally, the cost of soil stabilization by sand glass powder might be estimated and compared with the other material stabilizers.

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