Stabilization of Clayey Soil Using Mineral Additives

Sabah Zahoor and Tarun Sharma

April 10, 2024

Clayey Soil Stabilization Using Mineral Additives

[1]Sabah Zahoor, [2]Tarun Sharma
[1]*ME Scholar, Department of Geotechnical Engineering, Chandigarh University, Chandigarh*
[2]*Professor, Department of Geotechnical Engineering, Chandigarh University, Chandigarh*

Abstract: Soil improvement is a process aimed at enhancing resilience &strength of soil. This involves modifying characteristics of less stable soil to enhance its compressive strength or modifying properties of foundation soil to ensure their suitability. By augmenting shear strength & managing soil shrink-swell behaviour, it elevates ability of a subgrade to uphold pavements & foundations. Fortified soil ameliorates tensile strength, bearing capacity, & overall soil performance. Procedure of soil stabilization involves utilization of various chemicals. Among prominent approaches for enhancing engineering attributes of problematic soil is chemical stabilization. In contemporary era, lime has emerged as a popular chemical stabilizer. Given current scenario of depleting resources & energy consumption, there is a growing inclination towards utilizing waste materials as soil stabilizers. Sugarcane bagasse ash, a silica-enriched by-product obtained from incineration of sugarcane , is one such material. Main objective is to compare stabilizing effectiveness of lime, bagasse ash(BA) & Granulated Blast Furnace Slag(GBFS). Percentage of lime used is 4%,8%,12%.BA)& GBFS is used in 6%,12%, 18% and 9%,18% & 27% respectively. Laboratory investigations were conducted to assess impact of varying proportions of lime, BA, & GBFS on stabilization of clayey soil. Findings indicate that this stabilization technique can substantially enhance the geotechnical attributes of clayey soil, offering practical &enduring solutions for construction endeavours.

Keywords: Granulated Blast Furnace Slag (GBFS), Bagasse Ash (BA), California Bearing Ratio (CBR), Optimum Moisture Content (OMC), Maximum Dry Density (MDD), Liquidity Index (LI), Plasticity Index (PI)

Introduction:

Soil is the top layer of the earth , composed of water, air, and densely packed particles created when rocks break down. It is a building material, its properties vary especially when the soil is clayey, from place to place. Engineering issues result from low strength, little water-holding capacity, high compressibility,& low bearing capacity in clay. Clayey soils are not suitable for construction such as paving, embankments, constructs, etc, therefore need to be treated. Stabilization is beneficial for Clay's properties can be improved by using various stabilizing agents. Primary characteristic of soil is shear strength, crucial for any type of soil-based structure. Clayey soil in wet conditions, have low shear strength& undesirable engineering properties. Clayey soil on coming in contact with water undergoes volume changes. Treatment of clayey soil using BA, steel slag & GBFS is not that challenging, rather economical & pollution controlling. Soil stabilization involves modifying soil characteristics to enhance its engineering performance. This process can encompass altering qualities of foundation soil to attain desired traits or bolstering compressive strength of less stable soil. Its application extends to improving a soil's capacity to support foundations & pavements by regulating its shrink-swell behaviour &augmenting shear strength. The resulting improvement encompasses heightened tensile strength, bearing capacity, &overall soil performance. This enhancement is achieved by incorporating various additives, including lime, fly ash, & Portland cement. On a global scale, sugarcane stands as most extensively cultivated crop, generating substantial quantities of wet bagasse. Proper management of this by-product is vital from an environmental perspective. One commonly adopted approach is the combustion of bagasse, leading to the generation of Sugarcane Bagasse Ash (SBA) or Bagasse Ash. This residue, enriched with silica (SiO_2), holds potential as a stabilizing material. In recent times, lime has emerged as one of the prevalent stabilizing agents. In order to conduct a deep & thorough study, below mentioned works were keenly studied.

In this study emphasizes was laid on notable improvement in characteristics of black cotton soil attained at 6.2% replacing of BA. Compressive strength increased by 43.58%. Findings indicated that adding BA improves compressive strength & CBR by almost 40%, but only significantly affects density. Mixture recommended by this study is black cotton soil plus 6% bagasse replacement [1,8,30]. Lime can act right away & enhance a number of soil characteristics, including carrying capacity, resistance to shrinkage under most conditions, reduction of PI, enhancement in CBR value, & subsequently an elevation in compressive resistance over time. Lime was concluded to be great soil stabilizing material for highly active soils that frequently expand &contract.[2,10,22]. It was analysed, effects of dry soil containing up to 12% BA on the lateritic soil. Compactions were using British Standard Light (BSL) energy that when lateritic soil treated with 2% BA, it produced peak 7-day UCS & CBR values of 836.0 KN/m^2 &15%, respectively.[9,14,12,25].Soil was blended using lime and/or BA in varying proportions of 0, 2, 5, 7% by mass of the soil to generate treated specimens. Plasticity index(PI) measure of 13.02%, a plastic threshold measure of 21.37, a fluid threshold measure of 36.32 was seen, optimum moisture content (OMC) measure was 16.72%, max.dry density density(MDD)2.69 kg/m3. Unrestrained compressive potency (UCS) measures for the inherent soil were 268, 403, 592 KN/m2 at 7, 14, & 28 days of solidifying, respectively. Lateritic soil possessed a California Bearing Ratio of 13 for unsaturated soil , 5% for soaked soil, respectively.UCS & CBR measures for soil treated with 7% lime/4% bagasse ash were 697 KN/m2 & 42%, respectively. It was deduced that 7% lime & 4% BA will effectively alter lateritic soil[4,7,8,10].

Treatment of clayey soil using lime, BA, GBFS is economical & less polluting as compared to the traditional techniques. It has been a topic of significant interest in geotechnical engineering due to challenges posed by clayey soils in construction &infrastructure projects. These materials offer pozzolanic, cementitious properties, allowing them to react with clay minerals & promote formation of stable soil-aggregate matrices. Main objective is to determine effectiveness of lime, BA, GBFS in stabilizing clayey soil & to ascertain the optimal mix proportions for achieving improved engineering performance, examine the distinct & combined impacts of lime, BA, and GBFS on consolidation of clayey soil & to ascertain their optimum blending ratios to attain compaction.

2. Materials

2.1 *Soil*

Clay studied was taken from Parihaspora, Srinagar, Jammu & Kashmir. Specific gravity lies in the range 2.65-2.80. Table 2.1 depicts physical properties of soil. Before mixing, soil sample has been dried at 105^0 C in oven for 24 hours & then crushed into finer particles passing 4.75 mm sieve.

Table 2.1 Physical Composition of soil used

Physical properties	Values
Moisture Content	17%
LL%	34.1
Plastic Limit%	16.62
OMC%	14.3%
Specific Gravity	2.7
MDD(KN/m^3)%	17.65%

2.2 *Lime*

Stabilizing agent i.e., Lime, was bought from Lalchowk market, Srinagar, J&K. Tests performed were CBR, Atterberg limits test, UCS & proctor compaction test. Specific gravity of lime lies in the range 2.48. Lime is calcined limestone & white in colour. In powdered form it is almost neutral but once it reacts with water it becomes highly basic with a ph of about 12.4. Table 2.2 represents the chemical characteristics of lime[10,22,27]

Table 2.2 Chemical Properties of lime[10,22]

Chemical oxides	***% by weight***
SiO_2	0.25-2.48
Fe_2O_3	0.04-0.39
Al_2O_3	0.05-0.91
CaO	54.48-92.03
MgO	0.30-14.6
P_2O_5	≤0.005
Na_2O	0.05-0.11
K_2O	≤0.003
Loss of ignition	0.66-40.37

2.3 *Baggase Ash(BA)*

Stabilizing agent BA was bought from Lalchowk market, Sgr, J&K. Tests performed were CBR, Atterberg limits test, UCS & proctor compaction test. Specific gravity of lime lies in range 2.31-2.68, BA is actually a by product of sugarcane and is also known as sugarcane ash. It has a fibrous texture with grey-black in colour. Chemical properties of BA are depicted in Table 2.3[8,9,12,25]

Table 2.3 Chemical composition of BA [8,9,12,25]

Chemical oxides	***% by weight***
SiO_2	32.4-86.5
Fe_2O_3	1.02-7.36
Al_2O_3	0.2-5.63
K_2O	2.44-6.22
CaO	2.01-5.55
MgO	0.91-3.4
P_2O_5	0.5-4.3
Na_2O	0.01-1.4
Loss of ignition	0.9-9.78

2.1.4 *Granulated Blast furnace Slag (GBFS)*

The stabilizing agent i.e., GBFS was bought from Lalchowk market, Sgr, J&K). Tests performed were CBR, Atterberg limits test, UCS & proctor compaction test. Specific gravity of lime lies in range 2.90.Gbfs is an industrial waste emitted as a by product from steel and silicon alloy factories. They have almost the same properties as OPC thereby reducing some quantities of cement required. Chemical composition of GBFS is represented in Table 2.4[10,11,21,22,25]

Table 2.4 Chemical Composition of GBFS[10,11,21,22,25]

Chemicals	% by weight
CaO	27.1-40
SiO_2	32.1-42.5
Al_2O_3	13-16
MgO	1.33-9.33
P_2O_5	<0.1
Na_2O	0.2-0.55
K_2O	0.8-0.94

4. Experimental Program

The empirical scheme strives to check efficiency of lime, BA, and pulverized GBFS as stabilizing elements for clay-rich soil. Experiment encompasses a sequence of lab examinations to assess technical characteristics of the treated soil & ascertain best blend ratios to attain enhanced functionality. Test carried out on the specimen viz Compaction Test &Unconfined Compressive Strength(UCS) are shown in Table 2.5. UCS tests (ASTM D1633) were conducted after curing under un-soaked & soaked conditions (ASTM D1635)[3,5,10]. ASTM D698-12 is a standard test method laying down procedures for compaction tests, helping to determine relationship between water content & dry unit weight of soils or material, known as compaction curve.[5,6,17,26]

Table 2.5 represents the % of stabilizing agents used along with the tests performed

Materials Used		Tests performed		
		OMC	*MDD*	*UCS*
Lime	4%,8%, 12%	✔	✔	✔
BA	6%,12% ,18%	✔	✔	✔
GBFS	9%,18% ,27%	✔	✔	✔

The compaction tests i.e., OMC and MDD were performed on all the three materials as well as the soil sample itself. UCS was also carried for all the three materials vis-a-vis, lime, BA and GBFS. For carrying out UCS three soil specimens were formed and their average taken.

5.Results and Discussion

5.1 Effect of Lime, BA & GBFS on OMC of soil.

Against different quantities of lime i.e., 4%,8%,12%, the OMC of the soil goes on increasing as 17.3%,17.98% 19.56% respectively as shown in fig 5.1. Maximum OMC is achieved at 12% lime content. With rising lime content ,OMC rises, because of clay materials having tendency to react with lime as the lime increases, fines content also increased causing enlarged surface area & growth in requirement of moisture content as much as possible [26].

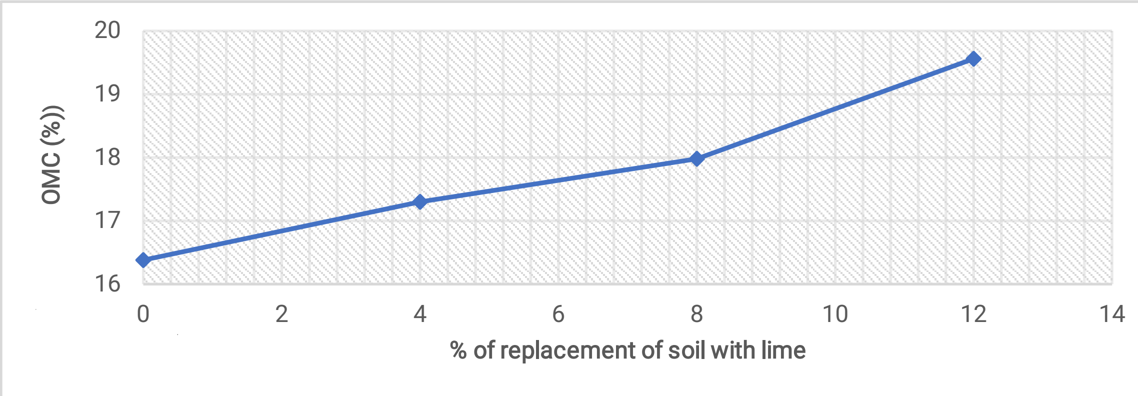

Fig 5.1 Change in OMC with different % of lime.

BA 6%,12%,18% causes an increase in OMC as 21.9%,24.5%,26.5%,27.6% .Fig 5.2 shows an increase in OMC with raising percentage of BA mixture. BA causes soil particles to inflate making the soil more easily workable and raising its strength &stiffness. OMC increases with BA content depicting growth with higher % of BA . Rise in OMC was probably due to pozzolanic reaction of lime in BA in accordance with clayey portion of soil[17]

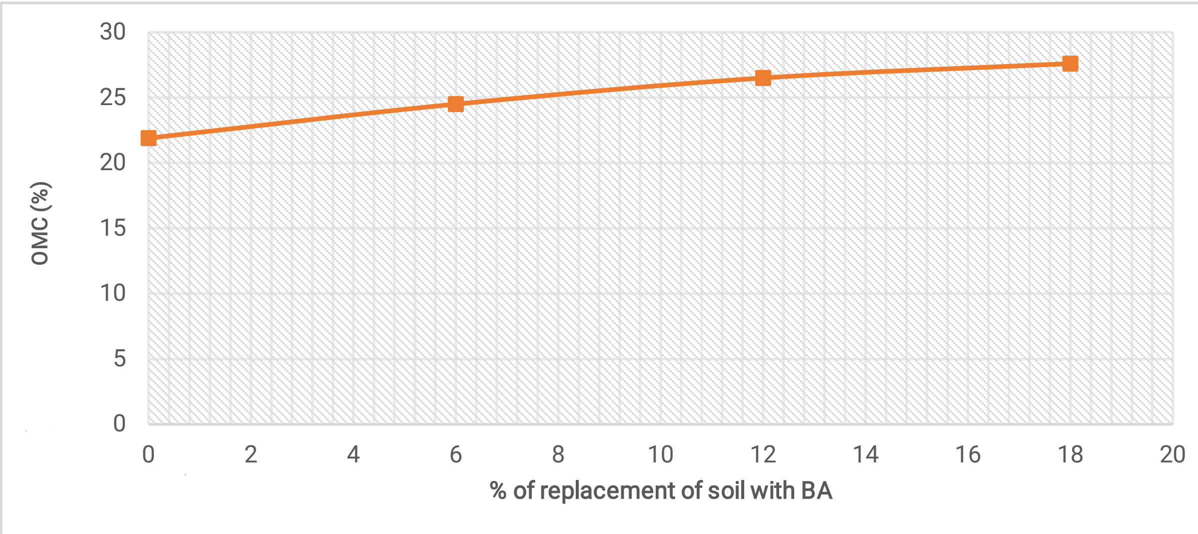

Fig 5.2 Change in OMC with different quantity of BA.

Combined effect of Lime(12%), BA(12%) & varying quantity of GBFS, clearly reveals their is a decline in OMC with increasing quantity of GBFS as a result of hydration reactions, in addition to this, lime and BA also contribute to decrease in OMC as is evident from the fig 5.3 OMC declined with growing % of slag from because GBFS as shown in fig 5.3 added is completely utilized for hydration reactions in spite of reactions like base-exchange, accumulation and inflation, thereby reducing water content of the sample[5].Optimum value of GBFS achieved is 27%.

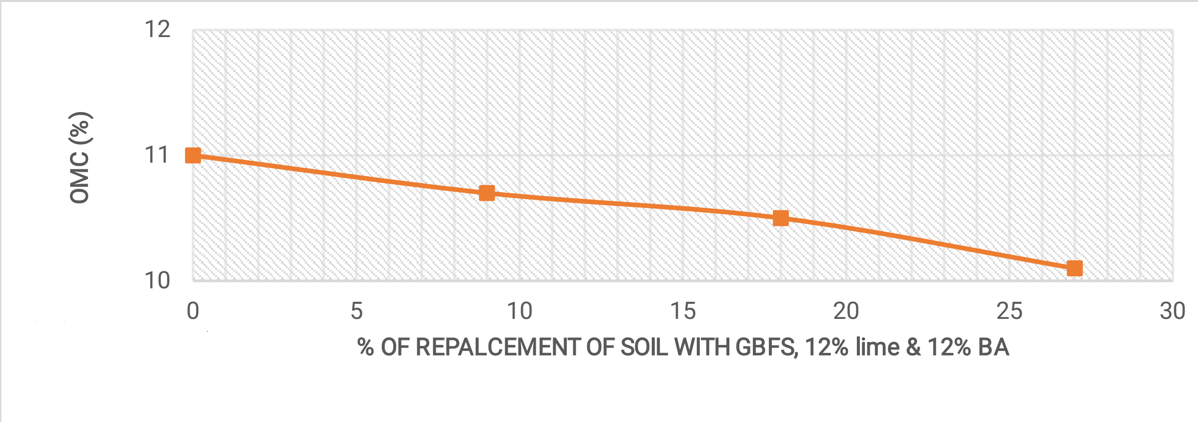

Fig 5.3 represents the change in OMC with different dosages of GBFS, Lime(12%) &BA(12%)

5.2 Effect of Lime, BA & GBFS on MDD of the soil.

MDD values for 4%,8%&12% lime are 15.03 kN/m^3,14.58 kN/m^3,14.44 kN/m^3 respectively showing a continuous decrease as shown in fig 5.4.MDD decreases as OMC increases. Including lime, requires water for reaction & formation of stable products to promote accumulation of soil particles causing an increase in water needed for compaction, thereby reducing total solids content & increasing voids ratio ,thereby causing dry density to decrease in the soil specimen. Also, calcium ion of lime reacts with silicates & aluminates of soil to form CSH &CAH gel, a slow process[6].

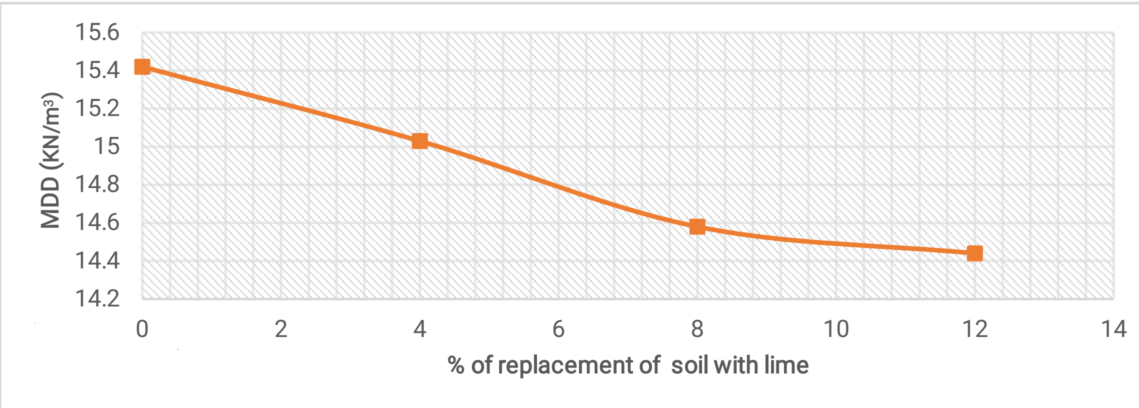

Fig 5.4 Graph of MDD with varying % of lime.

BA 6%,12%,18% causes an decrease in MDD as 15 KN/m^3,15.0 KN/m^3,12.8 KN/m^3 Fig 5.5 shows a decrease in MDD with growing % of BA mixture. Reduction in MDD is because of swelling & accumulation of tiny particles (caused by cation exchange) filling larger spaces [17].

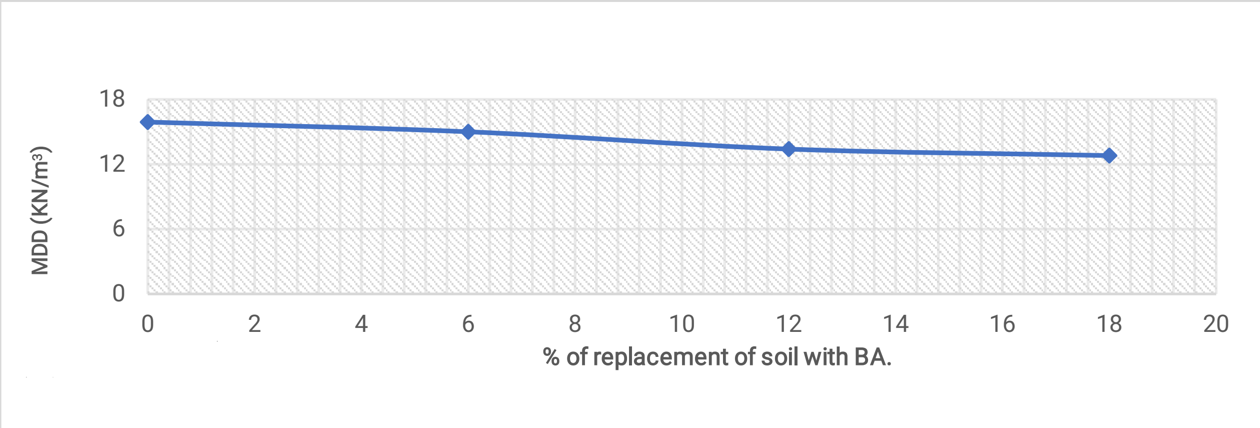

Fig 5.5 MDD against different dosages of Bagasse Ash

MDD rises with growing % of GBFS as shown in fig 5.6, as specific gravity of GBFS is slightly more therefore replacement of soil by the same amount of slag will surely elevate dry density of compressed mass[5], although lime & BA cause a decline in dry density but since their quantity remains fixed they do not show a visible reduction in dry density in presence of GBFS as quantity of GBFS used is more.

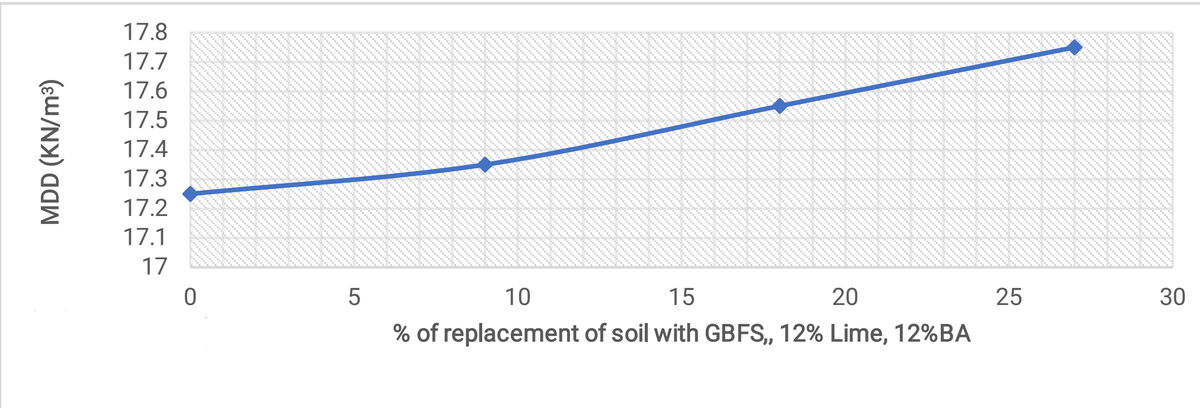

Fig 5.6 MDD with different dosages of GBFS, Lime(12%),BA(12%)

5.3 *Unconfined Compressive Strength(UCS)*

UCS of soil treated with lime is seen to increase because of pozzolanic reaction as silica & alumina in clay react with calcium from lime forming cementitious products like calcium-silicate-hydrates (CSH) & calcium-aluminate- hydrates (CAH) [3]as is evident from fig 5.7

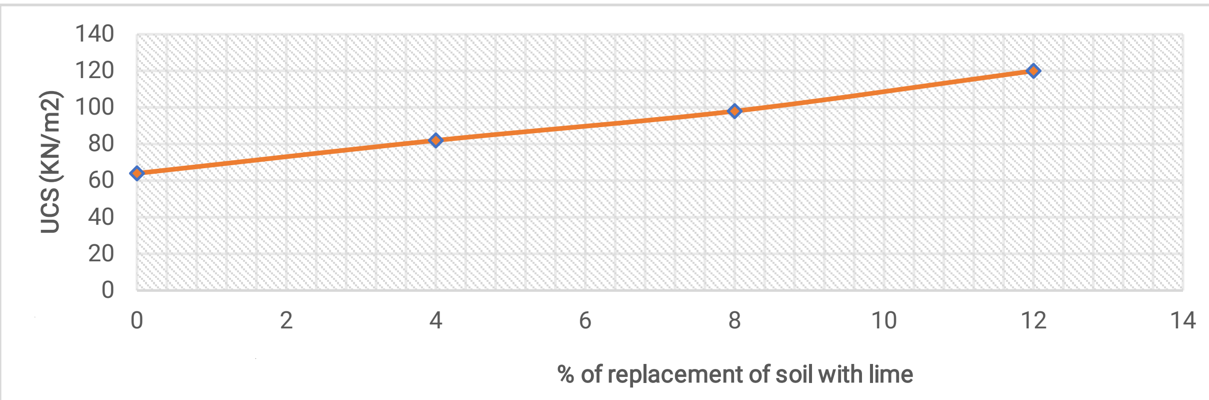

Fig 5.7 Unconfined Strength test with different dosages of lime.

Due to addition of BA soil particles swell, thereby making the soil more easily workable &increasing its strength as shown in fig 5.8& stiffness thereupon[3].But beyond a certain limit it showed a decrease in strength because BA is highly porous and has good water absorption capacity thereby causing a decrease in strength.

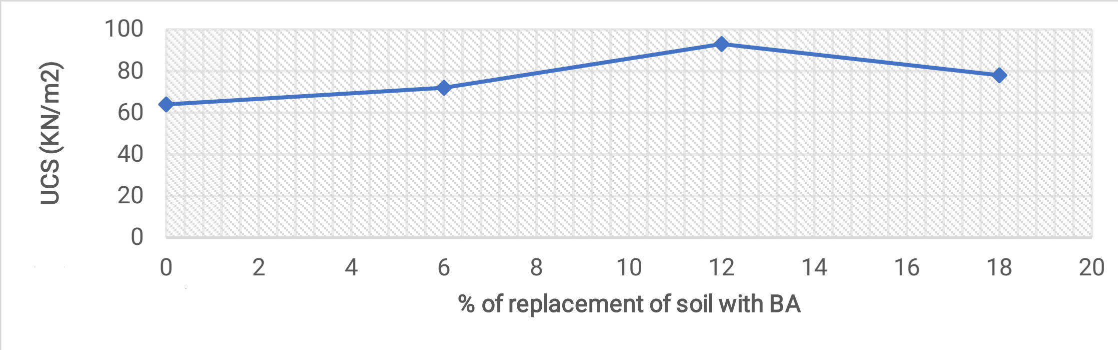

Fig 5.8 shows UCS results with different percentage of Bagasse Ash.

Fig 5.9 shows increasing UCS with more GBFS content, lime & BA taken 12% & 12% respectively. There was a visible increase in UCS due to pozzolonic reaction, moreover lime & BA also contribute to increase in strength, the lime by forming cementitious compounds & BA by pozzolonic reactions. The UCS increased with increasing percentage on curing. Optimum amount of GBFS as shown in fig 5.11 was found to be on 27%. Improvement in strength was credited to the genesis of pozzolanic compounds[5].

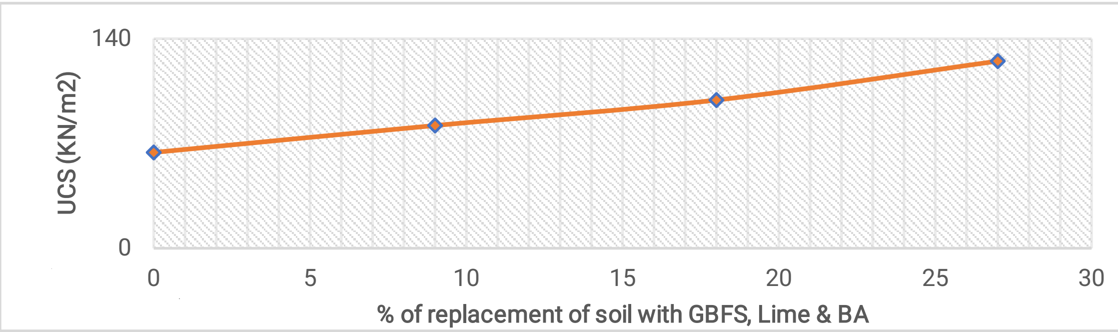

Fig 5.9 UCS with different quantities of GBFS, Lime(12%), BA(12%)

6 Traditional Methods

Bitumen, tar, cement, gypsum, cement fly-ash, lime fly-ash, slag, alum, kiln dust, stone dust etc. are traditionally used soil stabilizers. These are preferential for stabilization of soft soils. These are also beneficial in neutralizing acidity and strength improvement for various soils preferably soft soils. Soils stabilized with cement were discovered to be dependable engineering alternatives to fulfil the whole demand of sustainable structure. Besides, these stabilizers are ordinarily acquirable in market.

Unfortunately, the traditional stabilizers have an adverse effect on the environment. It is mainly connected with emission of carbon dioxide gas. 8% of total emissions is contributed by the cement industries. This is where the stabilizers like lime, bagasse ash & GBFS are useful. These are economical and less polluting than the traditional stabilizers.

7 Conclusions

From the empirical deductions & computations, the subsequent conclusions can be inferred:

- Inherent moisture content of the Clay collected from Parihaspora, Srinagar is 17%.
- MDD decreased as a consequence of blending lime & GBFS, whereas it initially increased & subsequently decreased due to BA with a peak value of 19.67 KN/m^3 at 12% dosage.
- Ideal moisture content displayed a comparable pattern of escalation followed by reduction due to all three stabilizing agents, with peak values observed as 19.56% at 12% dosage of lime, 19.67% at 12% dosage of BA, & 19.96% at 27% GBFS.
- UCS of natural clay soil, initially at 64 KN/m3, ascended to a maximum &then demonstrated a decline following stabilization with all three agents. Highest values attained were 120 KN/m^3 at 12% lime, 108 KN/m3 at 18% Bagasse Ash, & 125 KN/m^3 at 27% GBFS.
- On adding Lime 12%, BA 12% and GBFS 27%, OMC got declined by 90%, however MDD and UCS both got enhanced by 50% and 61% respectively.

7.References

1 Amit S. Kharade, Vishal V. Suryavanshi, Bhikaji S. Gujar, Rohankit R. Deshmukh, (2014) Waste product bagasse ash from sugar industry can be used as stabilizing material for expansive soils, IJRET.

2 Ankit Singh Negi, Mohammed Faizan, Devashish Pandey and Rehanjot Singh (2013), Soil stabilization using lime, Environmental Science.

3 Azeem, Md & Singh, Saurabh & Divya, S & Mir, Shahnawaz. (2020). Effect of Bagasse ash and Lime on the Compaction and Strength Properties of Black Cotton Soil. International Journal of Engineering Research and. V9. 10.17577/IJERTV9IS050505.

4 Ochepo, J. Stabilization of laterite soil using reclaimed asphalt pavement and sugarcane bagasse ash for pavement construction. J Engin Res 2, 21 (2014)

5 Niken Silmi Surjandari *et al* 2017 *J. Phys.: Conf. Ser.* **909** 012068S.P. Singh, D.P. Tripathy, P.G. Ranjith, Performance evaluation of cement stabilized fly ash–GBFS mixes as a highway construction material, Waste Management, Volume 28, Issue 8, 2008.

6 Rehman, Inayat & Raheel, Muhammad & Khawaja, Muhammad Wajahat Ali & Khan, Rawid & Li, Jie & Khan, Arsalaan & Khan, Muhammad. (2021). Characterization of Engineering Properties of Weak Subgrade Soils with Different Pozzolanic & Cementitious Additives. Case Studies in Construction Materials. 15. e00676. 10.1016/j.cscm.2021.e00676.

7 B. Manjula Devi, Hemant S. Chore,Feasibility study on bagasse ash as light weight material for road construction,Materials Today: Proceedings,Volume 27, Part 2,2020.

8 K.C.P. Faria, R.F. Gurgel, J.N.F. Holanda, Recycling of sugarcane bagasse ash waste in the production of clay bricks, Journal of Environmental Management, Volume 101,2012.

9 Anjani Kumar Yadav, Kumar Gaurav, Roop Kishor, S.K. Suman, Stabilization of alluvial soil for subgrade using rice husk ash, sugarcane bagasse ash and cow dung ash for rural roads, International Journal of Pavement Research and Technology, Volume 10, Issue 3,2017.

10 J.F. Rivera, A. Orobio, N. Cristelo, R. Mejía de Gutiérrez, FLY ASH-BASED

GEOPOLYMER AS A4 TYPE SOIL STABILISER, Transportation Geotechnics (2020).

11 Mahdi Salimi, Ali Ghorbani, Mechanical and compressibility characteristics of a soft clay stabilized by slag-based mixtures and geopolymers, Applied Clay Science, Volume 184, 2020.

12 Kezdi. A. 1979. Stabilized Earth Roads. Elsevier Science Publishing Company, New York.

13 Khan S. and Khan H. 2016. “Improvement of Mechanical Properties by Waste Sawdust Ash Addition into Soil”, Jordan Journal of Civil Engineering, 10(1).

14 K.J. Osinubi, V. Bafyau, A , O. Eberemu, and O. Adrian (2009), Bagasse ash stabilization of lateritic soil, Appropriate Technologies for Environmental Protection.

15 Kumar.K A., Narayanan P. and Chiranthana N. 2014. “Stability of Red Clay and Laterite Soil with Sawdust Ash as an Amendment”, International Journal of Combined Research & Development IJCRD- eISSN:2321225X;p ISSN:2321-2241 Volume: 2; Issue: 2

16 MeronWubshet and Samuel Tadesse (2014), Stabilization of expansive soil using bagasse ash and lime, Journal of EEA.

17 Ogunribido T.H.T. 2012. “Geotechnical Properties of Saw Dust Ash Stabilized Southwestern Nigeria Lateritic Soils”, Environmental Research, Engineering and Management, 60(2): 29-33.

18 Biradar, Kiran & Kumar, U Arun&narayana, Dr.PVV. (2014). Influence of Steel Slag and Fly Ash on Strength Properties of Clayey Soil: A Comparative Study. International Journal of Engineering Trends and Technology.

19 Standard-IS, I., 1498–1970. “Classification and Identification of Soils for General Engineering Purposes”, New Delhi, India. Page 5 of 5

20 Sujith Kumar Dash and Monowar Hussain (2016), Lime stabilization of soil: Reapprrisal, American society of civil engineer.

21 Preetham, H.K., Nayak, S. Geotechnical Investigations on Marine Clay Stabilized Using Granulated Blast Furnace Slag and Cement. *Int. J. of Geosynth. and Ground Eng.* **5**, 28 (2019).

22 Cokca, E., Yazici, V. & Ozaydin, V. Stabilization of Expansive Clays Using Granulated Blast Furnace Slag (GBFS) and GBFS-Cement. *Geotech Geol Eng* **27**, 489–499 (2009).

23 F.G. Bell,Lime stabilization of clay minerals and soils,Engineering Geology,Volume 42, Issue 4,1996.

24 Shivaramaiah, A., Ravi Shankar, A.U., Singh, A. *et al.* Utilization of lateritic soil stabilized with alkali solution and ground granulated blast furnace slag as a base course in flexible pavement construction. *Int. J. Pavement Res. Technol.* **13**, 478–488 (2020).

25 Sharma, Tarun & Kaushik, Rohin. (2019). Effect of Polypropylene Fiber on Properties of Bagasse Ash-Cement Stabilized Clay Soil. 10. 255-266.

26 Peter, M. (2023). Effects of Stone Dust on Lime Stabilized Granular Soil.. IOP Conference Series: Earth and Environmental Science. 1110. 012024. 10.1088/1755-1315/1110/1/012024.