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# EFFECT OF FLY ASH AND LIME ON THE STABILIZATION OF A CLAYEY SOIL

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**ABSTRACT:** Clayey soils normally can possibly show unfortunate designing conduct, like low bearing limit, high shrinkage and swell qualities and high dampness suscepti-bility. Adjustment of these soils is a typical practice for working on the strength. This review reports the improvement in the strength of a locally accessible cohesive soil by expansion of both fly debris and lime. Investigation utilizing X-ray diffraction, scanning electron microscopy, combined with energy dispersive spectros-duplicate, warm gravimetric examination, zeta potential and pH esteem test was done to explain the adjustment component. The micro level examination affirmed the breaking of montmorrillonite structure present in the untreated clay after adjustment. In the examination, it was additionally affirmed that in the adjustment interaction, pozzolanic response overwhelmed over the cation exchange capacity.

**Keywords:** Clayey soil · Fly ash · Lime · Stabilization · SEM · XRD

## 1 Introduction

The design and construction of rural roads requires engineers to use the locally available soils for the pavement foundation. This necessity is often dictated by the non-availability of quality materials, haul distances and economic considerations. The poor-quality soils usually have the potential to demonstrate undesirable engineering behavior, such as low bearing capacity, high shrink and swell potential and high moisture susceptibility. Pavement structures on poor soil sub grades show early distresses causing the premature failure of the pavement. Stabilization of these types of soils using different additives is a usual practice as it becomes uneconomical to replace the foundation material with good quality soils. Many additives such as lime, cement, fly ash, bitumen and different chemicals are being used for stabilization of these types of soils. Since, fly ash is a waste material from thermal power plants and shows pozzolanic characteristics, it is always encouraged to use fly ash for stabilization where easily and economically available. Fly ash is extracted from flue gases of a furnace fired with coal and is non-plastic fine silt. Its composition varies according to the nature of coal burned. Many efforts are being directed toward beneficial utilization of this waste product in several ways. Fly ash has been used as a pozzolana to enhance the strength of composites (Joshi and Lohtia 1997), as a potential material for waste liner (Edil et al. 1987), as a backfill and embankment material, and as a material for the stabilization of road base courses (Kim et al. 2005; Kumar 1996; Phani Kumar and Sharma 2004). The strength characteristics of stabilized soils used in pavements are measured by means of unconfined compressive strength (UCS) or California bearing ratio (CBR) values. Depending upon the soil type, the effective fly ash content for improving the engineering properties of the soil varies between 15 and 30 % (Brooks 2009).

The improvements noticed in some of the geotechnical properties of clayey soils only with fly ash are not adequate for its use in roadwork and foundation design (Christopher et al. 2006; NRRDA 2007). However, lime which is considered to be a good stabilizing agent for clayey soil may be added to fly ash in the stabilization of the soil to further improve the properties. Fly ash is a waste product of a thermal power plant where as lime is very cheap and readily available. Very few studies (Bhuvaneshwari et al. 2005; Rao and Rao 2008; Little and Nair 2009; Rao 2011; Guyer 2011) have been carried out, which uses fly ash in conjunction with lime for stabilizing clayey soils.

An experimental program was taken up to evaluate the effect of the fly ash content on the free swell index, plasticity, compaction characteristics, unconfined compressive strength, California bearing ratio and Atterberg limits of a cohesive soil commonly found in the eastern part of India. Dosages of fly ash and lime were determined to yield optimum strength of soil. Also, a micro level investigation was carried out using XRD, SEM, EDS, TGA, and zeta potential in order to elucidate the stabilization mechanism. Some significant results were obtained and presented herein.

## 2 Materials and Methodology

### Materials

The clayey soil used in the study was collected from the banks of the River Jhumar, Ranchi, India and fly ash was procured from a nearby Thermal Power plant in Patratu, Ranchi, India. Grain size distribution, specific gravity, Atterberg limits, maximum dry unit weight, optimum moisture content (OMC), UCS, CBR, free swell index in accordance to respective Indian standards and ASTM standards. UCS of the tested specimens was defined as either the stress at failure of the specimen or stress corresponding to 20 % vertical strain of the soil specimen. The general relationship between UCS and the quality of the sub-grade soils used in pavement applications (Das 1994) is as given in Table 1.

Soils with larger clay content show higher swelling and shrinkage characteristics causing differential settlements under various structures. The potential swell is a usual term used to classify expansive soils, from which soil engineers ascertain how good or bad the cohesive soils are. The degree of expansion and degree of severity for the soil can be determined from the guidelines laid down by Indian Standard code of Practice (IS:1498 1997) as given in Table 2.

The results of the all the geotechnical tests carried out on soil and fly ash are given in Table 3. For the results shown in Table 3, the soil may be classified as clay with high plasticity (CL) as per the unified soil classification system. Based on the UCS the soil may be categorized as 'soft clay' (Das 1994) which are not suitable for subgrade layer (Table 4). The gradation curves for soil and fly ash are shown (FSI) tests were performed on the soil sample and flyash in Fig. 1. As per the swelling characteristics of the soil, the soil can be categorized as an expansive soil with 'medium' degree of expansion and 'marginal' degree of severity based on the classification given in Table 2.

## Methodology

The experimental program was carried out in three stages to achieve the objective as given below:

1. Optimum percentage of fly ash to be added to the clayey soil
2. Minimum Lime content based on pH value consideration
3. Micro level analysis of the stabilization mechanism

Table 1 Quality of sugbrade based on UCS value

| UCS (kPa) | Quality of sub-grade |
|---|---|
| 25–50 | Soft sub-grade |
| 50–100 | Medium sub-grade |
| 100–200 | Stiff sub-grade |
| 200–380 | Very stiff sub-grade |
| ≥380 | Hard sub-grade |

Table 2 IS classification system, as per (IS:1498 1997)

| Liquid limit (%) | Plastic limit (%) | Shrinkage limit (%) | Free swell index (%) | Degree of expansion | Degree of severity |
|---|---|---|---|---|---|
| 20–35 | ≤12 | ≤15 | ≤50 | Low | Non critical |
| 35–70 | 12–23 | 12–30 | 50–100 | Medium | Marginal |
| 50–70 | 23–32 | 30–60 | 100–200 | High | Critical |
| 70–90 | ≥32 | ≥60 | ≥200 | Very high | Severe |

Table 3 Properties of soil and fly ash

| Property | Soil | Fly ash |
|---|---|---|
| Gravel (%) | 0.22 | 0.00 |
| Sand (%) | 13.16 | 59.16 |
| Silt (%) | 74.49 | 32.72 |
| Clay (%) | 7.45 | 3.76 |
| Classification | CL | Class C |
| Specific gravity | 2.63 | 1.95 |
| Liquid limit (%) | 34.79 | – |
| Plastic limit (%) | 20.44 | – |
| Plasticity index (%) | 13.34 | Non plastic |
| Free swell index (%) | 85.71 | – |
| OMC (%) | 17.81 | 34.63 |
| MDD (g/cm$^3$) | 1.77 | 1.10 |

### Optimum Dosage of Fly Ash

Tests to find out Atterberg limits, FSI, UCS and CBR value were carried out on the soil samples with different percentages of fly ash (i.e., 10, 15, 20 and 25 %). Some of the tests were repeated as many as three times to assure the repeatability of the results. The optimum dosage of the fly ash was determined based on the results of the strength tests. The test results have been reported in Sect. 3.1.

### Optimum Dosage of Lime

The pH of the samples were determined using the pH meter, which involves mixing the solids with pure water (1:5 solid: water), periodically shaking samples, and then testing the sample. The pH value test as per Eades and Grim (1966) was conducted to determine minimum lime content. According to the test, the minimum lime content of a soil is reached when the pH of the soil, lime, and water mixture with 25 g of soil passed through the 425 lm (No. 40) sieves, a certain percentage of lime, and 100 g of distilled water reaches 12.4. In this case, the soil with optimum dose of the fly ash was taken as the base material for test.

### Micro-level Analysis of the Stabilization Mechanism

A micro level investigation was carried out using XRD, SEM, EDS, TGA, and zeta potential in order to elucidate the stabilization mechanism. X-ray diffraction data were obtained by a diffractometer (Shimadzu XRD-6000) in the range of 2*h* = 1°–90° (Nickel filtered Cu K*a* radiation, Wavelength 1.59 nm). Scanning electron micrographs of the sample was obtained by Jeol JSM 6390 LV Scanning Electron microscope. The sample was coated with platinum for 30 s at a current of 50 mA before the SEM micrograph was obtained. EDS analysis was obtained at an accelerating voltage of 20 kV and working distance of 10 mm. The soil sample was dispersed in Millipore water and sonicated for 10 min. The zeta potential of the dispersed soil sample was measured by electrophoresis method using Malvem Zeta meter (model Nano ZS). The thermo gravimetric analysis was performed on a Shimadzu instrument (DTG 60) in nitrogen atmosphere under a flow of 30 ml/

Table 4 Results of the geotechnical tests on soil blended with flyash

| Sample | LL (%) | PL (%) | PI (%) | SL (%) | OMC (%) | MDD (g/cc) | Free swell (%) | UCS (kPa) | CBR (%) |
|---|---|---|---|---|---|---|---|---|---|
| Soil ?0 % fly ash | 34.79 | 20.24 | 13.34 | 18.95 | 17.82 | 1.77 | 85.71 | 24.73 | 2.06 |
| Soil ?10 % fly ash | 34.48 | 20.79 | 13.89 | 17.72 | 18.65 | 1.87 | 75.82 | 34.73 | 3.12 |
| Soil ?15 % fly ash | 33.83 | 21.28 | 12.55 | 15.75 | 19.42 | 1.92 | 70.11 | 38.83 | 3.76 |
| Soil ?20 % fly ash | 33.21 | 21.54 | 10.68 | 14.54 | 19.87 | 2.02 | 69.05 | 63.38 | 4.03 |
| Soil ?25 % fly ash | 32.85 | 22.09 | 9.16 | 12.75 | 20.46 | 2.04 | 71.25 | 45.11 | 4.28 |

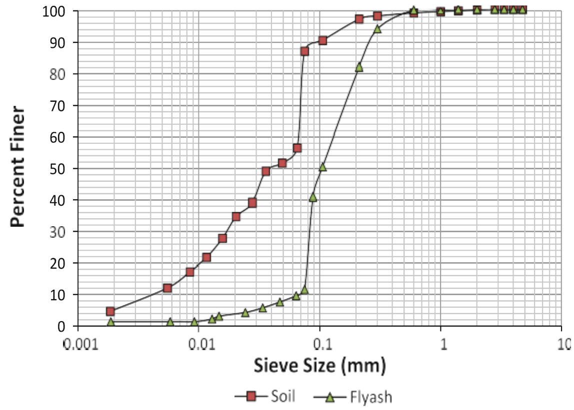


Fig. 1 Gradation curves for soil and flyash

min and heating rate of 10 °C per min varying the temperature from 25 to 1,000 °C.

## 3 Results and Discussions

### Optimum Fly Ash Content

The results of various geotechnical tests carried out on the soil samples mixed with different percentage of flyash are summarized in Table 4.

From the results, it may be observed that, addition of fly ash from 10 to 20 % increased the Unconfined Compressive Strength of soil increased from 35.28 kPa to 63.38 kPa. Further increase in fly ash decreased UCS, indicating that 20 % is the optimum percentage of fly ash. Also we need to use the fly ash economically, as more than 20 % fly ash would not be feasible in the site or highways. Addition of 20 % fly ash increased the CBR value of the soil from 2.06 to 4.03. All the UCS tests were carried out on fresh soil samples without any curing. The results will be much higher after curing, which has been indicated by several researchers earlier.

It was also observed that liquid limit decreases and the plastic limit increases with an increase in fly ash content. The plasticity index is reduced by about 50 % when the fly ash content is 20 %. Results indicate that optimum moisture content and maximum dry density increases with an increase in percent of fly ash. The optimum moisture content increased by 15 % and maximum dry density increases by about 15 % by addition of 20 % fly ash. Based on the UCS value, the stabilized soil may now be categorized as stiff clay (Das 1994).

The free swell index decreased considerably with an increase in fly ash content, reaching almost 15 % less than the initial FSI of the soil at 20 % fly ash. At low percentages of fly ash, a greater decrease occurred in the swell potential. Fly ash contents of more than 20 % do not produce a significant reduction in the free swell index of the soil. The decrease in free swell index with an addition of fly ash may be due to cation exchange in the fly ash-soil mix or due to pozzolanic reaction.

### 3.2 Minimum Lime Content

In the pH test, The lime dosages ranged from no lime to 2 g of lime mixed with just distilled water. In between, the lime dosage is incrementally increased until the pH of this mixture reaches 12.4. The pH readings are taken after 60 min of shaking the mixtures for 30 s at 10 min intervals. From the Fig. 2, it may be observed that if 8.5 % of lime is added to the soil and 20 % fly ash mix, the target pH value of 12.4 is achieved indicating that 8.5 % is the minimum dosage of lime.

From the results reported in the preceding paragraphs, it was found that 20 % of fly ash and 8.5 % of lime are the optimum dosages to be added to the clayey soil for improvement in the geotechnical characteristics. Unconfined compressive strength and CBR tests were also conducted on the soil sample with optimum dosages of fly ash and lime. The UCS value increased to 105.2 kPa and CBR value increased to 5.7 % by when 20 % fly ash and 8.5 % lime was added to the soil. The UCS tests have been carried out on the freshly prepared soil samples and hence, the strength will definitely increase further after curing of the samples up to 28 days.

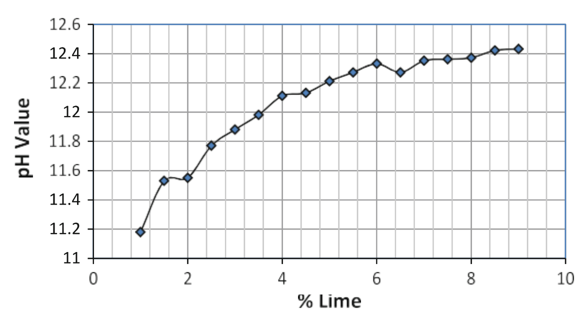


Fig. 2 Result of the pH test

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## Micro-level Analysis of the Stabilization

### *Zeta Potential*

The values of zeta potential of untreated soil and treated soil with additives are presented in Table 5. The result of this study shows that the zeta potential value is not significantly changed with increase in additives to the untreated soil. So, in the present study, the pozzolanic reaction is more effective than the Cation Exchange reaction for stabilization of expansive soil treated with additives (like fly ash and lime). Similar observations were also recorded by other researchers (Chen 1975; Bell 1976; Cokca 2001; Arasan 2005).

### *Energy Dispersive Spectrosopy (E.D.S.)*

The E.D.S. was employed to analyze the composition of soil, fly ash and lime used. Figure 3a, b, c shows the E.D.S. spectra of soil, soil ?20 % fly ash and soil ?20 % fly ash ?8.5 % lime. The Si: Al ratio of the soil was found to be 2.31, which confirms the presence of Montmorillonite mineral in the soil (Peethamparan et al. 2009).

Table 5 Change in zeta potential values with stabilization

| Percentage fly ash | Zeta potential |
|---|---|
| 0 | −27.0 |
| 10 | −26.5 |
| 15 | −25.9 |
| 20 | −24.5 |
| 20 % fly ash and 8 % lime | −19.5 |

### *XRD Analysis*

The mineralogical analysis of the untreated soil, treated stabilized soil with 20 % of fly ash and 8.5 % lime was carried out by XRD analysis and shown in Figs. 4, 5 and 6. In Fig. 4, the broad peak at 8.96° of the untreated soil confirms the presence of Montmorillonite mineral. Also, the peaks become sharper with the addition of fly ash and lime which confirms the breakage of montmorillonite structure.

In Figs. 5 and 6, the appearance of the peaks at 28.48° and 14.00° for the stabilized soil with fly ash and lime confirm the formation of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) and absence of those peaks in the untreated soil illustrates that stabilization occur due to the pozzolanic reaction.

In the puzzolanic reaction, the calcium from lime and fly ash reacts with soluble alumina and silica from clay and fly ash, in presence of water to produce stable calcium silicate hydrate and calcium aluminate hydrate which generates long term strength gain and improve the geotechnical properties of the soil, which may be observed from Eqs. 1 to .4.

$$CaO + H_2O \rightarrow Ca(OH)_2 + Heat(D) \quad (1)$$

$$Ca(OH)_2 \rightarrow Ca^{2+} + 2(OH)^- \quad (2)$$

$$Ca^{2+} + 2(OH)^- + SiO_2 \rightarrow \text{Calcium Silicate Hydrate} \quad (3)$$

$$Ca^{2+} + 2(OH)^- + Al_2O_3 \rightarrow \text{Calcium Aluminate Hydrate:} \quad (4)$$

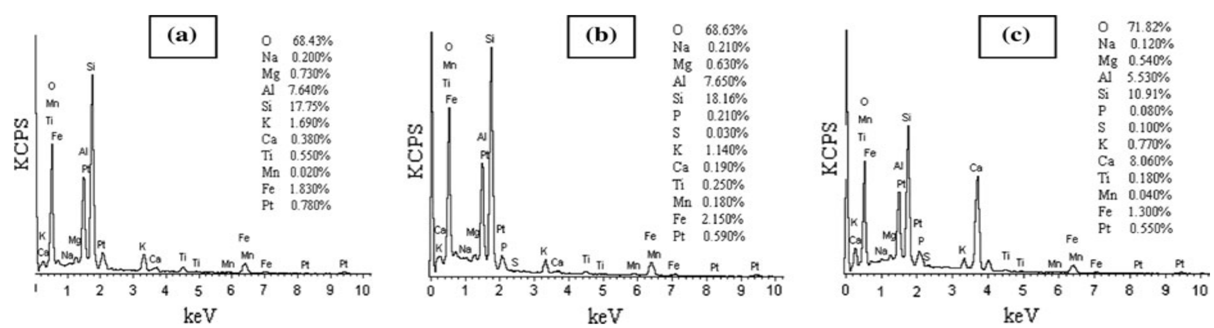
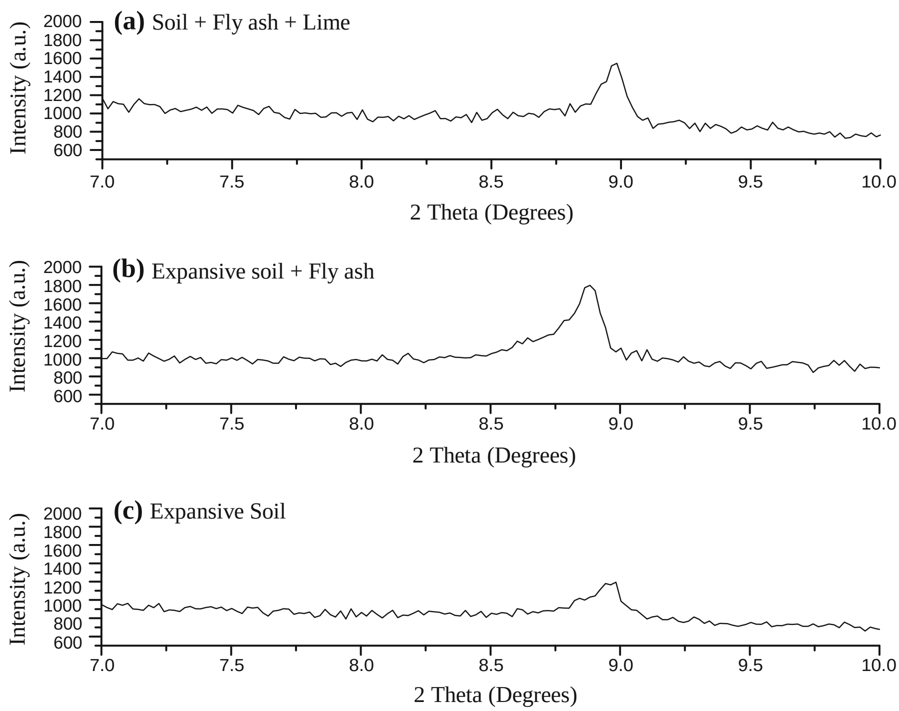



Fig. 3 EDS spectra of a Soil, b Soil ?20 % fly ash, c Soil ?20 % fly ash ?8.5 % lime

Fig. 4 Presence of montmorillonite (at 8.96°)




*SEM Images*

The slices of air dried samples were observed using SEM to further validate the results obtained from XRD. Figure 7a,b, c represent the untreated soil samples and treated stabilized soil. The large voids present in the untreated soil (Fig. 7a) diminishes in the soil treated with 20 % fly ash (Fig. 7b), which gets further reduced when it is treated with 20 % fly ash and 8.5 % lime (Fig. 7c). So, the micrograph illustrates the formation of new cementitious compounds (calcium silicate hydrate CSH and calcium aluminate hydrate CAH) as a result of pozzolanic reaction which were shown within the pore spaces resulting in a reduction in the radius of pore spaces.

*Thermo Gravimetric Analysis*

The TGA results for the original clay and for the lime and fly ash treated clay specimens are shown in Fig. 8. The sudden dip signified as a weight loss for the dehydroxylation of montmorillonite between 450 and 600 °C, appears to be much smaller for untreated clays than that for stabilized clays. The weight loss occurring for the original untreated sample between 450 and 600 °C is due to the breaking of the crystalline

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structure of Montmorillonite which results in rear- rangement of octahedral and tetrahedral structures of alumina and silica (Peethamparan et al. 2009). Thus, the stabilization process occurs for the untreated soil as the swelling characteristics of the expansive soil is reduced due to the enhanced breaking of Montmoril- lonite bonds in the stabilized soils indicated by sharper peak drops in Fig. 8. The weight loss occurring for the original untreated sample between 450 and 600 °C is due to the breaking of the crystalline structure of Montmorillonite which results in rearrangement of octahedral and tetrahedral structures of alumina and silica (Peethamparan et al. 2009). The sudden dip which is signified as a weight loss for the dehydroxy- lation of montmorillonite between 450 and 600 °C, appears to be much smaller for untreated clays than that for stabilized clays. The sharper peak drops in Fig. 8 for treated soil clays accounts for the unreacted hydrated calcium carbonate which decomposes to release $CO_2$ and CaO and hence the increased weight losses. Also, additional losses have been developed at temperatures from 115 to 150 °C for treated stabilized soil samples, thus confirming the formation of CSH or CAH, which was initially absent in the untreated soil samples. The weight loss occurring between 115 to 150 °C, was 0.131 % for only soil, 0.187 % for soil

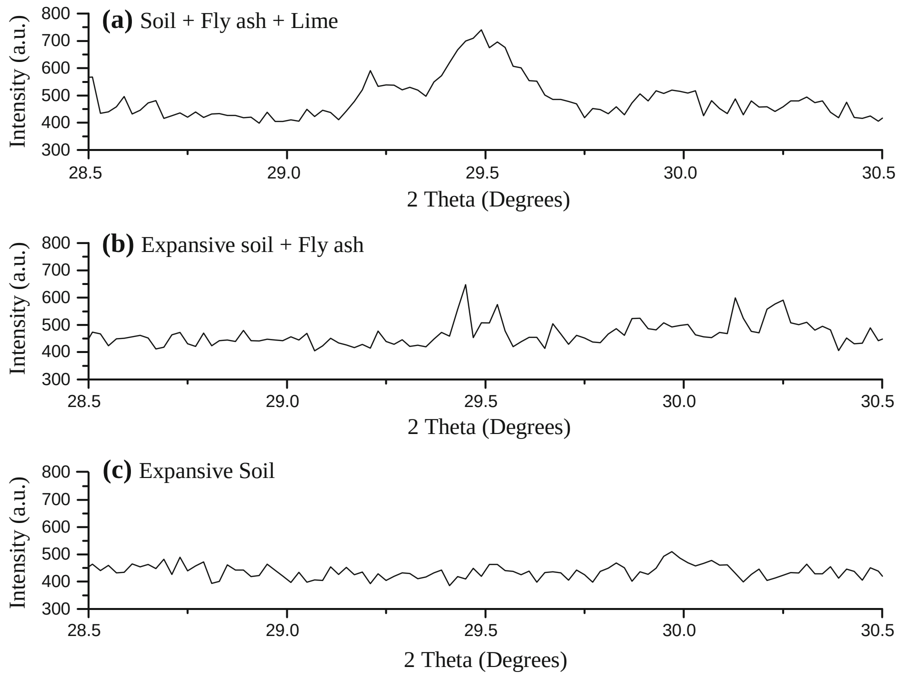


Fig. 5 Formation of calcium silicate hydrate (at 28.48°)

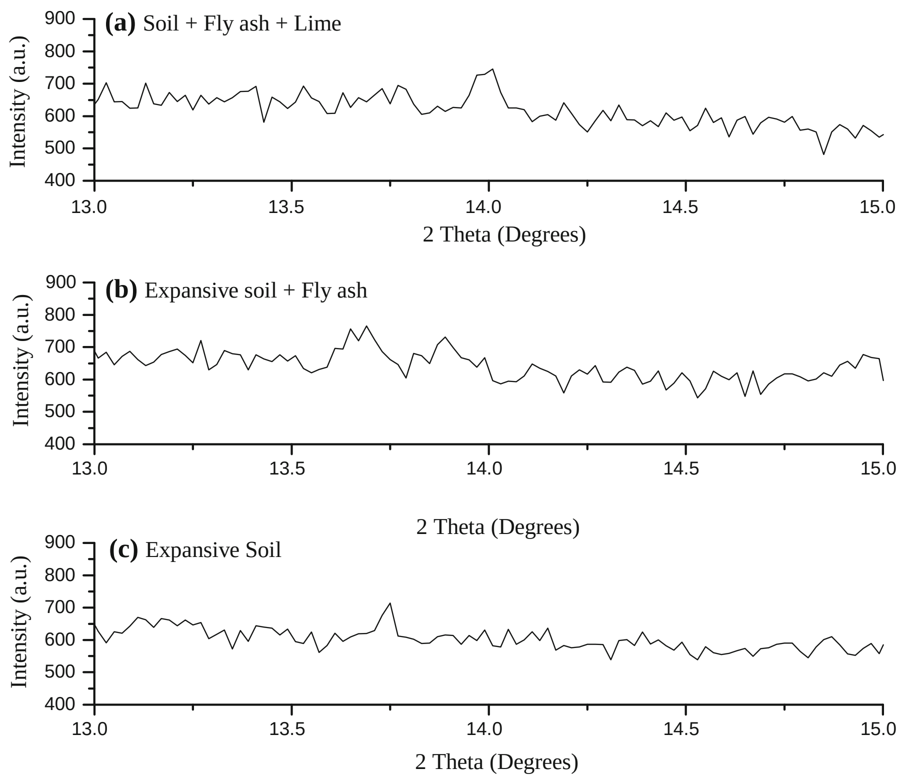


Fig. 6 Formation of calcium aluminate hydrate (at 14.00°)

?20 % fly ash and 0.455 % for soil ?20 % Fly ash ?8.5 % lime, thus indicating the increased presence and decomposition of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) at these temperatures in the treated soil samples (Bhatty and Miller 2004; Peethamparan et al. 2009).

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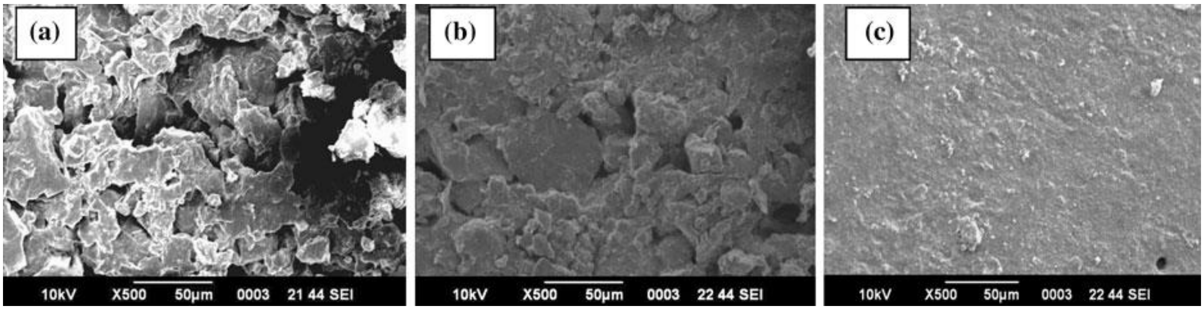


Fig. 7 SEM image of a Soil, b Soil ?20 % fly ash, c Soil ?20 % fly ash ?8.5 % Lime

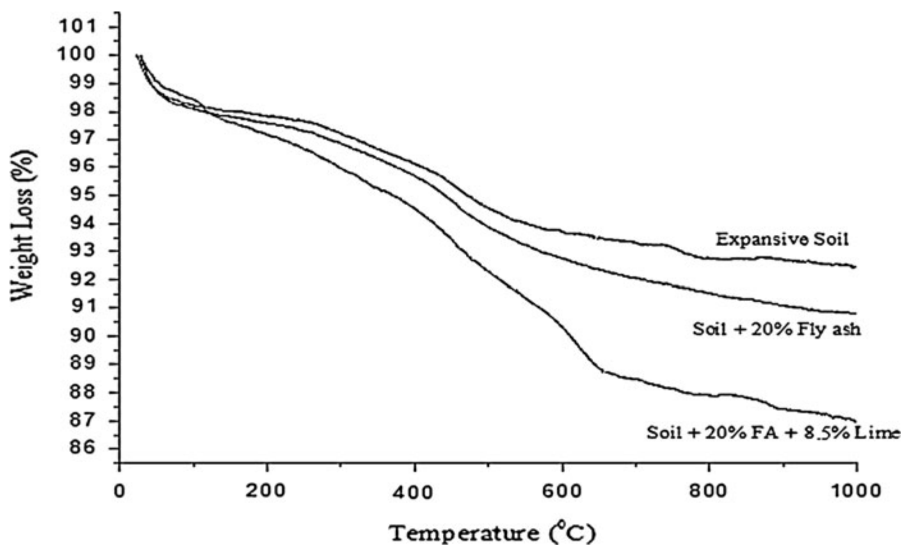


Fig. 8 TGA results for untreated and stabilized soils

## 4 Conclusions

In the study, the stabilization of a clayey soil with fly ash and lime was investigated and the effects of the stabilization on the geotechnical and chemical properties of a clayey soil were studied. The optimum fly ash content was found at 20 % considering the unconfined compressive strength of treated soil. As the increased strength of soil with addition of fly ash was not adequate enough to be used as good foundation material, addition of lime in conjunction with fly ash was adopted for stabilization. A minimum lime content of 8.5 % was recommended for stabilizing the soil as resulted from the pH value test. The UCS value increased to 105.2 kPa and CBR value increased to 5.7 % by addition of 20 % fly ash and 8.5 % lime. The addition of fly ash also improved the geotechnical properties of the soil.

The zeta potential value of the untreated soil did not significantly change by stabilization from additives, confirming that the pozzolanic reaction dominated over the cation exchange capacity (C.E.C.) for the untreated soil. EDS analysis confirmed the presence of montmo- rillonite mineral in the soil, which is responsible for the expansive characteristics of the soil. From the XRD analysis, broad peak at 8.96° of the untreated soil showed the presence of Montmorillonite mineral which become sharper with the addition of fly ash and lime confirming the breaking of montmorillonite structure. Also in the XRD charts, the appearance of the peaks at 28.48° and 14.00° for the stabilized soil with fly ash and lime confirmed the formation of CSH and CAH and absence of those peaks in the untreated soil illustrates that stabilization occur due to the pozzolanic reaction. TGA results also supported the formation of CSH and CAH and breaking of montmorillonite mineral present in the untreated soil. SEM images illustrated the formation of new cementitious compounds (CSH and CAH) as a result of pozzolanic reaction which were shown within the pore spaces resulting in a reduction in the radius of pore spaces.

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