# Investigation on the Utilization of Waste Materials and Reinforcement Techniques in Flexible Pavement Construction

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**Abstract -** With the continuous growth of the road construction industry and the rapid rise in traffic volumes, the need for innovative, sustainable, and high-performance construction materials has become increasingly important. The depletion of conventional natural resources, combined with growing environmental concerns, has shifted the focus toward identifying and incorporating alternative materials in pavement applications. As a result, numerous unconventional, secondary, and tertiary materials—particularly industrial by-products and waste materials—have been explored for their potential use in road construction. Many of these recycled materials have been assessed through laboratory testing and field applications, and several have demonstrated favourable engineering properties when compared to traditional materials. Their performance, however, varies widely depending on their physical and chemical characteristics, which influence their suitability for different pavement layers. Although some recycled materials have shown superior performance, concerns regarding long-term durability, variability in material properties, and field performance have been raised. These issues emphasize the need for continued research to better understand their behaviour and ensure their safe and effective use in road construction.

The present study investigates the improvement of subgrade soil characteristics by incorporating recycled materials such as fly ash and plastic waste. Five mix combinations were prepared using varying proportions: 0%FA + 0%PW, 5%FA + 1%PW, 10%FA + 2%PW, 15%FA + 3%PW, and 20%FA + 4%PW. The treated soil samples were subjected to a series of geotechnical tests to evaluate key engineering properties, including liquid limit, plastic limit, standard Proctor compaction characteristics, unconfined compressive strength (UCS), and California Bearing Ratio (CBR). The results obtained from the modified soil specimens were compared with those of natural soil to determine the effectiveness of fly ash and plastic waste in enhancing subgrade strength and stability. This study contributes to the ongoing efforts to utilize waste materials in sustainable pavement construction while addressing environmental and resource-related challenges.

**Keywords:** Recycled material, sub grade soil, fly ash, lastic waste,

## 1.INTRODUCTION

The rapid development of the road construction industry and the rise in vehicle usage have increased the demand for durable pavements, leading to excessive extraction of natural materials such as aggregates and bitumen. This has raised environmental concerns and encouraged the search for alternative and sustainable construction materials. Since the 1980s, various recycled products—including plastic waste, fly ash, scrap tires, reclaimed asphalt, and steel slag—have been explored for their suitability in pavement applications. Research shows that many of these materials can improve engineering properties, enhance durability, and reduce costs when properly processed and blended with conventional materials.

Among these, plastic waste has gained significant attention due to its non-biodegradable nature and growing disposal challenges. Incorporating plastic waste into concrete and pavement layers reduces environmental pollution, minimizes the overuse of natural aggregates, and improves resistance to rutting, cracking, and moisture damage. Thus, recycled materials, especially plastic waste and fly ash, offer an effective and sustainable solution for modern road construction.

## 1.2 RESEARCH SIGNIFICANCE

The growing depletion of natural construction materials and the escalating environmental impacts associated with their extraction have compelled the pavement industry to seek sustainable alternatives. Waste materials, when effectively incorporated into road construction, offer a promising solution by reducing the dependence on natural aggregates, minimizing environmental degradation, and easing the burden on governments to manage expanding landfills. Numerous studies have demonstrated the potential of recycled and secondary materials to enhance pavement performance, yet many waste products still require comprehensive evaluation to fully understand their engineering behaviour, long-term durability, and structural compatibility.

This research is significant as it contributes to global efforts aimed at sustainable infrastructure development, reducing greenhouse gas emissions, and conserving natural resources. By exploring the feasibility of using non-traditional and recycled materials in pavement layers, the study aligns with international goals of environmental protection and circular economy adoption. It also provides critical insights for policymakers and transportation agencies that face challenges in regulating, standardizing, and implementing waste-based construction materials. Understanding how these materials behave individually and in combination with conventional aggregates is essential for developing cost-effective, durable, and environmentally responsible pavement systems. Thus, the study supports the transition toward greener road construction practices that benefit both the environment and the economy.

### 1.3 Objectives of the Present Study

The present investigation is carried out with the following objectives:

1. To evaluate the Atterberg limits of subgrade soil incorporating various proportions of fly ash and plastic waste, and to determine their influence on soil consistency characteristics.
2. To examine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of soil treated with different percentages of fly ash (5%, 10%, 15%, 20%, and 25%) combined with plastic waste additions of 1%, 2%, 3%, and 4%.
3. To assess the improvement in soil strength parameters for different combinations of fly ash and plastic waste, identifying the mix proportion that yields the highest enhancement in engineering properties.
4. To determine the Unconfined Compressive Strength (UCS) of the treated soil for all selected proportions of fly ash and plastic waste and to compare the results with natural soil.
5. To analyze the overall stabilization effectiveness of fly ash and plastic waste by correlating changes in consistency limits, compaction behaviour, and strength characteristics.

## 2. LITERATURE REVIEW

**Ankita Sonkar, S. Srividhya, et al.,(2017)** This study investigates the influence of randomly distributed palm fibers on the strength and swelling behaviour of expansive soil, along with the stabilizing effects of bagasse ash. Expansive soils are known for their high plasticity and significant volume changes, making them unsuitable for construction without proper stabilization. In this research, palm fibers were introduced into the soil at four different proportions—0.25%, 0.5%, 1%, and 1.25%—to evaluate their ability to enhance soil strength and modify its index and compaction properties.

**Amit Tiwari, H.K. Mahiyar et al. (2014)** examined the improvement of Black Cotton Soil, which exhibits undesirable engineering properties such as excessive volume changes with moisture variation, high shrinkage leading to cracking, significant swelling upon wetting, low compressive strength, and poor performance at higher water contents. The study aimed to evaluate soil characteristics—including Atterberg limits, compaction behaviour (OMC and MDD), shrinkage limit, CBR, swelling pressure, permeability, and shear strength—by incorporating Fly Ash, Coconut Fiber, and Crushed Glass in varying proportions. The objective was to explore waste materials as alternatives to conventional stabilizers like lime and cement while improving cost-effectiveness.

A total of 48 test specimens were analysed in two phases. The first phase assessed the natural properties of Black Cotton Soil through grain size distribution, specific gravity, Atterberg limits, shear strength, swelling pressure, compaction, CBR, and permeability tests. In the second phase, stabilization was performed using Fly Ash (10–25%), Coconut Coir Fiber (0.25–1%), and Crushed Glass (3–7%) to evaluate their combined effects on soil performance.

## 3.MATERIAL AND METHODOLOGY

### 3.1 Materials

#### 3.1.1 Expansive soil

As part of this investigation, expansive Black Cotton Soil was collected directly from the project site. The retrieved soil was transported to the laboratory in sealed bags to preserve its natural condition. A representative portion of the soil was then taken for preliminary testing, sieved through a 4.75 mm sieve, weighed, and air-dried before being weighed again to determine its natural moisture content. The detailed geotechnical properties of the collected soil are presented below.

#### 3.1.2 Fly ash

Fly ash is a waste material extracted from the flue gases of coal-fired furnaces, typically produced in thermal power plants. It represents the fine mineral residue left after the combustion of coal and is collected using Electrostatic Precipitators (ESPs). Composed primarily of silica, alumina, and iron oxides, fly ash consists of micro-sized, predominantly spherical particles. This spherical shape enhances its flowability and mixing characteristics, allowing it to blend easily with other materials. Fly ash contains both amorphous and crystalline mineral phases, and its composition varies depending on the type and quality of coal used in the combustion process. Generally, it is classified as a non-plastic silt-sized material.

For this study, fly ash was procured from Sesa Sterlite, Jharsuguda, Odisha. To remove impurities such as vegetation

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and foreign particles, the material was sieved through a 2 mm

| 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% |

mesh. The cleaned fly ash samples were then oven-dried for approximately 24 hours before being used in the experimental program.

## 4. EXPERIMENTAL INVESTIGATION

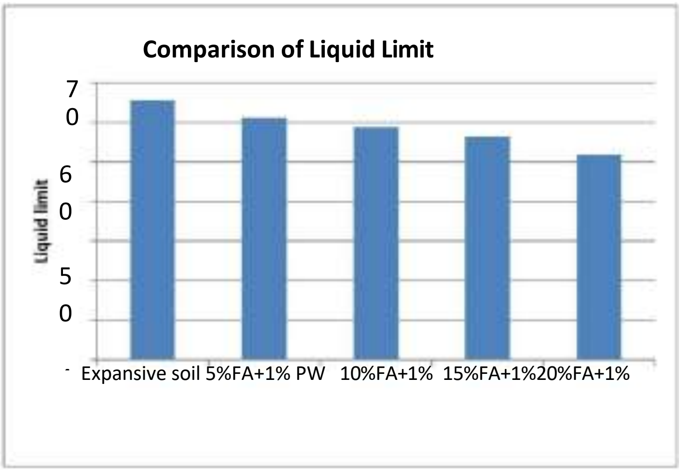
### 4.1 Atterberg's limit (Liquid limit & Plastic limit).

Atterberg limits define the fundamental relationship between moisture content and the behaviour of fine-grained soils. These limits include the shrinkage limit, plastic limit, and liquid limit, which indicate how soil transitions through different states—solid, semi-solid, plastic, and liquid—as water content increases. Introduced by Albert Atterberg and later refined by Arthur Casagrande, these limits are essential for identifying and classifying silts and clays.

As dry clayey soil absorbs water, it undergoes significant changes in consistency and engineering properties. Clays and silts swell and shrink with moisture variations, affecting shear strength and volume stability. Therefore, Atterberg limit tests are mainly applied to these soils during preliminary stages of foundation and pavement design. When moisture reaches the shrinkage limit, soil shifts from a hard solid to a brittle semisolid. Beyond the plastic limit, it becomes moldable, and exceeding the liquid limit turns it into a viscous mass that flows under slight disturbance.

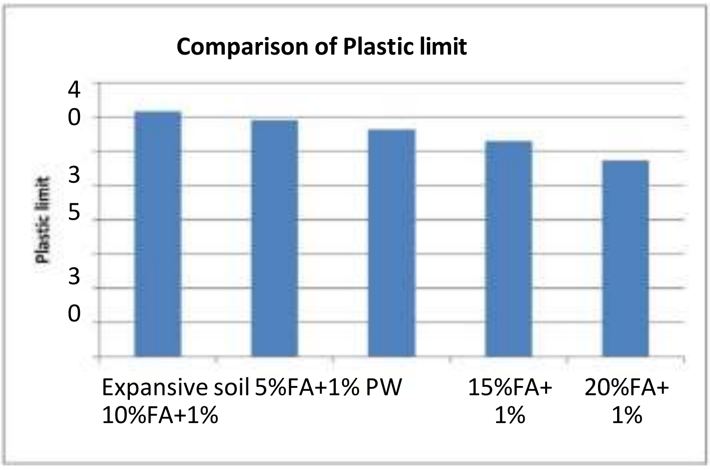
## 5. RESULTS AND ANALYSIS

### 5.1 Comparison of liquid limit



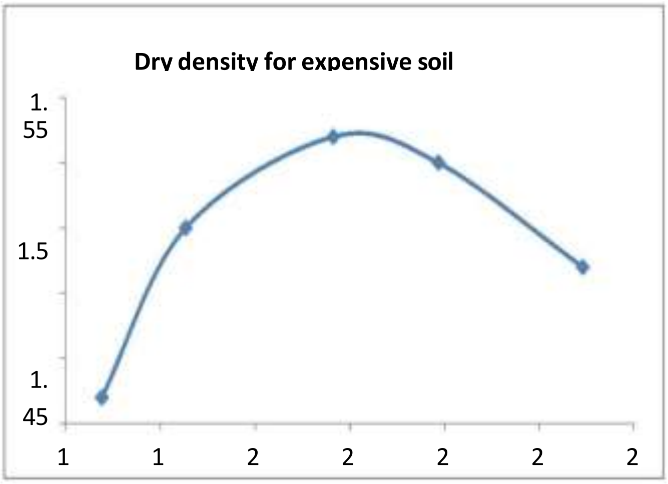

The liquid limit of the expansive soil decreases consistently with the addition of fly ash (FA) and 1% plastic waste (PW). The untreated expansive soil exhibits the highest liquid limit of approximately 65%, indicating high water-holding capacity and strong plastic behavior. With the addition of 5% FA + 1% PW, the liquid limit decreases to around 60%, showing an initial reduction in soil plasticity. Further replacement with 10% FA + 1% PW brings the liquid limit down to nearly 58%, while 15% FA + 1% PW reduces it further to about 55%. The lowest liquid limit of approximately 52% is recorded at 20% FA + 1% PW.

### 5.2 Comparison of plastic limit



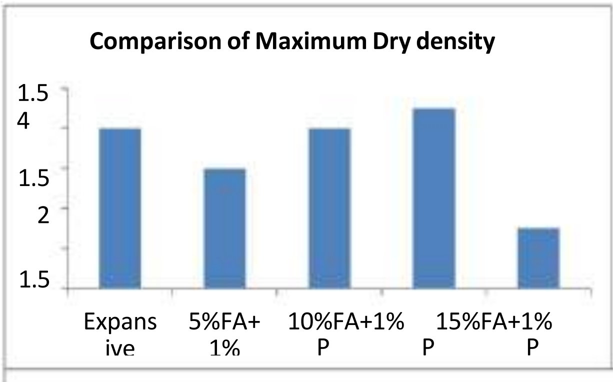

The plastic limit of the expansive soil decreases progressively with the addition of fly ash (FA) and 1% plastic waste (PW). The untreated expansive soil shows the highest plastic limit of around 36%, indicating high plasticity and moisture sensitivity. With 5% FA + 1% PW, the plastic limit slightly decreases to 34%, showing initial improvement in workability and reduced plasticity. Further addition of FA to 10% FA + 1% PW reduces the plastic limit to about 33%, while 15% FA + 1% PW shows a more noticeable reduction to approximately 31–32%. The minimum plastic limit of around 29% is observed at 20% FA + 1% PW, indicating a significant reduction in soil plasticity.

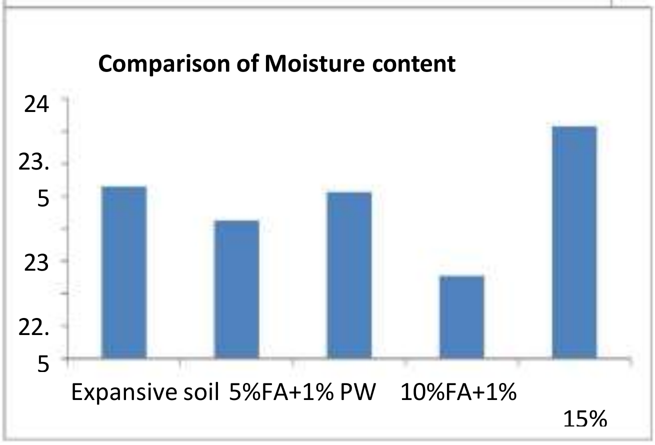
### 5.3 Standard proctor test




The dry density of the expansive soil increases initially with increasing moisture content and then decreases after reaching the optimum point. At lower moisture levels, the dry density is around **1.32 g/cc**, indicating insufficient lubrication for proper soil compaction. As moisture content increases, the soil particles achieve better rearrangement, resulting in a gradual rise in dry density. The maximum dry density (MDD) of approximately **1.52 g/cc** occurs at around **23%** moisture content, representing the optimum moisture content (OMC) where compaction is most efficient.

### 5.4 **Comparison of Standard proctor test**



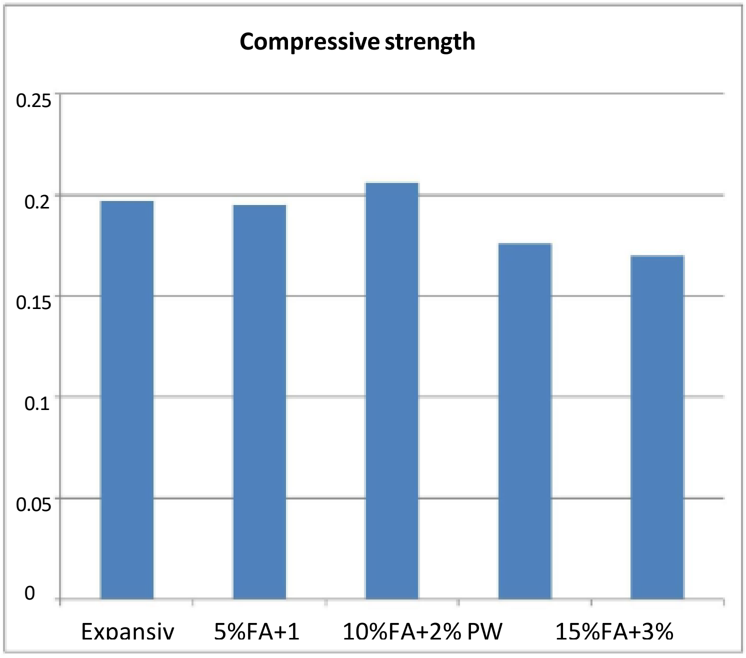

Maximum Dry Density (MDD)

The expansive soil shows an initial MDD of approximately 1.51 g/cc. With 5% FA + 1% PW, the MDD slightly decreases to around 1.49 g/cc, indicating a minor reduction in soil compactability due to the low-density nature of fly ash. At 10% FA + 1% PW, the MDD improves to nearly 1.52 g/cc, showing better particle packing and filler action. The highest MDD of about 1.53 g/cc is observed at 15% FA + 1% PW, indicating optimum stabilization where fly ash effectively fills voids and improves gradation. However, at 20% FA + 1% PW, the MDD decreases sharply to around 1.46 g/cc due to excess fly ash causing increased void ratio and reduced compaction efficiency.

Optimum Moisture Content (OMC)

The natural expansive soil shows an OMC of approximately 22.5%. With 5% FA + 1% PW, the OMC reduces to around 22%, indicating improved workability. At 10% FA + 1% PW, the OMC returns close to 22.5%, while 15% FA + 1% PW shows the lowest OMC of about 21%, corresponding to better compaction and lower water demand. At 20% FA + 1% PW, the OMC increases significantly to roughly 23.7%, implying that higher fly ash content requires more water for lubrication due to its higher surface area and pozzolanic reactivity

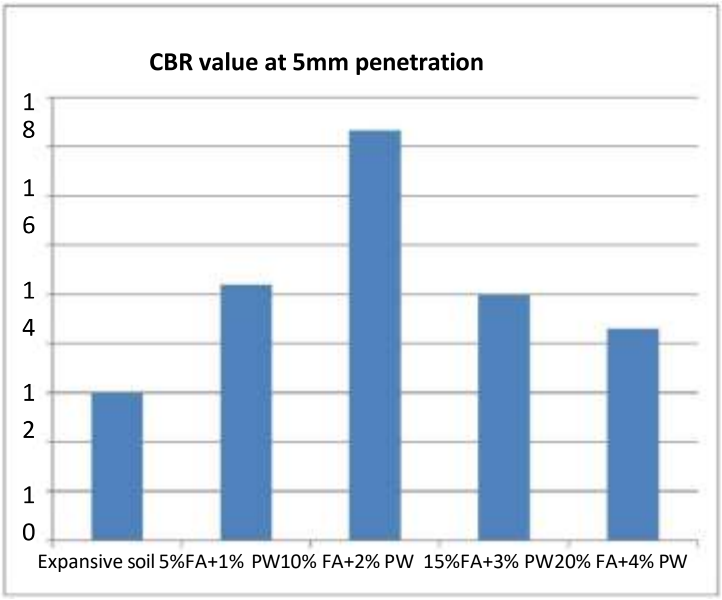
### 5.5 Comparison of compressive strength




The untreated expansive soil exhibits a compressive strength of approximately 0.195 MPa. With the addition of 5% FA + 1% PW, the strength remains nearly the same (around 0.19 MPa), indicating minimal improvement at lower stabilizer content.

A significant increase is observed at 10% FA + 2% PW, where the compressive strength reaches the highest value of approximately 0.21 MPa. This enhancement is attributed to improved bonding, better particle filling by fly ash, and the reinforcing effect of plastic waste fibers, which together enhance load distribution.

5.6 **Comparison of CBR Values**




The natural expansive soil exhibits a CBR value of approximately 6%, indicating poor load-bearing capacity. With the addition of 5% FA + 1% PW, the CBR value increases significantly to about 11%, showing improved shear strength and particle interlocking.

The maximum improvement occurs at 10% FA + 2% PW, where the CBR value reaches the highest value of around 17%. This peak performance is due to the optimal combination of fly ash (providing pozzolanic bonding and void filling) and plastic waste fibers (offering reinforcing action), resulting in enhanced densification and load resistance.

## 6.Conclusion

1. Fly ash and plastic waste, when properly mixed, significantly improve the engineering properties of expansive soil, making them highly effective recycled materials for soil stabilization. Fly ash reduces swelling and enhances strength, while plastic fibers improve reinforcement and stability.
2. The compaction characteristics showed that the highest Maximum Dry Density (MDD) occurred at 15% fly ash with 1% plastic fiber, whereas the highest Optimum Moisture Content (OMC) was observed at 20% fly ash with 1% plastic fiber, indicating improved compaction behavior with moderate FA–PW combinations.
3. Mechanical strength parameters improved notably, with the optimal Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) both recorded at 10% fly ash and 1–2% plastic waste, demonstrating the most effective mix for load-bearing capacity and subgrade stabilization.
4. Consistency parameters such as liquid limit and plastic limit showed a decreasing trend with increasing fly ash content (0–20%) at 1% plastic fiber, confirming a reduction in soil plasticity and moisture sensitivity, which is beneficial for road construction applications.

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