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Effect of Geopolymer Contents on Strength Development of Soft Soils

M. H. Nabi[1], S. Acharjee[2], M. M. Banu[3], M. A. Rahman[4]

[1]Department of Civil Engineering, CUET, Bangladesh (u1601017@student.cuet.ac.bd)
[2]Department of Civil Engineering, CUET, Bangladesh (u1601120@student.cuet.ac.bd)
[3]Department of Civil Engineering, CUET, Bangladesh (muktabanu@cuet.ac.bd)
[4]Department of Civil Engineering, CUET, Bangladesh (maftabur@cuet.ac.bd)

Abstract

The low bearing capacity and highly compressible nature are the primary concern for soft soils. Structures constructed over such soils require a deep foundation which increases project cost. The conventional usage of binder material to treat poor soil poses an environmental threat. Therefore, exploring alternate materials is a promising tool in ground improvement research. Fly Ash (FA), a waste by-product of the coal-based power industry, has been found abundant due to rapid industrial growth. FA with alkali activator when added with soil, typically enhance the strength of soft soils. A series of experimental works have been conducted in this research to explore the wide range of binders and activators on the strength development of treated soils. Three binder-to-activator ratios (i.e. 0.2, 0.5 and 0.8) have been considered for this research in addition to five binder contents ranging from 0-25% of dry weight of soil. It has been found that the strength gain has occurred with increasing binder content while the effects of activator content have not been found sensitive in the current research. The maximum 28-days strength has been found when the binder content is maximum of 25% and the alkali activator to binder ratio is the minimum of 0.2.

Keywords: *Geopolymer; Fly Ash; Binder; Activator; UCS.*

1 Introduction

Due to the potential for structural failure on clayey soils, experts have been searching for effective and affordable corrective actions (Han, 2015). Numerous strategies have been created to this point, and the effectiveness of those strategies has been confirmed by experimental and in-situ applications. It is a rational approach to treat clayey soils using stabilizing agent(s) to mitigate the linked issue. Ordinary Portland Cement (OPC), Lime, Ground Granulated Blast Furnace Slag (GGBFS), Fly Ash (FA), and others are popular stabilizing agents (Han, 2015; Taj et al., 2022). Additives together with the stabilizing agent speeds up the binding process and, in many cases, increases in strength (Debanath et al., 2021). Till date, the most widely utilized and effective stabilizing substance for use in improving soils has been regular Portland cement. However, the usage of OPC is linked to some environmental problems as CO_2 is released during cement manufacturing process. Utilizing an environmentally friendly chemical as an alternative to the traditional strategy is preferable. The industrial by-product known as Fly Ash (FA) may be an excellent choice because it poses no environmental risk and can be disposed of safely. To make fly ash functional in the bonding process when using geopolymers, chemical additives must be applied. In contrast to traditional Portland cement/lime type admixtures, the geo-polymerization process involves fundamentally distinct chemical reactions. The number of coal-fired power plants in Bangladesh is growing daily, which increases the generation of fly ash. Industrial by-products can be used to improve the soil properties while simultaneously offering a chance for safe disposal, according to studies in the field of ground improvement. Many times, the usage of those industrial by-products may be constrained by their slow reaction rates. A special type of binder called geopolymer uses by-products as a binder and can be an excellent way to directly use fly ash while also enhancing soil strength metrics. As a result, the focus of the current research is to incorporate geopolymer into ground improvement techniques. Ground improvement techniques used in foundations are quite widespread already.

Different types of physical and and chemical methods are used for improving the strength of the subsoil. Chemical methods include lime stabilization, cement stabilization and geopolymer stabilization. Cement stabilization is very much expensive due to high cost of cement and higher production cost. Besides, shrinkage cracks and water loss make it unpreferable. Apart from that, high carbon footprint of manufacture of cement causes huge environmental degradation. Although relatively cheaper, lime stabilization also has its own share of problems (Jawad et al., 2014), some of which include carbonation and sulphate attack. Carbonation refers to the reaction of CO2 with sulphate. A lot of researches have been done to find out alternative ways of different types of problematic soils, ranging from sandy large particle soils to finer clayey ones, from cohesionless sand to cohesive organic clays. The effect of the soil type, i.e. the amount of clay in soil shows that higher clay content provided higher strength, which illustrates a responsiveness of clay soil to alkali activated fly ash treatment (Okamura et al., 2004). Using soil recycled aggregates mixture with geopolymer binders had similar or better performance than soil-cement mixture in durability, stiffness, resistance to permanent deformation, and strength at the cost of longer curing time at ambient temperature. The additives lowered the swelling pressure with increasing proportion. Although the co-efficient of permeability increased. From another study, it is seen that the geo-polymerization with blended ash geopolymer significantly improves the strength of expansive soils and at the same time makes it less prone to swelling and shrinkage (Rahman et al., 2018). Thus, stabilized with blended ash geopolymer can be used as a sustainable alternative to conventional stabilizers. A technique is investigated for creating GPC with required characteristics and assessed their long-term real-world service condition performance when exposed to considerable water infiltration during flooding or heavy rain. The results showed a significant increase in compressive strength where low plastic clay showed faster compressive strength development whereas high plastic clay showed higher final strength up to 400% upon the use of Fly Ash and Clay-based GPC treatment. When alkali activator used with no fly ash, low seven days strength of 159 kPa was observed, which increased by 226% when the POFA content increased by 15%, attributed to Si-O-Si and Al-O-Si bond formation. For alkali activation, NaOH is more feasible for cheaper cost, compared to KOH. The study showed a respectable reduction in settlement of up to 192%.

2 Methodology

2.1 Materials

The raw soil was collected from Betagi road, Rangunia, Chattogram (Figure 1.a). The soil was then dried in oven at 110^0C for 24 hours, pulverized, passed through No. 40 sieve and stored in sealed bag for further work. The tests were performed in Optimum Moisture Content. The Optimum moisture content is determined by Standard Proctor test (Figure 2). Grain size distribution curve is shown in the Figure 3 and the soil properties are summarized in the Table 1.

(a) (b)

Figure 1. (a) Raw Soil (b) Class F Fly Ash

Class F Fly Ash, which is a biproduct of coal based power plant, is used as precursor binder (P) in the present study (Figure 1.(b)). Five proportions of fly ash precursor: 5%, 10%, 15%, 20%, 25% of oven dry soil weight was used for each predetermined activator (L) to precursor (P) ratio (L/P). Water to Binder ratio is taken 0.45 to make the binder workable with the soil mix.

Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) were used as alkali activator (L) (Figure 5). The geopolymer used in the study was created by mixing these two chemicals in a Na_2SiO_3 : NaOH = 2:1 ratio to form alkali solution. Three ratios of activator to precursor (L/P) of 0.2, 0.5 and 0.8 are used in this study. For each ratio, five percentages of fly ash were used. Material proportions are summarized in Table 2.

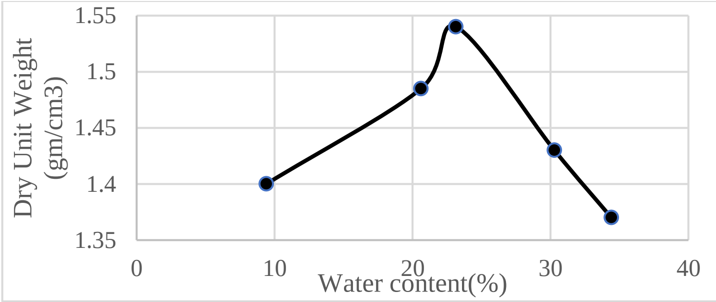


Figure 2. Optimum Moisture Content (by Standard Proctor Test)

Table 1. Index Properties of Collected Soil

Index Property		**Value**
Grain Size Distribution (ASTM D422 – 63)	Fine Content (%)	32.32
Atterberg Limit (ASTM D4318 − 10)	Liquid Limit (%)	40.26
	Plastic Limit (%)	30.62
Specific Gravity (ASTM D854 − 14)		2.66
Standard Proctor Test (ASTM D698 − 12)	OMC (Optimum Moisture Content) %	23.15

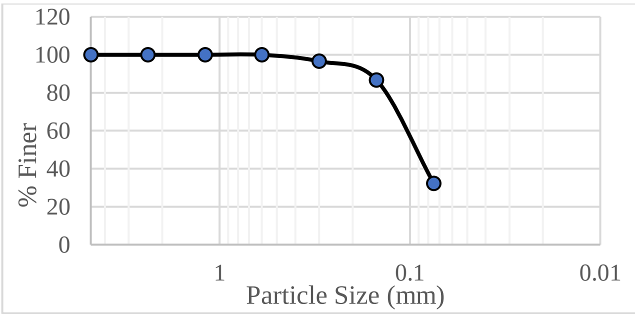


Figure 3. Particle Size Distribution of Parent Soil

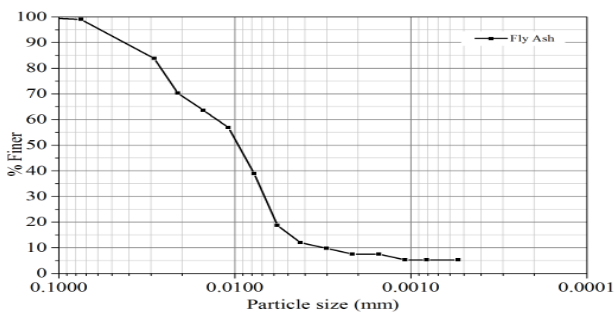


Figure 4. Grain Size Analysis of fly ash (Debanath, 2019)

2.2 Sample Preparation and Testing

At first, the soil is brought to the optimum moisture content. Sodium hydroxide is dissolved in water which is taken from water to binder ratio. Liquid sodium silicate and dissolved sodium hydroxide are mixed with binder (fly ash). After that, the soil and the geopolymer mix is put together in a mechanical mixer and mixed for 10 minutes. The prepared slurry is poured into preciously made uPVC mold having a height to diameter ratio of 2. Slight tamping is made to remove air pockets in the mold and this sampling is done in three layers. Identical 3 samples are made for each proportion of mix for each curing period. The molds then sealed and kept for curing in humid condition. At the definite curing age, the sample is removed from the mold and tested for Unconfined Compressive Strength (UCS). Figure 6 shows the prepared sample and testing method.


(a) (b)

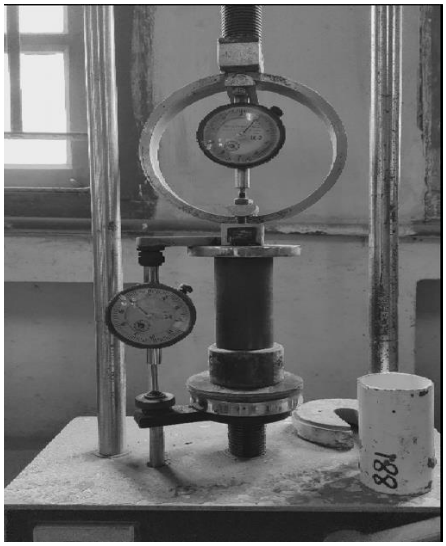
Figure 5. (a) Sodium Hydroxide Pellets and (b) Sodium Silicate Solution

Table 2. Proportion of Fly Ash and Alkali Activator

Fly Ash, P (% of dried soil)	**Alkali Activator, L** (% of dried soil) (Na_2SiO_3 : NaOH = 2:1)								
	L/P=0.2			**L/P=0.5**			**L/P=0.8**		
	Total	Na_2SiO_3	NaOH	Total	Na_2SiO_3	NaOH	Total	Na_2SiO_3	NaOH
5	1	0.67	0.33	2.5	1.67	0.83	4	2.67	1.33
10	2	1.53	0.67	5	3.33	1.67	8	5.33	2.67
15	3	2.0	1.0	7.5	5.0	2.5	12	8.0	4.0
20	4	2.67	1.33	10	6.66	3.33	16	10.67	5.33
25	5	3.33	1.67	12.5	8.33	4.17	20	13.33	6.67

(a)

(c)

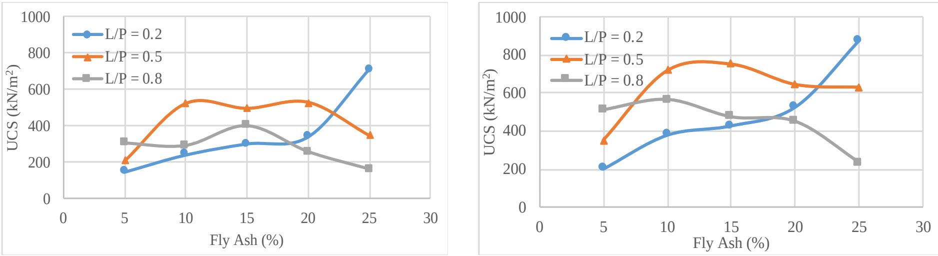


(b)

Figure 6. (a) Cured Sample (b) Sample on testing machine (c) Broken Sample after test

3 Results and Discussion

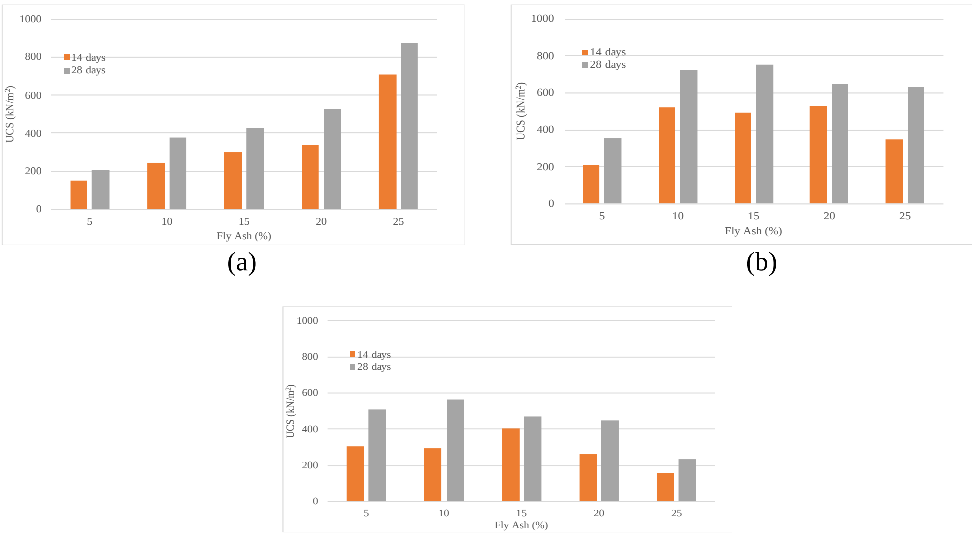
The test is conducted for 14 days and 28 days unconfined compression strength (UCS) of the parent sample and the samples with geopolymer admixture according to ASTM D2166/D2166M – 13. Average strength of 3 samples are calculated for the analysis. Figure 7 explains the results of geo-polymerization. For L/P ratio of 0.2, the maximum UCS value ranges from 156 kN/m^2 at 5% fly ash to 725 kN/ m^2 at 25% fly ash content. For L/P ratio of 0.5, the maximum UCS value ranges from 214 kN/m^2 for 5% fly ash to 554 kN/m^2 for 10% fly ash. For L/P ratio of 0.8, the maximum UCS values range from 163 kN/m^2 for 25% fly ash to 417 kN/m^2 for 15% fly ash content when the curing period is 14-days. At 28-days curing period, the UCS varies from 210 kN/m^2 to 890 kN/m^2 .



(a) (b)

Figure 7. Unconfined Compressive Strength at (a) 14-days and (b) 28-days

Initially the average Unconfined Compressive Strength (UCS) increases with increasing fly ash percentage and L/P ratio when fly ash content is limited to 5%. Hence, The strength is greater at L/P ratio of 0.5 than 0.8 when fly ash content is 5% to 15%. When the Fly Ash content is greater than 20%, L/P=0.8 shows the lowest strength. Maximum average UCS is found at FA=25% and L/P=0.2 for both 14 days and 28 days curing age. From the above discussion, it can be concluded that, UCS increases with increasing FA content when L/P is limited to 0.2. This is due to the fact that, the addition of fly ash and alkali activators causes the soil particles to engage in a geo-polymerization process, increasing the soil's compressive strength. The fly ash and alkali activator interaction decreases the soil's porosity, increasing the soil's strength. At L/P > 0.2 shows an initial increase in strength and decrease later on with increasing fly ash content. This might be caused due to the surplus of alkali activated precursor than the active ions present in the soil to react with. There could have more voids in the sample while mixing and sampling as the mix becomes harder with increasing fly ash content.

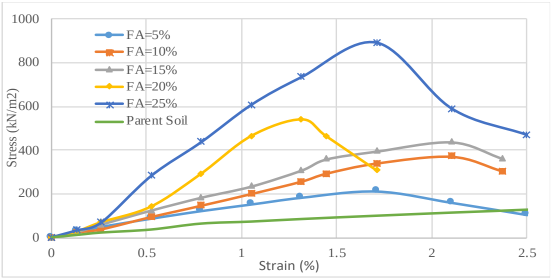


(a) (b)

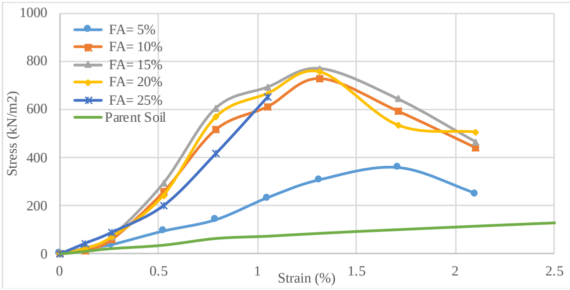
(c)

Figure 8. Unconfined Compressive Strength at (a) L/P=0.2 (b) L/P=0.5 and (c) L/P=0.8

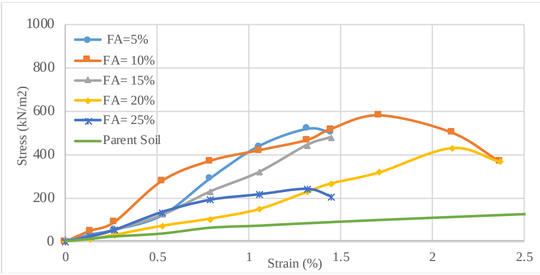
Curing time plays a very important role in strength gain which is shown in the Figure 8. Strength increases when curing age increases from 14-days to 28-days in every combination. Figure 9 shows the stress-strain behavior of Geopolymerized and parent soil at 28-days curing period. Also the increase in strength compared to the parent soil is visible from stress-strain curve. The maximum 28-days strength is found 890 kN/m^2 of at FA=25% and L/P=0.2 which is more than 560% of parent soil strength having UCS of 156.7 kN/m^2. Similarly, 486% increase in strength for 15% fly ash and 363% for 10% fly ash are found at L/P= 0.5 and 0.8 respectively. If the failure strain is analyzed, it can be concluded that the stronger sample fails at a lower strain which indicates brittleness whereas low strength can go a longer strain.



(a)



(b)



(c)

Figure 9. Stress-Strain Curve for (a) L/P=0.2 (b) L/P=0.5 and (c) L/P=0.8

4 Conclusions and Recommendations

The findings suggest that using an alkali-based geopolymer treated with fly ash can be useful way to increase the resilience of soft soil. L/P =0.2 and FA=25% found the most effective and economic proportion for strengthening soft clay soil. Further studies can be carried out on large scale with various soil type, different precursor binder, alkali activator with different proportion, larger curing period, soil moisture content, water-binder ratio etc. to have a wide range of knowledge on ground improvement with deep mixing method. Microstructural analysis can also be carried out with X-Ray Diffraction (XRD) Pattern and Scanning Electron Microscopic (SEM) image to understand the bond formation.

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