CHARACTERIZATION OF FERROCHROME SLAG AS AN EMBANKMENT PAVEMENT MATERIAL

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Abstract

Incorporating industrial waste into construction materials is a growing practice to conserve resources and promote sustainability. This study explores ferrochrome slag, a promising but under-characterized by-product in Indian construction, for its potential use in embankment and pavement construction. Laboratory tests were conducted to evaluate its geotechnical and material properties, comparing its performance against other industrial wastes like fly ash and red mud, as well as natural soil. Tests included specific gravity, grain size distribution, compressive strength, shear strength, and durability to assess ferrochrome slag's viability as a substitute for traditional materials. The study also investigated the stabilization of low-strength residual soil using ferrochrome slag to improve strength and California Bearing Ratio (CBR), making it more suitable for embankments and pavements. Results revealed that ferrochrome slag possesses favorable engineering properties, surpassing fly ash, red mud, and natural soil, with strong potential as a construction material. Ferrochrome slag effectively improves load-bearing capacity and durability when applied to residual soils. This research underscores the value of industrial by-products in construction, reducing waste while fostering sustainable infrastructure development.

Keywords: *Ferrochrome Slag, Fly Ash, Red Mud, Residual Soil, Specific Gravity, Grain Size Distribution, Compressive Strength, Shear Strength, California Bearing Ratio, Durability.*

1. INTRODUCTION

The use of large quantities of natural materials in constructing roads, embankments, and other civil engineering structures has raised concerns due to the rapid depletion of these resources, necessitating the search for sustainable alternatives (Yadav et al., 2021). Industrialization has led to the accumulation of significant quantities of by-products or industrial waste, posing environmental risks through land, air, and water pollution. Effective management and utilization of industrial by-products have thus become vital for industry sustainability (Kumar et al., 2020). To address these issues, numerous attempts have been made to incorporate industrial wastes—such as fly ash, blast furnace slag, and red mud—into civil engineering construction projects as substitutes for natural resources (Sharma and Singh, 2019).

One notable by-product is ferrochrome slag, generated from ferrochrome steel plants, with annual global production estimated at 6.5 to 9.5 million tons, increasing annually by approximately 2.8 to 3% (Kauppi and Peka, 2007). Ferrochrome slag composition typically includes 13-39% SiO_2, 10-29% MgO, 16-43% Al_2O_3, 1-6% CaO, 6-18% Chromium, and 3-11% Iron (Rao et al., 2019). This study characterizes ferrochrome slag's properties and explores its potential use as fill material for geotechnical structures such as embankments, given the limited research on its application within Indian civil engineering (Patel et al., 2022).Although ferrochrome slag remains underutilized globally in civil engineering, this research aims to address the gap by evaluating the material's potential as an alternative geotechnical material. Laboratory tests conducted on local ferrochrome slag provide insights into its physical characteristics, morphology, mineralogy, chemical properties, index properties, and shear characteristics for geotechnical and transportation applications. Testing followed established standards, including IS: 2720–1985 and SP36 (Part 1) for geotechnical properties, and IS: 2386 and MoRTH standards for aggregates in transportation applications (BIS, 1985; MORTH, 2013). Comparative assessments were also conducted with industrial wastes such as red mud, fly ash, and local red soil to evaluate the feasibility of ferrochrome slag as a sub-grade material (Vijay et al., 2023).

1.1 Objectives

1. To determine the pH and chemical composition of ferrochrome slag to assess its suitability for construction applications.
2. To evaluate the mineralogy and morphology of ferrochrome slag through SEM and XRD analyses.

3. To analyze specific gravity, grading, and compaction properties of ferrochrome slag to establish its use as an alternative fill material.
4. To investigate the CBR and internal friction angle to assess the load-bearing capacity and stability of ferrochrome slag in embankments.
5. To assess the performance of ferrochrome slag-stabilized red soil, focusing on CBR improvement and moisture-density relationships.
6. To conduct strength and durability tests on ferrochrome slag, ensuring compliance with Indian standards for construction materials.
7. To evaluate the impact of blending red soil with ferrochrome slag on permeability and strength, with a view to optimizing embankment materials.

3. Materials

3.1 Ferrochrome Slag (FS)

Ferrochrome production involves chromate and iron oxides as raw materials, with chromite used in either lumpy or fine concentrate forms, often agglomerated for furnace use. Fine concentrates are ground and pelletized in a sintering plant, with the pellets then sintered in a furnace at around 1400°C. Various minerals, including quartzite, bauxite, dolomite, corundum, lime, and olivine, serve as fluxing agents to attain the desired slag composition. Ferrochrome smelting yields both alloy and slag, with slag production varying from 1.1 to 1.6 tons per ton of ferrochrome, depending on feed materials. has about ten ferrochrome plants.as shown in table 1for chemical composition .

Constituents	Present Study (% by Weight)	(% by Weight)
Al_2O_3	26	16-43
SiO_2	30	13-39
MgO	23	10-29
CaO	2	1-6
Cr_2O_3	15	6-18
FeO	4	3-11

Table.1 chemical composition ferro chrome slag

3.1.2 Red Mud (RM)

Red mud, collected from Vijayawada, Andhra Pradesh, India, is a waste product generated during alumina extraction from bauxite ore. The process involves grinding bauxite with caustic liquor, followed by desilication, digestion at 110–300°C, and classification in thickeners. Aluminates liquor overflows for filtration, while red mud underflow is washed and disposed of in ponds. Red mud generation, often 55-65% of processed bauxite, typically results in 1.2–1.4 tons per ton of alumina. Fig.1 show the red mud samples collected for the study.

Fig.1.Redmud

Fly ash, a byproduct of coal combustion, is captured before exiting through power plant chimneys. In this study, dry fly ash was collected from the hopper at JSP, Vijayawada, as shown in table.2

3.1.4 Red Soil (RS)

Red soil, a fine-grained residual soil, was collected from the college campus and is shown in Figure.2. Not suitable for pavement construction, red soil serves as a comparative sub-grade material to ferrochrome slag in this study

Fig.2 Redsoil

Elements	Elements% (by weight)CFS	Elements%(by weight)FFS	Elements%(by weight)RM	Elements%(by weight)FA	Elements% (by weight)RS
O	42.39	22.09	46.70	57.47	43.82
Mg	8.78	---	---	---	---
Si	24.52	12.03	3.65	18.92	3.84
Ca	12.43	---	---	---	---
Cr	---	31.49	---	---	---
Fe	---	11.56	16.86	---	32.60
Zr	---	14.47	---	---	---
Al	11.78	8.36	7.74	15.54	13.62
Na	---	---	23.98	---	4.36
Ti	---	---	1.07	1.39	1.76
C	---	---	---	2.54	---
K	---	---	---	0.94	---

Table.2.Comparison of the Percentage of Chemicals Present in Ferrochrome Slag, Red Mud, Fly Ash, and Red Soil from EDX Analysis

4. Methods

The study employs experimental methods to characterize ferrochrome slag, examining its morphological, chemical, mineralogical, geotechnical, and pavement-related properties as follows:

The geotechnical study evaluates essential properties such as particle size distribution, specific gravity, and bulk density, conducted in alignment with IS: 2720 and SP: 36 (Part 1), and includes pH measurements with an electronic pH meter per SP: 36 (Part 1). Specific gravity is assessed using the pycnometer method, according to IS: 2720 Part III Sec 2 (1980) for fine-grained materials and IS: 2386 (Part III) (1963) for coarse-grained ferrochrome slag. Particle size is analyzed using the wet sieve method (IS: 2720 Part 4 - 1985), while compaction characteristics (moisture content and dry density) are examined through light and heavy compaction tests (IS: 2720 - 1980). Consistency limits, including liquid limit, plastic limit, and plasticity index, follow IS: 2720 (Part 5) - 1985. Soil permeability is tested using both falling and constant head parameters (IS: 2720 Part 17 - 1987), and shear strength is measured under normal stresses of 0.5, 1, and 1.5 kN through direct shear tests (IS: 2720 Part 13 - 1986). California Bearing Ratio (CBR) tests are performed on unsoaked and soaked samples per IS: 2720 Part 16 - 1961, and Unconfined Compressive Strength (UCS) is assessed following IS: 2720 (Part 10) - 1991. Additional assessments for ferrochrome slag include bulk density (loose and compacted) as per IS: 2386 Part 3 (1963), void ratio, shape characteristics (flakiness, elongation, angularity) in accordance with IS: 2386 Part 1 (1963), and soundness testing using sodium sulfate solution as per IS: 2386 Part 5 (1963). Abrasion resistance is evaluated with IS:

2386 Part 1 - 1963 standards, while aggregate crushing strength adheres to IS: 2386 Part 4 (1963) requirements, with specified limits for base courses and pavement surface layers.

Samples	Specific Gravity	IS:2386-1963 (Part 3)Specifications
FFS	3.27	2.4 to 2.9
CFS	3.21	
RM	2.99	
FA	2.26	
RS	2.77	
RS+10%FFS	2.79	
RS+20%FFS	2.81	
RS+30%FFS	2.82	
RS+40%FFS	2.86	
RS+50%FFS	2.9	

Table.3 The specific gravity of fine and coarse-grained ferrochrome slag, red mud, fly ash, and red soil.

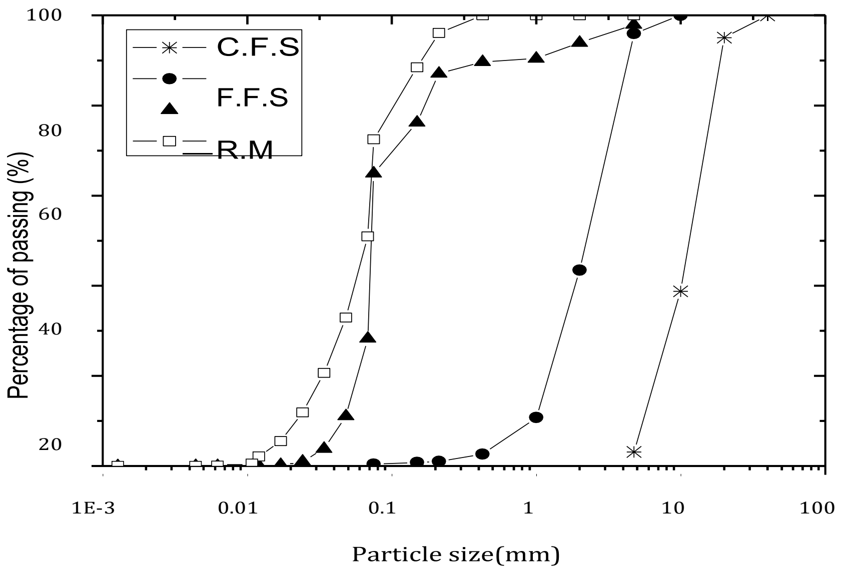

Fig.3. Grain size analysis of fine and coarse grain ferrochrome slag ,red mud, flyash, red soil

The grain size analysis for coarse-grained ferrochrome slag was conducted according to IS: 2386-1963 (Part 1), while the analysis for fine-grained ferrochrome slag, red mud, fly ash, and red soil was performed using the sieve analysis method as per IS: 2720 (Part 4)-1985. The values of the uniformity coefficient (Cu) and the coefficient of gradation (Cc) for ferrochrome slag, red mud, fly ash, and red soil are provided in fig.3. Additionally, the particle size classifications for ferrochrome slag and red soil, along with other industrial wastes (red mud and fly ash), are detailed based on the Unified Soil Classification System (USCS) and IS Classification (IS: 1498 – 1970), as presented in Table 4.6 and Table 4.7, respectively. The Cu values for ferrochrome slag, red mud, fly ash, and red soil are 2.79, 1.89, 1.50, and 3.04, respectively, while the Cc values are 0.95, 1.75, 1.42, and 1.26 for ferrochrome slag, red mud, fly ash, and red soil, respectively. Hence, the ferrochrome slag is classified as a poorly graded material.

5. CHARACTERIZATIONASSUBGRADE MATERIAL

In India, flexible pavements rely heavily on sub-grade soil, which supports the pavement structure. The strength of sub-grade soil significantly influences the design of pavement layers, with inadequate conditions leading to issues like wave formation and cracking. The California Bearing Ratio (CBR) test is essential for assessing sub-grade strength, determining appropriate pavement thickness. This chapter examines a laboratory study of Ferrochrome Slag (FS) and FS-stabilized red soil, evaluating CBR values, compaction, unconfined compressive strength (UCS), consistency limits, and specific gravity for red soil mixed with varying FS proportions (10% to 50%). Results show that adding FS reduces liquid and plastic limits of red soil.

6. Result and discussion

6.1 California Bearing Ratio (CBR)

Prior to actual implementation, it is essential to confirm that the sub-base material satisfies the California Bearing Ratio (CBR) and other physical specifications. Specifically, the material must attain a density of at least 95% of the maximum dry density as determined by the method specified in IS: 2720 (Part 8). Experimental studies were conducted on ferrochrome slag mixes for granular sub-base (GSB), as well as on red soil blended with varying proportions (10%, 20%, 30%, 40%, 50%) of ferrochrome slag. These studies included four-day soaked CBR tests, adhering to IS: 2720 (Part 16) – 1986.
Figure 6.3 displays the Load vs. Settlement curve for ferrochrome slag mixes for GSB, comparing it with ferrochrome slag alone, red soil, and different proportions of red soil mixed with ferrochrome slag after four days of soaking. The CBR values for these materials are presented. The result as shown in fig.4

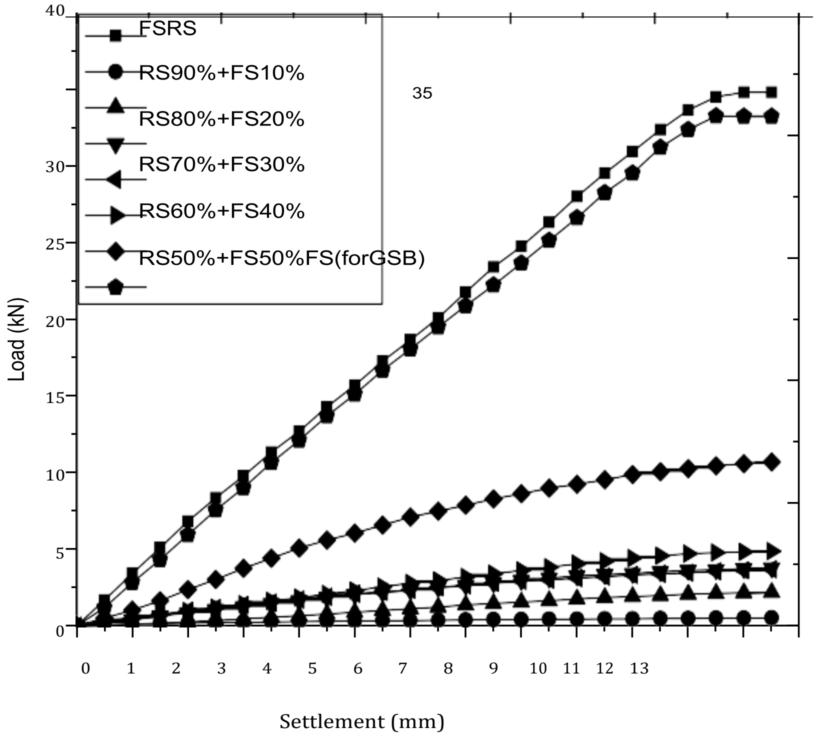

Fig.4.graph re presents the Load vs. Settlement curve for ferrochrome slag mixes for GSB

The CBR values of the ferrochrome slag mix for granular sub-base (GSB) are compared with those of ferrochrome slag, red soil, and various proportions of red soil blended with ferrochrome slag (i.e., 10%, 20%, 30%, 40%, and 50%).

Description	CBR(%)
Ferrochrome Slag (Fine grain)	34.62
Red Soil	1.56
RedSoil90%+FS10%	4.44
RedSoil80%+FS20%	10.1
RedSoil70%+FS30%	10.34
RedSoil60%+FS40%	11.42

RedSoil50%+FS50%	30.06
GSB	74.97

Table 4: CBR values of the ferrochrome slag mix for granular sub-base (GSB)

CBR values of the ferrochrome slag mix for granular sub-base (GSB) compared with those of ferrochrome slag, red soil, and various proportions of red soil blended with ferrochrome slag (10%, 20%, 30%, 40%, and 50%). rubber.

6.2 Shear Strength Test

In this study, experimental investigations were conducted on ferrochrome slag, a ferrochrome slag mix for GSB, and red soil, including various proportions (10%, 20%, 30%, 40%, 50%) of red soil mixed with ferrochrome slag. The testing employed a conventional saturated Direct Shear test in accordance with IS 2720 (Part 39) - 1977. Figure 6.4 presents the comparison of normal stress versus shear strength for the ferrochrome slag mix in GSB, as well as the comparison with pure ferrochrome slag, red soil, and the various proportions of red soil mixed with ferrochrome slag. The results include cohesion values (C) in kPa and the angle of internal friction (φ) in degrees for the GSB mix with ferrochrome slag, as well as for each composition of red soil mixed with ferrochrome slag.as result shown in fig.5

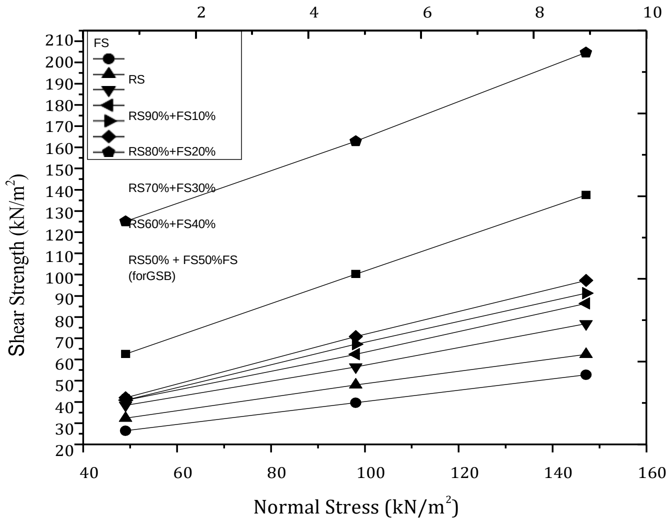

Fig.5 comparison of Normal stress v/s Shear strength of ferrochrome slag mix for GSB and comparison with ferrochrome slag, red soil and different proportion (i.e.10%, 20%, 30%,40%,50%)of red soil with ferrochrome slag

7. CONCLUSION:

Conclusions drawn from the study are as follows:

1. The pH values for coarse- and fine-grained ferrochrome slag are 9.88 and 9.79, respectively, indicating an alkaline nature due to high MgO content.
2. Chemical analysis reveals the presence of approximately 56% alumina silicate compounds and 23% MgO as the primary components.
3. SEM analysis shows that particles are angular to sub angular in shape, with XRD analysis identifying quartz, for sterite, olivine, and spinel as predominant minerals.
4. Ferrochrome slag exhibits specific gravity values between 3.21 and 3.27. The coefficients of uniformity (Cu) and curvature (Cc) are 2.78 and 0.95, respectively, categorizing it as poorly graded.
5. Compaction characteristics indicate that, for light compaction, the optimum moisture content (OMC) is 8.32% with a maximum dry density (MDD) of 2.18 g/cc, and for heavy compaction, the OMC is 7.64% with an MDD of 2.44 g/cc.
6. High MDD values correlate with high specific gravity. When used to stabilize red soil, an increase in ferrochrome slag (FS) content leads to reduced OMC and increased MDD, compared to red soil alone.
7. Ferrochrome slag shows a high California Bearing Ratio (CBR) value of 34.62, which is superior to red mud (18.1) and red soil (1.56).
8. The CBR of red soil improved with the addition of FS, reaching 10.1 with 10% FS content.
9. The angle of internal friction for fine-grained FS is measured at 37°.

10. Soundness testing on coarse-grained slag shows a maximum loss of 2.11% after 10 cycles in sodium sulfate. The bulk density is 1.785, and water absorption is 0.8%, meeting Indian standards. The impact value is 8.613, crushing value is 21.666, and abrasion value is 25.84.
11. Blending red soil with FS enhances its unconfined compressive strength, shear strength, and CBR values. FS has high permeability compared to other materials, whereas red soil has low permeability, limiting its use in embankment applications. Blending red soil with FS reduces the k-value, though further leachate analysis is recommended to assess the effects of FS addition.

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16. These recent sources should provide further insights into ferrochrome slag’s environmental, geotechnical, and structural applications. Let me know if you need additional assistance!