



Effect of Fly Ash on the Characteristics of Expansive Soils in Sudan

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Abstract: This paper discusses the effect of Fly ash on the engineering properties of expansive soils. As reviewed in literature, many previous investigations have shown promising results for improvement of expansive soil after stabilization with Fly ash. Laboratory tests have been conducted on expansive soils obtained from three different regions in Khartoum state. Various percentages of Fly ash such as 0%, 10%, 20%, 25%, and 30% by weight of soil were added to the three soils and their influence on the soil plasticity, swell characteristics and unconfined compression strength are discussed. Additions of Fly ash to the three soils resulted in significant improvement in the strength and reduction in plasticity and swell properties of soils. The unconfined compression strength of soils treated with 10% Fly ash showed almost 2 times improvement compared with untreated soils. For the addition of 10% fly ash, the reduction in free swell, swell pressure and swell potential is in the range 50% to 70%. Further addition of fly ash caused a reduction in the swell characteristics of 90% at 25% fly ash. Hence, it is concluded that the fly ash has a good potential to be used as a additive for improving the engineering properties of expansive soil.

Keywords: Fly ash; expansive soil; improvement; stabilization.

1. INTRODUCTION

Expansive soils are mostly found in arid and semi-arid regions of the world where annual evaporation exceeds precipitation [1] or where significant moisture fluctuations occur over different seasons [2]. These soils undergo swelling and shrinkage as the moisture content changes observed in them. Due to high swelling and shrinkage, these soils pose a lot of problems to the structures founded on them. The presence of montmorillonite mineral in expansive clay imparts high swell-shrink potentials.

In Sudan, expansive soil covers more than 30% of the country area where most of the nation's population centers and development projects are located. The potential problem of expansive soil has resulted in severe damage to road pavements and light buildings [3]. Various techniques are practiced to mitigate the problem posed by expansive soil. Chemical stabilization with various additives such as lime, cement, calcium chloride and fly ash has been experienced to improve the properties of expansive soils.

The fine residue from thermal power plant and some industries is known as fly ash and considered as a waste material. The quantity of fly ash produced worldwide is huge and keeps increasing every day. Recently, the use of fly ash for stabilization of expansive soils has attracted the attention of researchers.

The primary benefits of using fly ash for soil stabilization are environmental incentives, because material used does not have to be wasted; cost savings, because fly ash is typically cheaper than cement and lime; and availability, because fly ash as industrial waste sources are widely distributed in many countries. Therefore, this research aims to discuss the effect of using fly ash as stabilizer on the engineering properties of expansive soils.

2. LITERATURE REVIEW

Expansive soils are a worldwide problem that poses several hazards and challenges for civil engineering constructions. The problems associated with expansive soil are related to its high swelling and low strength due to seasonal moisture variations. Continued efforts are being made all over the world to devise ways and means to solve the problems due to expansive soils. Several techniques such as application of adequate surcharge load, pre-wetting, moisture control [4]. Chemical stabilization was suggested to alleviate the problems posed by expansive soils. Chemical modification by adding lime, cement, calcium chloride and fly ash has been practiced in many countries [5], [6]. Lime tends to be much more expensive for a large stabilization project such as road subgrade stabilization, while fly ash is industrial by-products and is commonly available and environmentally and economically attractive [7].

2.1 FLY ASH

Fly ash is produced in power plants as a by-product from the burning of coal. A great portion of industrial wastes is composed of fly ash materials. Therefore, there have been intensive researches going on particularly those focused on the utilization of fly ash as a stabilizer for expansive soil due to its pozzolonic effect [7]- [10].

Fly ash is a fine textured alkaline material which is primarily composed of spherical non-crystalline silicate, aluminum and iron oxides compounded with some microcrystalline material, free lime and unburned carbon [7]. The composition of fly ash varies considerably depending on the nature of the coal burned and power plant operational characteristics [8]. When fly ash mixed with soil, it can develop cementation bonds due to the pozzolanic reaction or an inherent self-hardening property under favorable conditions of moisture and compaction [9].

Fly ash can provide multivalent cations (Ca^{+2} , Al^{+3} , Fe^{3+} , etc.) under ionized conditions which can promote flocculation of dispersed clay particles. As a result, the surface area and water affinities of the samples decrease, which implies a reduction in the swell potential [7].

Fly ash is classified into two major classes, class "C" and class "F". The former is produced from burning anthracite or bituminous coal and the latter is produced from burning lignite and sub bituminous coal. Both classes of fly ash are pozzolanic, which are defined as siliceous and aluminous materials [7]. Ahmed [10] studied the use of fly ash, obtained from Gary in Khartoum North, in soil stabilization. She stated that Gary fly ash is obtained from burning Petroleum Coke, this fly ash is well known for its high Loss of Ignition (LOI), this is not suitable for use as cement replacement material but could be used for other purposes. The chemical compositions of Gary fly ash are given in Table 1. According to ASTM C618 [11], she found that Gary Ash sample doesn't comply to the specification of both Class C and Class F.

2.2 SOIL PLASTICITY

Many Many researchers investigated the influence of fly ash admixture on plasticity of expansive soils [12] – [14]. Hakari [12] investigated the effect of fly ash on consistency limits. He found that the liquid limit decreases with the addition of fly ash is due to the effect of reduction in the diffused double layer thickness as well as effect of dilution. Also possible explanation may be related to the flocculation and

aggregation of the clay particles by addition of fly ash. The addition of 10% fly ash slightly increases the plastic limit, which is due to flocculation owing to the presence of free lime in the fly ash. Further increase in the addition of fly ash results in the marginal increase of plastic limit [13]. Also he observed the gradual increase in shrinkage up to 30% of fly ash added and is considerable on further addition of fly ash.

According to Murugan and Vijayarangam [14], the addition of fly ash to expansive soils decreases the liquid limit. The reductions of liquid limit values were optimum at 10% of fly ash on commercial soil and 30% of fly ash on natural soil. The soil classification of natural soil moves to CI from CH which implies degree of expansion is reduce to intermediate from high level of expansion.

2.3 SWELLING BEHAVIOUR

Fly ash has been found to reduce the swelling behaviour of highly plastic clay soils [15]. He documented that the application of fly ash to expansive soils decreases the swell potential in three ways: fly ash contains some calcium ions that reduce the surface charge of the clay particles, fly ash acts as a mechanical stabilizer by replacing some of the volume held by clay particles, and fly ash cements the soil particles together. A similar study was carried out by Phanikumar and Sharma [16] for the effect of fly ash contents of 0, 5, 10, 15 and 20% by weight on swelling parameters like free swell, swell potential and swell pressure of expansive soils. They found that the addition of 20% fly ash reduces the free swell index (i.e. percent of length increment to the initial length) by about 50% of the initial amount. Significant reduction on swell potential and swell pressure was also observed.

Cokca [7] carried out investigations using fly ash to stabilize expansive soils at 0 to 25%. Samples of soil-fly ash mixture were cured for 7 days and 28 days and then subjected to swelling tests. His findings confirmed that the swell potential of the samples decreased with increasing percent of fly ash and curing time and the optimum content of fly ash is 20%. Nalbantoglu [17] measured the swell potential of a soil ($\text{LL} = 68\%$, $\text{PI} = 46\%$) stabilized with fly ash. The sample mixtures were cured for 1 day, 7days and 30 days before subjected to compaction. It was observed that the swell potential decreased as curing time increased. After curing of 7 days, the swell values of 4.8% and 3.7% were measured for 15% and 20% fly ash addition, respectively. Thirty days of curing reduced the swell potential to nearly zero for both addition rates.

Mollamahmutoglu et al. [18] reported that the untreated clay's swell percent and swell pressure values are 17.9% and 650 KN/m^2 respectively but the swell percent and the swell pressure of 35% fly ash treated clay mixtures are reduced to 8.1% and 257 KN/m^2 respectively, which is acceptable for a fill of highway material. Al-Dahlaki [19] studied the effect of 0 to 25% fly ash on the swelling properties of expansive soils when subjected to various curing time (0, 10-days and 30-days). Al-Dahlaki findings showed an increase in swelling reduction with increasing fly ash percent and curing time as illustrated in Figure 1.

Table 1 Chemical Compositions of Fly Ash (source [10])

Chemical component	Gary Fly ash	Typical Fly ash	
		Class C	Class F
Silica (Si O_2)	46.47	40	55
Alumina (Al_2O_3)	ND	16	26
Ferric oxide (Fe_2O_3)	1.08	6	7
Calcium oxide (CaO)	18.52	24	9
Magnesium oxide (MgO)	0.18	2	2
Sulfate oxide (SO_3)	0.03	3	1
Loss of ignition (LOI)	18.97	6	6

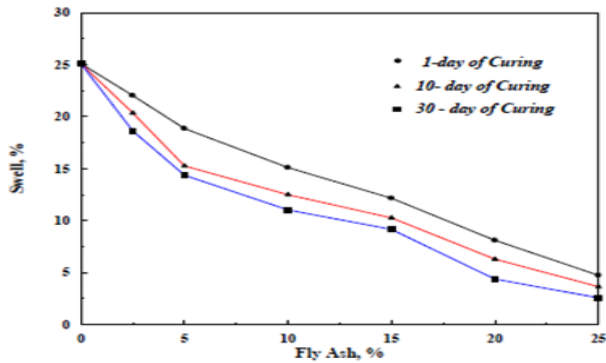


Fig. 1. Effect of fly ash on swell percent (source [19])

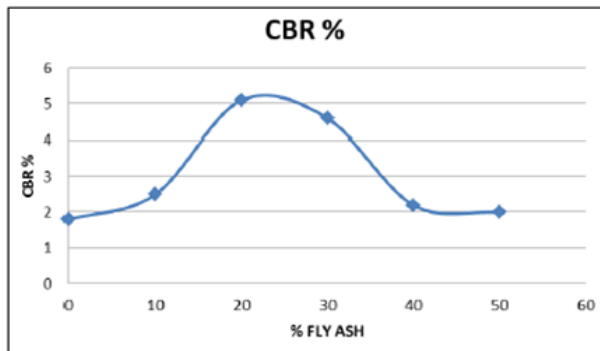


Fig. 2. Variation of CBR for black cotton soil mixed with fly ash (source [26])

2.4 STRENGTH CHARACTERISTICS

The most widely used application for fly ash is for improving the strength of expansive soil. The strength is usually determined from unconfined compression tests and CBR tests [20]–[22]. Generally, expansive soils have soaked CBR values from 1.5% to 5% that provides very little support to the pavement structure [23].

Zia and Fox [24] found that the CBR increased five times with 10% fly ash addition, but a fly ash addition rate of 15% showed lower CBR than the 10% mixtures. They found that the reduction in CBR at 15% was due to the formation of ettringite. Pandian et.al. [25] studied the effect of two types of fly ashes (Class F and Class C) on the strength characteristics, measured by CBR, of black cotton soil. The fly ash content was increased from 0 to 100%. He found that the addition of fly ash increases the CBR of the mix up to the first optimum level due to the frictional resistance from fly ash in addition to the cohesion from black cotton soil. Further addition of fly ash beyond the optimum level causes a decrease up to 60% and then up to the second optimum level there is an increase. Thus the variation of CBR of fly ash-black cotton soil mixes can be attributed to the relative contribution of frictional or cohesive resistance from fly ash or black cotton soil, respectively. In fly ash (Class C) also there is an increase of strength with the increase in the fly ash content, here there will be additional pozzolonic reaction forming cementitious compounds resulting in good binding between black cotton soil and fly ash particles.

Rajput and Yadav [26] investigated black cotton soil mixed with fly ash content from 0 to 50% and found that the maximum CBR value obtained at 20% fly ash (see Fig. 2).

Unconfined compressive strengths of soils stabilized with fly ash are typically on the order of 100 psi, but can be as high as 500 psi at curing of seven days, depending on fly ash content and properties [20]. Khoury and Zaman [27] reported on the effect of wet-dry cycles on resilient modulus (M_r), elastic modulus (E), and unconfined compressive strength (UCS) for Class C fly ash-stabilized soft limestone aggregate. M_r increased 55% for specimens cured for 3 days and then subjected to 30 wet-dry cycles. Several cured specimens exhibited an increase in M_r for up to 12 cycles, at that time M_r began to decrease. They also observed that E and UCS values increased as the number of wet-dry cycles increased.

3. MATERIALS AND METHODS

The experimental work was carried out to achieve the objective of the research. Laboratory tests were performed on natural expansive soils and stabilized soils with fly ash. Various percentages of fly ash (0, 10, 20, 25, and 30%) were added to the soils to investigate their effect on soil properties.

3.1 MATERIALS USED

Fly ash used for this research was obtained from thermal power generation station in Khartoum North. The fly ash sample used in testing is shown in Fig. 3. The chemical composition of the fly ash were measured in accordance to ASTM C618 [11]. The test results are given in Table 2. Fly ash in varying percentages was added to expansive soils. The fly ash content of 0, 10, 20, 25 and 30% by weight was used in this study.

a) Expansive Soils

Three expansive soils were collected from different regions in Khartoum state: Almenshia (Soil A) in Khartoum, Alhalfaya (Soil B) in Khartoum North and Wad Alagali (Soil C) in Omdurman. The soils were excavated from 1 to 2 m depth below the ground level. The soils obtained were air-dried and stored in airtight bags in the laboratory. The properties of the soils are determined and listed in Table 3.



Fig. 3 The sample of fly ash used in the study

Table 2 Chemical properties of fly ash used

Property	Result
Silica (SiO_3)	53.6
Alumina (Al_2O_3)	34.0
Ferric oxide (Fe_2O_3)	3.5
Calcium oxide (CaO)	3.6
Magnesium oxide (MgO)	1.0
Titanium oxide (TiO_2)	0.2
Loss of ignition	1.7

Table 3 The properties of soils tested

Property	Soil A	Soil B	Soil C
Liquid limit, %	77	54	76
Plastic limit, %	28	23	24
Plasticity index, %	49	31	52
Specific gravity	2.72	2.76	2.64
Clay content, %	63	34	53
Max. dry density, kN/m^3	1.480	1.529	1.490
Optimum moisture content, %	26.5	20.0	26.0
Free Swell Index, %	240	100	170
Swell Potential, %	32.7	8.5	18.5
Swell Pressure, kPa	250	123	210
Unconfined Compression Strength, kPa	370	961	294
Soil classification	CH	CH	CH

3.2 TESTS METHODS

The laboratory tests were carried out on the expansive soils mixed with different proportion of fly ash. They were performed in accordance with BS 1377. The tests include:

- Atterberg's limits (Liquid limit, Plastic limit)
- Proctor compaction to determine optimum moisture content and maximum dry density
- Swelling tests include free swell, swell potential and swell pressure tests
- Unconfined compression strength test

4. RESULTS AND DISCUSSION

The tests results are presented and discussed in the following sections.

4.1 ATTERBERG'S LIMITS

The variation in liquid limit and plastic limit of the three expansive soils treated with Fly ash is presented in Figs 4 and 5. From these figures, it can be seen that addition of Fly ash to the three expansive soils is causing around 20% reduction in the liquid limit values at 30% of fly ash. Also from the plastic limit results (Fig. 5), it is noticed that as the percent of fly ash increases from 0 to 30%, there is a little increase in the plastic limit values for the three soils tested. Furthermore, plasticity index decreases as fly ash content increases. At

30% fly ash, the reduction in plasticity index is around 55%. Overall from the results, it is understand that the plasticity characteristics of three expansive soils treated with Fly ash are decreasing marginally and hence, Fly ash can be used to control the swelling and shrinkage problems which are associated with these expansive soils.

4.2 FREE SWELL INDEX (FSI)

The variation of FSI with percentages of Fly ash of the three soils is presented in Figure 6. From this figure, it can be seen that as the percentage of Fly ash increases from 0 to 30%, there is significant reduction in FSI. Almost similar reduction can be noticed in the FSI for the three soils. The reduction in FSI is noticed higher up to about 25% of Fly ash and thereafter almost little decrement is noticed with addition of Fly ash. At 10% Fly ash, the reduction in FSI in all the three soils is about 50%. From the FSI variations, 90% reduction in FSI was observed at 25% Fly ash dosage.

4.3 SWELL POTENTIAL AND SWELL PRESSURE

In expansive soils the swell potential and swell pressure are the important parameters to understand the severity of problem posed by expansive soil. The swell potential and swell pressure variations of Fly ash stabilized the three expansive soils are presented in Figs 7 and 8. From Fig. 7, it

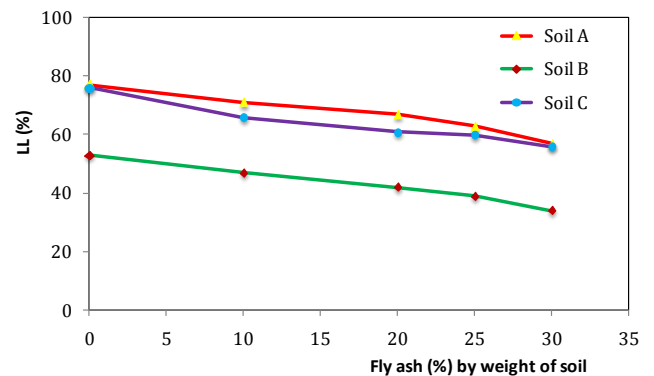


Fig.4. Influence of Fly ash on Liquid Limit

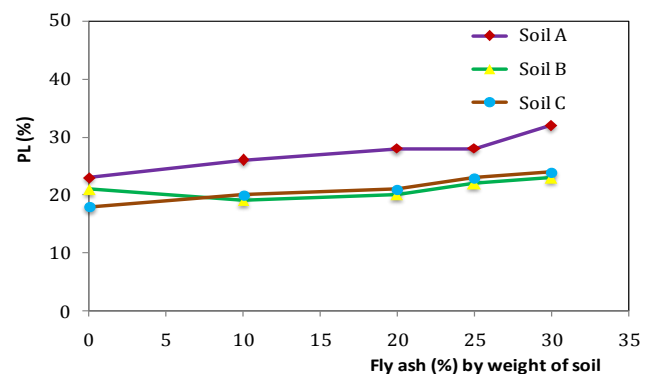


Fig. 5. Influence of Fly ash on Plastic Limit

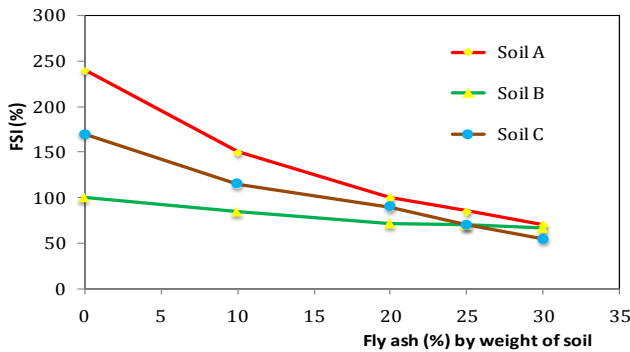


Fig.6. Variation of Fly ash with Free Swell Index (FSI)

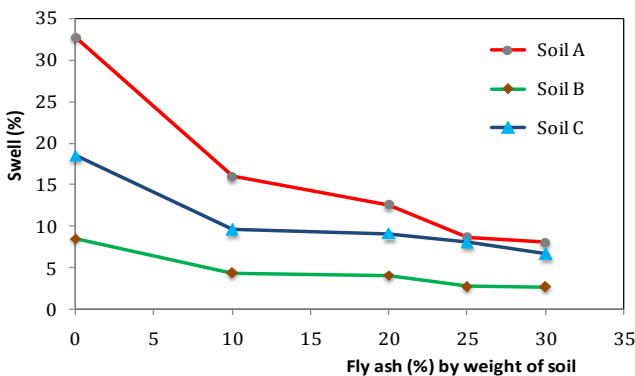


Fig.7. Influence of Fly ash on Swell Potential

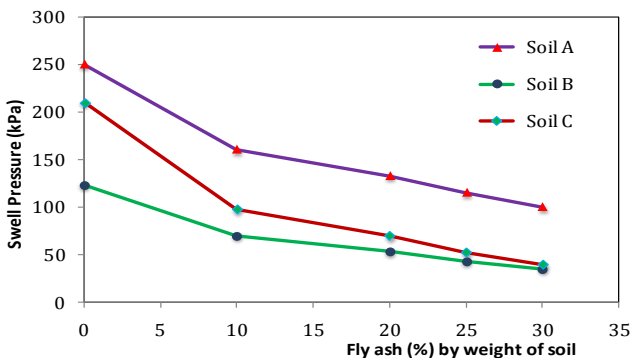


Fig.8. Variation of Fly ash with Swell Pressure

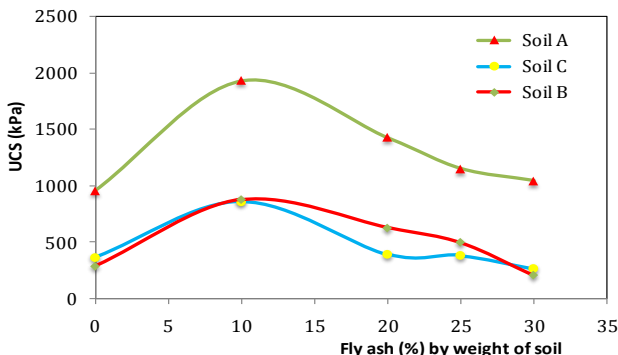


Fig.9. Effect of Unconfined Compression Strength

is noticed that at 10% Fly ash, there is drastic fall in swell potential of the three soils and thereafter, further addition of Fly ash is causing gradual change in variation of swell potential. The reduction in swell potential observed is about 70% at 10% Fly ash. The swell pressure of expansive soils stabilized with Fly ash is presented in Fig. 8. From this figure, it can be seen that as the Fly ash increases from 0 to 30%, the swell pressure is falling rapidly at 10%. Thereafter further increase of Fly ash is effecting gradual change in swell pressure. The reduction in swell pressure in all the three soils noticed is about 60% at 10% Fly ash. At 25% Fly ash, the reduction in swell potential and swell pressure observed in all the three soils is above 90%. Hence, it is noticed that 25% of Fly ash can be effectively adopted for reducing the swell potential.

4.4 Unconfined Compression Strength

The variation of unconfined compressive strength (UCS) of three soils A, B and C stabilized with Fly ash are presented in Fig. 9. From this figure, it is observed that almost all soils are showing similar variation in the UCS with the Fly ash. The higher UCS is noticed at 10% Fly ash. The soils stabilized by 10% of Fly ash and more, the UCS values are reduced below the values of untreated soil. Also, it is noticed that at 10% Fly ash, the UCS values of all three soils are about two fold higher as compared to untreated soils.

5. CONCLUSIONS

This study has concentrated on the effects of fly ash stabilizer on common engineering characteristics in particular the swelling and strength properties of a highly expansive soil. Based on the findings, the following conclusions can be drawn:

- The liquid limit decreases with an increase in fly ash content. Addition of Fly ash to the three expansive soils is causing around 20% reduction in the liquid limit values at 30% of fly ash. For plastic limit, as fly ash increases from 0 to 30%, there is a little increase in the plastic limit values for the three soils tested. Moreover, plasticity index reduces by 55% with the addition of 30% fly ash.
- Swelling characteristics are significantly decreased as fly ash increases and the amount of reduction depends on fly ash content. At 10% Fly ash, both the swell potential and the swell pressure of the three soils are largely decreased and thereafter, further addition of Fly ash is causing gradual decreased in them. For the addition of 10% fly ash, the reduction in free swell, swell potential and swell pressure is in the range 50 % to 70%. While at 25% Fly ash, the reduction in swelling parameters observed in the three soils is almost 90%. Therefore, an optimum value of fly ash may be taken as 25% with respect to swell properties.
- The strength of expansive soil can be effectively improved by addition of fly ash. The Unconfined Compression Strength (UCS) values increases with increase in fly ash. The UCS values of the three soils are increased with higher rate up to 10 % fly ash and then

decrease with slower rate. The UCS value at 10% Fly ash showed almost 2 times improvement as compared to untreated soils.

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