Journal of Civil Engineering and Environmental Technology
p-ISSN: 2349-8404; e-ISSN: 2349-879X; Volume 11, Issue 1; January-March, 2024, pp. 8-13

http://www.krishisanskriti.org/Publication.html

Improvement of Geotechnical Properties of Clayey Soil Using Siliceous Fly Ash: A Sustainable Approach for Soil Stabilization

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Abstract—*In India, about 270 million tonnes of fly ash is produced each year, which poses major health and environmental issues. Due to compressibility, swell and shrink behaviour with moisture change, clayey soils are not fit for engineering projects. The most popular technique for making clayey soil fit for construction is inclusion of fly ash as a stabilizing agent, which is typically used in combination with soils. In this study, siliceous fly ash was mixed with clayey soil in varying percentages by weight (5, 10, 15, 20, 25, 30 and 35%). Laboratory tests were carried out to determine physical and chemical properties, compaction characteristics and shear strength, penetration resistance, Scanning Electron Microscopy (SEM) and X-ray diffractometer (XRD).*

The results of this investigation reveal that the consistency limits, compaction characteristics, shear strength, penetration resistance of clayey soil-fly ash combinations have been greatly modified. Test results indicate that adding fly ash to clayey soil reduces the plasticity characteristics and maximum dry unit weight. Additionally, when fly ash was added to clayey soil, an increment in the optimum moisture content was also seen. It is also observed that 20% and 25% fly ash are the optimum amounts to improve clayey soil's penetration resistance and shear strength, respectively. CBR value increased by 101% when 20% Fly Ash was added to clayey soil.

Keywords: *Soil Stabilization, Fly Ash, Clayey Soil, Shear Strength, California Bearing.*

INTRODUCTION

With an ever-increasing population, building structures on poor soil is inevitable because there isn't enough land to build on. In such cases, a proper ground improvement process is necessary, and it should also be sustainable. Soil, such as clay, must be treated to prevent its problematic behaviour. Common admixtures that can be used to improve clay properties include lime, cement, etc. Sherwood (1993), Bell (1996), Mitchell (1981), Lee (1991), Yong (1991), Uddin (1997), fibres (Mahan and Ho, 1994), etc. Other commonly used admixtures include fly ash and pond ash, and tyre waste. The use of fly Ash as admixtures for clay properties is becoming increasingly popular. These waste materials are hazardous to the environment; therefore, using these materials in various civil engineering construction projects is also more effective for waste management. In this study, waste materials like fly Ash were used to improve the behaviour of clayey soil.

Fly Ash is a type of industrial waste generated during the combustion of coal in a thermal power plant. The production of fly Ash takes place on a large scale: over 100 million tons of fly Ash are produced annually. However, fly ash utilization is very low (Pandian, 2001; Krishna, 2003). Disposing of such large quantities of fly ash presents a major challenge for engineers as it has adverse environmental effects. Fly Ash can also be used in large quantities geotechnically. Fly ash can be used as a subgrade material in roads and railways (Raymond 1958, DiGioia & Nuzzo 1972, Winterkorn 1975, Tooth et al. 1988, Glogowski & Glogowski 1972), in the construction of embankments of roads & railways (Gray & Lin 1972, Huang 1990, Huang & Lovell 1990, Rai et al., 2006), in landfill liner (Bowders et al., 1987), and in the stabilization of waste (Martin et al., 1987). Fly ash can also be effectively used in reinforced retaining structures (Hazra & Patra 2008, Lal & Mandal 2012, Gonawala & Joshi 2013). Studies have shown that when mixed with clay, fly ash improves its engineering properties and suppresses the swelling behaviour of soil (Hunter 1988, Hoyos et al., 2004, Phanikumar & Sharma 2004). Studies have also shown that the strength of clay increases due to the addition of fly ash using California bearing ratio test.

The use of siliceous fly ash, a byproduct of coal combustion in thermal power plants, is one such promising option. Amorphous silica and pozzolanic features of siliceous fly ash have been shown to be effective in changing the mechanical and hydraulic properties of clayey soils. This environmentally sound solution not only tackles issues with soil stabilization but also helps to responsibly utilize industrial waste, which is in line with the sustainability principles of the environment.

This study explores the crucial field of geotechnical engineering, concentrating on the use of siliceous fly ash to improve clayey soil qualities. It seeks to shed light on the transformative potential of siliceous fly ash as a soil stabilizer and its broader implications for sustainable building practices by using this sustainable method. The study examines a number of topics, such as the basic characteristics of clayey soils, the chemistry and engineering qualities of siliceous fly ash, and the methods through which their interaction can result in better geotechnical properties. Additionally, this study evaluates the environmental advantages of this strategy, such as lowering carbon footprint and trash disposal concerns.

As the global demand for infrastructure development increases amid growing environmental concerns, developing innovative, sustainable solutions for soil stabilization becomes essential. With the ultimate goal of promoting eco-friendly building techniques and encouraging a more resilient and sustainable built environment, this research paper aims to contribute to this ongoing discussion by demonstrating the exciting possibilities of siliceous fly ash as a sustainable soil stabilization agent for clayey soils.

2. Test Materials

2.1. Soil

In this investigation, clay was used as the soil. The clayey soil was collected for study from the Aligarh. The soil sample was taken from a depth of 2.0 meters below the natural ground's surface. The soil was air dried before the strength and compaction tests were carried out, and then the fundamental tests were performed. Dry sieve analysis and hydrometer analysis were used to determine the particle size distribution. Figure 1 depicts the clay's distribution of grain sizes. It was discovered that clay had a specific gravity of 2.70. Plasticity index, liquid limit, and plastic limit values were found to be 16, 36, and 20%, respectively. According to the Indian Standard Soil Classification System (ISSCS), the soil is categorized as CI (clay with intermediate plasticity).

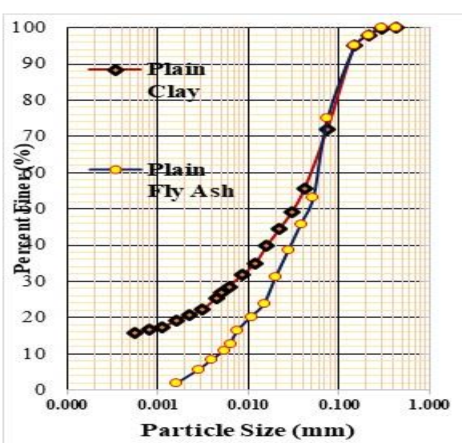

Figure. 1: Particle size distribution curve for clay and fly ash

Table 1: Geotechnical properties of plain clayey soil

S. No.	Engineering Properties	Values
1	Specific gravity	2.70
2	Optimum moisture content	18.3 %
3	Maximum dry density	16.8 kN/m^3
4	Liquid limit	35.62 %
5	Plastic limit	20.03 %
6	Plasticity index	15.59 %
7	Cohesion	32.0 kPa
8	Angle of internal friction	5.56°
9	IS Classification of soil	CI
10	CBR Value	4.02 %

Table 2: Chemical Composition of Clayey soil

S. No.	Elements	Weight (%)	Atomic weight (%)
1	O	59.63	73.20
2	Na	0.10	0.08
3	Mg	2.92	2.36
4	Al	9.97	7.26
5	Si	20.43	14.29
6	K	2.14	1.08
7	Ca	0.38	0.19
8	Mn	0.21	0.08
9	Fe	4.21	1.48
Total		**100**	

2.2 FLY ASH

Fly ash was collected from the Harduaganj thermal power plant in the Indian state of Uttar Pradesh. Fly ash's grain size distribution is seen in Fig. 1. Most of the fly ash particles, as can be seen, are silt sized. It can be categorized as ML under the IS system of classification. In Table 3, the fundamental physical and index characteristics of fly ash are shown. Fly ash is categorized as grade-II fly ash according to Indian standards. Grade-II fly ash also known as siliceous fly ash which comes from the burning of bituminous coal or anthracite coal. In Table 4, chemical properties of fly ash are shown.

Table 3: Physical properties of fly ash

S. No.	Properties	Values
1	Specific gravity	2.2
2	Optimum moisture content	31 %
3	Maximum dry density	11.52 kN/m3
4	Liquid limit	31 %
5	Plastic limit	-
6	Plasticity index	Non-Plastic

7	Cohesion	0.75 kPa
8	Angle of internal friction	21.38°
9	CBR Value	13.78 %
10	IS Classification	Grade-II
11	Color	Light Gray

Table 4: Chemical Composition of Fly Ash

S. No.	Elements	Weight (%)	Atomic weight (%)
1	**O**	**60.20**	**72.70**
2	**Na**	**0.03**	**0.03**
3	**Mg**	**0.06**	**0.05**
4	**Al**	**14.46**	**10.35**
5	**Si**	**23.19**	**15.95**
6	**K**	**1.03**	**0.51**
7	**Ca**	**0.05**	**0.02**
8	**Ti**	**0.83**	**0.33**
9	**Fe**	**0.15**	**0.05**
Total		**100**	

3. METHODOLOGY

In this study, the compaction and strength characteristics of clay and fly ash are investigated and compared. On the clay-fly ash mixture, a number of typical compaction tests, triaxial tests, and CBR testing were carried out. Two different series tests 1, and 2 were performed in order to carry out the laboratory work for this investigation. Compaction, triaxial, and CBR tests were performed on the Plain Clay, Plain Fly Ash in Tests in series 1. In Test series 2, 5%, 10%, 15%, 20%, 25%, 30% and 35% fly ash were mixed with the plain clayey soil sample in order to investigate whether or not the utilization of fly ash improved the engineering properties of clayey soil itself Proctor tests and CBR tests were used to assess the compaction behaviour and strength behaviour, respectively. On various proportions of soil mixtures, standard proctor tests were carried out. In proctor tests, soil-admixture mixtures were prepared by replacing out soil for admixtures. All CBR tests were performed on a soil-admixture mixture that had been prepared at the maximum dry unit weight and optimum moisture content (OMC), which was determined by a standard compaction test. The unsoaked condition was used for all CBR tests. According to the applicable Indian requirements, each test was carried out. The hand mixing process was used to create soil mixtures. First, the necessary amount of soil and admixtures was weighed out and evenly mixed by hand. The required amount of water was added and well mixed after the soil and admixtures had been combined. The amount of each mix component is calculated as a percentage of the total weight of the mixture.

4. RESULTS AND DISCUSSION

4.1. Impact of addition of fly ash on Atterberg's limits

The Plasticity Index results for clay that has been stabilized with fly ash and natural clay are shown in Table 5. The observed liquid and plastic limits for natural soil are 36% and 20%, respectively. As a result, the soil can be characterized as clay with a medium plasticity index of 16%. Table 5 shows how the addition of fly ash consistently reduces the soil's plasticity index. Table 5 demonstrates a significantly decreased plasticity index as the fly ash content increases up to 20%.

Table 5: LL, PL and PI of clay, Fly Ash different proportion

S. No.	Material	L. L. (%)	P. L. (%)	P. I. (%)
1	Plain clay	36	20	16
2	Plain Fly Ash	31	-	-
3	Clay + 5% Fly Ash	34.93	20.41	14.52
4	Clay +10% Fly Ash	33.64	20.65	12.99
5	Clay + 15%Fly Ash	32.17	20.77	11.40
6	Clay + 20% Fly Ash	31.25	21.10	10.15
7	Clay + 25% Fly Ash	29.74	21.46	8.26
8	Clay +30% Fly Ash	29.05	21.91	7.14
9	Clay + 35% Fly Ash	28.93	22.06	6.87

4.2 Effect of fly ash on compaction characteristic of clayey soil.

Figure 2 shows the compaction behaviour of the kaolin clay and fly ash as determined by the standard proctor test (SPT). It is clear that the maximum dry unit weight of clay is higher than that of fly ash. This occurs as a result of clay's higher specific gravity. The compaction curves show that the influence of moisture content change on the dry unit weight of soil is less for fly ash than for clay. It demonstrates that fly ash is less susceptible to moisture content. This is explained by the fact that fly ash has more air voids than clay. When the amount of fly ash is increased to 20%, the clayey soil's MDD falls to 15.80 kN/m3 from 16.80 kN/m3, while its OMC increases quickly from 18.30% to 19.00% (30.74%). Since the MDD and OMC of clayey soil change slowly with further addition of fly ash, therefore 20% considered as a optimum value of fly ash. Compaction curves of clay mixed with fly ash are depicted in Figure 2.

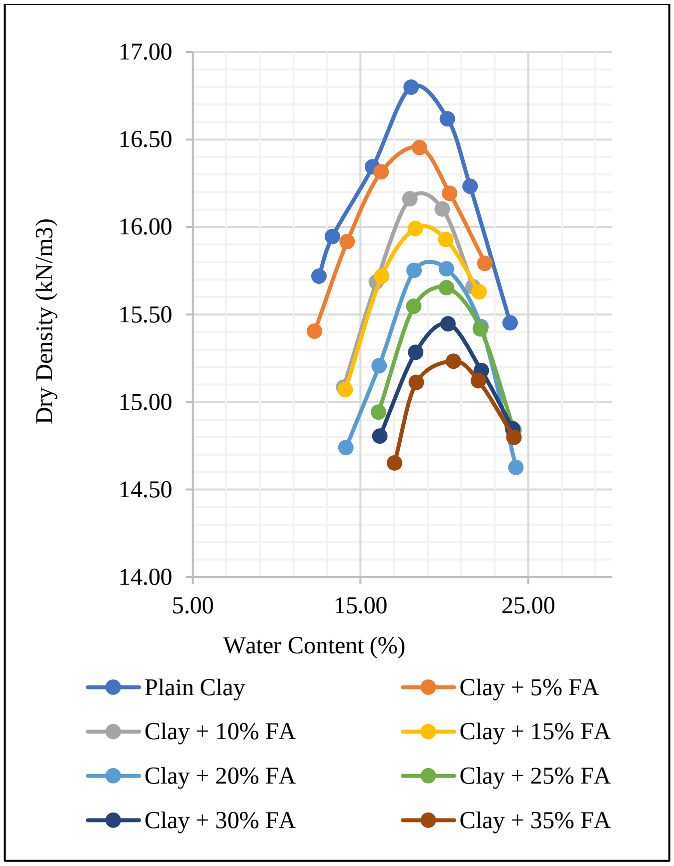

Figure 2: Compaction curve for clayey soil mixed with fly ash

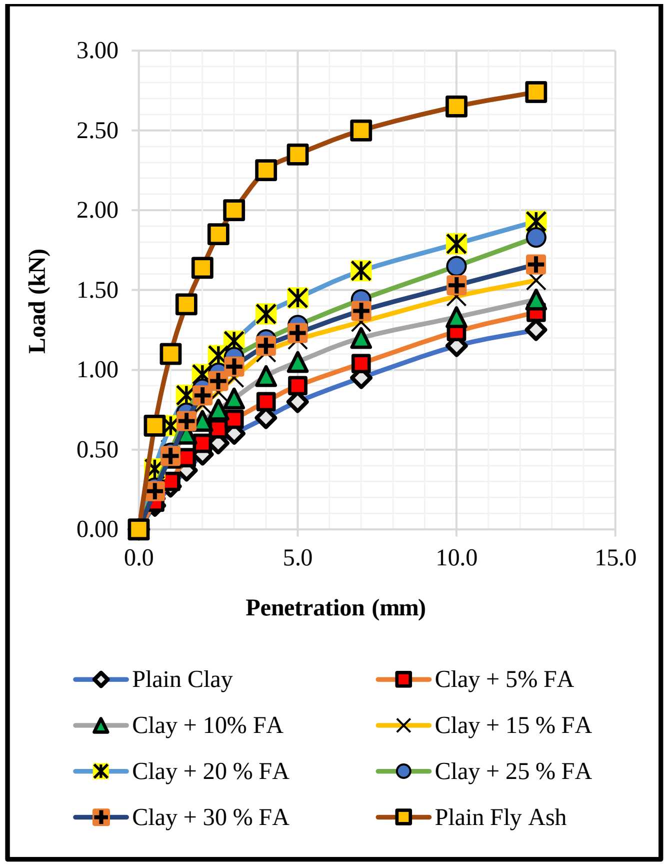

Figure 3 Load vs penetration curve for clay mixed with varying percentages of fly ash

4.3 Impact of Fly Ash mixing on CBR value of clayey soil

The CBR values of the majority of the clayey subgrades are lower. Using different admixtures, it is important to increase the CBR value of clay subgrade. The addition of fly ash might increase the CBR value. Therefore, it was important to research the effects of incorporating fly ash into clayey soil. To accomplish this, a series of CBR tests were performed on unsoaked samples of plain clay, plain fly ash, and samples with various amounts of fly ash-mixed clayey soil. Figure 3 depicts the load carried by the specimen at various penetration values. Clay carries 0.54 kN and fly ash takes 1.85 kN at 2.5 mm penetration. Fly ash carries 3.4 times more load than clay. At 5.0 mm penetration, clay carries 0.80 kN and fly ash carries 2.35 kN. Fly ash can carry 2.9 times more load than clayey soil. The load penetration curve for samples containing different percentages of clayey soil and fly ash is shown in figure 3. The result clearly shows that the load carrying capacity for both 2.5 mm and 5.0 mm penetration increases with increasing percentage of fly ash, but not endlessly. The load carrying capacity of the mixed soil begins to decline after 20% fly ash. The maximum load carrying capacity increases for 2.5 mm and 5 mm penetration were found to be 102% and 81.36% more than the plain clay soil. corresponding increases of 72.13% and 53.65% were observed for 30% fly ash, respectively.

4.4 Impact of Fly Ash on net safe bearing capacity and bearing capacity of clayey soil

The following procedure was adopted to find out the bearing capacity utilizing shear strength parameters obtained from triaxial shear strength test. Take footing of size 2.0 m x 2.0 m (for calculation purpose) is provided at depths of 2.0 m. Using equation given below as per (I.S:6403-2017) for local shear failure condition. As the values of angle of internal friction for different mixes of Clay, Fly Ash less than 29^{o}, therefore local shear failure conditions have been assumed and accordingly the bearing capacity factors have been obtained corresponding to the reduced or mobilized values of cohesion (c) and angle of internal friction (ϕ) as (c_m) and (ϕ_m) that is c_m = 2/3 (c) and ϕ_m = tan-1 [2/3 tan (ϕ)].

Table 6 shows the variation of safe and net safe bearing capacity of clayey soil with different percentages of fly ash, Table 6 clearly indicate that the safe bearing and net safe bearing capacity increases significantly up to the 30 % of fly ash further increment is not significant.

Table 6 Net safe and safe bearing capacity of clayey soil with different proportion of fly ash

Proportion of Mix	Net Safe Bearing Capacity, q_{ns} (kPa)	Safe Bearing Capacity, q_s (kPa)
Clay+ 0% Fly Ash	76.40	116.10
Clay + 5% Fly Ash	90.70	129.70
Clay + 10% Fly Ash	100.6	139.30
Clay + 15% Fly Ash	115.30	153.30
Clay + 20% Fly Ash	132.70	170.30
Clay + 25% Fly Ash	172.20	209.60
Clay + 30% Fly Ash	165.29	205.03
Clay + 35% Fly Ash	155.32	195.06

CONCLUSION

- The greater the amount of Fly Ash added, the lower the maximum dry density of clay became. For clay mixed with Fly Ash, the density decreased from 16.8 to 15.46 kN/m3 when the Fly Ash content went from 0% to 30%.
- The optimum moisture content for clay increased as we added more Fly Ash. This happened because Fly Ash naturally has a higher moisture content compared to clay on its own, which in turn raised the moisture level in the mixture.
- The optimum quantity of fly ash to apply to clay soil was 25%, which increased the parameters related to shear strength. In contrast to 32 kPa and 5 degrees for untreated clay soil, this produced cohesion and internal friction angle values of 46 kPa and 15 degrees, respectively. Recycling thermal power plant waste and improving soil stability are two benefits of using fly ash waste.
- By adding 25% Fly Ash to clayey soil, the Net Bearing Capacity is increased by 126%. Additional.
- Fly Ash above this quantity does not appreciably improve bearing capacity, making 25% the optimum content for this purpose.
- Shear strength increases by 51% in clayey soil when 25% Fly Ash is added. Beyond this point, though, adding more Fly Ash actually causes the shear strength to decrease. Consequently, 25% fly ash content is the optimum amount to increase shear strength.
- When 20% Fly Ash was added to clayey soil, the CBR value improved by 101%.
- When 20% Fly Ash was added to the clayey soil, the modulus of resilience increased by 76.26%.
- The enhanced strength of clayey soil achieved through the incorporation of fly ash content is sufficient for its application as reliable subgrade and foundation materials.
- The notable increase in CBR value enables us to decrease the pavement thickness, resulting in cost-effective savings in construction of flexible pavement.
- Fly ash is non-plastic in nature, indicating that the increase in strength due to increase in the frictional resistance of the mix.
- Fly ash is a by product of coal combustion and incorporating it into construction projects can reduce the amount of waste send to landfills. However, it is important to consider local regulations and specific project requirements to ensure proper use and disposal of fly ash.

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