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# INNOVATIVE APPROACHES TO SOIL STABILIZATION THE ROLE OF FLY ASH AND PLASTIC FIBERS IN EXPANSIVE SOILS

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**ABSTRACT**
*The influx of people into big cities has surged over the past few decades due to various factors. This urban migration, driven by business opportunities, has led to overcrowding and an increase in civil engineering projects, particularly residential buildings. A significant challenge in these projects is inadequate soil, such as Black cotton soil, which is notably problematic in India. This soil type expands and becomes sticky during the wet season and shrinks, causing deep cracks during the dry season. Covering 16.6% of India's geotechnical regions, Black cotton soil necessitates stabilization to ensure construction stability. Various methods, including mechanical, chemical, electrical, and thermal techniques, enhance the soil's engineering properties. Chemical stabilization, especially for roads and airports, is highly effective. Expansive soil's properties vary with different stabilizers, and in this project, fly ash and plastic fibers are used to stabilize the soil. The assessment includes testing the expansive soil's swelling potential, Atterberg limits, and compaction in both its natural state and when mixed with varying amounts of fly ash and plastic fibers. This approach aims to improve the soil's engineering qualities, making it suitable for construction projects.*

*Keywords: Soil Stabilization, Black cotton soil, fly ash and plastic fibers.*

## 1. INTRODUCTION

### 1.1 Expansive Soil

Expansive soils, also called swell-recoil soils, expand and contract based on moisture levels. This variability leads to major issues, often damaging structures built on them. During heavy rain, such as storms, these soils absorb water and swell, becoming weaker and less able to hold water. Conversely, in dry seasons like summer, they lose moisture, shrink, and become more compact. Predominantly found in semi-arid and dry regions, untreated expansive soils pose a continual risk, potentially causing severe damage to dependent systems and infrastructure.

These soils, rich in montmorillonite clay, can cause billions of dollars in damage to structures worldwide each year. In India, these soils are known as Black Cotton soils or Regur soils, covering the Deccan Plateau regions like Maharashtra, Andhra Pradesh, Gujarat, Madhya Pradesh, and parts of Odisha. They are also present in the river basins of Narmada, Tapi, Godavari, and Krishna. The soil in these regions is often residual, formed from the weathering of basalt rock or from volcanic activity.

Black Cotton soils are rich in iron, calcium, magnesium, alumina, and lime but lack organic matter, phosphorus, and nitrogen. They range in color from dark to chestnut and cover about 20% of India’s land. These soils are well-suited for dry farming and crops like cotton, rice, wheat, tobacco, and sugarcane due to their high moisture retention.

### 1.2 Fly Ash

Fly ash is a waste product generated from the gases of coal-burning in thermal power plants. It is similar to volcanic ash, which was historically used for hydraulic bonding. Compared to other pozzolans used worldwide, fly ash is considered highly effective.

The demand for energy has surged due to industrialization and urbanization, leading to an increase in coal-fired power plants. Fly ash is the mineral residue left after coal combustion and is collected by the plants' Electrostatic Precipitator (ESP).

The production of fly ash raises two critical issues: its management and safe disposal. Due to the complex and hazardous nature of these wastes, they must be handled carefully to prevent environmental damage and potential health hazards. If not properly managed before transportation or disposal, fly ash can cause significant environmental contamination.

Fly ash primarily consists of fine particles of iron, silica, and alumina, usually spherical in shape, which facilitates easy mixing and flow. It contains both crystalline and amorphous minerals. While it is essentially a non-plastic sediment, its composition varies depending on the type of coal used. Fly ash can be used to create landfill liners and, when mixed with bentonite and lime, can form barriers.

### 1.3 Classification of Fly Ash

The ash removed from flue gases through an Electro Static Precipitator, after the pulverization process, is called fly ash. Among bottom ash, pond ash, and fly ash, it contains the finest particles. Fly ash primarily consists of non-combustible particulate matter, with some unburned carbon, generally composed of silt-sized particles. Based on a lime reactivity test, fly ash is classified into four types:

- Cementitious fly ash
- Cementitious and pozzolanic fly ash
- Pozzolanic fly ash
- Non-pozzolanic fly ash

## 2. MATERIALS AND METHODOLOGY

### 2.1 Materials Used

#### 2.1.1 Expansive Soil

As part of this study, expansive black cotton soil was collected from the site. The soil was transported to the laboratory in bags. A small amount of soil was taken, sieved through a 4.75 mm sieve, weighed, and then air-dried before weighing again to determine its natural moisture content. The various geotechnical properties of the collected soil are as shown in table no.1

**Table 1:** Geotechnical properties of the secured soil

| Sl. No. | Properties | Code referred | Value |
|---|---|---|---|
| 1 | Specific Gravity | IS 2720 (Part 3/Sec 1) - 1980 | 2.44 |
| 2 | Maximum Dry Density (MDD) | IS 2720 (Part 7) - 1980 | 1.52 gm/cc |
| 3 | Optimum Moisture Content (OMC) | IS 2720 (Part 7) - 1980 | 22.65% |
| 4 | Natural Moisture Content | IS 2720 (Part 2) - 1973 | 7.28% |
| 5 | Free Swell Index | IS 2720 (Part 40) - 1977 | 105% |
| 6 | Liquid Limit | IS 2720 (Part 5) - 1985 | 65% |
| 7 | Plastic Limit | IS 2720 (Part 5) - 1985 | 37.08% |
| 8 | Shrinkage Limit | IS 2720 (Part 6) -: 1972 | 17.37% |

#### 2.1.2 Fly Ash

Fly ash is a waste material extracted from the gases emitted by coal-fired furnaces, typically from thermal power plants. It is the mineral residue left behind after the combustion of coal. The Electro Static Precipitator (ESP) in power plants collects this fly ash. Composed mainly of alumina, silica, and iron, fly ash particles are micro-sized and generally spherical, which facilitates easy mixing and flow to form a uniform mixture. Fly ash contains both amorphous and crystalline minerals, and its composition varies depending on the quality of coal used in the combustion process, but it is primarily a non-plastic silt. For the purposes of this study, fly ash was sourced from Sesa Sterlite in Jharsuguda, Odisha. To remove vegetation and extraneous material, the fly ash was sieved through a 2 mm sieve and then dried. in the broiler for around 24 hours before further utilization.

**Fig 1:** Fly ash

### 2.1.3 Plastic fiber

Plastic fibers were obtained from waste plastic packaging (milk and curd packets). After thorough cleaning and air drying, the plastic packaging was shredded into fibers, each with an average thickness of 2 mm. These plastic materials are typically considered waste.

**Fig 2:** Plastic fiber

### 2.2 Methodology Adopted

To assess the impact of fly ash and plastic fibers as stabilizing additives in expansive soils, a series of tests were conducted. The fly ash content in the expansive soil was varied in increments of 5%, ranging from 5% to 40%, with an additional 1% plastic fiber by weight of the total mixture. The tests were conducted in accordance with the Indian Standard codes, as follows:

- Standard Proctor Test – IS: 2720 (Part 7) - 1980
- Unconfined Compressive Strength (UCS) Test – IS: 2720 (Part 10) - 1991
- California Bearing Ratio (CBR) Test – IS: 2720 (Part 16) - 1987
- Liquid and Plastic Limit Test – IS: 2720 (Part 5) - 1985

## 3. METHODOLOGY

### 3.1 Atterberg's limit (Liquid limit & Plastic limit)

Atterberg limits are critical measures that define the key water content thresholds of fine-grained soils, including the shrinkage limit, plastic limit, and liquid limit. As dry, clayey soil absorbs water, its behavior and consistency change significantly. Depending on moisture content, soil can be in one of four states: solid, semi-solid, plastic, or liquid, each with distinct properties.

Developed by Swedish agronomist Albert Atterberg and refined by Arthur Casagrande, these limits are crucial for evaluating soils used in construction. Wet soils can retain water and expand in volume, with the extent of expansion depending on their mineral content. These tests are particularly relevant for clayey or silty soils, which expand and contract with moisture changes. The interaction of clays and silts with water affects their dimensions and shear strength, making these tests vital in structural planning to ensure soil stability and minimal volumetric change.

In its dry state, soil is a hard, rigid solid. As it absorbs water to the plastic limit, it becomes a brittle, semi-solid. For expansive soils, reaching the plastic limit triggers volume expansion. Beyond this limit, the soil becomes a malleable, plastic mass, leading to further swelling. Once it surpasses the liquid limit, it transforms into a viscous liquid that flows when disturbed.

### 3.1.1 Plastic Limit

To determine the plastic limit of black cotton soil

**Procedure**

1. Take about 8g of the dirt and move it with fingers on a glass plate. The pace of rolling ought to be between 80 to 90 strokes for every moment to shape a 3mm dia.
2. If the dia. of the strings can be decreased to under 3mm, with no splits showing up, it implies that the water substance is more than its plastic breaking point. Work the dirt to diminish the water substance and fold it into a string once more.
3. Repeat the procedure of interchange rolling and manipulating until the string disintegrates.
4. Collect and keep the bits of disintegrated soil string in the holder used to decide the dampness content.
5. Repeat the procedure in any event twice more with crisp examples of plastic soil each time.

1. W=w2-w3/w2X100

**Fig 3:** Plastic limit

### 3.1.2 Liquid Limit

To determine the liquid limit of black cotton soil, follow these steps:

1. Place a portion of the soil paste into the cup of the liquid limit device, ensuring it forms a layer with a maximum depth of 1 cm.
2. Use Casagrande's instrument (for typical fine-grained soil) or the ASTM apparatus (for sandy soil) to cut a groove. For fine-grained soil, the notch should be 2 mm wide at the base, 11 mm wide at the top, and 8 mm deep.

3. After cutting the soil pat, rotate the crank of the device at approximately 2 cycles per second while counting the number of blows until the two halves of the soil specimen come into contact over a length of about 10 mm.
4. Take approximately 10 g of soil from near the closed groove and determine its water content. Mix the soil in the cup thoroughly with the soil paste after adding a little more water. Repeat the test.
5. Adjust the water content of the soil by repeating the previous steps, aiming to obtain at least 5 readings ranging from 15 to 35 blows. Avoid adding dry soil to alter its consistency.
6. The liquid limit is determined by plotting a 'flow curve' on a semi-logarithmic graph, with the number of blows on the abscissa (log scale) and the water content on the ordinate. Draw the best-fit straight line through the plotted points.

$W=w2-w3/w2X100$

**Fig 4:** Liquid limit

## 4. RESULTS AND DISCUSSION

### Standard Proctor Test Results

### Expansive Soil

**Table 2:** Standard proctor test results for expensive soil

| Volume of mould ($m^3$) | Weight of soil in mould (kg) | Bulk density ($g/cm^3$) | Moisture content (%) | Dry density ($g/cm^3$) |
|---|---|---|---|---|
| **0.00099795** | 1.56 | 1.56 | 17.76 | 1.32 |
| **0.00099795** | 1.73 | 1.73 | 19.53 | 1.45 |
| **0.00099795** | 1.86 | 1.86 | 22.65 | 1.52 |
| **0.00099795** | 1.87 | 1.87 | 24.87 | 1.5 |
| **0.00099795** | 1.82 | 1.82 | 27.92 | 1.42 |

**Table 3:** Comparison of Standard proctor test

| S. No | % Fly ash +%Plastic fiber | Maximum Dry density ($g/cm^3$) | Moisture content in % |
|---|---|---|---|
| **1** | Expansive soil | 1.52 | 22.65 |
| **2** | 5%FA+1% Plastic Fiber | 1.50 | 22.13 |
| **3** | 10%FA+1% Plastic Fiber | 1.52 | 22.56 |

| | | | |
|---|---|---|---|
| **4** | 15%FA+1% Plastic Fiber | 1.53 | 21.27 |
| **5** | 20%FA+1% Plastic Fiber | 1.47 | 23.57 |

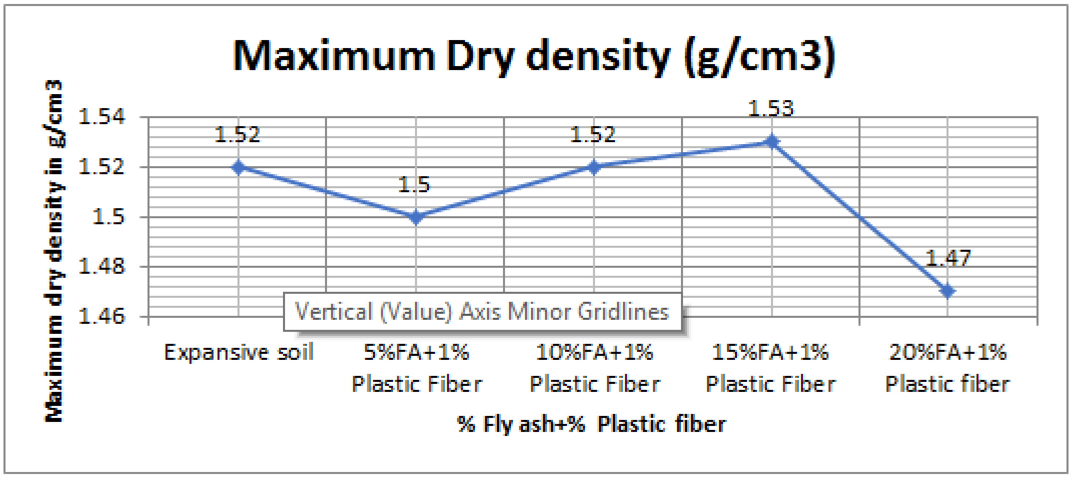


**Figure 5:** Comparison of maximum dry density

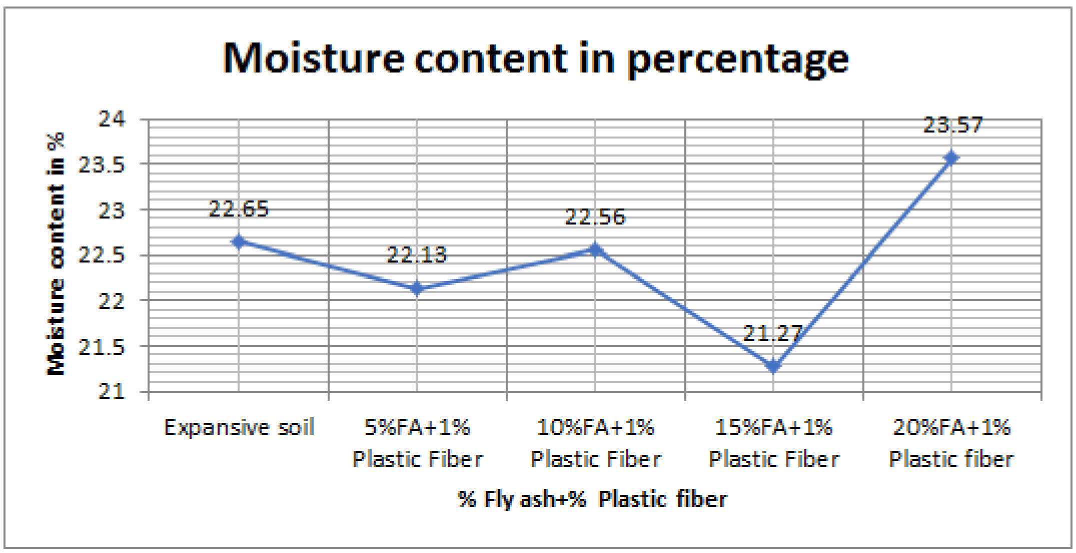


**Figure 6:** Comparison of moisture content in percentage

**Table 4:** Unconfined Compressive Strength (UCS) test for expansive soil

| Sl. No | Dial gauge reading | Deformation (mm) | Proving ring reading | Load (kN) | Strain (%) | Corrected area (mm2) | Compressive strength (N/mm2) |
|---|---|---|---|---|---|---|---|
| **1** | 0 | 0 | 0 | 0 | 0 | 1133.54 | 0 |
| **2** | 50 | 0.5 | 14 | 0.019 | 0.6 | 1141.04 | 0.017 |
| **3** | 100 | 1 | 36 | 0.052 | 1.3 | 1148.65 | 0.044 |
| **4** | 150 | 1.5 | 69 | 0.098 | 1.9 | 1156.36 | 0.085 |
| **5** | 200 | 2.0 | 101 | 0.144 | 2.6 | 1164.17 | 0.123 |
| **6** | 250 | 2.5 | 111 | 0.158 | 3.3 | 1172.09 | 0.135 |
| **7** | 300 | 3.0 | 131 | 0.186 | 3.9 | 1180.12 | 0.158 |
| **8** | 350 | 3.5 | 149 | 0.212 | 4.6 | 1188.26 | 0.178 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **9** | 400 | 4.0 | 159 | 0.226 | 5.3 | 1196.51 | 0.189 |
| **10** | 450 | 4.5 | 166 | 0.236 | 5.9 | 1204.88 | 0.196 |
| **11** | 500 | 5.0 | 168 | 0.240 | 6.6 | 1213.36 | 0.197 |
| **12** | 550 | 5.5 | 169 | 0.241 | 7.2 | 1221.97 | 0.197 |
| **13** | 600 | 6.0 | 169 | 0.241 | 7.9 | 1230.70 | 0.196 |
| **14** | 650 | 6.5 | 168 | 0.240 | 8.5 | 1239.55 | 0.193 |
| **15** | 700 | 7.0 | 168 | 0.240 | 9.2 | 1248.53 | 0.191 |
| **16** | 750 | 7.5 | 167 | 0.238 | 9.8 | 1257.65 | 0.189 |
| **17** | 800 | 8.0 | 165 | 0.235 | 10.5 | 1266.89 | 0.185 |
| **18** | 850 | 8.5 | 165 | 0.235 | 11.2 | 1276.28 | 0.184 |
| **19** | 900 | 9.0 | 163 | 0.232 | 11.8 | 1285.80 | 0.180 |
| **20** | 950 | 9.5 | 162 | 0.231 | 12.5 | 1295.47 | 1.78 |

**Table 5:** Comparison of compressive strength

| SL. No | Strain (%) | Compressive strength (N/mm2) for expansive soil | Compressive strength (N/mm2) for 5%FA+1%Plastic Fiber | Compressive strength (N/mm2) for 10%FA+1% Plastic Fiber | Compressive strength (N/mm2) for 15%FA+1% Plastic Fiber | Compressive strength (N/mm2) for 20%FA+1% Plastic Fiber |
|---|---|---|---|---|---|---|
| **1** | 0 | 0 | 0 | 0 | 0 | 0 |
| **2** | 0.6 | 0.017 | 0.012 | 0.013 | 0.007 | 0.01 |
| **3** | 1.3 | 0.044 | 0.029 | 0.043 | 0.029 | 0.026 |
| **4** | 1.9 | 0.085 | 0.06 | 0.087 | 0.059 | 0.057 |
| **5** | 2.6 | 0.123 | 0.082 | 0.119 | 0.086 | 0.087 |
| **6** | 3.3 | 0.135 | 0.109 | 0.132 | 0.113 | 0.111 |
| **7** | 3.9 | 0.158 | 0.122 | 0.159 | 0.129 | 0.137 |
| **8** | 4.6 | 0.178 | 0.142 | 0.183 | 0.153 | 0.158 |
| **9** | 5.3 | 0.189 | 0.15 | 0.195 | 0.168 | 0.166 |
| **10** | 5.9 | 0.196 | 0.162 | 0.201 | 0.174 | 0.17 |
| **11** | 6.6 | 0.197 | 0.169 | 0.203 | 0.176 | 0.17 |
| **12** | 7.2 | 0.197 | 0.17 | 0.206 | 0.176 | 0.169 |
| **13** | 7.9 | 0.196 | 0.195 | 0.204 | 0.175 | 0.168 |
| **14** | 8.5 | 0.193 | 0.193 | 0.204 | 0.172 | 0.165 |
| **15** | 9.2 | 0.191 | 0.191 | 0.201 | 0.17 | 0.163 |
| **16** | 9.8 | 0.189 | 0.189 | 0.198 | 0.167 | |
| **17** | 10.5 | 0.185 | 0.185 | 0.196 | | |
| **18** | 11.2 | 0.184 | 0.184 | 0.194 | | |
| **19** | 11.8 | 0.18 | | 0.191 | | |

**Table 6:** Variation of compressive strength with percentage variation of fly ash and plastic fiber

| S. No | % Fly ash +%Plastic fiber | Compressive strength in N/mm2 |
|---|---|---|
| **1** | Expansive soil | 0.197 |
| **2** | 5%FA+1% Plastic Fiber | 0.195 |
| **3** | 10%FA+1% Plastic Fiber | 0.206 |
| **4** | 15%FA+1% Plastic Fiber | 0.176 |
| **5** | 20%FA+1% Plastic Fiber | 0.17 |

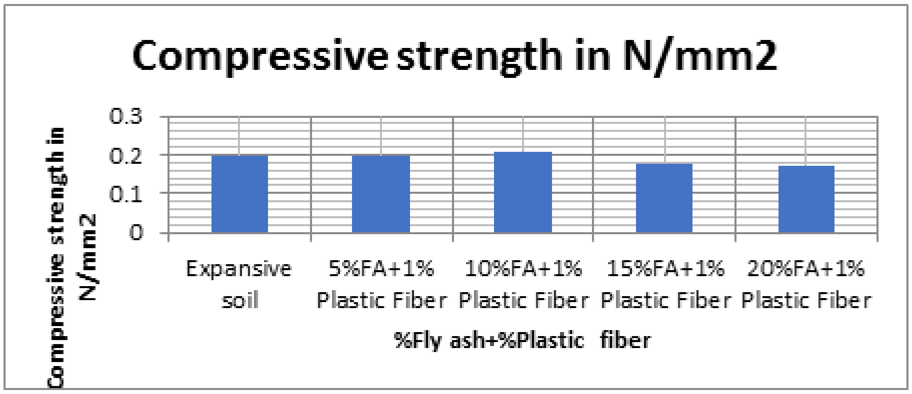


**Figure 7:** Comparison of compressive strength values

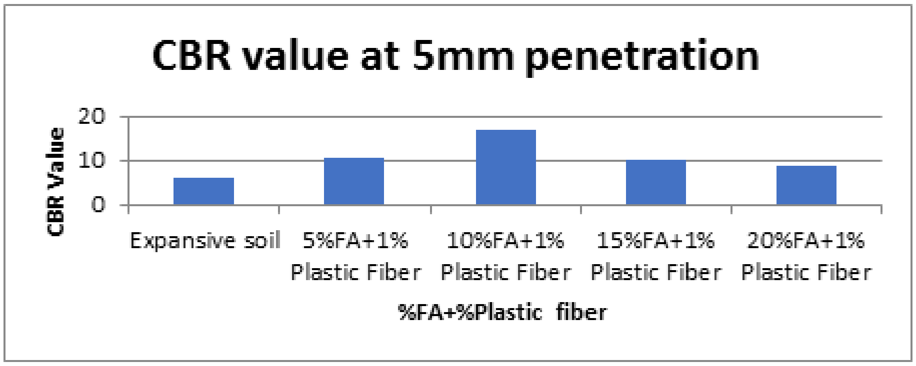


**Figure 8:** Comparison of CBR value at 5mm penetration

**Table 7:** California Bearing Ratio (CBR) test for soil for expansive soil with 5%FA+1% Plastic Fiber

| S. No | Plunger penetration (mm) | Dial gauge reading | Applied load (kg) | CBR stress (kg/cm2) | Standard load intensity (kg/cm2) | CBR intensity (%age) |
|---|---|---|---|---|---|---|
| **1** | 0 | 4 | 9.88 | 0.49 | | |
| **2** | 0.5 | 10 | 24.71 | 1.23 | | |
| **3** | 1 | 28 | 69.19 | 3.45 | | |
| **4** | 1.5 | 44 | 108.72 | 5.43 | | |
| **5** | 2 | 52 | 128.49 | 6.42 | | |
| **6** | 2.5 | 59 | 145.79 | 7.28 | 70 | 10.4 |
| **7** | 3 | 66 | 163.08 | 8.14 | | |
| **8** | 3.5 | 72 | 177.91 | 8.88 | | |
| **9** | 4 | 78 | 192.74 | 9.63 | | |
| **10** | 4.5 | 83 | 205.09 | 10.24 | | |
| **11** | 5 | 90 | 222.39 | 11.11 | 105 | 10.58 |
| **12** | 5.5 | 95 | 234.74 | 11.72 | | |
| **13** | 6 | 98 | 242.16 | 12.09 | | |
| **14** | 6.5 | 100 | 247.1 | 12.34 | | |
| **15** | 7 | 101 | 249.1 | 12.46 | | |
| **16** | 7.5 | 102 | 252.04 | 12.59 | 134 | 9.39 |
| **17** | 8 | 102 | 252.04 | 12.59 | | |

**Table 8:** Variation of liquid limit, plastic limit

| S. No | % Fly ash +%Plastic fiber | Liquid Limit |
|---|---|---|
| 1 | Expansive soil | 65.6 |
| 2 | 5%FA+1% Plastic Fiber | 61.2 |
| 3 | 10%FA+1% Plastic Fiber | 58.8 |
| 4 | 15%FA+1% Plastic Fiber | 56.4 |
| 5 | 20%FA+1% Plastic Fiber | 51.8 |

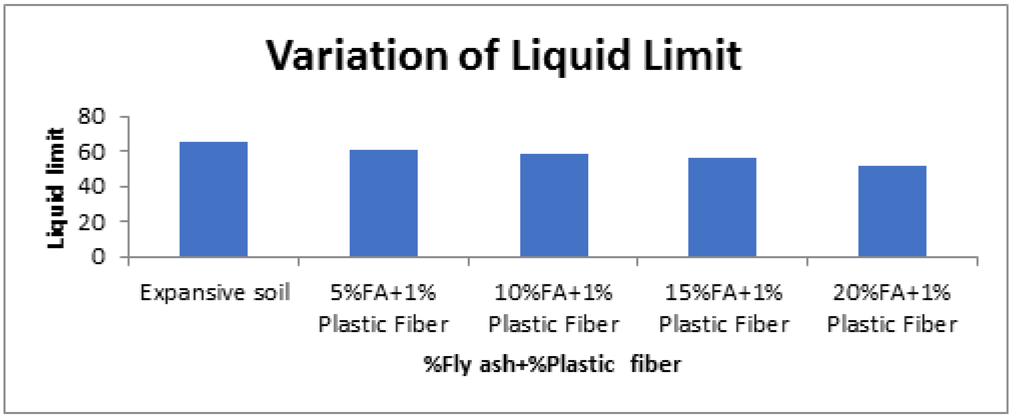


**Figure 9:** Variation of liquid limit, plastic limit

**Table 9:** Variation of plastic limit

| S. No | % Fly ash +%Plastic fiber | Plastic limit |
|---|---|---|
| 1 | Expansive soil | 35.8 |
| 2 | 5%FA+1% Plastic Fiber | 34.6 |
| 3 | 10%FA+1% Plastic Fiber | 33.2 |
| 4 | 15%FA+1% Plastic Fiber | 31.5 |
| 5 | 20%FA+1% Plastic Fiber | 28.67 |

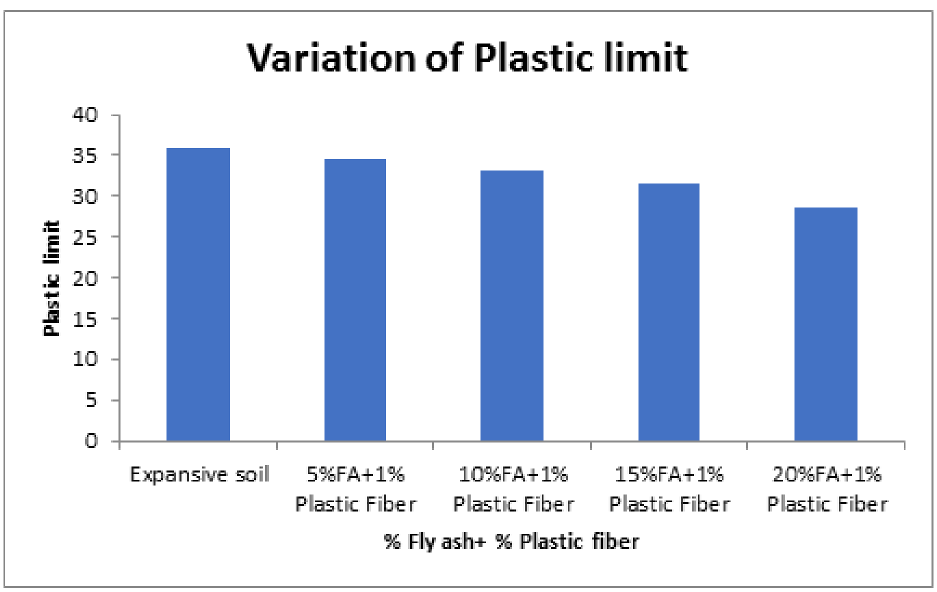


**Figure 10:** Variation of plastic limit values

The plastic limit of expansive soil is 35.8%. When 5% fly ash and 1% plastic fiber are added, the plastic limit decreases to 34.6%. Further addition of 10% fly ash and 1% plastic fiber reduces the plastic limit to 33.2%. With 15% fly ash and 1% plastic fiber, the plastic limit drops to 31.5%. Finally, incorporating 20% fly ash and 1% plastic fiber lowers the plastic limit to 28.67%.

## 6. CONCLUSIONS

This article evaluates the use of plastic fiber and fly ash for soil stabilization. It found that combining these materials effectively stabilizes soil. Fly ash is particularly effective for soils that expand and contract, reducing swelling and increasing strength. A mix of 15% fly ash and 1% plastic fiber provided the highest dry density, while 20% fly ash and 1% plastic fiber yielded the highest moisture content. The best unconfined compressive strength and cbr value were achieved with 10% fly ash and 1% plastic fiber. Increasing fly ash from 0% to 20% with 1% plastic fiber improved soil properties.

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