Effect of Fiber on the Strength Performance of Echo-Friendly Geopolymer-Sand Matrix

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Abstract
Geopolymer (GP) has recently developed as an innovative and environmentally friendly alternative to traditional soil stabilization agents such as lime and Ordinary Portland Cement (OPC) to minimize its impacts on environmental, which have negative environmental consequences. The addition of fibers to treated soil prevents crack propagation, increasing its strength even further. high calcium class C fly ash (CFA) reacted with 10 M NaOH was employed as a geopolymer (GP) binder in this study to treat weak sand soil. Polypropylene (PP) fibers with a length of 4.5 mm were employed as reinforcement in quantities ranging from 0.3 to 1.5%. The produced specimens were subjected to microstructure and unconfined compressive strength (UCS) testing. The study demonstrated the benefits of fiber inclusion in enhancing the mechanical behavior of the treated weak soil. Superior strength characteristics were observed in GP treated soil mixes with a binder content of 20% and an Activator/Binder (A/B) ratio of 0.4 reinforced with 1.5% PP fibers by weight, indicating that they can be used as a sustainable alternative to traditional binders in deep soil mixing applications.

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

INTRODUCTION

weak soils that are present in many places of many world nations are characterized by high natural water content coupled with low shear strength making them unsuitable to support any civil engineering structures (Han, 2015). However, due to high economic activity in such areas, the major infrastructure such as multi structures are to be built over such deposits (Porbaha, 1998). Several important engineering features of soils can be improved through chemical treatment using conventional binders (e.g., lime and cement). Over the last decade, the carbon footprint of such binders has produced more serious environmental concerns. Ordinary Portland Cement (OPC) manufacture is projected to emit 7% of artificial CO2 (Pacheco-Torgal et al., 2014). Given this emission risk and other unavoidable environmental impacts of nonrenewable raw materials, there is an incentive to identify more environmentally cost-effective and friendly alternative binders to replace OPC. Thus, recycling process materials from aluminosilicate industrial wastes and alkali-activated cement has been prioritized (Davidovits, 2008). Geopolymers (GP) are cementitious binders manufactured from industrial wastes with high amorphous (Si and Al) content, such as fly ash (FA) and metakaolin (MK), and an alkaline activator like potassium/sodium silicate or hydroxide (Singhi et al., 2016). Geopolymerization is a fast four-step chemical reaction: ion dissolution, diffusion, gel production by polymerizing Si and Al compounds with an activator, and gel hardening (M. Zhang et al., 2013a). Depending on synthesizing conditions, GP can have excellent mechanical properties such high strength, low permeability, great durability, and negligible volume changes (van Deventer & Xu, 2002). However, source material rate, activator chemical properties, temperature, and curing time may affect it. GP's mechanics. Implementing the curing temperature in the field is the hardest (van Deventer & Xu, 2002; M. Zhang et al., 2013a). Most GP 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 GPs at room temperature since treating them at high temperatures is impossible. GP-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 GP suitable for soil stabilization compared to cement. However, bulk activator content increases the expense of this stabilization technique (Bernal & Provis, 2014). FA GP study previously used class F fly ash (FFA) from bituminous coal combustion (Phair & van Deventer, 2002). This study employed FA with high Ca content to boost GP reactivity and reduce activator ratio (i.e., cost effectiveness) while maintaining acceptable curing at room temperature. FFA and class C fly ash differ mostly in calcium content (CFA). Both contain silica and alumina. GGBFS and FFA form CFA (Duxson & Provis, 2008). CFA can yield GP since GGBFS and FFA combinations are preferred for GP production. Brittle failure was seen in the stabilized soil as the dosage of GGBS-based geopolymer was increased (Sargent, 2015). Furthermore, when compared to cement, the shrinkage parameters of slag-geopolymer 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 fibers 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 (PP) fibers 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 CFA geopolymer with discrete PP 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 CFA-based geopolymers and fiber addition. As a result, in order to use Fiber Reinforced Geopolymer (CFA-GP) with PP fibers in DSM technology, a thorough evaluation of its mechanical and durability performance is required, as revealed in this study.

MATERIALS

In this study, soil, fly ash class c, activator, and fiber were mainly used.

Soil

The soil utilized in this study was locally available sand. Table 1 summarized its physical characteristics, including grain size distribution,
Specific gravity, voids ratio, relative density (RD), maximum and minimum dry density, and angle of internal friction (φ). This sand is categorized as (poorly graded) SP by the Unified Soil Classification System (USCS), as shown in Figure 1.

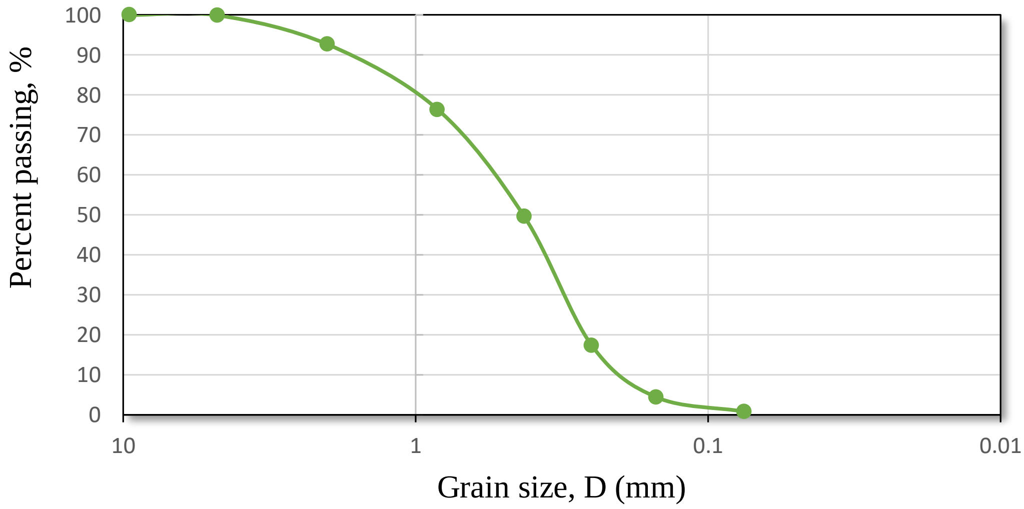

Figure 1Grain size distribution of sand soil

Table 1The physical properties of sand soil

Soil property	**Standard**	**Value**
Coefficient of uniformity (cu)	ASTM D 422	2.75
Coefficient of curvature (cc)		0.81
Mean effective diameter (D_{50})		0.443
Specific gravity (Gs)	ASTM D 854-00	2.65
Maximum dry density (gm/cm³)	ASTM D 4253	1.703
Minimum void ratio		0.558
Minimum dry density (gm/cm³)	ASTM D 4254	1.357
Maximum void ratio		0.84
Internal friction angle φ	ASTM D 3080	36
Relative density	---------------	50

Fly Ash

In this study, local fly ash was used, which was supplied by the Nasiriya power generating plant as byproduct waste materials generated during the production of electricity. Figure 2 depicts a picture of fly ash and the particle distribution as determined by the hydrometer test

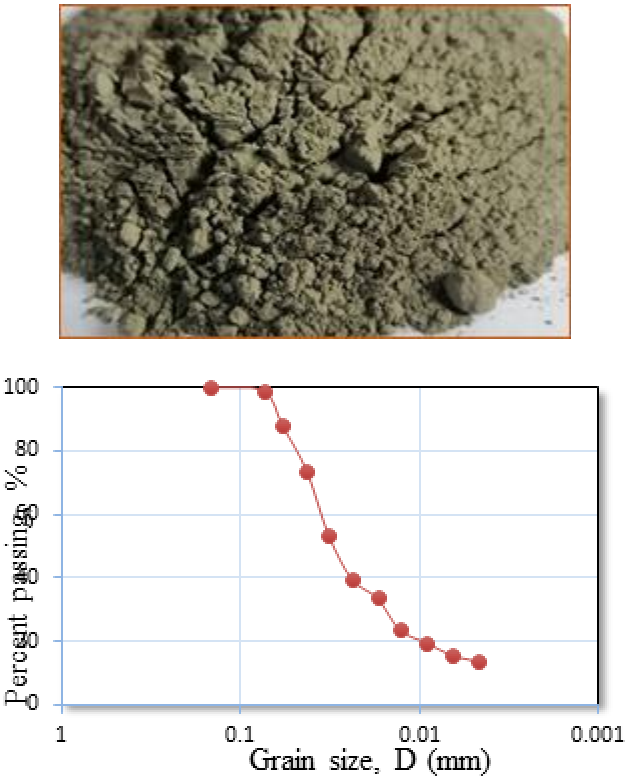

Figure 2The particle size distribution curve of fly ash

Alkali activator

Sodium silicate (Na_2Sio_3) and sodium hydroxide (NaOH) were used in this study to form the alkaline activator solution because they were cheaper and more available than a potassium-based solution. Furthermore, NaOH has demonstrated an excellent ability to liberate silicate and aluminate monomers. Sodium hydroxide pellets with a purity of 98 percent were purchased. While Sodium silicate was purchased in liquid form. To prepare NaOH solution, a specific amount of sodium hydroxide pellets was dissolved in distilled water. The molarity of the NaOH solution was kept constant throughout the study at 10 M. This molarity of the solution was achieved by dissolving 400 gm of the NaOH pellets in one liter of distilled water. The weight ratio of sodium silicate to sodium hydroxide used in this study was 2.

Fiber

Commercially available fiberglass was used in this study, as shown in Figure 3.

Table ***2*** illustrates some of its properties.

Table 2Fiberglass properties

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

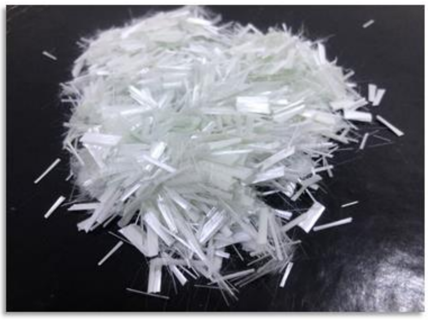

Figure 3Used Fiber

METHODOLOGY

A series of unconfined compressive strength tests were performed on treated samples) that had been cured for 28 days to investigate the compressive strength of geopolymer-treated soils. The UCS test samples were made with 50 mm diameter and 100 mm height cylindrical split tubes made of (PVC) with a height-to-diameter aspect ratio of 2:1. Many studies have recommended this type of plastic mold because it is more resistant to the alkali mixture. To facilitate sample extraction, a longitudinal slit was cut. The mold was restrained by three stainless steel clamps before compaction to prevent volumetric expansion caused by compaction and movement.

A compressive strength test of treated soil specimens was performed using a uniaxial machine with a loading capacity of 50 kN in accordance with (ASTM D1633-00, 2007). A load cell and a Linear Variable Displacement Transducer (LVDT) were used to determine the applied load and the resulting displacements. All UCS testing was done at a displacement rate of 0.1 mm per minute. The compression machine is depicted in Figure 4.Table 3 depicted the details of samples.

Figure 4UCS 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	0.3
2	M(f0.6)			0.6
3	M(f0.9)			0.9
4	M(f1.2)			1.2
5	M(f1.5)			1.5

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

Microstructure Analysis

The microstructure samples were examined by using Field Emission Scanning Electron Microscope (FESEM) with Energy-Dispersive Spectrometer (EDS). That test was performed on small prepared samples taken from samples tested by UCS.

RESULTS AND DISCUSSIONS

Compressive Strength

The main variable influences the effectiveness of fly-ash-based geopolymer as a binder. The effects of fiber ratios were examined for soil to determine a practical geopolymer mixture for soil stabilization and to investigate the reliability of using these new binders in the weak soil stabilization. According to the experimental described in methodology, the unconfined compressive strength (UCS) test was selected to examine the degree of reactivity of different geopolymer content fiber components in treated soils.

The UCS of treated fibers of the geopolymer-soil has been investigated using different fiber ratios (0,0.25, 0.5, 0.75, 1,1.25, and 1.5%), to determine the effect of fiber inclusion on soil-geopolymer strength behavior. The UCS of treated fibers of the geopolymer has been found for the above fiber ratios (1.85,2.15,2.3,2.55,2.62,2.75, and 2.81) MPa. From

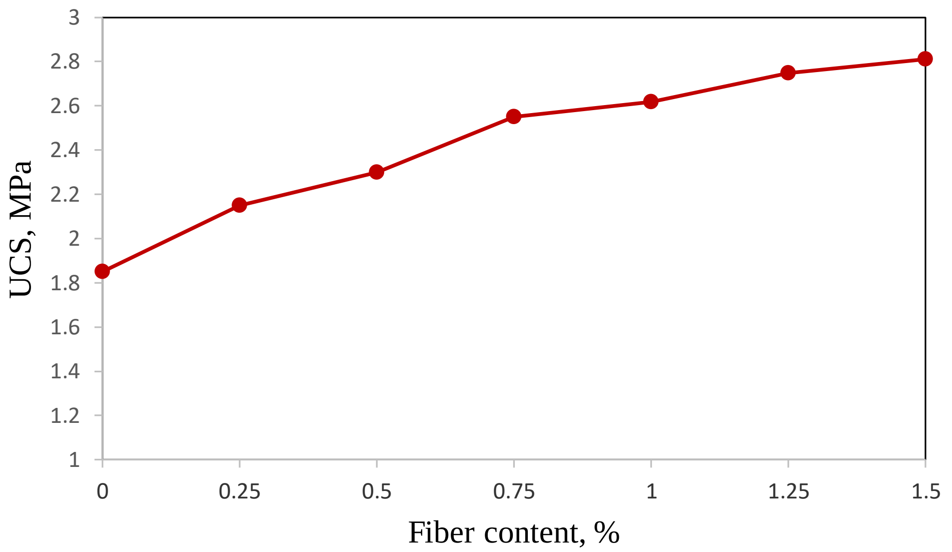

Figure ***5***, it can be noted that the UCS of the specimens has improved with an increase in fiber content from 0% to 1.5%. The increase in the strength can be attributed to the uniform distribution of fibers throughout the treated soil matrix which prevented the occurrence of micro-cracks under loading. This could be due to an increase in the ductility of the treated samples with an increase in the fiber content. The treated specimens reinforced with 1.5% fiber content have shown maximum ductility among the other considered fiber contents. Figure 6shows that the treated fibers reinforced geopolymer- soil led to an approximate 116, 124, 137,141, 148, and 152%, increase in UCS to untreated fibers at (0.25, 0.5, 0.75, 1, 1.25, 1.5%) fiber content, respectively. Although the increasing of the treated fibers ratios resulted in continues increasing in UCS, the rate of improvement become less after (0.75) fiber ratio. therefore, it is recommended to use in process of soil treatment.

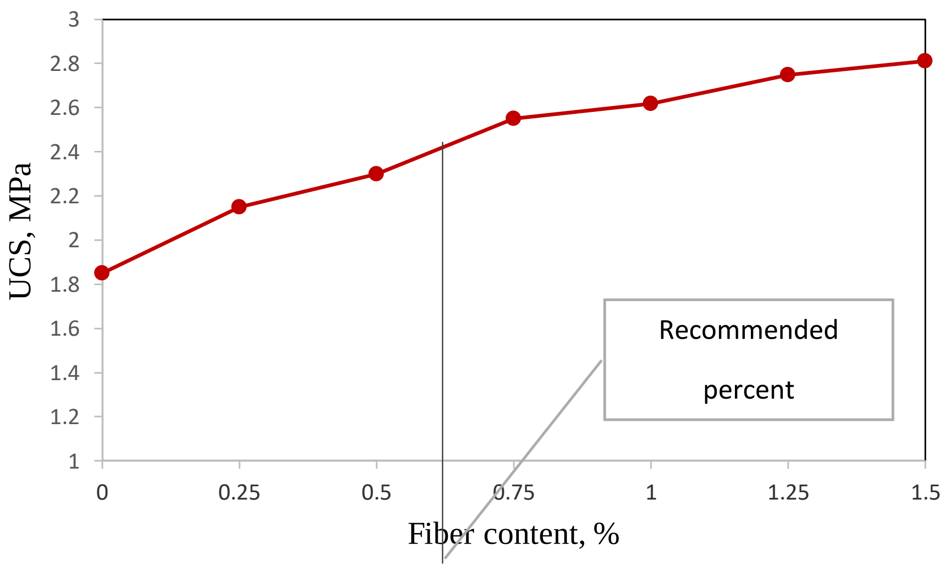

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Figure 5UCS values of fiber-reinforced specimens treated at geopolymer content (20%FA and 0.4 A/F)

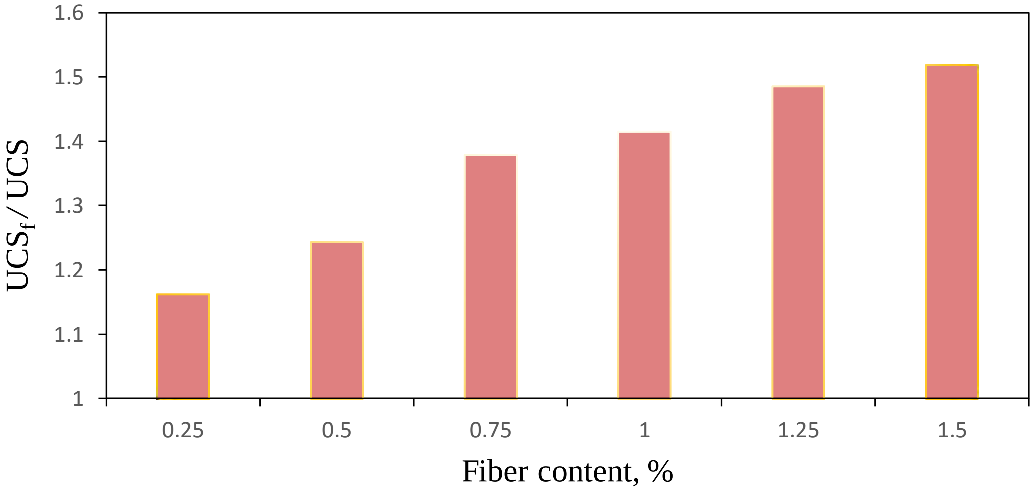

Figure 6Variation UCS for treated and untreated fibers reinforced geopolymer- soil at the different fiber content

Stiffness Behavior of Geopolymer-Treated Soil

stiffness of geopolymer treated soil estimated from the unconfined condition, might help better understand the influence of various experimental variables (such as fiber ratio, and soil type) on the stiffness of the stabilized sand. The measured stiffness E50, the secant modulus at 50% peak strength, of geopolymer-treated sand is shown in Figure 7. In general, increasing the ratio of fiber increased the stiffness of stabilized sand. The observed increase in E50 is primarily due to the increase in effective bonding between the fibers and the surrounding treated soil matrix.

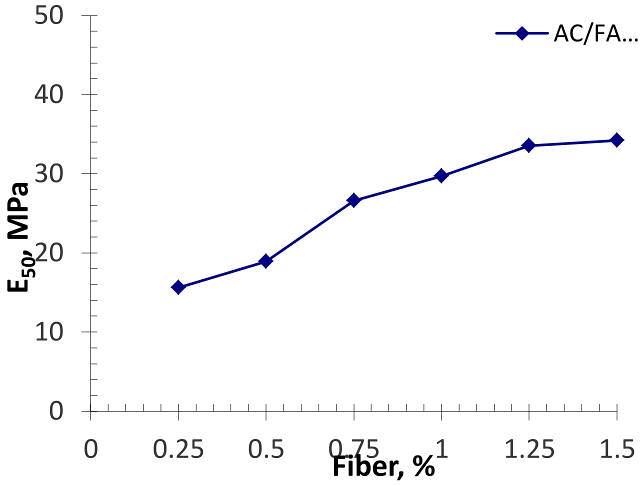

Figure 7Variation of secant modulus with the activator ratio

SEM of Geopolymer Stabilized Soil

Geopolymer-treated samples had compact, stable structures, improving engineering properties. Industrial reinforcement products of soil bonding cause this primary reinforcing. An alkaline medium dissolves silica and alumina oxides from fly-ash particles in geopolymer, forming Sodium Aluminum Silicate Hydrate (N-A-S-H) that hardens and cements soil particles (Cristelo, Glendinning, Miranda, et al., 2012b; Phummiphan et al., 2016). (**Error! Reference source not found.**5) show SEM investigation of soil-geopolymer sample with 20% fly ash and activator/fly ash ratio (0.4). Increased fly ash ratio improves dissolution rate and binding activity, resulting in the most compact structure (Figure 8). Fly ash spaces etched by silica and aluminum decomposition are usually filled with smaller particles and cementitious products, creating a dense matrix. This mechanism alters soil structure and strengthens treated soil, similar with geosynthetic soil research (Abdullah et al., 2019; Cristelo et al., 2013; M. Zhang et al., 2013b).

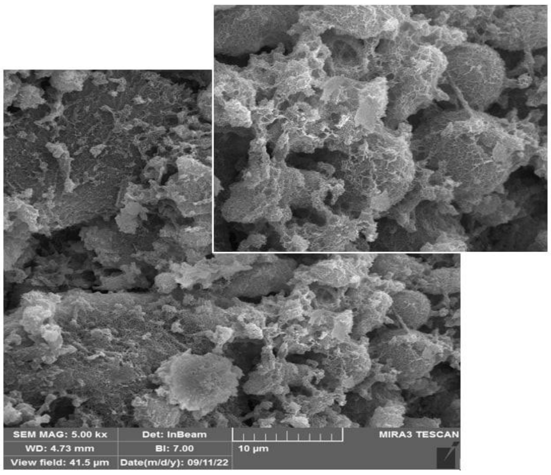

Figure 8SEM images of geopolymer sample (20% fly ash, 0.4 activator)

CONCLUSIONS

1. The strength and stiffness enhancement of sand soil treated with different combinations of fly-ash, activator, and /or fiber was evaluated in the first stage, of this study by conducting UCS tests on treated specimens. The main variable investigated here were the effect of fiber-to-fly ash ratio. It was found that the strength and stiffness characteristics of soil treated with fly ash-based geopolymer could be enhanced significantly with the addition of fiber. Based on the tests' results, The optimum ratio of fiber was1.5% for sand soil.
2. In FESEM analysis, the cementitious products on the fly ash surfaces are observed, indicating a geopolymerization reaction. The etched holes in fly ash surfaces caused by the decomposition of silica and aluminum are mostly filled with smaller particles, resulting in a dense matrix.

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