Characterization of Ferrochrome Slag, Fly Ash with Red soil as an Embankment and Pavement Material

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Abstract - This study explores the partial replacement of red soil with ferrochrome slag (FCS) at varying proportions (0%, 10%, 20%, 30%, and 40%) and the effect of adding 5% fly ash to enhance its properties. Initially, red soil without any FCS replacement or fly ash addition is subjected to laboratory tests to establish baseline characteristics. Laboratory investigations include compaction, Atterberg limits, unconfined compressive strength (UCS), and California Bearing Ratio (CBR). Results indicate that the inclusion of ferrochrome slag significantly improves the soil's strength and durability, while the addition of fly ash further enhances its stabilization properties. The optimum replacement level is identified based on mechanical performance and economic feasibility. These findings demonstrate the potential of utilizing industrial by-products to improve soil properties for sustainable construction practices.

Keywords: Red soil, ferrochrome slag (FCS), fly ash, soil stabilization, compaction, Atterberg limits, UCS, CBR, industrial by-products, sustainable construction, soil strength.

1.NTRODUCTION

The construction of roads, embankments, and other civil engineering structures traditionally relies on natural materials. However, the depletion of natural resources has necessitated the search for alternative materials to replace conventional ones. Industrialization has led to the generation of vast amounts of by-products and industrial waste, posing significant environmental challenges such as land, air, and water pollution. Effective management and utilization of these by-products have become crucial for sustainable industrial practices. Consequently, efforts are being made to integrate industrial waste materials into civil engineering applications, thereby reducing environmental impacts and conserving natural resources.

One such industrial by-product is ferrochrome slag, a waste material generated from ferrochrome steel plants. Globally, the production of ferrochrome slag is estimated to range between 6.5 and 9.5 million tons annually, with a steady increase of 2.8–3% per year. Comprising various minerals such as SiO_2, MgO, Al_2O_3, CaO, chromium, and iron, ferrochrome slag possesses unique properties that make it suitable for geotechnical and construction applications. Despite its potential, the utilization of ferrochrome slag in civil engineering remains limited, particularly in India, where comprehensive characterization studies are scarce.

This study aims to address this gap by investigating the geotechnical properties of ferrochrome slag for use as a sustainable alternative in fill materials, embankments, and pavement construction. Laboratory tests were conducted to analyze its morphology, mineralogy, chemical composition, and physical and shear characteristics. The results were compared with other industrial waste materials, such as fly ash and red soil, to evaluate its suitability for sub-grade applications in road construction. By demonstrating the potential of ferrochrome slag, this research contributes to sustainable construction practices while addressing environmental concerns associated with industrial waste disposal.

1.1 Previous Studies in Flexible Pavement Design

Several researchers have investigated the use of industrial by-products, such as fly ash, blast furnace slag, and ferrochrome slag, in flexible pavement design. Gupta et al. (2018) demonstrated that replacing traditional aggregates with slag significantly enhanced the mechanical properties of subgrades and base layers. Similarly, Kumar et al. (2020) explored the pozzolanic properties of fly ash and highlighted its effectiveness in stabilizing weak soils, resulting in increased pavement durability. **Sharma et al. (2017)** focused on stabilizing expansive soils using blends of fly ash and ferrochrome slag. Their findings indicated reduced plasticity, improved shear strength, and higher California Bearing Ratio (CBR) values, making these materials suitable for subgrade applications.

Mehta et al. (2019) evaluated the performance of alternative materials in flexible pavements, reporting that slag-based subgrades exhibited superior resistance to moisture damage and deformation. Reddy et al. (2021) supported these findings, emphasizing that soil and fly ash mixtures performed well under repeated traffic loads. In addition to performance benefits, Agarwal et al. (2016) highlighted the environmental and economic advantages of using industrial waste materials, including reduced reliance on natural resources and effective waste management. Finally, Patel et al. (2020) conducted a detailed characterization of ferrochrome slag and concluded that it has significant potential for use as base and subbase material in pavements, while stressing the need for field validation of laboratory results. These studies collectively underscore the potential of industrial by-products as sustainable alternatives in flexible pavement construction, offering economic, environmental, and performance benefits.

1.2 RESEARCH GAP:

As highlighted earlier, ferrochrome slag, despite being a waste inorganic material, has the potential for utilization in various applications, contributing to economic benefits while promoting a pollution-free environment. In this study, the focus is on the characterization of ferrochrome slag for use as a fill and embankment material, as well as its application as a pavement material in road construction. It demonstrates the potential of ferrochrome slag to serve as an alternative material in civil engineering, specifically for filling, embankments, and pavement in road construction.

1.3 OBJECTIVES:

1. To evaluate the baseline geotechnical properties of red soil without any replacement or addition of ferrochrome slag (FCS) or fly ash.
2. To investigate the effects of partial replacement of red soil with FCS at varying proportions (0%, 10%, 20%, 30%, and 40%) on soil strength and durability.
3. To examine the impact of adding 5% fly ash to red soil-FCS mixtures on improving soil stabilization properties.
4. To determine the optimum replacement level of FCS and the effectiveness of fly ash in achieving enhanced mechanical performance and economic feasibility.
5. To assess the potential of utilizing FCS and fly ash as sustainable alternatives in geotechnical and construction applications.

2.MATERIALS AND METHODOLOGY

2.1 Materials

Ferrochrome Slag (FS):
Ferrochrome slag is a byproduct generated during ferrochrome production, primarily consisting of oxides such as chromite and iron. It is produced by smelting chromite ore with fluxing agents like quartzite, lime, and dolomite at a high temperature of 1400°C. The slag has a high specific gravity (2.8–3.2), low water absorption, and a granular structure, making it dense, stable, and highly suitable for load-bearing applications. Chemically, it is rich in silica (SiO_2), alumina (Al_2O_3), magnesia (MgO), and contains traces of chromium oxide (Cr_2O_3) and iron oxide (Fe_2O_3), contributing to its chemical stability. FS sourced from industries in Visakhapatnam, India, is used for pavement applications due to its excellent mechanical and physical properties.

Red Soil (RS):
Red soil is a fine-grained material generated as a byproduct during alumina extraction from bauxite. It is reddish due to its high iron oxide (Fe_2O_3) content and has moderate plasticity with low permeability. The soil is cohesive, with a specific gravity ranging between 2.6 and 2.7, but has poor load-bearing capacity in its natural state, making it unsuitable for direct construction use. Chemically, red soil comprises significant amounts of silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3), with smaller amounts of lime (CaO) and magnesia (MgO). In this study, samples were collected from Visakhapatnam, India, and compared with stabilized materials for pavement subgrade applications.

Fly Ash (FA):
Fly ash is a lightweight, fine-grained byproduct produced during coal combustion in thermal power plants. It is collected using electrostatic precipitators and is characterized by its pozzolanic properties, which make it an excellent material for soil stabilization. Physically, fly ash has a specific gravity of 2.1–2.6, a spherical particle shape, and fine particle size, contributing to its stability and binding potential. Chemically, it is rich in silica (SiO_2) and alumina (Al_2O_3) with notable amounts of calcium oxide (CaO) and iron oxide (Fe_2O_3). The fly ash used in this study was sourced from Visakhapatnam and is effective in enhancing the engineering properties of soils.

Compaction Characteristics of soil

Comparing the test results from the present study with the acceptable values as per IS: 2386-1963

Parameter	PresentStudy	Acceptable Values (IS: 2386-1963)
Specific Gravity	3.21	2.4 to 2.9
Bulk Density(kg/lit)	1.785	-
Water Absorption (%)	0.8	Max. 2
Void Ratio	41.7	-
Impact Value (%)	8.61	Max. 30 for wearing coarse, 35 for bituminous macadam, and 40 for water-bound macadam base coarse.
Crushing Value(%)	21.64	Max. 45 for base coarse, and 30 for surface coarse
Abrasion Value(%)	25.84	Max. 30 for water-bound and 50 for bituminous macadam base courses
Flakiness Index(%)	9.286	15
Elongation Index(%)	14.448	20
Angularity Number (%)	8.159	0 to 11

2.2 METHODOLOGY

The study investigates the potential of ferrochrome slag (FS) as a partial replacement for red soil in soil stabilization applications, particularly for subgrade construction in pavements. FS content was varied incrementally from 0% to 40%, while maintaining a constant fly ash (FA) proportion of 5% in all samples. The red soil content was adjusted accordingly to achieve the desired mix proportions.

The following mix proportions were prepared and tested:

- 0% FS: Red soil 95% + Fly Ash 5%

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- 10% FS: Red soil 85% + Fly Ash 5%

- 20% FS: Red soil 75% + Fly Ash 5%

- 30% FS:Red soil 65% + Fly Ash 5%

- 40% FS: Red soil 55% + Fly Ash 5%

The methodology involved collecting ferrochrome slag, red soil, and fly ash from specific locations in Visakhapatnam, India. The materials were dried, sieved, and mixed in the proportions mentioned above. Each mix was prepared by thoroughly blending FS, red soil, and FA to achieve uniform consistency.

Laboratory tests were conducted to evaluate the physical and mechanical properties of the mixtures. Key tests included specific gravity, Atterberg limits, compaction, unconfined compressive strength (UCS), California bearing ratio (CBR), and permeability. The focus was on analyzing how incremental FS replacement influences soil strength, bearing capacity, and stability.

%of Replacement of FS	CBR Value (%)	%of Replacement of fs + Fly Ash 5%	CBR (%)
0	38.3	0	45
10	42.3	10	48
20	60.8	20	76
30	90.6	30	105
40	60.3	40	80.1

The study aimed to determine the optimum replacement level of red soil with FS to enhance subgrade performance while addressing environmental concerns by utilizing industrial waste materials.

3. RESULT AND ANALYSIS

Table.1 %of Replacement of FS with CBR(%)

Slag Content (%)	Red Soil Content (%)	Fly Ash (%)	SPT Value (N)
0	95	5	12
10	85	5	18
20	75	5	23
30	65	5	28
40	55	5	26

Table.2 Ferrochrome slag mixed with red soil at varying percentages (0% to 40%) and 5% Fly ash for SPT

Slag Content (%)	Red Soil Content (%)	Fly Ash (%)	UCS Value (kPa)
0	95	5	180
10	85	5	250
20	75	5	320
30	65	5	400
40	55	5	360

Table.3 ucs test result

Slag Content (%)	Red Soil Content (%)	Fly Ash (%)	Liquid Limit (LL) (%)	Plastic Limit (PL) (%)
0	95	5	48	24
10	85	5	43	23
20	75	5	38	21
30	65	5	33	19
40	55	5	30	18

Table.4 Liquid Limit (LL) and Plastic Limit (PL)

Slag Content	Red Soil	Fly Ash	OMC	MDD
(%)	Content (%)	(%)	(%)	(g/cm³)
0	95	5	17.5	1.62
10	85	5	15.5	1.72
20	75	5	14	1.82
40	55	5	13.5	1.84

Table.5 OMC and MDD VALUES

Slag Content (%)	Red Soil Content (%)	Fly Ash (%)	Cohesion (c, kPa)	Angle of Internal Friction (φ, degrees)
0	95	5	28	22
10	85	5	34	26
20	75	5	40	30

30	65	5	45	34
40	55	5	42	32

Table.6 angle of internal friction, Cohesion

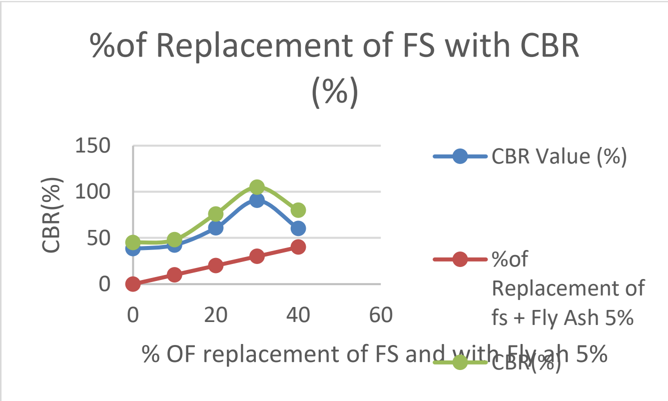

Fig.1%of Replacement of FS with CBR (%)

The study highlights the effect of fine sand (FS) replacement and fly ash (FA) addition on California Bearing Ratio (CBR) values. Without FA, CBR rises from 38.3% at 0% FS to a peak of 90.6% at 30% FS, then declines to 60.3% at 40% FS. With 5% FA, the CBR values improve significantly, increasing from 45% at 0% FS to a maximum of 105% at 30% FS, followed by a slight drop to 80.1% at 40% FS. The results indicate that the optimal FS replacement level is 30%, with fly ash enhancing soil strength across all proportions, as shown in Figure 1.

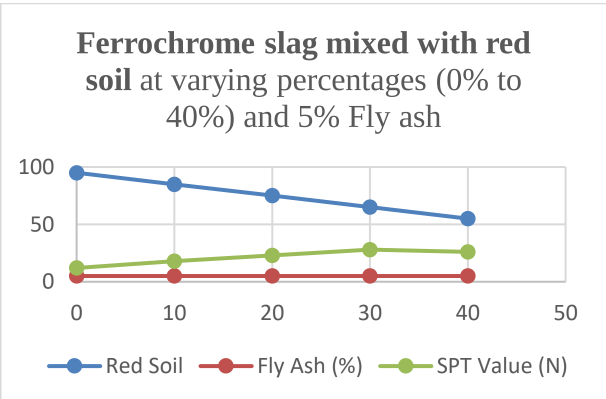

Fig.2 **Ferrochrome slag mixed with red soil** at varying percentages (0% to 40%) and 5% Fly ash

The inclusion of 5% fly ash consistently enhances the SPT values of the soil-slag mix, increasing by 2–4 units compared to mixes without fly ash. Both cases show a peak at 30% slag content, with maximum SPT values of 25 (without fly ash) and 28 (with fly ash). Beyond 30% slag, SPT values decline, highlighting reduced particle interlock. Fly ash addition improves cohesion and load distribution, resulting in a more stable mix, especially at optimal slag content.

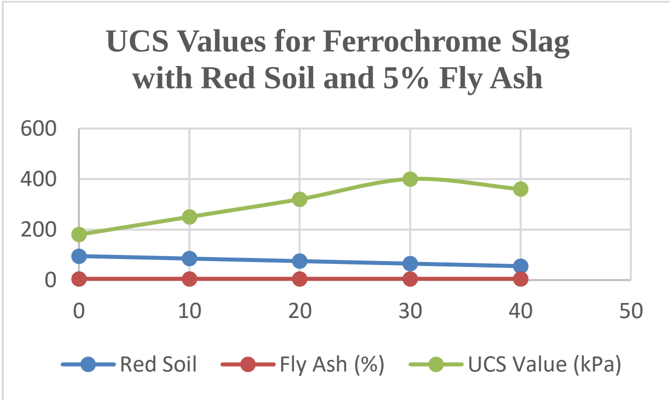

Fig.3 **UCS Values for Ferrochrome Slag with Red Soil and 5% Fly Ash**

This study evaluates the UCS of ferrochrome slag mixed with red soil, with and without 5% fly ash. Without fly ash, UCS peaks at 350 kPa at 30% slag, reducing to 320 kPa at 40% due to cohesion loss. Adding 5% fly ash enhances UCS across all mixes, peaking at 400 kPa at 30% slag, owing to improved bonding from pozzolanic reactions. Fly ash increases UCS by 20–50 kPa consistently, demonstrating better cohesion and strength, with 30% slag as the optimal mix for soil stability.

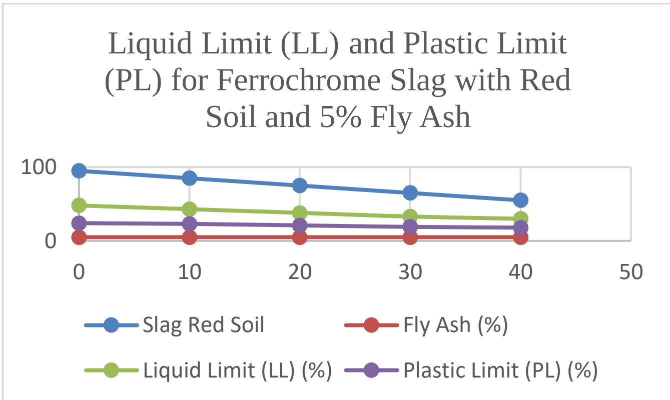

Fig. Liquid Limit (LL) and Plastic Limit (PL)

for Ferrochrome Slag with Red Soil and 5% Fly Ash The study evaluates the impact of ferrochrome slag on the Liquid Limit (LL) and Plastic Limit (PL) of red soil, with and without 5% fly ash. Without fly ash, increasing slag content from 0% to 30% reduces LL from 50% to 35% and PL from 25% to 20%, improving soil workability. At 40% slag, LL and PL slightly rise to 38% and 21%, respectively. With 5% fly ash, LL decreases further, from 48% at 0% slag to 30% at 40%, while PL reduces from 24% to 18%. Fly ash enhances soil stability by significantly reducing plasticity, making it construction-friendly.

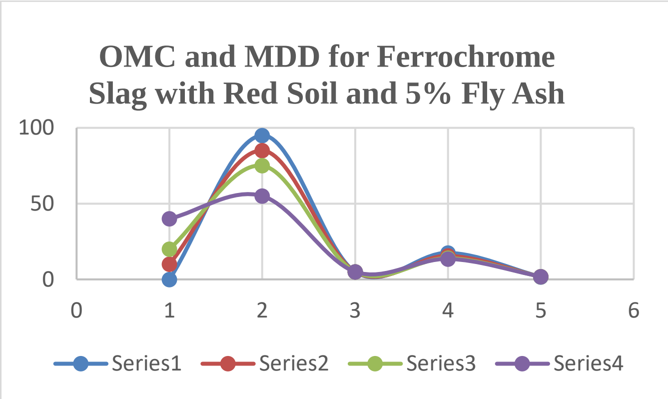

Fig. **OMC and MDD for Ferrochrome Slag with Red Soil and 5% Fly Ash**

The study shows that ferrochrome slag reduces OMC and increases MDD, peaking at 30% slag (OMC: 13%, MDD: 1.85 g/cm³). Adding 5% fly ash further enhances these properties, lowering OMC and slightly increasing MDD across all slag levels. Fly ash improves compaction and water efficiency, optimizing the mix for construction.

CONCLUSION

The study concludes that incorporating ferrochrome slag and 5% fly ash significantly enhances the geotechnical properties of red soil, making it suitable for construction and load-bearing applications. The optimal mix is identified as 30% ferrochrome slag with 5% fly ash, offering the best balance of strength, compaction, and stability. This combination achieves peak values in California Bearing Ratio (CBR), Standard Penetration Test (SPT), and Unconfined Compressive Strength (UCS), along with reduced Liquid Limit (LL) and Plastic Limit (PL), demonstrating improved soil workability and stability. Furthermore, it minimizes Optimum Moisture Content (OMC) while maximizing Maximum Dry Density (MDD), ensuring efficient compaction.

Fly ash enhances cohesion and the angle of internal friction, further stabilizing the mix, even at higher slag levels. This sustainable approach not only reduces dependence on conventional materials but also utilizes industrial byproducts effectively, highlighting its potential for eco-friendly geotechnical engineering solutions.

4.1 FURTHER STUDY

There is a vast scope to use ferrochrome slag as fill, embankment and pavement material in huge quantities. The geotechnical characterization of ferrochrome slag

In this study is limited to a single source and laboratory investigations. Some of the followings are recognized for future studies.

1. More tests and particularly the leachate analysis of the solution required before using the FS in actual construction.
2. It is also required to study its effect stabilizing other problematic soil like expansive

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