# Plasticity Characteristics of Geopolymer Stabilized Expansive Soil

**Manaswini Mishra, Soumyaprakash Sahoo, and Suresh Prasad Singh**

**Abstract** Marginal and weak soils are conventionally stabilized by cement and lime in civil engineering applications. However, the production process of these traditional stabilizers is energy intensive and it also serves as a major source of greenhouse gas emission leading to serious problems like global warming. But due to scarcity or non-availability of suitable soils at construction sites, use of cement is unavoidable. Geopolymer is a new generation alternative binding material for conventional cement. This is primarily produced from industrial wastes and rich in aluminosilicates when activated with alkalis. It has high strength, low cost, low energy consumption and it emits fewer greenhouse gases during synthesis. This study explores the efficiencies of ground granulated blast furnace slag (GGBS)-based geopolymer binder in stabilizing the expansive soil. The expansive soil is mixed with 0 to 20% of GGBS at 5% intervals and is activated with sodium hydroxide solutions of 0.5, 1, 2, 4, 6 and 8 M. The consistency limits, swelling and shrinkage characteristics of geopolymer treated soils are evaluated at curing periods of 0, 3, 7, 30 and 90 days. It is found that the plasticity characteristics and expansive properties of stabilized soil are strongly influenced by the geopolymer contents and the curing periods.

**Keywords** Expansive soil · Slag-based geopolymer · Consistency limits · Curing period

## 1 Introduction

Expansive soils are considered as problematic soils with their unpredictable performance in the presence of moisture. A little change in moisture content in this type of soil may lead to decrease in their shear strength associated with high swelling,

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shrinkage, settlement and consolidation. Improvement of expansive soils by treating with lime, cement, slag and fly ash is, nowadays, 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.

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 utility having similar strength and durability properties that of conventional concrete. This alkali source provider, in the presence of alkaline medium forms geopolymerization products, that has comparable or even better characteristics than calcium-silicate-hydrate products of conventional concrete. Geopolymer is a type of inorganic material which is emerging as an analogues of thermosetting organic cross-linking materials [11]. The concept of geopolymers was proposed by Davidovits [1], who found that kaolinite could be polymerized by alkalis, producing a concrete-like material. High curing temperature and long curing time corresponded to higher compressive strength. The formation of geopolymer gel due to better geopolymerization enhanced the strength capabilities. The geopolymer structure became more rigid after curing for a certain period in comparison with its early stage [2]. Marginal lateritic soil could be stabilized by high calcium fly ash-based geopolymer and used as an environmentally friendly pavement material, which would furthermore decrease the need for high-carbon portland cement [10]. Increasing the molarity of alkali activator and alkali activator/clay improves the compressive strength of the geopolymer treated soil [3]. In this present study, an attempt has been made to study various mix parameters which control the stabilizing process in the soil geopolymer (Figs. 1 and 2).

## 2 Materials

### *2.1 Expansive Soil*

Locally, available soil is collected from sector 19 area of Rourkela steel city. The soil is oven dried at least for 24 h at 110 °C and then pulverized in a ball mill and mixed thoroughly to bring homogeneity in the mass. It is passed through 425 μm IS sieve before conducting experiments.

### *2.2 Blast Furnace Slag*

Blast furnace slag is taken from Rourkela steel plant. It is grounded in ball mill for 4–5 h and mixed thoroughly to make it suitable for use in experimental works.

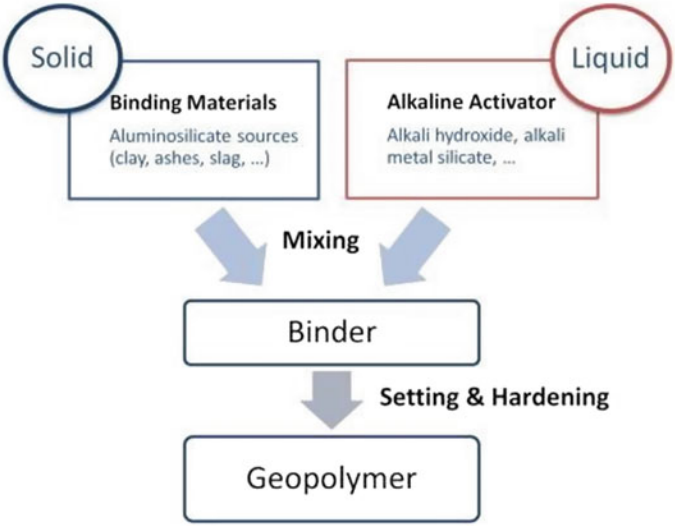


**Fig. 1** Geopolymer components [8]

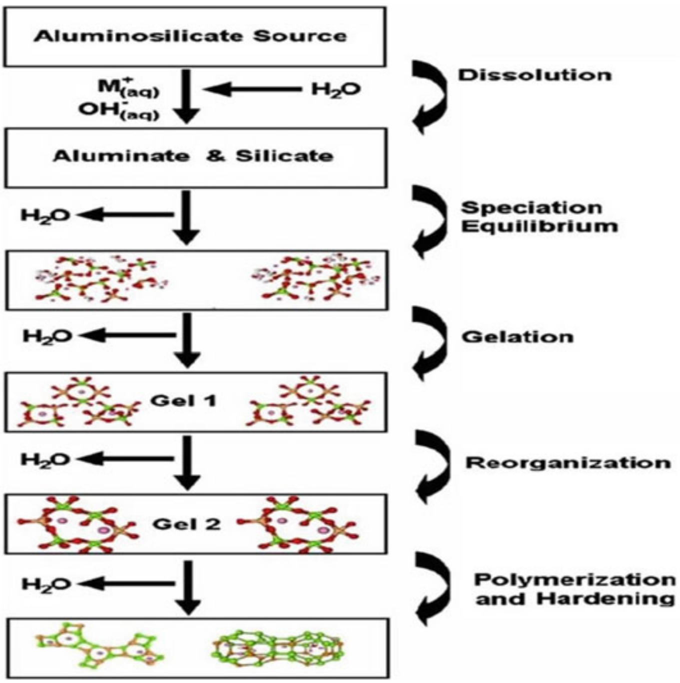


**Fig. 2** Conceptual model of geopolymerization [9]

### *2.3 Alkali Activators*

Sodium hydroxide solution is used as the alkali activator. Sodium hydroxide solutions of 1, 2, 4, 6 and 8 M are prepared 24 h prior to the experiments for homogeneous mixing and are kept in air tight containers.

## 3 Methodology

The experimental programme consists of treating the expansive soil with different percentages of blast furnace slag and different concentrations of sodium hydroxide solution. The varying percentages of slag used were 0–20% with an increment of 5%, and the concentration of sodium hydroxide used is 1, 2, 4, 6 and 8 M. The range of the slag contents and the concentration of the solution are chosen to study the effect of stabilization on a broader range. The soil is mixed with slag and sodium hydroxide solution and left for maturing at a constant temperature of 30 °C to conduct various tests at 0, 3, 7, 30 and 90 days. Atterberg limits [liquid limit (LL), plastic limit (PL) and plasticity index (PI)], differential free swell and pH are conducted following IS 2720 (part 5)-1985, IS 2720 (part 6)-1972, IS 2720 (part 40)-1977 and IS 2720 (part 26)-1987, respectively, to study the effect of stabilization on high swelling and shrinkage properties of soil (Table 1).

**Table 1** Characteristics of expansive soil

| | |
|---|---|
| Specific gravity | 2.78 |
| Free swell index | 110% |
| Linear shrinkage | 20.8% |
| Shrinkage limit | 10% |
| Plastic limit | 28% |
| Liquid limit | 78% |
| Light compaction test | OMC = 12.10% |
| | MDD = 1.972 g/cc |
| Heavy compaction test | OMC = 10.95% |
| | MDD = 2.072 g/cc |

# 4 Result and Analyzes

## *4.1 Liquid Limit*

The typical curves in Figs. 3 and 4 present liquid limit values of soil-slag mixtures treated with distilled water and NaOH solution for different curing periods. For a given concentration of NaOH solution, the liquid limit values decrease with slag content. The NaOH solution activates the slag, which produces calcium ions, and these calcium ions replace the exchangeable cations in the expansive soil and stabilize the surface charge causing the diffused double layer (DDL) to shrink. The increase in NaOH concentration and slag contents increases the reduction of DDL, thus decreasing the liquid limit values.

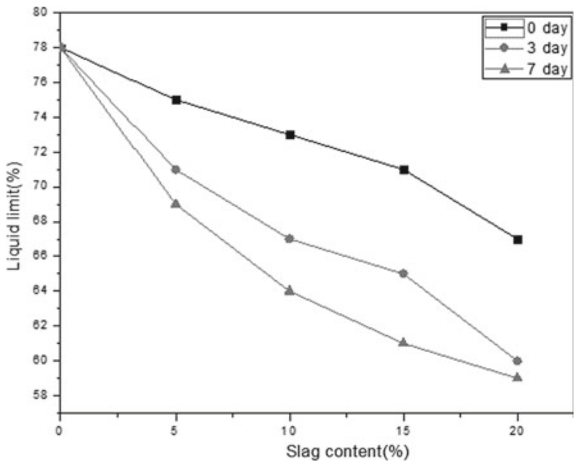


**Fig. 3** Liquid limit of soil-slag mix treated with distilled water

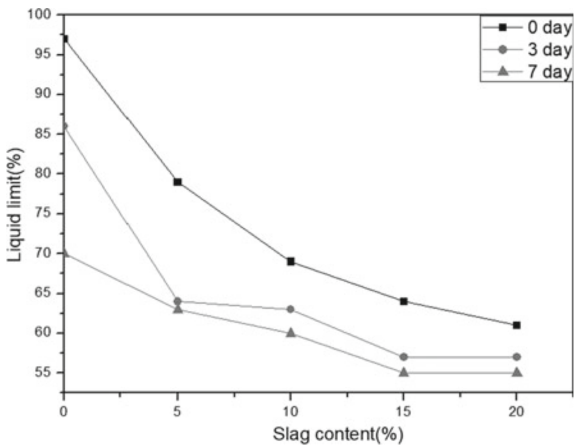


**Fig. 4** Liquid limit of soil-slag mix treated with 2 M NaOH solution

### *4.2 Plastic Limit*

The typical curves presenting plasticity index values of soil-slag mixes with different contents of slag at a given concentration of sodium hydroxide (NaOH) are presented Figs. 5 and 6. It is seen that the plasticity index value decreases with slag content for a given concentration of NaOH solution with increase in curing period.

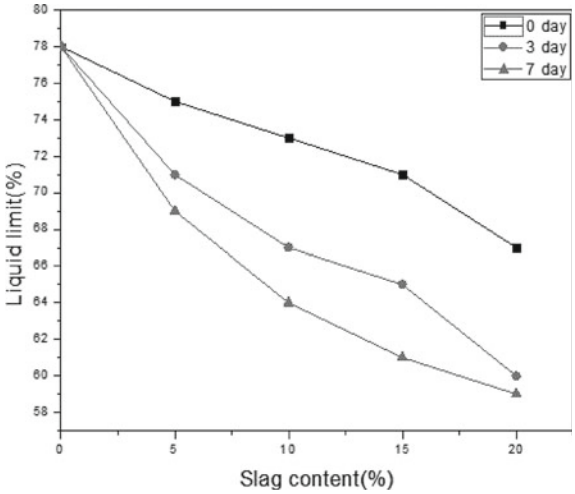


**Fig. 5** Plasticity index of soil-slag mix treated with distilled water

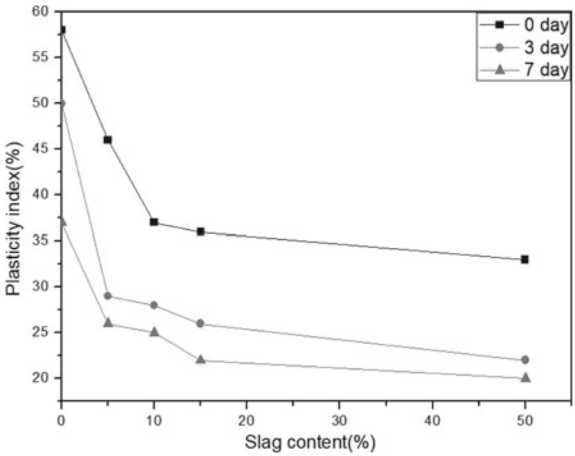


**Fig. 6** Plasticity index of soil-slag mix treated with 2 M NaOH solution

## 4.3 Shrinkage Limit

The set of curves representing shrinkage limit values of soil-slag mixes with different contents of slag at a given concentration of sodium hydroxide for different curing periods are presented in Figs. 7 and 8. It is seen that the shrinkage limit value increases with slag content for a given concentration of NaOH solution and it also increases with increase in curing period.

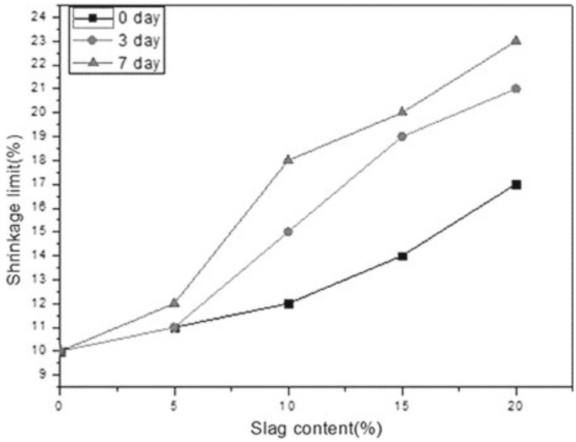


**Fig. 7** Shrinkage limit of soil-slag mix treated with distilled water

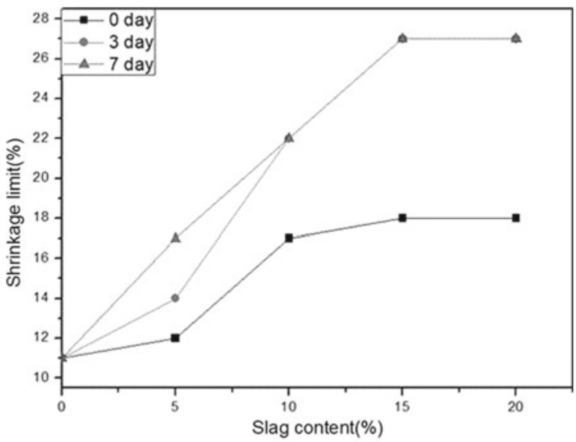


**Fig. 8** Shrinkage limit of soil-slag mix treated with 2 M NaOH solution

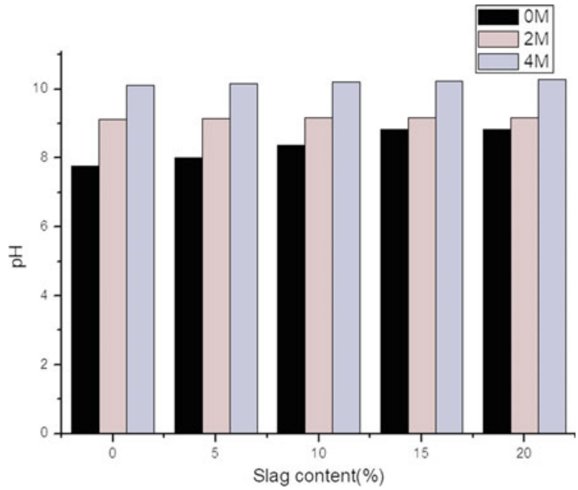


**Fig. 9** Variation of pH of soil-slag mixes with concentration of sodium hydroxide (NaOH) solution

### *4.4 pH*

The variation of pH values of soil-slag mixes with different contents of slag for different concentrations of sodium hydroxide solution is shown in the bar chart. There is not much increase in the pH values with increase in slag content for a given concentration of NaOH. With increase in concentration of NaOH, the pH value increases due to its alkaline nature (Fig. 9).

### *4.5 Differential Free Swell*

There is a decrease in the value of differential free swell (DFS) value with increase in slag content for soil-slag mixes. The DFS values also decrease with increase in concentration of sodium hydroxide solution and with increase in curing period (Fig. 10).

## 5 Conclusion

This paper investigated the influence of the mineral admixture slag and alkali activator on the plasticity and swelling characteristics of expansive soil.

- It is observed that both liquid limit and plasticity index are reduced significantly by adding sodium hydroxide solution. Further, both LL and PL reduce with increase in curing period.

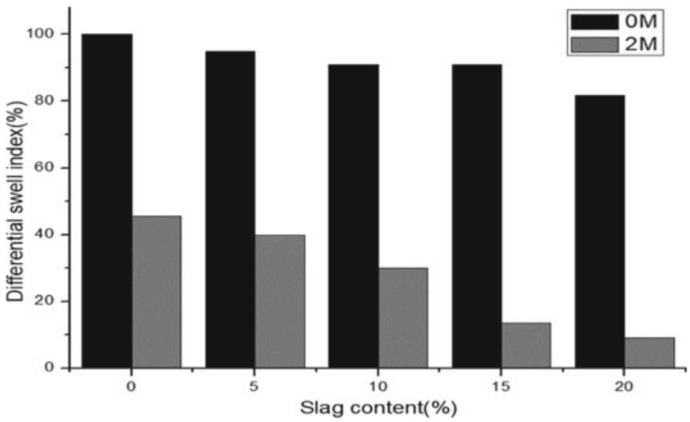


**Fig. 10** Variation of differential swell index of soil-slag mixes with concentration of NaOH solution

- Similarly, a reduction in swelling index is observed with increase in sodium hydroxide content and curing period.
- However, shrinkage limit increases when the slag content, concentration of NaOH solution and curing period increase.
- A marginal increase of pH value is observed with increase in slag content, whereas a substantial increase in pH is noticed with addition of NaOH concentration.

From the above observations, it is obvious that the sodium hydroxide (NaOH) solution activated slag is suitable as an alternative to conventional stabilizing agents. Addition of slag-based geopolymer to expansive soil modifies the plasticity and swelling properties of expansive soil. Geopolymer has hardly any harmful effect on environment.

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