Journal of Advanced Sciences and Engineering Technologies (2025); 8 (1):1-24

DOI: http://doi.org/10.32441/jaset.8.1.6

Journal of Advanced Sciences and Engineering Technologies

www.jasetj.com

Journal of Advanced Sciences and Eng. Technologies

JASET

Shear Strength of Gypseous Soils Enhanced by Ceramic Powder-Based Geopolymers

*Noaf R. A. Al-Rifai**, *Farouk. M. Muhauwiss*

[a] *Civil Engineering Dept./ College of Engineering/Tikrit University /Tikrit, Iraq.*

Keywords:

Alkali-activated materials, Ceramic waste powder, shear strength of soils, Geopolymer, Gypseous soil.

Highlights:

- *Ceramic waste powder-based geopolymer improved the soil by increasing the soil's shear resistance.*
- *Using eco-friendly resources, ceramic waste powdered.*
- *The alkaline activator was made with 6 M sodium hydroxide and a 1:2 ratio of sodium hydroxide to sodium silicate.*

ARTICLE INFO

Article history:

Received	08 Aug	2024
Received in revised form	15 Dec	2024
Accepted	31 Dec	2024
Final Proofreading	10 Oct	2025
Available online	20 Oct	2025

Corresponding author:

Noaf R. A. Al-Rifai*

Civil Engineering Dept./ College of Engineering/Tikrit University /Tikrit, Iraq.

Abstract: When Gypseous soils are prone to loss of strength due to gypsum dissolution and subsequent structural collapse, especially when wet. As a result, it requires environmentally friendly, sustainable treatments, such as recycling building waste and using it to enhance soil properties. To improve gypseous soil, this study employed a geopolymer based on ceramic waste powder. This method offers favorable environmental and mechanical properties, making it a sustainable alternative to ordinary Portland cement. It depends on the use of raw materials high in alumina and silica. Various amounts of ceramic powder are applied to three gypseous soils with variable gypsum content (20, 30, and 53%). 6 M sodium hydroxide and a 1:2 ratio of sodium hydroxide to sodium silicate were used to prepare the alkaline activator. Direct shear tests were performed on specimens in both dry and soaked states to evaluate soil behavior under different loading conditions and to determine the shear strength parameter (cohesion C and the angle of internal friction ϕ) for treated and untreated soil. After the soil is treated with a geopolymer based on ceramic waste, its shear strength increases. As a binding agent, this geopolymer fills gaps and improves soil particle cohesion. It has a comparable effect to cement in terms of increasing shear resistance and cohesion.

INTRODUCTION

In countries with gypseous soils, engineers are increasingly concerned about mitigating their impact on engineering projects. Gypseous soils consist of hydrated calcium sulphate.($CaSO_4.2H_2O$). When dry, gypseous soil is hard, but when water-saturated, it loses its strength [1,2,3]. Both chemical and physical processes can be used to generate the improvement. According to the physical, soil properties can be enhanced by mechanical methods such as dynamic compaction, pre-wetting, stone columns, and compaction [4,5,6]. However, chemical stabilization methods used to improve soil properties include adding chemical additives such as cement, fly ash, rice husk ash, volcanic ash, dehydrated calcium, lime, and chloride [7,8,9].

Chemical stabilization has been widely used recently to treat gypseous soils, along with other stabilizing techniques. Even if chemical stabilizers that improve soil behavior are not considered environmentally beneficial, they may still have harmful consequences, alter soil pH, contaminate groundwater, and pollute the soil [10,11]. Recent research has increasingly focused on sustainable materials made from renewable sources or recycled waste, such as Xanthan Gum, Arabic Gum, Biopolymer, and Fly Ash, along with eco-friendly materials that reduce their environmental impact [12,13].

Because it is environmentally safe and can combine with soil's mineral components to create a more cohesive structure, geopolymer has emerged as one of the most promising alternative materials for soil development in recent years. An alkaline solution and a dry solid, usually an aluminosilicate rich in Al and Si, are combined to create geopolymers, which are inorganic materials with polymeric structures [14]. Alkali hydroxides and silicate solutions are frequently used to activate aluminosilicate wastes or precursors to form geopolymers, which are environmentally friendly alternatives [15,16]. Studies have shown that a geopolymer based on fly ash can improve the properties of a variety of soil types, including gypseous, expansive, backfill, and generated brick soils. By improving compressive strength, reducing plasticity, reducing swelling and shrinkage, reducing collapse potential, and increasing the angle of internal friction, geopolymer has proven to be an environmentally benign material [17,18,19]. However, another study stabilized silty sand using only ceramic powder and sodium hydroxide, thereby increasing the soil's unconfined compressive strength and stabilization [20].

Ceramic powder-based geopolymer has never been used to enhance gypsum soils. Therefore, the purpose of this study is to investigate the additive effects on soil characteristics.

MATERIALS

Soil

Natural gypseous soil was used. Three soil samples were selected from various areas in Salah al-Din Governorate. These specimens were collected between 0.5 and 6 meters below the surface. A considerable 20% gypseous content was found in Soil 1. The second sample, Soil 2, has a high gypseous concentration of 30%. At 53, Soil 3 has a highly gypseous content. A set of physical and chemical tests was conducted on the three soils, including dissolved materials, organic materials, acidity, maximum density, gypsum content, optimal moisture content, sieve analysis, and Atterberg limits. Table 1 lists the physical and chemical characteristics of soils.

Table 1 Physical and chemical properties of three soil samples

Characteristics		Value			ASTM Standard
		Soil 1	Soil 2	Soil 3	
Unified Soil Classification System (USC's)		SP	SP	SP	
Uniformity Coefficient (Cu)		12	10.11	5.29	
Curvature Coefficient Of (Cc)		0.278	0.34	0.26	
Specific Gravity (Gs)		2.64	2.62	2.41	ASTM D854
Atterberg's Limits	(L.L) %	30	28	25	ASTM D4318
	(P.L) %	N. P	N. P	N. P	
Unit Weight in Field (γ_{field}) kN/m^3		14	13	15.5	ASTM D1556
Max Dry Unit Weight ($\gamma_{dry)\ max}$ kN/m^3		19.5	18.8	17	ASTM D1557
Optimum Moisture Content (O.M.C) %		10	9.5	11.7	ASTM D1557
Gypsum Content %		20	30	53	
Total Soluble Salts (T.S.S) %		31.1	41.02	61.07	
Organic Materials (O.M) %		0.015	0.02	0.09	
pH		7.8	7.45	7.94	

Ceramic Waste Powder

One sustainable resource is ceramic waste powder (CWP). Building waste at Tikrit University was used to gather ceramic pieces, which were crushed to a suitable size with particles smaller than 0.075 mm after passing through sieve No. 200

Alkaline Geopolymer Solution

Sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) are used in the alkaline solution at a weight ratio of 1:2, meaning that for every 1 weight part of NaOH, 2 weight parts of Na_2SiO_3 are employed, as illustrated in the figures 1 and 2. Sodium silicates have an alkaline pH of 11 to 13, making them a sticky liquid. Sodium hydroxide, a white, solid ionic compound, contains the ions sodium (Na+) and hydroxide (OH-). Water was used to dissolve 6M sodium hydroxide to create the solution. The solution was usable after a day, after which the silicate content had doubled.

Fig. 1 The Solid White Flakes of Sodium Hydroxide

Fig. 2 Viscous Liquid of Sodium Silicates

SAMPLE PREPARATION AND TESTING

The experimental procedures are listed below:

1. To prepare the alkaline solution, 240 grams of sodium hydroxide were dissolved in one liter of water, resulting in a 6M concentration. The solution was then left to stand at room temperature for 24 hours in a glass beaker.
2. After the reactions were complete, twice the amount of sodium silicate, 480 grams, was added, and the mixture was thoroughly stirred.
3. Several tests were carried out to find the ideal amount of ceramic powder to add and the curing time. After testing a range of CWP ratios (3%, 5%, 10%, 15%, and 25%) across 0, 3, and 14 days, three ratios were chosen using a single oedometer test.
4. This trial was conducted on soil 3 (53% gypsum content). Then, (2%,4%,8%),14 days were selected for the tests, and an alkaline activator solution with a 6 M concentration was used.
5. The test was conducted according to ASTM D3080 (2011) to determine the shear strength characteristics of both the untreated soil and the soil treated with a ceramic powder-based geopolymer, under both dry and soaked conditions.

RESULTS AND DISCUSSION

The direct shear test is an engineering test used to determine the shear properties of soil, including the angle of internal friction and cohesion. This test is performed by subjecting a soil sample to horizontal shear forces under a constant vertical load, thereby providing insight into the soil's response to various loads. Table 2 displays the results of both dry and soaked soil.

Table 2 displays the outcomes of untreated soils.

Parameter	Soil 1	Soil 2	Soil 3
Cohesion (c) (kPa)	14.2	16.5	17.2
Cohesion(c)after soaking (kPa)	5.3	4.2	2
Friction angle (ϕ) (degree)	32.9	34.6	36.1
Friction angle (ϕ) after soaking (degrees)	28.9	30.6	32.3

Three different proportions of ceramic powder (2%,4%,8%) and an alkaline solution were added to three different soils of different contents of gypsum (20,30,50%) to enhance them. To determine how the addition affected the soils' engineering properties, the performance of the improved soils was evaluated in two different scenarios: moist and dry. Figures. 3 to 8 shows the shear strength of treated soil and untreated soil for both conditions (dry and soaked)

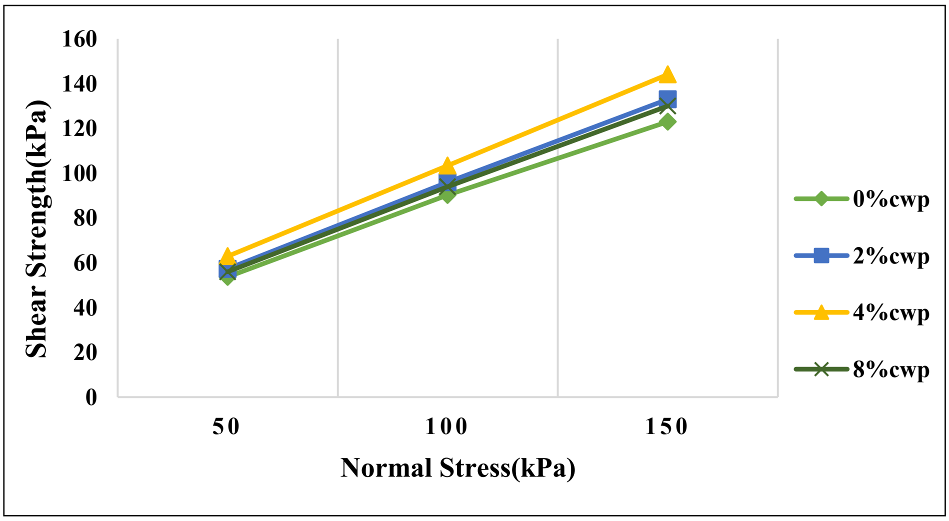

Figure 3. Shear strength of CWP-treated and untreated soil 1 (dry condition)

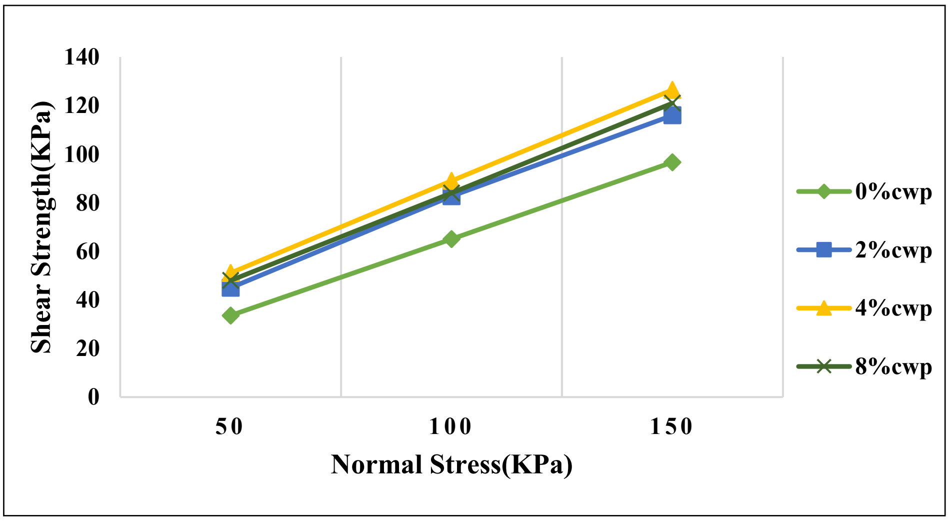

Figure 4. Shear strength of CWP-treated and untreated soil 1 (soaked condition)

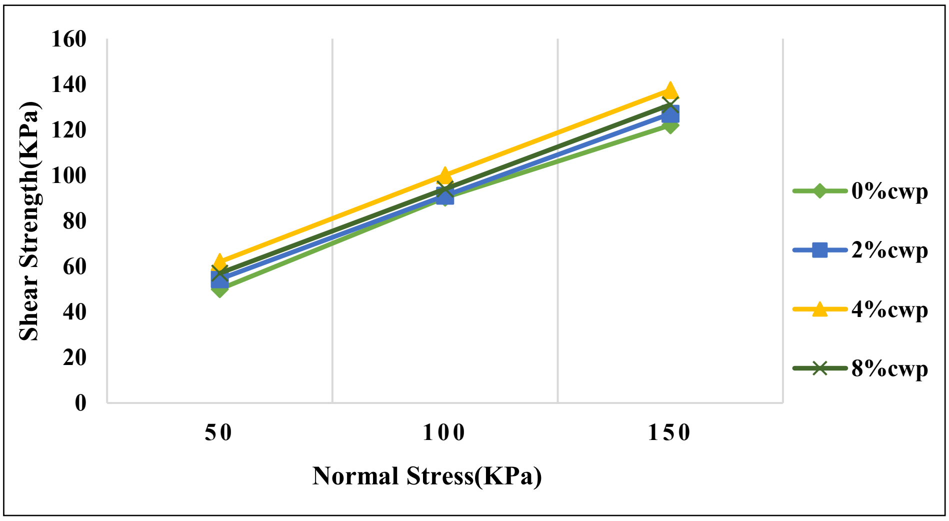

Figure .5 Shear strength of CWP-treated and untreated soil 2 (dry condition)

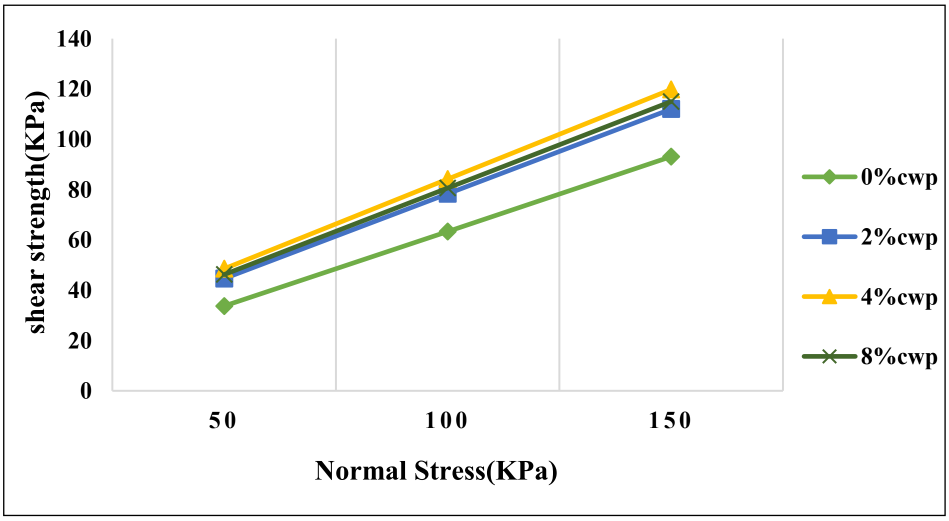

Figure 6: Shear strength of CWP-treated and untreated soil 2 (soaked condition)

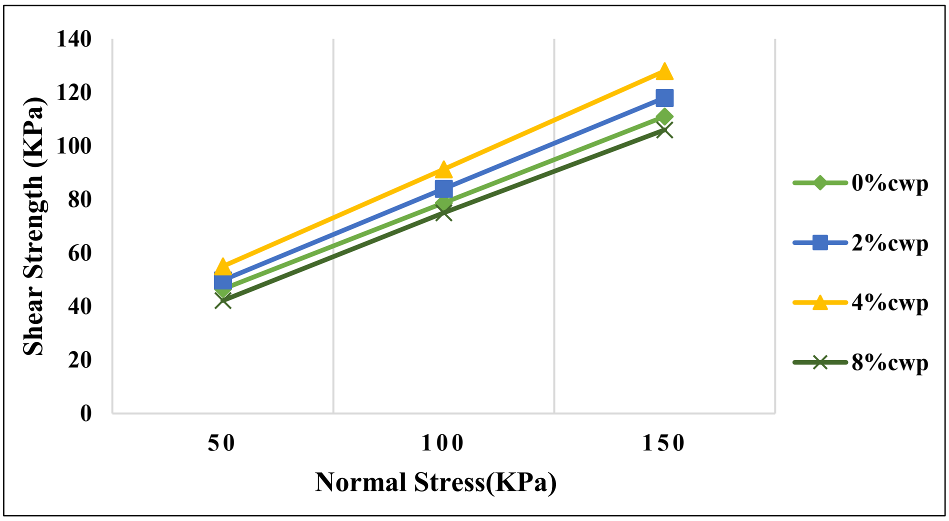

Figure .7 Shear strength of CWP-treated and untreated soil 3 (dry condition)

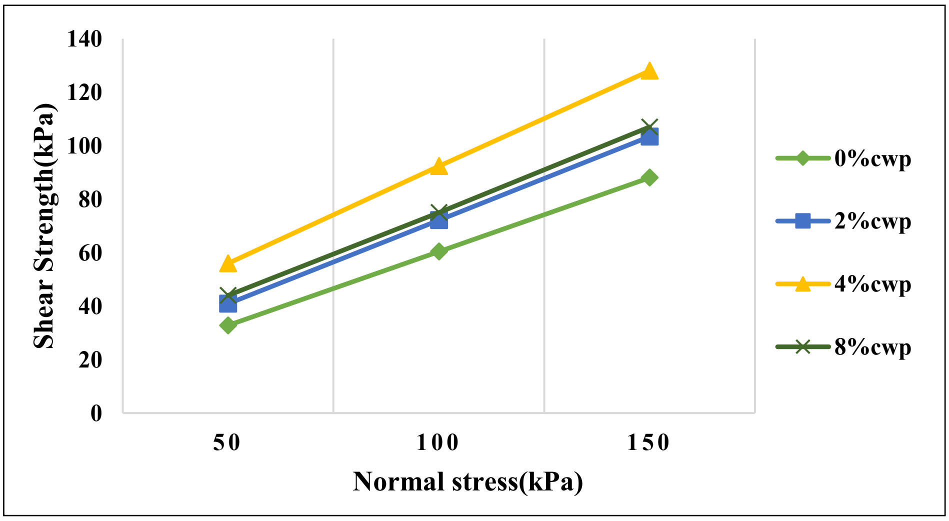

Figure .8 Shear strength of CWP-treated and untreated soil 3 (soaked condition)

CONCLUSIONS

The use of ceramic powder-based geopolymers with varying gypsum contents (20, 30, 53%) to improve gypseous soil was investigated. The activator molarity (6M), the activator ratio Na_2SiO_3 to NaOH 2:1, the curing period of 14 days, and different percentages of CWP are the primary parameters examined in this work.

• The direct shear test findings show that every gypseous soil has a cohesiveness value. The cementing action of gypsum alone in the untreated gypseous soil and the combined cementing action of gypseous, geopolymer, and CWP in the treated gypseous soil could be the reason for this. Adding a 4% CWP ratio increased the soil cohesiveness of CWP-treated soils from 14.2 kPa to 19.9 kPa under dry conditions, with an increase of up to 40.14%. However, the cohesiveness rate increased by 16.2% and 19.72%, respectively, with CWP ratios of 2% and 8%, respectively. For 0 and 4% CWP ratios, the angle of internal friction (ϕ) likewise increased from 32.9° to 36.7°. At a rate of up to 34.55%, the cohesiveness of soil 2 increased from 16.5 kPa to 22.2 kPa upon the addition of a 4% CWP ratio. The cohesion, however, increased by around 15.15% and 21.21%, respectively, with 2% and 8% CWP. Additionally, the angle of internal friction (ϕ) improved from 34.6° to 38.4° for a CWP ratio of 0 and 4%. Additionally, applying 4% of the CWP raised the cohesiveness value of the soil with the highest gypsum content (soil 3) by 38.39%, from 17.2 kPa to 23.9 kPa. In parallel, the cohesion values increased by 16.86% and 20.35% for CWP ratios of 2 and 8%, respectively. In addition, the angle of internal friction (ϕ) increased for both 0 and 4% cwp ratios from 36.1° to 40°.

ACKNOWLEDGEMENTS

The authors are grateful for the financial support for this research from the Civil Engineering Department, College of Engineering, Tikrit University. Postgraduate Research Grant (PGRG) No.TU.G/2021/HIR/MOHE/ENG/39 (19351-7-3).

NOMENCLATURE

CWP	Ceramic Waste Powder
M	Molarity
FA	Fly Ash
SH	Sodium Hydroxide
SS	Sodium Silicate
GP	Geopolymer

REFERENCES

[1] Hassan, N. A., Ahmed, H. A., & Mohammed, A. K. (2024). Original Research Article: Enhancing the engineering properties of gypseous soils by adding the Anthan polymers.

[2] Fattah, M. Y., Al-Obaydi, M. A., & Al-Jalabi, F. A. (2018). Effect of number of piles on load sharing in a piled raft foundation system in saturated gypseous soil. Int. J. Civ. Eng. Technol, 9, 932-944.

[3] Muhauwiss, F. M. (2018). Physical properties of gypseous soil after gypsum removal using EDTA solution. Tikrit Journal of Engineering Sciences, 25(2), 68-73.

[4] Majeed, A. H., & Al-Rkaby, A. H. (2023). Improving weak soils with reinforced stone columns. 3c Tecnología: glosas de innovación aplicadas a la pyme, 12(2), 78-91.

[5] Awn, S. H. A., Abd-Alsattar, W., & Abbas, H. O. (2012). Improvement of gypseous soil by compaction and addition of cement. Journal of Engineering and Sustainable Development, 16(2), 74-88.

[6] Awn, S. H. A. (2011). Improvement of gypseous soil by pre-wetting.

[7] Al-Juari, K. A. (2009). Volume change measurement of collapsible soil stabilized with lime and waste lime. Tikrit Journal of Engineering Sciences, 16(3), 38-54.

[8] Muhauwiss, F. M., & Hassoun, S. S. (2021). Effect of wetting and drying cycles on the durability of gypsum soils treated with calcium chloride or cement additives. Tikrit Journal of Engineering Sciences, 28(2), 80-92.

[9] Hussein, A. H., Muhauwiss, F. M., Hassan, N. A., & Theyab, A. F. (2023). Evaluating the shear strength of agar gum-treated gypseous soil. In Smart Geotechnics for Smart Societies (pp. 498-504). CRC Press.

[10] Ayeldeen, M., Negm, A., El-Sawwaf, M., & Kitazume, M. (2017). Enhancing the mechanical behaviors of collapsible soil using two biopolymers. Journal of rock mechanics and geotechnical engineering, 9(2), 329-339.

[11] Al-Obaidi, A. A., Al-Mukhtar, M. T., Al-Dikhil, O. M., & Hannona, S. Q. (2020). 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, 27(1), 72-78.

[12] Theyab, A. F., Muhauwiss, F. M., & Alabdraba, W. M. (2020). Effects of xanthan gum biopolymers on gypseous soils characteristics. Tikrit Journal of Engineering Sciences, 27(2), 22-28.

[13] Muhauwiss, F. M., Hussein, A. H., & Hussein, M. A. (2024). Shear strength durability investigation for gypseous soil enhanced by pectin biopolymer. Tikrit Journal of Engineering Sciences, 31(2), 175-183.

[14] Sbahieh, S., McKay, G., & Al-Ghamdi, S. G. (2023). Comprehensive analysis of geopolymer materials: Properties, environmental impacts, and applications. Materials, 16(23), 7363.

[15] Raoof, S. M., & Hameed, A. M. (2025). Compressive Strength of Geopolymer Mortar Produced from Fire Brick and Ceramic Waste.

[16] Mahmood, T. E., Hamed, M. H., & Ibrahim, A. K. (2023). Geotechnical Behaviour of Gypseous Soil Treated by Geopolymer Additives.

[17] Murmu, A. L., & Patel, A. (2020). Studies on the properties of fly ash–rice husk ash-based geopolymer for use in black cotton soils. International Journal of Geosynthetics and Ground Engineering, 6, 1-14.

[18] Ahmad, M. M., Muhamad, K., Razak, R. A., Abdullah, M. M. A. B., Hashim, N. H., & Othman, N. A. F. (2023, July). The effect of fly ash on the alkaline activator ratio on the mechanical properties of stabilized lateritic soil using fly ash-based geopolymer. In IOP Conference Series: Earth and Environmental Science (Vol. 1216, No. 1, p. 012029). IOP Publishing.

[19]Leong, H. Y., Ong, D. E. L., Sanjayan, J. G., & Nazari, A. (2018). Strength development of soil–fly ash geopolymer: Assessment of soil, fly ash, alkali activators, and water. Journal of Materials in Civil Engineering, 30(8), 04018171

[20] Kasehchi, E., Arjomand, M. A., & Elizei, M. H. A. (2024). Experimental investigation of the feasibility of stabilizing inshore silty sand soil using geopolymer based on ceramic waste powder: An approach to upcycling waste material for sustainable construction. Case Studies in Construction Materials, 20, e02979.

[21]ASTMD3080/D3080M-11. (2011). "Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions," ASTM International, West Conshohocken, PA.

[22] ASTM D1556/ D1556M-15e1. (2015). "Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method." ASTM International, West Conshohocken, PA.

[23] ASTM D1557-12e1. (2012). "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft3 (2,700 kN-m/m3))." ASTM International, West Conshohocken, PA.

[24] ASTM D4318. (2017). Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. ASTM International, West Conshohocken, PA.