

Plasticity and Swelling Characteristics of Geopolymer Treated Expansive Soil

Manaswini Mishra ¹[0000-0002-2446-8703], Prabodha Kumar Sahoo ² and Suresh Prasad Singh ³[0000-0002-5818-3415]

¹M.Tech, Civil Engineering Department, NIT Rourkela, Rourkela-769008
E-mail: 217ce1029@nitrkl.ac.in

²M.Tech, Civil Engineering Department, NIT Rourkela, Rourkela-769008
E-mail: 218ce1489@nitrkl.ac.in

³Professor, Civil Engineering Department, NIT Rourkela, Rourkela-769008
E-mail: spsingh@nitrkl.ac.in

Abstract. Expansive soil causes extensive damage to geotechnical structures owing to its high volume instability. Cement and lime are the most commonly used material to improve these soils by reducing its plasticity, swelling characteristics, and increasing strength. However, the production process of these traditional stabilizers is energy intensive and it also serves as a major source of green-house gas emission leading to severe problems like global warming. Geopolymer is a new generation alternative binding material for conventional cement. This is primarily produced from industrial wastes like slag or fly-ash which are rich in alumino-silicates. When activated with alkalis, these products form geopolymers, which provides high strength to soil and have low cost, low energy consumption and is eco-friendly. This study explores the efficiencies of ground granulated blast furnace slag (GGBS) based geopolymer binder in improving the properties of expansive soil in comparison to cement and lime. In this study the expansive soil is mixed with 0, 5, 10, 15 and 20% of GGBS and activated with sodium hydroxide solutions of 0.5, 1, 2 and 4M concentrations. However, cement and lime are mixed with the soil in the proportions of 1, 2, 4, 8, 12 and 15% by weight of the soil. The consistency limits and swelling characteristics of geopolymer, lime and cement treated soils are evaluated at 0, 3, 7 and 30 days of curing. It is found that the plasticity characteristics are improved and swelling and shrinkage of the expansive soil is greatly reduced with increasing concentration of these admixtures. Curing period also influences these properties. It is also observed that the performance of geopolymer is comparable to that of cement and lime. So, geopolymer can be effectively used as an alternative stabilizing agent to modify the plasticity and swelling properties of expansive soil.

Keywords: Expansive Soil, Geopolymer, Consistency Limits, Plasticity characteristics

1 Introduction

Expansive soils are considered as problematic soils because of their highly unpredictable performance in the presence of moisture. A marginal change in moisture content in this soil lead to reduce the shear strength associated with high swelling, shrinkage, settlement, and consolidation [28]. These soils are mostly found in arid and semi-arid regions of the world and the presence of montmorillonitic clay mineral imparts swell-shrink potential to these soils. Improvement of expansive soils by treating them with lime and cement are the established methods which are used widely around the world. However, the production process of these traditional stabilizers is energy intensive and it also serves as a major source of carbon dioxide emission leading to serious problems like global warming [18].

Geopolymer is a new generation alternative binding material for conventional cement. The intense amount of work on geopolymeric binders derived from these industrial by-products have proved its effectiveness having similar strength and durability properties as that of conventional concrete. This alkali source provider, in the presence of alkaline medium forms geopolymerization products which is shown in fig 1, that have comparable or even better characteristics than calcium-silicate-hydrate products of conventional concrete. The concept of geopolymer was first proposed by Davidovits(2013), it was found that kaolinite could be polymerized by alkalis, producing a concrete like material[8]. High curing temperature and long curing time resulted in higher compressive strength. The formation of geopolymer gel from the geopolymerization improved the strength capabilities. Marginal lateritic soil could be stabilized by high calcium FA-based geopolymer and used as an environmentally friendly pavement material, which would furthermore decrease the need for high carbon Portland cement [26]. The compressive strength of the geopolymer treated soil improves by increasing the molarity of alkali activator and alkali activator/clay [11]. The chemical process to produce geopolymers involve three steps: (1) Dissolution of raw materials in alkaline solution to form Si and Al gel on the material's surface, (2) Reorientation, which is condensation of precursor ions into oligomers and (3) Polycondensation to form networked polymeric oxide structures as depicted in fig 2. In the present study, an attempt has been made to study various mix parameters which control the stabilizing process in the soil-geopolymer.

2 Materials and Methodology

Usually geopolymer is derived from alkali activation products of alumino silicate source materials. Here in the present study ground granulated blast furnace slag, an industrial by-product is used. It is collected from Rourkela steel plant which is rich in alumino silicate and activated by sodium hydroxide solution. The solutions of 0.5, 1, 2 and 4M are made with distilled water 24 hours prior to geopolymerization to get homogeneous solutions free from precipitates. The blast furnace slag is mixed in the proportions of 5%, 10%, 15% and 20% to that with locally available expansive soil. To make the mixture stable, the mixtures are then added with sodium hydroxide solu-

tion of each concentration. For a comparative study, the soil is also mixed with dry weights of 1%, 2%, 4%, 8%, 12% and 15% lime and cement separately. The mixed samples are left for curing at constant temperature in a sealed container for conducting the experimentations at 0, 3, 7 and 30 days. After each curing period the test samples are again mixed thoroughly and grounded by a wooden hammer to pass these through 425 micron IS sieve. All the tests are done as per the IS codes.

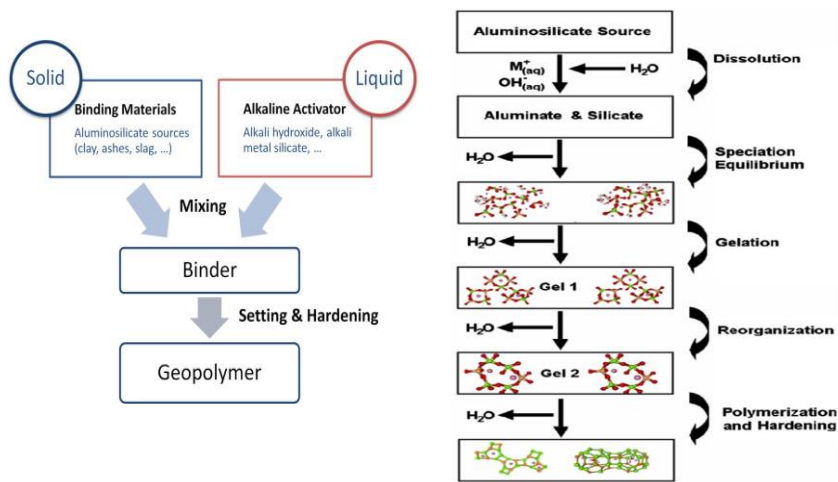


Fig. 1. Geopolymer components [3] Fig. 2. Conceptual model of geopolymerization [24]

3 Results and discussions

3.1 Liquid limit

The variation of liquid limit with slag content and curing period for different soil-slag mixes are depicted in Fig. 3 to Fig. 5 and with lime and cement content are depicted in Fig. 6 and Fig. 7. It is observed that, for all soil mixes initially there is a decrease in liquid limit with increases in additive content. In the alkaline environment, formation of Calcium Silicate Hydrate (C-S-H) gel occurs, which consists of solid products of hydration and water that is held physically or adsorbed on surface of the hydrates. In addition to gel, water exists which is combined chemically or physically with the hydrates. This large amount of water significantly marginalizes the influence of the double layer reduction by inducing decrease in water content and thereby the liquid limit.

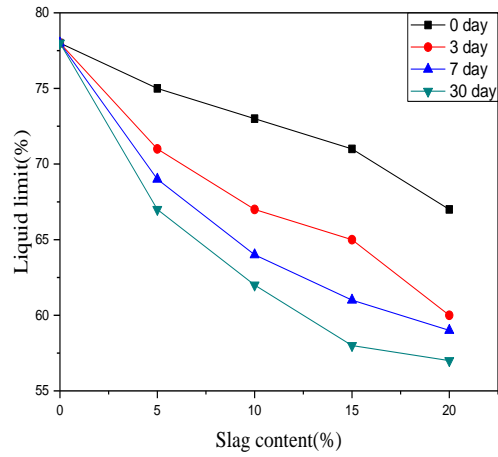


Fig. 3. Variations of liquid limit for soil-slag mix with slag content

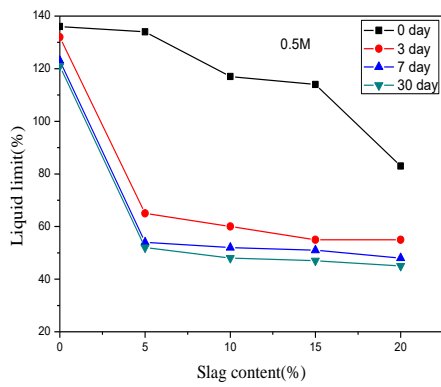


Fig. 4. Variations of liquid limit for soil-slag mix with slag content treated with 0.5M NaOH solution

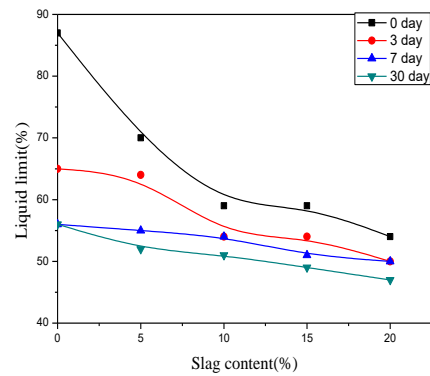


Fig. 5. Variations of liquid limit for soil-slag mix with slag content treated with 2M NaOH solution

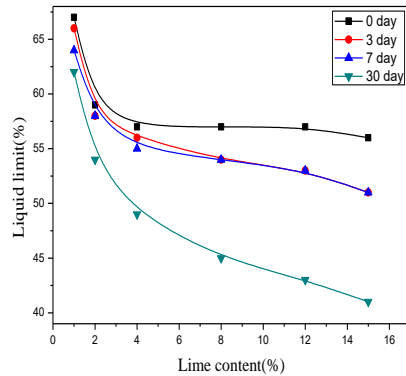


Fig. 6. Variations of liquid limit of soil-lime mix with lime content

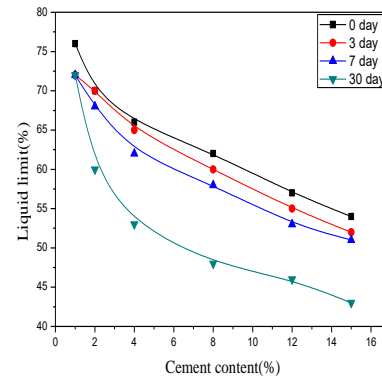


Fig. 7. Variations of liquid limit of soil-cement mixes with cement content

3.2 Plasticity index

The plastic limit is a measure of soil cohesion against cracking while beading the soil. The shear resistance between the particles of the soil should be sufficiently low to be able to slide partially over each other at ease. At the same time, the resistance of the inter-particle shear should be sufficiently high to hold the soil mass in the re-formed place. The plastic limit is therefore a measure of the soil water content when approaching a certain resistance to shear or shear strength. Fig. 8 shows the variation of plastic index of soil-slag mix with slag content. Fig. 9 and 10 shows the variation of plastic index of soil-slag mix treated with 0.5M NaOH and 2M NaOH solution. Fig. 11 shows the variation of plastic index of soil-cement mixes with cement content. The thickness of the diffuse double layer decreases with the addition of lime, cement, or geopolymer, which increases the concentration of the load and thus the viscosity of the pore fluid. As a result, the inter-particle shear resistance increases, resulting in a sharp increase in the plastic limit. As the liquid limit decreases and plastic limit increases, the plasticity index also reduces with additive content and with curing period. With the addition of lime more than 4% and for the concentration of NaOH more than 2M, the soil is modified into crumbly as silt soil and becomes non-plastic after 3 days of curing.

3.3 Shrinkage limit

The increase in shrinkage limit as shown in Fig. 12 to 16 with the additive content (slag, lime, cement) is attributed to the aggregation of particles by the amendment of additive. The soil being highly plastic was initially in a dispersed state. With the addition of lime, the diffused double layer thickness decreases with increased electrolyte concentration and thus the repulsion between the clay particles decreases. As a result, the soil particles are coming closer to form aggregated clusters. These aggregated

clusters offer increased resistance to capillary suction resulting in volumetric shrinkage resulting in increased shrinkage void ratio and hence water content (i.e. shrinkage limit). With the increase in the curing period, the shrinkage limit has increased further. This is because with prolonged curing aggregation increases which mobilizes increased resistance against shrinkage leading to enhanced shrinkage limit.

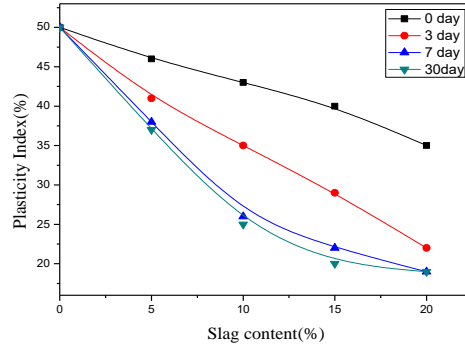


Fig. 8. Variations of plasticity index of soil-slag mix with slag content

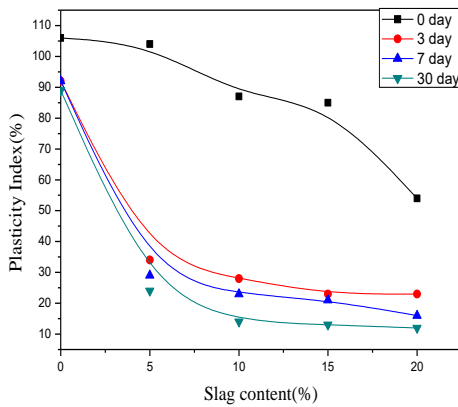


Fig. 9. Variations of plasticity index of soil-slag mix treated with 0.5M NaOH solution

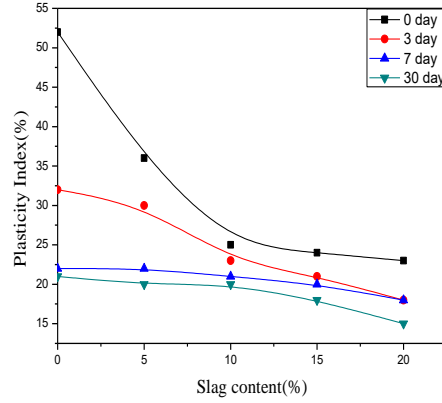


Fig. 10. Variations of plasticity index of soil-slag mix treated with 2M NaOH solution

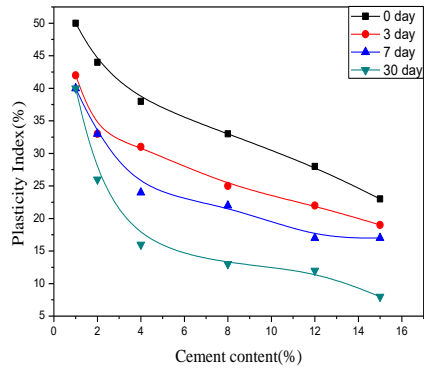


Fig. 11. Variations of plasticity index of soil-cement mixes with cement content

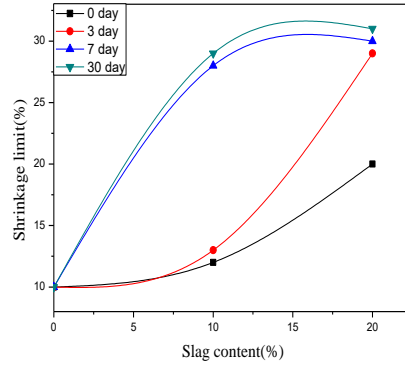


Fig. 12. Variations of shrinkage limit for soil-slag mix with slag content

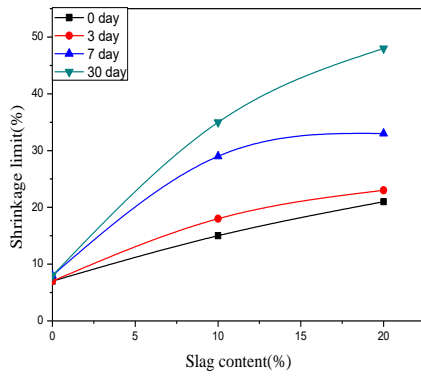


Fig. 13. Variations of shrinkage limit for soil-slag mix with slag content treated with 0.5M NaOH solution

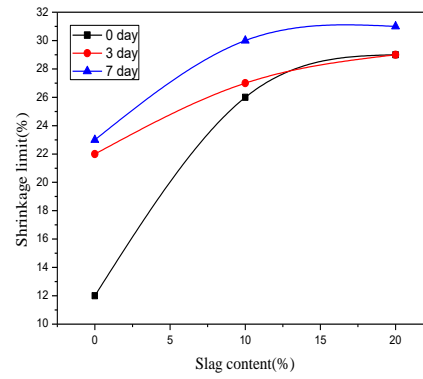


Fig. 14. Variations of shrinkage limit for soil-slag mix with slag content treated with 2M NaOH solution

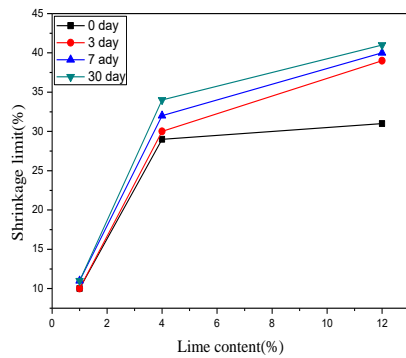


Fig. 15. Variations of shrinkage limit of soil-lime mixes with lime content

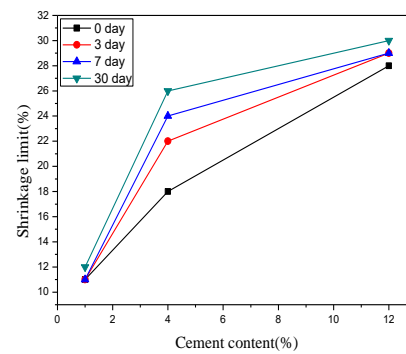


Fig. 16. Variations of shrinkage limit of soil-cement mixes with cement content

3.4 Linear shrinkage and differential free swell

The thickness of the diffused double layer decreases with the addition of lime, cement or geopolymer, which increases the concentration of charge and thus the viscosity of the pore fluid. As a result, the inter-particle shear resistance increases, resulting in a sharp increase in the linear shrinkage index as shown in Fig. 17 to 21 and free swell index as shown in Fig. 22 to 26.

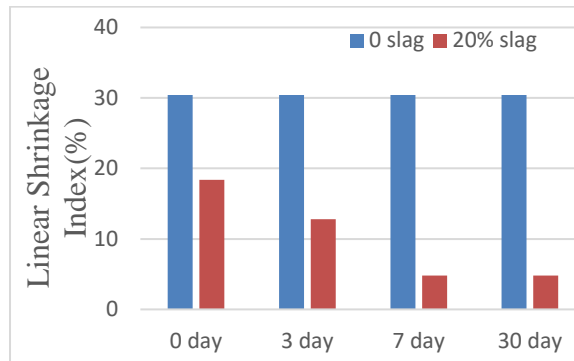


Fig. 17. Variation of linear shrinkage index for soil-slag mix for different curing periods

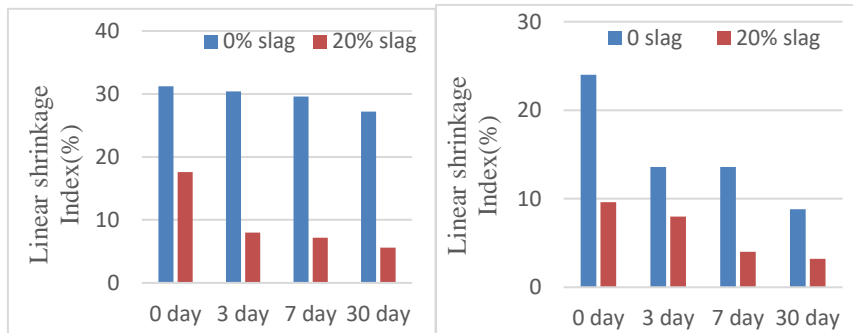


Fig. 18. Linear shrinkage index variation for soil-slag mix treated with 0.5M NaOH solution for different curing periods

Fig. 19. Linear shrinkage index variation for soil-slag mix treated with 2M NaOH solution for different curing periods

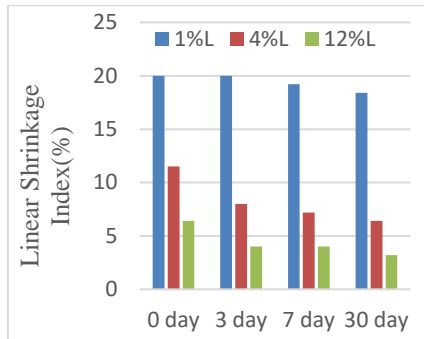


Fig. 20. Linear shrinkage index variation for soil treated with lime for different curing periods

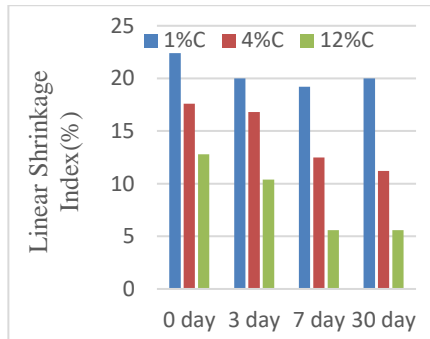


Fig. 21. Linear shrinkage index variation for soil treated with cement for different curing periods

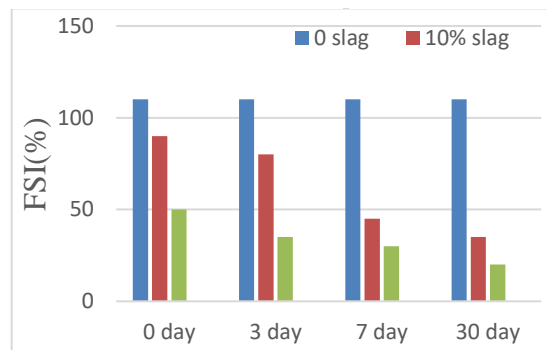


Fig. 22. Variation of free swell index for soil-slag mix for different curing periods

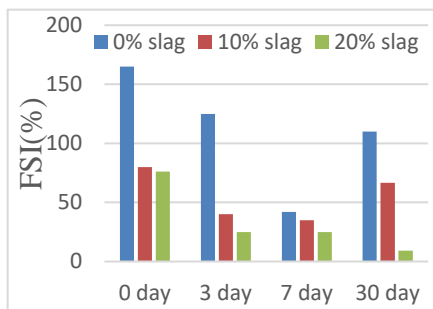


Fig. 23. Free swell index variation for soil-slag mix treated with 0.5M NaOH solution for different curing periods

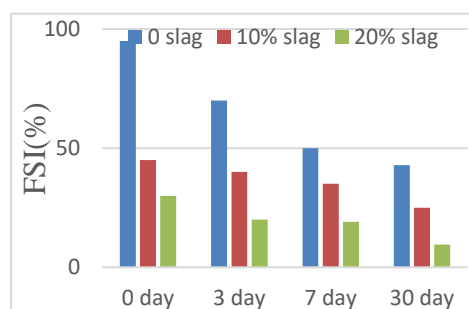


Fig. 24. Free swell index variation for soil-slag mix treated with 2M NaOH solution for different curing periods

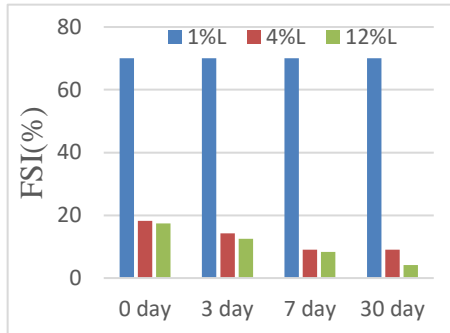


Fig. 25. Free swell index variation for soil treated with lime for different curing periods

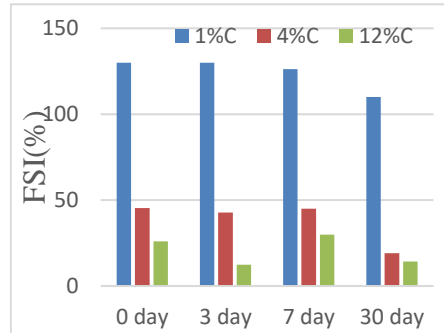


Fig. 26. Free swell index variation for soil treated with cement for different curing periods

3.5 Scanning Electron Microscopy

With an objective of gaining a textural insight of the stabilized soil, microscopy analysis and spectral analysis of the specimen is conducted in scanning electron microscopy. The as-received stabilized sample exemplifies extensive amorphization attributed to loss of hydration product during the initial stages of curing. However, the specimen predominantly shows flocculation of the specimen due to the formation of gel like structure after being cured for 30 days as envisaged by the flaky structure in Fig. 27. Furthermore, the chemical composition of the specimen is analysed via energy dispersive analysis which exemplifies that silica is the major constituent in the given stabilised soil specimen. Following silica, alumina predominates the soil composition with traces of calcium oxide, iron oxide and magnesium oxide.

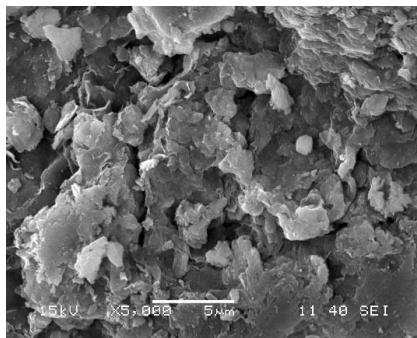


Fig. 27.1



Fig. 27.2

Fig. 27. SEM image of Soil-slag mix treated with 2M NaOH solution after (10)day curing

4 Conclusions

This study made an attempt to improve the plasticity and swelling characteristics of expansive soil on the objective of preparing a suitable binder utilizing industrial by-products like blast furnace slag which proved as better additives than conventional stabilizers like lime and cement. Based on the experimental results the following conclusions can be drawn. Liquid limit for slag treated soil was reduced from 78% to 58% following 30 days of curing, however when it is alkali activated with 4M of NaOH solution then this reduction is critical from 78% to 40%. Similarly, plasticity index also reduced from 50% to 23% for slag treated soil and with alkali activation, the soil becomes non-plastic for 4M NaOH solution after 3 days of curing. The soil became crumbly like silty soils. Shrinkage is reduced largely by adding geopolymers to expansive soil. Free swell index values are reduced from 110% for natural soils to almost 0% for geopolymer treated soils. Similarly, linear shrinkage index values were reduced from 30.4% to almost about 0% (0.79%). The Scanning Electron Microscopy also confirmed the formation of a gel like product because of synthesis of geopolymer leading to flocculation of clayey particles after 30 days of curing.

References

1. A.M. Mustafa Al Bakria a, H. Kamarudin, M. BinHussain, I. K. N.: The Effect of Curing Temperature on Physical and Chemical Properties of Geopolymers. 22, 286–291(2011).
2. Abdullah, H. H., Shahin, M. A., Sarker, P. Stabilisation of Clay with Fly - Ash Geopolymer Incorporating GGBFS(2017).
3. Abdullah, M. M., Hussin, K., Bnhussain, M., Ismail, K. N., Ibrahim, W. M.: Mechanism and chemical reaction of fly ash geopolymer cement-A review. Journal of Asian Scientific Research, 1(JANUARY), 1–12 (2011).
4. Bayat, M., Branch, N., Mousivand, M.:Effects of cement and lime treatment on geotechnical properties of a low plasticity clay. (April 2015).
5. Dahale, P. P., Nagarnaik, P. B., Gajbhiye, A. Y.: Engineering Behavior of Remolded Expansive Soil with Lime and Flyash. Materials Today: Proceedings, 4(9), 10581–10585(2017).
6. Davidovits, J. : Geopolymer Cement a review. Institute Geopolymer, (0), 1–11(2013).
7. Eades, J., Grim, R.: Reaction of hydrated lime with pure clay mineral in soil stabilization. Highway Research Board, 262(8), 51–63 (1960).
8. Fernández-Jiménez, A., Palomo, A., Criado, M.: Microstructure development of alkali-activated fly ash cement: A descriptive model. Cement and Concrete Research, 35(6), 1204–1209(2005).
9. Ghadir, P., Ranjbar, N.:Clayey soil stabilization using geopolymer and Portland cement. Construction and Building Materials, 188, 361–371(2018).
10. Hameed, A., RR, R., SA, A.:Effect of Various Factors on the Manufacturing of Geopolymer Mortar. Archives Od Science, 1(3), 1–8(2017).
11. Hussain, M., Dash, S. K.: Influence of Lime on Plasticity Behaviour of Soils. Indian Geotechnical Conference (2010).

12. Iyengar, S. R., Masad, E., Rodriguez, A. K., Bazzi, H. S., Little, D., Hanley, H. J. M.: Pavement Subgrade Stabilization Using Polymers: Characterization and Performance. *Journal of Materials in Civil Engineering*, 25(4), 472–483(2012).
13. K.S. Subba Rao, E.: Swell-Shrink Behaviour of Expansive Soils - Geotechnical Challenges. 30(1) (2000).
14. Khale, D., Chaudhary, R.: Mechanism of geopolymerization and factors influencing its development: A review. *Journal of Materials Science*, 42(3), 729–746(2007).
15. Liu, Z., Cai, C. S., Liu, F., Fan, F.: Feasibility Study of Loess Stabilization with Fly Ash-Based Geopolymer. *Journal of Materials in Civil Engineering*, 28(5), 04016003(2016).
16. Miao, S., Shen, Z., Wang, X., Luo, F., Huang, X., Wei, C.: Stabilization of Highly Expansive Black Cotton Soils by Means of Geopolymerization. *Journal of Materials in Civil Engineering*, 29(10), 04017170(2017).
17. Mir, B.: Challenges Associated with Expansive Soils and Remedial Measures. 50Th Indian Geotechnical Conference, (October 2016).
18. Morales, E. M., Morales, M. K.: Expansive Soils – Identification, Detection and Remediation Strategies. 3–5(2004).
19. Palomo, A., M. Grutzeck, and M. B.: Alkali-activated fly ashes: a cement for the future. *Cement and concrete research*. *Cement and Concrete Research*, 29(8):, 1323-1329(1999).
20. Pandey, A., Rabbani, A.: Soil stabilisation using cement. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, 14(5–6), A95(2005).
21. Phummiphan, I., Horpibulsuk, S., Sukmak, P., Chinkulkijniwat, A., Arulrajah, A., & Shen, S. L. Stabilisation of marginal lateritic soil using high calcium fly ash-based geopolymer. *Road Materials and Pavement Design*, 17(4), 877–891(2016)
22. Popescu, M. E.: Engineering Problems Associated with Expansive Clays. *Engineering Problems Associated with Expansive Clays from Romania*. *Eng.Geol.*, 14: 43-53, 14, 43–53(1979).
23. Singhi, B., Laskar, A. I., & Ahmed, M. A. ; Investigation on Soil–Geopolymer with Slag, Fly Ash and Their Blending. *Arabian Journal for Science and Engineering*, 41(2), 393–400(2016).