Performance of soil Foundation Improved Using fiber reinforced geopolymer

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ABSTRACT:

Recently, geopolymer (FGP) has become a new and environmentally friendly substitute to traditional soil stabilization agents such as lime and Ordinary Portland Cement (OPC) in order to reduce environmental concerns. The addition of fibers to treated soil increases its strength by slowing the spread of cracks. In this research, weak low plasticity silt soil was remediated using a geopolymer (FGP) binder made from high calcium class C fly ash (FAC) treated with 10 M NaOH. As reinforcement, polypropylene (FPP) fibers with a length of 4.5 mm were used in amounts ranging from 0.25 to 1.5%. Microstructure and unconfined compressive strength (UCS) measurements were performed on the manufactured specimens. The investigation revealed that fiber incorporation enhanced the treated weak soil's mechanical behavior. In comparison to conventional binders, FGP-treated soil mixes with a 20% binder content and an A/B ratio of 0.4 and reinforced with 1.5% FPP fibers by weight were found to have superior strength properties.

Keywords: (Sustainable material, Fiber, Geotechnical application, geopolymer, soil stabilization, SEM) .

تحسين أداء أساس التربة باستخدام الجيوبوليمر المقوى بالألياف

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الملخص:

في الآونة الأخيرة ، أصبح الجيوبوليمر (FGP) بديلاً جديدًا وصديقًا للبيئة لعوامل تثبيت التربة التقليدية مثل الجير والأسمنت البورتلاندي العادي (OPC) من أجل تقليل المخاوف البيئية. تزيد إضافة الألياف إلى التربة المعالجة من قوتها عن طريق إبطاء انتشار الشقوق. في هذا البحث ، تمت معالجة تربة الطمي الضعيفة منخفضة اللدونة باستخدام مادة رابطة جيوبوليمر (FGP) مصنوعة من الرماد المتطاير C عالي الكالسيوم (FAC) المعالج بـ ١٠ M NaOH. كتعزيز ، تم استخدام ألياف البولي بروبلين بطول ٤,٥ مم بكميات تتراوح من ٠,٢٥ إلى ١,٥٪. تم إجراء قياسات البنية المجهرية ومقاومة الضغط غير المحصورة (UCS) على العينات المصنعة. كشف التحقيق أن دمج الألياف عزز السلوك الميكانيكي للتربة المعالجة. بالمقارنة مع المواد الرابطة التقليدية ، تمتزج التربة المعالجة بـ

FGPمع محتوى رابط ٢٠٪ ونسبة A / B 0.4 وعُززت بألياف FPP بنسبة ١,٥٪ من حيث الوزن وُجد أنها تتمتع بخصائص قوة فائقة.

الكلمات المفتاحية:(المواد المستدامة ، الألياف ، التطبيقات الجيوتقنية ، الجيوبوليمر ، تثبيت التربة ، (SEM.

INTRODUCTION

When it becomes necessary to build buildings on weak soil beds with little to no shear strength, Therefore, stabilization of these soils by established physical and/or chemical methods is essential for ensuring that the treated ground provides a stable medium for load transfer. To improve the engineering performance of such soils, many ground improvement techniques can be used, with the most effective technique depending on the physico-chemical parameters of the soil in issue. Chemical treatment with conventional binders can improve several significant engineering properties of soils (e.g., lime and cement). As a result of chemical reactions between the soil and the binder, the engineering properties of the in-situ soil are improved. The conventional binders used to improve the weak soil have been Portland cement and/or lime.(Bruce et al., 2013; Horpibulsuk et al., 2011; Shen et al., 2003). When using these traditional binders, the mechanism of strength growth is through hydration and pozzolanic reactions, which are interactions between silica and/or alumina, calcium hydroxide, and water. The most frequent hydration/pozzolanic product is calcium silicate hydrate, however calcium aluminate hydrate and calcium aluminosilicate hydrate are also produced, depending on the availability of alumina and silica. (Dodson, 1990). Because of the large use of energy and natural resources, as well as the CO2 emissions produced during the manufacturing of these conventional binders, the use of cement and lime is related with environmental problems. As a result, researchers are actively looking for alternative binders that have a lower carbon footprint. Using widely available industrial byproducts like fly ash (FA), which is typically intended for landfills, to make alternative binders eliminates the production and environmental concerns associated with standard cement and lime binders. FA is produced as a byproduct of coal combustion in power plants and iron. Furthermore, using FA wastes in the ground-improvement business would lessen the need to enlarge existing landfills or build new landfills. Using FA-based FGP, this study seeks potential low carbon binders.

Two of the probable alkaline activators widely acknowledged by cement and concrete industry researchers are sodium hydroxide (NaOH) pellets and sodium silicate (Na2SiO3) solution (used in conjunction). Though alkaline-activated material or FGP technology has only recently been introduced to soil stabilization research, several studies over the past few years have shown the use of both activators together to make FGP with a wide variety of by-products such as slags, fly ash, rice husk ash, palm oil fuel ash, and so on.(Arulrajah et al., 2018; Kuun Reddy & Bala Murugan, 2020; Neupane, 2016; Sargent et al., 2016; Singhi et al., 2016; Yaghoubi et al., 2018; M. Zhang et al., 2013a). However, given the lower environmental impact of NaOH flakes, the higher Ca/Si ratio (1.2) in NaOH-activated slags, and the lower carbonation depth when NaOH is used in cementitious pastes when compared to the production and use of Na2SiO3, it is reasonable to prefer NaOH over Na2SiO3 as an activator for making FGP. (Kuun Reddy & Bala Murugan, 2020).

In order to make FGP, a material with a high alumina and silica content, like FA, is mixed with a liquid alkaline activator (L) that is high in soluble metals, like sodium.(Gao et al., 2013; Pourakbar et al., 2016; Xu & van Deventer, 2002). The alumina and silica, however, must be amorphous. (Hardjito & Rangan, 2005). The geopolymerization process is a quick chemical reaction that involves the dissolution of aluminum and silicon in the L, the synthesis of monomers, and the development of a FGP structure. (polycondensation) (al Bakri Abdullah et al., 2012; Hardjito & Rangan, 2005). A sodium aluminosilicate hydrate would be the geopolymeric result. (Pourakbar et al., 2016; Xu & van Deventer, 2002).

Most FGP can only be used in dry heat-cured or steamed concrete since they are treated at 60–90°C (Gianoncelli et al., 2013). Geotechnical engineering uses FGP at room temperature since treating them at high temperatures is impossible. FGP-soil has lower impact strength and takes longer to impact than cement-treated soil because geopolymerization is slower at low temperatures (Cristelo et al., 2012a). Thus, greater activator concentrations are needed to make FA-based FGP suitable for soil stabilization compared to cement. However, bulk activator content increases the expense of this stabilization technique (Bernal & Provis, 2014) FA FGP study previously used class F fly ash (FFA) from bituminous coal combustion (Phair & van Deventer, 2002). This research used FA high in Ca content to improve FGP reactivity and decrease activator ratio (i.e., cost effectiveness) while still allowing for satisfactory curing at room temperature. Most notably, the calcium content of FFA and class C fly ash is different (FAC). Silica and alumina are common components of both. In combination, GGBFS and FFA make up the FAC. (Duxson & Provis, 2008). FAC can yield FGP since GGBFS and FFA combinations are preferred for FGP production. Brittle failure was seen in the stabilized soil as the dosage of GGBS-based FGP was increased (Sargent, 2015). Furthermore, when compared to cement, the shrinkage parameters of slag-FGP stabilized soil are several orders of magnitude higher (Collins & Sanjayan, 2001), which may reduce its ability to manage failure. As a result, reinforcing the treated soil with FPP improves the mechanical performance of the treated matrix by reducing crack development (Aydın & Baradan, 2013; Syed et al., 2020). Several researches showed in the recent decade that incorporating Polypropylene (FPP) fiber into soil increased strength and ductility (Freitag, 1986; Gaspard et al., 2003; Syed et al., 2020; L. Zhang et al., 2008; Ziegler et al., 1998) As a result, reinforcing the FAC FGP with discrete FPP fibers may be considered a potential solution/alternative for improving engineering qualities such as toughness and ductility (Syed et al., 2020). There is little literature on soil stabilization using

FAC-based FGP and FPP addition. As a result, in order to use fiber Reinforced Geopolymer (FAC-FGP) with FPP fibers in DSM technology, a thorough evaluation of its mechanical and durability performance is required, according to the findings of this study.

MATERIALS

Soil, class C fly ash, an activator, and fiber were used heavily in this investigation.

Soil

The soil sample used in this investigation was gathered in the Almuhia region of Nasiriyah, which is located about 343.5 kilometers south of Baghdad, the capital of Iraq. One to two meters below the current ground level is where soil samples are typically taken. Soil's geotechnical properties can be assessed through measurements of its specific gravity (Gs), sieve analysis, Atterberg's limits (LL and PL), compaction test, and direct shear test. The soil has a low plasticity silt classification in the Unified Soil Classification System (ML).
Table 1depicts these properties. The soil has a low plasticity silt classification in the Unified Soil Classification System (ML).

Table 1The physical properties of the soil

Property	Value	Standard of the test
Specific gravity (Gs)	2.73	ASTM D 854
Sand %	20	ASTM D 422 and ASTM D 2487
Fines content %	80	
Silt %	55	
Clay %	25	
Soil classification	ML	
Liquid limit %	40	

Plastic limit %	30	ASTM D 4318
Cohesion, c (kPa)	50	ASTM D 3080
Internal friction angle Ø°	5	
$\gamma field$ (kN/$m3$)	17.65	ASTM D 2216
moisture content Wc%	13	
Maximum dry unit weight (KN/$m3$)	18.12	ASTM 698
Optimum moisture content %	15.5	

Fly Ash

The local FAC used in this study was supplied by the Nasiriya power generating plant as waste products from the electricity generation process. Figure -1depicts a picture of FAC and how the hydrometer test found the distribution of

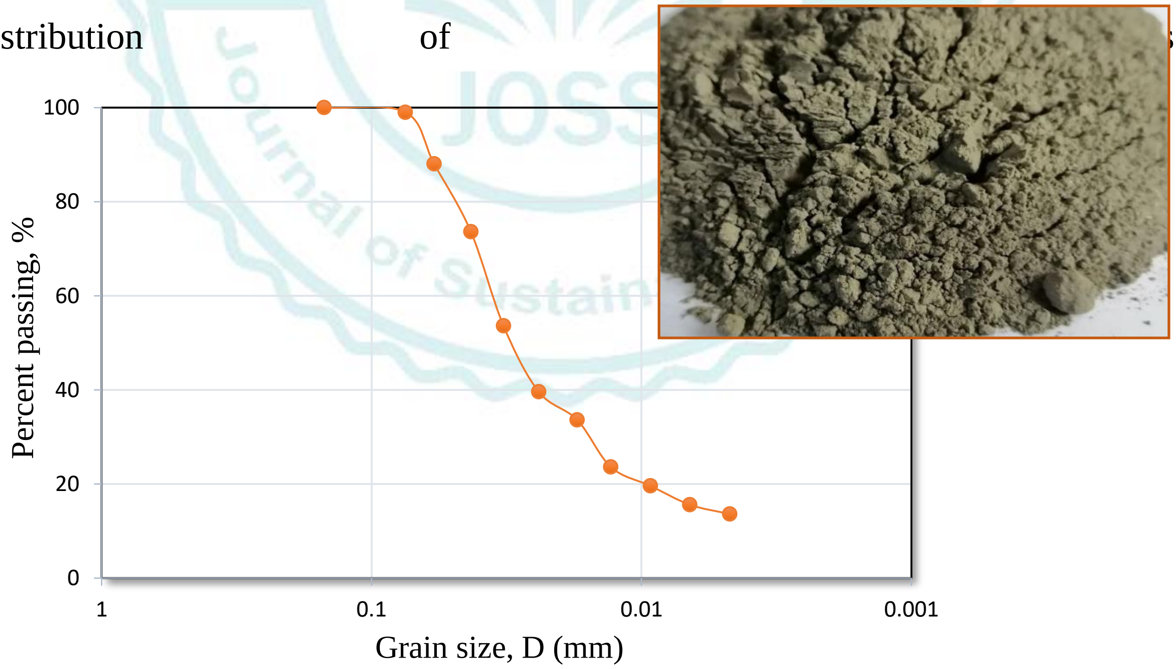

Figure -1The particle size distribution curve of FAC

Alkali activator

In this study, the alkaline activator solution was made from Sodium silicate (Na_2Sio_3) and sodium hydroxide (NaOH), which were used because they were cheaper and easier to get than a potassium-based solution. Also, NaOH is very good at getting rid of silicate and aluminate monomers. 98 percent pure sodium hydroxide pellets were acquired. Liquid sodium silicate was bought. To make NaOH solution, a certain number of pellets of sodium hydroxide were mixed with distilled water. The NaOH concentration in the solution was held constant throughout the experiment at 10 M. The solution's molarity was determined by dissolving 400 grams of NaOH pellets in one liter of pure water. In this study, the amount of sodium silicate to sodium hydroxide in terms of weight was 2.0.

Fiber

Commercially available fiberglass was used in this study, as shown in Figure -2.

Table 2illustrates some of its properties.

Table 2Fiberglass properties

Properties	Value
Length (mm)	4.5
Diameter (µm)	10
Strength (MPa)	650

Figure -2Used Fiber

METHODOLOGY

For a study on the compressive strength of FGP-treated soils, treated samples that had been cured for 28 days were put through a series of unconfined compressive strength tests. The UCS test samples were made from PVC split tubes with a diameter of 50 mm and a height of 100 mm. The ratio of height to diameter was 2:1. Several studies have suggested this kind of plastic mold because it is more resistant to the alkali mixture. A cut was made down the middle to make it easier to get the samples out. Before compaction, the mold was held together with three clamps made of stainless steel so that the movement and compaction wouldn't cause the volume to grow. A compressive strength test was done on samples of treated soil using a uniaxial machine with a 50 kN loading capacity (ASTM D1633-00, 2007). A load cell and a Linear Variable Displacement Transducer were used to measure the applied load and the resulting displacements (LVDT). All UCS tests were done at a rate of 0.1 mm per minute. The compression machine is depicted in Figure -3.Table 3 depicted the details of samples.

Figure -3UCS test device

Table 3Details of samples

Mixture No.	Mixture ID*	Fly ash, %	Activator/Fly ash (A/FA)	Fiber, %
1	M (f0.3)	20	0.4	0.50
2	M (f0.6)			0.75
3	M (f0.9)			1.00
4	M (f1.2)			1.25
5	M (f1.5)			1.50

*The combinations were identified using M(*f*). The letter M is a shortened version of the word "Mixture," followed by ratio (FPP), denoted by brackets.

Microstructure Analysis

Field Emission Scanning Electron Microscope (FESEM) with Energy-Dispersive Spectrometer was used to look at the microstructure samples (EDS).

Small, ready-made samples were taken from samples tested by UCS and used in that test.

RESULTS AND DISCUSSIONS

Compressive Strength

The important factor that determines the efficiency of a fly-ash-based FGP as a binder. The effects of FPP ratios on soil stabilization were investigated in order to identify a viable FGP mixture for soil stabilization and to evaluate the dependability of employing these new binders in weak soil stabilization. Based on the methodology, the unconfined compressive strength (UCS) test was chosen to find out how reactive different FGP content FPP components are in treated soils.

The UCS of FGP-soil treated FPP was explored using various FPP ratios (0, 0.5, 0.75, 1,1.25, and 1.5%) to determine the effect of FPP inclusion on soil-FGP strength behavior. The UCS of FGP-treated FPP was determined for the above FPP ratios (1.75,2.0,2.2,2.45,2.52,2.64, and2.71) MPa. From Figure -4, The percentage of FPP in the specimens has increased from 0% to 1.5%, which has resulted in an improvement in their UCS. The increased strength may be attributable to the uniform distribution of FPP throughout the treated soil matrix, which stopped the formation of micro-cracks when it was loaded. This may be due to an increase in the ductility of the treated samples, which occurs when there is a greater proportion of FPP in the material. When compared to the other FPP contents that were investigated, the treated specimens that were reinforced with 1.5% FPP content demonstrated the highest level of ductility. Figure -5shows that the treated FPP reinforced FGP- soil led to an approximate 117,126,140,144,151, and155%, increase in UCS to untreated FPP at (0.25, 0.5, 0.75, 1, 1.25, 1.5%) FPP content, respectively. Although the increasing of the treated FPP ratios resulted in continues increasing in UCS, the rate of improvement become less after (0.75) FPP ratio. therefore, it is recommended to use in process of soil treatment.

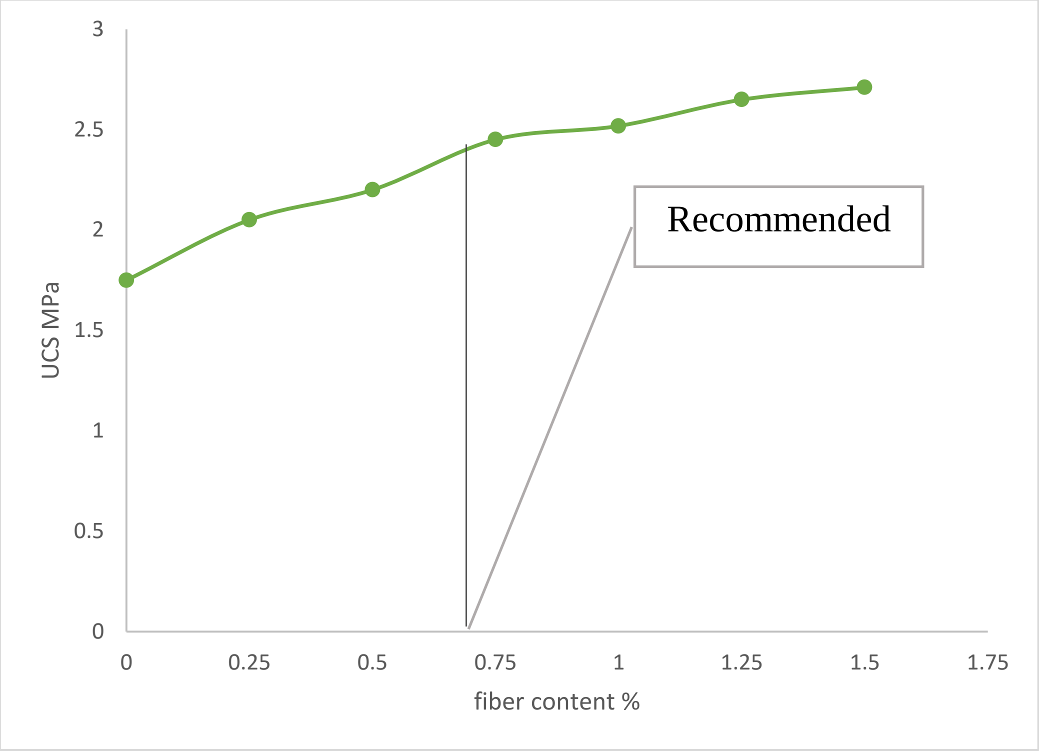

Figure -4UCS values of fiber-reinforced specimens treated at FGP content (20%FA and 0.4 A/F)

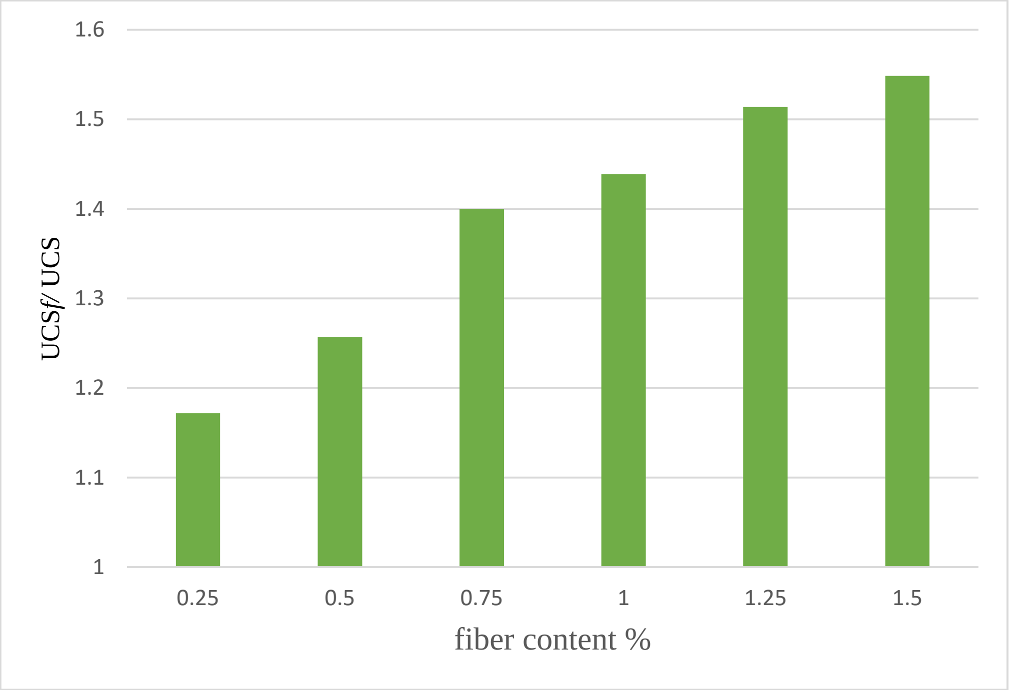

Figure -5Variation UCS for treated and untreated fibers reinforced FGP- soil at the different fiber content

Stiffness Behavior of FGP-Treated Soil

stiffness of FGP treated soil estimated from the unconfined condition, might help better understand the influence of various experimental variables (such as FPP ratio, and soil type) on the stiffness of the stabilized soil. The measured stiffness E50, the secant modulus of FGP-treated soil is shown in the following Figure -6 at 50% peak strength. In general, increasing the ratio of FPP increased the stiffness of stabilized low plasticity silt. The increase in E50 that was observed is primarily attributable to the increase in effective bonding that occurred between the FPP and the treated soil matrix that was all around them.

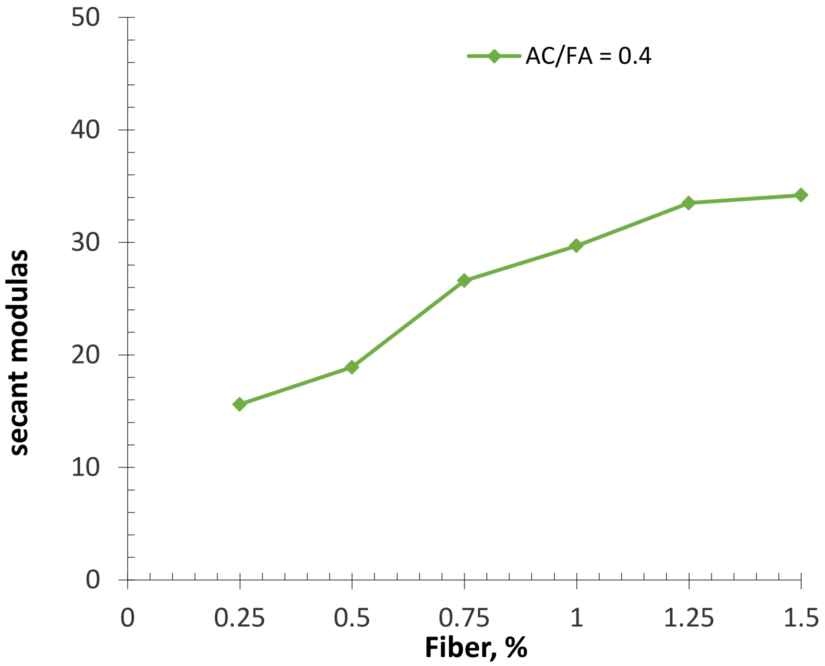

Figure -6Variation of secant modulus with the activator ratio

SEM of FGP Stabilized Soil

The compact, stable structures of FGP-treated samples improved engineering properties. This primary reinforcing is caused by industrial soil bonding reinforcement materials. An alkaline medium is used in the process of making FGP, which dissolves silica and alumina oxides from fly-ash particles to produce sodium aluminum silicate hydrate (N-A-S-H), which is a compound that cements and hardens soil particles.(Cristelo, Glendinning, Miranda, et al., 2012b; Phummiphan et al., 2016). show SEM investigation of soil-FGP sample with 20% FAC and activator/FAC ratio (0.4). A higher FAC ratio increases dissolution rate and binding activity, resulting in the most compact form.Figure-7. Most of the time, when silica and aluminum decompose, the holes that are left in FAC are filled with smaller particles and cementitious products, making a dense matrix. This mechanism, along with research on geosynthetic soil, modifies the structure of the soil and makes the soil that has been treated more robust.(Abdullah et al., 2019; Cristelo et al., 2013; M. Zhang et al., 2013b).

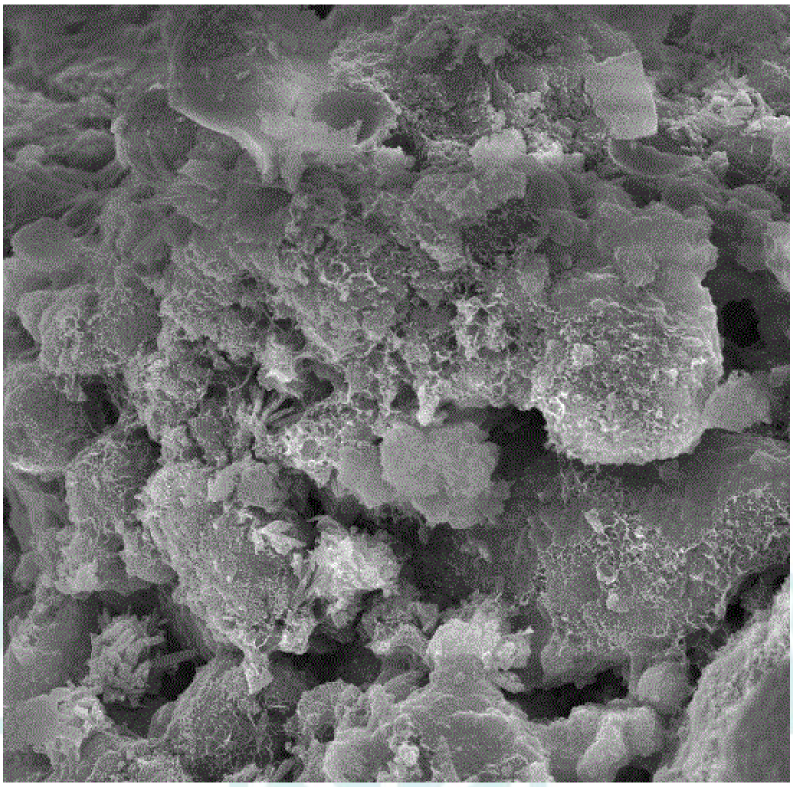

Figure-7SEM images of FGP sample (20% fly ash, 0.4 activator)

CONCLUSIONS

1. 1. During the initial phase of this research project, unconfined compression shear (UCS) tests were performed on treated specimens in order to evaluate the strength and stiffness improvement of low plasticity silt soil that had been treated with a variety of different combinations of FAC, activator, and/or FPP. The primary focus of this investigation was on determining how the FPP-to-fly-ash ratio affected the final product. The soil that had been treated with a FGP based on FAC exhibited significantly improved levels of strength and stiffness after FPP was added to the mix. The findings of the studies indicated that a FPP ratio of 1.5% was optimal for low plasticity silt soil.
2. The fact that cementitious products were found on the FAC surfaces during the FESEM analysis shows that there was a geopolymerization response.

In most cases, the etched holes in the surfaces of FAC that were created as a result of the breakdown of silica and aluminum are filled with smaller particles, resulting in a dense matrix.

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