CHARACTERIZATION OF FERROCHROME SLAG AS AN EMBANKMENT AND PAVEMENT MATERIAL

Master of Technology (Research)
In
Civil Engineering

By

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By

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CERTIFICATE

This is to certify that the thesis entitled **"CHARACTERIZATION OF FERROCHROME SLAG AS AN EMBANKMENT AND PAVEMENT MATERIAL**" submitted by **BIBHUTI BHUSAN DAS** in partial fulfillment of the requirements for the award of **Master of Technology (Research)** Degree in **Civil Engineering** with specialization in **Geotechnical Engineering** to the **National Institute of Technology, Rourkela** is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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ABSTRACT

Various efforts are being made to use the industrial wastes as an alternate construction material to conserve the natural resources and effective utilization of the industrial waste to sustain the industrialization. But limited attempts have been made to characterize Indian ferrochrome slag as a construction material. In the work an effort has been made to characterize the ferrochrome slag as an embankment and pavement material. Different laboratory tests pertaining to Geotechnical and highway material characterization has been made and the results have been compared with other industrial wastes like fly ash, red mud and natural soil. An effort also has been made to use stabilize the low strength, residual soil in terms of increasing its strength and California bearing ratio values.

Keywords: Ferrochrome slag, Red mud, Fly ash, Red soil, Specific Gravity, Grain size classification, compressive strength, Shear strength, CBR, Durability, XRD, SEM, EDX.

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LIST OF SYMBOL

NALCO	Notational Aluminium Company
MT	Million Ton
OPC	Ordinary Portland cement
m	Meter
mg	Milligram
NH4	Ammonium
kg	Kilogram
RM	Red mud
P	Phosphorous
°C	Degree centigrade
XRD	X-Ray Diffraction
g	Gram
mm	Millimeter
%	Percentage
EDXRF	Energy dispersive X-ray fluorescence
SEM	Scanning Electron Microscope
Mpa	Mega Pascal
kW	Kilo Watt
SiO_2	Quartz
Al_2O_3	Iron oxide
CO_2	Carbon Dioxide
CO	Carbon monoxide
NaOH	Sodium hydroxide
Hr	Hour
φ	Angle of internal friction
Cc	Compression index
K	Potassium
Cv	Coefficient of consolidation
0	Degree
LL	Liquid limit
PI	Plasticity index
PL	Plastic limit
GS	Specific gravity

μm	Micrometer
Cs	Swelling Index
Ca	Calcium
Fe	Iron
Si	Silicon
Al	Aluminum
Ti	Titanium
Na	Sodium
C	Carbon
Mg	Magnesium
JSP	Jindal steel & power
Cu	Copper
ρ	Bulk density
Na_2O	Sodium oxide
MgO	Magnesium oxide
K_2O	Potassium oxide
SO_3	Sulfur trioxide
MnO	Manganese oxide
Cr_2O_3	Chromium(III) Oxide
P_2O_5	Phosphorus pentoxide
H, Fe_2O_3	Hematite
B	Boehmite
Gb	Gibbsite
R, TiO_2	Rutile
Go, FeO(OH)	Goethite
S, $Na_4(Si_3Al_3)O_{12}Cl$	Sodalite
SW	Well graded sand
CBR	California bearing ratio
IRC	Indian Road Congress
CFS	Coarse grain Ferrochrome Slag
FFS	Fine grain Ferrochrome Slag
RM	Red Mud
FA	Fly Ash
RS	Red Soil

CHAPTER - 1

INTRODUCTION

1.1 Introduction

Large quantities of natural materials are traditionally used in the construction of roads, embankments and other similar civil engineering structures. Due to the depletion of natural materials, there is a need to find suitable alternative material, which will replace the conventional materials. The large scale industrialization has resulted accumulation of huge amount of by products or industrial waste, endangering the environment in terms of land, air and water pollution. The sustainability of industries now depends upon the effective management and utilization of it's by-products. In order to use the industrial waste in huge quantities efforts are being made to use the same as a substitute of natural resources. Various efforts have been made to use industrial wastes like fly ash, blast furnace slag, red mud etc. in some civil engineering construction works. Ferrochrome slag is the by-product of waste generated from the ferrochrome steel plant. Globally, generation of Ferrochrome slag is 6.5 to 9.5 million tons and increased by 2.8 to 3 % per annum (Kauppi and Peka, 2007). It contains 13-39% of SiO_2, 10-29% of MgO, 16-43% of Al_2O_3, 1-6% of CaO, 6-18% of Chromium, 3-11% of Iron and other minerals. The present work focuses to characterize the largely available ferrochrome slag in the geotechnical applications and to find the applicability of such material as fill in Geotechnical structures such as embankment and other similar structures etc.

Very limited efforts have been made worldwide to use ferrochrome slag as an alternate civil engineering material. The characterization of Indian slag is not reported. Hence, an effort is being carried out to characterize the local ferrochrome slag as an alternate civil engineering material. The findings based on the limited laboratory tests of the basic material properties, physical properties suggest that ferrochrome slag has the potential to be used as an alternate geotechnical material.

Figure 1.1 Ferrochrome plant around the world (www.ferro-alloys.net)

1.2 Scope of Present Investigation, Research Objective

From the above, it can be seen that although ferrochrome slag is a waste inorganic material but it can be utilized in various work to develop on economical point of view and making the environment as pollution free. In the present study, characterization of ferrochrome slag to be used as a fill and embankment material and also used as a pavement material in road construction. However, it has the potential to be used as an alternate civil engineering material for filling and embankment as well as pavement material for road construction.

The scope of the present thesis consists of the laboratory tests for finding out the morphology, mineralogy, chemical properties, index properties and shear characteristics (for both Geotechnical and Transportation Engineering point of view)of ferrochrome slag using procedure as that for soil. The geotechnical laboratory investigations were conducted as per Indian Standards (IS: 2720 – 1985 and SP36, Part 1) for soil and transportation laboratory investigations were conducted as per IS: 2386 and MORTH for aggregate. The comparison of some geotechnical properties has been made with other industrial waste materials like red mud, fly ash and also local red soil for using as sub-grade material. Hence, the present research will be helpful to use the Ferro-chrome slag as a fill and embankment material and pavement material.

1.3 Thesis Outline

After the brief introduction (Chapter 1), the review, based on the use of ferrochrome slag both in geotechnical and transportation engineering as well as its other aspects has been discussed in Chapter 2.

Chapter 3 describes the different materials which are used for present study. Different methods for finding the characteristics of ferrochrome slag with other industrial waste products like red mud, fly ash and also with local red soil has been discussed in this chapter. The experimental methods used to characterize ferrochrome slag as a fill and embankment material and pavement material are discussed in this chapter.

Chapter 4 pertains to presentation and discussion of material properties of ferrochrome slag and the results are compared with other geotechnical engineering material like, red mud, fly ash and local soil.

Chapter 5 describes the characterization of ferrochrome slag as a sub-grade material using experimental methods and comparison test results for finding the compaction, shear strength and California bearing ratio (CBR) values of the local red soil mixed with different proportion of ferrochrome slag.

Chapter 6 describes the characterization of slag as a highway material using experimental methods on ferrochrome slag like compaction, shear strength and CBR values.

Chapter 7 conclusions drawn from various studies made in this thesis presented and scope for the future work is indicated. The general layout of the thesis work based on each chapter is shown in flow diagram (Figure 1.2).

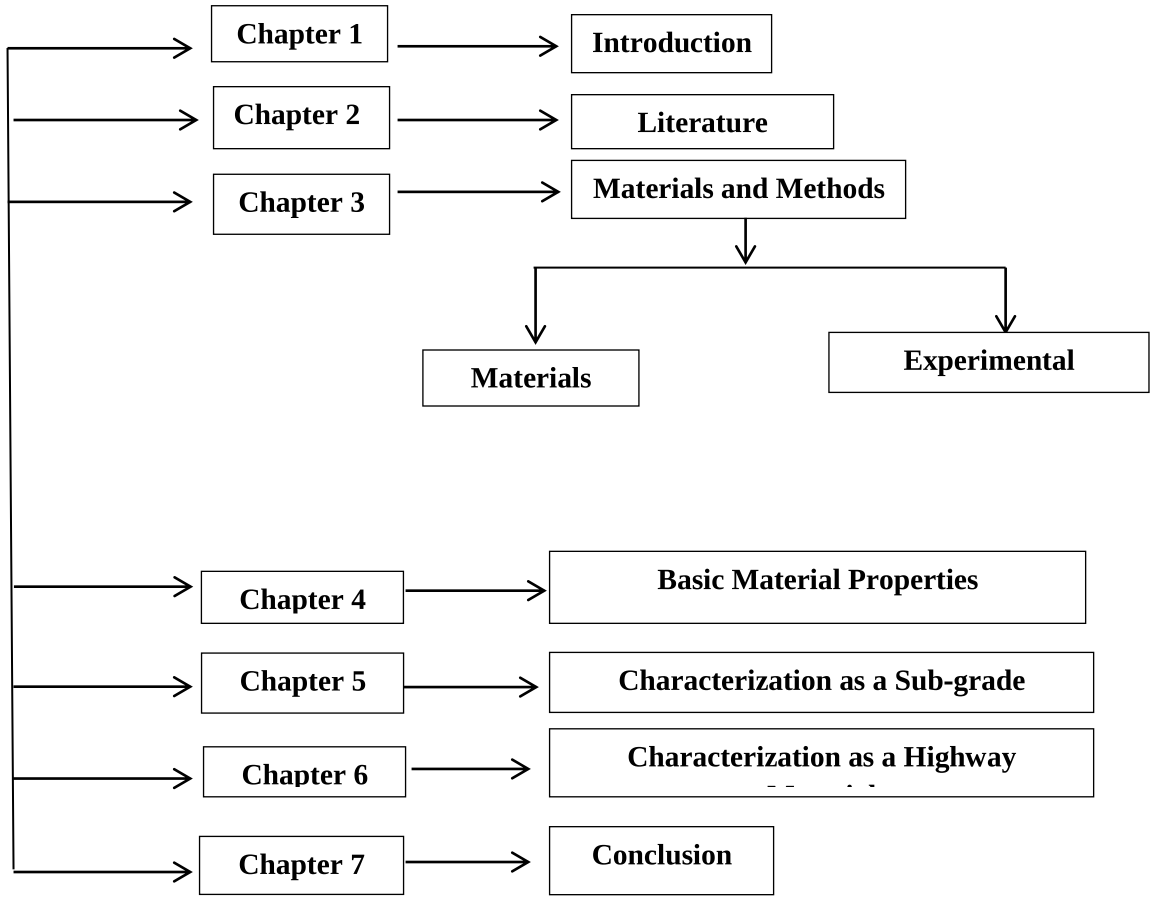


Figure 1.2 Flow diagram showing the organization of the thesis

CHAPTER - 2

REVIEW OF LITERATURE

2.1 Introduction

This chapter discussed about the literature review for the ferrochrome slag. In this, some studies related to characterization of other industrial waste like red mud, fly ash and quarry dust is discussed, in order to pave the methodology for the characterization of ferrochrome slag. Then limited study available of characterization of ferrochrome slag is enclosed. Since 2001's various efforts have been made towards characterization and utilization of ferrochrome slag for different engineering purpose. This chapter discusses about the different investigation for effective use of ferrochrome slag in different applications in general. There, specific literature pertains to geotechnical engineering application is presented.

2.2 Different Experimental and Geotechnical Study on Ferrochrome Slag

Lind (2001) investigated that "leaching tests with salt seawater and P^H adjusted water reveal low leachability from the slag for most elements. It was also reported that in road construction, there was a low migration of particles from the slag to the under lying soil and that the leaching from the Ferrochrome slag to the groundwater was low for the elements analyzed, with the exception of potassium.

Shao-peng *et al*., (2003) analyzed to use steel slag stone matrix aggregate (SMA) is usable as a concrete materials for design. This material was found to highly rigid and excellent friction resistance on the basis of its characteristics.

Tossavainen (2005) noted that the extraction of rock material and ore for construction and metal production involves large quantities of wastes and by-products such as iron and steel making slag has durability qualities and latent cementious properties which are positive in construction.

Nkohla (2006) investigatedthat the best practices for the characterization of ferrochrome smelter slag by following the robust and accurate analytical techniques which is essential for process control, and he discussed its implications to the performance of the smelting process. Slag samples from a ferrochrome smelter were analysed using an XRF powder pellet an analytical technique in contrast to the ICP technique used at the plant laboratory, to determine their composition.

Kauppi *et al.*, (2007) reported that the structure of the slag is partly crystalline and partly glassy. Significant phases are amorphous glass, Fe-Mg-Cr-Al-spinels, forsterite, Mg-Al-silicate and metal alloy. The ferrochrome slag products are chemically very stable.

Kok *et al.*, (2009) reported the properties of hot bituminous mixtures containing ferrochromium slag with neat and strong-butadiene styrene modified binders used in flexible pavements. Based on experimental results, use of ferrochromium slag as total aggregate did not exhibit good performance in terms of stability and stiffness. However the mixture prepared entirely with ferrochromium slag showed good resistance to moisture damage.

Yilmaz *et al.*, (2009) reported the results of experiments, to use ferrochromium slag as an aggregate for granular layers of flexible pavements. The results indicate that the physical and mechanical properties of air-cooled ferrochromium slag are as good as or better than those of natural aggregates. Therefore, FeCr slag and SiFeCr slag have potential to be used as a pavement base layer material in applications where crushed limestone aggregate materials are traditionally used.

Konarbaeva *et al.*, (2010) mineralogical composition of low-carbon ferrochrome slags was studied by means of petrographic analysis. Ferrochrome was produced with ferrosilicon-aluminum used as a reductant. Petrographic analysis of slags indicates the presence of helenite in various forms. Isolated impregnations of melilite, larnite and vitreous phase are distinctly separated which proves the possibility of their separation from helenite phase in further processing.

2.3 Utilization of fly ash in particular, can be broadly grouped into three categories.

The Low Value Utilizations includes, Road construction, Embankment and dam construction, back filling, Mine filling, Structural fills, Soil stabilization, Ash dykes etc. The Medium Value Utilizations includes Pozzolana cement, Cellular cement, Bricks/Blocks, Grouting, Fly ash concrete, Prefabricated building blocks, Light weight aggregate, Grouting, Soil amendment agents, etc. The High Value Utilizations includes Metal recovery, Extraction of magnetite, Acid refractory bricks, Ceramic industry, Floor and wall tiles, Fly ash Paints, and distempers etc.

Since 1970's various effort have been made in utilization of fly ash in geotechnical engineering field.

Sherwood and Ryley (1970) studied that, the fraction of lime present in fly ash, behaves self-hardening properties of fly ash, in the form of calcium oxide.

Mclaren and Digioia (1987) studied that the fly ashes have low values of specific gravity as compared to soil, so it can use as backfill material for embankments, weak foundation soil. Hence, earth pressure exerted by fly ashes are small.

Martin *et al*., (1990) stated that fly ash in moist and partial saturated conditions, shows apparent cohesion values, due to capillary rise and it is not to be used as long term stability of fly ash. For shear criteria shear strength is the major one.

Yudbir and Honjo (1991) found that lime content of fly ash behaves as self-hardening properties, depends upon availability of free lime and carbon content in the samples.

Wesche (1991) studied that, the loss of ignition percentage on fly ash, determine the presence of unburnt carbon in fly ash.

Rajasekhar (1995) found that fly ashes are mainly consists of cenosphere and plerosphere. The low values of specific gravity are due to spherical particle present in which the entrapped air bind within it.

Singh (1996) studied that the unconfined compressive strength is a function of free lime content and apparent cohesion.

Singh and Panda (1996) shows that shear strength of a sample of freshly compacted fly ash is a function of and of internal friction angle, which in turn depends upon the maximum dry density of fly ash sample.

Pandian (1998) reported the low specific gravity, good draining nature, ease way of compaction, good frictional properties etc., can easily gain the use of any geotechnical engineering applications.

Pandian and Balasubramonian (1999) the coefficient permeability was found to decrease upto 200% with 30% increase in MDD value. However, this depends upon the origin of the coal, plant type and collection of sample. Another aspect is that the main emphasis of this thesis was on characterization of ferrochrome slag.

Cokca (2001) fly ash consists of hollow spherical cells of silicon, aluminium and iron oxide, so it provides an array of bivalent and trivalent cation like Ca^{+2}, Al^{+3} anf Fe^{+3} in ionized state, which can promotes the disperse clay minerals.

Das and Yudhbir (2005) found that the lime content, iron content, loss on iginition, morphology and mineralogy affect the geotechnical properties of fly ashes.

Sridharan *et al*., (1998) conducted direct shear box test under as compacted condition, fly ashes exhibits apparent cohesion, due to capillary stresses as a consequence of partial saturation.

Prasad and Bai (1999) studied that due to high reactive silica present in fly ash, fly ash exhibit greater lime reactivity than bottom ash or pond ash.

Sridharan and Prakash (2000) Fly ashes show negative free swell indices due to, low values of specific gravity and due to flocculation and as a consequence of their free lime content.

Sridharan *et al*., (2001) found that the principal constituents of fly ashes are silica (SiO_2), alumina (Al_2O_3), and ferric oxide (Fe_2O_3). Oxides of calcium, magnesium and sodium are also present in fly ashes. If carbon particles do not burn in furnace of boiler, then unburnt carbon particles are also present in fly ashes, and this can be determined from loss on ignition test. He also studied that the pH of fly ashes vary in the range of low value 3 to high value about 12. About 50% of Indian fly ashes are alkaline in nature.

Sridharan *et al.*, (2001) study that the morphology of fly ash contains glassy solid spheres, hollow spheres, sub rounded porous grains, irregular agglomerates and irregular porous grains of unburned carbon (black in colour). If iron particles are present, they can be spotted as angular grains of magnetite (dark gray in colour). The low reactivity of fresh sample indicates low reactive silica or free lime content or high unburned carbon content in fly ash. The particle size distribution and grain characteristics of fly ashes, determine the constitutive behavior and other physical and engineering properties of fly ashes. As fly ashes are predominantly silt size particles, specific surfaces of fly ashes are quite low as compared to kaolinite. The range of specific surface of Indian fly ashes are 130-530 m^2/kg.

Sridharan and Pandian (2001) studied that compacted fly ash tested in un soaked condition, have higher CBR values, than soaked condition of most of the fine grained soils. Such higher CBR value is due to capillary force that exists in the partly saturated state.

Das and Kalidas (2002) found that the specific surfaces of fly ash, subjected to grain size in ESP hoppers may vary considerably.

Trivedi and Sud (2004) found that the specific gravity increases, with increase in fineness and finest fly ash has maximum specific gravity. Table shows that, some of variation in specific gravities.

Prakash and Sridharan (2006) proposed a classification scheme for fly ash if more than 50% of fines (i.e., fraction of size finer than 75µm) belongs to either coarse silt size category or the medium silt size category or (fine silt+clay) size category, then the ash is represented as MLN or MIN or MHN respectively.

Prakash and Sridharan (2007) found that the fly ashes exhibit lower γ_{dmax} and higher OMC. This is due to their low specific gravity, poorly graded particles and presence of more cenospheres. The coarser fly ashes higher OMC and lower γ_{dmax} , while finer fly ashes exhibits a lower OMC and higher γ_{dmax}. The coefficient of permeability is a function of grain size distribution, degree of compaction and pozzolanic property of fly ashes. For compacted ashes, k decreases with the degree of compaction increases. Fly ashes fall in the range of k of silts. For partially saturated compacted fly ash, exhibits some UCC strength due to capillary stress induced some apparent cohesion and pozzolanic action.

Miners (1973) observed that red mud consists of sand and silt size particles with clay size up to 20-30%, with complete absence of quartz minerals. He classified coarse grained fraction as red sand and fine grained fraction as red mud.

Vogt (1974) described in situ undrained shear strengths are typically very high compared to uncemented, clayey soils at equivalent liquidity indices. The sensitivities vary from 5 to 15 with very high friction angles (φ) of $38\text{-}42^0$ are also found for red mud.

Parekh and Goldberger (1976) observed that red mud is highly alkaline and its mineral components are generally hematite, goethite, gibbsite, calcite, sodalite.

Somogyi and Gray (1977) described red mud is highly alkaline, having 20-30% clay sized particles, with the majority of particles in the silt range. One-dimensional compression tests indicate the values for C_c = 0.27-0.39, permeability k = 2-20 $x10^7$ cm/s and $C_v = 3 – 50 \times 10^3$ cm^2/s.

Vick (1981) observed that red mud is of low plasticity with liquid limit (LL) of 45% and plasticity index (PI) of 10% with relatively high specific gravity (G_S) of 2.8-3.3. Due to its lack of clay mineralogy, these wastes show many geotechnical properties similar to clayey tailings found in other mineral processing [e.g., mineral sands, gold, etc].

Li (1998) found that red mud is highly alkaline (pH = 11-13) waste material, whose mineral components includes hematite, goethite, gibbsite, calcite, sodanite and complex silicates and some red mud have been found to have greater than 50% of the particles less than 2µm. The cation exchange capacities of red mud are comparable with kaolin or illite minerals.

Newson *et al*., (2006) carried out the investigation on physiochemical and mechanical properties of red mud at a site in the United Kingdom. Based on a set of laboratory tests conducted on the red mud, the material has compression behavior similar to clayey soils, but frictional behavior closer to sandy soils. The red mud appears to be "structured" and has features consistent with sensitive, cemented clay soils. Chemical testing suggests that the agent causing the aggregation of particles is hydroxylsodalite and that the bonds are reasonably strong and stable during compressive loading and can be broken down by subjecting the red mud to an acidic environment. Exposure of the red mud to acidic conditions causes dissolution of the hydroxysodalite and a loss of particle cementation. Hydration of the hydroxysodalite unit cells is significant, but does not affect the mechanical performance of the material. The shape, size, and electrically charged properties of the hydroxysodalite, goethite, and hematite in the red mud appear to be causing mechanical behavior with features consistent with clay and sand, without the presence of either quartz or clay minerals.

Liu *et al.*, (2006) observed that the pH value of red mud decreases with increase in duration of storage time and Oxygen(O) accounted for about 40% with the other major elements included Calcium (CA), Iron(Fe), Silicon(Si), Aluminum(Al), Titanium(Ti), Sodium(Na), Carbon, Magnesium(Mg) and Potassium(K) . XRD analysis shows calcite, perovskite, illite, hematite and magnetite are present in red mud and the old red mud also contained some kassite and portlandite. In addition, there are about 20% of amorphous materials in all red mud.

Sundaram and Gupta (2010) have made some in-situ investigation on the red mud to be used as a foundation material and they have observed that red mud is highly alkaline (9.3-10.2) with liquid limit of 39-45 %, plastic limit of 27-29% and shrinkage limit of 19-22%. They also found that undrained shear strength is 0.4 to 1.4 kg/cm^2, specific gravity is 2.85-2.97, cohesion is 0.1 to 0.2 kg/cm^2 and angle of internal friction is $26\text{-}28^0$. Table 2.2, shows the comprehensive work done on geotechnical characterization of red mud.

Rout *et al*., (2013) Characterized red mud as a pavement and tailing dam material and found that it has the potential to be used as a fill and embankment material.

2.4 Different experimental study on quarry dust

Quarry dust can be defined as residue, tailing or other non-voluble waste material after the extraction and processing of rocks to form fine particles less than 4.75mm, which is abundantly available to the extent of 200 million tons per annum. Quarry dust is fine rock particles. It is gray in color and it is like fine aggregate. The utilization of quarry fines is seen as a way to minimize the accumulation of unwanted material which has landfill disposal problems and health and environmental hazards and at the same time to maximize resource use and efficiency in different constructional work.

Ali and Koranne (2011) investigated the effect of stone dust & flyash combine at different percentage on expansive soil, the test results such as index properties, Proctors compaction, swelling and unconfined compression strength obtained on expansive clays mixed at different proportions of fly ash and stone dust admixture. From the results, observed that at optimum percentages, i.e., 20 to 30% of admixture found the swelling of expansive clay is almost controlled and also improved in the other properties of soil.

Koustuvee et al. (2013) attempted to understand the influence of the quarry dust content on the shear strength of sandy soil that the addition of quarry dust increases the shear strength of the sandy soil significantly. The added advantage is that this helps in the saving of sand availability in the variance in shearing strength of sand and quarry dust and the shearing behaviour of quarry dust-sand mixes having different fractions of natural sand and quarry dust.

Patel and Pitroda (2013) evaluated various properties of quarry dust and its suitability in conventional concrete and used as surface dressing in highway work, manufacturing of building material, such as lightweight aggregates, bricks, tiles, autoclave blocks, synthetic rock and kerbs, embankment construction, landfill capping, filler applications, manufactured sand, cement making, green roofs, straw and clay blocks.

Satyanarayana et al. (2013) evaluated the geo-technical properties of compacted crusher dust along with the recycled aggregate. The strength characteristics of compacted crusher dust are evaluated through a series of CBR tests and compaction tests varying the crusher dust dosage from 60% to 10% with respect to recycled aggregate and observed that crusher dust of 20-40% has greater strengths and can be used as a road base and sub-base material.

Sarvade and Nayak (2014) used quarry dust as a stabilizer to improve the geotechnical properties of lithomargic clay which is a dispersive type of soil and highly susceptible to erosion abundantly available in the western coastal belt of Southern India. The lithomargic clay blended with the quarry dust results showed that the geotechnical parameters of the lithomargic clay are improved substantially by the addition of quarry dust with good improvement in the consolidation values, permeability and also the variation in water content does not seriously affect its desirable properties. The settlement analysis of the lithomargic clay and the lithomargic clay blended with 10%, 20%, 30%, 40% and 50% quarry dust for a square footing by using Plaxis 3D and found that there is a decrease in the settlement and increase in the load carrying capacity when blended with quarry dust.

Subbulakshmi and Vidivelli (2014) investigated the effect of quarry dust towards the performance of High performance concrete and focused on its mechanical properties. Also used quarry dust in concrete as a partial replacement of sand. The strength characteristics such as compressive strength and flexural strength were investigated to find the optimum replacement of quarry dust of 0%, 50%, and 100% at 3 days, 7 days, 14 days, 28 days and 60 days of curing.

Based on the above studies, it was observed that various studies have been conducted to utilize industrial wastes like fly ash, red mud, and quarry dust as an alternate construction material in general and as a construction and fill material in particular. Though, above industrials wastes do not have constituents similar to that of soil but have properties similar to that of soil. Among them fly ash has been well investigated and are being used widely as construction and fill material followed by red mud and quarry dust. However, to best knowledge of the author no systematic study on ferrochrome slag have been made to use it as an embankment and pavement material. Hence, in this study an attempt has been to characterize the ferrochrome slag as an embankment and pavement material.

CHAPTER - 3

MATERIALS AND METHODS

3.1 Introduction

This chapter discusses about the materials used and the methodology followed in the present study. Though the main material characterized in the present study is ferrochrome slag, other materials like fly ash, red mud and red soil are also used to compare the results of ferrochrome slag with these materials. In this work completely experimental methodology followed for characterization of these materials is also discussed. A brief introduction about the above materials and methodology is presented as follows.

3.2 Materials

3.2.1 Ferrochrome slag (FS)

The raw material in the production of ferrochrome is chromite and iron oxides. The chromite is used as lumpy ores or fine concentrates, which must be generally agglomerated to make them useable charge for the furnace. Fine concentrate is first ground and made into pellets in the sintering plant and then the pellets are sintered in the furnace at a temperature of 1400°C. Different minerals like quartzite, bauxite, dolomite, corundum, lime and olivine are used as fluxing materials to get the right composition of slag. The smelted products obtained from the smelting furnaces are ferrochrome alloy and slag. The slag production is 1.1-1.6 t / t FeCr depending on feed materials. In Odisha there are nearly ten ferrochrome plants and some are shown in Table 3.1. In the present study ferrochrome slag from **Balasore Ferro Alloys Ltd.**, **Somonathpur,** in the district of Balasore of Odisha, India, was collected. Figure 3.1 shows the industries from which is collected and Figure 3.2 shows the dumping yard of ferrochrome slag.

Table 3.1 List of Ferrochrome Manufacturers in Odisha

Name of Manufactures	Place
BALASORE FERRO ALLOYS LTD.	BALASORE
FACOR	BHADRAKH
IMFA	THERUBALI
ICCL	CHOUDWAR
ROHIT FERROTECH	J.K.ROAD
VISA STEELS	J.K.ROAD
JINDAL STAINLESS	J.K.ROAD
TATA	BRAHMANIPAL
MAITHAN	J.K.ROAD

Figure 3.1 Ferrochrome Slag, Balasore Ferro Alloys Ltd., Somonathpur

Figure 3.2 Dumping yard of ferrochrome slag, Balasore Ferro Alloys Ltd., Somonathpur

Above Figure 3.2 shows the disposal of ferrochrome slag from the plant to the open area as a solid form where the materials are collected in two types i.e. (i) Fine grain ferrochrome slag (FFS) and (ii) Coarse grain ferrochrome slag (CFS) on the basis of particle size. In the present study both fine and coarse grain FS were collected.

3.2.2 Red Mud (RM)

In this work the red mud used was collected from NALCO, Damanjodi, Koraput in the state of Odisha, India. Red mud is the waste industrial material that is obtained during extraction of alumina from bauxite ore. Alumina production process consists of crushing and grinding of bauxite with caustic liquor in ball mills. The slurry after desilication is pumped to large tanks/autoclaves/tubes for digestion at 110°C to 300°C depending upon the mineralogy of bauxite. The digested slurry is diluted and classified in thickeners. The overflow (aluminate liquor) is pumped for controlled filtration and underflow containing red mud is washed and disposed to red mud pond. Depending upon the quality of bauxite, the quantity of red mud generated varies from 55-65% of the bauxite processed. The production of 1 ton of alumina generally results in the creation of 1.2-1.4 tons of red mud. Figure 3.3 and Figure 3.4 show the collected material red mud in the laboratory.

Figure 3.3 Red mud, Damanjodi, Koraput, Odisha

Figure 3.4 Discharge of red mud as slurry into the red mud pond

3.2.3 Fly Ash (FA)

The fly-ash is light weight coal combustion by product, which results from the combustion of ground or powdered bituminous coal, sub-bituminous coal or lignite coal. Fly ash is generally separated from the exhaust gases by electrostatic precipitators before the flue gases reach the chimneys of coal-fired power plants. In the present study the fly ash was collected from hopper of JSP, Jindal Steel Plant

(JSP), Raigard, of Chhattisgarh. In this JSP plant the fly ash is collected through the hopper and is transformed through trucks. Hence, the fly ash in dry state was collected from the plant shown in Figure 3.5.

Figure 3.5 Fly ash, Jindal Steel Plant (JSP), Raigard, Chhattisgarh

3.2.4 Red Soil (RS)

The residual soil collected from the NIT Rourkela campus defined here as Red soil. The red soil shown in Figure 3.6 is the red coloured fine grained residual soil collected from the shallow surface, which is not suitable for the construction of pavements. The red soil is used in the present study for comparison of properties as sub-grade soil to the ferrochrome slag and also characterization of stabilized red soil with ferrochrome slag as sub-grade soil for the construction of pavement.

Figure 3.6 Red soil, NIT, Rourkela campus

3.3 Methods

The present study consists of experimental methods for characterization of ferrochrome slag. The experimental methods refer to investigation of ferrochrome slag in terms of morphological, chemical, mineralogical, geotechnical and pavement material properties, which are elaborated as follows.

Material Characterization Method

3.3.1.1 Scanning Electron Microscope

Scanning Electron Microscope with Energy Dispersive X-ray micro analyser is used in the present study. The chemical and mineralogical characterization of ferrochrome slag is not only beneficial for knowing its composition, but also helps in its classification for its possible utilization as an engineering material. The particle morphology of the ferrochrome slag is analysed using Scanning Electron Microscope (SEM) fitted with Energy Dispersive X-ray (EDX) micro analyser. The particle shape is quantified by using image analysis and documented with micrographs. The SEM used in the present study is JEOL-JSM-6480 LV model. SEM is used to scan a finely focused beam of kilovolt energy. An image is formed by scanning electrode ray tube in synchronism with the beam and modulating the brightness of this tube with beam excited signals. The samples are prepared with carbon coating before being putting in the SEM. Figure 3.7 shows the layout of SEM set up with EDX microanalyses.

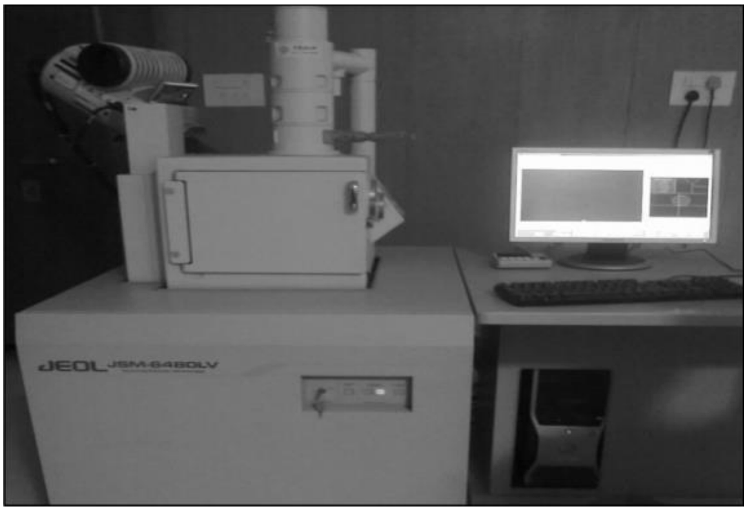


Figure 3.7 SEM model JEOL JSM-6480LV for SEM and EDX analysis, NIT Rourkela

3.3.1.2 X-ray Diffractometer Analysis

The mineral phases present in the collected ferrochrome slag is identified by X-Ray Diffraction (XRD) technique. X-ray diffraction method used to carry out on the samples for qualitative identification of the mineral phases and quantitative estimates of mineralogical composition using Rietveld refinement methods. The samples were dried at 110°C for 24 Hrs and mainly taken into powered form for X-ray diffraction analysis. X-ray powder diffraction was initially carried out on the powders for qualitative identification of mineral phases. The sample is analysed by passing through a Philips diffractometer with a Cu Kα radiation source and a single crystal graphite monochromatic. An angular range of 10–70° of 2θ value (where θ is the incident/glancing angle of X-ray beam) in 0.1° increments was used throughout. Figure 3.8 shows the XRD assembly used in the present study.

Figure 3.8 XRD model PW3040 for the mineralogical analysis

3.3.2 Study of geotechnical properties

Some of the geotechnical properties that are of particular interest on ferrochrome slag are particle size distribution, specific gravity, and bulk density etc. All the geotechnical properties of ferrochrome slag have been found as per IS: 2720 and SP: 36 (Part 1). The pH values are found out by Electronic pH meter and conducted as per SP: 36 (Part 1).

3.3.2.1 Determination of pH value

The acidic or alkaline characteristics of a soil sample can be quantitatively expressed by hydrogen ion-activity commonly designated as pH, which is conveniently expressed by the following:

$$pH = -\log_{10}(H^+) = \log_{10}\left[\frac{1}{H+}\right] \quad (1)$$

where, H^+ is the hydrogen ion-concentration in moles/litre.

The P^H values are found out by Electrometric pH meter by means of an electrode assembly consisting of one glass electrode and one calomel reference electrode with a saturated potassium chloride solution. Potassium chloride is used for salt bridge because of the fact that the transference of the K^+ and Cl^- ions takes place at the rate in true solution. In this experiment buffer Solutions of pH 4.0 (at 25°C) dissolve 5.106 g of potassium hydrogen phthalate in distilled water and dilute to 500 ml with distilled water. Then 30 g of the sample was taken as prepared as IS: 2720 (Part 1) -1983 in a 100-ml beaker with 75 ml of distilled water and stirred for a few seconds following as per SP 36(Part I) of IS: 2720 (Part 26) - 1987.

3.3.2.2 Determination of specific gravity

The specific gravity experiment is done in pycnometer method as per IS 2720 Part III Sec 2 1980 for fine grain ferrochrome slag, red mud, fly ash, red soil, red soil with different proportion (i.e. 10%, 20%, 30%, 40%, 50%) of ferrochrome slag and IS 2386(Part III) – 1963 for coarse grain ferrochrome slag.

3.3.2.3 Determination of particle size analysis

The percentage of various sizes of particles in a given dry sample is found by the mechanical analysis which performed in two stages, i.e. sieve analysis and hydrometer analysis. In this work particle size analyzed by wet sieve analysis method following as per IS: 2720 (Part 4) – 1985.

3.3.2.4 Determination of Compaction characteristics

Compaction test determine the moisture content and dry density relationship as per IS 2720 (1980) conducting two types of compaction i.e. (i) light compaction and (ii) heavy compaction.

3.3.2.5 Consistency Limits Analysis

The values of liquid limit, plastic limit and plasticity index help in classifying the cohesive soil. In this work, the consistency limits are determined or analyzed as per the following of the IS: 2720(Part 5) – 1985.

3.3.2.6 Determination of permeability

The permeability of soil sample is determined by falling head parameter and constant head parameter. The permeability of ferrochrome slag is determine by constant head parameter under condition of laminar flow of water as per IS: 2720 (Part 17) - 1987.

3.3.2.7 Determination of shear strength

Direct shear test is conducted to measure the shear strength of soil. The test is conducted as per IS: 2720 (Part 13) - 1986. Normal stress is given to the different soil samples are 0.5kN, 1kN, 1.5kN.

3.3.2.8 Determination of California bearing ratio

The CBR test is conducted on soil specimen as per IS: 2720(part16) - 1961. For all samples, unsoaked samples are tested for freshly and soaked samples are tasted after 4 days preparation of sample. The soaked samples are subjected 2.5kg surplus load.

3.3.2.9 Determination of unconfined compressive strength

The UCS test is performed as per IS: 2720 (Part 10) - 1991.The test specimen are prepared from freshly in different material with using 20 kN proving ring according to their strength.

3.3.3 Study of other properties as pavement material

Loose and compacted bulk densities of ferrochrome slag are determined in the laboratory as per the IS: 2386 (Part 3) – 1963.

- The ratio of loose bulk density to the compacted bulk density lies usually between 0.87 and 0.96.

3.3.3.2 Void ratio

For this present study for the coarse grained FS, void ratio was found in laboratory as per the IS: 2386 (Part 3) – 1963.

3.3.3.3 Shape test

The evaluation of shape of the FS coarse grained particles made in terms of flakiness index, elongation index, and angularity number. This shape test was done in laboratory as per IS: 2386 (Part 1) -1963.

3.3.3.4 Soundness value

The soundness test is intended to study the resistance of aggregates to weathering action by conducting accelerated weathering test cycle as per IS: 2386 (Part 5) – 1963. The resistance to disintegration of aggregate is determined 0.21% by using saturated solution of sodium sulphate taking five numbers of cycle. The average loss in weight of aggregates to be used in pavement construction after 10 cycles should not exceed 12% when tested with sodium sulphate and 18% when tested with magnesium sulphate. In the present study the soundness test was conducted for coarse grained FS.

3.3.3.5 Abrasion value

In order to check the hardness of coarse grained FS, Los Angeles abrasion tests are carried as per IS: 2386 (Part 1) -1963.

The Los Angeles Abrasion value of good aggregates acceptable for cement concrete, bituminous concrete and other high quality pavement materials should be less than 30%. Values up to 50% are allowed in base courses like water bound and bituminous macadam.

3.3.3.6 Crushing Strength

To achieve a high quality of pavement aggregates possessing high resistance to crushing or low aggregate crushing value are preferred. This experiment was done in laboratory as per IS: 2386 (Part 4) -1963.

The aggregate crushing value for good quality aggregate to be used in base coarse shall not be exceed 45% and the value for surface coarse shall be less than 30%.

3.3.3.7 Impact Value

This experiment was done in laboratory as per IS: 2386 (Part 4) -1963.As per code, the aggregate impact value should not normally exceed 30% for aggregate to be used in wearing coarse of pavements. The maximum permissible value is 35% for bituminous macadam and 40% for water bound macadam base coarse.

Table 3.2 Comprehensive list of experimental tests performed

SL No.	Tests Performed	Materials used
1	SEM	Ferrochrome Slag, Red Mud, Fly ash, Red Soil
2	EDX	Ferrochrome Slag, Red Mud, Fly ash, Red Soil
3	XRD	Ferrochrome Slag, Red Mud, Fly ash
4	pH value	Ferrochrome Slag, Red Mud, Fly ash, Red Soil
5	Sp. Gravity	Ferrochrome Slag, Red Mud, Fly ash, Red Soil
6	Particle size analysis	Ferrochrome Slag, Red Mud, Fly ash, Red Soil
7	Consistency Limits Analysis i. Liquid limit ii. Plastic limit iii. Plastic index	Ferrochrome Slag, Red Mud, Fly ash, Red Soil + Different percentage(10%, 20%, 30%, 40%, 50% respectively) of Ferrochrome Slag
8	Compaction i. Light weight ii. Heavy weight	Ferrochrome Slag, Red Mud, Fly ash, Red Soil + Different percentage(10%, 20%, 30%, 40%, 50% respectively) of Ferrochrome Slag
9	CBR i. soaking	Ferrochrome Slag, Red Mud, Fly ash, Red soil, Red Soil + Different percentage(10%, 20%, 30%, 40%, 50% respectively) of Ferrochrome Slag
10	Direct shear i. Saturated	Ferrochrome Slag, Red Mud, Fly ash, Red soil, Red Soil + Different percentage (10%, 20%, 30%, 40%, 50% respectively) of Ferrochrome Slag
11	UCS	Red soil, Red Soil + Different percentage (10%, 20%, 30%, 40%, 50% respectively) of Ferrochrome Slag
12	Permeability i. Constant head ii. Variable head	Ferrochrome Slag
13	Bulk density	Ferrochrome Slag
14	Void ratio	Ferrochrome Slag
15	Water absorption	Ferrochrome Slag
16	Impact value	Ferrochrome Slag
17	Crushing value	Ferrochrome Slag
18	Abrasion value	Ferrochrome Slag
19	Soundness value	Ferrochrome Slag
20	Shape test i. Flakiness ii. Elongation iii. Angularity number	Ferrochrome Slag
21	Relative density	Ferrochrome Slag

CHAPTER - 4

BASIC MATERIAL PROPERTIES

4.1 Introduction

The results of basic material properties of FS are discussed in this chapter. Though the main aim is to characterize the FS as a structure of fill and pavement material, it is required to know its basic properties like chemistry, mineralogy, morphology etc. for better characterization. Hence in this chapter chemistry, mineralogy, morphology, particle size distribution and specific gravity are presented. The above properties of FS are compared to that with other industrial waste like fly ash, red mud and also with local soil.

4.2 Chemical Analysis

The total chemical analysis of FS is presented in Table 4.1. Ferrochrome slag consists of silica, aluminium, oxides of iron, calcium, chromium and magnesium. It can be observed that the values are comparable to that reported in literature (Kauppi and Keppa, 2007). It may be mentioned here that high magnesium (MgO) is a matter of concern as it may lead to expansion.

Table 4.1 Chemical Composition of ferrochrome slag

Constituents	Present study (% by Weight)	Kauppi and Keppa(2007) (% 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

4.3 pH value of ferrochrome slag and other materials

The P^H value of coarse grain and fine grain ferrochrome slag are found to 9.88 and 9.79 respectively. Hence, this sample reacts with alkali in nature and the high pH value is due to high MgO value. The pH values of other material like red mud, fly ash, red soil are also given in Table 4.2. It can be seen that fly ash and red soil are slightly acidic, due to presence of less CaO content and more silica content (Yudhbir and Honjo, 1991).

Table 4.2 pH value of ferrochrome slag, red mud, fly ash and red soil

Samples	P^H value
Fine grain ferrochrome slag	9.79
Coarse grain ferrochrome slag	9.88
Red mud	10.43
Fly Ash	6.65
Red soil	6.78

4.4 Energy-dispersive x-ray analysis

The particles chemistry of the ferrochrome slag was determined through EDX is shown in Figure 4.1, for fine grain ferrochrome slag and Figure 4.2 with presence of chemicals like silicon (Si), aluminium (Al), chromium (Cr), iron (Fe) etc.. It was observed that there is some variation in the chemical composition of the slag based on different size fraction. The percentage by weight of chemical present in ferrochrome slag from EDX test is presented in Table 4.3. Similarly, the particles chemistry of the red mud, fly ash, red soil was determined through EDX and are shown in Figure 4.3, Figure 4.4 and Figure 4.5 respectively Finally, the percentage of chemicals present in ferrochrome slag, red mud, fly ash, red soil from EDX test is presented in Table 4.3. It can be seen that these are major difference between different materials particularly the Mg content and chromium content. But it may be mentioned here that the EDX result refers to any particle chemistry and not the gross chemical analysis.

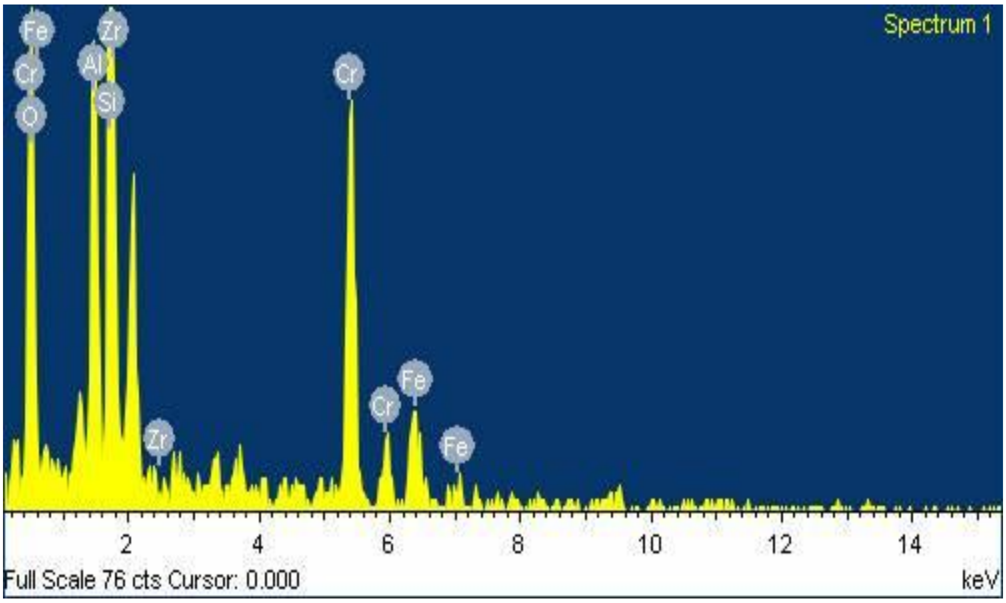


Figure 4.1 EDX plot for fine grain ferrochrome slag

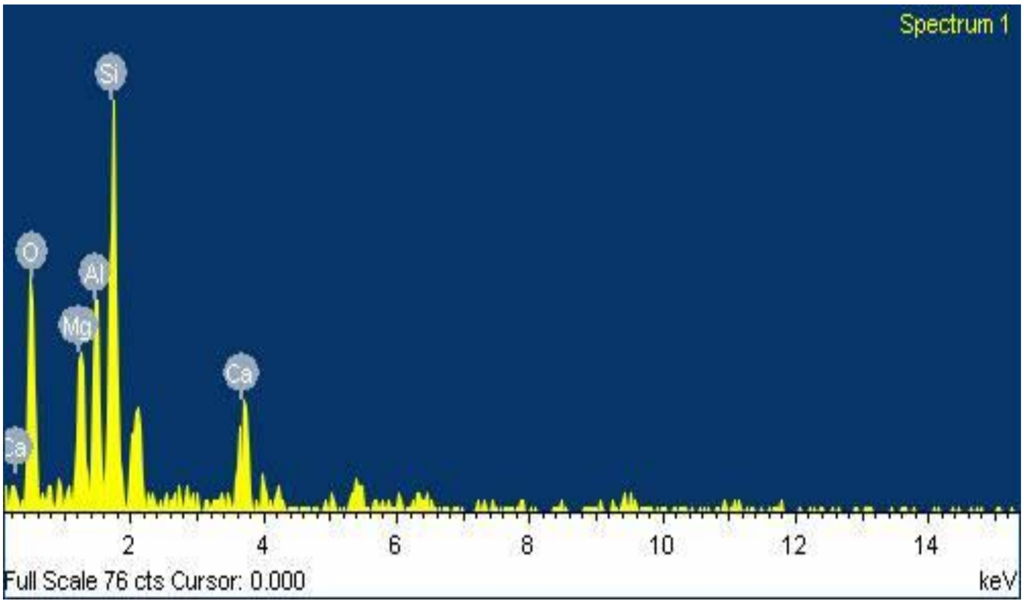


Figure 4.2 EDX plot for coarse grain ferrochrome slag

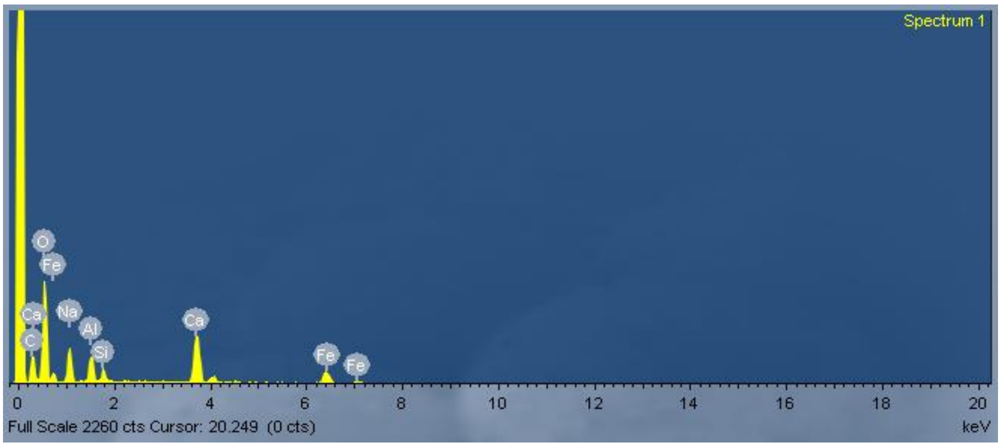


Figure 4.3 EDX plot for red mud

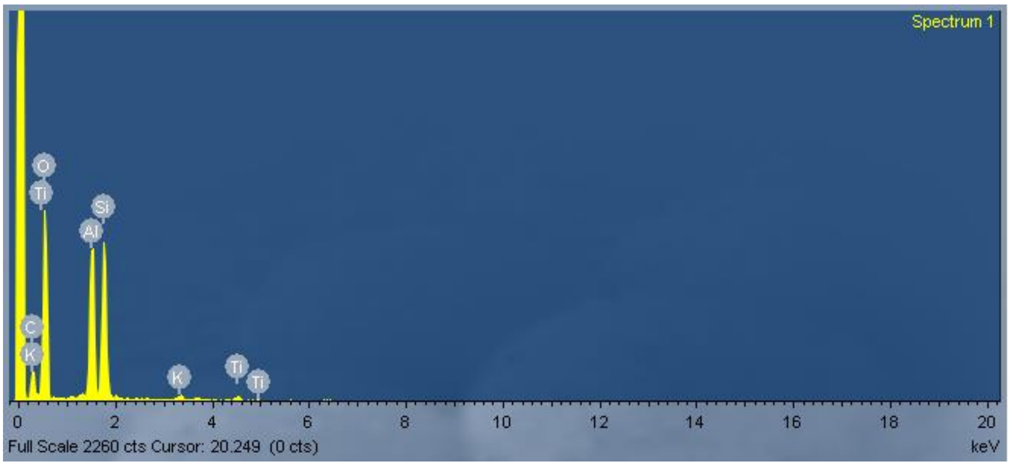


Figure 4.4 EDX plot for fly ash

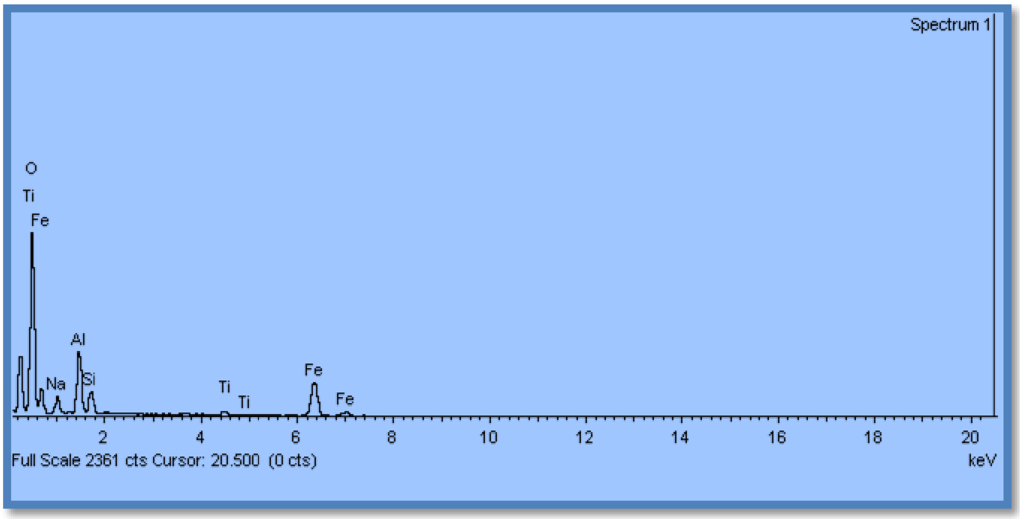


Figure 4.5 EDX plot for red soil

Table 4.3 Comparison percentage of chemicals present in ferrochrome slag, red mud, fly ash, red soil from EDX analysis

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	---

4.5 Scanning Electron Microscope Test

The micro morphology of materials is tested using Scanning Electron Microscope (SEM). The SEM is used to scan a specimen with a finely focused beam of kilovolt energy. The SEM micrograph of fine grain FS at different magnification is presented in figures 4.6 to 4.7. It can be seen that FS contains very irregular particles. The magnified irregular particles as shown in Figure 4.7 that particles, the FS particles are not plate like, rather like spinal structure. Similarly the SEM micrograph of coarse grain FS is shown in Figure 4.8 and 4.9. For comparison the micro photograph of red mud, fly ash and red soil are shown in Figures 4.10, 4.11 and 4.12 respectively.

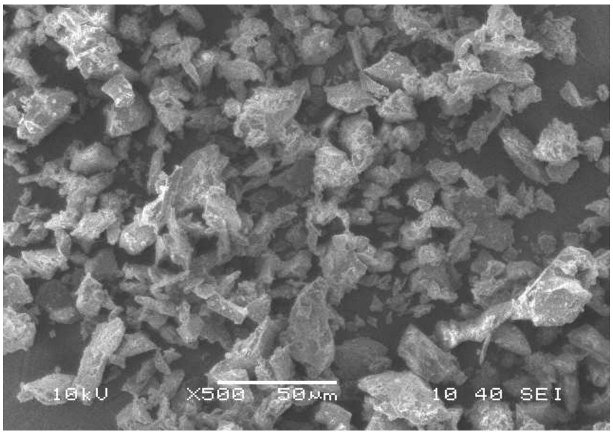


Figure 4.6 Scanning electron micrograph of fine grain ferrochrome slag at 500 magnification

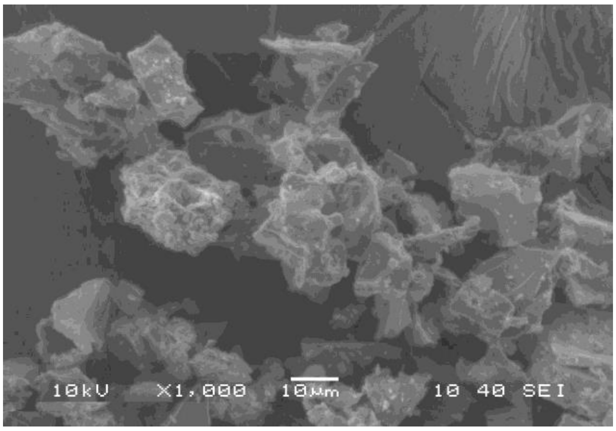


Figure 4.7 Scanning electron micrograph of fine grain ferrochrome slag at 1000 magnification

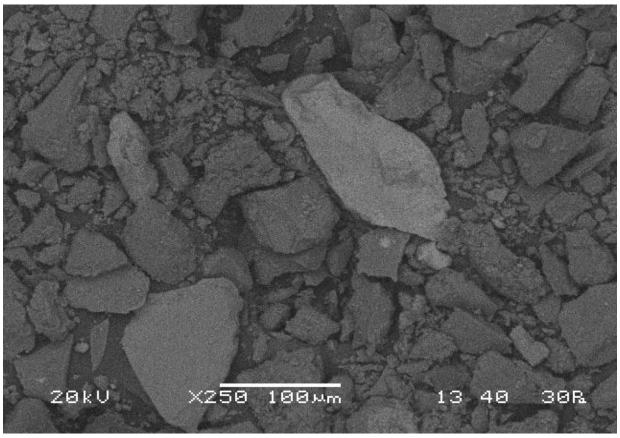


Figure 4.8 Scanning electron micrograph of coarse grain ferrochrome slag at 250 magnification

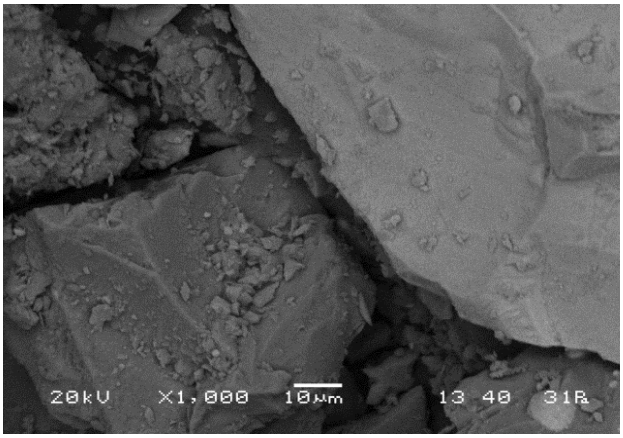


Figure 4.9 Scanning electron micrograph of coarse grain ferrochrome slag at 1000 magnification

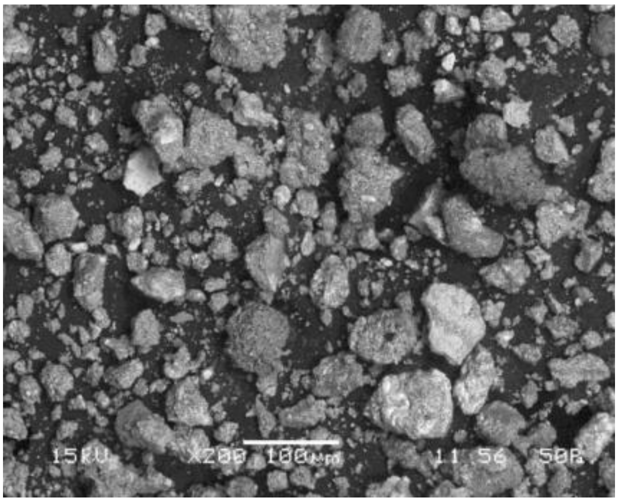


Figure 4.10 Scanning electron micrograph of red mud at 200 magnification

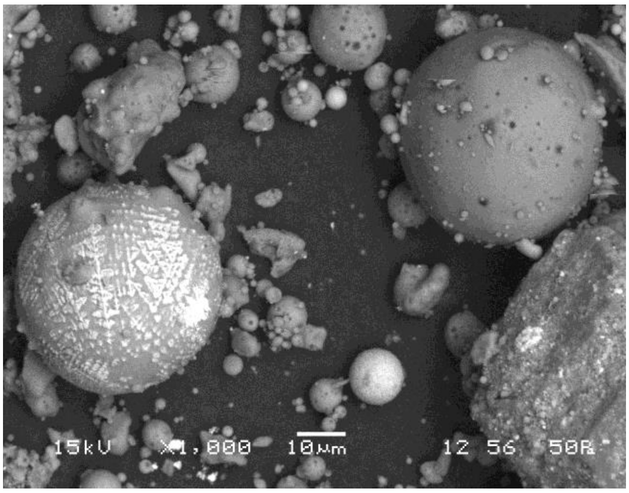


Figure 4.11 Scanning electron micrograph of fly ash at 1000 magnification

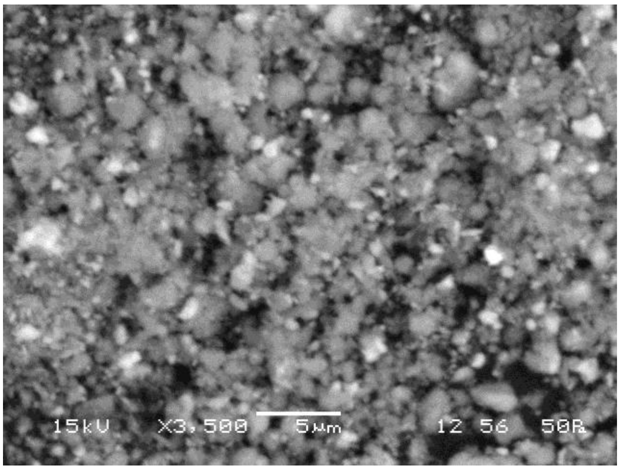


Figure 4.12 Scanning electron micrograph of red soil at 3500 magnification.

4.6 X-ray Diffraction Analysis:

The X-ray diffraction (XRD) test was used to determine the phase compositions of ferrochrome slag particles of both fine grain and coarse grain FS. The basic principles underlying the identification of minerals by XRD technique is that each crystalline substance has its own characteristics atomic structure which diffracts X-ray with a particular pattern. In general the diffraction peaks are recorded on output chart in terms of 2θ, where θ is the glancing angle of X-ray beam. The values are then converted to lattice spacing "d" in Angstrom unit using Bragg's law.

$$d = \frac{\lambda}{2n\sin\theta}$$

where λ = wave length of X-ray specific to target used

n = an integer

The XRD test results of fine grain and coarse grain ferrochrome slag sample are shown in Figure 4.13 and Figure 4.14 below. From these figures it can be observed that quartz, forsterite, olivine and spinel are predominantly present. Similarly, the test results of red mud and fly ash samples are shown in Figure 4.15 and Figure 4.16, respectively and from these figures hematite, boehmite, gibbsite, rutile, goethite, sodalities are found in red mud and soil and quartz, hematite, mullite, aluminium silicate are found in fly ash.

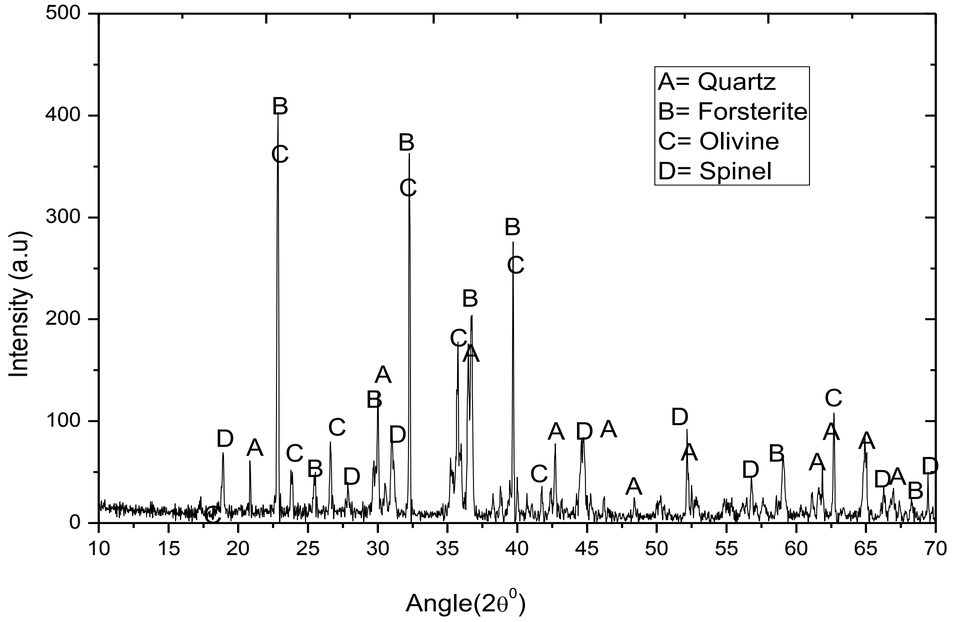


Figure 4.13 XRD plot for fine grain ferrochrome slag

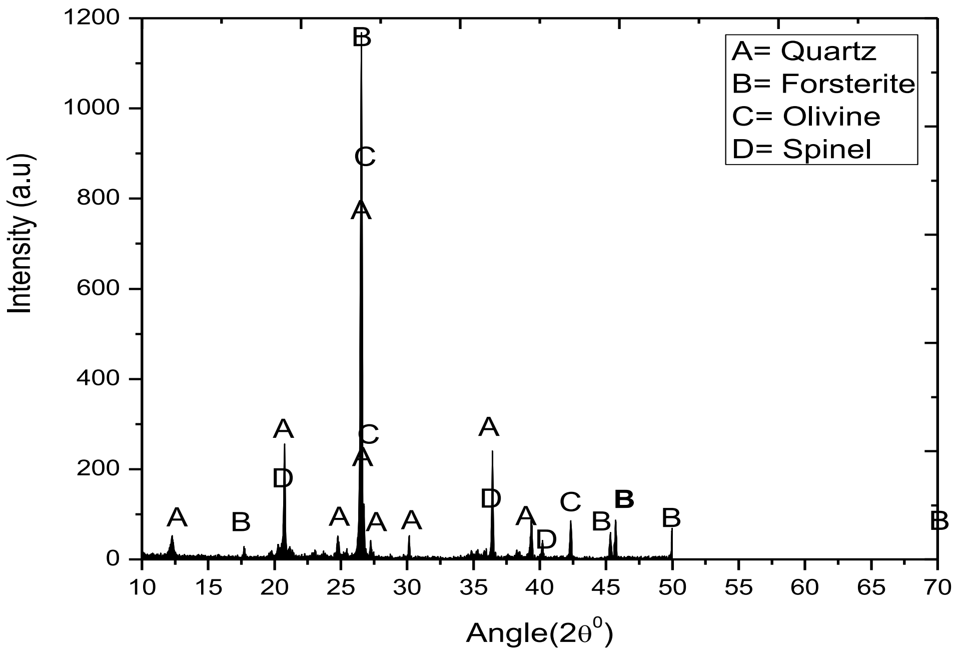
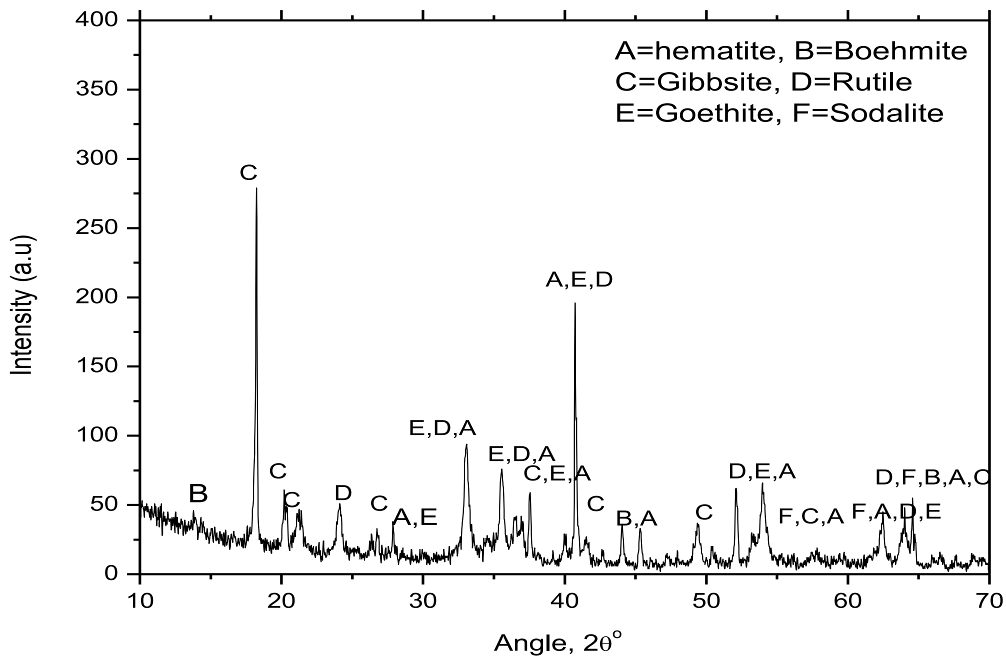


Figure 4.14 XRD plot for coarse grain ferrochrome slag

Figure 4.15 XRD plot for red mud



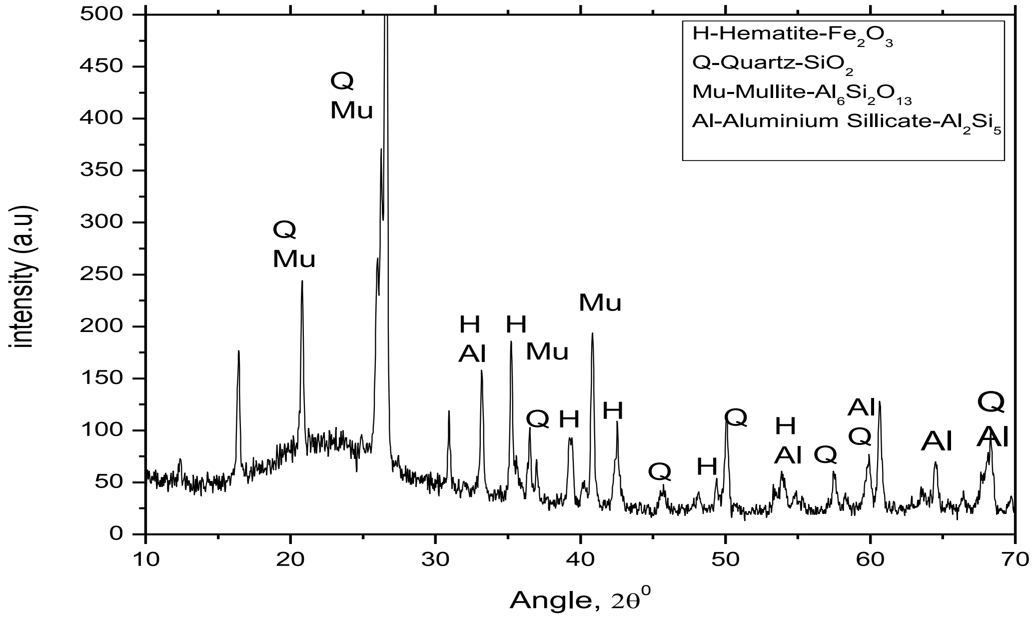


Figure 4.16 XRD plot for fly ash

4.7 Specific Gravity

The specific gravity is determine by the experiment by using pycnometer following as per IS: 2720-1980 (Part 3, Sec 2) for red mud, fly ash, red soil and IS: 2386 - 1963 for ferrochrome slag. Here, the values of specific gravity of fine and coarse grain ferrochrome slag, red mud, fly ash, red soil are given in Table 4.4 below. The specific gravity of fine and coarse grained ferrochrome slag are 3.27 and 3.21 respectively and the specific gravity of other materials like red mud, fly ash, red soil and red soil with ferrochrome slag (i.e. proportion varies from 10% to 50%) are 2.99, 2.26, 2.77, 2.79, 2.81, 2.82, 2.86, 2.9, respectively also presented here. Here the higher specific gravity found for FS than other materials. So, it indicates, ferrochrome slag is heavy weight material than others. The lowest specific gravity of 2.26 was obtained for fly ash and the specific gravity of red soil, FS mixture increased with increase in FS content.

Table 4.4 The specific gravity of fine and coarse grain ferrochrome slag, red mud, fly ash, red soil

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	

4.8 Grain Size Analysis

Figure 4.17 shows the grain size analysis of coarse grain ferrochrome slag following as per IS: 2386-1963 (Part 1), and fine grain of ferrochrome slag, red mud, fly ash, red soil as per IS: 2720 (Part 4) - 1985 of sieve analysis method. Here, the values of C_u and C_c of ferrochrome slag, red mud, fly ash, red soil are given in Table 4.5 below. Also particle size classifications of ferrochrome slag and red soil with other industrial wastes (red mud, fly ash) are presented based on USCS and IS Classification (IS: 1498 – 1970) in Table 4.6 and Table 4.7 respectively. The C_u value of ferrochrome slag, red mud, fly ash, red soil are 2.79, 1.89, 1.50, 3.04, 1.60, respectively and the C_c

value of ferrochrome slag, red mud, fly ash, red soil are 0.95, 1.75, 1.42, 1.26, 1.43, respectively. Hence the FS is a poorly graded material.

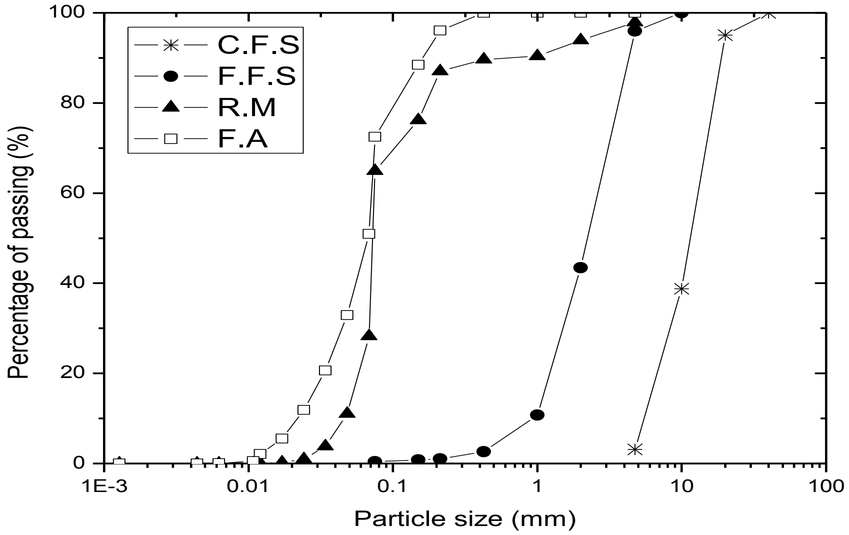


Figure 4.17 Grain size analysis of fine and coarse grain ferrochrome slag, red mud, fly ash, red soil

Table 4.5 The values of C_u and C_c of ferrochrome slag, red mud, fly ash, red soil

Samples	Value of C_u	Value of C_c
Fine grain ferrochrome slag	2.79	0.95
Coarse grain ferrochrome slag	1.89	1.75
Red mud	1.50	1.42
Fly Ash	3.04	1.26
Red soil	1.60	1.43

Table 4.6 Particle size classifications of ferrochrome slag and red soil with other industrial wastes (red mud, fly ash) based on USCS

Type of sample	Gravel (%)	Sand (%)	Silt & Clay (%)
Based on Unified soil Classification system	76.2 to 4.75mm	4.75 to 0.075mm	<0.075mm
Fine grain ferrochrome slag	4.04	95.94	0.014
Coarse grain ferrochrome slag	96.9	3.1	0.0
Red mud	2.08	33.02	64.9
Fly ash	0	27.52	72.48
Red soil	0.04	10.47	89.49

Table 4.7 Particle size classifications of ferrochrome slag and red soil with other industrial wastes (red mud, fly ash) based on IS Classification (IS: 1498 – 1970)

Type of sample	Boulder	Cobble	Gravel		Sand			Silt	Clay
			Coarse	Fine	Coarse	Medium	Fine		
As per IS Classification (IS: 1498 – 1970)	>300mm	≥80mm to ≤300mm	≥20mm to ≤80mm	≥4.75mm to ≤20mm	≥2mm to ≤4.75mm	≥0.425mm to ≤2mm	≥0.075mm to ≤0.425mm	≥0.002mm to ≤0.075mm	<0.002mm
Fine grain ferrochrome slag	00	00	00	4.04	52.52	40.8	2.236	0.404	00
Coarse grain ferrochrome slag	00	00	4.92	91.98	3.1	00	00	00	00
Red mud	00	00	00	2.08	4.02	4.24	24.76	64.9	00
Fly ash	00	00	00	00	00	0.02	27.5	72.48	00
Red soil	00	00	00	00	1.28	1.99	7.2	89.49	00

CHAPTER - 5

CHARACTERIZATION AS SUBGRADE MATERIAL

5.1 Introduction

Flexible pavements are generally adopted for construction of roads in India. Sub-grade soil is an integral part of the road pavement structure as it provides the support to the pavement from beneath. Design of the various pavement layers is very much dependent on the strength of the sub-grade soils over which the pavement is going to be laid. The sub-grade soil and its properties are important in the design of pavement structure. The main function of the sub-grade soil is to give adequate support to the pavement and for this; the sub-grade should possess the sufficient stability under adverse climate and loading conditions. The formation of waves, corrugations, rutting and shoving in black top pavements and the phenomena of pumping, blowing and consequent cracking of pavements are generally attributed due to the poor sub-grade conditions. Generally, in highway engineering, California bearing ratio (CBR), test is performed to determine the strength of sub-grade soil and these CBR values will be helpful to design the thickness of flexible pavement. This chapter presents laboratory study of FS and FS stabilized red soil as sub-grade soil. Here, the CBR values are determined under both unsoaked and soaked condition and compaction, unconfined compressive strength (UCS), consistency limits, specific gravity values are also determined by taking red soil with different proportions of ferrochrome slag from 10% to 50%, so that of different proportion of ferrochrome slag red soil mixture can be used as subgrade material.

5.2 Properties of ferrochrome slag as a subgrade material

5.2.1 Consistency Limits

5.2.1.1 Liquid limit (LL), Plastic limit (PL) and Plastic index of ferrochrome slag

The liquid limit was determined by using cone penetration method following the code IS: 2720 (Part 5) - 1985. The values of liquid limit, plastic limit, plastic index of fine grain ferrochrome slag, red mud, fly ash, red soil and red soil with different proportion (i.e. 10%, 20%, 30%, 40%, 50%) of ferrochrome slag are presented in

Table 5.1. It can be seen that the liquid limit and plastic limit of red soil decreased with addition of FS. Also found that FS and FA have no plasticity in nature. So both are in cohesion less type material and red mud and red soil have low and medium plasticity in nature according to (Das, 2007). The classification of red soil with FS along with other industrial waste are shown in Figure 5.1.

Table 5.1 The LL, PL and PI values of fine grain ferrochrome slag, red mud, fly ash, red soil and red soil with different proportion (i.e. 10%, 20%, 30%, 40%, 50%) of ferrochrome slag.

Types of sample	LL (%)	PL (%)	PI (%)	Description
Fine grain ferrochrome slag	17.22	0	0	Non plastic
Red mud	24.75	17.5	7.25	Low plasticity
Fly ash	30.37	0	0	Non plastic
Red soil	31.26	17.22	14.04	Medium plasticity
Red soil + 10% Fine grain ferrochrome slag	30.47	17	13.47	Medium plasticity
Red soil + 20% Fine grain ferrochrome slag	28.19	16.304	9.88	Low plasticity
Red soil + 30% Fine grain ferrochrome slag	24.65	15.715	8.93	Low plasticity
Red soil + 40% Fine grain ferrochrome slag	22.31	15.099	7.21	Low plasticity
Red soil + 50% Fine grain ferrochrome slag	19.16	13.544	5.61	Low plasticity

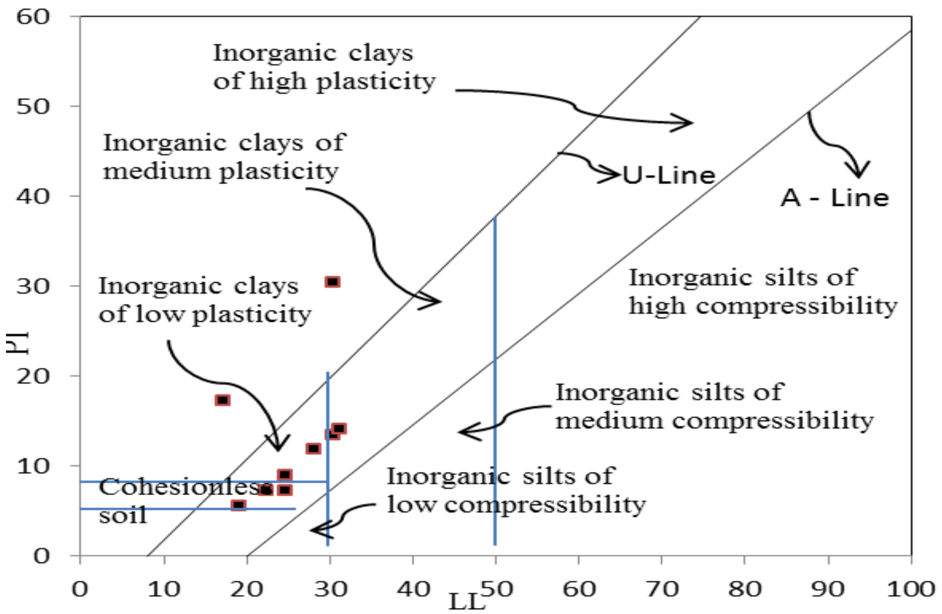


Figure 5.1 Plasticity Chart

5.2.2 Compaction Characteristics

This compaction characteristic was found with the help of Proctor test of both light and heavy weight compaction following as per code IS 2720:1986(Part-III). Figure 5.2 shows the light weight compaction curve of ferrochrome slag, red mud and fly ash, Figure 5.3 shows the heavy weight compaction curve of ferrochrome slag, red mud and fly ash, Figure 5.4 shows the light weight compaction curve of ferrochrome slag, red soil and red soil with different proportion (i.e. 10%, 20%, 30%, 40%, 50%) of ferrochrome slag and Figure 5.5 shows the heavy compaction curve of ferrochrome slag, red soil and red soil with different proportion (i.e. 10%, 20%, 30%, 40%, 50%) of ferrochrome slag are given below. From the compaction curve graph, the value of light weight compaction are 2.18g/cc, 1.93g/cc, 1.27g/cc, 1.89g/cc, 1.91g/cc, 2.02g/cc, 2.05g/cc, 2.16g/cc, 2.22g/cc respectively and the value of heavy weight compaction are 2.44g/cc, 2.05g/cc, 1.45g/cc, 1.94g/cc, 2.09g/cc, 2.11g/cc, 2.16g/cc, 2.22g/cc, 2.28g/cc respectively. Also got the maximum Optimum Moisture Content (%) of light weight compaction of ferrochrome slag, red mud, fly ash, red soil and red soil with different proportion (i.e.10%, 20%, 30%, 40%, 50%) of ferrochrome slag are 8.03%, 16.74%, 22.89%, 13.26%, 11.29%, 11%, 10.87%, 10.10%, 9.61% respectively and maximum Optimum Moisture Content (%) of heavy weight compaction of ferrochrome slag, red mud, fly ash, red soil and red soil with different proportion (i.e.10%, 20%, 30%, 40%, 50%) of ferrochrome slag are 24.01%, 20.10%, 14.30%, 19.06%,20.51%, 20.71%, 21.17%, 21.83%, 22.36% respectively. From the comparative values of maximum dry density (g/cc) and optimum moisture content (%) of for both light and heavy weight compaction of ferrochrome slag, red mud, fly ash, red soil and red soil with different proportion (i.e.10%, 20%, 30%, 40%, 50%) of ferrochrome slag are given in Table 5.2, got that the decrease of moisture content (%) with increase of dry density (g/cc). The water content was determined at three points of the mould and only upto 15%, the average value is reported. Hence, the reported value is representative.

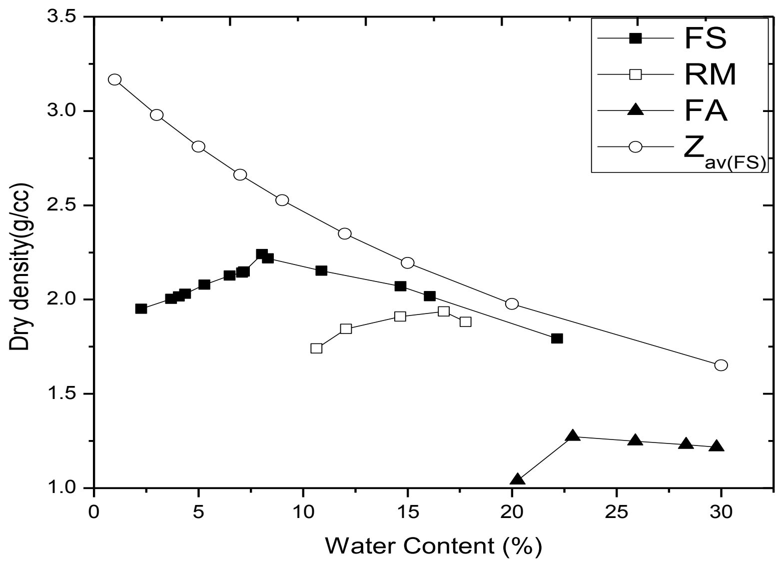


Figure 5.2 Lightweight compaction curve of ferrochrome slag, red mud and fly ash

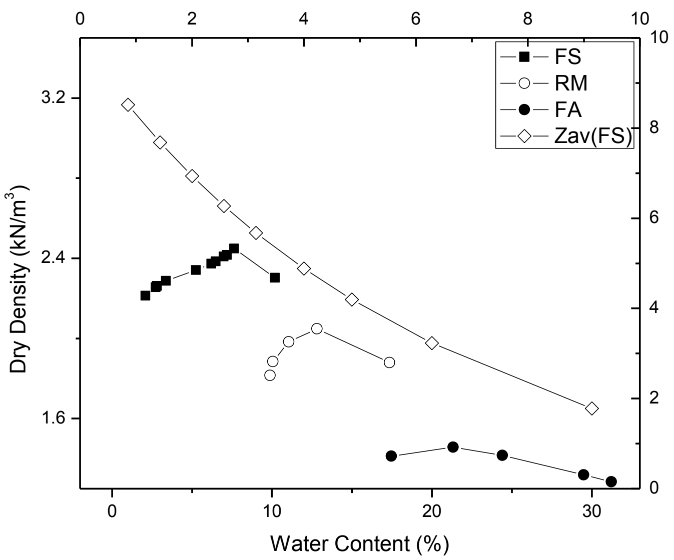


Figure 5.3 Heavyweight compaction curve of ferrochrome slag, red mud and fly ash

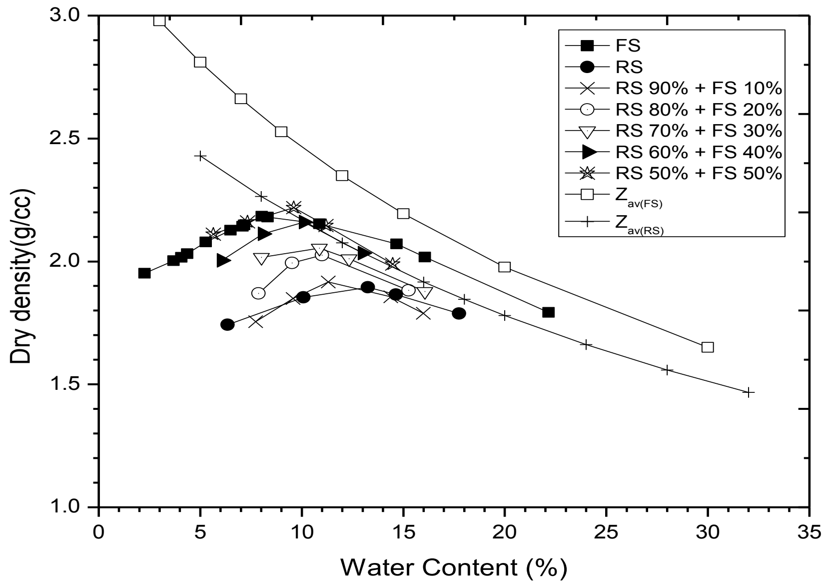


Figure 5.4 Lightweight compaction curve of ferrochrome slag, red soil and red soil with different proportion (i.e.10%, 20%, 30%, 40%, 50%) of ferrochrome slag

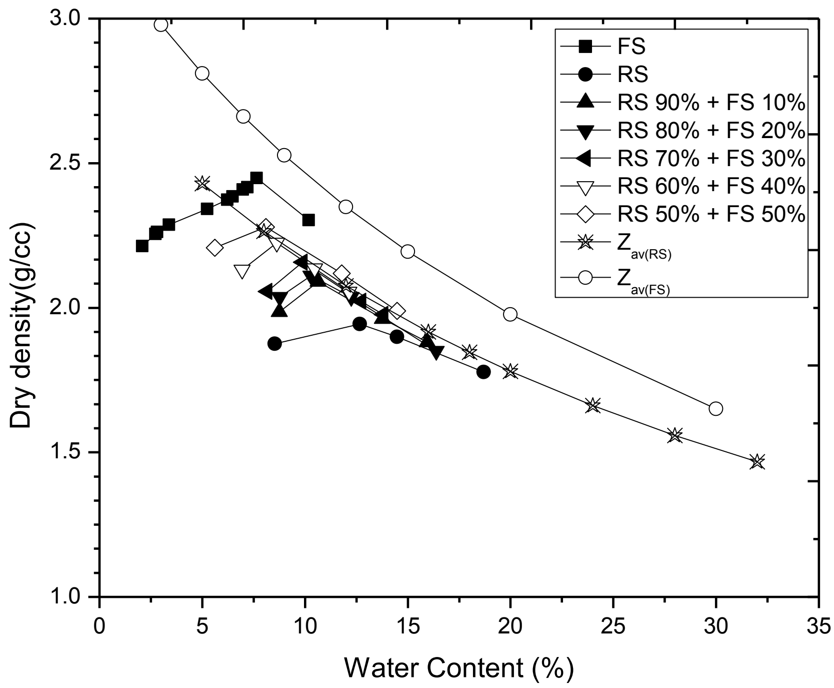


Figure 5.5 Heavyweight compaction curve of ferrochrome slag, red soil and red soil with different proportion (i.e.10%, 20%, 30%, 40%, 50%) of ferrochrome slag

Table 5.2 The values of O.M.C and M.D.D for both light and heavy weight compaction of ferrochrome slag, red mud, fly ash, red soil and red soil with different proportion (i.e.10%, 20%, 30%, 40%, 50%) of ferrochrome slag

Description	Light weight compaction		Heavy weight compaction	
	OMC(%)	MDD(g/cc)	OMC(%)	MDD(g/cc)
Ferrochorme Slag	8.03	2.18	7.64	2.44
Red Mud	16.74	1.93	12.82	2.05
Fly Ash	22.89	1.27	21.32	1.45
Red Soil	13.26	1.89	12.67	1.94
Red Soil 90 %+FS 10 %	11.29	1.91	10.65	2.09
Red Soil 80 %+FS 20 %	11.00	2.02	10.28	2.11
Red Soil 70 %+FS 30 %	10.87	2.05	9.88	2.16
Red Soil 60 %+FS 40 %	10.10	2.16	8.63	2.22
Red Soil 50 %+FS 50%	9.61	2.22	8.10	2.28

5.2.3 California Bearing Ratio (CBR) Test of Ferrochrome Slag

The ratio of force per unit area required to penetrate a soil mass with a circular plunger of 50mm diameter at the rate of 1.25mm/min to that required for corresponding penetration of 2.5mm and 5mm. Where the ratio at 5mm is consistently higher than that at 2.5mm. This test is arbitrary and the results give an empirical strength number, which may not be directly related to fundamental properties governing the strength of soils such as cohesion and angle of internal friction etc.

But the CBR value is related to the properties of soil such as the bearing capacity and the plasticity Index. Its value is used for design of flexible pavement. Here, the experimental studies of ferrochrome slag, red mud, fly ash, red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag including conventional four days soaked CBR test as per IS: 2720 (Part 16) – 1986 are given in Table 5.3 below for using as sub-grade material. The Load v/s settlement curve of ferrochrome slag, red mud and fly ash after 4 days soaking in water are given in Figure 5.6 and the Load v/s settlement curve of ferrochrome slag, red soil and red soil with different proportion (i.e.10%, 20%, 30%, 40%, 50%) of ferrochrome slag after 4 days soaking in water are given in Figure 5.7. From the experimental study, it was observed that the ferrochrome slag has a very high CBR value and the red soil is a very low CBR value. The CBR value of the red soil increased with increase in the percentage of ferrochrome slag.

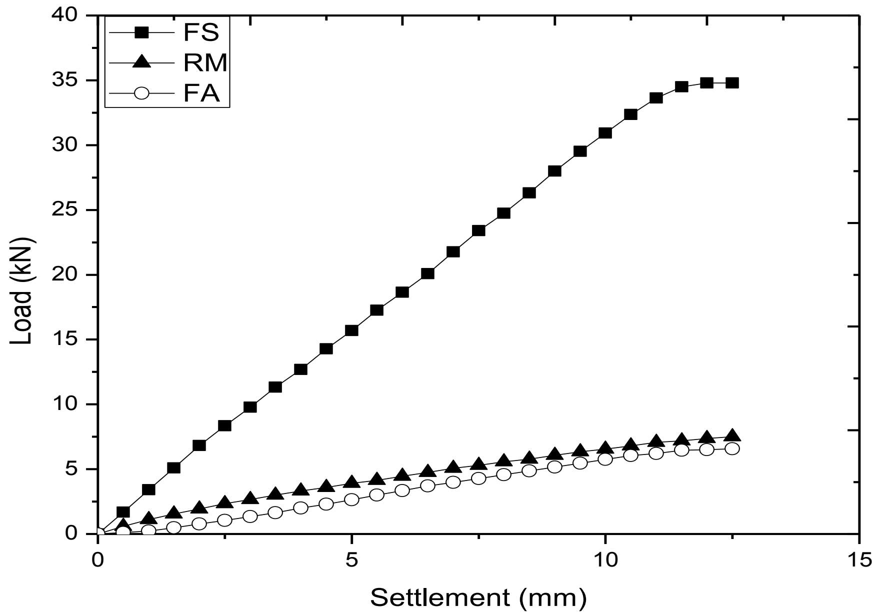


Figure 5.6 Load v/s settlement curve of ferrochrome slag, red mud and fly ash after 4 days soaking in water

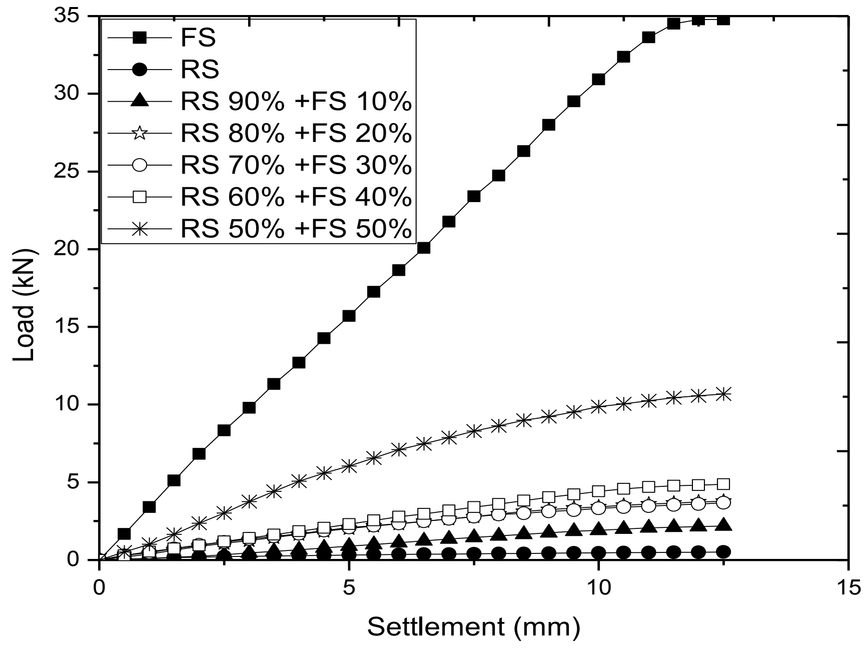


Figure 5.7 Load v/s settlement curve of ferrochrome slag, red soil and red soil with different proportion (i.e.10%, 20%, 30%, 40%, 50%) of ferrochrome slag after 4 days soaking in water

Table 5.3 The CBR value of ferrochrome slag, red soil and red soil with different proportion (i.e.10%, 20%, 30%, 40%, 50%) of ferrochrome slag

Description	CBR (%) Soaking
Ferrochrome Slag(Fine grain)	34.62
Red Mud	18.1
Fly Ash	14.56
Red Soil	1.56
Red Soil 90 %+FS 10 %	4.44
Red Soil 80 %+FS 20 %	10.1
Red Soil 70 %+FS 30 %	10.34
Red Soil 60 %+FS 40 %	11.42
Red Soil 50 %+FS 50%	30.06

5.2.4 Direct Shear Strength of Ferrochrome Slag

The shear strength is one of the most important engineering properties of a soil, for determining the stability of slopes or cuts, finding the bearing capacity for foundations, and calculating the pressure exerted by a soil on a retaining wall. Here, the direct shear test as per IS 2720(Part-39) – 1977 of ferrochrome slag, red mud, fly ash, red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag has been investigated. The values of cohesion (C) in kPa and angle of internal friction (φ) in degree(^{0}) of ferrochrome slag, red mud, fly ash, red soil and different proportion(i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag are given in Table 5.4 below. Figure 5.8 shows the comparison of Normal stress v/s Shear strength of ferrochrome slag, red mud and fly ash and Figure 5.9 shows the comparison of Normal stress v/s Shear strength of ferrochrome slag and with red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag. From the experimental study, it was observed that ferrochrome slag is having high cohesion and internal friction compared to other material.

Table 5.4 The values of cohesion and angle of internal friction values of ferrochrome slag, red mud, fly ash, red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag

Samples ➞	FS	RM	FA	RS	Red Soil 90 % + F.S 10 %	Red Soil 80 % + F.S 20 %	Red Soil 70 % + F.S 30 %	Red Soil 60 % + F.S 40 %	Red Soil 50 % + F.S 50%
Cohesion (C), kPa	25	40	4.1	130	170	190	170	160	150
Angle of internal friction(ϕ), °	37.52	24.36	21.38	15.06	17	21.38	24.9	27.2	29.35

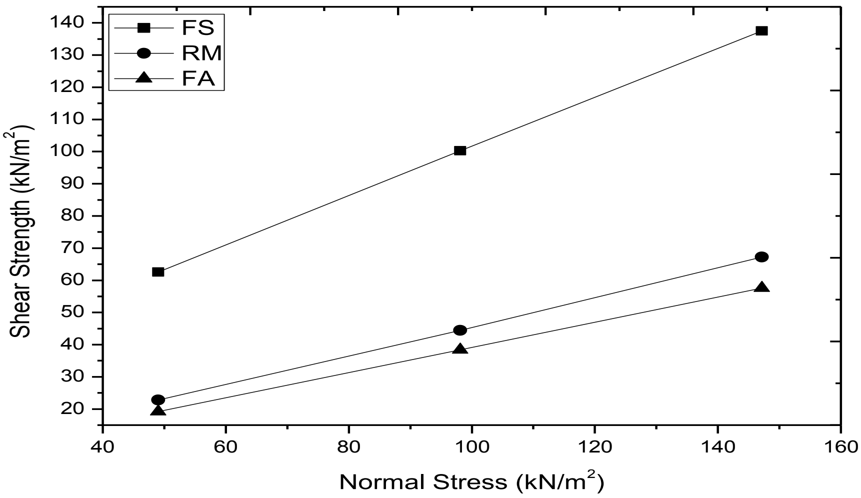


Figure 5.8 The comparison of Normal stress v/s Shear strength of ferrochrome slag, red mud and fly ash

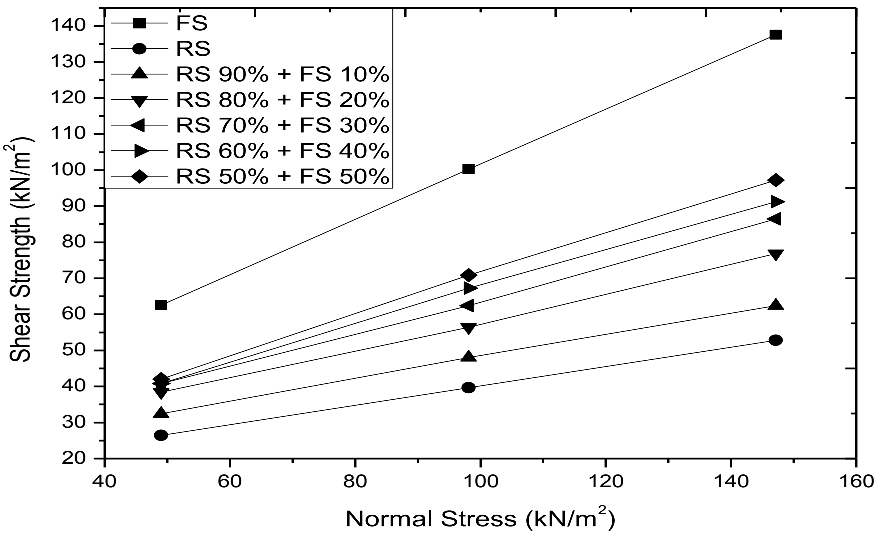


Figure 5.9 The comparison of Normal stress v/s Shear strength of ferrochrome slag and comparison with red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag

5.2.5 Determination of unconfined compressive Strength (UCS)

Here, the experimental studies of red mud, fly ash, red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag are carried out as per the IS: 2720 (Part 10) - 1991. Figure 5.10 shows the Stress v/s Strain curve of red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag. The compressive strength (q_u) in kN/m^2 and cohesion (C) in kN/m^2 of red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag are given in Table 5.5. From the experimental study, it can be seen that the unconfined compressive strength of red soil increased with increased the percentage of ferrochrome slag.

Table 5.5 The compressive strength and cohesion value of red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag

Description	Unconfined Compressive Strength(q_u) kN/m^2)	cohesion (C) =q_u/2 (kN/m^2)
Red Soil	18.66	9.33
Red Soil 90 %+FS 10 %	37.79	18.90
Red Soil 80 %+FS 20 %	38.68	19.34
Red Soil 70 %+FS 30 %	49.67	24.84
Red Soil 60 %+FS 40 %	52.38	26.19
Red Soil 50 %+FS 50%	60.06	30.03

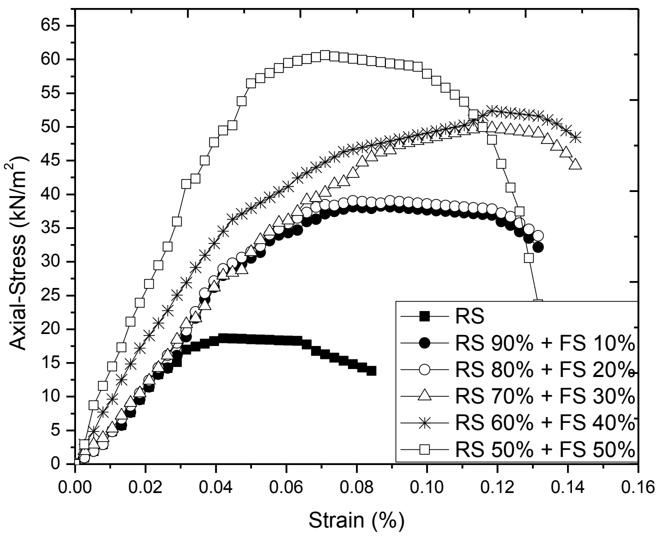


Figure 5.10 The Stress v/s Strain curve of red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag

5.2.6 Permeability Test

Here, the experimental studies of ferrochrome slag, red mud, fly ash, red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag are carried out as per following IS: 2720 (Part 17). The coefficient of permeability values of ferrochrome slag, red mud, fly ash, red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag are given in Table 5.6. From the experimental study, it can be seen that the ferrochrome slag is a high permeable material compared to other material and hence is not suitable material to be used as an embankment material. But as shown in Table 5.6, the coefficient of permeability of red soil is very low and also not suitable for embankment material. But as the red soil is blended with FS the k valued decreased. Hence, it can be used as an embankment material if red soil is blended with ferrochrome slag.

Table 5.6 The coefficient of permeability values of ferrochrome slag, red mud, fly ash, red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag

Description	Coefficient of permeability, k (cm/sec)
Ferrochrome Slag(Fine grain)	1.3×10^{-3}
Red Mud	2.5×10^{-7}
Fly Ash	5×10^{-4}
Red Soil	0.3×10^{-6}
Red Soil 90 %+FS 10 %	1.4×10^{-6}
Red Soil 80 %+FS 20 %	1.2×10^{-5}
Red Soil 70 %+FS 30 %	1.6×10^{-5}
Red Soil 60 %+FS 40 %	1.4×10^{-4}
Red Soil 50 %+FS 50%	1.7×10^{-4}

CHAPTER - 6

CHARACTERIZATION AS A HIGHWAY MATERIAL

6.1 Introduction

A highway network is an indicator of economic health of any region or country. For a vast country like India requirement of the highway network is too high, which necessitate huge requirement of crushed stone (coarse and fine) is in millions of tones, fast depleting natural resources lavishly worldwide including India. As per Indian Road Congress guidelines for design of flexible pavements a granular Sub Base (GSB) of 150 to 460mm thickness is essential pavement layer (depending upon he commercial traffic, the road will be subjected to during design life and California Bearing Ratio (CBR) of the sub-grade soil), inevitable pavement layer. Normally crushed sand / stone dust is used as fine aggregate in construction of GSB. This not only increases the cost of flexible pavement, but also puts additional pressure on the environment in the form of energy consumption and pollution for blasting during quarrying operations, crushing rocks, transportation of this material to plants, mixing, laying etc.. On the other hand, locally available industrial waste like ferrochrome slag, soil can be effectively used alone or in combination with other materials with significant economy after studying their physical and engineering properties for their suitability in road construction. Here, in this present study fine grained ferrochrome slag is used in replacement of fine aggregate and coarse grained ferrochrome slag is used replacement of coarse stone aggregate in construction of GSB. Laboratory testing of physical and engineering properties like relative density, bulk density, water absorption, void ratio, impact value, crushing value, abrasion value, shape test, soundness value, compaction, CBR, shear strength and required mixing proportion confirms the suitability of these naturally occurring fine and coarse grained ferrochrome slag in the construction of the GSB layer of flexible pavement is evaluated.

6.2 Ferrochrome slag use as GSB Material

Basically, this layer is made of broken stones, bound and unbound aggregates. Sometimes in sub-base course a layer of stabilized soil or selected granular soil is also used. In some places boulder stones or bricks are used as a sub-base or soiling course. However, in the sub-base course, it is desirable to use smaller size graded aggregates or soil aggregate mixes or soft aggregates instead of large boulder stone soling course of brick on edge soling course, as these have no proper interlocking and therefore have lesser resistance to sinking into the weak subgrade soil when wet. When the subgrade consists of fine grade soil and when the pavement carries heavy wheel loads, there is a tendency for these boulder stones or bricks to penetrate into the wet soil, resulting in the formation of undulations and uneven pavement surface in flexible pavements. The sub-base course primarily has the similar function as of the base course and is provided with inferior materials than of base course. This work shall consist of laying and compacting well-graded material on prepared subgrade in accordance with the requirements of these Specifications should followed as per the specification of MORTH. The material shall be laid in one or more layers as sub-base or lower sub-base and upper sub-base as per the requirement of design. Presently, this ferrochrome slag is not utilized and is dumped on the costly land available near the plants. Ferrochrome slag is highly crushable material. So, it is recommended that it should be crushed by rollers before application in road construction. For that, this study was carried out to utilize the slag in different layers of road construction. Being a cohesion less material, it was used as a granular sub-base materials and determine the feasibility of slag material as a replacement, of coarse aggregate in Granular Sub-base (GSB, course graded III, MORTH, 2001), gradation design was carried out by mixing the crushed ferrochrome slag material with conventional 20mm, 10mm aggregates, fine grained ferrochrome slag in different proportions in the range of 23%-17%-60% and their Geotechnical characteristics were evaluated. The aggregates shall conform to the physical requirement set MORTH in Table 400-6. If the water absorption value of the coarse aggregate is greater than 2 percent, the soundness test shall be carried out on the material delivered to site as per IS: 2386 (Part 5). The crushed or broken stone shall be hard, durable and free from excess flat, elongated, soft and disintegrated particles, dirt and other deleterious material.

In the present study an attempt has been also made to design a GSB layer using different size fraction of FS. The Rothfutch's graphical method as shown in Figure 6.1 is used to do the mix design. The final mix design with different proportion of FS is presented in table 6.1.

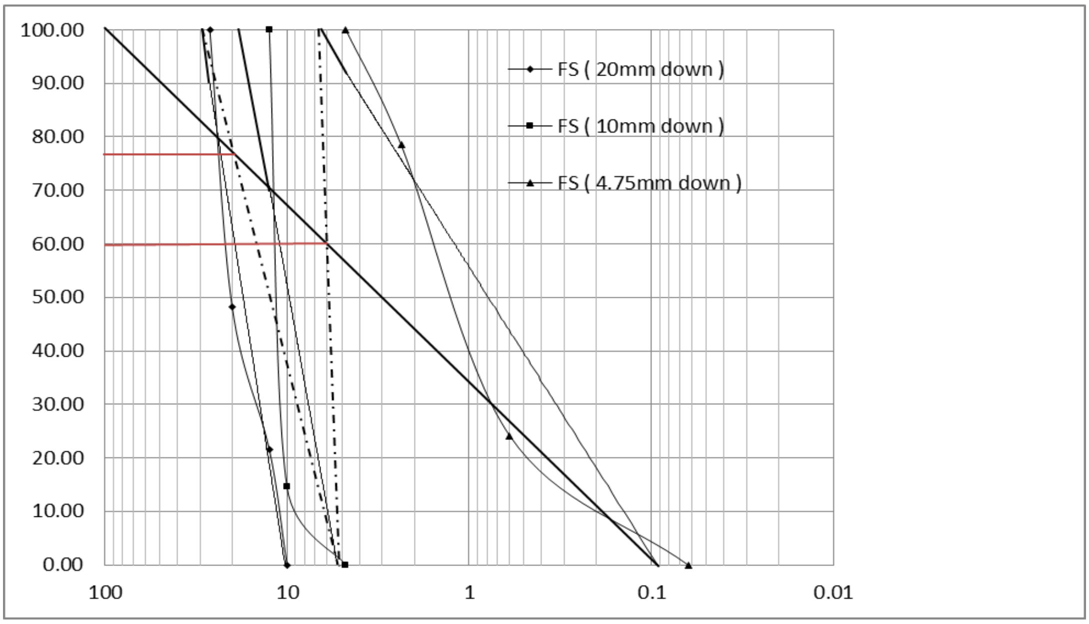


Figure 6.1 To evaluate mix proportion for GSB following the Rothfutch ' s Graphical method

Table 6.1 The mix proportion for GSB in percentage

Sample	20mm down (%)	10mm down (%)	4.75mm down (%)
Ferrochrome slag	27	13	60

Note: The material passing 425 micron (0.425 mm) sieve for all the three grading's when tested according to IS : 2720 (Part 5) shall have liquid limit and plasticity index not more than 25 and 6 percent respectively.

6.3 Properties of Designed GSB layer

Different experimental investigation were made on the GSB material as designed above to characterize it as the sub base layer.

6.3.1 Compaction Characteristic

The results of the heavy compaction test on the GSB material is shown in Figure 6.2. The OMC and the MDD value of the compaction test is presented in Table 6.2.

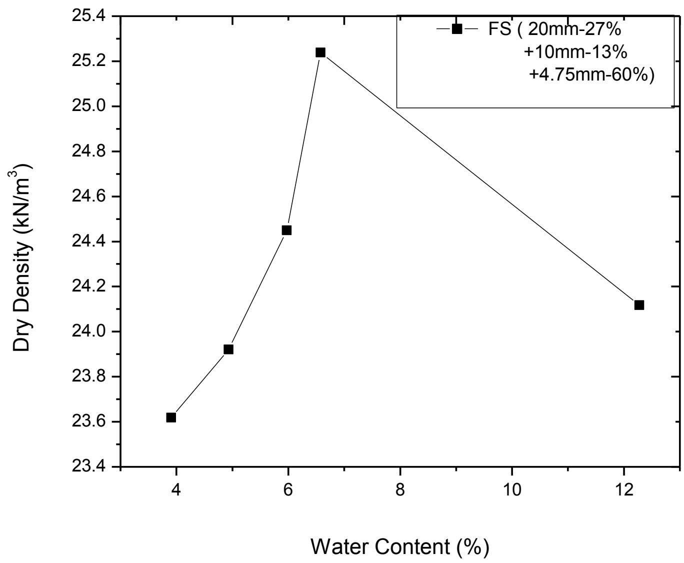


Figure 6.2 Density curve of ferrochrome slag mix (20mm down 27%, 10mm down 13% and 4.75mm down 60%) for GSB

Table 6.2 The OMC and Density values of ferrochrome slag mix (20mm down 27%, 10mm down 13% and 4.75mm down 60%) for GSB

Sample	OMC (%)	MDD (kN/m^3)
Mix (20mm down 27%, 10mm down 13% and 4.75mm down 60%) of ferrochrome slag	6.58	25.25

6.3.2 California Bearing Ratio (CBR)

It shall be ensured prior to actual execution that the material to be used in the sub–base satisfies the requirements of CBR and other physical requirements when compacted the density achieved is at least 95 per cent of the maximum dry density for the material as determined by the method outlined in IS : 2720 (Part 8). Here, the experimental studies of ferrochrome slag mix for GSB, red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag for four days soaked CBR test as per IS: 2720 (Part 16) – 1986 are made. Figure 6.3 shows the Load v/s settlement curve Load v/s Settlement curve 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 after four days soaking. The values of CBR 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 are given in Table 6.3.

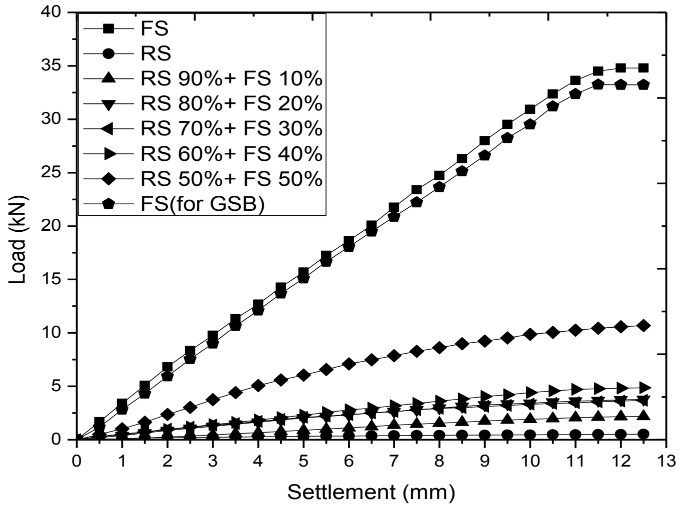


Figure 6.3 Load v/s Settlement curve of ferrochrome slag mix for GSB and comparison with ferrochrome slag, red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag after four days soaking

Table 6.3 The values of CBR 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

Description	CBR (%)
Ferrochrome Slag(Fine grain)	34.62
Red Soil	1.56
Red Soil 90 %+FS 10 %	4.44
Red Soil 80 %+FS 20 %	10.1
Red Soil 70 %+FS 30 %	10.34
Red Soil 60 %+FS 40 %	11.42
Red Soil 50 %+FS 50%	30.06
GSB	74.97

6.3.3 Shear Strength Test

Here, the experimental studies of ferrochrome slag, ferrochrome slag mix for GSB, red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag include conventional saturated Direct Shear test as per IS 2720 (Part 39) - 1977. Figure 6.4 shows the 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. The values of cohesion (C) in kPa and angle of internal friction (φ) in degree (^{0}) of for GSB of ferrochrome slag mix, ferrochrome slag, red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag are given in Table 6.4 below.

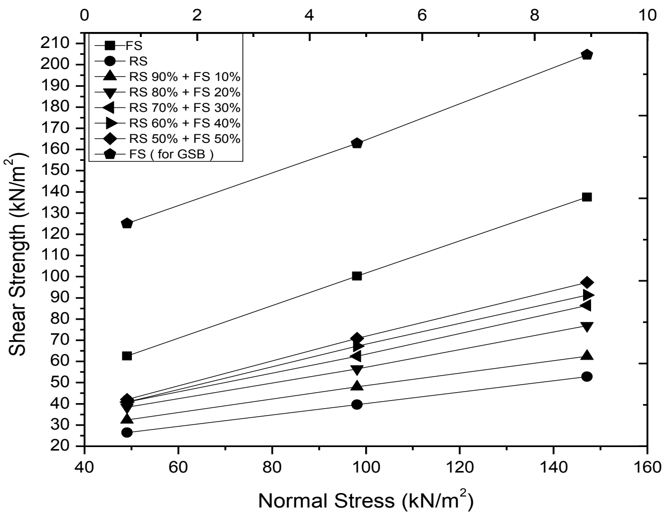


Figure 6.4 comparison of Normal stress v/s Shear strength of ferrochrome slag mix for GSB and comparison with ferrochrome slag, red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag

Table 6.4 The values of cohesion and internal friction for GSB of ferrochrome slag mix, ferrochrome slag, red soil and different proportion (i.e.10%, 20%, 30%, 40%, 50%) of red soil with ferrochrome slag

Samples ⟶	FS	RS	Red Soil 90 %+F.S 10 %	Red Soil 80 %+F.S 20 %	Red Soil 70 %+F.S 30 %	Red Soil 60 %+F.S 40 %	Red Soil 50 %+F.S 50%	GSB
Cohesion (C),kPa	250	130	170	190	170	160	150	840
Angle of internal friction(ϕ), °	37	15	17	21.38	24.9	27.2	29.35	39

6.4 Properties of ferrochrome slag as a highway material

6.4.1 Relative Density

The values of relative density may vary from a minimum of 0% for very loose soil to a maximum of 100% for very dense soils. In place soils seldom have relative densities less than 20 to 30%. The compacting a granular soil to a relative density greater than about 85% is difficult. This laboratory test of relative density of ferrochrome slag is determined as per the IS: 2386 (Part 3) – 1963 and the value is found to 79.01.

6.4.2 Bulk Density

IS:2386 (Part 3) -1963specifications of Road aggregate the bulk density is used to calculate the bulk density of aggregate. The bulk density of fine and coarse grained

FS is shown in Table 6.5. It can be seen that the fine grained FS has higher bulk density compared to coarse grained FS.

Table 6.5 The bulk Density of ferrochrome slag

Samples	Values of Bulk Density (kg/lit)
Fine grain ferrochrome slag	1.870
Coarse grain ferrochrome slag	1.785

6.4.3 Water Absorption

Due to porosity of aggregates water can be absorbed into the body of particles is called absorption which affects the w/c ratio of the concrete significantly. If absorption reduces, the w/c ratio increases due to increase of surface moisture. The value of water absorption of Coarse and fine grained ferrochrome slag are 0.8% and 0.801% respectively which is less than 2% as per specification of codeIS: 2386(Part 3) – 1963 as presented in Table 6.6.

Table 6.6 The water absorption of ferrochrome slag

Sample	Water absorption (%)	IS: 2386(Part 3)– 1963 Specifications
Coarse grain Ferrochrome slag	0.8	2%
Fine grain Ferrochrome slag	0.801	

6.4.4 Void Ratio

The ratio of void volume with total volume of aggregate. The void ratio of Ferrochrome slag is calculated by following IS: 2386 (Part 3) - 1963 and the values are presented in Table 6.7 and the values are comparable.

Table 6.7 The void ratio of ferrochrome slag

Sample	Void ratio
Coarse grain Ferrochrome slag	41.7
Fine grain Ferrochrome slag	45.7

6.4.5 Impact Value

IS: 2386 (Part 4) - 1963 test is designed to evaluate the toughness of stone or the resistance of the aggregates to fracture under repeated impacts, which has a different effect than the resistance to gradually increasing compressive stress. The impact value was found to 8.613. As per IS code the aggregate Impact value should not normally exceed 30% for aggregate to be used in wearing coarse of pavements. The maximum permissible value is 35% for bituminous macadam and 40% for water bound macadam base coarse.

6.4.6 Crushing Strength

IS: 2386 (Part 4) - 1963 the strength of coarse aggregate may be assessed by aggregate crushing tests. The aggregate crushing value provides a relative measure of resistance to crushing under gradually applied compressive load. To achieve a high quality of pavement, aggregates possessing high resistance to crushing or low aggregate crushing value are preferred. The crushing strength of FS was found to be 21.65. The aggregate crushing value for good quality aggregate to be used in base coarse shall not be exceed 45% and the value for surface coarse shall be less than 30%.

6.4.7 Abrasion Value

IS: 2386 (Part 4)-1963 Los Angeles abrasion tests are carried out to test the hardness property of stone and decide whether they are suitable for the different road construction works. In the study the FS of two gradation are considered and designated as Type B and Type C. The abrasion value of both grade is shown in Table 6.8

Table 6.8 The abrasion value of ferrochrome slag

Type of Sample	Abrasion Value (%)
Ferrochrome slag- Type-B	25.84
Ferrochrome slag -Type-C	38.66

The Los Angeles Abrasion value of good aggregates acceptable for cement concrete, bituminous concrete and other high quality pavement materials should be less than 30%. Values up to 50% are allowed in base courses like water bound and bituminous macadam.

6.3.8 Soundness Value

IS: 2386 (Part 5)- 1963 the soundness test is intended to study the resistance of aggregates to weathering action by conducting accelerated weathering test cycle. The resistance to disintegration of aggregate is determined 0.21% by using saturated solution of sodium sulphate taking 5nos of cycle.

The average loss in weight of aggregates to be used in pavement construction after 10 cycles should not exceed 12% when tested with sodium sulphate and 18% when tested with magnesium sulphate. The soundness test on different size fraction of FS is shown in Table 6.9. It was observed that the values are within the limit.

Table 6.9 The soundness value of ferrochrome slag

Size of Sample (mm)	After 5 Cycle	After 10 Cycle
25-20	0.00	0.20
20-12.5	0.00	0.24
12.5-10	0.00	0.36
10-6.3	1.60	2.11
6.3-4.75	*0.25*	*0.75*

6.4.9 Shape Test

IS: 2386-1963 (Part 1) the particle shape of aggregate mass is determine by the percentage of flaky and elongated particles contained in it and by its angularity. The evaluation of shape of the particles made in terms of flakiness index, elongation index and angularity number. The elongated and flaky aggregates are less workable; they are also likely to break under smaller loads than the aggregate which are spherical or cubical. Different shape test on the coarse grained FS is shown in Table 6.10. Based on the values it was found that it is suitable as construction material.

Table 6.10 The shape test value of ferrochrome slag

Different Shapes of Samples	Experimental results
Flakiness Index (%)	9.286
Elongation Index (%)	14.448
Angularity Number (%)	8.159

Notes as Per Code:

- The flakiness index of aggregates used in road construction is less than the 15% and normally does not exceed 25%.
- Flakiness index and elongation index values in excess of 15% are generally considered undesirable.
- However no recognized limits have been laid down for elongation index.
- The range of angularity number for aggregates used in constructions is o to 11.

The comprehensive results of above test along the acceptable limit as per Indian standard is shown in Table 6.11. It can be seen that the FS satisfies all the required to be used as a pavement material except specific gravity. The value is marginally higher than the acceptable value and should be considered while designing the macadam.

Table 6.11 The properties of coarse grained material as a pavement material and corresponding allowable values.

Test results	Specific gravity	Bulk Density (kg/lit)	Water absorption (%)	Void ratio	impact value (%)	Crushing Value (%)	Abrasion value (%)	Flakiness Index (%)	Elongation Index (%)	Angularity Number (%)
Present study	3.21	1.785	0.8	41.7	8.61	21.64	25.84	9.286	14.448	8.159
Acceptable value as per IS: 2386-1963	2.4 to 2.9		Max. 2		Max. 30 for wearing coarse, 35 for bituminous macadam and 40% for water bound macadam base coarse.	Max. 45 for base coarse, and 30 for surface coarse	Max. 30 for water bound and 50 for bituminous macadam base courses	15	20	0 to 11

CHAPTER - 7

GENERAL OBSERVATION, CONCLUSION AND SCOPE OF FUTURE STUDY

7.1 Introduction

In the present study an attempt was made to characterize ferrochrome slag to be used as a construction material. The ferrochrome slag is a byproduct from the ferrochrome steel industry. Approximately 6.5-9.5 million tons of ferrochrome slag being generated worldwide during the extraction of ferrochrome from Ferro alloys industries every year. However, to prevent environmental pollution it is required to be used in huge quantities like filling, embankment and pavement. The fine grained and coarse grained component of the slag was considered. The fine grained soil was characterized like as fill and embankment material and the coarse grained as pavement material. The present study includes the laboratory tests like morphology, chemistry, mineralogy and various geotechnical properties f ferrochrome slag. The comparison of some properties has been made with other industrial waste like red mud, fly ash and local red soil. Based on different experimental investigations and discussions thereof following conclusions can be made.

7.2 General observations and concluding remarks

Based on the limited studies above from Chapter 1 to Chapter 6 following observations and conclusions can be made.

1. The P^H value of coarse grain and fine grain ferrochrome slag has exceeded are 9.88 and 9.79, respectively with alkaline in nature due to presence of high MgO value.
2. The chemical analysis shows that it contains about 56% of alumno silicate compound and 23 % of MgO as the major components.
3. The SEM photographs show the particles are angular to subangular. Based on XRD analysis it was observed that that quartz, forsterite, olivine and spinel are predominantly present.

4. The specific gravity of ferrochrome slag found to vary between 3.21 to 3.27. The values of C_u and C_c of ferrochrome slag are found to be 2.78 and 0.95, respectively, showing poorly graded.
5. The compaction characteristics of FS show that for light compaction the OMC is 8.32 % and MDD as 2.18g/cc. Similarly for heavy compaction, the OMC is 7.64 and 2.44g/cc, respectively.
6. The high MDD value is due to high specific gravity values. While using FS as a stabilizing agent for red soil it was observed that as the FS % increased, the OMC decreased and MDD increased in comparison to red soil.
7. It was also observed that FS has high CBR value of 34.62 in comparison to 18.1 of red mud and 1.56 of red soil.
8. It was observed that the CBR values of stabilized red soil increased with increase in FS. The CBR value 10.1 was observed with addition of 10% of FS.
9. The angle of internal friction of fine grained FS is 37^0.
10. The soundness test on coarse grained slag shows the maximum loss of 2.11% after 10 cycle in sodium sulphate. The bulk density was found to be 1.785 with water absorption of 0.8% and within limits of Indian standard. Similarly the impact value was found to be 8.613 and the crushing value of 21.666. The abrasion value was found to be 25.84.
11. Based on the above tests it can be seen that FS has some advantages over FA and RM in terms of having good compaction properties and high permeability to be suitable as a pavement material. But it has higher density compared to fly ash, for which it will have higher pressure on soil subgrade.
12. There are advantages of blending red soil with FS as the unconfined compressive strength, shear strength and CBR value of red soil increased with increased the percentage of ferrochrome slag. Similarly ferrochrome slag is a high permeable material compared to other material and permeability of red soil is very low and also not suitable for embankment material. But as the red soil is blended with FS the *k* valued decreased. However, there is a need to check the leachate analysis due to addition of FS.

7.3 Scope of future studies

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 soil.
3. It is also required to characterize and study the long term effect of ferrochrome slag in concrete and its effect on the reinforcement.

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