https://doi.org/10.26682/sjuod.2023.26.2.19
Journal of University of Duhok., Vol. 26, No.2 (Pure and Engineering Sciences), Pp 189-200, 2023
(Special Issue)

UTILIZING GLASS POWDER AND LIMESTONE DUST AS AN ALTERNATIVE TO PORTLAND CEMENT FOR STABILIZATION OF CLAYEY SOILS

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(Accepted for Publication: November 27, 2023)

ABSTRACT

This study investigates the potential of limestone dust and glass powder, byproducts of limestone quarrying and recycled glass waste, respectively, as environmentally-friendly alternatives to cement for soil stabilization. Laboratory tests were carried out on clayey soils mixed with varying dosage rates (3%, 6%, and 9%) of glass powder, limestone dust and Portland cement. The geotechnical properties, including Atterberg limits, compaction and unconfined compressive strength, were evaluated to assess their effectiveness in soil stabilization. The results demonstrate that both glass powder and limestone dust can serve as applicable alternatives to cement, offering sustainable solutions with improved soil stability. This research contributes to reducing the reliance on cement for soil stabilization, promoting environmentally-friendly practices in construction.

KEYWORDS: *Limestone dust; Glass powder; Soil stabilization; Geotechnical properties; Recycled materials*

1. INTRODUCTION

A multitude of waste materials is generated worldwide, necessitating the development of proper disposal methods and effective soil stabilization techniques. It is crucial to establish economical, and efficient ways of assessing the pollution risks associated with such materials by emissions and leachates. Various waste materials, including plastics, glass, incinerator ash, scrap tires, foundry wastes, boiler slag, quarry waste, carpet fibers, wood waste, waste iron powder, and others, exhibit potential for use in geotechnical engineering applications. These materials offer numerous environmental benefits, including cost-effectiveness in terms of disposal and the possibility of recycling.

Traditionally, soil stabilization has relied on agents for instance cement, lime, bitumen, and fly ash. These additives have been proven to enhance the strength and stability of soils, as confirmed by laboratory and field tests. However, the cost of using these additives has risen in recent years. Consequently, this has created an opportunity for the development and introduction of alternative soil additives (Ingles and Metcalf, 1972).

In response to the growing demand for infrastructure, significant advancements have been made in soil stabilization techniques. These advancements have led to the emergence of more cost-effective and efficient methods. One such alternative is the use of waste materials. Various waste materials, including plastics, glass, incinerator ash, scrap tires, and others, have shown potential for application in geotechnical engineering. Not only do these materials offer environmental benefits, but they are also cost-effective in terms of disposal and possible recycling (Naeini et al., 2008; Okonkwo et al., 2012; Barazesh et al., 2012).

The increase in population growth and construction activities has led to a high demand for crushed gravel and limestone in various construction projects worldwide. However, a significant amount of the resulting dust from blasting and crushing these materials is not being reused but rather disposed of, posing health and environmental problems. Recycling these materials has become a pressing concern for many countries. One potential method is using them as soil stabilizers, particularly in treating problematic soils like soft and expansive clays. The stability of various structures, including foundations, highways, roads, and runways built on these soils is affected by excessive swelling and shrinkage. Thus, Hassan et al. (2020) found

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that limestone and gravel dusts are cost-effective waste materials, possess properties that can be efficiently utilized for soil stabilization in expansive clay.

Similarly, due to the improvement in living standards and industrial development, a high amount of wastes are generated globally each year. The major contributors to this waste are glass powder, plastic, and e-waste, amounting to millions of tonnes (Abdel-Shafy and Mansour, 2018; Rai et al., 2020). The Kurdistan Region of Iraq also faces challenges in dealing with waste materials, particularly waste glass. The continuous production of these wastes has led to the accumulation of big garbage dumps, causing various health and environmental issues. Recent research suggests that waste materials can be used as stabilizing agents with problematic soils, and the use of glass powder, in particular, can enhance several engineering and index properties of the soil, providing a cost-effective solution for waste disposal and soil stabilization (Vijayakumar, 2019; Chaugule et al., 2017; Hotti et al., 2019; Rai et al., 2020).

Researchers have explored the use of glass powder waste to improve the characteristics of soils in engineering applications and minimize their environmental consequences. Zaid and Noor (2018) investigated the usage of waste glass powder in subgrade soils for pavement applications by determining the ideal proportion of glass powder that enhanced the UCS and CBR values. Muhammad et al. (2018) analyzed the effects of waste glass powder on loose soils, finding positive changes in geotechnical properties and highlighting environmental, technical, and economical advantages. A study by Babatunde et al. (2019) examined the impact of waste glass powder on the engineering properties of black cotton soil, determining the efficient percentages that yielded favorable results in CBR and UCS tests. Olufowobi et al. (2014) investigated the impact of glass powder on clayey soil, finding variations in MDD, OMC, CBR, and internal friction angle. Canakci, Al-Kaki, and Celik (2016) blended waste soda-lime glasses (WSLGP) with clayey soil, resulting in increased MDD and CBR values, reduced optimum water content and plasticity index, and improved strength. Ikara, Kundiri, and Mohammed (2015) utilized waste glass and cement to improve black cotton soil, observing reductions in LL, PL, and PI with increased waste glass content, and identifying the optimum proportions for achieving high UCS and CBR values. Gowtham et al. (2018) founded the optimal percentages for improving the properties of silty soil treated with glass and plastic powder.

Researchers have also conducted many investigations into the mechanical and physical properties of soil when incorporating waste materials. Tiwari et al. (2016) utilized polypropylene fibers with stone dust to enhance the properties of weak soil, resulting in significantly increased strength. Pastor et al. (2019) conducted standardized tests and X-ray analysis to assess the effects of limestone powder on clayey soil, observing improved geotechnical properties such as increased strength and reduced volume changes. Memon et al. (2015) examined the use of limestone dust to improve the swelling properties of expansive soil, finding a significant reduction in the free swelling ratio. Dixit and Patil (2016) studies the use of stone dust to enhance soil properties through standard laboratory tests like Atterberg limits, compaction, and CBR, showing improvements in these properties. Malik and Priyadarshee (2018) carried out compaction tests and swell tests on clayey soil stabilized with stone dust and fly ash as additives, resulting in improved compaction and swelling behavior. Sabat and Muni (2015) highlighted that the clayey soil treated with limestone dust led to an increase UCS, CBR, and improved Atterberg limits. Bshara et al. (2014) examined the utility of stone dust in improving weak soil for subgrade applications, finding improvements in CBR and MDD of the soil. Additionally, the study highlighted a decrease in LL, PL, PI, and OMC after addition of stone dust, supporting its usefulness in subgrade soil stabilization. Hassan et al. (2020) studied the effects of limestone and gravel dusts on clayey soil, observing significant improvements in LL, PL, PI, OMC, MDD, CBR, and swelling behavior.

The current study centers around investigating the impact of waste materials, specifically glass powder and limestone dust as potential alternatives to Portland cement, on the geotechnical properties of soil. Various standard laboratory tests were conducted to assess the effects of these waste materials on soil characteristics. These tests included determining liquid and plastic limits, standard compaction, and unconfined compressive.

2. MATERIALS

2.1 Soil

The soil used in this study was collected from Peshkhabir area, Zakho district, Kurdistan Region of Iraq. Table 1 below highlight the physical properties of the natural soil used in this study.

Table (1):- Properties of the Investigated Soil

Property	Value	Standard
Soil type	CL	ASTM D2487
Liquid limit (LL) (%)	48.5	ASTM D4318-10
Plastic limit (PL) (%)	27.4	ASTM D4318-10
Plasticity index (PI) (%)	21.1	ASTM D4318-10
Maximum Dry Density (MDD)(kN/m^3)	14.1	ASTM D1557-09
Optimum Moisture content (OMC) (%)	25	ASTM D1557-09
Unconfined Compressive Strength (UCS) (kPa)	189	ASTM D-2166

2.2 Glass Powder

Glass powder was obtained from the glass wastes by utilizing a specialized hammer for manual crushing at the Soil Mechanics Laboratory of the College of Engineering, University of Duhok. Subsequently, the resulting glass particles were carefully sieved through a #40 sieve (refer to Figure 1).

a: Glass Waste used for tests before pulverization

b: Glass Waste used for tests after pulverization

Fig.(1): -Glass waste materials used for this study

2.3 Limestone Dust

Limestone dust was sourced from the crusher plant during the extraction of subbase type R7 from limestone found in the Sijee area of Duhok city, Iraq. The generated limestone dust was sieved on a #40 sieve. The limestone originated from Bekhir Mountain (see Figure 2).

Fig.(2): -: Limestone dust used for this study

https://doi.org/10.26682/sjuod.2023.26.2.19
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2.4 Portland Cement

Ordinary Portland cement was employed for stabilizing the soil. Using such materials is considered a conventional soil stabilizer. Therefore, the impact of cement on the soil is compared with the impact of glass powder and limestone dust on the same soil.

2.5 Percentage of soil stabilizer

Table 2.2 below shows the percentage of each stabilizer that was used for this study.

Table (2):- Dosage rates of the soil stabilizers

Property	Stabilizer dosage rate (%)1		
Natural soil	-	-	-
Soil + Glass Powder	3	6	9
Soil + Limestone dust	3	6	9
Soil + Portland Cement	3	6	9
1 = percentage of clay mass			

3. Laboratory Tests

The laboratory tests conducted encompassed the determination of Atterberg limits, compaction properties, and unconfined compressive strength for both the natural soil and the soil stabilized with glass powder, limestone dust, and Portland cement. In each test, the selected stabilizer content (3%, 6%, and 9% of the soil weight) was meticulously mixed with the oven dry soil in small increments by hand. To ensure a well-blended mixture, particular attention was given to preventing the stabilizers from forming lumps. As depicted in Figure 3, the necessary amount of water was subsequently added to the mixture.

Fig.(3): -Mixing the stabilizers with soil

3.1 Atterberg limits tests

The Atterberg limits tests were carried out following the guidelines of ASTM D4318 - 10. The objective of these tests was to examine the influence of glass powder, limestone dust, and cement on the LL, PL, PI of the soil.

3.2 Compaction Test

The compaction tests were carried out following the ASTM D698 procedure. The primary objective of these tests was to assess the influence of glass powder, limestone dust, and cement on OMC and MDD of stabilized soils. Additionally, the parameters obtained from these tests were utilized to prepare samples for UCS test.

3.3 Unconfined Compressive Strength Test (UCS Test)

This test was done to assess the impact of incorporating glass powder, limestone dust powder and cement on the UCS of the clayey soil. This test was conducted following the guidelines of ASTM D2166. Each UCS test specimen was prepared at its respective MDD and OMC.

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4. RESULTS AND DISCUSSION

4.1 Atterberg limits tests:

The natural soil had LL, PL, and PI values of 48.5%, 27.4%, and 21.1%, respectively. In general, Atterberg limits decreased with the increase in the percentage of stabilizers. The impact of glass powder, limestone dust, and cement on the Atterberg limits of the soil is illustrated in figures (4), (5), and (6) respectively.

Figure 4 demonstrates the relationship between the dosage rates of glass powder and their effect on PL, LL, and PI. In overall, the results clearly show that LL, PL, and PI of soil decreases as the percentage of glass powder increases. According to Nuruzzaman and Hossain (2014), this decrease can be attributed to the high silica content in waste glass powder. Similarly, Parihar, Garlapati, and Ganguly (2018) stated that the decrease in Atterberg limits is due to the low calcium oxide content and high silica content. These results align with the results obtained by Fauzi, Rahman, and Jauhari (2013) and Ibrahim et al. (2021).

Likewise, increasing the content of limestone leads to a reduction in LL, PL, and PI. Figure 5 illustrates that for limestone dust contents of 3%, 6%, and 9%, LL decreases by 5.6%, 3.9%, and 6.2% respectively, PL decreases by 2%, 3.9%, and 4.9%, and PI decreases by 0.1%, 1.3%, and 2.6% respectively. Similarly, to these results were reported by Hassan et al. (2020), Ahmed et al. (2020), and Bshara et al. (2014). As per Brooks et al. (2011), with addition of limestone dust, the calcium cations in the dust exchange the soil cations, resulting in a reduction in the thickness of the diffuse double layer. This, in turn, leads to a decrease in LL and PL. The mixture of soil and limestone dust undergoes a pozzolanic reaction, creating cementitious compounds that fill the soil voids and reduce the PI of the soil as per Al-Swaidani, et al. (2016). (Ahmed et al. (2020) also mentioned that adding limestone dust improves the consistency and workability of weak soil. Negi et al. (2013) highlighted that by adding lime dust to the soil causes the soil particles to flocculate and agglomerate, thereby improving the soil's consistency.

Figure 6 shows the results of Atterberg limit tests on soil stabilized with cement, a traditional soil stabilizer. The results reveal a significant reduction in LL and PI after the addition of cement.

Overall, the addition of glass powder, limestone dust, and cement led to a decrease in the PI of the soil. The decrease in this aspect is regarded as an enhancement in soil properties, as it leads to decrease the soil's affinity to water, as mentioned by Hassan et al. (2020). The study results showed that cement has a greater efficacy in reducing PI when compared to limestone dust and glass powder.

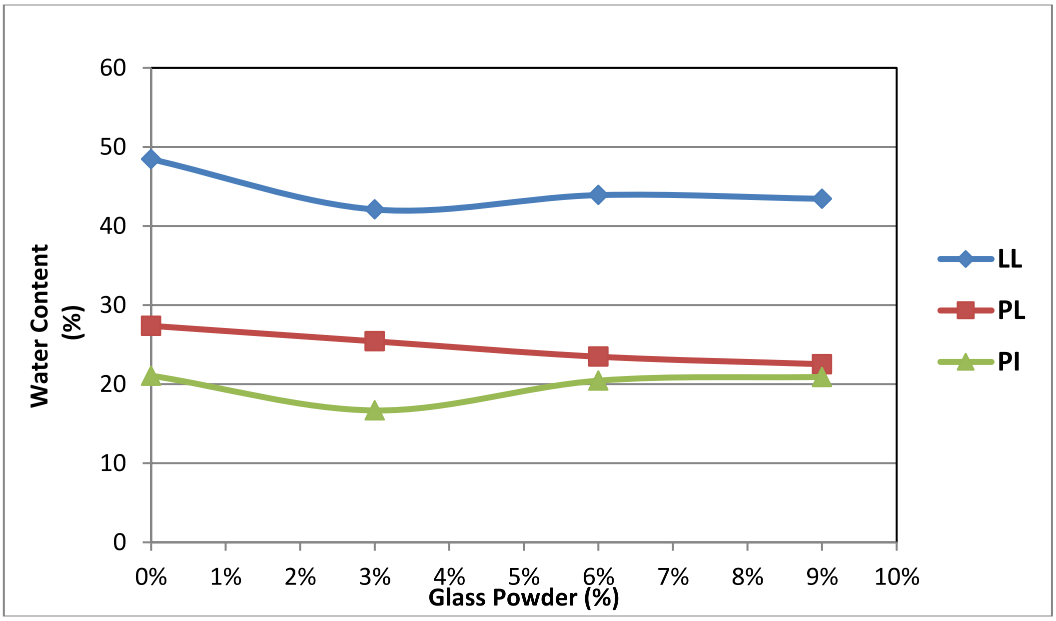

Fig.(4): -Variation of LL, PL and PI with Glass powder

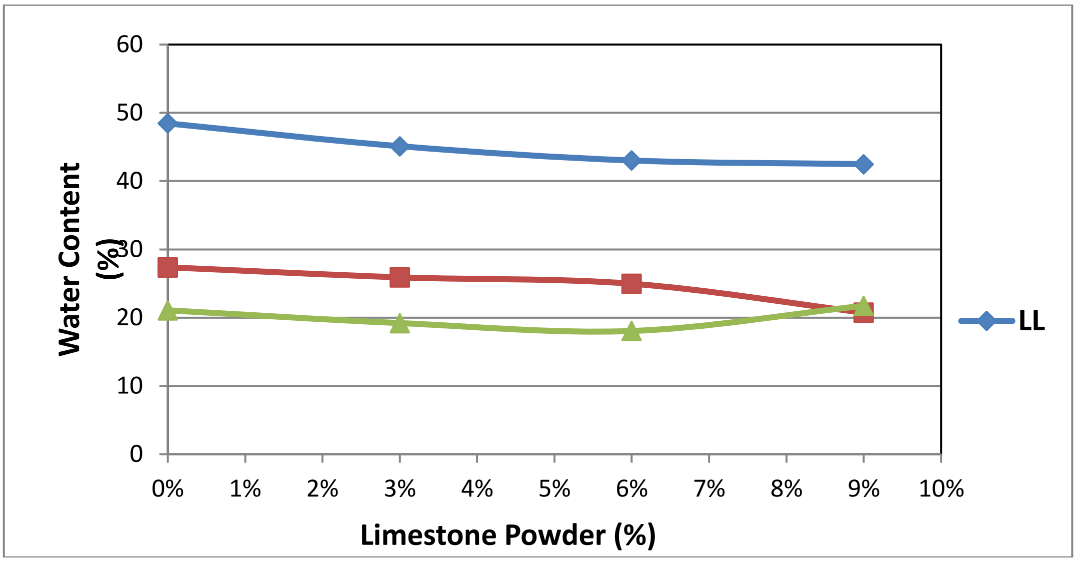

Fig.(5): -Variation of LL, PL and PI for clay with Limestone dust

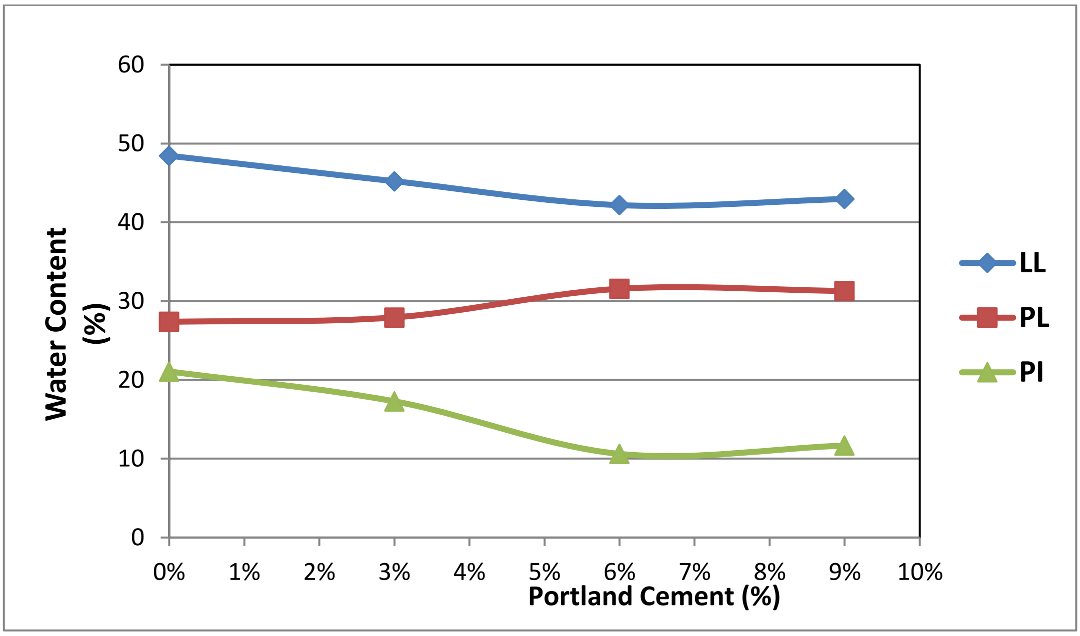

Fig.(6): -Variation of LL, PL and PI for clay with Portland cement

4.2 Compaction Test:

Compaction tests were carried out to assess the impact of glass powder, limestone dust and cement on the OMC and MDD of clayey soil. The unstabilized soil had an OMC of 25% and an MDD of 14.1 kn/m3. The compaction tests followed ASTM D698 for unstabilized soil and ASTM D558 for stabilized soil.

Figure 7 presents the results of the dry density-moisture content tests for soil stabilized with glass powder. By adding glass powder, resulted in an increase in MDD and a decrease in OMC. With glass powder dosages of 3%, 6%, and 9%, the MDD values were 14.6, 14.38, and 14.4 kN/m^3 respectively, while the corresponding OMC values were 20, 20.5, and 23%.

Similarly, Figure 8 displays the dry density-moisture content test results for soil stabilized with limestone dust. Adding limestone dust resulted in an increase in MDD and a decrease in OMC. For limestone dust dosages of 3%, 6%, and 9%, the MDD values were 14.8, 15.15, and 15.5 kN/m^3 respectively, while the OMC values were 22.9.5, 23.5, and 24%.

Furthermore, Figure 9 illustrates the dry density-moisture content test results for soil stabilized with cement. The inclusion of cement resulted in an increase in MDD and a decrease in OMC. With cement dosages of 3%, 6%, and 9%, the MDD values were 14.8, 15.1, and 14.7 kN/m^3 respectively, while the corresponding

OMC values were 21.5, 20.5, and 19.5%.

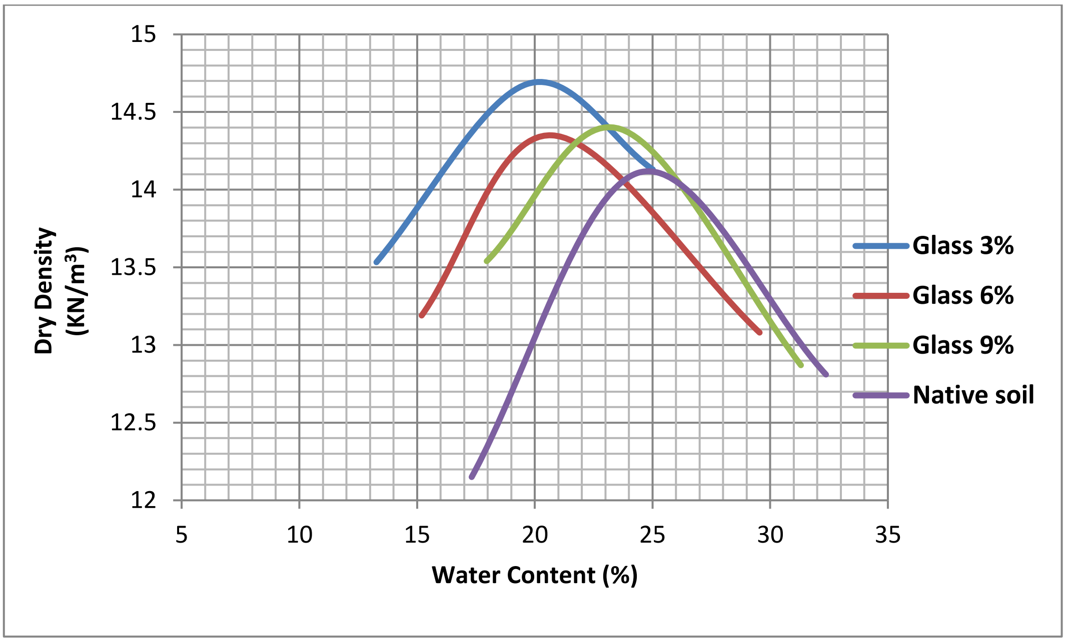

Fig.(7): -Compaction Test Results of soil stabilized with (3%, 6% and 9%) Glass powder

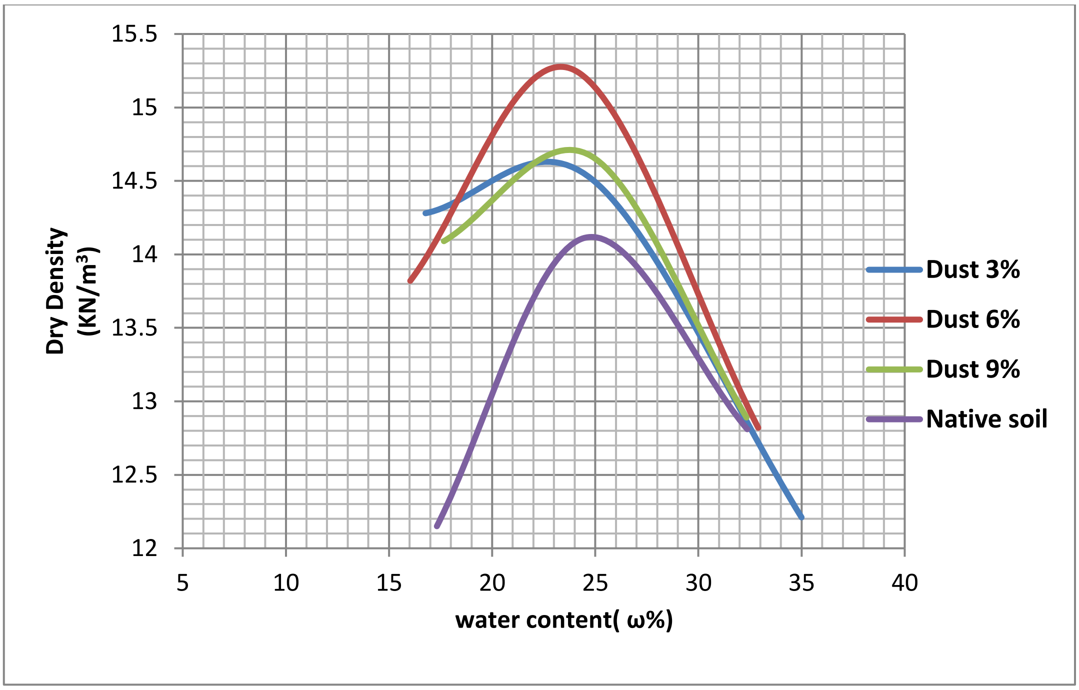

Fig.(8): -Compaction Test Results of soil stabilized with (3%, 6% and 9%) Limestone Dust

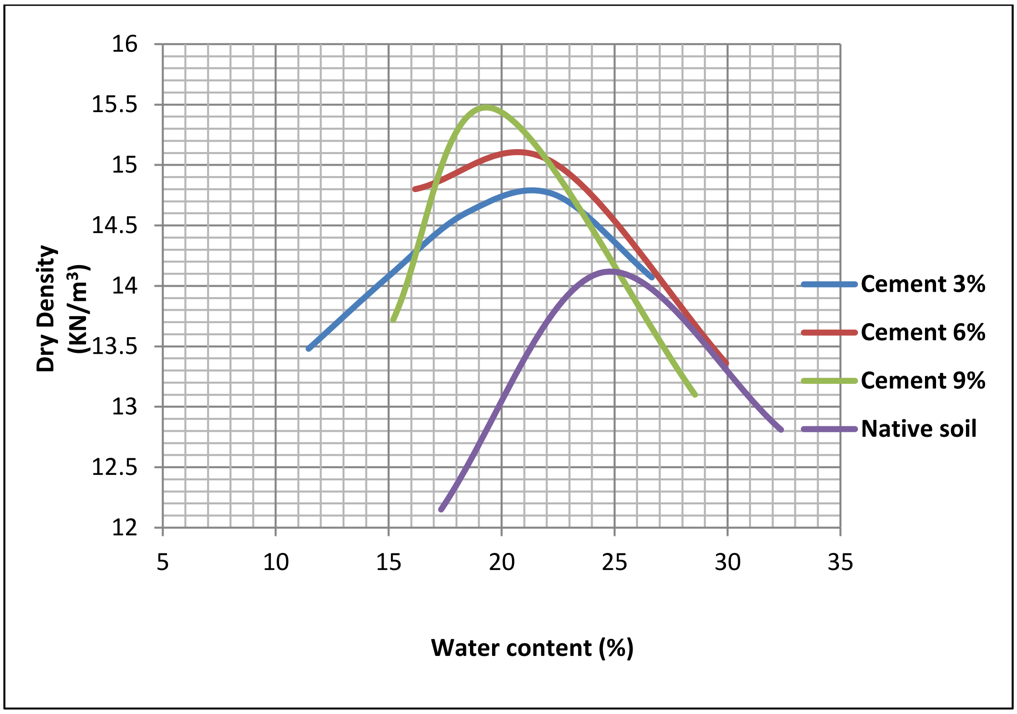

Fig.(9): -Compaction Test Results of soil stabilized with (3%, 6% and 9%) Cement

Figure 10 shows the values of MDD at different dosage rates of glass powder, limestone dust, and cement. The findings demonstrate that the addition of these additives in varying quantities has a positive impact on the soil, as they enhance the dry density of the soil. The highest MDD value was achieved at 9% for cement, 3% for powdered glass, and 6% for limestone dust.

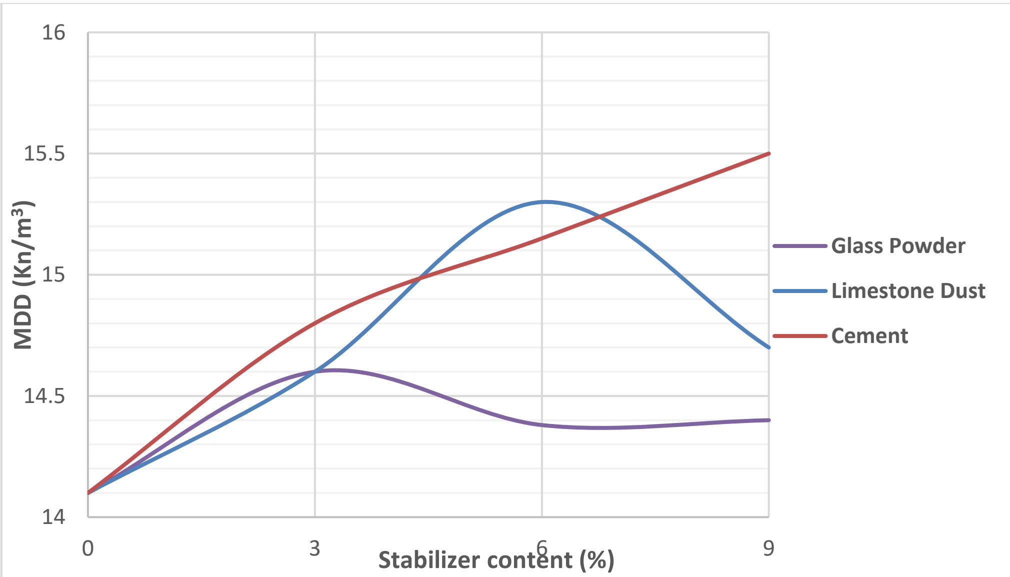

Fig.(10): -Values of MDD at different percentages of stabilizers

Figure 11 illustrate the values of OMC at different dosage rates of glass powder, limestone dust, and cement. The comparison of these results reveals that the addition of these additives in varying quantities has a beneficial impact on the soil, as they all lead to a decrease in OMC for the specific clay soil being studied. The most favorable outcome was observed at 9% for cement, 3% for powdered glass, and 3% for limestone dust.

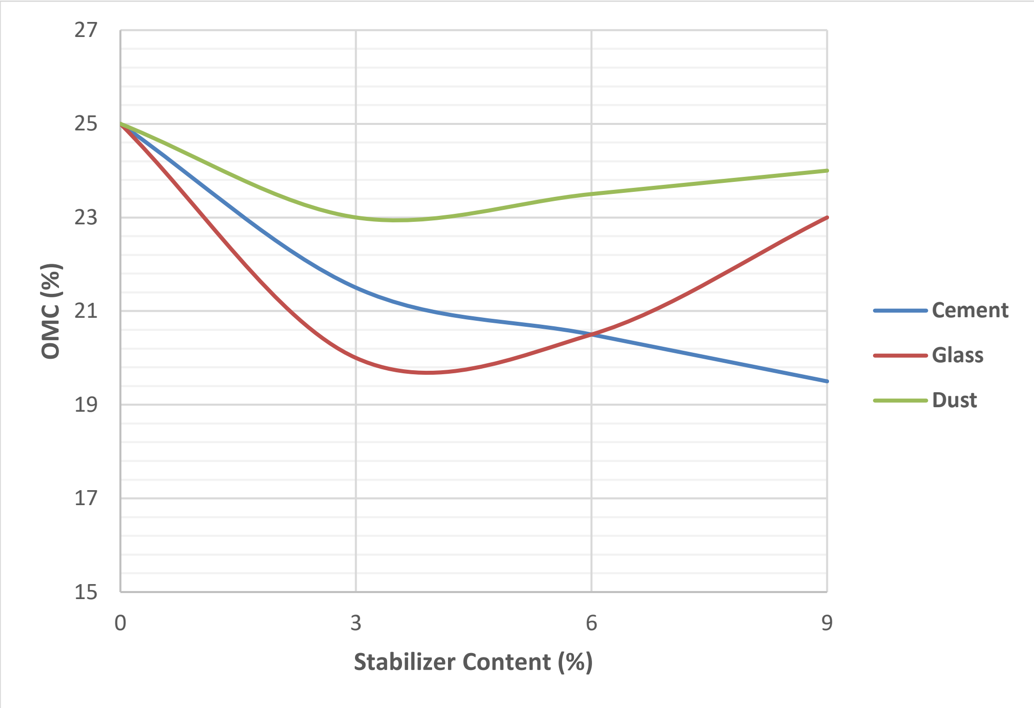

Fig.(11):- Values of OMC at different percentages of stabilizers

According to the results, there is a direct correlation between the increase in MDD and amount of added glass powder. Conversely, the OMC decreases with a higher percentage of glass powder. It is worth to mention that the primary component of glass powder is silica, which has a lower specific surface area compared to clay minerals. (Nuruzzaman and Hossain, 2014) reported that a decrease in surface area of soil particles in the blender leads to a decrease in OMC. The obtained results are consistent with the findings of Ibrahim et al. (2021), Canakci, Al-Kaki, and Celik (2016), and Khan, Tufail, and Mateeullah (2018).

In general, by increasing the amount of limestone dust in the composite, the MDD also increases. These results align with previous studies conducted by Memon et al. (2015), Ogila (2016), Ahmed et al. (2020), and Hassan et al. (2020). Also, adding limestone dust coarsens the soil and results in higher value of MDD (Ahmed et al., 2020). According to (Ogila, 2016), adding limestone dust to clay facilitates compaction at lower moisture content and leads to a denser structure with lower void ratio and great density. Moreover, the OMC of clay decreases as the contents of limestone dust in the mixture increases. This decrease can be explained to the decrease in clay content by replacing it with dust, which has a lower affinity for water (Hassan et al., 2020).

4.3 UCS Test:

This test was conducted as per ASTM D2166 and that is used to measure soil strength. The test has been widely used by researchers as an indicator of stabilizer performance due to its simplicity. The UCS is used to assess the impact of different waste materials on various soil types. The UCS specimens were prepared using a specific mold at OMC and MDD obtained from compaction tests. The UCS test was performed on fresh specimens, and all samples were tested until failure. The initial UCS value for the untreated soil was 189 kPa.

Table 4.1 presents the values of the UCS for clay soil with and without glass powder, limestone dust, and Portland cement. Generally, all additives are increased the UCS value of soil. For soil stabilized with 3%, 6%, and 9% glass powder, the UCS value increased by 322.15 kPa, 338.65 kPa, and 223.22 kPa, respectively. The highest UCS value for stabilized soil was observed at 6% glass powder. Similarly, for soil stabilized with 3%, 6%, and 9% limestone dust, the UCS value increased by 223.35 kPa, 41.85 kPa, and 25.36 kPa, respectively. The highest UCS value for stabilized soil was obtained at 3% limestone dust. Likewise, for soil stabilized with 3%, 6%, and 9% cement, the UCS value increased by 190.25 kPa, 355.13 kPa, and

239.71 kPa, respectively. The highest UCS value for stabilized soil was observed at 6% cement.

Figure 12 illustrates that the UCS value increases with an increase in glass powder and cement content up to 6% of the stabilizer content, after which it tends to decrease. Conversely, for soil stabilized with limestone dust, a lower amount of the stabilizer initially increases the UCS value, but it subsequently decreases. The UCS value increases with an increase in the percentage of cement until reaching its maximum value at 6%, after which it decreases with further cement content. The modified statement: As for glass powder, the UCS increased to its highest value up to 6%, then start to decline little bit at 9%. In the case of limestone dust, the UCS value increases with an increase in the percentage of limestone dust until reaching 3%, after which it decreases with further limestone dust content. Nonetheless, in all cases, the UCS values of soil after the addition of glass powder, limestone dust, and cement were higher than the UCS value of the original soil. Thus, these results demonstrate that the addition of these additives in varying quantities positively affects the soil by improving its compressive strength, particularly for this specific clay soil.

Table (3):- Results of UCS test with various percent of Glass Powder, Limestone Dust and Cement

Materials	Stabilizer content (%)	Corrected Area (cm^2)	Failure point	Load (kg)	Sample Stress(kPa)
Soil	0	18.1	11	34.87	189.0
Glass Powder	3	18.86	31	98.27	511.15
	6	18.86	32	101.44	527.64
	9	18.86	25	79.25	412.22
Limestone Dust	3	18.1	24	76.08	412.35
	6	18.86	14	44.38	230.84
	9	18.86	13	41.21	214.35
Cement	3	18.86	23	72.91	379.24
	6	18.86	33	104.61	544.13
	9	18.86	26	82.42	428.71

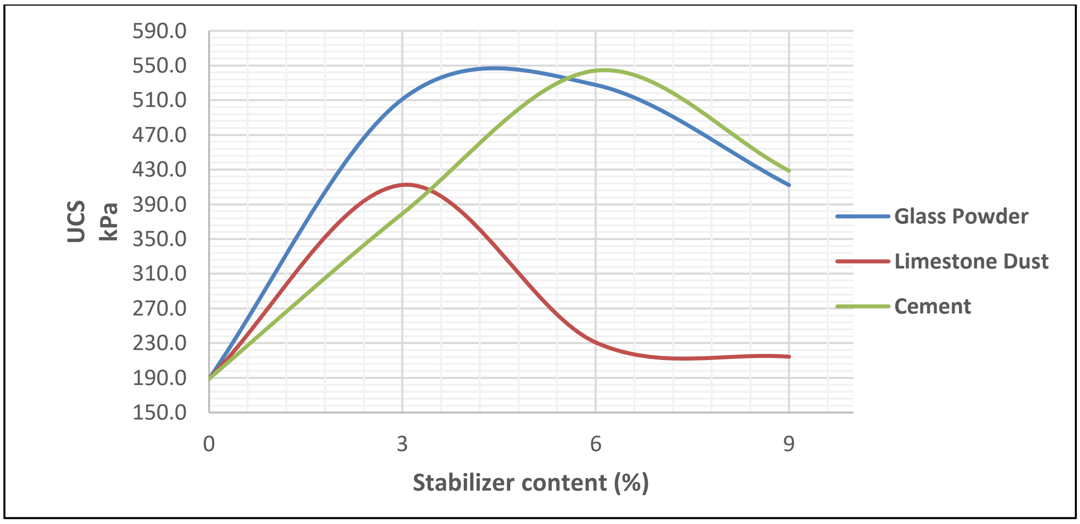

Fig.(12):- UCS at various percentages of Glass Powder, Limestone Dust and Cement

The addition of glass powder significantly increased UCS. By increasing the amount of glass powder up to 6%, the UCS gradually increased. However, beyond 6%, the UCS value dropped to 412.22 kPa. This decrease occurred as OMC has not changed significantly when glass powder was added from 6% to 9%, and most of the added material lacked cohesion. Glass powder, being predominantly cohesion less, tends to reduce the Plasticity Index (PI) when added in small percentages. Consequently, MDD and UCS increase. Initially, the UCS strength of the samples improved due to the lime present in the glass powder reacting with the soil. However, as the glass powder was added to the soil sample, the lime content within the glass powder was insufficient to significantly enhance cohesion. Consequently, the adhesion between the soil surface and glass powder diminished. Comparing this with glass powder, it was found that the addition of limestone dust lesser increased UCS value of the soil. However, further additions of limestone dust led to a slight decrease in the UCS value. Ogundipe (2013) noted that the limited improvement in UCS is attributed to the great amount of lime content in the clay, which hinders early strength gain as a result of flocculation. Hence, glass powder exhibits a potentially greater efficacy in enhancing Unconfined Compressive Strength (UCS) in comparison to limestone dust. The UCS values of soil stabilized with glass powder closely approach those achieved with cement stabilization. These findings suggest that glass powder could present a more viable alternative to cement than limestone dust, considering its notable impact on UCS improvement.

5. CONCLUSION

This study investigates the impact of glass powder, limestone dust, and Portland cement on the geotechnical characteristics of clay. The test results indicated that waste glass powder and limestone dust can serve as viable alternatives to cement for soil stabilization. These waste materials demonstrated a positive influence on various geotechnical properties, including Atterberg limits, MDD, OMC, and UCS of the soil. Based on the obtained results, the following conclusions were drawn:

- The incorporation of glass powder and limestone dust generally resulted in a decrease in Atterberg limits. Notably, the application of 3% glass powder exhibited the most pronounced reduction in the plasticity index (PI) of the soil when compared to other stabilizers.
- Both glass powder and limestone dust exerted a positive influence on the compaction properties of the soil. The inclusion of these materials led to a decrease in OMC and an increase in MDD, indicating an enhancement in the soil's compaction characteristics.
- Glass powder exhibited a noteworthy enhancement in the Unconfined Compressive Strength (UCS) of the soil. The optimal stabilizer content that yielded the highest UCS value was determined to be 6% glass powder.
- The addition of limestone dust to the soil resulted in a marginal increase in the Unconfined Compressive Strength (UCS) value up to 3%. However, beyond this percentage, the UCS experienced a subsequent decrease with further increments in limestone dust content.
- The results of the study revealed that glass powder exhibited a higher effectiveness than limestone dust in increasing the UCS value of the soil.
- This study establishes the promising potential of waste glass powder and limestone powder as advantageous alternatives to conventional Portland cement for soil stabilization. The incorporation of these materials has been found to yield positive effects on various geotechnical properties. As such, they hold significant promise for application in geotechnical engineering projects and highlights an environmentally sustainable solution for waste materials.

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