International Journal of Innovative Research in Engineering & Management (IJIREM)
ISSN: 2350-0557, Volume-9, Issue-2, April 2022
https://doi.org/10.55524/ijirem.2022.9.2.92
Article ID IJIR-2295, Pages 592-596
www.ijirem.org

# Stabilization of Expansive Soils using Alkali Activated Fly Ash

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**ABSTRACT-** Soil is one of fundamental components of life. It supports life and human habitat. The human habitats have evolved with advancement in science and technology. Humans tend to increase their living standards by constructing large number of utilities and infrastructure to accommodate their growing needs. Civil engineering has reached its new heights consequently more challenges are posed. Due to urbanisation and industrialisation population of cities and towns is increasing. This has resulted in growing networks of roads, rails and public places. Residential and commercial infrastructures are also on demand. Interesting thing to mention here is that all these activities are only possible if the underlying strata of crust called soil is able to withstand all these changes. Therefore the nature of soil on which a foundation or pavement is constructed determines the strength and durability of these structure. Interestingly some waste materials like Fly Ash with suitable activators may be use to make weak and expansive soils stable. By adding these materials the chemical as well as physical properties of the poor expansive soil can be suitably adjusted. In this research work the use of sodium based alkaline activators and fly ash as an additive in improving the geotechnical characteristics of expansive soils is worked out. Sodium hydroxide solutions 10, 12.5 and 15 molal with 1 Molar solution of sodium silicate were used as an activators. In this mix the activator to ash ratio was kept between 1 and 2.5, and ash percentages of 20, 30 and 40%, relatively to the total solids. Then it is tested by conducting the Unconfined compressive strength UCS at curing peri ods of 3,7 and 28 days respectively and then it is compared with that of a common fly ash based binder.

**KEYWORDS-** Alkali Activated Expansive Soils, Fly Ash, Soil Stabilization, Unconfined Compressive Strength

## I. INTRODUCTION

The stabilization of soil refers to the process or procedure in which a special soil mass, a chemical, or a cementing material is added to a natural soil to enhance its properties. This can be achieved by mechanically mixing the natural soil and stabilizing material together so as to achieve a homogeneous mixture. It can be done also by adding the stabilizing material to an undisturbed Soil deposit so that it interacts with the soil and permeate through its voids. This soil and stabilizing agent are blended and worked together. In addition soil stabilizing additives are used to improve the properties of less desirable road soils [1]. When used, these stabilizing agents can improve and maintain moisture content of soil, increase cohesion and serve as water proofing and cementing agents. There has been increase in number of thermal power plants to meet the increasing demand of power supply due to large scale industrialization and urbanization. Fly ash is a by-product from these thermal power plants. At present fly ash production is in excess of its utilization. Dumping and overall managing in a safer way of fly ash are two concerns with fly ash production [2]. Normally the waste of these thermal power plants is very harmful having multiple characteristics hence making it inevitable for safer disposal of these wastes, which later on ensures safer environment and better human life thereby. In order to avoid environmental pollution, pre treatment provisions of these harmful wastes before dumping and storage must be carried out. According to central electricity authority report 2019-2020 fly ash utilization has increased to 78.19% which is highest as of now. In civil engineering works when the sub-grade is found to be a clay soil, various soil stabilization methods are adopted to overcome these problems. Soils with high clay content swell when their moisture content increases. By using these wastes or by products, there is an appreciable enhancement in the engineering properties of the soil [3].

In the field of civil engineering there are different methods of soil stabilisation. Different types of stabilisations are deployed as per requirement and situational demand. Some of the popular methods of soil stabilisation are mentioned as under.

- Lime stabilization
- Fibre stabilization
- Fly ash stabilization
- Alkali activated fly ash stabilization

### A. *Alkali Activated Fly Ash*

Soil is important material for construction for its accessibility and economical nature. Soil is used in construction and in any branch of civil engineering. It is used in foundation construction and pavements as it offers soundness to structure overlaying by giving much needed strength. So that requirements of bearing capacity and other important properties of soil are met. In the field of civil engineering we face the problems of expansive soils in urban areas during the construction infrastructure and pavements. Therefore speaking precisely of expansive soil it is unavoidable to improve basic properties of soils. It is worth to mention here that waste products like fly as with alkali activators are quite helpful in providing the much needed strength and stiffness to these soils. These by products or waste products can be plastics, flume products, stone quarry, fibre rich wastes and recycled combination of materials, lime, fibre, fly ash and plastics. In this research work, alkali activated fly ash is used as a stabilizer for the expansive soil. Soil stabilization means to mix and blend certain additives with soil to make properties of that soil better. Fly ash is a by product of combustion of coal and is extracted from gases arising of thermal power plant.

Fly ash consists of particulate matter of non-combustible nature including very little proportion of unburned carbon. Fly ash also consists of silica, alumina and iron. These particles can easily blend with the mix because of their spherical shape. The minerals in fly ash have both crystalline and amorphous nature. Fly ash size varies from 0.5 to 300 microns in size. The process of Alkaline activation may be termed as chemical process in which alumina-silicate in powder form like fly ash get mixed with alkaline activator to produce paste which sets and then hardens within a shorter time period. It is known as poly-condensation process, where alumina ($AlO_4$) and silica ($SiO_2$) tetrahedrics interconnect with sharing of the ions of oxygen. The activated fly ash by alkali is environment friendly product. This alkali activated fly ash is found very useful in stabilizing expansive soil by enhancing their engineering properties. Alkali activated fly ash is extensively used in construction spheres of civil engineering. Fly ash enriched by alkali activators in different concentrations has improved the engineering properties of fly ash. Alkali activation of fly ash actually decreases permeability and increases compressive strength of fly ash, and also gives optimum viscosity when fly ash reacts with alkali in optimum amount. An experiment on stabilization of expansive soil by alkali activated fly ash was done with different percentages of fly ash, varying ash-soil ratio, varying activator-total solids ratio. Compressive strength was also found out and compared at different percentages of fly ash and alkali activated fly ash. It has been found that the compressive strength of expansive soils improve generally with addition of fly ash and more effectively with alkali activated fly ash. Hence alkali activation of fly ash and its application to expansive soil for stabilization turns out to be the good utilization practice for fly ash generated from coal based thermal power plants and thus meeting two purposes of stabilization and proper utilization.

### *B. Advantages of Using Alkali Activated Fly Ash in Soil Stabilisation*

- It is useful in stabilisation of expansive soil by improving its geotechnical properties
- It has better mechanical properties and durability
- It is resistive to aggressive acids, fire and aggregate alkali reaction.
- It is effective way of utilising the waste, toxic and hazardous materials from coal based thermal plants.

### *C. Properties of Fly Ash*

Fly ash used in soil stabilisation has some chemical and physical properties which are mentioned as under:

*1) Physical Properties of Fly Ash*

- Colour: Light Grey
- Specific Gravity: 2.08

*2) Chemical Properties of Fly Ash*

Important and significant chemical components of fly ash ( n percentage) are mentioned as under:

- $SiO_2$ 41.65
- $Al_2O_3$ 22.38
- $Fe_2O_3$ 15.04
- MgO 4.76

## II. LITERATURE REVIEW

The favourable properties associated with soft soils such as poor shear strength and high compressibility, makes it necessary for engineers to adopt a proper stabilization method to improve engineering properties (Ghasemi et al., 2019; Saberian et al., 2020). [4]. The most common and conventional method for soft soil improvement is chemical stabilization in which lime and Portland cement are the most widely utilized binders (Jahandari et al., 2017a,b; Saberian et al., 2017 [5], 2018; Bahmani et al., 2019; Farhangi et al., 2020; Kazemi et al., 2020a,b). Strength development in these methods is provided through the pozzolanic reactions and hydration, which are well-known reactions among calcium hydroxide alumina and/or silica and water. The final products of these reactions depend on the content of the available silica and alumina, which can be calcium aluminate hydrate, calcium silicate hydrate and calcium alumina slica hydrate (Dodson, 1990). Cement is the most common binder used in the road and construction industry, and the annual production rate of cement is increasing at a ground-breaking pace. In 2015, cement manufacturers produced 4.6 billion tons worldwide (Scrivener et al., 2018) [6]. It is estimated that this amount will reach 4.83 billion tons by 2030 (Scrivener et al., 2018; Gopalakrishnan and Chinnaraju, 2019). This amount of production is responsible for plenty of adverse environmental impacts, for instance, manufacturing 1 ton cement and 1 ton lime accounts for 0.95 and 0.79 tons of $CO_2$ emission (about 5%e8% global anthropogenic $CO_2$ emission) and also consumes 5000 MJ and 3200 MJ energy, respectively (Shand, 2006 [7]; Higgins, 2007; Lemougna et al., 2017a, 2018). Moreover, cement production accelerates the depletion of natural resources, and results in the consumption of about 1.5 ton limestone and clay per each ton of cement (McLellan et al., 2011). Apart from the environmental issues, Portland cement has some other drawbacks such as mechanical strength reduction due to the loss of water, unfinished hydration at the beginning stages and high plastic shrinkage, which are of special importance for geotechnical engineering applications, particularly in torrid zones (Bushlaibi and Alshamsi, 2002 [8]; Ghadir and Ranjbar, 2018) [8] Sara Rios and António Viana da Fonseca (2014) [9] this experimentation inculcates fly ash, silty sand and an alkali solution mix. Unconfined compression test at curing period of 90 days was conducted on this mix and stiffness and strength were evaluated by strain instrumentation. Ghosh A. and Dey. Li., Bearing ratio of reinforced fly ash overlying soft soil and deformation modulus of fly ash [10]. Also geomechanical characteristic and its evolution with time were evaluated by calculations of seismic wave velocities along the curing period. This indicates material behaviour as time passes by. Comparisons of these results without application of alkali activated fly ash were made. A vital rise in stiffness and strength because of activator was determined highlighting the capacity of this methodology as a replacement of cement and bonding agent. The use of waste products like fly ash instead of cement makes this technique especially respectable for the environment, prospectively competitive economically and friendly for the sustainability of our resources. This methodology of utilizing fly ash in place of cement makes it vital as waste product utilization has been done and proving to be environment friendly, sustainable and economical method Prashant Hiremath et.al (2016) This investigation was carried out on expansive soil for its stabilization by using fly ash and alkali activated fly ash as stabilizers. Varying amount of fly ash as 5%, 10%, 15%, 20%, 25% and 30% was used with respect to total solids. Prabakar J., Dendorkar N. and Morchhale R.K., Influence of fly ash on strength behaviour of typical soils, Construction and Building Materials, 18, 2004, 263-267 [11]. Sodium hydroxide having 2M concentration was used as an activator. The specific gravity, atterberg limits, standard Proctor and unconfined compressive strength tests were performed on expansive clay soil. Basic characteristics like liquid limit, plastic limit (Atterberg's limits), compressive strength and compaction were determined. The results indicated that liquid limit and plasticity decreases and plastic limit of expansive clay soil increases after addition of fly ash and alkali activated fly ash to expansive clay soil.Saeid A., Amin C., and Hamid N., Laboratory investigation in the effect of lime on compressibility of soil [12]. Arbani M.and Karmani M.V., Geomechanical properties of lime stabilized clayey sands, 2007 [13]. Khattab S.A., Ibrahim M., Abderrahmane H. and Al-Zubaydi, Effect of fibers on some engineering properties of cement and lime stabilized soils,2011 [14]. Buhler R.L., and Cerato A.B., Stabilization of Oklahoma Expansive Soils Using Lime and Class C fly ash 2007 [15]

## III. METHODOLOGY

The soil used was collected by the method of disturbed sample and placed into sacks to the laboratory after removing the top soil at 500mm depth. Some portion of soil was sealed and placed into polythene bag for moisture content determination. The soil is air dried, pulverized and sieved with 4.75 mm sieve. The soil is passed through this sieve and is used for laboratory tests. The geotechnical characteristics of soil sample as per ASTM standards as shown in Table 1. Specific gravity is 2.64, maximum dry density is 16.12 KN/m³, optimum moisture content is 20.4% and natural moisture content is 8.23%, liquid limit is 73%, plastic limit is 24% , As per the ASTM the soil is classified as clay.

The sodium silicate originally in powder form and having molecular weight of 284.20 gm/mole, and specific gravity of 1.5.While the sodium hydroxide was originally in flake form with a molecular weight of 40gm/mole, and specific gravity of 2.13 at 20ºC and purity of 95-99%.1 mole of sodium silicate solution was prepared by adding the 284.20 gm of sodium silicate powder to 1 litre of distilled water. Sodium hydroxide of different concentrations of 10, 12.5 and 15 molal were prepaid before testing. In the present study the ratio of sodium silicate to sodium hydroxide solution by mass was kept as 2 as per Hardijito and rangan(2005), Criado et al. (2007) and villa et al. (2010) as a guide line.

Three different fly ash percentages regarding the total solids (soil + fly ash) weight, were used 20, 30 and 40% corresponding to ash/soil ratios of 0.25, 0.43, and 0.67 moreover to study the effect of activator on the gain in mechanical strength, the activator/total solids ratios are kept as 0.15, 0.2 and 0.25, respectively with each percentage of fly ash mixed with the soils.

The marshal funnel viscometer is used to calculate the viscosity of both cement and alkali activated grouts .by using this we can measure the time taken for a known volume of liquid to flow from the base to the bottom end of the inverted funnel.

Table 1: Properties of expansive soil

| Properties | Value ASTM standard |
|---|---|
| Specific gravity (G) | 2.64 |
| Optimum moisture content (OMC) | 20.45% |
| Natural moisture content | 8.23% |
| Maximum dry density (MDD) | 16.12 kN/m3 |
| Plastic limit | 24% |
| Liquid limit | 73% |
| Classification of soil | CH |

## IV. RESULTS AND CONCLUSION

The following results of stabilizing the expansive black cotton soil, with alkaliactivated fly ash. The increment in strength is determined by performing unconfined compression tests at 3, 7 and 28 days. The samples used were 50 mm in diameter and 100 mm in height, hence ensuring an L/D ratio as 2. Such samples contain fly ash by weight of dry mass and in 20, 30 and 40 per cent of the dry mass and overall solid activator ratio ranges between 15%, 20% and 25%. Upon casting all the samples is coated with cling film and are held for 48 hours in an airtight container. The samples were removed from the moulds after 48 h and covered in cling film and left at ambient temperature and humidity (50–60 percent RH and 32–35°C). At 3, 7 and 28 days. The samples were trimmed to 100 mm in length and tested on an Aimil hydraulic measuring system for unconfined compressive strength (UCS) at a constant strain rate of 1.2 mm / min. Every single result that was obtained was an average of 3 samples tested.

Table 2: UCS results of AF-100-20-15, AF-100-30-15, AF-100-40-15

| **Curing Time (Days)** | **Unconfined compressive strength (kPa)** | | |
|---|---|---|---|
| Specimen Name | AF-100-20-15 | AF-100-30-15 | AF-100-40-15 |
| 3 | 189.55 | 166.75 | 132.35 |
| 7 | 280.20 | 220.30 | 180.25 |
| 28 | 424.91 | 211.23 | 165.78 |

Table 3: UCS results of all 10 molal sample

| **Curing Time (Days)** | **Unconfined Compressive Strength (kPa)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | AF-100-20-15 | AF-100-30-15 | AF-100-40-15 | AF-100-20-20 | AF-100-30-20 | AF-100-40-20 | AF-100-20- 25 | AF-100-30-25 | AF-100-40-25 |
| 3 | 194.18 | 173.39 | 140.75 | 330.34 | 422.23 | 370.30 | 101.40 | 98.35 | 95.65 |
| 7 | 255.40 | 175.60 | 131.21 | 365.20 | 459.80 | 573.98 | 140.40 | 152.80 | 106.75 |
| 28 | 3 66.20 | 200.32 | 130.43 | 496.93 | 615.4 | 743.86 | 282.15 | 265.24 | 206.20 |

Table 4: UCS results of all 12.5 molal sample

| **Curing time (Days)** | **Unconfined Compressive Strength (kPa)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | AF-125-20-15 | AF-125-30-15 | AF-125-40-15 | AF-125-20-20 | AF-125-30-20 | AF-125-40-20 | AF-125-20-25 | AF-125-30-25 | AF-125-40-25 |
| 3 | 110.23 | 163.44 | 180.33 | 305.36 | 177.33 | 257.98 | 130.00 | 111.33 | 110.00 |
| 7 | 250.23 | 159.32 | 279.23 | 215.85 | 288.90 | 423.23 | 155.30 | 170.32 | 200.56 |
| 28 | 401.32 | 271.95 | 489.56 | 501.32 | 530.33 | 970.23 | 315.44 | 566.32 | 859.77 |

Table 5: UCS results of all 15 molal sample

| **Curing time (Days)** | **Unconfined Compressive Strength (kPa)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | AF-150-20-15 | AF-150-30-15 | AF-150-40-15 | AF-150-20-20 | AF-150-30-20 | AF-150-40-20 | AF-150-20-25 | AF-150-30-25 | AF-150-40-25 |
| 3 | 286.24 | 245.43 | 158.45 | 200.32 | 235.39 | 174.31 | 112.34 | 96.73 | 73.43 |
| 7 | 338.5 | 427.83 | 501.58 | 344.86 | 446.43 | 502.48 | 136.52 | 180.69 | 254.55 |
| 28 | 576.45 | 601.23 | 640.26 | 393.53 | 714.42 | 642.56 | 180.35 | 463.54 | 294.5 |

The following conclusions can be made on the basis of results obtained above as indicated in Table1, Table2, Table 3, Table4,and Table 5.

- The unconfined compressive strength of soil varies with concentration of chemical in the activated fly ash and curing period. The results of 10 molal samples give better strengths of 3 and 7 days than 12.5 and 15 molal samples as sown in tables above, making it cost-effective combination as compared with 12.5 and 15 molal samples. In case of 12.5 molal samples 28 days Curing time is more reliable and best way to opt for
- The overall 3day strength of the 10 molal sample is 4 22.23 kPa, which is 2.5 times greater than that of the samples treated with fly ash.
- The average strength of 7 days obtained by the desired sample is 573.98 kPa, which is 3 times greater than that reached by the samples
- The average 28 day strength of the desired sample is 743.6 kPa, which is 4.5 times greater than that of the samples treated with fly ash.
- Also the activator / ash ratio and strength of the mix are dependent one another.
- Results from above showed that raising the activator/ash ratio is beneficial because it has a plus effect on intensity or strength outcomes, hence also has a positive effect on final cost.

## CONFLICTS OF INTEREST

- The authors declare that they have no conflicts of interest.

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