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Evaluate The Engineering Properties of Low Load-Carrying Capacity of Expansive Soil by Using Magnesium Chloride and Dry Leaf Ash Powder

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Abstract

The swell-shrink behavior of expansive soils poses numerous challenges with the substructure and distress in infrastructures such as buildings, pavements, breast walls, etc. The behavior of expanding soil has been carefully examined by geotechnical engineers, who have then put adequate management techniques into place. Present investigation intends to investigate potential benefits of dry leaf ash (DLA) powder and magnesium chloride (MgCl2) to enhance geological characteristics of soil, particularly addressing problems of limited load-bearing capacity, significant swelling, and substantial shrinking, all of which are advantageous to civil engineering. The effects of dry leaf ash (2.5, 5.0, 7.5, and 10%) and MgCl2 (0.25, 0.5, 0.75, and 1%) on the Atterberg limits, MDD (maximum dry density), UCS (unconfined compressive strength), XRD, OMC (optimal moisture content), SEM, as well as other crucial soil properties have been computed using an experimental program. The two admixtures were mixed into expanding soil after being introduced separately. The incorporation of specific admixtures significantly reduced plasticity index, liquid limit, optimal moisture content, as well as swelling parameters of expansive soil. After 56 days, UCS gradually increased from 47.57kPa - 1386kPa, mostly as a result of the synergistic interaction between 7.5% dry leaf ash and 0.75% magnesium chloride with the soil. This interaction was noticeably more successful than that of other admixture combinations. Establishment of C-A-H (Calcium Aluminate Hydrates) along with M-S-H (Magnesium Silicate Hydrate), as well as other cementitious compounds found in SEM and XRD investigations, contribute to the strength improvement. Accordingly, the results showed that adding 0.75% MgCl2 and 7.5% DLA greatly improved high swell-shrink soil with insufficient bearing capacity, proving that the admixture is a practical stabilizer and that it also lowers construction costs by optimizing natural ash powder.

Keywords: Expansive soil, dry leaf ash (DLA), shrinking, swelling, UCS

INTRODUCTION

One of the most difficult soils for civil engineering to work with is black cotton soil, which expands and contracts as a result of changes in water flow [7]. The foundations of structures built on expansive soil are seriously at risk. Due to its natural shrinking and swelling behaviour [2, 30] when it reacts with water, this type of soil can generate uplift forces that V. Jaladevi significantly damage lightly loaded buildings such as sidewalks, basements, etc. [34, 37]. As a result, the problematic soils are distinguished by their severe hardness when dry and by their great swelling potential during the soaking process. On practically every continent on the planet, clay soils are present. As a result, damage from expansive soils is very common where the yearly loss exceeds the annual rainfall in arid and semi-arid areas [39, 40]. These soils tend to expand

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when there is a warm temperature and inadequate drainage. The soil can range in color from a deep black to grey and, on rare occasions, even to a reddish or yellowish color. These soils are typically referred to as clay soil in India and account for around 20% of the country's total land area [38, 40]. They have a total size of almost two million square miles. Andhra Pradesh, Karnataka, Gujarat, Madhya Pradesh, Tamil Nadu, along Maharashtra were among states where they produce. Other than India, a significant amount of such soil is also obtained from Africa, Australia, the United States, Jordan, etc. Basalt is important volcanic ash, calcareous aluminium, and sedimentary rocks such as calcareous shales, limestone, slates, and sandstones are the main sources of this type of soil [3].

Basalt is the main component of expansive soil. It originates as a result of in-situ subaerial weathering of basalts and subsequent admixture of the weathered products with iron and organic matter. The width of the soil ranges from 30 cm to 15 m, and its topography exhibits a significant variance at various depth strata, especially in terms of its clay content and lime segregation. The clay component of soil is only 25% alumina and exceptionally rich in silica (60%) and iron (15%). Montmorillonite is the primary clay mineral in expansive soil, according to distinct thermal analysis and XRD pattern analysis. Additionally, Kaolinite and Illite, which are present in lesser amounts, are clay minerals that have a substantial impact on the engineering qualities of soil. The infrastructure, road, and base layer are affected here. To achieve the desired strength, mechanical stabilization, such as compaction, and a chemical admixture approach were utilized to strengthen the soil qualities. Utilizing a waste product can restore the soil's strength and minimize these minerals, hence many admixtures have been utilized [4, 5, 6, 9, 10, 12, 14, 15, 18, 19, 25, 26, 27]. These include fly ash, bagasse ash, coir pith, sisal fibre, and plastic waste.

To improve the subgrade soil's ability to support pavement and foundations, it is necessary to regain the soil index and strength properties as well as its shrinking and swelling characteristics. An investigation by [40] employed varying percentages of alccofine as well as CaCl2 additives to stabilize clay soil, which serves as a cushion for lightweight buildings made of soils CNS (cohesive non-swelling), revealing that 6% alccofine & 1% CaCl2 provide expanding soil its maximum strength. Conversely, CaCl2 and MgCl2 are hygroscopic substances, making them particularly effective for stabilizing expansive soils, as they absorb atmospheric moisture and mitigate the formation of shrinkage cracks in these soils over the summer months [30]. Moreover, Soft soils may become stronger and more rigid if waste materials as well as fibers are combined with chemical agents [16, 17].

The study by [20] indicates that applying hydrated lime as well as bagasse ash stabilizing expansive soils enhances strength efficiency making it’s simpler to mitigate environmental problems by reusing waste from sugarcane industry [28]. found that treating consolidation characteristics of expansive soil using mixture of hydrated lime alongside bagasse ash is superior utilizing bagasse ash independently. Thus, for "black cotton soil," a 3 percent lime & 0.75 percent sisal fiber content [29] had been ideal ratios to increase CBR value. In its normal form, the soil's CBR value was 10.42%; adding 4% BLA (banana leaf ash) by soil weight increased it to an optimal value of 28.10%. At 4% BLA, the UCS increased from 209.18 kN/m2 in its normal condition to 233.77kN/m2. Thus, it was determined that BLA functions as economical stabilizing agent for subgrade purposes in satisfactory manner [13]. By incorporating 2 percent plastics & 6 percent pozzolanic leaf ash mixtures into soils, soaked CBR along with MDD may enrich to their maximum potential. Additionally, PI and shear strength characteristics can be enhanced [42]. As a stabilizing agent, combination of two materials might come out more beneficial than employing them independently. Nevertheless, there are currently no published investigations on collaborative stimulation of MgCl2 & DLA as stabilizing agents for expanding soils. In order to stabilize expansive soil, this study has attempted to use a binder consisting of a mixture of MgCl2 and DLA. When assessing performance, consideration has been given to the binder's impact on the expansive soil's swelling potential, compaction, plasticity, FSI, as well as strength properties.

MATERIALS AND METHODOLOGY

Black Cotton Soil

Bharathi Nagar, in Puducherry region of India, provided the soil employed in the present investigation due to their high swell, low load-carrying capacity, along high shrink. Soil had gathered at profundity of two meters below surface. Any gravel fraction is eliminated by drying it and sieving it through a 4.75mm screen. It is also kept in the laboratory. Inorganic clay with high plasticity [36] makes up soil, which had categorized as 'CH' by the IS Classification [22]. The index as well as engineering parameters of extremely expansive and shrinkable soil as shown in Table 1.

Table 1. Physical properties of soil.

Properties of soil	**Results**
Color of soil	Blackish Grey
G_s	02.39
Clay (%)	65.00
Silt (%)	16.26
Sand (%)	18.74
W_L (%)	91.00
W_P (%)	36.93
W_S (%)	09.40
PI (%)	54.07
SI (%)	27.53
FSI (%)	40.00
FSR	01.40
W_A (%)	82.81
S (%)	36.55
Unified soil classification	CH
OMC (%)	22.00
MDD (KN/m3)	16.25
UCS (kPa)	47.57

Magnesium Chloride

The scientific name for magnesium chloride, an inorganic salt, is $MgCl_2$. This causes certain hydrates to consume a molecular weight of 203.301g/mol, most notably the hexahydrate $MgCl_2*6H_2O$. It is a crystalline substance without color. The salt absorbs a lot of moisture. Because of its exothermic interactions with water, magnesium chloride works well as a de-icing agent. It is offered in 3 unique formats: powder, flakes, and liquid. The salt utilized in this investigation was magnesium chloride hexahydrate, represented by chemical formula ($MgCl_2 \cdot 6H_2O$). The purity varied between 98 - 100 percent. Sri Rajendra Scientific and Surgical Private Limited, located in Puducherry, India, is source of it. $MgCl_2$'s chemical properties as enumerated in Table 2.

Table 2. Chemical properties of Magnesium Chloride ($MgCl_2$).

Properties of $MgCl_2$	**Results**
Boiling point	1412° C, 1685 K, 2574° F
Molecular weight (g/mol)	203.31 (hexahydrate)
Water solubility	235g/100ml water @20° C
Density (g/cm^3)	1.569
Appearance	White (or) colorless crystalline solid
Melting point	117° C, 390 K, 243° F

Dry leaf ash (DLA)

Initially, seven kinds of commonly available leaves in India, i.e., Coconut, Mango, Banana, Neem, Jand, Cannonball, and Indian Bael leaves, are collected and sun-dried in an open space for one month. Then, those leaves are burnt in an open atmosphere which has been shown in Figure1 and sieved through a 0.075 mm sieve. Compared to the percentage of dried leaves by weight, around 30-35% of ashes are obtained. It implies that it is possible to obtain around 2-2.5 kg ashes from 10 kg of dried leaves. The leaf ashes which possess the pozzolanic characteristics are mixed in equal quantity by weight. The mixture of leaf ashes in the weight percentages 2.5, 5, 7.5, and 10 % will then be mixed with the selected air-dried soils to study their effectiveness as a soil stabilizer. Table 3 shows the chemical composition of dry leaf ash (DLA).

Table 3. Chemical composition of dry leaf ash (DLA).

Major elements	Results	Major elements	Results
SiO2	44.89	CaO	22.31
TiO2	00.01	Na2O	01.98
Al2O3	00.23	K2O	11.65
MnO	00.04	P2O5	08.97
MgO	08.54	Fe2O3	00.76

RESULT & DISCUSSION

The influence of magnesium chloride ($MgCl_2$) and dry leaf ash (DLA) on several expansive soil characteristics was assessed using “Indian standards” and detailed in the sections below: Index and compaction characteristics, unconfined compressive strength (UCS), free swell index, mineralogical and microstructural analysis.

Index and Compaction Characteristics

The effect of magnesium chloride ($MgCl_2$) and dry leaf ash (DLA) on the W_L, W_P, and I_P of expansive soil. Results specify that the shrinkage limit increased while the plastic and liquid limit gradually decreased. As a result, the variations between the shrinkage and plastic limit are known as the shrinkage index, and the variation between the plastic and liquid limit is known as the plasticity index. It is decreased by approximately 73 percent, and the shrinkage index is raised by approximately 61 percent when the soil is mixed with 0.75% $MgCl_2$ + 7.5% DLA. Due to the pozzolanic reaction and the cation exchange capacity of blended soil once compared with individual admixture, the combination of admixture proves the possible reduction of index properties, it is shown in Table 4. Based on IS [22, 23] classification, the laboratory experiments have been conducted in the Geotechnical Engineering lab, Civil Engineering department, PTU. The outcomes demonstrated that the accumulation of 0.75% $MgCl_2$ + 7.5 percent DLA caused the index characteristics of natural soil is alter from highly compressible (CH) to medium or intermediate compressible (CI) soil [24]. has proposed that plasticity is a reliable predictor of swell potential and that a lower “plasticity index” corresponds to a lower swell potential.

Dry leaf | Dry leaves are burnt in an open atmosphere | Dry leaf ash (DLA)

Figure 1. Preparation of dry leaf ash.

Figures 2 and 3 depict the compaction parameters like MDD and OMC of treated soils. The compaction results indicate that the MDD raises from 14.3 to 17.6 kN/m^3, and the content of optimum moisture decreases from 24-11.8 percent with a rise of 0.75 percent $MgCl_2$ and 7.5 percent DLA; that is, for the sample with the highest strength. Similar MDD and OMC behavior was seen when industrial waste or GGBS ("Ground- Granulated Blast Furnace Slag") was utilized as a stabilizing agent [8, 15, 31]. The use of construction materials benefits from a rise in dry density for compaction impact since it suggests soil improvement [32, 35].

Unconfined Compressive Strength (UCS)

The UCS of the soil sample is prepared with magnesium chloride and DLA, which were applied separately and combined with the expansive soil. It has been conducted on natural soil as well as chemically treated soil. The natural soil's value of UCS is 47.57 kPa. The percentages of magnesium chloride ($MgCl_2$) (0.25, 0.5, 0.75, & 1%) and DLA (2.5, 5.0, 7.5, & 10%) have been based on [21] dry soil's weight. Similarly, the impact of curing interval on the strength enhancement of soil was investigated for periods of 0, 7, 14, 28, & 56 days. Fig. 5 depicts the UCS values. The optimal strength was obtained at 0.75 percent $MgCl_2$ with 7.5 percent DLA. The strength of UCS improved from 47.57-211, 547, 613, 1051, and 1386 kPa on 0,7,14,28, & 56 days with accumulation of 0.75 percent $MgCl_2$ with 7.5 percent DLA. And, the optimum result is obtained on expansive soil blended with magnesium chloride and dry leaf ash as shown in Table 5. When the stabilizer content outdoes a certain threshold, the compressive strength of the soil is significantly reduced. Therefore, adding 0.75 percent $MgCl_2$ and 7.5 percent dry leaf ash is advised as the optimum content to successfully stabilize this expansive soil based on the behaviour of unconfined compressive strength. Similar findings were made by [41], demonstrating that the best strength was obtained using natural soil and an alccofine concentration of 8% and 1% $CaCl_2$.

Table 4. Effects on Index and strength properties of soil blended with admixtures.

Admixtures (%)	GS	FSI (%)	WL (%)	WP (%)	WS (%)	IP (%)	IS (%)	UCS (kPa)	WA (%)	S (%)
Soil – S	2.39	72.00	91.00	36.93	09.40	54.07	27.53	47.57	82.81	36.55
S + 0.25 $MgCl_2$	2.46	64.71	80.00	30.09	08.47	49.91	21.62	85	72.80	30.06
S + 0.5 $MgCl_2$	2.49	55.56	61.40	25.71	11.53	35.69	14.18	99	55.87	13.26
S + 0.75 $MgCl_2$	2.58	31.82	53.00	26.89	13.22	26.11	13.67	132	48.23	06.18
S + 1 $MgCl_2$	2.62	47.36	47.20	29.11	14.17	18.09	14.94	178	42.95	02.53
S + 2.5 DLA	2.49	36.36	77.00	33.85	09.06	43.15	24.79	137	70.07	21.08
S + 5 DLA	2.58	21.43	64.50	27.58	11.77	36.92	15.81	152	58.69	14.41
S + 7.5 DLA	2.69	12.00	56.00	26.74	13.68	29.26	13.06	172	50.96	08.17
S + 10 DLA	2.72	04.50	47.80	29.40	16.29	18.40	13.11	184	43.49	02.63
S + 0.25 $MgCl_2$+ 2.5 DLA	2.69	46.25	57.00	24.79	14.20	32.31	10.59	154	51.87	10.40
S + 0.5 $MgCl_2$ + 5 DLA	2.65	0	51.00	32.55	15.60	18.45	16.95	178	46.41	02.65
S + 0.75 $MgCl_2$+ 7.5 DLA	2.77	0	44.00	29.48	18.70	14.52	10.78	211	40.04	01.47
S + 1 $MgCl_2$ + 10 DLA	2.72	09.52	48.5	27.64	18.10	20.86	09.54	192	44.40	03.58

Note: G_S-Specific gravity; FSI-Free swell index; W_L-Liquid limit; W_P-Plastic limit; W_S-Shrinkage limit; I_P- Plasticity index; I_S-Shrinkage index; W_A-Water absorption; S-Swell potential.

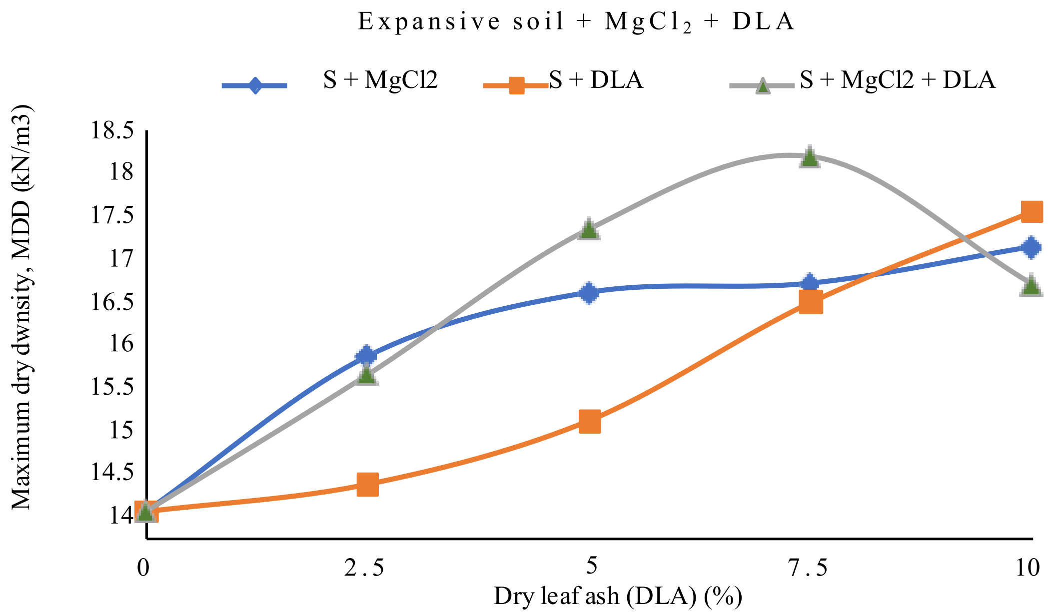


Figure 2. Effect of MDD on treated soil.

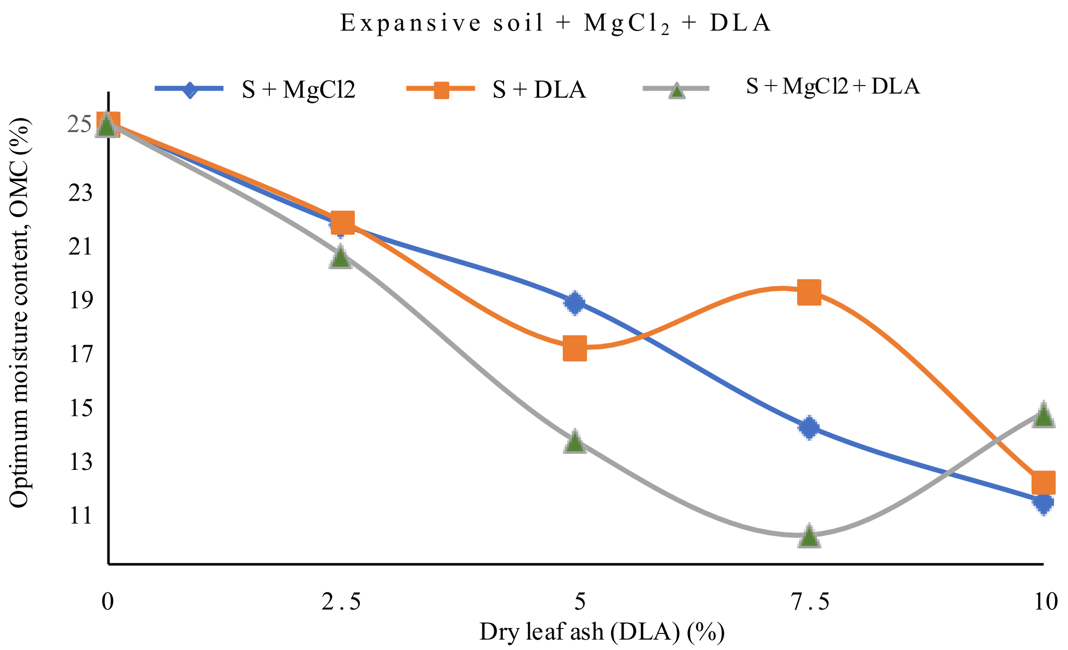


Figure3. Effect of OMC on treated soil.

Free Swell Index (FSI)

Table 4 illustrates the behavior of soil swelling combined with various amounts of magnesium chloride and DLA. Having montmorillonite minerals significantly influences swelling characteristics of soils. The FSI is gradually reduced by adding each of these admixtures individually, ranging from 72 percent to 31.82 percent at 0.75 percent magnesium chloride and 4.5 percent at 10 percent DLA. Therefore, both admixtures decreased the soil's swell potential from high to low swelling, and when the soil is mixed using the combined action of 0.75 percent $MgCl_2$ and 7.5 percent DLA admixture is changed from high swelling to zero swelling under IS 1498-1970 as shown in Fig.4, a similar result is produced [36].

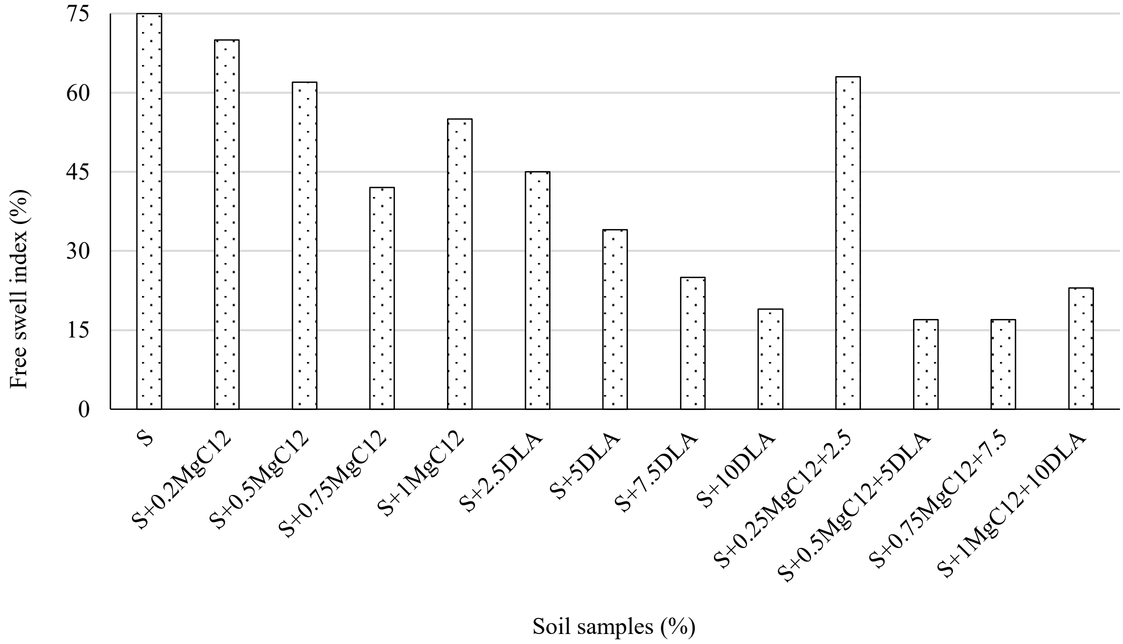


Figure 4. Effects of free swell index on treated and untreated soil.

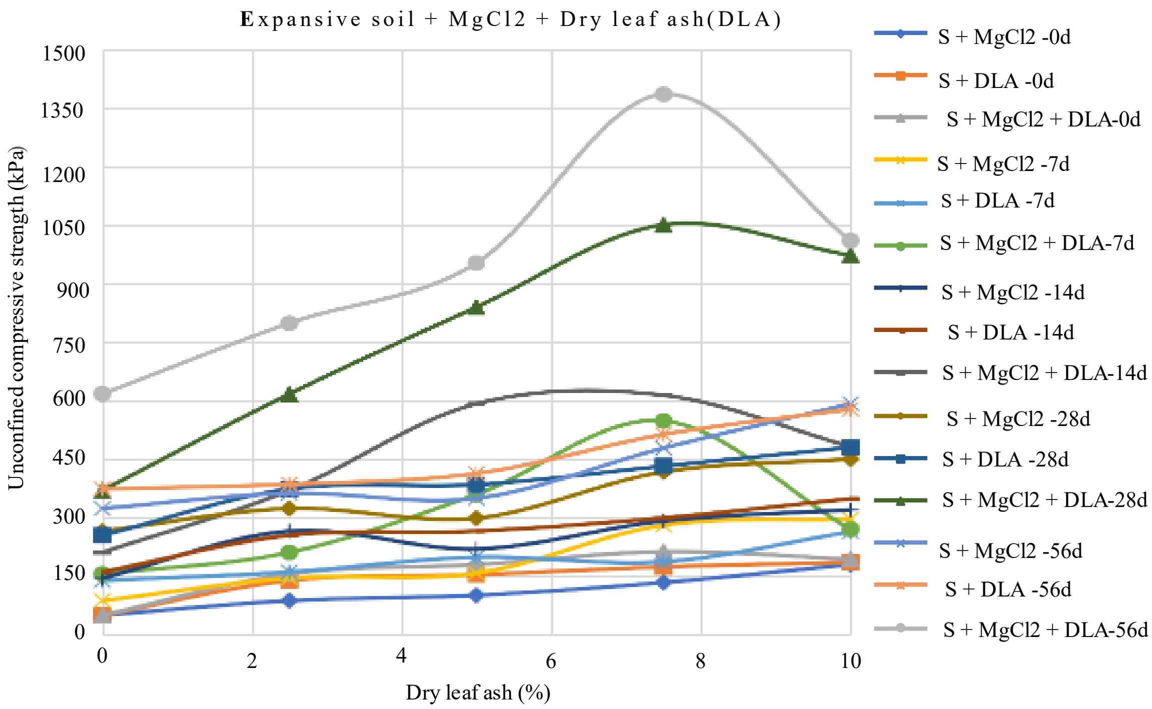


Figure 5. Effects of UCS on treated soil with different curing periods.

Mineralogical & Microstructural Analysis

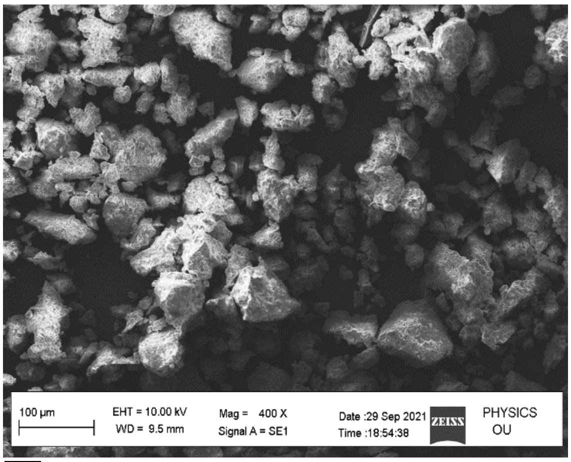
SEM analysis

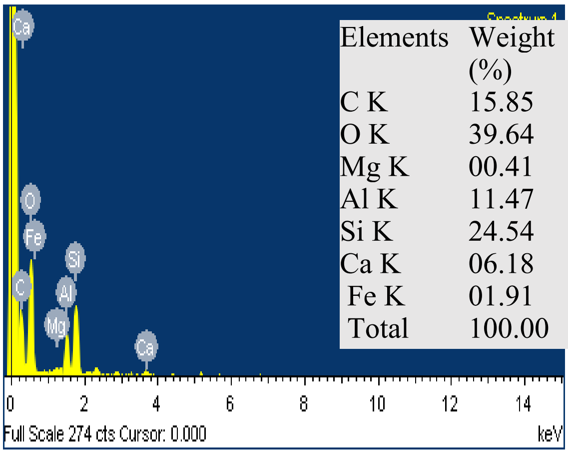
Among the most effective devices for examining the soil particles microstructure is the scanning electron microscope (SEM). A sample surface emits secondary electrons, which are seen as three-dimensional pictures [11]. SEM and EDAX technologies were used to determine changes in the chemical composition and surface matrix between the interactions of soil minerals. In this research, EVO 18 Carl Zeiss is applied for the EDAX and SEM study. The experiment was conducted to track the changes in an intrinsic soil, and the results are presented in Figure 5 for soil + magnesium chloride

+ dry leaf ash. These tests were conducted to examine the individual, and a modification in the soil was mixed with admixtures of 0 and 56-days curing. Ca, Mg, and Si are recognized as prominent peaks in Fig 6 (a), while Ca, Mg, Al, C, O, Si, Au, Na, and Fe are the significant peaks seen in Fig 6 (b) and (c). The main purpose of the test was to identify the different cementation compounds on the clay soil stabilized with 0.75% magnesium chloride + 7.5% dry leaf ash mixture, or for the sample that exhibits the highest level of strength. Therefore, the key factor in reducing swelling in expansive soil is the development of aggregation [1]. Aggregation can be seen in the SEM-micrograph of cement hydration materials like M-S-H gel when combined with magnesium hydroxide. Pore areas that are not empty but rather contain solidified epoxy glue are frequently used to combine hydration solutions [33].

XRD

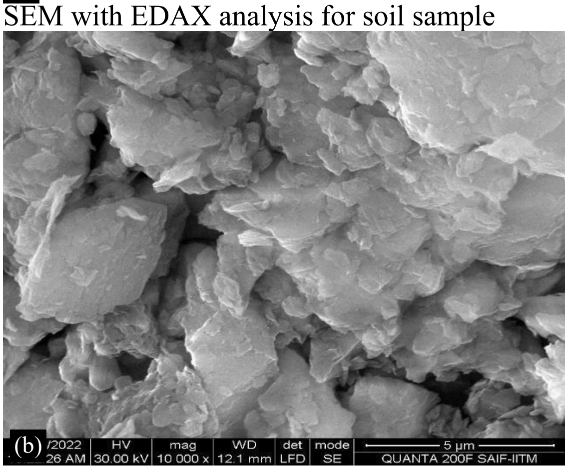
XRD ("X-ray diffraction") analysis is a relatively well-established technique for the mineralogical characterization of fine-grained soils. Most of the soil minerals have crystalline shapes, and a specific geometry governs how they are structured. Then, for the qualitative and quantitative evaluation of minerals, the soil sample diffraction pattern as per its crystal structure, which is based on polycrystalline diffraction or powder diffraction is examined [11]. The soil + 0.75% magnesium chloride + 7.5% dry leaf ash and natural soil are identified by the X-ray diffraction peaks. According to Figure 7, the most significant peak traced was associated with magnesium hydroxide (MH) and was located at 2ϴ = 26° to 39° [33]. It was done to support the development of new minerals that have the potential to significantly improve soil admixture behavior while also strengthening the existing minerals. From the X-ray data, it is clear that the intensity has risen for magnesium chloride and dry leaf ash materials treated when evaluated with the expansive soil, which is all clear from the data of X-ray. The most significant peak traced has been connected to MH and was found at 2 = 26° to 39°.

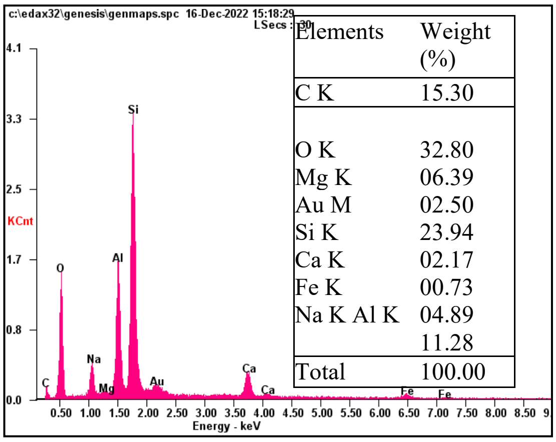




Elements	Weight (%)
C K	15.85
O K	39.64
Mg K	00.41
Al K	11.47
Si K	24.54
Ca K	06.18
Fe K	01.91
Total	100.00

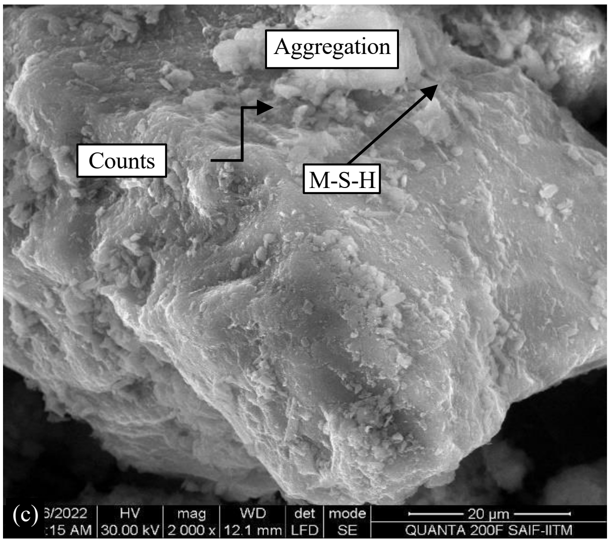
(a)
SEM with EDAX analysis for soil sample

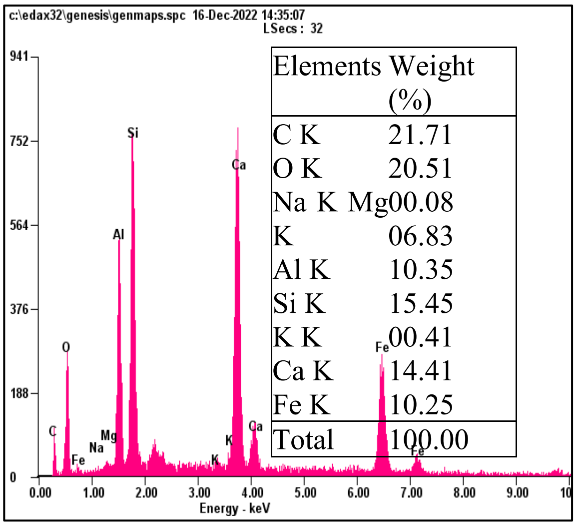




Elements	Weight (%)
C K	15.30
O K	32.80
Mg K	06.39
Au M	02.50
Si K	23.94
Ca K	02.17
Fe K	00.73
Na K Al K	04.89 11.28
Total	100.00

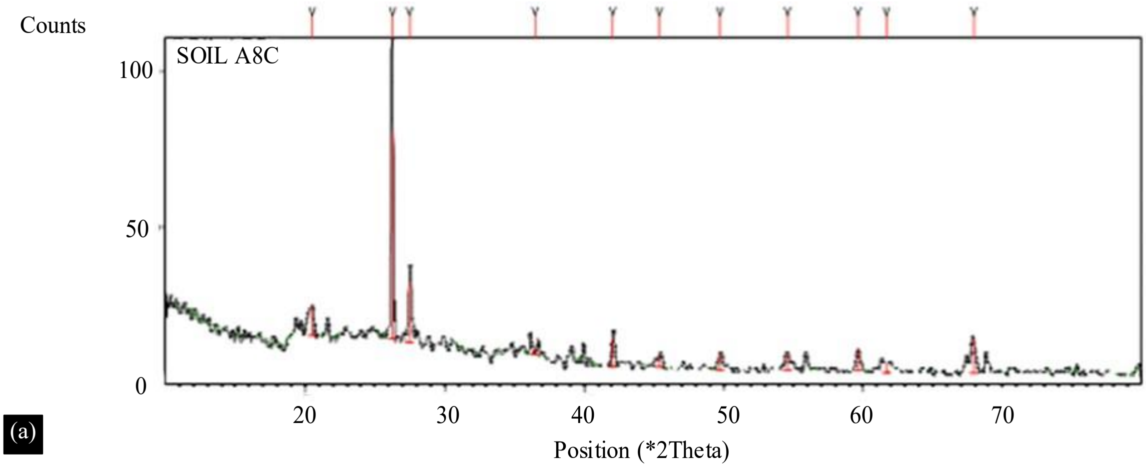
SEM with EDAX analysis for soil sample + 0.75% MgCl2 + 7.5% DLA 28 days



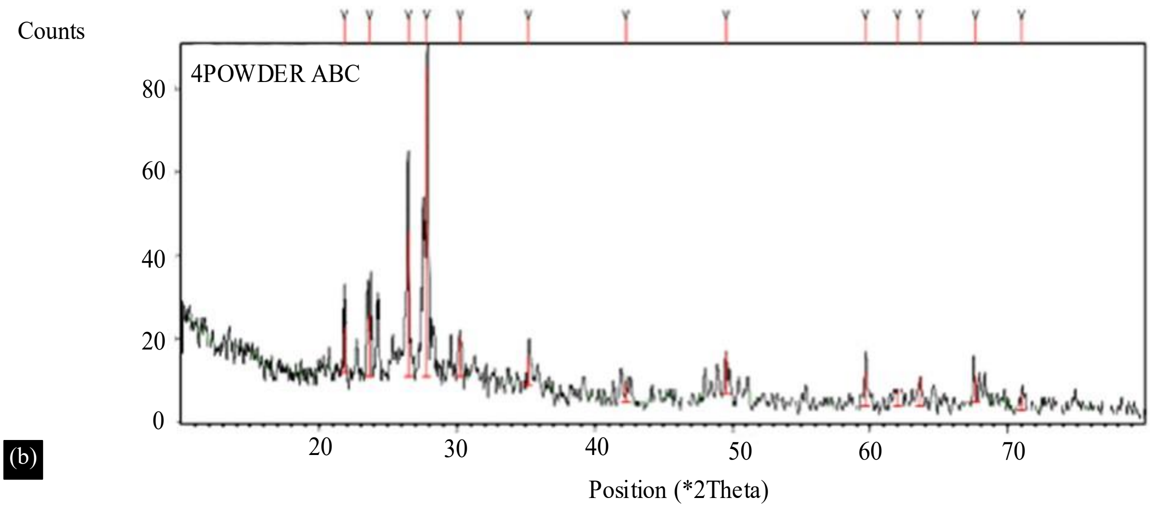


SEM with EDAX analysis for soil sample + 0.75% MgCl2 +7. 5% DLA 56 days

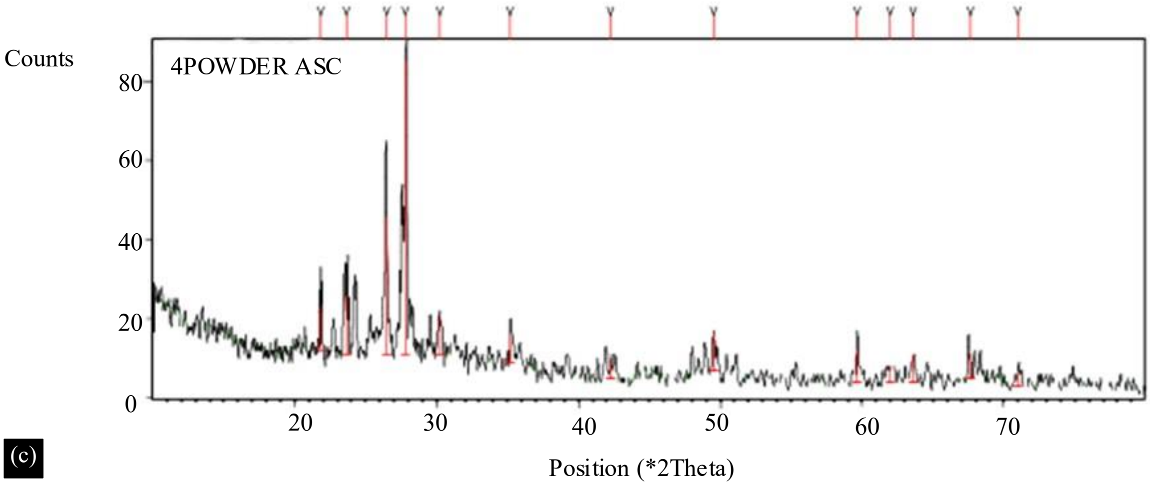
Figure 6. SEM with EDAX analysis for (a) soil; (b) soil + 0.75% MgCl2 + 7.5% DLA 28 days; (c) soil + 0.75% MgCl2 + 7.5% DLA 56 days.



XRD analysis for soil sample 4.



XRD analysis for soil sample 4 + 0.75% MgCl2 + 7.5% DLA 28 days.



XRD analysis for soil sample 4 + 0.75% MgCl2 + 7.5% DLA 56 days.

Figure 7. XRD analysis for (a) soil; (b) soil + 0.75% $MgCl_2$ + 7.5% DLA 28 days; (c) soil + 0.75% $MgCl_2$ + 7.5% DLA 56 days.

Table 5. Optimum result obtained on Soil (S) + MgCl2 + Dry leaf ash (DLA).

Properties	Soil	91.75% S + 0.75% Mg Cl2 + 7.5% DLA	Properties	Soil	91.75% S + 0.75% Mg Cl2 + 7.5% DLA
GS	02.39	2.77	SI (%)	27.53	10.78
Sand (%)	18.74	18.25	USCS	CH	CI
Silt (%)	16.26	32.40	FSI (%)	72	0
Clay (%)	65.00	52.35	S	36.55	1.47
LL (%)	91	44	WA (%)	82.81	40.04
PL (%)	36.93	29.48	OMC (%)	24	11.8
SL (%)	09.40	18.70	MDD (kN/m^3)	14.3	18.2
PI (%)	54.07	14.52	UCS (kPa)	47.57	211

CONCLUSION

Several laboratory tests were used in this work to evaluate the impact of magnesium chloride as well as Dry leaf ash (DLA) on swelling properties and strength behavior. The following are the results of this study's data analysis:

The accumulation of "magnesium chloride" and DLA in the soil increased the shrinkage limit while decreasing the liquid limit and plasticity index. It has been discovered that the addition of stabilizers induces clay particle flocculation and an increase in the number of coarse particles, hence lowering the Atterberg limits. The OMC ("Optimal Moisture Content") decreased from 24-11.8%, whereas the MDD ("Maximum Dry Density") increased from 14.3-18.2 kN/m^3 with the content of binding. UCS has performed with MgCl2 and DLA injected separately and combined with the expansive soils. It took place on natural as well as chemically treated soil.

Natural soil has a UCS value of 47.57 kPa. The highest strength of UCS increased from 47.57-1386 kPa after 56 days of curing along with soil + 0.75 percent MgCl2 +7.5 percent DLA. Soil swells behavior; the swell index is decreased from 72 to 0%, indicating that soil swelling is modified from "high to zero" with the addition of 0.75 percent MgCl2 and 7.5 percent of dry leaf ash. Studies using SEM and XRD demonstrate that the reaction products like Si, Ca, and Mg are formed and greatly contribute to strength. The above-mentioned 2Θ is a CH-related peak that appears in XRD as a result of the addition of DLA and magnesium chloride to the expansive soil. Based on the favourable results, the expansive soil containing magnesium chloride and dry leaf ash can be described as a beneficial

CNS: "Cohesive Non-Swelling Soil" for roads, floorings, and pavements. As a result of the findings, it was found that adding 0.75 percent magnesium chloride and 7.5 percent DLA to soil with high shrink, high swell, and poor bearing capacity demonstrated that the addition was a necessary stabilizer and that the addition of the admixture may improve even the most problematic soil.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

1. A.A. Al Rawas. (2002). "Microfabric and mineralogical studies on the stabilization of an expansive soil using cement by-pass dust and some type of slags". Canadian Geotech. Journal. 39(5), 1150–1167 http://dx.doi.org/10.1139/t02-046
2. Abdullah W S, Alshibli K A, Al-Zoubi M S. (1999). "Influence of pore water chemistry on the swelling behavior of compacted clays". Applied Clay Science. pp 447-462. https://www.scribd.com/document/271728017/Abdullah-Alshibli-Al-Zou-Bi-1999-Influence-of-Pore-Water-Chemistry-on-the-Swelling-Behavior-of-Compacted-Clays
3. Amer Ali Al-Rawas, Hago A W, Hilal Al-Sarmi. (2005). "Effect of Lime, Cement and Sarooj (artificial pozzolan) on the swelling potential of an expansive soil from Oman". Building and Environment 40. Elsevier, ISSN: 0360-1323, pp 681-687. https://doi.org/10.1016/j.buildenv.2004.08.028
4. Ankur Mudgal, Raju Sarkar, Sahu A K. (2014). "Effect of lime and Stone dust in the Geotechnical Properties of Black Cotton Soil". International Journal of GEOMATE. Vol. 7, Issue 2, ISSN: 2186-2982, pp 1033-1039. http://dx.doi.org/10.21660/2014.14.140402
5. Arvind Kumar, Baljit Singh Walia, Asheet Bajaj. (2007). "Influence of Fly ash, Lime and Polyester Fibers on Compaction and Strength Properties of Expansive Soil". Journal of Materials in Civil Engineering. Vol.19, Issue 3, ISSN: 0899-1561, pp 242-248. DOI:10.1061/(ASCE)0899-1561(2007)19:3(242)
6. Avishek Baboria, Anoop Sharma, Neeraj Sharma. (2019). "Effects of Wood Ash and Calcium Chloride on the Clayey Soil". International Journal of Advanced Research in Science, Engineering and Technology (IJARSET). Vol. 6, Issue 6, ISSN: 2350-0328, 9749-9754. http://www.ijarset.com/
7. Azam S, Ito M, Chowdhury R. (2013). "Engineering properties of an expansive soil". Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris. https://www.cfms-sols.org/sites/default/files/Actes/199-202.pdf
8. B.R. Phani Kumar, Radhey S. Sharma.: Effect of fly ash on engineering properties of expansive soils. Journal of Geotechnical and Geoenvironmental Engineering. 764-767 (2004). http://dx.doi.org/10.1061/(ASCE)1090-0241(2004)130:7(764)
9. Bidula Bose. (2012). "Geo-Engineering Properties of Expansive Soil Stabilized with Fly Ash". EJGE. https://www.researchgate.net/publication/290694106_Geoengineering_properties_of_expansive_soil_stabilized_with_fly_ash
10. Boobathiraja S, Balamurugan P, Dhansheer M, Anuj Adhikari. (2014). "Study on Strength of Peat Soil Stabilized with Cement and Other Pozzolanic Materials". International Journal of Civil Engineering Research. Vol. 5, Issue No. 4, ISSN: 2278-3652, pp 431-438. http://www.ripublication.com/ijcer.htm
11. Darshan C Sekhar, Sitaram Nayak. (2017). "SEM and XRD investigations on lithomargic clay stabilized using granulated blast furnace slag and cement". International Journal of Geotechnical Engineering. Vol. 13, Issue 6. pp 1-15. http://dx.doi.org/10.1080/19386362.2017.1380355
12. Dr. Murali K, Ashok S, Giridharan N, Kaniyan pandiarasan K, Logesh P. (2018). "A Review on Stabilization of Expansive Soil with various admixtures". International Journal of Scientific and Research Publications. Vol. 8, Issue 4, ISSN: 2250-3153. http://dx.doi.org/10.29322/IJSRP.8.4.2018.p7629

13. Emeka Segun Nnochiri and Olufikayo Aderinlewo. (2016). "Geotechnical Properties of Lateritic Soil Stabilized with Banana Leaves Ash". FUOYE Journal of Engineering and Technology. 1(1), 116-119. https://doi.org/10.46792/fuoyejet.v1i1.24
14. Emilliani Anak Geliga, Dygku Salma Awg Ismail. (2010). "Geotechnical Properties of Fly Ash and its Application on Soft Soil Stabilization". Journal of Civil Engineering, Science and Technology. Vol. 1, Issue 2. https://doi.org/10.33736/jcest.73.2010
15. Erdal Cokca. (2001). "Use of Class C Fly Ashes for the Stabilization of an Expansive Soil". Journal of Geotechnical and Geoenvironmental Engineering. Vol. 127, Issue 7, ISSN: 1090-0241, pp 568-573. https://doi.org/10.1061/(ASCE)1090-0241(2001)127:7(568)
16. Fatahi B, Khabbaz H. (2012). "Mechanical characteristics of soft clay treated with fibre and cement". Geosynthetics International. 19(3), 252-262. https://doi.org/10.1680/gein.12.00012
17. Fatahi B, Thu Minh Le, Fatahi B, Hadi Khabbaz. (2013). "Shrinkage properties of soft clay treated with cement and geofibers." Geotechnical and Geological Engineering. 31(1), 1421-1435. http://dx.doi.org/10.1007/s10706-013-9666-y
18. Grytan Sarkar, Rafiqul Islam MD, Muhammed Alamgir, Rokonuzzaman MD. (2012). "Study on the Geotechnical Properties of Cement based Composite Fine-grained Soil". International Journal of Advanced Structures and Geotechnical Engineering (IJASGE). Vol.01, No. 02, ISSN: 2319-5347, pp 42-49. https://www.scribd.com/document/751236553/2012-Study-on-the-Geotechnical-Properties-of-Cement-based-Composite-Fine-grained-Soil
19. Hawkar Hashim Ibrahim, Yousif Ismeil Mawlood, Younis Alshkane M. (2019). "Using waste glass powder for stabilizing high-plasticity clay in Erbil city-Iraq". International Journal of Geotechnical Engineering. https://doi.org/10.1080/19386362.2019.1647644
20. Hayder Hasan, Liet Dang, Hadi Khabbaz, Behzad Fatahi, Sergei Terzaghi. (2016). "Remediation of Expansive Soils Using Agricultural Waste Bagasse Ash". Advances in Transportation Geotechnics, The 3rd International Conference on Transportation Geotechnics (ICTG 2016). 143, 1368-1375. https://doi.org/10.1016/j.proeng.2016.06.161
21. IS: 2720 (Part 10)-1973. Methods of test for soil: Determination of unconfined compressive strength. Bureau of Indian Standards, New Delhi.
22. IS: 2720 (Part 5)-1985. (Reaffirmed 2006). Methods of test for soil: Determination of liquid and plastic limits. Bureau of Indian Standards, New Delhi.
23. IS: 2720 (Part 7)-1980. (Reaffirmed 2002). Methods of test for soil: Determination of water content – dry density relation using light compaction. Bureau of Indian Standards, New Delhi.
24. J. Mitchell.: Fundamentals of soil Behaviour. (1993). Wiley, New York.
25. Jayant Singh, Singh U K, Sing R K. (2020). "Stabilization of Clayey Soil Using Gypsum and Calcium Chloride". International Journal of Recent Technology and Engineering (IJRTE). Vol. 9, Issue 2, ISSN: 2277-3878, 668-673. DOI:10.35940/ijrte. B3828.079220. http://www.ijrte.org/
26. Jijo James, Kasinatha Pandian P. (2014). "Effect of Phosphogypsum on Strength of Lime Stabilized Expansive Soil". Gradevinar. pp 1109-1116. http://dx.doi.org/10.14256/JCE.1097.2014
27. Ji-ru, Zhang and Cao Xing. (2002). "Stabilization of expansive soil by lime and fly ash". Journal of Wuhan University of Technology-Material Science. pp 73-77. http://dx.doi.org/10.1007/BF02838423
28. Manikandan A. T, Maganraj M. (2014). "Consolidation and rebound characteristics of expansive soil by using lime and bagasse ash". International Journal of Research in Engineering and Technology. 3(4), 403-411. http://www.ijret.org/.
29. Manjunath K.R, Venugopal G, Rudresh A.N. (2013). "Effect of random inclusion of sisal fibre on strength behavior of black cotton soil". International Journal of Engineering Research and Technology (IJERT). 2(7), 2278-0181. https://www.ijert.org/research/effect-of-random-inclusion-of-sisal-fibre-on-strength-behavior-of-black-cotton-soil-IJERTV2IS70815.pdf
30. Mishra, A.K., Dhawan, S., Rao, S.M., (2008). Analysis of swelling and shrinkage behavior of compacted clays. Geotechnical and Geological Engineering. Vol. 26, Issue 3, pp 289-298. https://doi.org/10.1007/S10706-007-9165-0.
31. Rajesh Prasad Shukla, Niraj Singh Parihar. (2016). "Stabilization of Black Cotton Soil Using Micro-Fine Slag". Journal of The Institution of Engineers (India): Series A. http://dx.doi.org/10.1007/s40030-016-0171-1.

32. Rajesh Prasad Shukla, Niraj Singh, Pravar Yadav, Nitesh Mankotia. (2015). "Problems and treatment of black cotton soil". 50th Indian Geotechnical Conference. http://ir.juit.ac.in:8080/jspui/jspui/handle/123456789/4707
33. Sayedhessam Bahmani et.al. (2016). "The effect of size and replacement content of nano silica on strength development of cement treated residual soil". Construction and building materials. 118, 294-306. https://doi.org/10.1016/j.conbuildmat.2016.05.075
34. Selvamsagayaradja M, Murugaiyan V, Sundarajan T. (2021). "Geotechnical mapping of expansive soil problems associated with damages in low rise buildings along south east coast of India". International Journal of Science, Engineering and Management (IJSEM). Vol. 6, Issue 4, ISSN: 2456-1304. https://www.researchgate.net/publication/365184732
35. Sivapullaiah, P.V, Subba rao, K.S, Gurumurthy, J.V. (2004). "Stabilization of rice husk ash for use as cushion below foundation on expansive soils". Ground Improvement. 8(4), 137-149. https://doi.org/10.1680/grim.2004.8.4.137
36. Sridharan A, Nagaraj H.B. (2009). "Absorption water content and Liquid limit of soils". Geotechnical Testing Journal. http://eprints.iisc.ac.in/id/eprint/17721
37. Subba Rao K.S. (2000). "Swell-Shrink Behavior of Expansive Soils - Geotechnical Challenges".Indian Geotechnical Journal. Vol.30 Issue. 1. https://igs.org.in/storage/annual-lecture/annual-lecture-1999-180523065135.pdf
38. Suresh R, Murugaiyan V. (2018). "Amelioration of highly sensitive clay using natural fiber and chemical admixture". IEEE International Conference on System, Computation, Automation and Networking (ICSCAN). http://dx.doi.org/10.1109/ICSCAN.2018.8541235
39. Suresh R, Murugaiyan V. (2018). "Review of nano materials for predicting strength and volume change behavior of expansive soils". STM Journals-Journal of Geotechnical Engineering. Vol. 5, Issue 3, ISSN: 2394-1987, pp 8-13. http://dx.doi.org/10.13140/RG.2.2.11823.48801
40. Suresh R, Murugaiyan V. (2019). "Experimental studies on influence of alccofine and calcium chloride on geotechnical properties of expansive soil". Indian Geotechnical Conference. GeoIndus. SVNIT Surat. India. https://www.researchgate.net/publication/340885271
41. Suresh R, Murugaiyan V. (2020). "Experimental study on the influence of coir and calcium chloride on the strength characteristics of expansive soil". 2nd International Conference on Environmental Geotechnology, Recycled Waste Materials and Sustainable Engineering, UIC, Chicago. http://dx.doi.org/10.1007/978-3-030-51354-2_31
42. Vasudevan Yathushan, Udeni Gnanapriya Anuruddha Puswewala. (2021). "Effectiveness of Pozzolanic Leaf Ashes and Plastics on Geotechnical Characteristics". International Journal of Engineering and Technology Innovation. 12(2), 155-166. https://doi.org/10.46604/ijeti.2022.8912

