IMPACT OF SILICA FUME AND BIOCHAR TREATMENT ON THE MECHANICAL CHARACTERISTICS OF LOW PLASTIC SOILS

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Abstract- Bio-cementation soil treatment technique has shown significant strength improvement in the soils. Low plastic silt soils are present in many areas of Pakistan, making the need for acceptable engineering properties to support construction activities necessary. In the current study, silica fume and biochar were used in an attempt to test the unconfined compressive strength (UCS). Several tests including the liquid limit, plastic limit, compaction test and unconfined compressive strength, were carried out on two types of soils with various additions to access the strength parameter. This study aimed to assess the impact of silica fume and biochar treatments on soil UCS results. According to the results, adding silica fume raised the UCS strength by up to 52.85%, while adding biochar enhanced it by up to 117%. Overall, this study highlights that silica fume and biochar have the potential to improve soil properties as a cost-effective and efficient solution for enhancing soil characteristics, particularly in construction projects that require compaction.

Keywords- Biochar, Unconfined compressive strength, silica fume, compaction test.

1 Introduction

Many countries, including Pakistan have a significant presence of low-plasticity silt within their territories. Liquefaction of low plasticity silt is a frequent occurrence during earthquakes, leading to infrastructure damage and the risk of loss of life and this phenomenon has been observed in various earthquakes [1]. Nevertheless, the detrimental consequences on infrastructure and the potential for loss of life are not limited solely to earthquakes. In certain cases, slope failures have been attributed not only due to earthquakes but also to substantial deformations during reconsolidation, accompanied by diminished shear strength [2]. Characterizing low-plasticity silt in laboratory settings poses significant challenges. The preparation and handling of low-plasticity silt specimens for testing purposes are particularly troublesome. This difficulty arises from the material's apparent lack of cohesion, leading to its high friability. As a result, the fabric of low-plasticity silt tends to fracture during the sampling, trimming, and preparation processes [3]. Employing soils found within the project rights-of-way presents an alternative approach that promotes the preservation of natural resources. To implement this alternative, a commonly utilized technique is soil stabilization, which involves the use of lime, hydraulic binders, chemical grouting, and soil reinforcement with geosynthetics and other similar materials this technique aims to enhance the workability and hydromechanical properties of soils, enabling their improved performance [4-7]. Soil stabilization has become a crucial aspect of construction projects such as dam and road construction. The process involves adding and blending different materials to the soil to enhance its properties, leading to long-term stability and improved shear strength parameters. This ultimately enhances the soil's load-bearing capacity, enabling it to support the structure more effectively [8].

Al-Khalili et al. (2021) studied the effect of metakaolin and silica fume on the engineering properties of expansive soil. Their study found that adding silica fume decreased the maximum dry unit weight and the optimal moisture content increased with the addition of silica fume. The liquid limit, plastic limit, and plasticity index of the soil increased as the silica fume increased, reaching maximum values with 15% silica fume [9]. Al-Obaidi, Al-Mukhtar et al. (2020) a comparative study of silica fume and nano-silica that improve the shear strength and collapsibility of high gypseous soil was undertaken. The results of test showed that adding silica fume or nano silica fume to highly gypseous soils improved their engineering qualities, especially when the soil was saturated [10]. Bharadwaj and Trivedi (2016) conducted different experiments to check the impact of micro silica fume on engineering properties of expansive soil. During experiments the different percentages a variety of samples containing 0%, 5%, 10%, and 15% silica fume. It was found that by the addition of different percentages of silica fume, the index properties of the soil was improved [11]. The use of silica fume, phosphogypsum, and biomass ash as additives for soil improvement aims to increase the UCS of the soil, making it more suitable for construction and load-bearing purposes. These materials provide a cost-effective and sustainable approach to enhancing the strength and stability of the soil, reducing the need for extensive excavation and replacement [12]. However, it is important to consider the appropriate dosages and mix design to ensure optimal results and compatibility with specific soil types and project requirements. In the current study silica fume and biomass ash were used to improve the mechanical properties of the low-plastic soils.

2 Materials & Methodology

2.1 Materials

The soils were collected from the Tarnol and Chaklala district of Pakistan which are used in this investigation. The soil samples used in this study were disturbed and found to be silts of low compressibility (ML). The samples were obtained from a depth of 1.5 meter [13] and Table 1 lists the physical properties of soils.

Table 1 Physical properties of soils

Soil Type	**Classification**		**Atterberg's Limits**			**Grain size Distribution**			**Moisture Density Relationship**	
	AASHTO	**USCS**	**L.L (%)**	**P.L (%)**	**P.I (%)**	**Sand (%)**	**Clay (%)**	**Silt (%)**	**MDD (kN/m^3)**	**OMC (%)**
Chaklala	A – 4	ML	17.29	15	2.29	46	18	36	18.41	13.53
Tarnol	A – 4	ML	21.23	18.51	2.71	32	20	48	24.56	11.85

Silica fume, also known as micro silica, is a byproduct of the production of silicon metal and ferrosilicon alloys. It is a highly reactive pozzolanic material with fine particles that can fill the voids in the soil matrix [14]. When mixed with soil, silica fume reacts with the calcium hydroxide present in the soil to form an additional calcium silicate hydrate (CSH) gel. This gel acts as a binder, increasing the cohesion and strength of the soil. The incorporation of silica fume can significantly enhance the UCS of the soil, making it more resistant to deformation and load-bearing and are economic and environmental constraints.

Biomass ash is a byproduct of biomass combustion processes, such as the burning of agricultural residues or wood. It contains high amounts of silica and other mineral compounds [15]. Biomass ash has been found to be effective in improving the UCS of soil due to its pozzolanic and cementitious properties. When biomass ash is added to soil, it reacts with calcium hydroxide to form additional binding compounds, similar to silica fume [16]. This reaction leads to increased strength and durability of the soil. Biomass ash is a carbon-rich material and has been recognized for its potential in carbon sequestration, soil improvement, and wastewater treatment and are economic and environmental constraints.

2.2 Methodology

Sieve Analysis: The soil underwent classification through a sieve analysis test in accordance with the ASTM D 422 standard. A 500gm soil sample was pulverized, dried in an oven, and then subjected to shaking within a set of sieves for a duration of five to ten minutes using a sieve shaker. After removing the sieve set from the shaker, the weight of the material retained on each sieve was measured separately.

Hydrometer Analysis: The hydrometer analysis method is commonly used to estimate the distribution of soil particle sizes from the #200 (0.075 mm) sieve down to approximately 0.001 mm.

Atterberg limits:

Liquid Limit: The testing procedure adhered to the ASTM D423-66 standard, employing a soil sample that had been dried in an oven and filtered through a #40 sieve. The liquid limit was ascertained by counting the number of blows required for the two sections of soil to come into contact with each other.

Plastic Limit: The plastic limit test was conducted following the guidelines of the ASTM D698-70 standard. A soil sample weighing 20 grams was mixed with water until it reached a pliable consistency and then filtered through a #40 sieve. The soil was then rolled into a ball and compressed between a glass plate and palm to form a thread with a uniform diameter of 1/8" or 3mm. The moisture content of the soil was determined by placing it in a container after it was crumbled.

Plasticity Index: The plasticity index, a significant property, is used to assess the swelling characteristics of various soils. It is determined by calculating the difference between the plastic limit and the liquid limit values.

Compaction Test: In order to assess the compaction characteristics of a soil sample, the procedures outlined in the ASTM D1557-12 standard were adhered to, and a modified proctor test was performed. The test commenced with the addition of 3% water by weight, and each subsequent trial increased the water content by 3%.

Unconfined compressive strength: The test was conducted in accordance with ASTM D 2166 (ASTM 2006) guidelines. The mold used in the test had dimensions adhering to the standard ratio of 2:1, with a height of 2.5cm and a diameter of 5cm. The soil samples were prepared based on the optimum moisture content (OMC) and maximum dry density (MDD) of the soil. The strain rate applied during the test was 1mm/min.

3 Results

3.1 Grain Size Analysis

According to the test results, Tarnol soil has 32% sand, 20% clay, and 48% silt, while Chaklala soil has 46% sand, 18% clay, and 36% silt. According to the grain size distribution, the Tarnol soil has a higher proportion of coarser particles than the Chaklala soil, while the Chaklala soil profile has a wider variety of finer particles as shown in Figure 1.

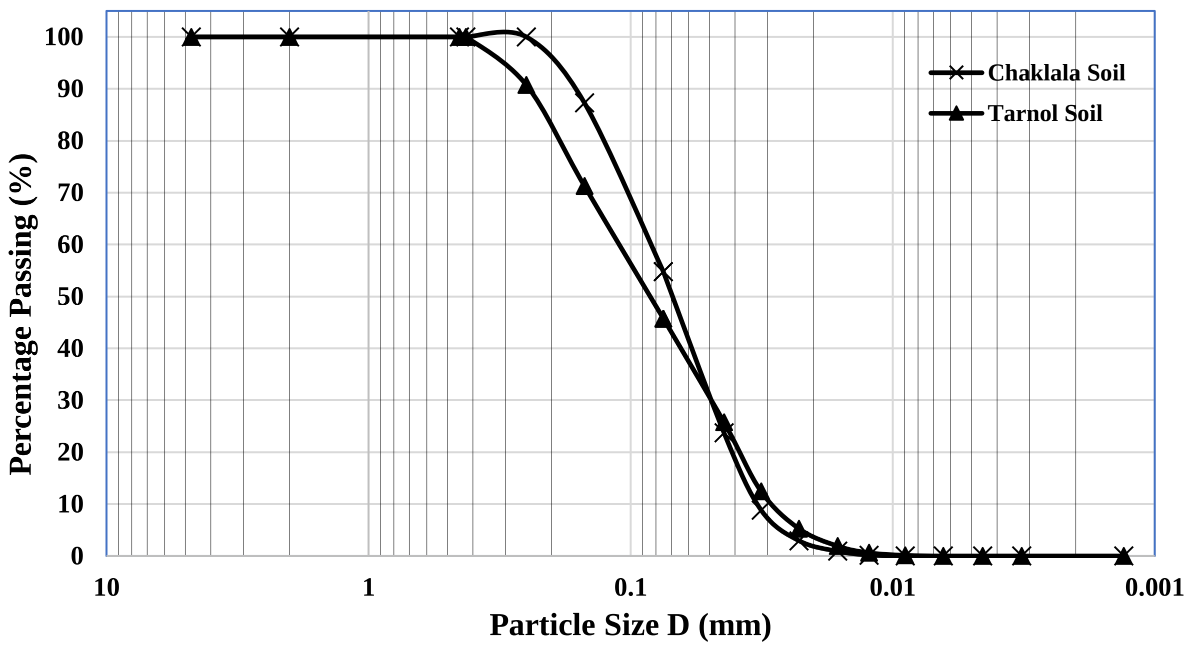

Figure 1 Gradation Curve of Chaklala and Tarnol Soil

3.2 Compaction Test Results

Figure 2 displays compaction curves for both Tarnol and Chaklala soil. The Tarnol soil has a MDD of 24.56 kN/m^3 at an OMC of 11.85% while Chaklala soil has an MDD of 18.41 kN/m^3 at an OMC of 13.53 %. The Tarnol soil has a higher maximum dry density than Chaklala soil, this is due to the soil profile which has a wider variety of finer particles

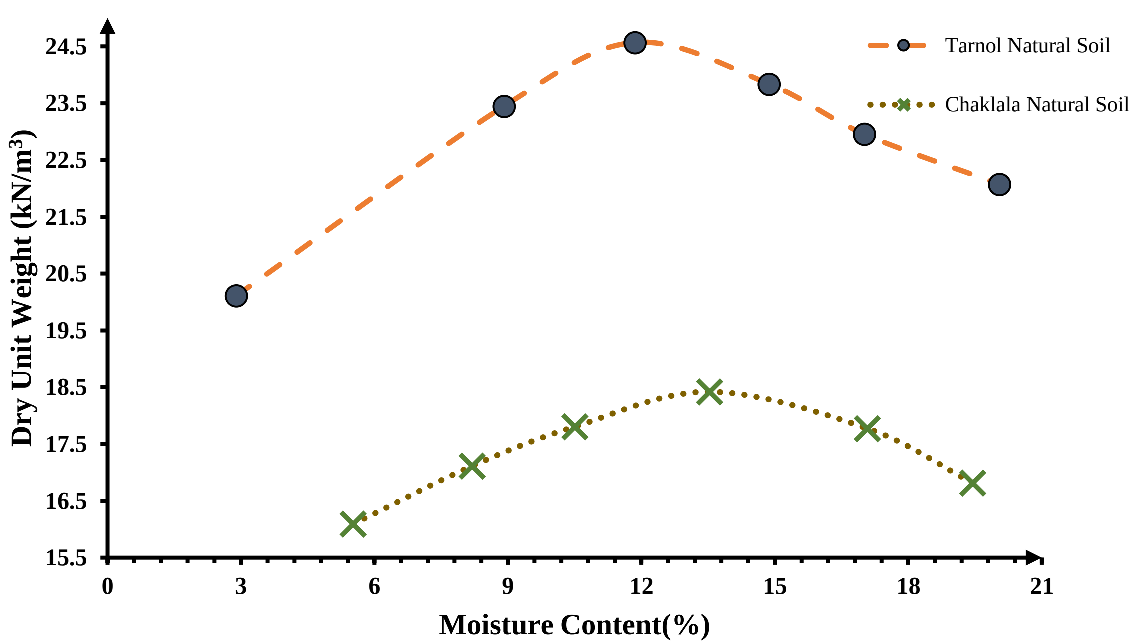

Figure 2: Moisture density relationship of soils

3.3 Unconfined compression test

Figure 3 shows the UCS of both treated and untreated soils the maximum optimum value of silica fume and biochar was calculated by using a compaction test and optimum values were used for the preparation of soil samples. The test results show that with the addition of biochar in Chaklala soil the UCS increased from 45.5 kPa to 98.75 kPa and with the addition of silica fume in Tarnol soil the UCS increased from 60.96 kPa to 93.18 kPa. The enhancement in strength is attributed to the cementitious effect of additives, which leads to better interlocking between the particles which increased its strength significantly.

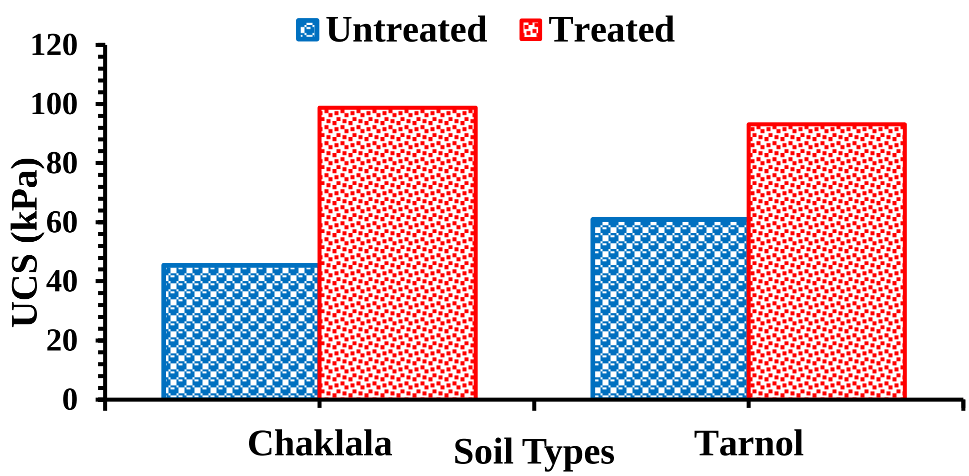

Figure 3: UCS of treated and untreated soils

4 Conclusions

After investigating the influence of silica fume and biochar on the engineering characteristics of the soils, it has been determined both these additives are suitable for modifying geotechnical and engineering properties. The following conclusions have been made based on the outcomes of the tests.

1. The use of silica fume and biochar stabilization has resulted in significant enhancements in the engineering characteristics of each of the two types of soil.
2. The Tarnol soil has an MDD of 24.56 kN/m^3 at an OMC of 11.85% while Chaklala soil has MDD of 18.41 kN/m^3 at an OMC of 13.53 %.
3. With the addition of biochar in Chaklala soil the UCS value increased from 45.5 kPa to 98.75 kPa and with the addition of silica fume in Tarnol soil the UCS value increased from 60.96 kPa to 93.18 kPa. The silica fume improved the UCS strength up to 52.85% and biochar increased the UCS up to 117%.

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References

[1] C. Yilmaz, V. Silva, and G. Weatherill, "Probabilistic framework for regional loss assessment due to earthquake-induced liquefaction including epistemic uncertainty," *Soil Dynamics and Earthquake Engineering,* vol. 141, p. 106493, 2021.

[2] X. Fan *et al.*, "Earthquake-induced chains of geologic hazards: Patterns, mechanisms, and impacts," *Reviews of geophysics,* vol. 57, no. 2, pp. 421-503, 2019.

[3] S. Wang and R. Luna, "Compressibility characteristics of low-plasticity silt before and after liquefaction," *Journal of materials in civil engineering,* vol. 26, no. 6, p. 04014014, 2014.
[4] I. Chang, J. Im, and G.-C. Cho, "Introduction of microbial biopolymers in soil treatment for future environmentally-friendly and sustainable geotechnical engineering," *Sustainability,* vol. 8, no. 3, p. 251, 2016.
[5] G. Archibong, E. Sunday, J. Akudike, O. Okeke, and C. Amadi, "A review of the principles and methods of soil stabilization," *International Journal of Advanced Academic Research| Sciences,* vol. 6, no. 3, pp. 2488-9849, 2020.
[6] M. K. Alhamdi and B. S. Albusoda, "A Review on Deep mixing method for soil improvement," in *IOP Conference Series: Materials Science and Engineering*, 2021, vol. 1105, no. 1: IOP Publishing, p. 012110.
[7] H. Verma, A. Ray, R. Rai, T. Gupta, and N. Mehta, "Ground improvement using chemical methods: A review," *Heliyon,* vol. 7, no. 7, p. e07678, 2021.
[8] H. Afrin, "A review on different types soil stabilization techniques," *International Journal of Transportation Engineering and Technology,* vol. 3, no. 2, pp. 19-24, 2017.
[9] A. M. Al-Khalili, A. S. Ali, and A. J. Al-Taie, "Effect of metakaolin and silica fume on the engineering properties of expansive soil," in *Journal of Physics: Conference Series*, 2021, vol. 1895, no. 1: IOP Publishing, p. 012017.
[10] A. A. Al-Obaidi, M. T. Al-Mukhtar, O. M. Al-Dikhil, and S. Q. Hannona, "Comparative study between silica fume and nano silica fume in improving the shear strength and collapsibility of highly gypseous soil," *Tikrit Journal of Engineering Sciences,* vol. 27, no. 1, pp. 72-78, 2020.
[11] S. Bharadwaj and M. Trivedi, "Impact of micro silica fume on engineering properties of expansive soil," *Int J Sci Technol Eng,* vol. 2, no. 12, p. 435e40, 2016.
[12] A. H. Campos Teixeira, P. R. R. Soares Junior, T. H. Silva, R. R. Barreto, and A. C. d. Silva Bezerra, "Low-Carbon Concrete Based on Binary Biomass Ash–Silica Fume Binder to Produce Eco-Friendly Paving Blocks," *Materials,* vol. 13, no. 7, p. 1534, 2020.
[13] V. Kaushal and S. Guleria, "Geotechnical investigation of black cotton soils," *International Journal of Advances in Engineering Sciences,* vol. 5, no. 2, pp. 15-22, 2015.
[14] C. Negi, R. Yadav, and A. Singhai, "Effect of silica fume on engineering properties of black cotton soil," *Int. J. Comput. Eng. Res.(IJCER),* vol. 83, 2013.
[15] B. S. Thomas, J. Yang, K. H. Mo, J. A. Abdalla, R. A. Hawileh, and E. Ariyachandra, "Biomass ashes from agricultural wastes as supplementary cementitious materials or aggregate replacement in cement/geopolymer concrete: A comprehensive review," *Journal of Building Engineering,* vol. 40, p. 102332, 2021.
[16] N. Jiang, C. Wang, Z. Wang, B. Li, and Y.-a. Liu, "Strength characteristics and microstructure of cement stabilized soft soil admixed with silica fume," *Materials,* vol. 14, no. 8, p. 1929, 2021.