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Effect of Fly Ash on Geotechnical Properties of Soft Soil: A Critical Review †

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Abstract: An industrial by-product known as fly ash is produced when coal is burned for electricity production and is considered an environmental pollutant. A comprehensive fly ash utilisation programme must be implemented to reduce environmental pollution, including numerous factors at different levels. Fly ash's geotechnical qualities, including its specific gravity, permeability, internal angular friction, and consolidation characteristics, make it ideal for structural fill, particularly on clay soils, when building highways and embankments. Much research has been conducted on how fly ash affects soil stability. In order to determine the impact of fly ash addition on soil properties, this inquiry reviewed a few of these papers and conducted a critical assessment. This study also looked at combining fly ash and clay soil. Numerous investigations indicate that fly ash generally improves soil stability, notably when analysing CBR values and soil permeability, and reduces volumetric changes in the soil. The ground becomes compact due to particle size and form and a decrease in volumetric dilatation. Because the additives to the hardened soil do not dissolve, the soil's behaviour continues to be modified.

Keywords: fly ash; clay soil; strength parameters; waste material

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1. Introduction

Reduced construction sites are a significant issue globally, particularly in the highly populated nations of south and southeast Asia [1,2]. As a result, it became necessary to execute land reclamation to utilise this kind of land. Thus, it has been revealed that it is possible to transform such unproductive lands using ground development technologies. Numerous geotechnical construction techniques are used to improve the performance of weak/soft clay [3–5]. The rising demand for electrical power has resulted in millions of tonnes of rubbish being developed by coal-burning electric power thermal plants. Fly ash (FA) and ground-granulated blast furnace slag (GGBFS) are examples of this waste [6]. Ecology is now greatly concerned with the disposal and recycling of such waste goods, which also consumes vast funds. Some of these studies concentrated on increasing the soil's capacity using fly ash, a waste product of thermal power plants [7,8].

Fly ash is the primary by-product of thermal power plants, which use coal to produce energy. Numerous chemical substances and minerals, including unoxidized carbon, silicon, iron oxides, and aluminium, are found in fly ash [6]. It is possible to modify the volume of clay soils and increase their strength by stabilising them using admixtures [9]. Additionally, using FA can improve soil's engineering qualities [10]. By using FA in soil improvement, there was a reduction in settlement during construction, and hence the time required to achieve complete settlement [11]. FA can be used in soil to increase its bearing capacity, stability, and shear strength. Using FA to improve soil can make it less plastic and increase its free swelling index (FSI) values [12]. For the stabilisation of poor soil, a number of studies have been conducted that study the impact of fly ash in addition to other materials such as geopolymer, slag, bentonite, sand, and gypsum. The plasticity index, Atterberg limits, and free swell index fall when different amounts of cement and fly ash are mixed in soil, whereas there is an increase in unconfined compressive strength (UCS) and CBR [13]. Thus, as per the results, for subgrade and pavement applications, fly ash containing 5–20% geopolymer better increased the stability of black cotton soil when cured at 25 °C for a minimum of fourteen days [14].

A range of research investigations on FA productivity in clay soils are presented in this study. Though the problem of expanding soil and alternatives for recycling industrial waste must be dealt with separately, utilising such waste is a viable strategy to encourage long-term growth. Recent initiatives show that funds can be saved using effective waste management methods, including soil stability.

2. Fly Ash and Other Properties

To understand various properties and their effects, a brief analysis of a few of the methodologies adopted by various researchers is briefly explained. Salim [15] conducted a laboratory test where soil classification (as per ASTM D 854-000) and compaction tests (as per ASTM D 422-63) were carried out. Further, a swelling consolidation test (as per ASTM D 4829-03) was carried out to determine the swelling pressure and free swell of the soil. Various other researchers used unconfined compressive strength tests (UCSs) to determine the index characteristics, compaction impact, and compressive strength of clay soil, along with various combinations of using fly ash with it. The optimal moisture content (OMC) and maximum dry density (MDD) for various mixtures were determined. A 38.10 mm diameter and 76.20 mm height UCS cylindrical mould was used to create the samples. The samples underwent 7, 14, and 28 days of dehydration. Following that, their compressive strength was assessed in both soaked and unsoaked situations, and the findings were shared. The effects of fly ash on various properties are discussed below:

2.1. Fly Ash and Swelling of Soil

Salim conducted lab tests [15] to find out how the swell potential, FSI, and swelling pressure are affected by the FA content of soil of an expansive nature. Organic soils have a comparable impact as admixtures. It was seen that as the bentonite percentage rises, so does the swelling and swell pressure. There was a decline in the swelling pressure and the swelling itself, along with an increase in the percentage of fly ash. A drastic reduction in the said properties was noted at 5% fly ash content.

Zha et al. [16] added that FA and FA lime have a stabilising effect on expansive soil and noted an effective reduction in the ability of soil to expand and contract. Further, the soil properties of swelling pressure, swelling capabilities, and free swell were reduced with increased lime ash and FA content. Both the FA and lime ash soil samples' swelling capacity and inflation pressure decreased despite increased curing time, as illustrated in Figures 1 and 2.

In order to stabilise black cotton soil, Murmu and Patel [14] investigated the effectiveness of FA and geopolymer (RHA-based, which is a blend of sodium hydroxide (SH) and sodium silicate (SS)). It was noted that geopolymerisation leads to a great fall in the susceptibility to swelling and shrinkage of black cotton soil.

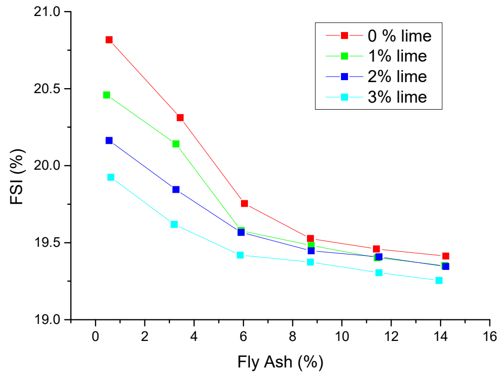

Figure 1. Impact of addition of FA–lime additive on FSI after 7-day curing time (modified from Zha et al. [16]).

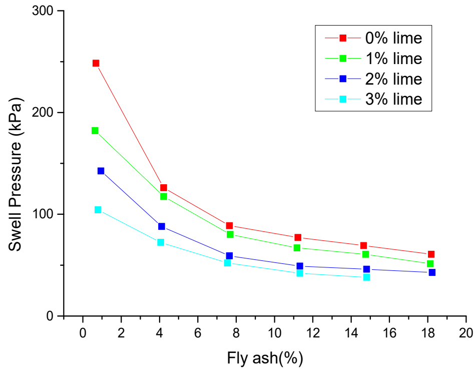

Figure 2. Effect of addition of FA–lime additive after 7-day curing time on swelling pressure (modified from Salim et al. [15]).

2.2. Fly Ash and Soil Settlement

Via oedometer studies in the lab, Saha and Pal [17] focused on the settlement behaviour of clay soil concerning FA content. The settlement of the Soil–FA–Soil module noted a reduction of 0.30 mm, and the FA–Soil–FA module noted a decrease of 0.26 mm, for reference. The actual initial settlement value of the FA specimens was 0.19 mm. The changes observed in the settlements can be attributed to modifying the molecular structures in the samples. The relation between applied pressure in the form of a logarithm axis (log p) and settlement is shown in Figure 3. The final consolidation settling of clay soil, according to Karim et al. [11], is achieved with a 20% concentration of fly ash, or 0.638 mm, at the optimal level. However, above this percentage, there was a minor rise.

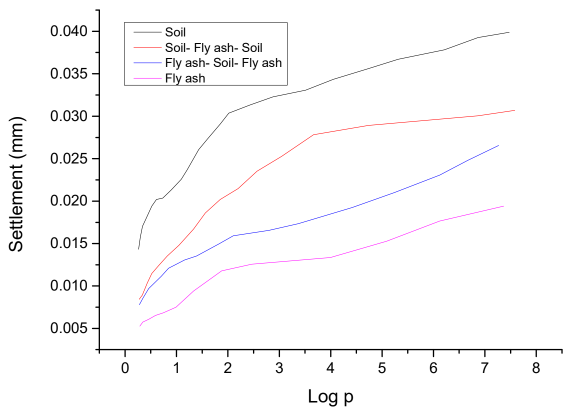

Figure 3. Settlement estimates for different specimens with and without FA (modified from Saha and Pal [17]).

During the research of Somnath [18], the researcher blended the soil specimens with various percentage levels of FA and observed the results with plain FA samples and plain soil samples. The maximum settlement noted for the plain soil samples was 0.45 mm, compared to 0.17 mm for the plain FA samples. Figure 4 displays the settlement values and log p. The settlement value was 0.27 mm for a 30% concentration of FA and 0.28 mm for a 20% concentration of FA.

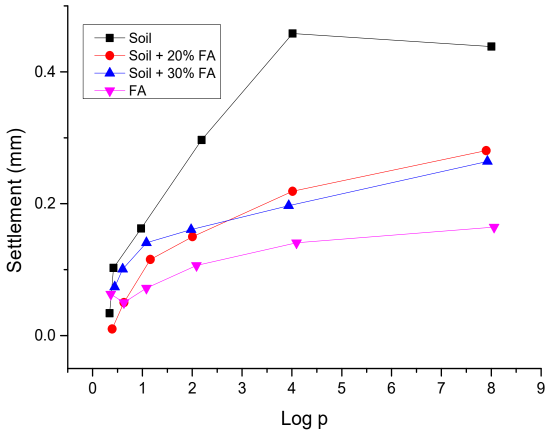

Figure 4. FA percentage's impact on settlement values (modified from Somnath [18]).

2.3. Fly Ash and Soil Shear Strength

Due to its very high water content, the excavated clay and black cotton soil could not be used directly again in geotechnical applications. Dewatering is, therefore, necessary before any further advancement. Because of their outstanding performance in flocculation, for dewatering, chemical flocculants are deployed [19,20]. The study conducted by Bose [21], where the researcher varied the FA content from 0 to 90%, is depicted in Figure 5. At a 20% FA concentration, the UCS increased; the data over this proportion indicate a UCS decrease. Under the given circumstances, a 20% concentration of FA is the amount that will best help the mixed soils acquire their shear strength. The results showed that adding FA to the ideal level can cause cemented materials to exhibit pozzolanic behaviour, significantly increasing their shear strength. Contrarily, when FA is present at more than the optimal level, it behaves as unbound silt particles that lack cohesion and perceptible friction, reducing the material's strength.

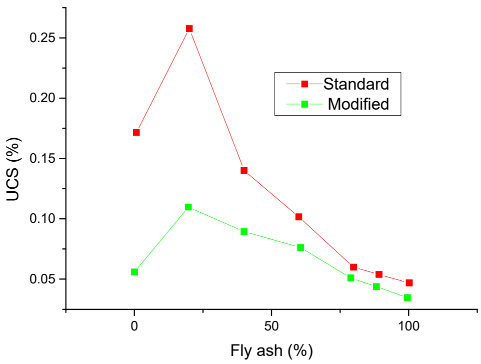

Figure 5. Unconfined compressive strength varies depending on the amount of FA (modified from Bose [21]).

From Figure 6, the increase in the UCS value was explained by Nath et al. [22]. The author defined that during the interaction of the CaO present in fly ash with the soil's Al_2O_3 and SiO_2, cementation gels (hydrate) were formed, which are responsible for an increase in the UCS value of the sample. Further, there was a rise in the compressive strength of the FA-stabilised soil with increasing curing time.

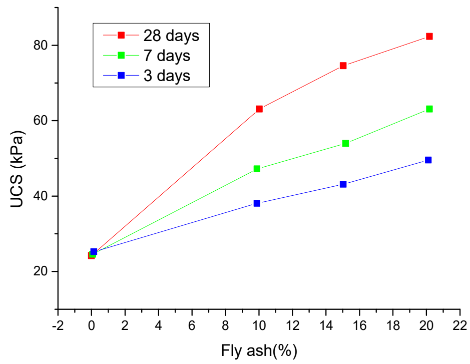

Figure 6. UCS variation with ash content (modified from Nath et al. [22]).

2.4. Fly Ash and California Bearing Ratio Test

The stabilisation of black cotton soil using fly ash was experimented with by Kumar and Harika [23]. The California Bearing Ratio test values for untreated soil were noted at 2.189%, but when the soil was treated with fly ash, the California Bearing Ratio test value reached 10.3%. Thus, the study recommended blending black cotton soil with 10% fly ash for pavement and foundation work.

Edil et al. [24] conducted an experimental investigation on soil–FA mixtures at varying FA levels (10–30%) to understand the effect of adding FA on the CBR value of the soil. The CBR value of the soil and fly ash combination rose with a rise in the FA content. With 10% FA added to the fine-grained soil, there was a 4% rise in the value of the CBR. The CBR value was noted to decrease with a rise in water content.

3. Future Scope

It is clear from the literature analysis above that different fly ash material sources will provide diverse fly ash properties and will affect the synthesis of fly ash and soil in different ways. Thus, additional research on various fly ash sources is required to determine the impact of the same FA contents on the soil's engineering qualities. Additionally, a great deal of research on the behaviour of fly-ash-mixed soil has been published. Examining bottom ash as a soil supplement in place of fly ash is necessary, though. Therefore, before applying this technology to geotechnical engineering, a thorough investigation is required to clarify and validate the knowledge that is currently accessible on this subject.

It is also possible to research how plastic debris, such as plastic bottle cuts and rubber tyre powder, affects soil stability. They are materials that pollute and do not biodegrade quickly.

4. Conclusions

The following statements show how fly ash and other additives are effective and act as a sustainable option in construction applications while summarising their exceptional engineering properties:

- FA use during clay soil treatment: Waste materials raise the standards for soil consolidation. The compressibility of soil is found to be increased multiple times by the addition of FA, as FA has excellent pozzolanic behaviour.
- The swelling potential and free swelling index decrease with increased fly ash and fine sand content added to clay soil of an expansive nature.
- When blending soil clay with fly ash, secondary consolidation occurs sooner than when the soil clay is not treated. This means that consolidation settling under buildings is reduced and attained in less time in engineering applications.
- The soil treated with fly ash was found to have a CBR value of 10.3% compared to the CBR value of the untreated sample, which was found to be 2.189%. The study suggests combining black cotton soil with fly ash in amounts up to 10% for foundation and pavement work.

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