Recent Advancement in Current Challenges and Opportunities for Civil Engineers: "Expansive Soil Stabilization Using Fly Ash as Stabilizing Agent"

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Abstract: Expansive soils are challenges for engineering applications in virgin state because of their shrink-swell nature with moisture variation. Numerous stabilizers and number of methods have been used to stabilize expansive soils as an effort to make them more practical for construction purposes. Searching for suitable stabilizers to overcome soil difficulties caused by the expansive nature of soil is the key issue, not only in terms of achieving the required soil engineering characteristics but also in terms of environmental and economic concerns. The purpose of this article was to assess the current trends, challenges, and opportunities of various admixtures utilized for expansive soil improvement, as well as their economic and environmental consequences. A critical use of various admixtures commonly as soil stabilizers, including marble waste powder, **fly ash**, eggshell powders, stone waste, and lime powder is conducted. Furthermore, this paper is also focused to analyze the offered stabilizers in terms of soil geotechnical properties and sustainability in the field application. Sustainable and eco- friendly challenges overcome by the various techniques used in geotechnical field. One of them expansive soil stabilization with fly ash. Main objective of this paper is that waste from thermal power plant utilized as stabilizing agent for expansive soil stabilization.

Keywords: Expansive soils, stabilization, fly ash, shrink-swell etc.

1. INTRODUCTION

Swelling and shrinkage of expansive soils exhibit when the seasonal moisture content fluctuates. Because of their global presence, the issues related with their volume fluctuation have received much interest. Furthermore, expansive soils exist in full-scale structural and geotechnical challenging situations worldwide. Soil deformations (volume change) cause of greater problems in lightweight engineering constructions. When exposed to expansive soil displacement, lightweight engineered constructions frequently collapse. The faults associated with expansive soils result from a failure to assess the existence and degree of volume change of these soils at an early stage of the project, rather than a lack of engineering solutions. South Africa, Morocco, Mexico, Israel, Spain, Turkey, Iran, India, high-quality Britain, Ethiopia, Ghana, Australia, the United States of America, Argentina, and othercountries have emphasized the damage caused by expanding soils. In South Africa, the annual repair bill for building losses caused by expansive soil is expected to be R100 million.
Additionally, expansive soil damages are predicted to cost around £ 400 million annually in the United Kingdom. According to the American Society of Civil Engineers, 25% of structures have some damage caused by expansive soil. As a result, improving the physical-chemical qualities of expansive soils is required to make them suitable for civil engineering projects. New solutions incorporating local resources must be examined based on the idea that more significant costs are inherent in raw materials and construction. Damage to structures built on these problematic soils is prompting study into strategies for enhancing in situ engineeringproperties through stabilization procedures
Soil stabilization is a geotechnical procedure consisting of mechanical, chemical, or other treatment techniques aiming to maintainbalance, improve engineering characteristics, limit water absorption capacity, and improve the compressibility of the treated soil. Soil stabilization is achieved through adopting several geotechnical procedures that modify and improve the condition of theground in situations where soil replacement isn't always possible for technical and environmental reasons or isn't cost-effective. Soil improvement communication is commonly used to improve clays' geotechnical – technogenic and natural properties. The most current strategy for soil enhancement is to replace disordered soil with more grounded materials such as concrete, actual soil, Geotextiles, and geo-cross sections. Soil stabilization experiences include: increasing liquefaction resistance, filling voids,providing lateral balance, reducing imposed masses, controlling deformations, improving shear strength, developing bearing capacity,increasing density, reducing soil plasticity, and limiting swelling/shrinkage capability.
Soil stabilization concept emerged almost 5000 years ago. In early days lime was employed by the Greeks and Romans as astabilizer and that stabilized earth roads were utilized in ancient Egypt and Mesopotamia.

However, heaving and early pavementfailures in sulfate-containing subgrade treated with lime and cement raised concerns about the efficacy of calcium-based stabilization.
When expansive soils with sulphates are treated with calcium-based stabilizers, the stabilizer's calcium combines with the sulphatesand alumina in the soil to create the expansive mineral ettringite. In the United States, the first soil stabilization tests wereconducted in 1904. In Sarasota, Florida, a street was built using cement as a stabilizer in 1915 (ACI 1997), and lime was first usedin 1924 when roads were widened to accommodate the increase in vehicle traffic.
The current review presents an in-depth review of recent advances in expansive soil stabilization using different admixtures. Thereview also focuses on characteristics, behavior, and engineering properties of expansive soils with regard to applications of widelyused admixture types. Further, the present review also concentrates on the geo-environmental and economic aspects of the offermentioned admixtures in the field application. Finally, recent challenges and opportunities in the soil stabilization practice usingvarious admixtures are also discussed.

2. EXPANSIVE SOIL STABILIZATION

In general, soil stabilization is a technique for enhancing the qualities of soil by blending and combining various admixtures. The purpose of soil stabilization is to increase the bearing capabilities, be resistant to volume change, improvement in dry unit weight to reinforce road surfaces and other geotechnical applications. In the following sections, a detailed mechanism of expansive soil stabilization, methods used, and commonly used additives/admixtures are provided.

2.1. Mechanism of expansive soil expansion

It is understood that clay particles have surface negative charges as a result of isomorphous replacement. Therefore, there are electrostatic forces between the exchangeable cations in the clay-pore fluid media and the negative clay surface, and the intensityof these forces is determined by the chemistry of the exchangeable cation. There is a natural attraction for the counter ions to be drawn onto the surface of clay particles, lowering their concentration with distance from the clay surface in order to maintain neutrality within the clay-pore fluid medium. The number of cations required to maintain neutrality on the clay surface is determined by the cation exchange capacity and this variation in concentration results in the surface electrostatic feature known as the diffuse double layer. As a result, the double layer separates the particles and minerals, resulting in swelling behavior for expandable clay minerals like montmorillonite. The diffuse double layer obviously has a considerable impact on all the engineering characteristics of clayey soil, particularly the hydraulic conductivity. The hydraulic conductivity is predicted to decrease as the diffuseDouble-layer thickness increases over time.
The expansive clay mineral, such as montmorillonite, whose structure is described by an expanding clay lattice, has a natural impact on the volume change behavior of expansive soil. Expansion clay minerals exhibit negative surface charges, substantial cation exchange capacity, and enormous specific surfaces in terms of mass despite having modest intermolecular forces of attraction between neighboring unit cells. Fig. 1 summarizes the overall mechanism process of soil stabilization using different stabilizers.

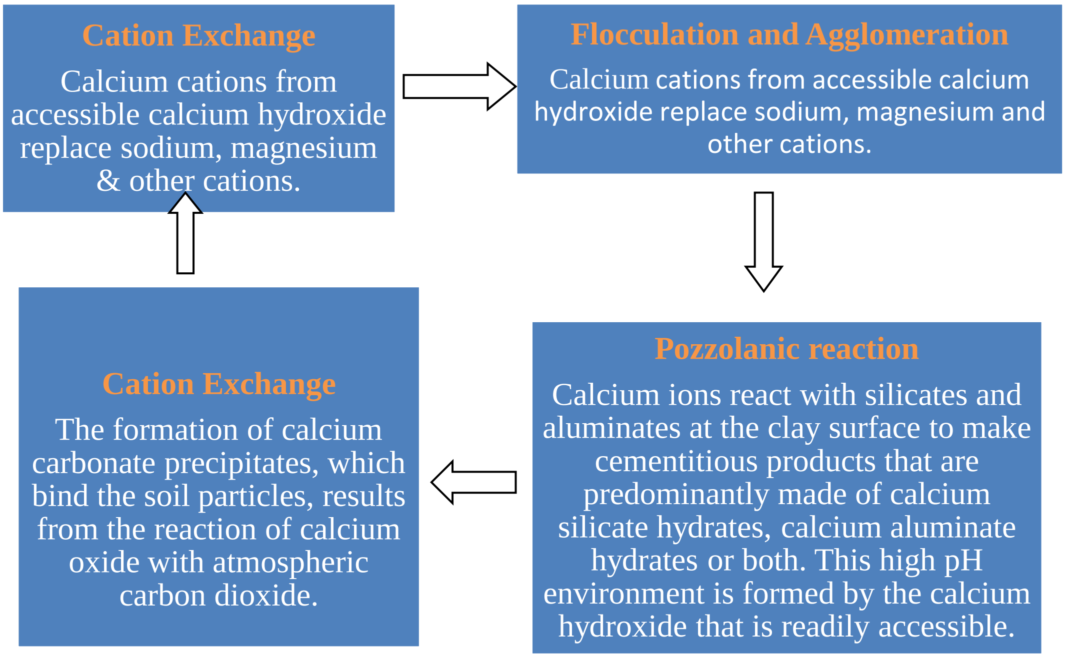

Fig. 1. Mechanism of soil stabilization.

3. MATERIALS & METHODOLOGY

3.1 Material Used

Black cotton soil- Black cotton soils are inorganic clays of medium to high compressibility. They are characterized by high shrinkage and swelling properties. The black cotton soil is very hard when dry, but loses its strength completely in wet condition.40-60% of the black cotton soil (BC Soil) has a size less than 0.001 mm. Black cotton soil was collected from Lambhua Sultanpur, Uttar-Pradesh, and then sent to soil laboratory.

Fly ash- Fly ash is a by-product of thermal power plants which use coal as fuel. It is finely divided residue that results from the combustion of pulverized coal and is transported from the combustion chamber by exhaust gases. Generally Fly ash can be classified as Class-c fly ash and Class-F fly ash. This classification is based on the percentage of calcium oxide available in fly ash .It is collected from NTPC Unchahar, Raibareli, Uttar-Pradesh. At present about 100 thermal power plants in India produce 1.3 million tones of fly ash. Environmental benefits of fly ash:

- Increasing the life of concrete roads.
- Net reduction in energy use and greenhouse gas.
- Less material for disposal in landfill.
- Fly ash is costless and abundantly available all over the country.
- Utilization of fly ash solves the problem of air and water pollution.

Based on the chemical composition of fly ash, fly ash has been categorized into two categories, as given:

- Class-C fly ash
- Class-F fly ash

3.2Methods and commonly used admixtures for expansive soil stabilization

Methods used for expansive soil stabilization fall under two main categories, i.e., mechanical stabilization and chemical stabilization.In an attempt to optimize the benefits, the methods may be used independently or simultaneously. For highly expansive soilssuch as clay a combination of the physiochemical method is generally preferred. **Mechanical stabilization** methods are aimed atreducing the swelling stresses (SS) and expansion potential of soil without altering the soil chemistry. The most widely used mechanical/physical techniques used for expansive soil stabilizations include compaction, pre-wetting, wetting-drying cycles, reinforcement,solid wastes, etc. These physical soil stabilization techniques have a number of advantages for expansive soil stabilizationsuch as easy and simple applications, lack of adverse environmental impacts, less stabilization costs, and also acting as viable alternativesfor waste management. However, on the downside, these techniques are supplementation by chemical methods, inhomogeneous treatment, and unpredicted results, and are also not suitable for heaving soils.

To address the limitations of mechanical methods, several chemical stabilization techniques were proposed. **Chemical stabilization** is frequently undertaken to impart stability to expansive soils by decreasing the plasticity index, increasing grain size particles of soil material, reducing the swelling-shrinking potential, and improving the soil cementation properties. Expansive soil stabilization through chemical methods is achieved by adding a certain chemical additive in a specific amount to the expansive soil. Chemical stabilization techniques are further classified into traditional stabilizers and non-traditional stabilizers. Chemical stabilization through traditional stabilizers includes the addition of well-established and existing additives and include the compounds such as cement, lime, and fly ash. On the other hand, non-traditional chemical stabilizers often involve the use of additives that chemically react with the soil in the presence of adequate moisture content and engender physiochemical interactions in the soil matrix. These additives include but are not limited to the following: lime kiln dust, cement kiln dust, steel slag, pulverized coal bottom ash, mine tailings, ground granulated blast furnace slag, waste products with calcium oxide content (like sludge ash and waste paper), ionic compounds, sulfonated oils, polymers, bitumen emulsions, and others. Chemical soil stabilization techniques are less prominent than mechanical soil stabilization procedures. Further demerits of expansive soil stabilization using chemical methods include potential hazards to the environment, attainment of quality control, lack of independent testing of the additives used, and significantperformance variations of stabilizers based on field conditions.

4. RESULTS AND ANALYSIS

• All results are discussed on the basis of the given sample criteria as below.

IV. DATA ANALYSIS		
Table.3. Test sample of natural soil with fly ash		
S.No.	**Test Name**	**Fly-ash proportion**
1	Liquid Limit	0%, 6%, 12%, 18%, 24%, 30%
2	Plastic Limit	0%, 6%, 12%, 18%, 24%, 30%
3	Plasticity Index	0%, 6%, 12%, 18%, 24%, 30%
4	Free Swell Index(FSI)	0%, 6%, 12%, 18%, 24%, 30%
5	Optimum Moisture Content	0%, 6%, 12%, 18%, 24%, 30%
6	Maximum Dry Density	0%, 6%, 12%, 18%, 24%, 30%
7	California Bearing Ratio(CBR)	0%, 6%, 12%, 18%, 24%, 30%
8	Unconfined Compressive Strength	0%, 6%, 12%, 18%, 24%, 30%

- Result Analysis as per experimental result in tabular form laboratory as given below.

Table 1. Expansive Soil in add fly ash mixture

S.No.	Sample		Atterberg limit (%)			F.S.I.	O.M.C.	M.D.D.	CBR	UCS
	Soil (%)	Fly Ash (%)	LL	PL	PI	(%)	(%)	KN/m^3	Value	KN/m^2
1	100	0	65	37.18	27.82	95	16	13.8	1.64	18.1
2	94	6	57	38.29	18.71	74	14.5	16.9	1.66	18.4
3	88	12	53	36.25	16.75	63	13.6	17.2	1.72	19.3
4	82	18	51	35.66	15.34	60	13.2	18.3	1.93	19.7
5	76	24	47	32.17	14.83	55	11.8	19.6	1.95	20.3
6	70	30	49	33	16	49	13.1	18.4	1.82	18.85

i) Atterberg's Limits (%)

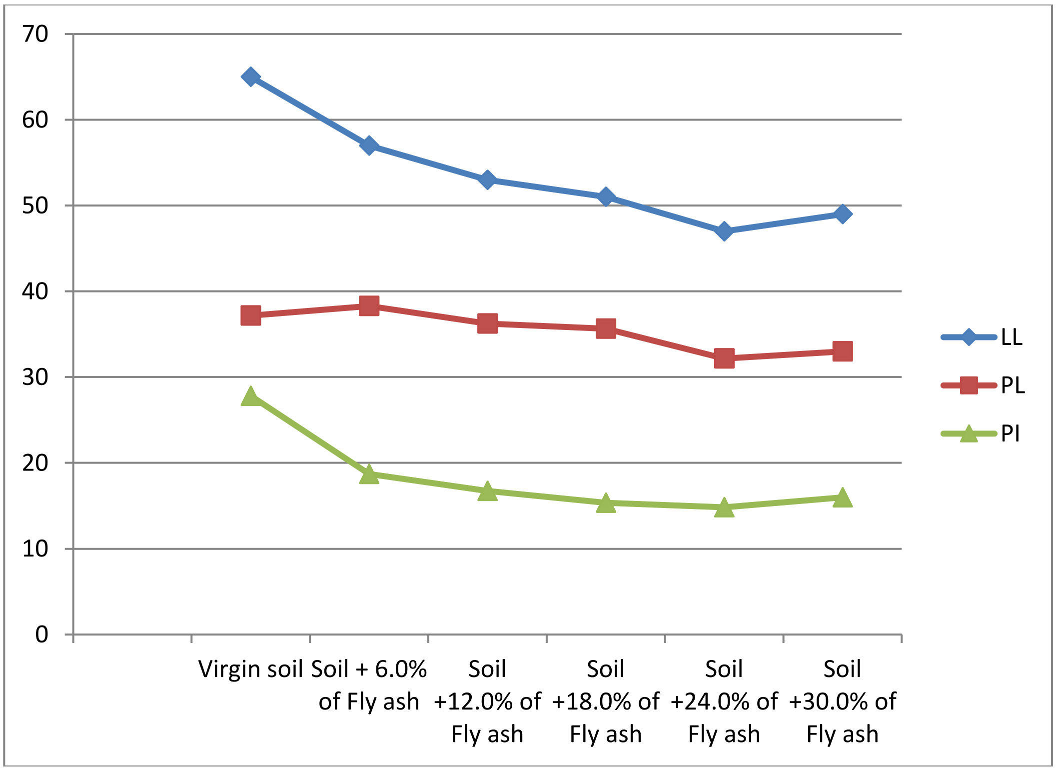

Figure: 1. Atterberg Limits (%)

ii) Free swell index (FSI) (%)

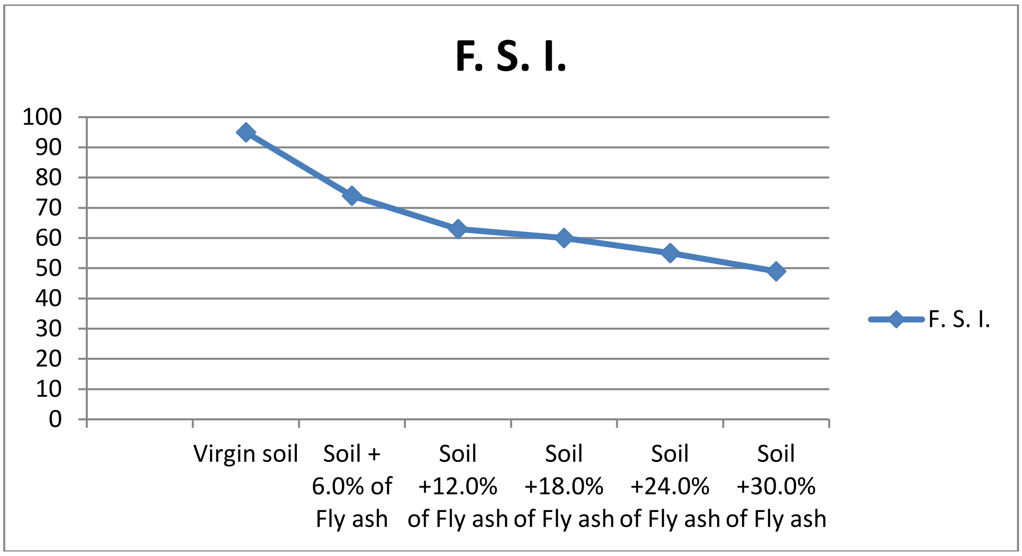

Figure: 2. Free Swell Index (FSI) (%)

iii) Optimum Moisture Content &Maximum Dry Density (%)

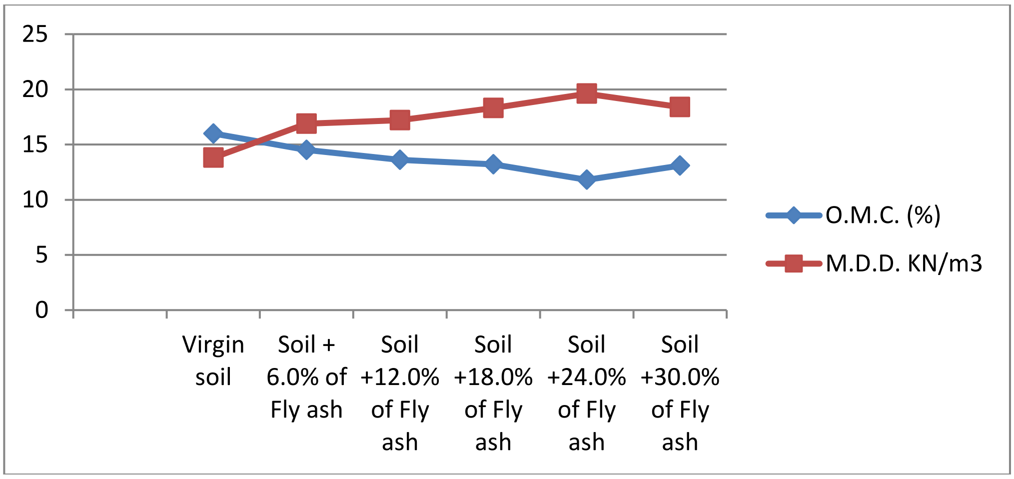

Figure: 3. Optimum Moisture Content & Maximum Dry Density (%)

iv) California Bearing Ratio (CBR)

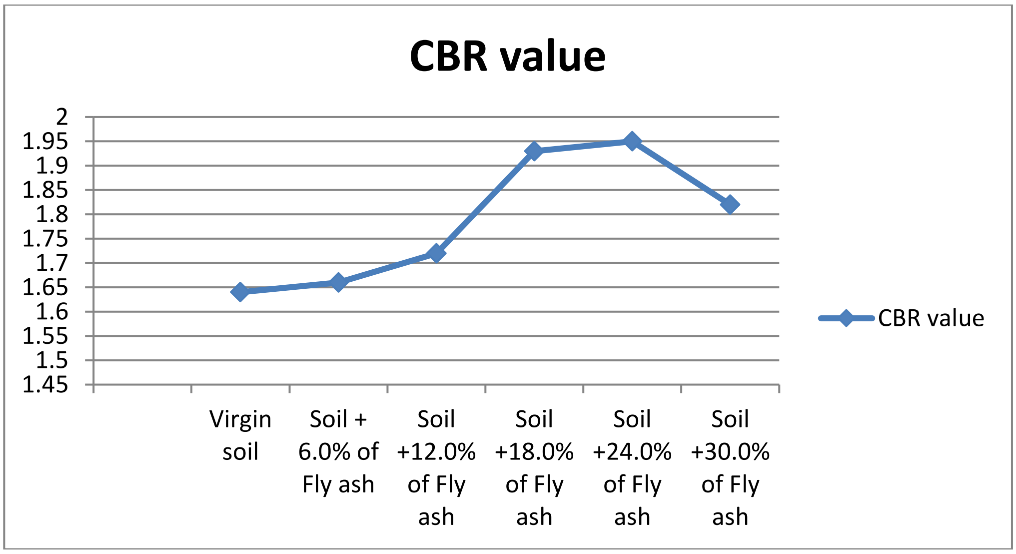

Figure: 4. California Bearing Ratio (CBR)

v) Unconfined Compressive Strength (KN/m^2)

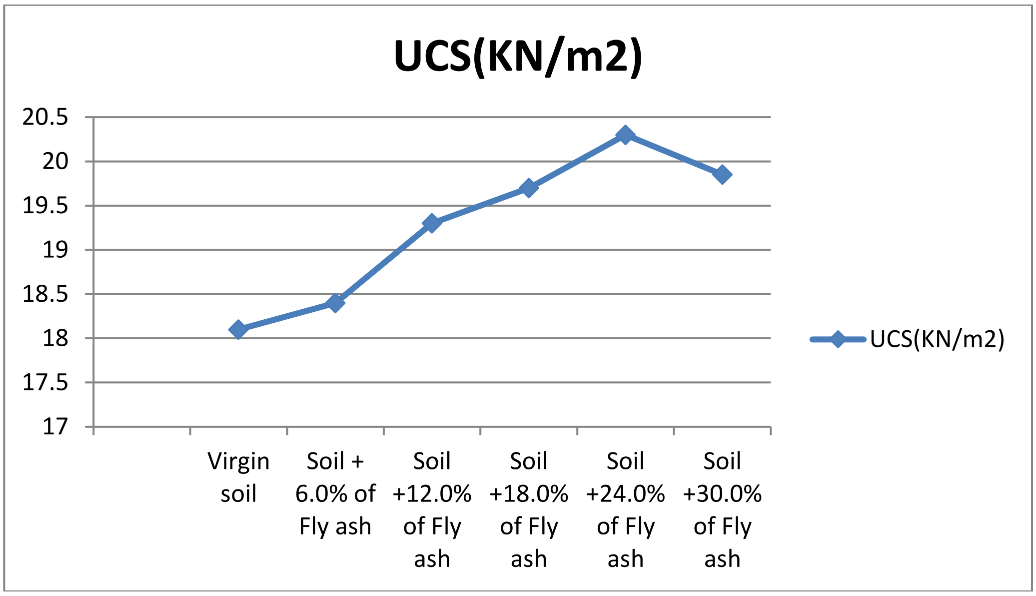

Figure: 5. Unconfined Compressive Strength (KN/m^2

5. DISCUSSION

According to the data and results acquired from the experimental work on soil stability investigation with different percentages of fly ash i.e.(0%,6%,12%,18%,24% &30%).The following conclusion can be drawn in the aspect of strength properties due to application of fly ash as a stabilizing agent for the natural black cotton soil.

1. Based on above figure 1, the results obtained in clayey soil with fly ash from the Casagrande apparatus the Atterberg's limits behave as follows:

i) Liquid Limit decreases as increase in fly ash percentage up to 24 % of fly ash content.
ii) Plastic Limit decreases as increase in fly ash percentage up to 24 % of fly ash content.
iii) Plasticity Index decreases as increase in fly ash percentage up to 24 % of fly ash content.

2. Based on above figure 2, graph shows that free swelling index of clayey soil decreases up to minimum 49 percent as increase up to 30% fly ash content. Minimum FSI obtained at30% fly ash content in clayey soil.

3. Based on above figure 3, the results from the compaction test, it can be stated that at 24% fly ash content the compaction parameter i.e. MDD (maximum dry density) is found out to be maximum and is equals to19.6 KN/m^3. Other compaction parameter i.e. OMC (optimum moisture content) is found out to be minimum (11.8 %) at 24% fly ash content.

4.Based on above figure 4, CBR test results, it is observed that addition of fly ash as stabilizing agent for clayey soils produces significant increase in CBR value. It is concluded that, with increase in fly ash the CBR values are also increased considerably and is found to be maximum 1.95 for 24 % fly ash.

5. Based on above figure 5, UCS test results, it is observed that addition of fly ash as stabilizing agent for clayey soils produces significant increase in UCS value. It is concluded that, with increase in fly ash the UCS values are also increased considerably and is found to be maximum 20.3$KN/m^2$for 24 % fly ash.

6. Conclusion

From the above discussion, it is inferred that addition of fly ash to the black cotton soil there is appreciable impact on the compaction parameters and bearing capacity of soil. It is also inferred that, expensive soil stabilization methods for stabilization of such soils can be supplanted together with fly ash as an alternative method to improve the weak black cotton soil properties. In above discussion the improvements in shear strength up to 24% of fly ash with weak soil.

7. Future Scope

Fly ash can be used for stabilization of pavement sub grade, embankment and other fields of civil engineering according to the requirements for black cotton soils. For stabilization of such soils with stabilizing agents cement, gypsum, lime, brick dust, bagasse ash, jute, plastic waste, stone dust etc. All waste products as above mentioned if used in soil stabilization or other like similar reuse of these waste minimize the problem of waste disposal. These are also clear the environment if these waste reuse in any waste reduction techniques. So much future of this study in civil engineering as well as in environmental; engineering.

REFERENCES

[1] M. Ashfaq, et al., Carbon footprint analysis on the expansive soil stabilization, Tech., IFCEE (2021) 213–222.
[2] A. Al-Swaidani, I. Hammoud, A. Meziab, Effect of adding natural pozzolana on geotechnical properties of lime-stabilized clayey soil, J. Rock. Mech. Geotech. Eng. 8 (5) (2016) 714–725.
[3] A.K. Anupam, P. Kumar, G. Ransingchung, RN, Performance evaluation of structural properties for soil stabilised using rice husk ash, Road. Mater. Pavement Des. 15 (3) (2014) 539–553.
[4] A.A. Fondjo, E. Theron, R.P. Ray, Stabilization of expansive soils using mechanical and chemical methods: a comprehensive review, Civ. Eng. Arch. 9 (2021) 1295–1308.
[5] A. Salahudeen, A.O. Eberemu, K.J. Osinubi, Assessment of cement kiln dust-treated expansive soil for the construction of flexible pavements, Geotech. Geol. Eng. 32 (4) (2014) 923–931.
[6] N.C. Consoli, et al., Key parameters establishing alkali activation effects on stabilized rammed earth, Constr. Build. Mater. 345 (2022), 128299.
[7] A.A. Firoozi, et al., Fundamentals of soil stabilization, Int. J. Geo-Eng. 8 (1) (2017) 1–16.
[8] A.A. Amadi, S. Lubem, Assessing stabilization effectiveness of combined cement kiln dust and quarry fines on pavement subgrades dominated by black cotton soil, Geotech. Geol. Eng. 32 (5) (2014) 1231–1238.
[9] Association, A.C.A., Soil Stabilization and Pavement Recycling with Self-Cementing Coal Fly Ash. American Coal Ash Association Education Foundation, Colorado, 2008.
[10] D. Jones and L. IanJefferson, Chapter 33 Expansive soils, in ICE manual of geotechnical engineering: Volume I. p. 413–441.
[11] H.C. Scheuermann Filho, G.D. Miguel, N.C. Consoli, Durability response of a cemented clayey sand over a wide range of porosities and cement contents, Clean.Mater. 5 (2022), 100117.
[12] A. Zinchenko, et al., Efficient stabilization of soil, sand, and clay by a polymer network of biomass-derived chitosan and carboxymethyl cellulose, J. Environ.Chem. Eng. 10 (1) (2022), 107084.
[13] Consoli, N.C., et al., Increasing density and cement content in expansive soils stabilization: Conflicting or complementary procedures for reducing swelling?2020.
[14] Schaefer, V.R., et al., Ground improvement in the 21st century: a comprehensive web-based information system, in 15. Geotechnical Engineering State of the Artand Practice: Keynote Lectures from GeoCongress 2012. 2012. p. 272–293.
[15] M. Maheepala, et al., A comprehensive review on geotechnical properties of alkali activated binder treated expansive soil, J. Clean. Prod. (2022), 132488.
[16] M. Saqlain, et al., Assessment of a Fast Proxy of Vs30 (Vs30m), Sustainability 14 (20) (2022) 13668.
[17] L. Sharma, et al., Experimental study to examine the independen14t roles of lime and cement on the stabilization of a mountain soil: a comparative study, Appl.Clay Sci. 152 (2018) 183–195.
[18] M. Amiri, M. Sanjari, F. Porhonar, Microstructural evaluation of the cement stabilization of hematite-rich red soil, Case Stud. Constr. Mater. 16 (2022), e00935.
[19] Porbaha, A., Ground improvement engineering–the state of the US practice: part 1. Methods. Proceedings of the Institution of Civil Engineers – GroundImprovement, 1998. 2(4): p. 189–190.
[20] R. Suresh, V. Murugaiyan, Influence of chemical admixtures on geotechnical properties of expansive soil, Int. J. Eng., Trans. A: Basics 34 (1) (2021) 19–25.
[21] D.C. Nwonu, C.C. Ikeagwuani, Evaluating the effect of agro-based admixture on lime-treated expansive soil for subgrade material, Int. J. Pavement Eng. 22 (12)(2021) 1541–1555.
[22] Y. Liu, et al., Utilization of cementitious material from residual rice husk ash and lime in stabilization of expansive soil, Adv. Civ. Eng. 2019 (2019).
[23] C. McDowell, Stabilization of soils with lime, lime-flyash, and other lime reactive materials, Highw. Res. Board Bull. 231 (1) (1959) 60–66.
[24] Puppala, A., et al. Sulfate induced heave distress: a case study. in Proceedings, transportation research board annual meeting, Washington DC, USA. 1999.
[25] L. Saussaye, et al., Influence of sulfate and chloride ions on the geotechnical and microstructural properties of soils treated with hydraulic binders: individualand coupling effects, Eng. Geol. 189 (2015) 98–103.
[26] Materials and structures 47 (11) (2014) 1901–1910.
[27] A.A. Firoozi, M.R. Taha, A.A. Firoozi, Nanotechnology in civil engineering, EJGE 19 (2014) 4673–4682.
[28] A.A. Firoozi, et al., Assessment of nano-zeolite on soil properties, Aust. J. Basic Appl. Sci. 8 (19) (2014) 292–298.
[29] M. Abu-Farsakh, S. Dhakal, Q. Chen, Laboratory characterization of cementitiously treated/stabilized very weak subgrade soil under cyclic loading, Soils Found.55 (3) (2015) 504–516.
[30] U. Zada, K. Haleem, A. Abbas, Re-utilization of stone industry waste materials for stabilization of expansive soil, NUST J. Eng. Sci. 14 (2) (2021) 61–65.
[31] A. Sridharan, D. Choudhury, Computation of hydraulic conductivity of montmorillonitic clays by diffuse double layer theory, Int. J. Geotech. Eng. 2 (1) (2008)1–10.
[32] R.M. Schmitz, Can the diffuse double layer theory describe changes in hydraulic conductivity of compacted clays? Geotech. Geol. Eng. 24 (6) (2006) 1835–1844.
[33] J. Yadav, S. Tiwari, The impact of end-of-life tires on the mechanical properties of fine-grained soil: a review, Environ., Dev. Sustain. 21 (2) (2019) 485–568.
[34] A. Besq, et al., Physicochemical characterisation and flow properties of some bentonite muds, Appl. Clay Sci. 23 (5–6) (2003) 275–286.
[35] D. Jahed Armaghani, et al., Developing a hybrid PSO–ANN model for estimating the ultimate bearing capacity of rock-socketed piles, Neural Comput. Appl. 28(2) (2017) 391–405.
[36] D.J. Armaghani, et al., Development of hybrid intelligent models for predicting TBM penetration rate in hard rock condition, Tunn. Undergr. Space Technol. 63(2017) 29–43.
[37] C. Okagbue, T. Onyeobi, Potential of marble dust to stabilise red tropical soils for road construction, Eng. Geol. 53 (3–4) (1999) 371–380.
[38] Puspitasari, P., V. Yuwanda, and J. Dika. The properties of eggshell powders with the variation of sintering duration. in IOP Conference Series: Materials Scienceand Engineering. 2019. IOP Publishing.
[39] Alabi, O.J., J. Ngambi, and D. Norris, Effect of egg weight on physical egg parameters and hatchability of indigenous Venda chickens. 2012.
[40] U. Zada, et al., Reutilization of eggshell powder for improvement of expansive clayey soil, Iran. J. Sci. Technol., Trans. Civ. Eng. (2022) 1–8.
[41] B. Bose, Geo engineering properties of expansive soil stabilized with fly ash, Electron. J. Geotech. Eng. 17 (1) (2012) 1339–1353.
[42] E.O. Tastan, et al., Stabilization of organic soils with fly ash, J. Geotech. Geoenviron. Eng. 137 (9) (2011) 819–833.
[43] N. Pandian, Fly ash characterization with reference to geotechnical applications, J. Indian Inst. Sci. 84 (6) (2004) 189.

[44] B. Phani Kumar, R.S. Sharma, Effect of fly ash on engineering properties of expansive soils, J. Geotech. Geoenviron. Eng. 130 (7) (2004) 764–767.
[45] A.A. Firoozi, et al., The influence of freezeˆa€“thaw cycles on unconfined compressive strength of clay soils treated with lime, J. Teknol. 76 (1) (2015).
[46] R. Abdulla, N. Majeed, Enhancing engineering properties of expansive soil using marble waste powder, Iraqi Geol. J. (2021) 43–53.
[47] D. Saxena, Effects of marble powder and fine sand on properties of expansive soil, Int J. Eng. Trends Technol. 52 (1) (2017) 12–16p.
[48] R. Ali, H. Khan, A. Shah, Expansive soil stabilization using marble dust and bagasse ash, J. Sci. Res. (IJSR) 3 (6) (2014) 2812–2816.
[49] A. Saygili, Use of waste marble dust for stabilization of clayey soil, Mater. Sci. 21 (4) (2015) 601–606.
[50] H.A. Abdelkader, M. Hussein, H. Ye, Influence of waste marble dust on the improvement of expansive clay soils, Adv. Civ. Eng. 2021 (2021).
[51] Zumrawi, M.M. and E.A. Abdalla. Stabilization of expansive soil using marble waste powder. in Conference Proceedings Civil Engineering 2018. 2018.
[52] C. Okagbue, T. Onyeobi, Potential of marble dust to stabilise red tropical soils for road construction, Eng. Geol. 53 (3–4) (1999) 371–380.
[53] C.K. Ror, S. Tejyan, N. Kumar, Effect of marble dust reinforcement in composites for different applications: a review, Mater. Today.: Proc. (2022).
[54] Puspitasari, P., V. Yuwanda, and J. Dika. The properties of eggshell powders with the variation of sintering duration. in IOP Conference Series: Materials Scienceand Engineering. 2019. IOP Publishing.
[55] Alabi, O.J., J. Ngambi, and D. Norris, Effect of egg weight on physical egg parameters and hatchability of indigenous Venda chickens. 2012.
[56] Alzaidy, M.N. Experimental study for stabilizing clayey soil with eggshell powder and plastic wastes. in IOP Conference Series: Materials Science andEngineering. 2019. IOP Publishing.
[57] M.T. de Araújo, et al., Mechanical and environmental performance of eggshell lime for expansive soils improvement, Transp. Geotech. 31 (2021), 100681.
[58] A. Paul, et al., Studies on improvement of clayey soil using egg shell powder and quarry dust, Int. J. Eng. Res. Appl. 4 (4) (2014) 55–63.
[59] Oluwatuyi, O.E., Adeola, B.O., Alhassan, E.A., Nnochiri, E.S., Modupe, A.E., Elemile, O.O.,.& Akerele, G. (2018). Ameliorating effect of milled eggshell oncement stabilized lateritic soil for highway construction. Case Studies in Construction Materials, 9, e00191.
[60] MN, M., &Obikara, F.O. Effect of Egg Shell Powder (ESP) on the Strength Properties of Cement-Stabilization on Olokoro Lateritic Soil.
[61] J.A. Oke, M.K. Olowoyo, Stabilization of laterite soil with eggshell powder and sodium silicate used as fill material in road construction, Arid Zone J. Eng.Technol. Environ. 15 (3) (2019) 586–597.

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