USE OF LOCALLY AVAILABLE MATERIALS IN PAVEMENT SUB-BASE

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Certificate

This is to certify that the work in the thesis entitled, "**Use of Locally Available Materials in Pavement Sub-Base"** by **Shubhakanta Barik** is a record of an original exertion carried out by him under my supervision and guidance in partial fulfilment of the requirements for the grant of the degree of **Master of Technology** in **Department of Civil Engineering** with specialization in **Transportation Engineering**. Neither this project nor any portion of it has been acquiesced for any degree or academic honour elsewhere.

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Date:

Dedicated to

My Parents

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Abstract

Now-a-days the depletion of natural resources has been a major issue in the construction sector from which the road segment cannot be excluded. Because of the extensive road construction processes the aggregate demand is so huge that lots of blastings, quarrying, crushing and transportation activities are consuming a lot of energies, but also the aggregate materials are depleting fast and are in short supply. On the other hand, industrial wastes, by-products and locally available unused materials which are considered as non-conventional materials are causing environmental and dumping problems, but can have a potential for their application in road constructions. In the present study, an attempt has been made to utilise two types of materials such as the slag, a waste material from the steel industries and locally and abundantly available gravel (moorum) in the road sub-bases. The chemical composition, phase composition, toxic and heavy metals present in both the slag and its leachate water are studied. Its gradation and other physical properties are studied by using suitable tests and techniques. Conventional crushed aggregates are also used in conjunction with the slag or moorum to satisfy the desired grading for use in a particular layer as per the specifications of the Ministry of Road Transport and Highways. The optimum percentage of the slag and moorum that can be used in sub-base layer is found to be 80% and 50% respectively. In case of moorum, cement has also been used in required quantity to get the desired strength. The physical properties have been studied. It is observed that both the slag and hard moorum have excellent properties as road aggregates and can be used in the road base and sub-base applications.

Key words: slag, moorum, XRD analysis, toxicity, unconfined compressive strength

CONTENTS

List of tables **Page No.**

List of figures **Page No**

List of Abbreviations

ASTM	: American Society for Testing and Materials
CA	: Crushed Aggregate
CBR	: California Bearing Ratio
EDS	: Energy Dispersive Spectrometer
EDX	: Electron Dispersive X-Ray spectroscopy
EPA	: Environmental Protection Agency
GSB	: Granular Sub-base
IS	: Indian Standard
IRC	: Indian Road Congress
MDD	: Maximum Dry Density
MoRTH	: Ministry of Road Transport and Highways
OMC	: Optimum Moisture Content
SEM	: Scanning Electron Microscope
SSA	: Steel Slag Aggregate
TCLP	: Toxic Leaching Characteristic Procedure
UCS	: Unconfined Compressive Strength
XRD	: X-Ray Diffraction
XRF	: X-Ray Fluorescence

Thesis Structure

- **Chapter 1** gives a brief idea about the conventional and non-conventional materials used in the road construction and points out the objectives of the study using slag and moorum as non-conventional materials.
- **Chapter 2** gives an overall idea about the findings in different past studies on the use of either slag or moorum in road base or sub-base application.
- **Chapter 3** deals with the experimental methodology in which several test methods, analytical techniques as per different standards, specifications and studies are used to determine the characterisation of slag and also to find the physical properties of slag, moorum and conventional crushed aggregates.
- **Chapter 4** provides the results of all the tests and techniques followed in chapter 3 and checks their validation with reference to corresponding standards and specifications.
- **Chapter 5** summarizes the conclusions obtained from the results and discussions and gives some scopes for future work.

Chapter 1

INTRODUCTION

1.2.Background of the study

Road transportation contributes to the economic, industrial, social and cultural development of a country. India now has the second largest road network in the world. The extensive road construction programme by the Government of India has resulted in a high development process in the road industry. Thousands of kilometres of roads are being constructed every year across India in the shape of either urban roads (under National Highways Development Programme) or rural roads (under Pradhan Mantri Gramin Sadak Yojna). [Indian Highways, May 2011]

Generally pavement structures used for road construction are flexible and rigid. A flexible pavement consists of four components: soil subgrade, sub-base course, base course and surface course where the vertical load transmission takes place from the top (surface) to the bottom (subgrade). A well compacted granular arrangement consisting of well-graded aggregates forms a good pavement (flexible) which transfers the compressive stresses through a wider area. The base layer, immediately below the surface layer provides support to the pavement transmitting the load to the layers below. The sub-base layer, below the base layer, not only provides the support to the pavement structure and transmits traffic loads to the subgrade but also provides frost action and drainage. The sub-base is generally composed of two layers, the lower (filter) layer forms the separation preventing the intrusion of subgrade soil into the upper layers and the upper (drainage)

layer composed of granular sub-base (or GSB) materials drains the water away which enters through surface cracks. [Yoder & Witczak, Principles of Pavement design]

A rigid pavement usually consists of a cement concrete slab, with a granular base or sub-base course provided below for drainage, to control pumping, to control frost action and to control shrink and swell of the subgrade. The rigid pavement differs from the flexible pavement in the load distribution phenomenon. In the rigid pavement, the critical condition occurs due to the maximum flexural stress in the slab due to the wheel load and the temperature changes whereas compressive stresses are distributed throughout the flexible pavement. Though rigid pavements possess the noteworthy flexural strength or flexural rigidity, flexible pavement is widely used in construction because of its smooth riding surface and lower cost of construction. [Yoder & Witczaak]

However in semi-rigid pavements bonded materials are utilized in the base or sub-base course of pavement layer, giving them higher flexural strength than the conventional flexible pavement layers. The materials for bound base or sub-base layer may consist of aggregate, soil or combination of both modified with stabilizers such as lime, cement, fly ash or commercial stabilizers to give desired strength. [IRC SP:89 (2010)]

1.3. Problem Statement

Traditionally, the materials which are used in highway construction are also used in other construction activities (like buildings, industrial set ups, dams, power houses etc.). Aggregates for base and sub-base use are composed of sand, crushed aggregates, gravels or natural materials that provide the necessary strength and durability. To meet the enormous demands of construction the

above natural aggregate resources are heavily consumed for the construction of roads, especially in urban markets. The extraction of aggregates from hills through quarrying operations, crushing and transportation etc. are not only responsible for the environmental degradation in the form of loss of forest lands, vibrations, dust, noise, pollution hazards etc. but also consume a large amount of energy depleting the energy sources.[Indian Highways, May 2011]

The generation of a vast quantity of waste materials from industries like iron, steel, coal, etc. is causing a shortage of dumping space and creating severe environmental pollution. Solid waste generation from steel industries such as power plant fly ash, acid sludge from by-product plant, tar sludge, B.F. slag, steel slag, coke breeze, calcined lime, dolomite dust and steel scrap etc. are generated in vast quantities causing environmental degradation. [Viswanathan & Gangadharan (1996)]

1.4. Locally available materials

Industrial wastes or by-products, locally available materials can be used to partially replace the natural aggregates in base or sub-base application, which are not used for other construction purposes but available in huge quantities at a nominal cost. These materials, may not match the desired standards or specifications but provide a prospect for their optimal utilization in road construction. Use of the above materials may result in a decrease in the construction cost of roads, satisfying the quality requirements and could also help in improving the strength and durability of the pavement. In the present work slag from steel plant industries and locally available hard moorum are used as non-conventional materials in road base and sub-bases.

1.4.1. Slag from steel plant industries

India is now the fourth largest crude steel producer in the world contributing pig iron, sponge iron, alloy and non-alloy steel. Slag is a by-product generated during the manufacturing of pig iron and steel. During the process of pig iron making (in the blast furnace) and steel production (in steel melting shop), slag is produced by the action of fluxes upon gangue materials within the iron ore. The slag primarily consists of silicon, calcium, aluminum, iron, magnesium and manganese in various combinations. Under controlled cooling slag becomes hard and dense, which can achieve the required strength to sustain heavy loads making it especially suitable for use in road construction. [Indian Mining Yearbook-2011].

The amount of slag generated is so vast that it produces a dumping problem and can also be hazardous to the environment. So due to the extensive growth of construction and sufficient availability of slag, it can be used as a partial substitute for the natural aggregate materials in road base and sub-base applications. The cost of slag is lower than that of natural aggregate materials, and it is sufficiently available. The slag when used in road sub base in bounded form, its hazardous effects can be minimized making it environmentally sheltered. So the above factors can make the use of slag in road base and sub-base layer economic and cost effective from a construction point of view and also take care of the environmental problems.

1.4.2. Locally available Hard Moorum

Moorum is a fragmented weathered rock that occurs with varying proportions of silt and clay. It is a low-grade marginal material having the low bearing capacity and high water absorption value than that of the conventional natural aggregates. India is rich in hard moorum, but the quality differs significantly from place to place [Ransinchung. et al. (2014)]. In the present study, the

locally available hard moorum is tried to be used in base, and sub-base layer of pavement and cement stabilization/modification is done to make it suitable for use in different layers of pavement.

1.5. Objectives

The present work is focussed on the use of a combination of slag or locally available hard moorum and conventional crushed aggregates (of different nominal size) for use in the base or sub-base layer of the pavement.

The objectives of this work are

- To determine the chemical composition, phase composition and explore the presence of hazardous materials in the slag and its leachate water.
- To determine the physical properties of slag and explore its suitability for use in the sub-base layer of pavement.
- To determine the physical characteristics of locally available hard moorum and explore its suitability for use in the base or sub-base layer of the pavement.
- To assess the effects of cement stabilization in base or sub-base with natural aggregates and locally available gravel (hard moorum).

Chapter 2

LITERATURE REVIEW

2.1. Introduction

This chapter is focussed on the literature review of some studies associated with the utilisation of slag and moorum in base and sub-base of road pavement within the recent past. The characterisation of slag and the physical properties and strength parameters of slag and moorum, as obtained in several works have been studied.

2.2. Characterisation of slag

Basic oxygen furnace (BOF) steel slag is a residue obtained from the basic oxygen converter during steel-making operations. It can be partially used as a construction material for roads. Though it is an attractive construction material, before the application its long-lasting behaviour and the related environmental influences should be considered into account. BOF slag is generally composed of silicon, calcium, iron and some potential toxic elements or known as toxic elements, like chromium and vanadium. **[P. Chaurand., et al. (2006)]**.

2.2.1. Chemical composition and phase analysis

The identification of various kind of phases present in slag, structural techniques used are: X-ray diffraction (XRD), SEM coupled with energy dispersive X-ray spectroscopy (EDS) micro-analysis and X-ray absorption spectroscopy (XAS) **[P. Chaurand., et al. (2006)]**.

X-ray diffraction technique is a non-destructive, rapid analytical method which provides the data regarding the crystal structure, atomic arrangements and phase composition of the material

under study. In the XRD technique, the slags were finely grounded and analysed with a Philips PW 3710 X-ray diffractometer using a Co Kα radiation at 40 kV (voltage) and 40 mA (current). The diffractograms were operated within the 2θ range of [8–90°] with a numeration time of 13 s/step.

The Scanning Electron Microscope is also a non-destructive and technique used to study the morphology and composition of the sample. Phillips SFEG (XL30) scanning electron microscope (SEM) coupled with an Oxford Instruments energy dispersive spectrometer (EDS) was used to observe the composition of elements present in the slag. It was operated at fifteen keV taking the size of slag varied between 200 to 500μm. Taking the counting time in the 60–200 s/point range, semi-quantitative analyses of particular portions were observed.

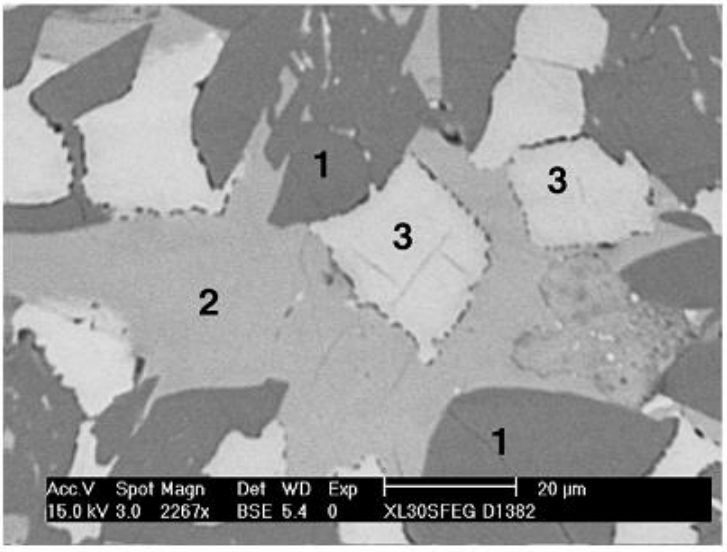


Figure 2.1. SEM photography of a polished section (grains> 2 mm) **[P. Chaurand., et al. (2006)]**

A new type material comprised of steel slag, fly ash and phosphogypsum were used as a road base material in China. The chemical composition of the raw materials: steel slag, fly ash,

and phosphor-gypsum were determined. The XRD patterns of two slag (steel slag) samples are illustrated in fig.2.2. **[Weiguo Shen., et al. (2009)]**.

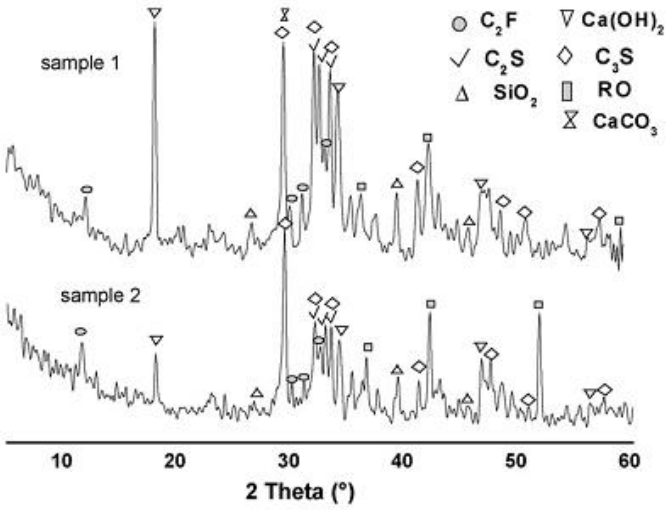


Figure 2.2. XRD patterns of steel slag samples **[Weiguo Shen., et al. (2009)]**

Electric arc furnace (EAF) steel slags were used as replacements for natural aggregates, within the base for flexible pavements. The chemical composition of the aggregates were analysed by XRF (X-ray fluorescence) and then the toxic characteristics of the EAF slags were measured with the ICPAES (inductively coupled plasma-atomic emission spectrometer) methodology in terms of initial concentration of heavy/toxic metals **[Pasetto and Baldo (2010)].**

The hydration products of steel slag can be mineralogically determined by X-ray diffraction. TTR ||| diffractometer was used having nickel-filtered Cu $K\alpha_1$ radiation (=1.5405 Å), the voltage of 50 kV and current of 200 mA **[Wang and Yan (2010)]**. The SEM was used to determine the microstructures and the EDX were used detect the element distribution.

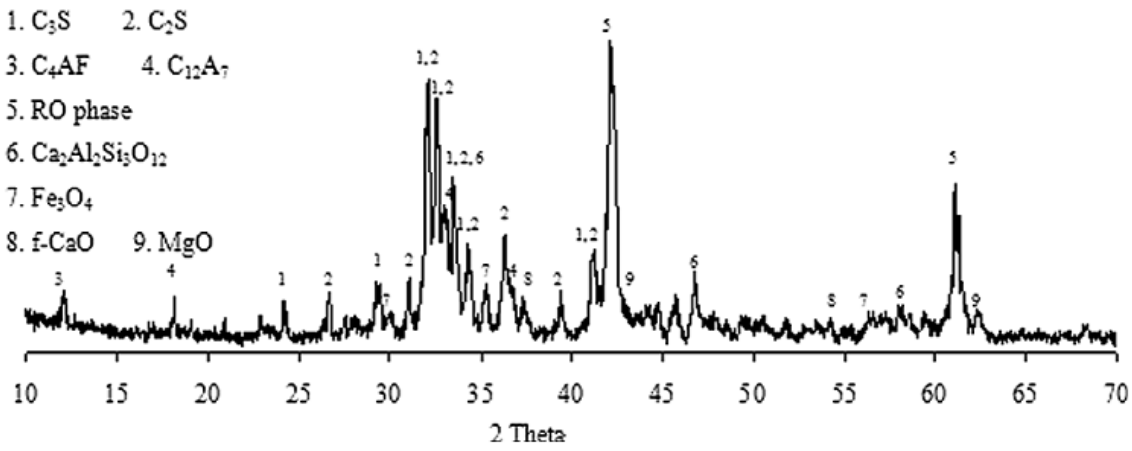


Figure 2.3. X-ray diffraction of steel slag **[Wang and Yan (2010)]**

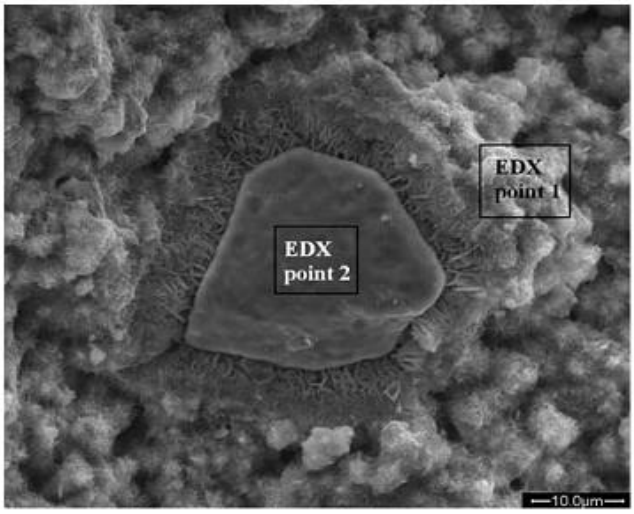


Figure 2.4 (a) SEM morphologies and EDX analysis of hydration products at the age of 28 days-SEM picture **[Wang and Yan (2010)]**

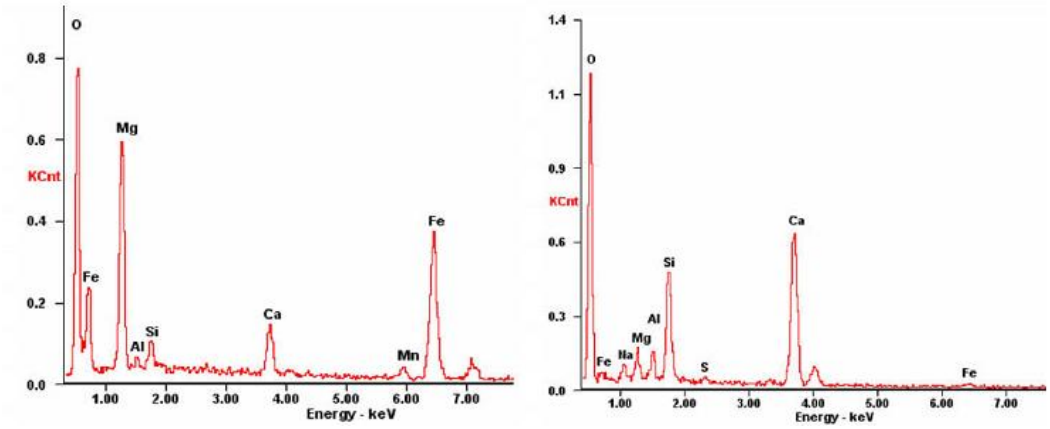


Figure 2.4 (b) EDX result of point 1 **Figure 2.4 (c)** EDX result of point 2

Various analytical methods are used to determine the chemical and mineralogical characterizations of LD slags and to identify the phases that are liable to pavement instability **[J. Waligora., et al. (2010)]**. The mineral phases present in the slag were identified by X-ray diffraction (XRD) technique using a Bruker AXS D8 Advance diffractometer having a Co source (Kα=1.79 Å), taking scanning range 2θ [5–99.9°] with a step of 0.005°/s at room temperature 25 °C. Complementary analyses were done using scanning electron microscopy (SEM) coupled with energy dispersive spectrometer (EDS) using a silicon drift detector (SSD), taking the operating distance 10 mm, acceleration tension of 20 kV and numeration time mounted at 40 s/point range (for semi-quantitative analyses).

The chemical composition of steel slag obtained from different studies is given in the table below. The chemical composition of steel slag (range of compounds) from various steel plants of India as per the **"Indian Mining Yearbook (IMYB)-2011"** is also given in table 2.1.

Table 2.1. Chemical composition of steel slag from different studies

Compound	Emery (1982)	Chaurand et al. (2006)	Aiban (2006)	Shen et al. (2009)	Wang and Yan (2010)	Huang et al. (2012)	IMYB (2011)
CaO	41.3	41.3	25-42	50.51	40.46	45-60	45-50
SiO_2	15.6	12.5	12-17	14.38	17.09	10-15	15-20
Al_2O_3	2.2	2.4	2-4	1.35	4.53	1-5	1-2
Fe_2O_3	20	31.2	20-28	5.22	23.86	3-9	-
FeO	-	-		14.8		7-20	15-25
MgO	6.9	4.3	6-10	4.49	10.46	3-13	5-10
P_2O_5	-	1.1	-	1.12	-	1-4	-
MnO	8.9	6.1	8-12	-	-	2-6	1-5
TiO_2	0.5	0.8	0-1	0.49	-	-	-

2.2.2. Toxic Leaching Characteristic Procedure (TCLP)

The Environmental Protection Agency of United States (or USEPA) in 1992 has introduced regulatory levels for toxic materials present in hazardous wastes. USEPA standards were used to determine the toxicity characteristics of the metal leachate obtained from steel slag aggregates [Aiban (2006)] or EAF slag aggregates [Pasetto and Baldo (2010)]. The detection of the concentration of heavy metals were done by either atomic absorption spectrophotometer (AAS) or inductively coupled plasma-atomic emission spectrometer (ICPAES) methodology following toxic characteristic leaching procedure (TCLP). The concentration of toxic or heavy metals was found to be within the limits.

2.3. Physical properties of slag and moorum

Slag as a residual or by-product is often utilised in the construction of cementitious applications to optimise the utilisation of natural available aggregate materials and conservation of natural resources. Ferrous slags (blast furnace slag, steel making, manufactory and ferroalloy) are the industrial by-products can be used in pavement construction because of their wide convenience and scope of applications. **[J. J. Emery (1982)]**. In an European stabilized base layer 60% blast furnace slag (0 to 60 mm), 25% steel slag (0 to 15mm) and 15% granulated blast furnace slag mixture was compacted with 10% water by mass using standard highway equipment that showed excellent results.

Industrial wastes and by-products are also utilised in recycling processes, manufacturing of new products, or as construction materials to minimise their environmental effects. The steel slag aggregate (SSA) was utilised in road construction in Saudi Arabia, which is a by-product of the steel manufacturing process **[Saad Ali Aiban (2006)]**. Two types of SSA materials were taken: material finer than 5 mm (labelled 0 – 5 mm) and material having sizes up to 37 mm (labelled 0 – 37 mm). Several gradations were tried taking mixture of SSA, locally available marl, marl fines, and sand and the gradation corresponding to the maximum CBR (as per ASTM method) was taken. The CBR value of proposed gradation was found to be 119 at moulding moisture content of 5%. In a modified gradation, 10 % SSA fines were added to the proposed gradation gave highest CBR value of 383. Similarly different percentages of dune sand were added to SSA and compacted at 5 % moisture content. The highest CBR value of 406 was obtained at a sand percentage of 15 %. Locally available marl (having maximum CBR value of 224) was used to reduce the consumption of SSA, taking a blend of equal proportions of SSA and marl produced CBR values reaching 400. These values were far more than the values presented by pure marl of same gradation.

A field trial was used having

- A compacted subgrade (comprised of the existing marl and mixed with sand in some places).
- A 100 mm thick fine SSA (0-5 mm) filter layer.
- A 200 mm SSA (0–37 mm) base course reconstituted to modified gradation
- The asphalt concrete layers (a 70 mm thick base layer and a 40 mm thick wearing layer)

The field trial showed an excellent performance over the years even under poor drainage and submerged conditions.

The steel slag combined with limestone aggregates were used in different proportions to achieve desired density and shear strength in Egyptian roads. The grain size distribution, porosity, unit weight, Los Angeles abrasion value, angle of internal friction, bulk specific gravity, water absorption of steel slag and limestone aggregates were found out. OMC and MDD for various blended mixes were determined; the OMC decreased, and the MDD increased with increase in slag percentage. California bearing ratio and resilient modulus were increased with increase in slag percentage up to 70%. For the blend mix of 70% steel slag percentage to 30% limestone gave highest CBR value (of 370 %) and resilient modulus (of 4000 Mpa). Theoretical analysis of the blended layer was achieved using a finite element (FE) computer programme (FENLAP) estimating the deflection, vertical strain, vertical stress and radial stress **[Behiry (2012)]**.

Fly ash and phosphor-gypsum modified steel slag aggregates were used in road base construction in China **[Weiguo Shen., et al. (2009)]**. The particle size distribution and apparent density of individual materials were determined. The mixture prepared by blending of materials was stored for 4 hours and then compacted (at optimum moisture content after 1 hour of cement

addition) into a 50 mm dia×50 mm height cylinder mould to prepare cylinder specimen. The relative compaction with the MDD was found to be 97%. For Standard Proctor compaction test and Unconfined Compression Test T0804-94 specifications (China) were followed which are similar to the ASTM codes. The stabilized soil samples were sealed in plastic bags and stored at room temperature and a 95% relative humidity, and then soaked in water for 24 hours (at room temperature) before compressive strength tests. A steel slag to fly ash ratio around 1:1 having phosphor-gypsum dosage of 2.5% was found to be optimum giving a 7-day strength of 1.86 Mpa and 28 day strength of 8.36 Mpa that meets the requirements (China criteria of semi-rigid road base material).

Basic oxygen furnace (BOF) slag as well as electric arc furnace (EAF) slag is also used for road base as well as road base asphalt concrete. In a trial, the mix design and performance characterization of the bituminous mixes was done in Italy. Gyratory compaction tests, indirect tensile strength tests, fatigue tests, permanent deformation tests and stiffness modulus tests (at various temperatures) of the mixtures of EAF slag and asphalt showed better mechanical characteristics than those of the conventional natural aggregate and asphalt mixture, satisfying the acceptable criteria for Italian road construction. **[Pasetto and Baldo (2010)]**. In a moisture damage investigation of the road, the BOF prepared asphalt mixtures were characterised by resilient modulus tests, indirect tensile strength tests. The freeze-thaw tests showed better moisture sensitivity of BOF slag mixture than that of the basalt mixture **[Jun Xie., et al. (2012)]**.

The moorum collected from Sukrut (Uttar Pradesh) was mixed with Ganga sand and cement stabilised for use in Wet Mix Macadam (WMM) **[Ransinchung., et al. (2014)].** The physical properties of moorum, Ganga sand, crushed aggregate and stone dust were found out. The proportions of individual aggregates were determined so that the mixture would satisfy the desired

gradation of MoRTH specifications. Ordinary Portland Cement was used as a stabiliser and varying the cement content the CBR tests and the unconfined compressive strength tests were conducted. The results showed highest CBR value (423%) and unconfined compressive strength (18.55 kg/cm^2) at 9 percent cement content.

2.4. Critical review

From different studies, it has been observed that steel slag can be used as a material for road construction. It's physical, and engineering properties were found to be superior as compared to those of natural aggregates. From the characterisation and leaching studies, it was confirmed that it has almost no hazardous effects on the environment. So there is scope for utilisation of slag in unbound road pavements after this satisfies the desired specifications and characteristics, leachate water toxicity.

A limited literature is observed on the application of hard moorum in road construction. From the studies, it can be observed that moorum has a potential for use in road base and sub-bases. As the properties of moorum vary from place to place, more studies are required to generalise the properties of moorum and how effectively it can be used in road pavement applications.

CHAPTER-3

EXPERIMENTAL METHODOLOGY

3.1. Introduction

The materials whether natural aggregates or industrial wastes/by-products or locally available materials must satisfy the desired physical properties and strength parameters (for use in base or sub-base layer of road pavement) before their application. Apart from these tests, the materials which have a potential to affect the environment are also subjected to some chemical tests and characterisation to check whether they are environmentally acceptable or not. In this work chemical composition and characterization of slag were undertaken. The physical properties of slag, natural crushed aggregates and moorum were determined as per respective codes, specifications and certain literature. The test methods carried out in this work are presented below.

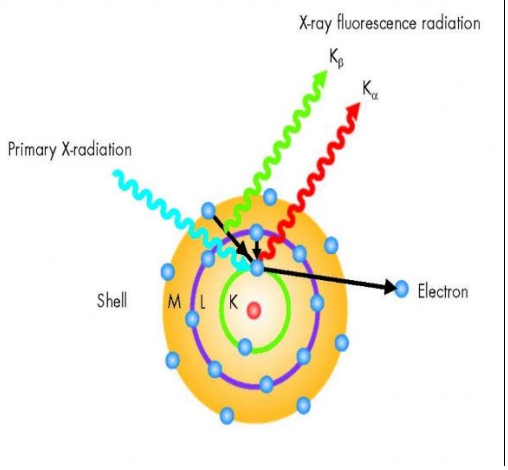
3.2. Characterisation of slag

As regards characterisation of slag is concerned, its chemical composition and phase compositions were determined. The presence of any toxic or heavy metals was studied both in the slag as well as in the leachate water collected from the slag. Several analytical techniques and their methodology used for the above are briefly discussed.

3.2.1. X-Ray Fluorescence

A high energetic primary X-radiation is bombarded on the sample, resulting ejection of electrons from the inner shell. Higher energy level electrons from the outer shell will jump down to fill the vacancy emitting fluorescence radiation which is different for different materials. So

using a detector, the presence of a particular compound in the sample can be found. Slag samples were finely grounded to get a homogeneous mixture and then analysed using an X-ray fluorescence spectrometer. The mean chemical composition of 12 slag samples was expressed in terms of percentage of total weight. The basicity was expressed as the ratio of CaO to SiO_2, which defines the chemical composition and metallurgical properties of slag. [Source: http://encyclopedia2.thefreedictionary.com/Basicity]



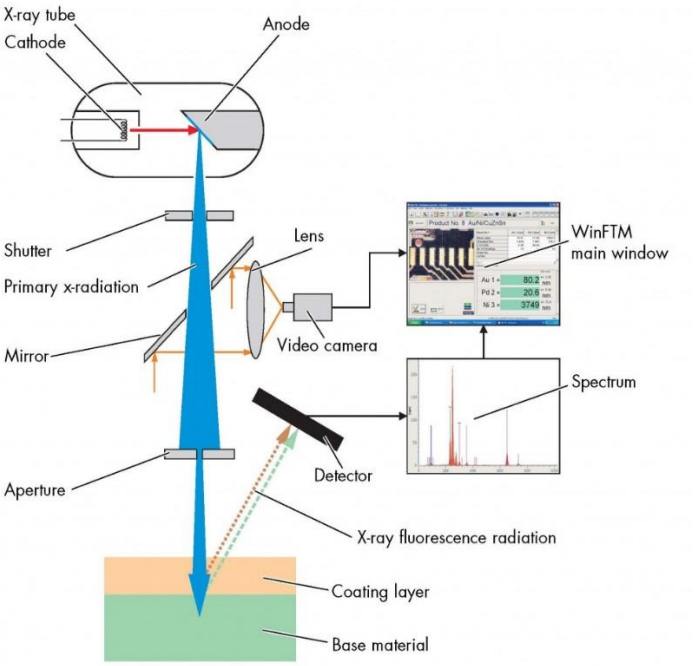


Figure 3.1 (a) Principle of XRF

Figure 3.1 (b) XRF Instrument

[Source: http://xrf-spectroscopy.com/]

3.2.2. X-Ray Diffraction

The X-ray diffraction technique was used to determine the phase composition of slag samples. The slag samples were grounded (to pass a standard 75μm IS sieve) and homogenised before analysis. XRD analysis was performed on a PW 3020 Philips diffractometer using Cu Kα (λ=0.15405 nm) radiation. The diffraction data was taken in the scanning range (2θ range) of 10° to 90°, taking a scan speed of 20° per minute and a step size of 0.05. "X'pert high score" software was used for analysis of the XRD data. The Cu $K\alpha_2$ radiation was stripped from the collected data by the software before analysis.

A correlation was made between the XRF and XRD data to confirm the composition and the phases present in the slag samples.

3.2.3. Scanning Electron Microscopy (SEM) and Electron Dispersive X-Ray spectroscopy (EDX)

The electron dispersive X-Ray spectroscopy is also a non-destructive, analytical technique used to determine the elemental composition of the materials under study [Wikipedia]. The principle of EDX is same as that of X-ray fluorescence but in case of the former the elemental composition of samples are determined. The slag samples were analysed by means of scanning electron microscopy using a NOVA NANO SEM FEG operated at a voltage of 310V and 90μA current). The samples were put in the holder, and EDX spectrum of different points were observed.

3.2.4. Toxic Characteristic Leaching Procedure (TCLP)

Toxic characteristics leaching procedure as per the Environmental Protection Agency (EPA) of United States (method 1311:1992) was used to prepare the leachate water as per the following. Deionized (DI) water was taken as reagent water. 5g of finely grounded slag samples was taken in a beaker, 96.5 ml DI water was added to it and mixed using a magnetic stirrer for 5 minutes. The pH of the solution was found to be 10, so 3.5 ml 1 N hydrochloric acid was added and heated at 50°C for 10 minutes. The pH of the sample was found to be more than 5. So extraction fluid 2 was used according to the procedure. The extraction fluid was prepared by taking 5.7 ml glacial acetic acid, and the volume was made up to 1 litre. 5g slag sample (total 6 number of samples) was taken in an extraction vessel and 100 ml (20 times the weight of the solid sample) extraction fluid was added to each vessel. Then the vessels were covered and rotated at a constant speed of 30±2 rpm for 18±2 hours at room temperature. Then each solution was filtered through a 0.7 µm glass fibre filter, and the filtrate was acidified (to a pH<2) with nitric acid for metal detection. Each solution was stored at 4°C before analysis using an Atomic Absorption Spectrometer in which the concentration of heavy and toxic elements was observed and compared with the regulatory levels of EPA.

3.3. Physical Properties and Strength Tests

In the present work, an attempt on the utilisation of slag has been made in the sub-base layer of the flexible pavement. For the lower sub-base layer (or filter layer) a closed grading (Grading II for Granular Sub-base Materials) was taken and for the upper layer (drainage layer) a relatively uniform grading (GSB Grading IV) was considered as per MoRTH (2013)

specifications. The crushed aggregates were stabilized with cement for use in the drainage layer of sub-base using GSB grading IV. Hard moorum was used both in cement stabilised base, and cement stabilised sub-base filter layer taking the GSB Grading II of MoRTH (2013) specification in both cases. The desired gradation of GSB grading II and IV as per MoRTH (2013) specification corresponding to the standard IS sieve sizes are given in table 3.1.

Table 3.1. Grading for Granular Sub-base Materials **[Table 400-1, MoRTH (2013) specifications]**

IS Sieve Size (in mm)	**Percentage passing the IS sieve**	
	GSB Grading II	**GSB Grading IV**
53	100	100
26.5	70-100	50-80
9.5	50-80	-
4.75	40-65	15-35
2.36	30-50	-
0.425	15-Oct	-
0.075	0-5	0-5

3.3.1. Gradation

Gradation of the materials was determined by sieve size analysis taking IS sieves as mentioned in table 3.1. The materials were stored in the oven for 24 hours and then cooled before the sieve analysis. Wet sieving was done to find the gradation of finer materials (finer than 4.75 mm) in respect of moorum by washing the materials on a 75 µm IS sieve (until all the finer materials were passed), drying the retained materials in oven (for 24 hours) and then sieving the dried materials (after cooling) in designated IS sieves finer than 4.75 mm. The sieve size analysis

of 15 samples of slag, 5 samples each of 40 mm, 20 mm, 10 mm, and 6 mm crushed aggregate and 15 samples of hard moorum was done and the gradation results were shown in graphical forms taking sieve size (in mm) in x-axis (log scale) and corresponding percentage passing in y-axis.

3.3.2. Blending of aggregates

After the gradation results of slag, moorum and crushed aggregates were obtained, blending of the same materials was done by mixing different proportions of crushed aggregates and also with slag or moorum to meet the desired gradation (either GSB grading II or grading IV as specified in table 3.1) on a trial and error basis and the aggregate blend for which the percentage passing was within the desired limits was used for further tests and analyses.

3.3.3. Determination of Water Absorption and Specific Gravity

The water absorption (%) of the samples were determined by the pycnometer method as per the IS: 2386 (Part III). The bulk specific gravity and apparent specific gravity of both fine (finer than 4.75 mm) and coarse aggregates (coarser than 4.75 mm) of slag and moorum, as well as crushed aggregates, were also determined by the same method.

3.3.4. Determination of Plasticity Index

The liquid limit and plastic limit of aggregates were determined (taking materials finer than 425μm sieve) as per IS: 2720 (Part V) -1985 and the difference was expressed as the plasticity index.

3.3.5. Aggregate Impact Test

The impact test of the individual materials, as well as the combined materials for use in different pavement layers, were determined as per IS: 2386 (Part IV) -1963. Moorum samples for which the water absorption values were found to be more than 2%, wet aggregate impact value was determined as per IS: 5640 -1970. In wet impact test, the materials passed through 12.5 mm sieve and retained on 10 mm sieve were filled in the container, weighed (A gram) and then immersed in water for 3 days before testing. After impact (14 blows having 1-second interval), the materials were washed through a 2.36 mm sieve and the retained materials were dried in an oven for 24 hours before taking weight (A_1). The wet impact value was expressed as the ratio of the weight of materials passed 2.36 mm sieve to the total weight of materials taken as expressed in equation 1.

$$Wet\ Impact\ Value\ (\%) = \frac{A-A_1}{A} \times 100 \quad (1)$$

3.3.6. Combined Flakiness Index

Specified thickness and length gauges are used to determine flakiness and elongation indices respectively as per IS: 2386 (Part I) –1963. To determine the combined flakiness index the aggregates were first passed through the thickness gauge, and the weight of the aggregates passed thickness gauge was noted (A). The materials retained were then passed in the length gauge, and the weight of the aggregates retained was noted (B). The combined flakiness index was expressed as a percentage of total weight as given in equation 2.

$$Combined\ Flakiness\ Index\ (\%) = \frac{A+B}{Total\ weight\ of\ aggregates\ taken} \quad (2)$$

3.3.6. Modified Proctor Test

Modified proctor test was conducted as per the IS: 2720 (Part 8) -1983 to find the maximum dry density (MDD) at corresponding optimum moisture content (OMC). Compaction of materials (up to a maximum size of 37.5 mm) was done taking a larger size mould (volume equal to 2250 cm^3), compacting the materials in 5 layers and giving 55 blows to each. The water content of the materials for each trial was determined by the oven dry method as per IS: 2720 (Part II)–1973.

3.3.7. Determination of California Bearing Ratio (CBR)

The CBR value of the combined blend of slag and crushed aggregates were determined as per IS: 2720 (Part 16) -1987. The materials with maximum size up to 19 mm were compacted in a standard CBR mould with an extension collar (with spacer disc at the top) by a compression testing machine (static compaction) at a constant rate. The materials having a size larger than 19 mm were replaced with an equal weight of materials passing 19 mm and retained on 4.75 mm sieve. The samples were stored in water for four days before the penetration tests. The CBR values were expressed in percentage at 2.5 mm penetration (which were found to be more than those at 5 mm penetration).

3.3.8. Unconfined Compression Test

The unconfined compression test was used to determine the compressive strength of moorum and crushed aggregate mixture. Cement was used as the binder to stabilise the non-plastic mixture (crushed aggregates or combination of moorum and crushed aggregates) for their use in road base and drainage or filter layer of sub-base.

3.3.8.1. Cube Specimen

The compressive strength of cement stabilised cube specimens (15 cm ×15 cm ×15 cm) was determined as per IS: 4332 (Part V) -1970. Specimens were prepared to the predetermined maximum dry density taking materials up to a maximum size of 37.5 mm compacted at the optimum moisture content. The compaction was done through a vibratory hammer fitted to three tampers with specified heights (as shown in fig.3.2.) for compaction in three layers (each of 5 cm) of the cube.

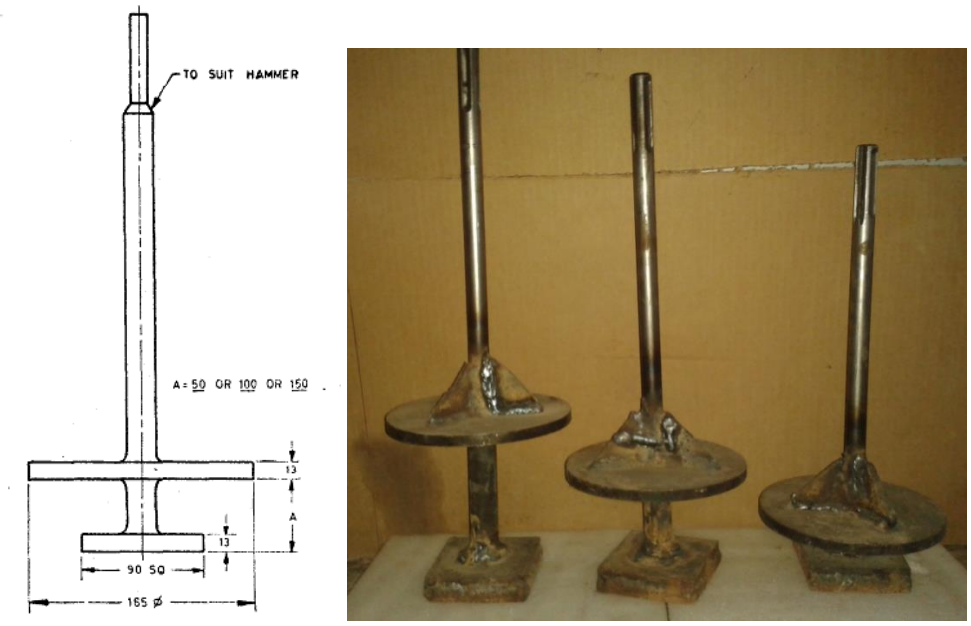


Figure 3.2. Tampers for use with a vibrating hammer for Unconfined Compressive Strength test [IS: 4332 (Part V) -1970]

The height A is different for all the tampers. The tampers with A=100 mm, 50 mm and 150 mm were used for compaction of the bottom 5 cm, the middle 5 cm and the top 5 cm of the cube respectively. During the compaction of the top layer, another cube without baseplate was placed squarely on the top of the cube to disallow spillage of any materials. The surface was levelled off

with a trowel, covered with a metal plate and stored at 27±2°C for 24 hours. Then the specimen was removed from the mould and stored for curing in a curing tin (160 mm x 160 mm x 155 mm deep with well-fitting lid sealed with tape to maintain the optimum moisture content) at 27±2°C. The difference in weight before storage and after removal (7 days from the time of compaction) was found to be within 2 g (which is much less than the allowable limit of 10 g) for all the specimens. The specimens after removal from the tin were then immediately tested in the Compression Testing Machine at a constant rate of loading (35 kgf/cm^2/min) until failure. Fig. 3.3 gives the sequences involved in preparation and testing of UCS of cube specimens.

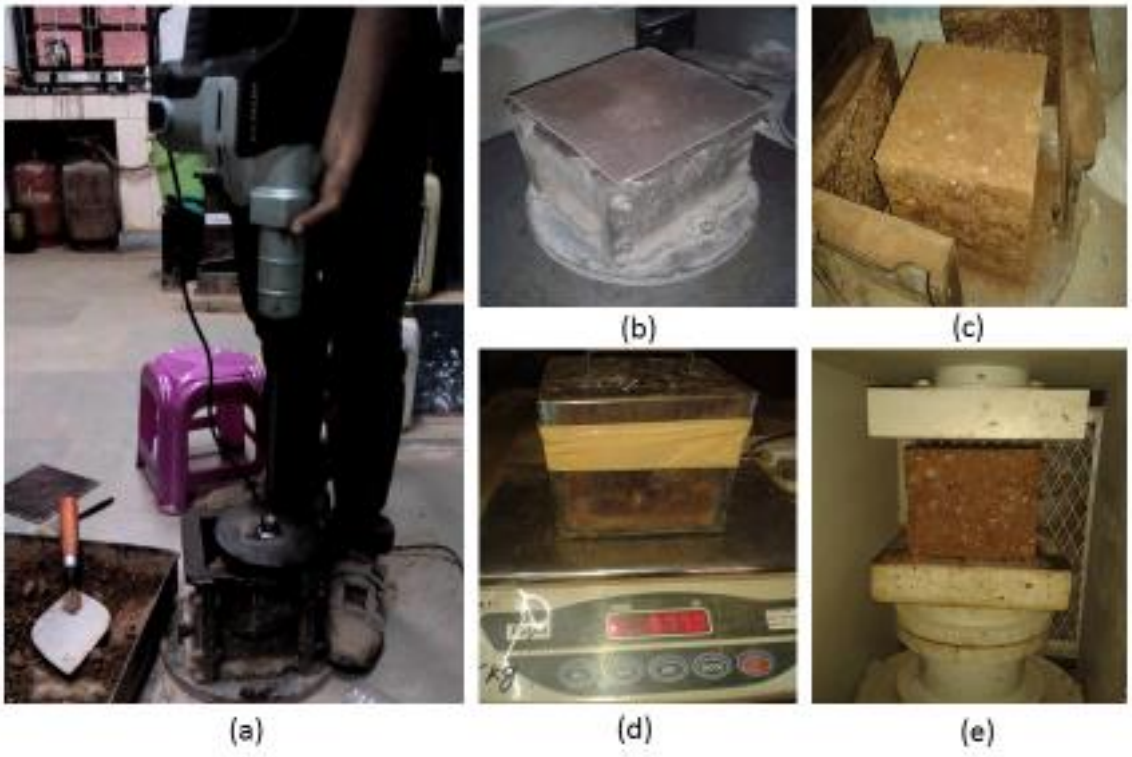


Figure 3.3. Sequences involved in preparation and testing of UCS of cube specimens **(a)** Compaction of materials in a cube mould using a vibratory hammer, **(b)** cube mould covered with a metal plate (160 mm× 160 mm× 3 mm), **(c)** removal of specimen from the mould after 24 hours,

(d) weight measurement of cube specimen inside a properly sealed curing tin (160 mm x 160 mm x 155 mm), **(e)** Unconfined compression test of specimen (after 7 days) using a Compression testing machine

3.3.8.2. Cylinder Specimen

The compressive strength of cylindrical specimens was determined using moulds having 101.6 mm diameter and 203.2 mm height as per ASTM-D1633 (2007). The height to diameter ratio (2.00) was more as compared to other cylindrical specimens giving a better practical measure (of compressive strength) reducing the complex stress conditions those may occur in case of the later (having lower height to diameter ratio) because of shearing of specimens. The materials up to a maximum size of 19 mm (larger size materials were replaced with equal weight of materials passing 19 mm and retained on 4.75 mm sieve) were compacted to the predetermined maximum dry density at the optimum moisture content. The specimens were removed from the moulds after 24 hours of compaction and stored at 23±1.7°C in a BOD incubator after proper sealing to maintain the moisture content. The difference in weight before and after curing was found to be within 1 g. The specimens (removed from incubator after 7 days from the time of compaction) were tested in the Compression Testing Machine and the compressive strength was multiplied by a height factor of 1.25 to obtain the equivalent compressive strength of cube [as per **IRC: SP:89-2010, Table 12:** Correction factors for various size and shape of test specimens]. Fig. 3.3 gives the sequences involved in preparation and testing of UCS of cylinder specimens.

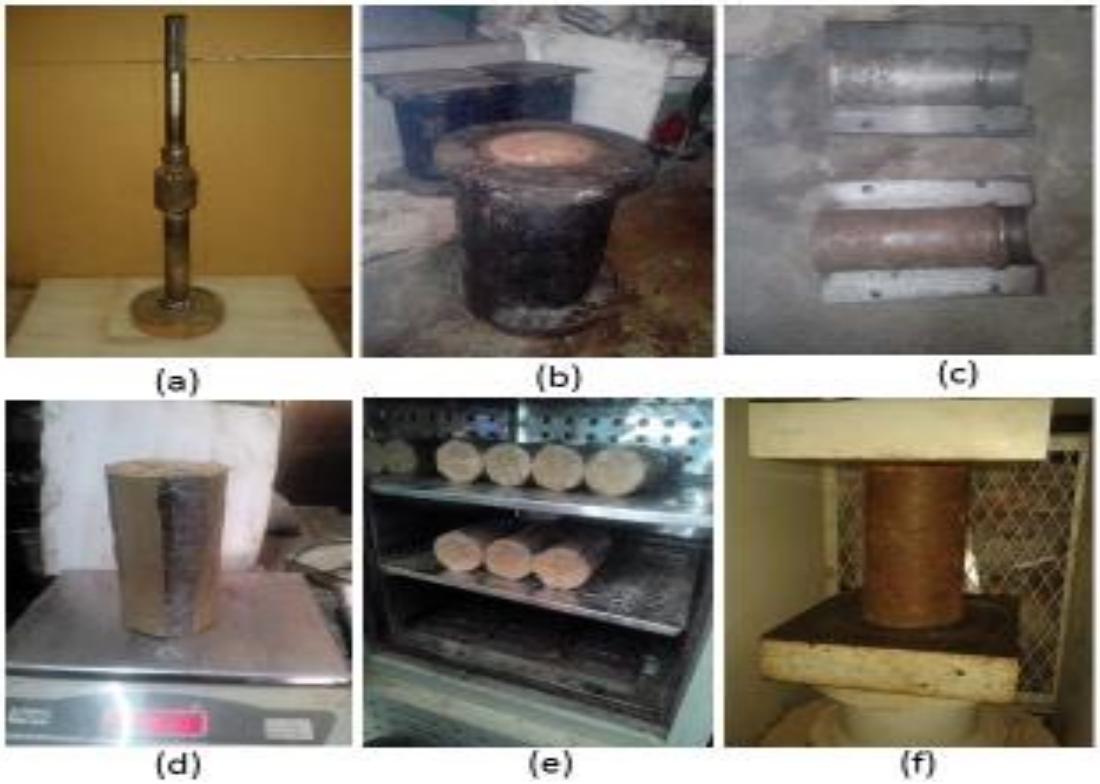


Figure 3.4. Sequences involved in preparation and testing of UCS of cylinder specimens **(a)** Tamper used with vibratory hammer for compaction of cylindrical specimens, **(b)** Cylindrical mould (101.6 mm diameter and 203.2 mm height) used for compaction, **(c)** Removal of specimen from the mould after 24 hours, **(d)** Weighing of specimen after proper sealing, **(e)** Curing of specimens in the BOD incubator at a constant temperature (23±1.7°C) **(f)** Unconfined compression test of specimen (after 7 days) using a Compression testing machine.

3.4. Materials used

- Slag remaining as waste material and obtained from Rourkela Steel Plant premises
- Locally available hard moorum
- Crushed aggregates to be blended with slag or moorum to meet the desired gradation as per MoRTH specification
- Cement as a binder for cement stabilisation
- Chemicals required to perform different chemical analyses

CHAPTER-4

RESULTS AND DISCUSSIONS

4.1. Characterization of slag

4.1.1. Chemical Composition

The chemical composition of the slag samples was determined by the XRF technique and is presented in table 4.1.

Table 4.1. Chemical composition of the slag samples determined by XRF technique

Chemical composition	Percentage
SiO_2	27.33
FeO	20.91
Al_2O_3	6.03
CaO	31.03
MgO	9.24
MnO	4.50
S	0.10
TiO_2	0.66
K_2O	0.14

The basicity (CaO/SiO_2) of the slag samples was found to be 1.14.

4.1.2. Phase Analysis

The phase composition of the slag samples was determined by the XRD method. The different phases (in terms of corresponding references of X'pert HighScore software) present in different slag samples were shown in table 4.2. The 2θ vs. the intensity variation of different slag samples and the phases corresponding to their peaks are shown in fig. 4.1 after analyzed by the software.

Table 4.2 (a) XRD peaks of slag samples corresponding to position [2θ (degrees)] and relative intensity [%], as analysed by X'pert HighScore software

Position [2θ (degrees)]	Relative Intensity	Matched by (References)
Slag-1		
18.6299	65	83-0114; 70-1435
26.6815	65.37	79-1910; 17-0445; 70-1435
29.4604	100	24-0027; 71-2108; 17-0445
31.4502	32.94	24-0027; 17-0445
38.0265	55.2	83-0114; 71-2108; 70-1435
42.1184	26.83	70-1435
Slag-2		
18.6226	89.83	83-0114
26.6715	49.18	79-1910
29.4484	100	24-0027; 71-2108
38.0507	60.31	83-0114; 71-2108

Slag-3		
18.6128	82.45	83-0114
26.6618	63.17	79-1910; 83-1563
29.4229	100	24-0027
38.011	59.86	83-0114; 83-1563
Slag-4		
18.5937	83.67	83-0114
20.9032	30.8	79-1910
26.5942	38.34	79-1910
29.4223	100	24-0027
38.0033	54.52	83-0114
42.9454	70.89	24-0027; 75-1609
Slag-5		
18.6097	88.11	83-0114
26.623	48.97	79-1910
29.4285	100	24-0027; 71-2108
38.0039	72.29	83-0114; 71-2108

Table 4.2 (b) Presence of phases in the slag samples corresponding to their reference codes used in table 4.2 (a)

Reference no.	Corresponding Phase
24-0027	$CaCO_3$
79-1910	SiO_2
83-0114	$Mg(OH)_2$
71-2108	$Ca_2Fe_2O_5$
75-1609	Fe_3O_4
17-0445	Ca_3SiO_5
70-1435	Al_2TiO_5
24-0234	Ca_2SiO_4
83-1563	Al_2SiO_5

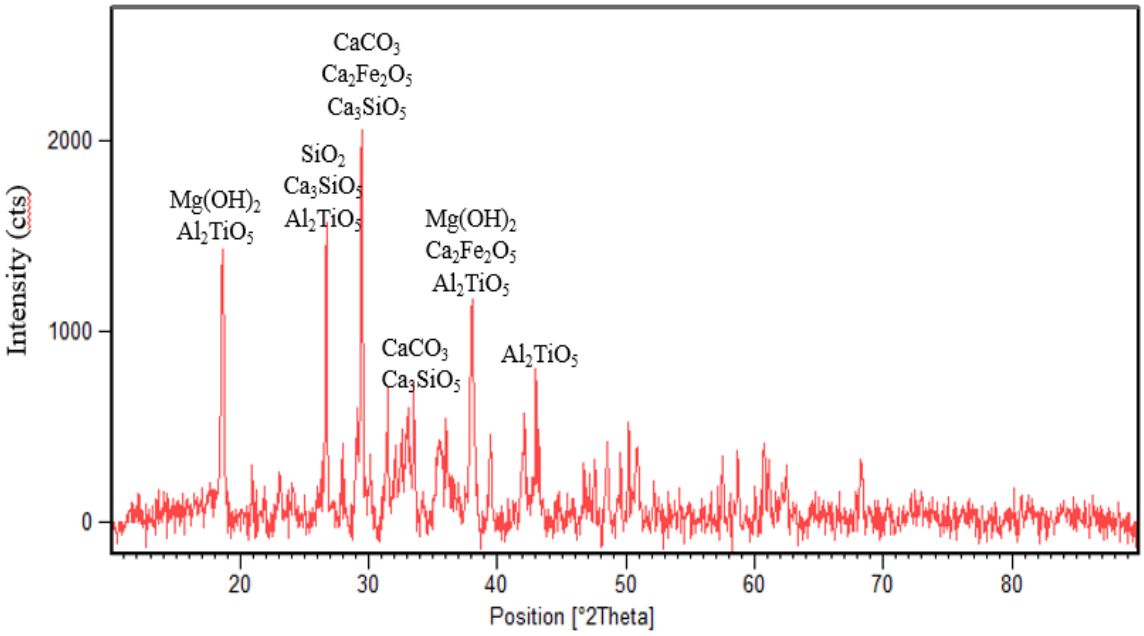


Figure 4.1 (a) Position (2θ) ~Intensity variation of slag sample no.1

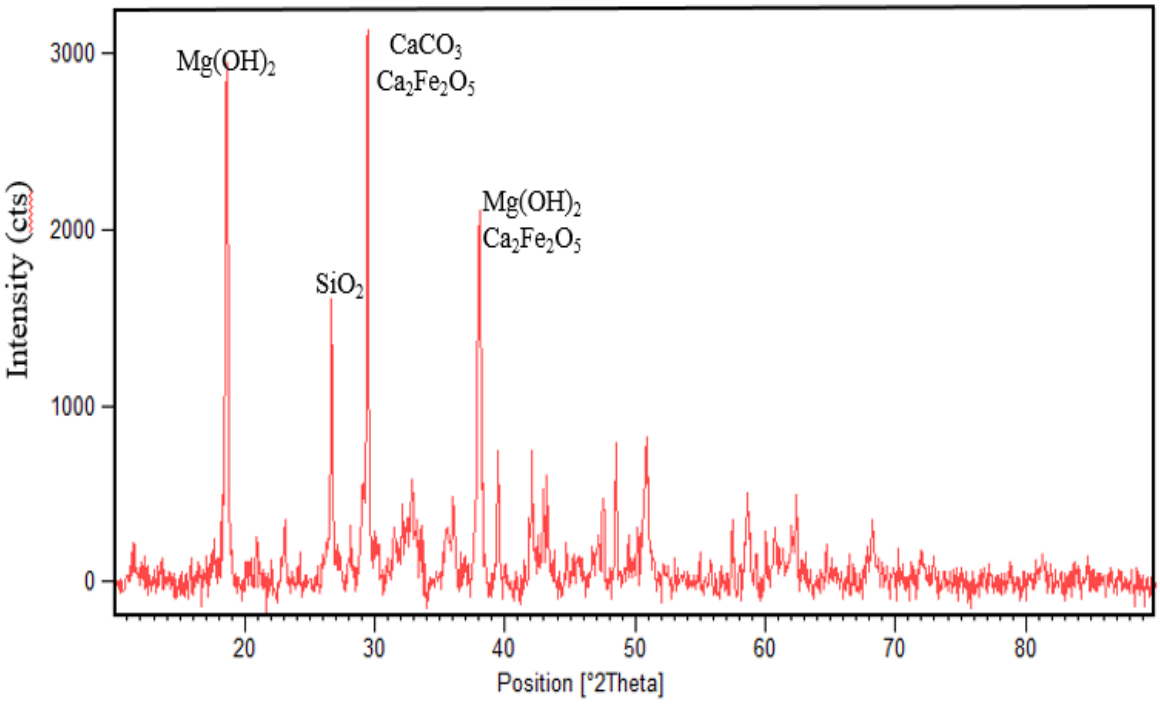


Figure 4.1 (b) Position (2θ) ~Intensity variation of slag sample no.2

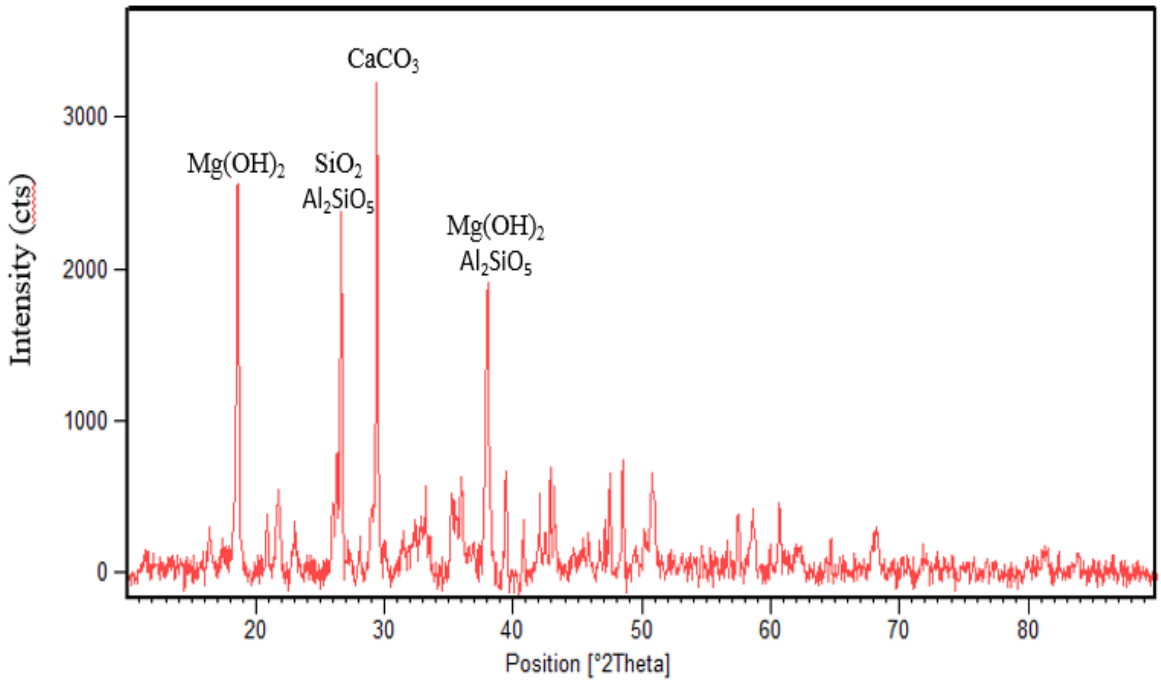


Figure 4.1 (c) Position (2θ) ~Intensity variation of slag sample no.3

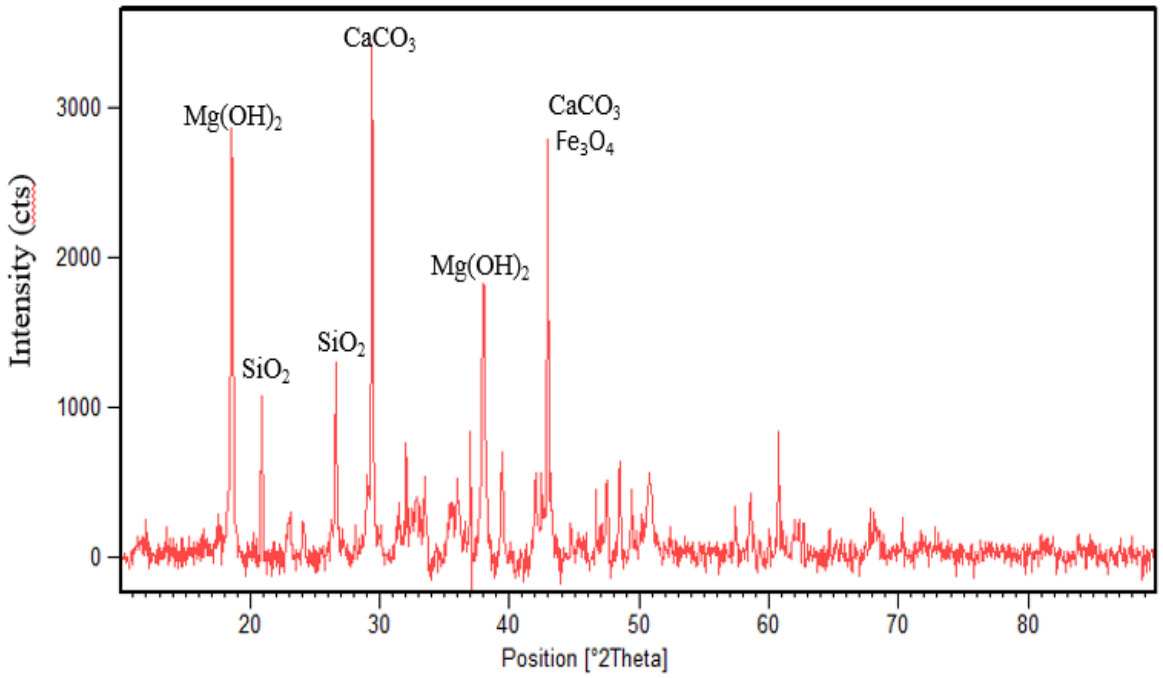


Figure 4.1 (d) Position (2θ) ~Intensity variation of slag sample no.4

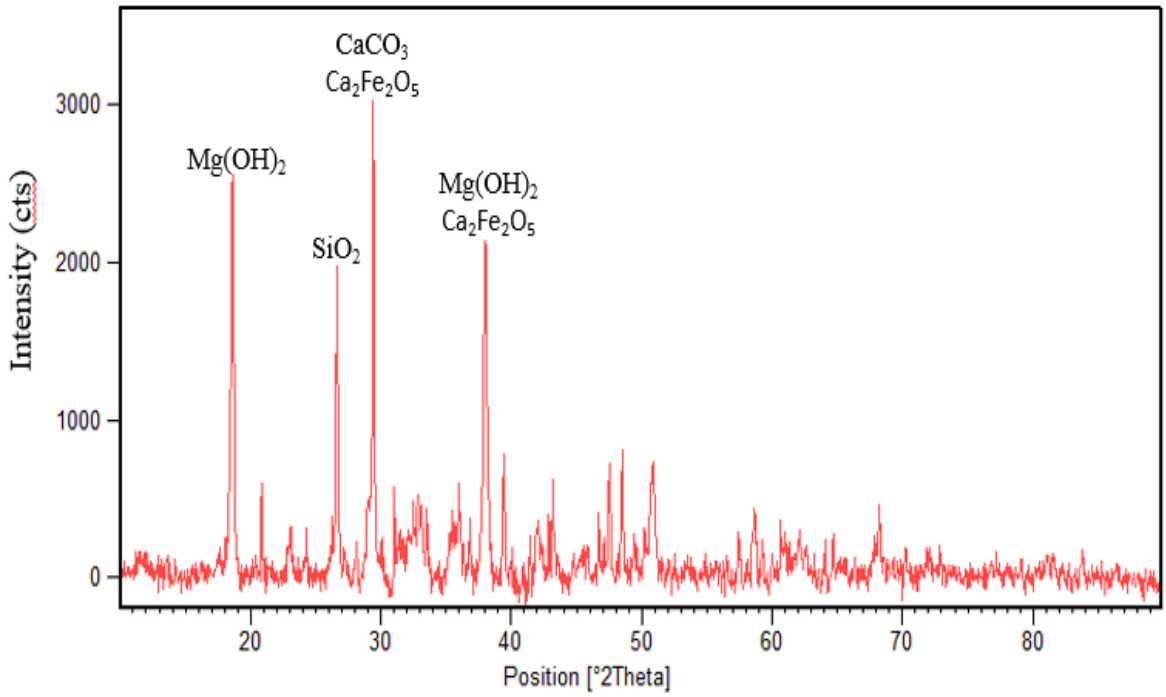
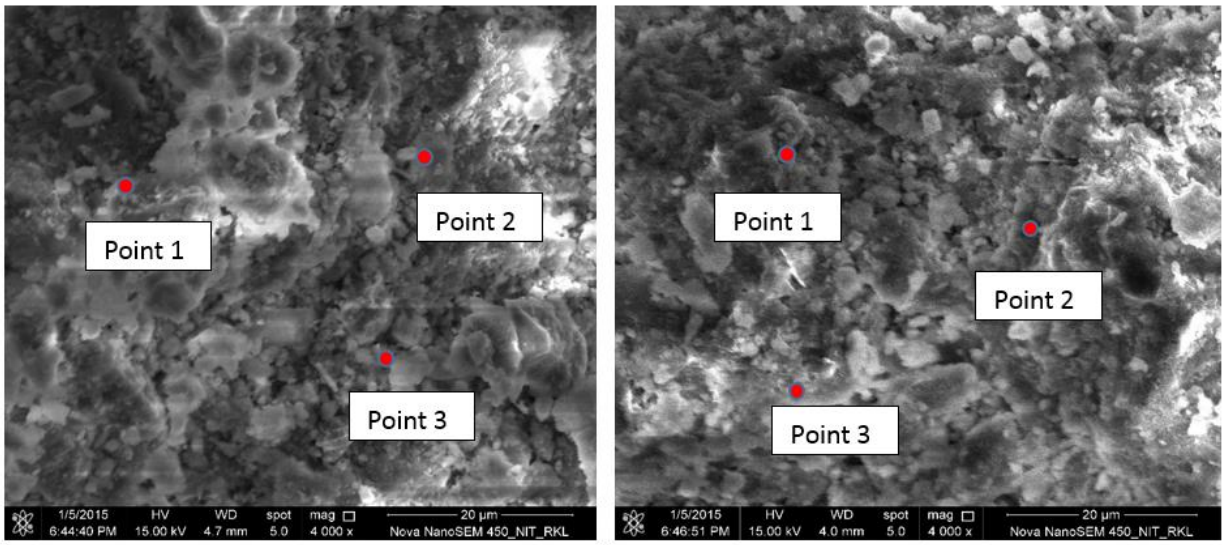


Figure 4.1 (e) Position (2θ) ~Intensity variation of slag sample no.5

From the XRD analysis, the phases of the slag samples were found to be either the same or a combination of the compounds as found in the chemical composition from the XRF technique. The phases were found to be either in carbonate, silicate or hydroxide form rather than oxide form which proves the slag being in a stable state and makes it suitable for construction applications.

4.1.3. Elemental Composition

The elemental composition of different points of the slag samples observed by the EDX technique are shown in graphical and tabular forms. The EDX spectrum of three different points from each of two slag samples (as shown in fig.4.2) are observed as in fig.4.2 and the presence of the elements at a specific point in the slag samples with their percentage (by atomic weight) are shown in table 4.3. The presence of any heavy metals present in the slag samples was also checked.



(a) Slag sample 1 (b) Slag sample 2

Figure 4.2. Magnified pictures (4000×) of two slag samples using Nova NanoSEM-450

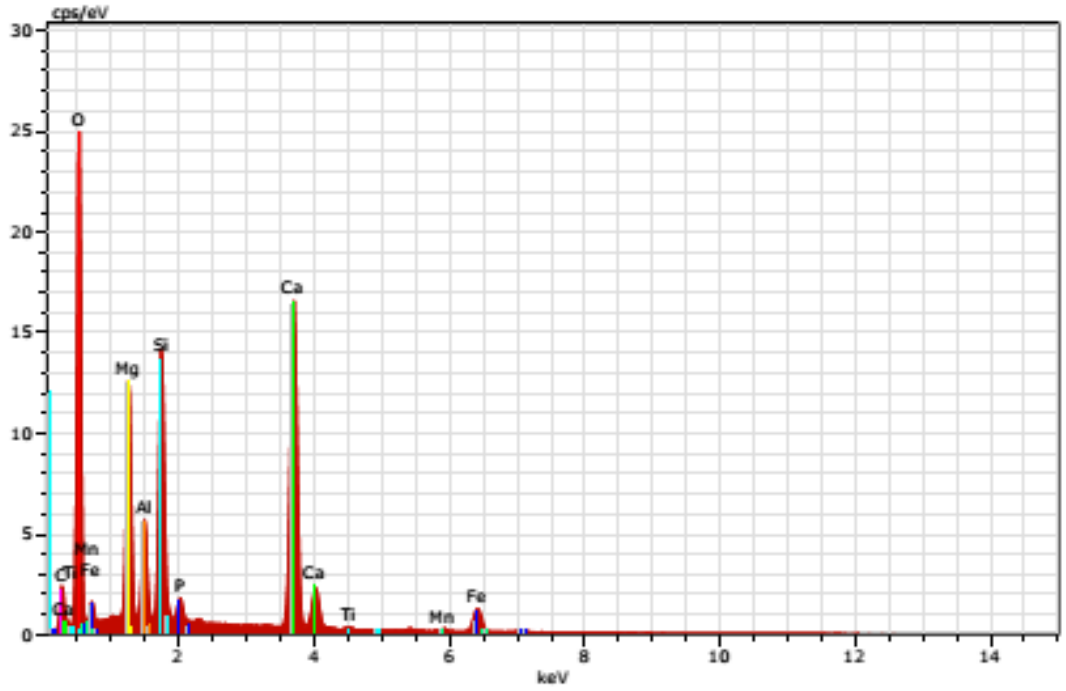


Figure 4.3 (a) EDX Spectrum of point 1 of slag sample no.1

Table. 4.3 (a) Elemental Composition of point 1 of slag sample no.1

El	AN	Series	Net	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
O	8	K-series	157567	54.13	47.90	62.08	5.98
Ca	20	K-series	203515	24.41	21.60	11.17	0.75
Si	14	K-series	119511	9.05	8.01	5.91	0.40
Mg	12	K-series	92367	8.28	7.33	6.25	0.46
C	6	K-series	12427	6.26	5.54	9.56	0.88
Fe	26	K-series	18447	5.80	5.13	1.91	0.20
Al	13	K-series	41319	3.38	3.00	2.30	0.18
P	15	K-series	11421	0.92	0.81	0.54	0.06
Mn	25	K-series	1989	0.52	0.46	0.17	0.05
Ti	22	K-series	1416	0.26	0.23	0.10	0.04
		Total:		112.99	100.00	100.00	

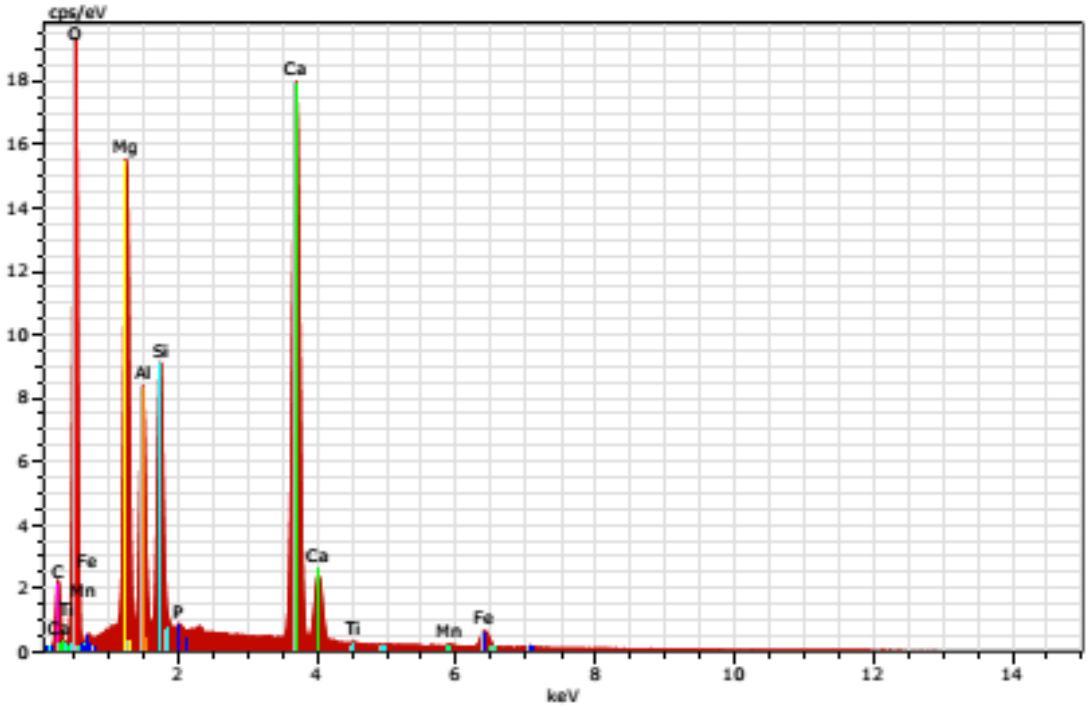


Figure 4.3 (b) EDX Spectrum of point 2 of slag sample no.1

Table. 4.3 (b) Elemental Composition of point 2 of slag sample no.1

El	AN	Series	Net	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
O	8	K-series	121247	43.65	45.60	60.03	4.89
Ca	20	K-series	220375	26.50	27.69	14.55	0.81
Mg	12	K-series	113156	8.09	8.45	7.32	0.45
C	6	K-series	11443	5.26	5.50	9.64	0.75
Si	14	K-series	72979	4.79	5.00	3.75	0.23
Al	13	K-series	60705	4.14	4.32	3.37	0.22
Fe	26	K-series	8222	2.89	3.02	1.14	0.12
Mn	25	K-series	902	0.26	0.27	0.10	0.04
P	15	K-series	1068	0.07	0.08	0.05	0.03
Ti	22	K-series	300	0.06	0.06	0.03	0.03
		Total:		95.71	100.00	100.00	

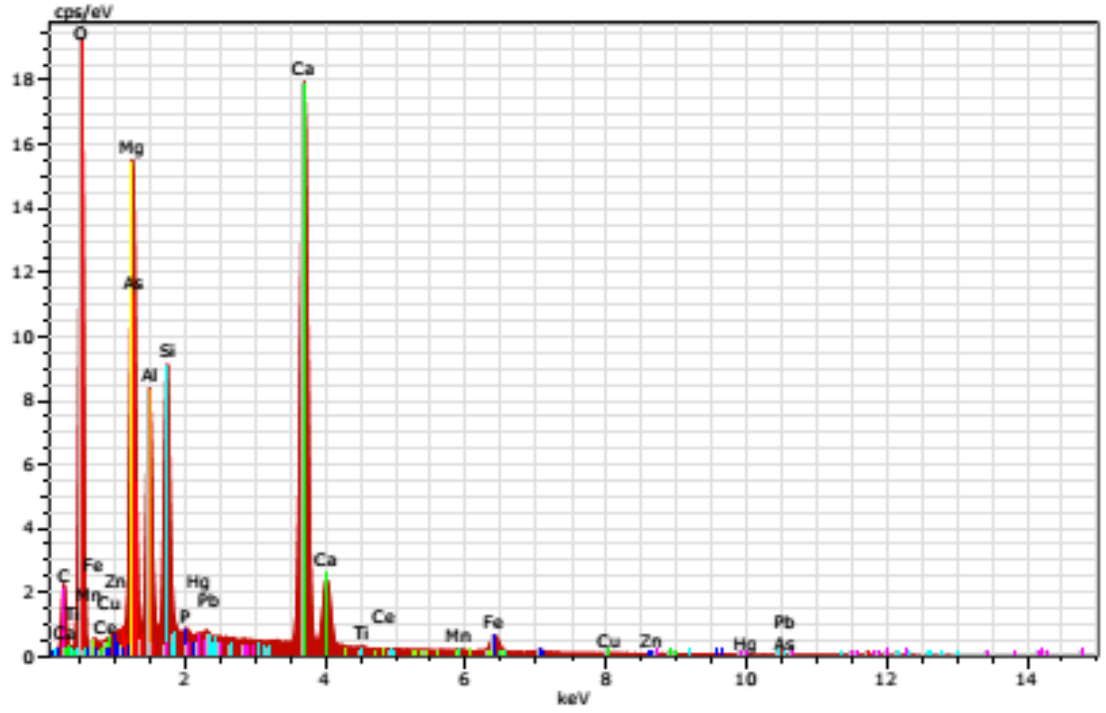


Figure 4.3 (c) EDX Spectrum of point 3 of slag sample no.1

Table. 4.3 (c) Elemental Composition of point 3 of slag sample no.1

El	AN	Series	Net	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
O	8	K-series	121012	40.22	44.78	59.57	4.51
Ca	20	K-series	219340	23.50	26.16	13.89	0.72
Mg	12	K-series	101603	7.38	8.21	7.19	0.42
C	6	K-series	11400	5.00	5.57	9.86	0.71
Si	14	K-series	72650	4.69	5.22	3.96	0.22
Al	13	K-series	60609	4.19	4.67	3.68	0.22
Fe	26	K-series	8001	2.67	2.97	1.13	0.11
As	33	L-series	19070	2.00	2.22	0.63	0.13
Mn	25	K-series	532	0.14	0.16	0.06	0.03
P	15	K-series	318	0.02	0.02	0.02	0.03
Cu	29	K-series	16	0.01	0.01	0.00	0.03
Ti	22	K-series	0	0.00	0.00	0.00	0.00
Ce	58	L-series	0	0.00	0.00	0.00	0.00
Pb	82	M-series	0	0.00	0.00	0.00	0.00
Hg	80	M-series	0	0.00	0.00	0.00	0.00
Zn	30	K-series	0	0.00	0.00	0.00	0.00
		Total:		89.82	100.00	100.00	

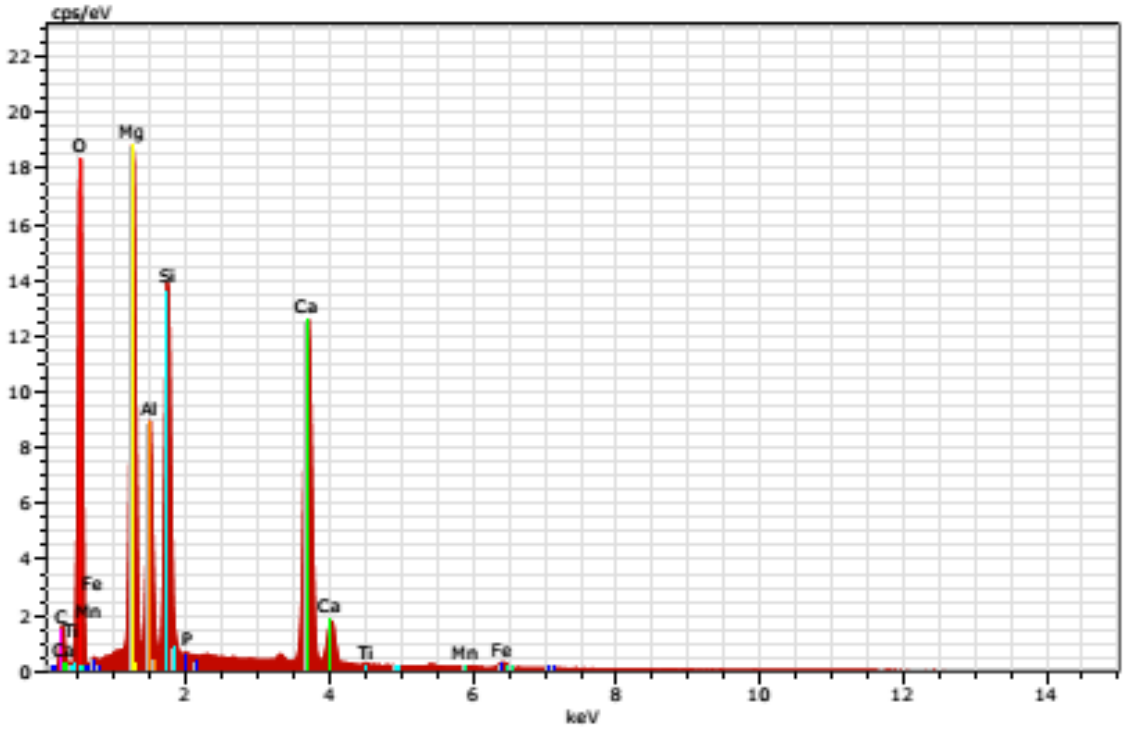


Figure 4.3 (d) EDX Spectrum of point 1 of slag sample no.2

Table. 4.3 (d) Elemental Composition of point 1 of slag sample no.2

El	AN	Series	Net	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
O	8	K-series	115468	42.39	44.28	57.37	4.76
Ca	20	K-series	156637	21.00	21.94	11.35	0.65
Mg	12	K-series	140797	11.45	11.96	10.20	0.63
Si	14	K-series	117791	8.93	9.32	6.88	0.40
Al	13	K-series	66492	5.30	5.54	4.26	0.27
C	6	K-series	8461	5.18	5.42	9.35	0.77
Fe	26	K-series	3105	1.13	1.18	0.44	0.07
Mn	25	K-series	722	0.22	0.23	0.09	0.04
Ti	22	K-series	488	0.10	0.10	0.04	0.03
P	15	K-series	355	0.03	0.03	0.02	0.03
		Total:		95.72	100.00	100.00	

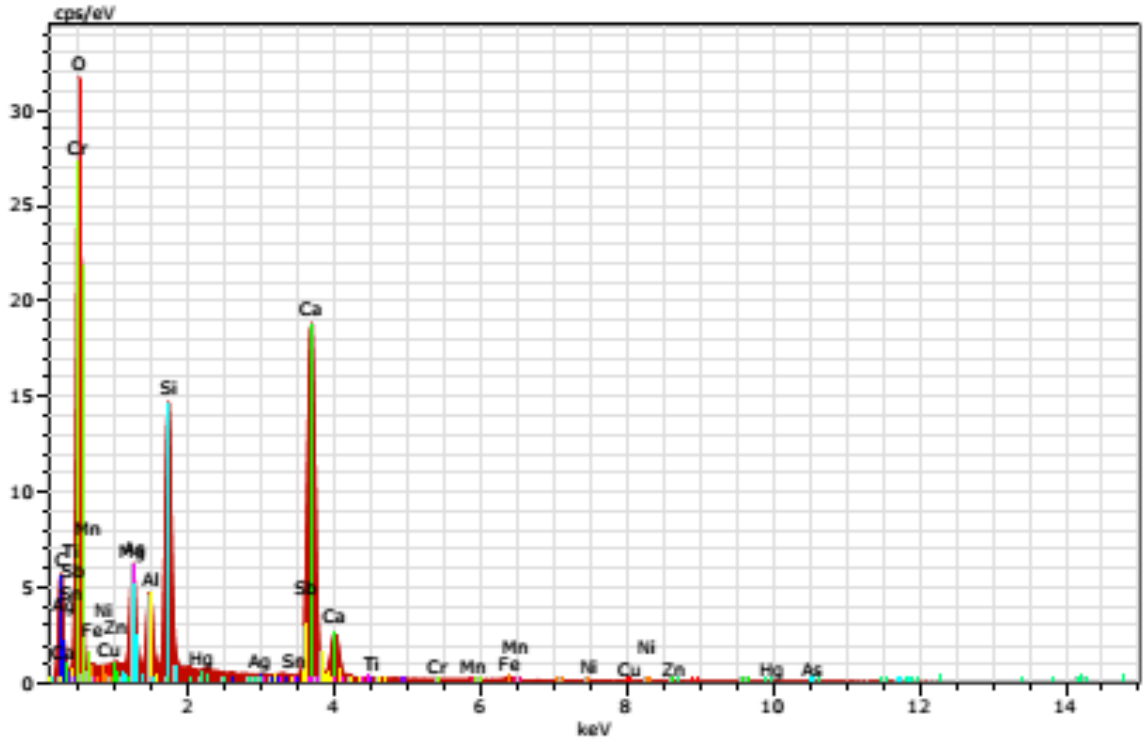


Figure 4.3 (e) EDX Spectrum of point 2 of slag sample no.2

Table. 4.3 (e) Elemental Composition of point 2 of slag sample no.2

El	AN	Series	Net	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
O	8	K-series	103123	68.69	53.27	63.85	7.75
Ca	20	K-series	121852	28.56	22.15	10.60	0.88
C	6	K-series	16934	13.60	10.55	16.84	1.80
Si	14	K-series	63887	8.44	6.55	4.47	0.38
Mg	12	K-series	19783	3.21	2.49	1.96	0.20
Al	13	K-series	17208	2.46	1.91	1.35	0.14
As	33	L-series	5070	1.19	0.92	0.24	0.09
Fe	26	K-series	1514	1.04	0.81	0.28	0.07
Zn	30	K-series	266	0.54	0.42	0.12	0.07
Ni	28	K-series	316	0.34	0.26	0.09	0.05
Cu	29	K-series	181	0.27	0.21	0.06	0.05
Mn	25	K-series	477	0.27	0.21	0.07	0.04
Hg	80	M-series	749	0.20	0.15	0.01	0.04
Ti	22	K-series	391	0.14	0.11	0.04	0.03
Ag	47	L-series	0	0.00	0.00	0.00	0.00
Sn	50	L-series	0	0.00	0.00	0.00	0.00
Sb	51	L-series	0	0.00	0.00	0.00	0.00
Cr	24	K-series	0	0.00	0.00	0.00	0.00
		Total:		128.95	100.00	100.00	

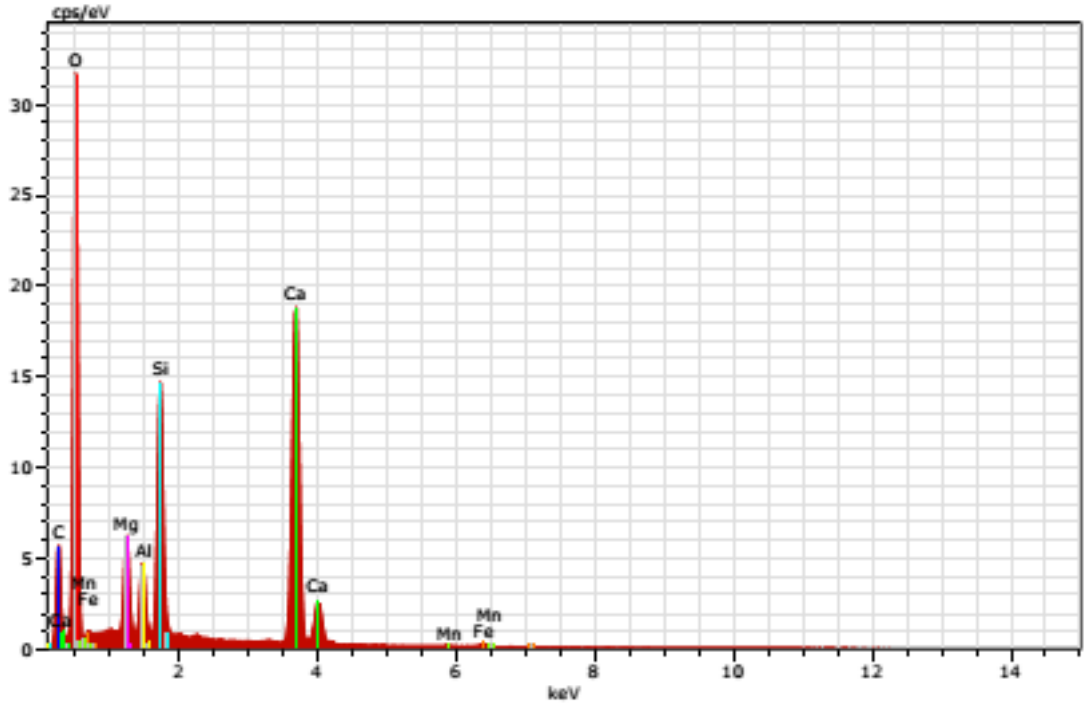


Figure 4.3 (f) EDX Spectrum of point 3 of slag sample no.2

Table. 4.3 (f) Elemental Composition of point 3 of slag sample no.2

El	AN	Series	Net unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
O	8	K-series	106164	70.83	55.65	65.42	7.98
Ca	20	K-series	121849	27.70	21.76	10.21	0.85
C	6	K-series	16443	12.91	10.14	15.88	1.72
Si	14	K-series	64155	8.63	6.78	4.54	0.39
Mg	12	K-series	23132	3.82	3.00	2.32	0.23
Al	13	K-series	17444	2.53	1.99	1.38	0.15
Fe	26	K-series	1395	0.86	0.67	0.23	0.06
		Total:		127.29	100.00	100.00	

The probable elements present in the slag samples were given as inputs, and the results have shown that the peaks of the elements (of EDX spectrum) match with the peaks of the corresponding phases of XRD spectrum. The input of heavy or toxic elements showed zero peaks in the spectrum and had zero percent (by weight) at the specific points in the slag samples.

4.1.4. Toxicity Characteristic Leaching Procedure (TCLP)

The concentration of toxic or heavy elements in the leachate water observed by the Atomic Absorption Spectrometer is given in table 4.4. These results are compared with the regulatory levels of corresponding elements as per the EPA of United States.

Table 4.4. The concentration of heavy or toxic elements in leachate water of the slag samples observed by AAS.

Heavy or toxic element	Concentration (mg/L)	US EPA Hazardous Waste Permissible Limit (mg/L)
Arsenic	0.02	5
Chromium	1.09	5
Lead	0.50	5
Mercury	NOT DETECTABLE	0.2
Copper	0.04	-
Nickel	0.13	-
Zinc	NOT DETECTABLE	-
Iron	0.55	-

The concentration of toxic elements in leachate water was found to be well within the regulatory levels, and the concentration of heavy elements were also found to be very low (within 1 ppm).

4.2. Physical Properties

4.2.1. Gradation

The sieve size analysis results for slag, crushed aggregates and moorum samples are presented in table 5.1 and the graph of sieve size and mean percentage passing is shown in the fig 5.1.

Table 4.5. Sieve size analysis of the slag, crushed aggregates and moorum samples

Sieve Size (in mm)	**Mean %age passing**					
	SLAG	**A40**	**A20**	**A10**	**A6**	**Moorum**
53.00	100.00	100.00	100.00	100.00	100.00	100
26.50	78.19	15.45	99.67	100.00	100.00	92.74
9.50	47.34	0.17	1.78	75.69	100.00	65.88
4.75	34.96	0.16	0.41	2.96	94.05	41.39
2.36	25.90	0.16	0.38	1.55	54.92	25.04
0.43	8.87	0.14	0.34	1.14	31.87	15.10
0.075	1.00	0.06	0.13	0.30	11.85	10.73

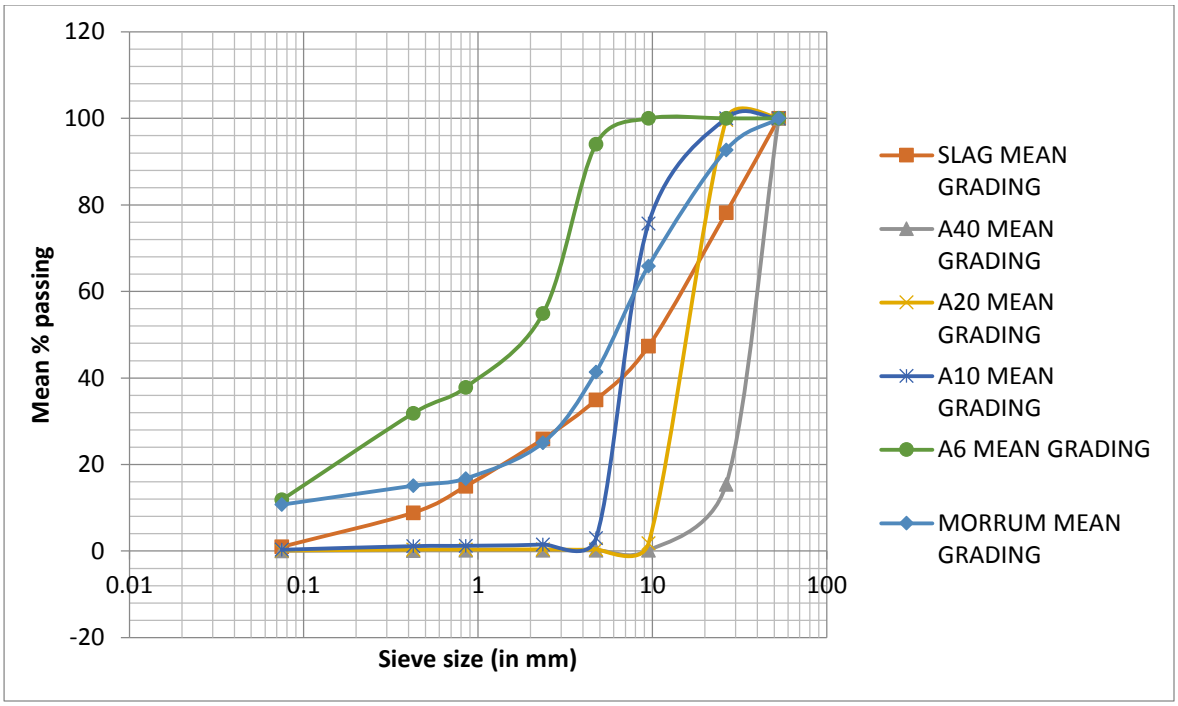


Figure 4.4. Graph of sieve size ~ mean %age passing of the slag, crushed aggregates and moorum

4.2.2. Blending

4.2.2.1. Blending of Slag and Crushed aggregates

Blending of slag and crushed aggregates was done to meet the requirements of GSB grading II (to be used in filter layer of GSB) and GSB grading IV (to be used in drainage layer of GSB) as per MoRTH specifications. After so many trials, the final proportion of the aggregates were found and are given in table 4.6.

Table 4.6 (a) Blending of the slag and crushed aggregates to meet the desired gradation for GSB Grading II

Grading II Limits			BLENDING
Sieve Size	**%passing (L)**	**%passing (U)**	**Slag=76%+A6=24%**
53	100	100	100.00
26.5	70	100	83.42
9.5	50	80	59.98
4.75	40	65	49.14
2.36	30	50	32.87
0.425	10	15	14.39
0.075	0	5	3.60

Table 4.6 (b) Blending of the slag and crushed aggregates to meet the desired gradation for GSB Grading IV

Grading IV Limits			BLENDING
Sieve Size	**%passing (L)**	**%passing (U)**	**Slag=80%+A40=20%**
53	100	100	100.00
26.5	50	80	65.64
4.75	15	35	28.00
0.075	0	5	0.81

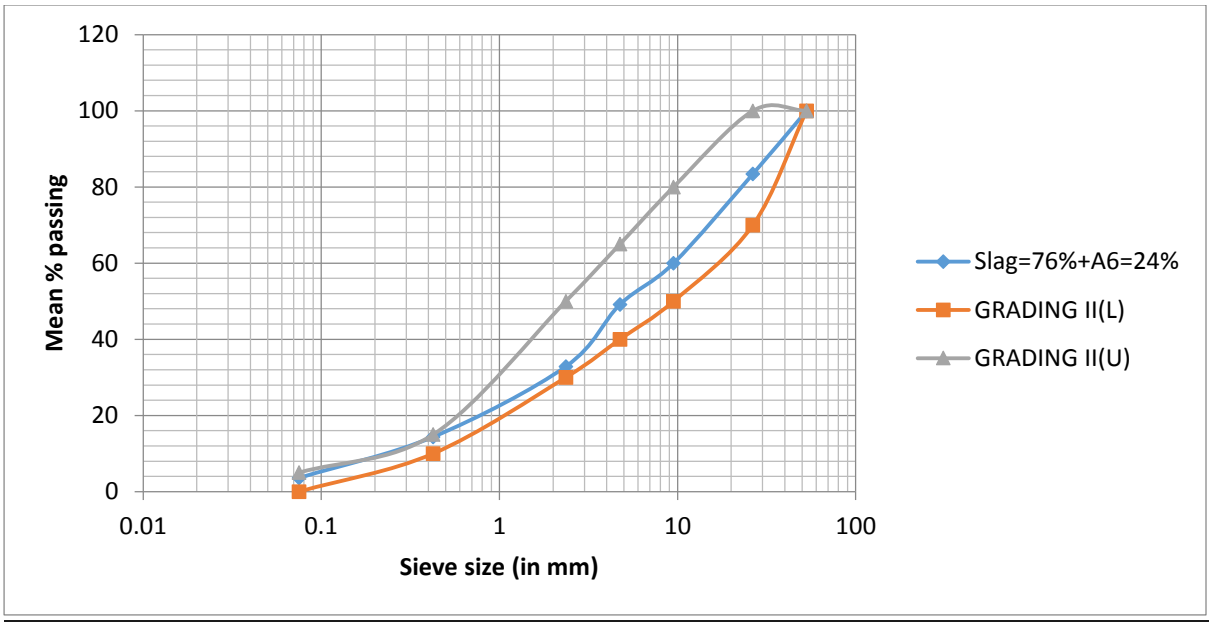


Figure 4.5 (a) Blending of the slag and crushed aggregates to meet the desired gradation for GSB Grading II

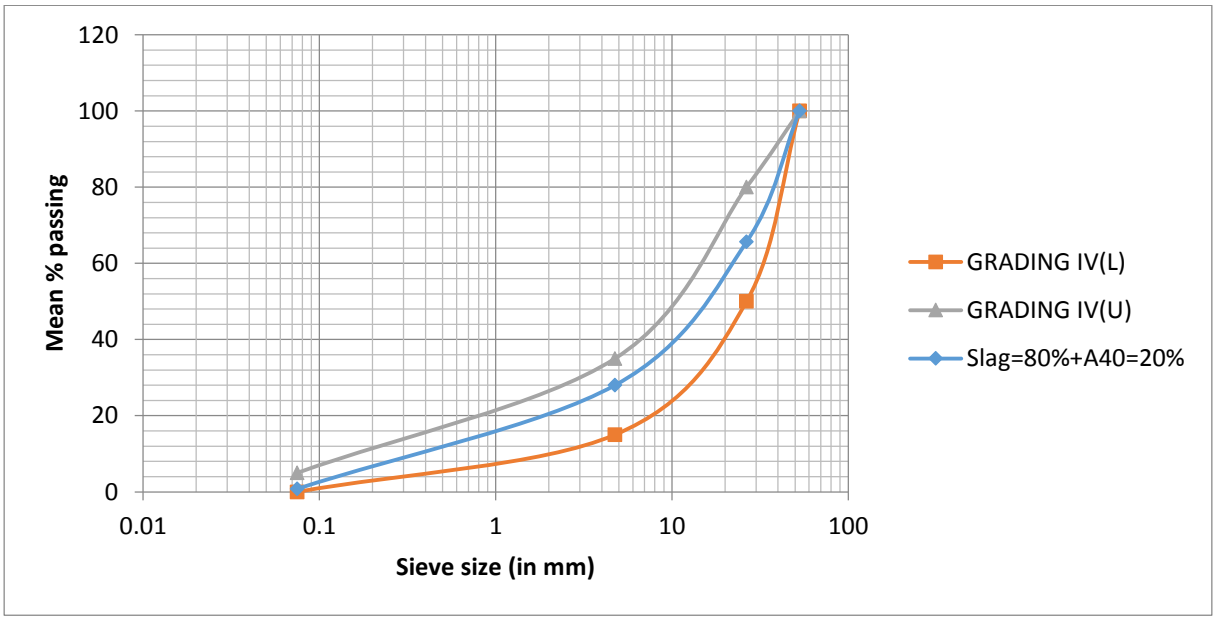


Figure 4.5 (b) Blending of the slag and crushed aggregates to meet the desired gradation for GSB Grading IV

4.2.2.2. Blending of Crushed aggregates

Blending of different size crushed aggregates was done to meet the requirements of GSB grading IV (for use in drainage layer of GSB) as per the MoRTH specifications using the same procedure (trial and error method).

Table 4.7. Blending of the crushed aggregates to meet the desired gradation for GSB Grading IV

Grading IV Limits			BLENDING
Sieve Size	**%passing (L)**	**%passing (U)**	**A40=35%+A10=50%+A6=15%**
53	100	100	100.00
26.5	50	80	70.41
4.75	15	35	15.64
0.075	0	5	1.95

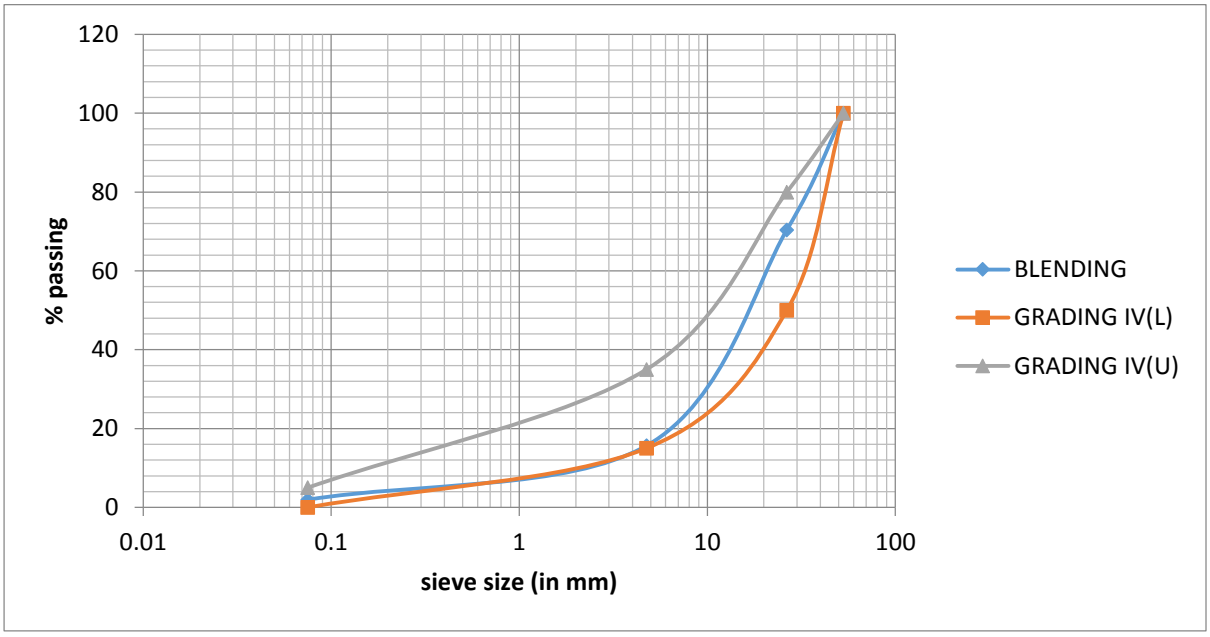


Figure 4.6. Blending of the crushed aggregates to meet the desired gradation for GSB Grading IV

4.2.2.3. Blending of Moorum and Crushed aggregates

Blending of moorum and crushed aggregates was done to meet the requirements of GSB grading II for use in the cement treated base and the filter layer of sub-base. The proportions of materials were selected for which the grading was best fitted within the desired limits.

But in case of moorum, the fines content was found to be very high and during blending it was difficult to satisfy the limits of grading II taking the quantity of moorum more than 20 % of the total weight of aggregates. So the blending of moorum and crushed aggregates was tried not only to achieve a grading as close as possible to the desired grading of GSB grading II as per the MoRTH Specifications but also to satisfy the grading limits of cement stabilization as per the MoRTH Specifications as well as the grading requirements of cement bound base and sub-base materials (Grading III) as per IRC SP: 89 (2010).

Table 4.8 (a) Blending of moorum and crushed aggregates to meet the requirements of GSB Grading II as per the MoRTH Specifications

Grading II Limits for Granular Sub-base Materials (MoRTH Specification)			**BLENDING**
Sieve Size	**%passing (L)**	**%passing (U)**	**Moorum=50%+A10=15%+ A6=35%**
53	100	100	100
26.5	70	100	96.37
9.5	50	80	79.29
4.75	40	65	54.06
2.36	30	50	31.97
0.425	10	15	18.88
0.075	0	5	9.56

Table 4.8 (b) Blending of moorum and crushed aggregates to satisfy the grading requirements of Materials for Stabilization with Cement as per MoRTH Specifications

Grading Limits of Materials for Stabilization with Cement (MoRTH Specification)			**BLENDING**
Sieve Size	**%passing (L)**	**%passing (U)**	**Moorum=50%+A10=15%+A6= 35%**
53	100	100	100
37.5	95	100	96.37
19	45	100	79.29
9.5	35	100	54.06
4.75	25	100	31.97
0.6	8	65	-
0.3	5	40	-
0.075	0	10	9.56

Table 4.8 (c) Blending of moorum and crushed aggregates to satisfy the Grading III Limits for Cement Bound Materials for Base/Sub-bases as per IRC SP: 89(2010)

Grading III Limits for Cement Bound Materials for Base/Sub-bases as per IRC SP: 89(2010)			**BLENDING**
Sieve Size	**%passing (L)**	**%passing (U)**	**Moorum=50%+A10=15%+A6= 35%**
53	100	100	100
26.5	70	100	96.37
9.5	50	80	79.29
4.75	40	65	54.06
2.36	30	50	31.97
0.425	15	25	18.88
0.075	3	10	9.56

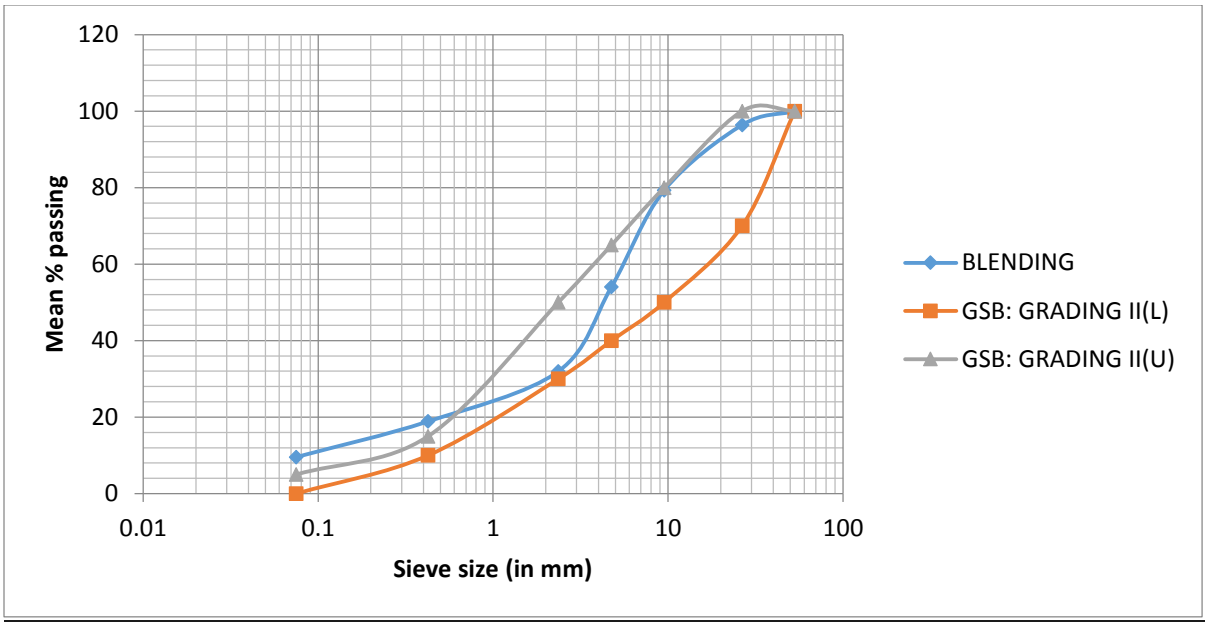


Figure 4.7 (a) Blending of moorum and crushed aggregates to meet the requirements of GSB Grading II as per the MoRTH Specifications

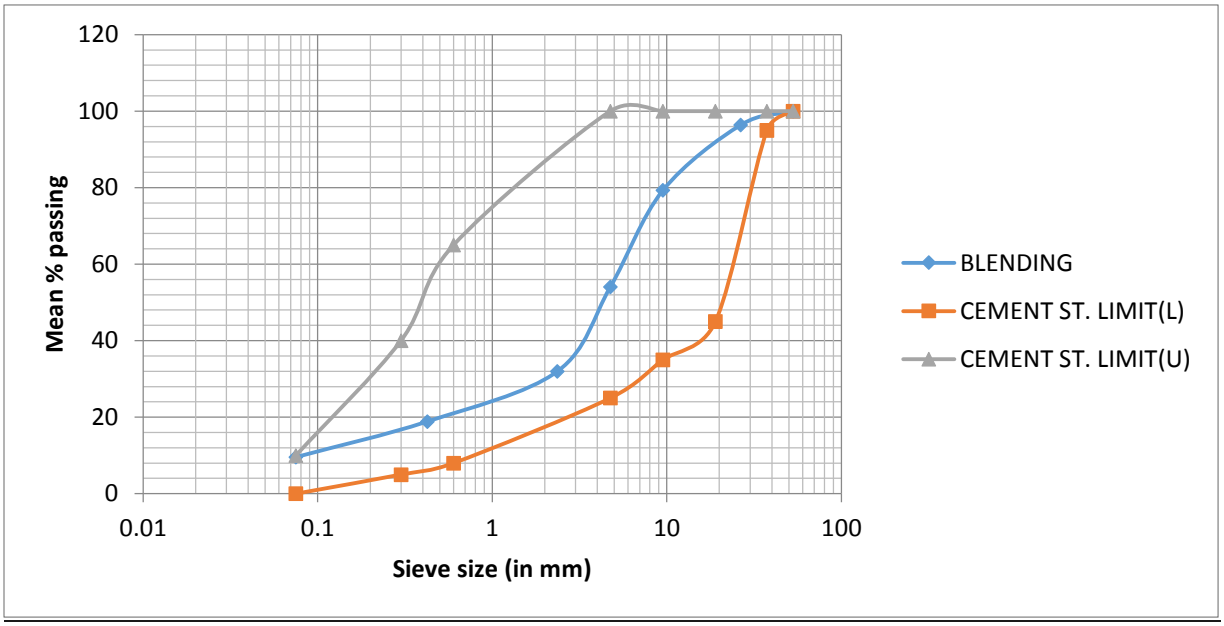


Figure 4.7 (b) Blending of moorum and crushed aggregates to satisfy the grading requirements of Materials for Stabilization with Cement as per the MoRTH Specifications

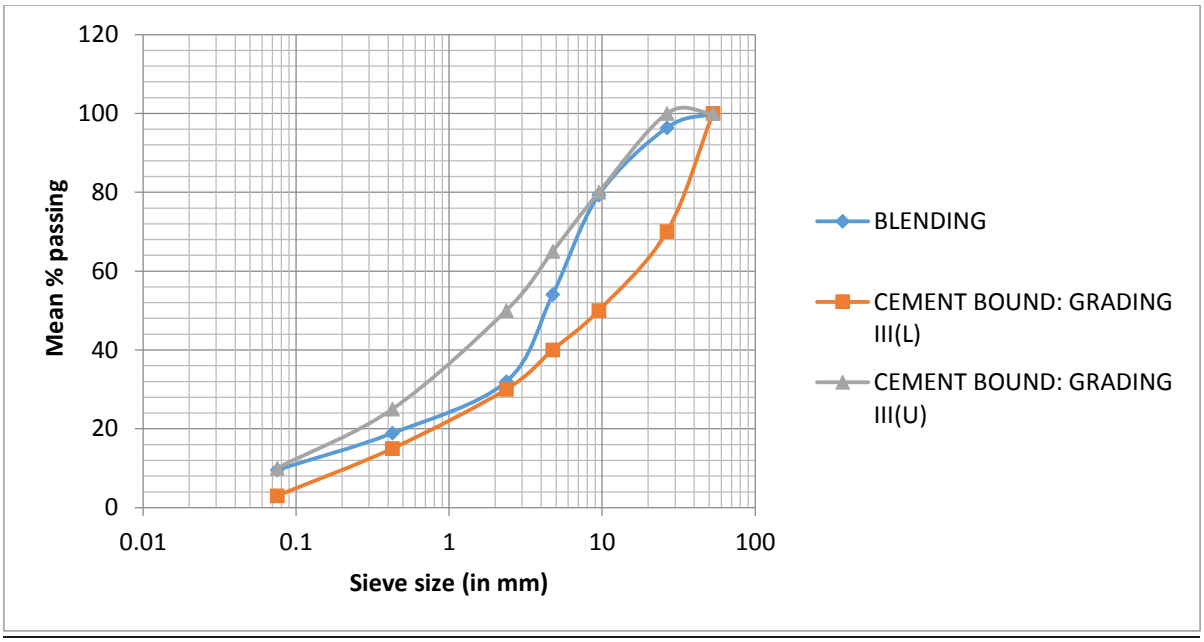


Figure 4.7 (c) Blending of moorum and crushed aggregates to satisfy the Grading III Limits for Cement Bound Materials for Base/Sub-bases as per IRC SP: 89(2010)

From different trials, the optimum proportion of moorum that can be used in base and sub-base was found to be 50 percent of the total weight of aggregates satisfying the above grading requirements.

4.2.3. Other Properties

The physical properties of individual aggregates were determined following the procedure as described in section 3.3 presented in table 4.9 (a). The physical properties of the combination of aggregates (slag and crushed aggregates or only crushed aggregates or moorum and crushed aggregates) were determined for their use in different layers taking the optimum proportions as obtained in blending and presented in table 4.9 (b).

Table 4.9 (a) Physical properties of the slag, individual crushed aggregates and moorum.

Property		**Slag**	**A40**	**A20**	**A10**	**A6**	**Moorum**
Plasticity Index (PI)	Liquid Limit (LL)	30.00	-	-	-	17.60	40.70
	Plastic Limit (PL)	-	-	-	-	-	20.60
	PI=LL-PL	NP	NP	NP	NP	NP	20.10
Water Absorption (%)	Coarse	1.95	0.22	0.30	0.41	0.76	4.60
	Fine	6.94					4.90
Specific Gravity (Bulk)	Coarse	3.10	2.76	2.75	2.74	2.65	2.74
	Fine	2.66					2.64
Specific Gravity (Apparent)	Coarse	3.33	2.78	2.78	2.77	2.66	3.14
	Fine	2.94					2.92
Combined Flakiness Index		17.59	54.68	65.65	92.03	-	-
Impact Value		14.72	12.93	19.76	22.98	-	33.39
Optimum Moisture Content (%)		-	-	-	-	-	6.20
Max. Dry Density (g/cc)		-	-	-	-	-	2.32

Table 4.9 (b) Physical properties of the combination of the slag and crushed aggregates, a combination of crushed aggregates only, and combination of moorum and crushed aggregates for use in different layers.

Property	**Granular Sub-base Filter layer (GSB II)**	**Granular Sub-base Drainage layer (GSB IV)**	**Cement treated Sub-base Drainage layer (GSB IV) 2% cement**	**Cement treated Base (GSB II) 4% cement**	**Cement treated Sub-base Filter layer (GSB II) 2.5% cement**	Remarks with ref. to
	slag=76% + A6=24%	**slag=80% + A40=20%**	**A40=35% +A10=50% +A6 =15%**	**Moorum=50% + A10=15% +A6=35%**	**Moorum=50% + A10=15% +A6=35%**	MOTRH /IRC
Liquid Limit (LL)	24.50	30.00	17.6	21.00	21.00	<45
Plastic Limit (PL)	-	-	-	-	-	-
Plasticity Index (PI)	NP	NP	NP	NP	NP	<20
Combined Flakiness Index	17.59	28.89	73.28	66.94	66.94	-
Impact Value	14.72	14.77	18.84	23.01	23.01	<40
Wet Impact Value	-	-	-	31.45	31.45	<40
Optimum Moisture Content (%)	9.56	9.15	4.92	7.04	6.35	-
Max. Dry Density (g/cc)	2.34	2.43	2.32	2.38	2.35	-
CBR (%)	78.90	215.30	-	-	-	>30

The combination of slag and crushed aggregates, a combination of crushed aggregates as well as a combination of moorum and crushed aggregates in above proportions also gave satisfactory results. The specific gravity of the slag samples was found to be much higher as compared to that of crushed aggregates and moorum. Hence, the maximum dry density value was found to be very high. The corresponding optimum moisture content (OMC) value was also found to be more because of the high water absorption value. The impact values were found to be well within the regulatory level of 40% for use in road base or sub-base applications as per the Bureau of Indian Standards. The water absorption value of moorum was found to be more than 2 percent. Hence, the wet impact value of the combination of moorum and crushed aggregates was determined and found to be within the limits. The MDD values were found to be high in the case of both base and sub-base layer applications with 4 percent and 2.5 percent cement content (as a binder for stabilization) respectively.

4.2.3.1. UCS Test Results

The unconfined compressive strength values of the combination of crushed aggregates and combination of moorum and crushed aggregate blends for use in different layers with varying cement content are presented in table 4.10. The UCS values of cube specimens for use in the drainage layer of cement treated sub-base is shown in fig.4.7 (a) and the comparison of UCS values of cube specimens with the equivalent UCS values of cylinder specimens for cement treated base and filter layer of cement treated sub-base is shown in fig.4.7 (b) and fig.4.7 (c) respectively.

Table 4.10 (a) Unconfined Compressive Strength results of cube specimens (7 days)

Cement treated Sub-base Drainage layer (GSB IV) 2% cement		**Cement treated Base (GSB II) 4% cement**		**Cement treated Sub-base Filter layer (GSB II) 2.5% cement**	
A40=35% +A10=50% +A6 =15%		**Moorum=50%+ A10=15% +A6=35%**		**Moorum=50%+ A10=15% +A6=35%**	
OMC=4.92% MDD=2.321 g/cc		OMC=7.04% MDD=2.378 g/cc		OMC=6.35% MDD=2.351 g/cc	
Cement content (%)	UCS value (MPa)	Cement content (%)	UCS value (MPa)	Cement content (%)	UCS value (MPa)
1.50%	1.1	3.50%	4.0	2.00%	2.8
2.00%	2.2	4.00%	4.9	2.50%	3.1
2.50%	2.8	4.50%	5.4	3.00%	3.3
3.00%	3.2	5.00%	5.2	3.50%	3.5

Table 4.10 (b) Unconfined Compressive Strength results of cylindrical specimens (7 days)

Cement Treated Base			**Cement Treated Filter layer of Sub-base**		
OMC=7.04% MDD=2.378 g/cc			OMC=6.35% MDD=2.351 g/cc		
Cement content (%)	UCS value (MPa)	Equivalent cube strength (MPa)	Cement content (%)	UCS value (MPa)	Equivalent cube strength (MPa)
3.50%	4.7	5.9	2.00%	2.7	3.4
4.00%	5.9	7.4	2.50%	3.3	4.2
4.50%	6.5	8.2	3.00%	3.7	4.6
5%	6.4	8.0	3.50%	3.9	4.9

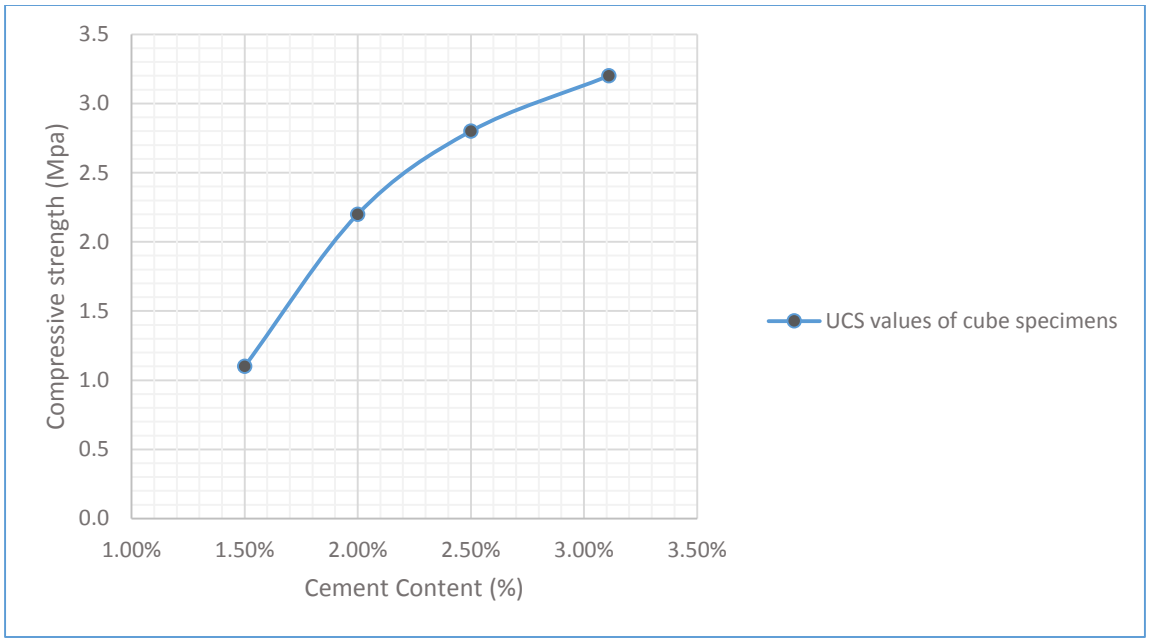


Figure 4.8 (a) UCS values of cube specimens for use in the drainage layer of cement treated sub-base [A40=35% +A10=50% +A6 =15%]

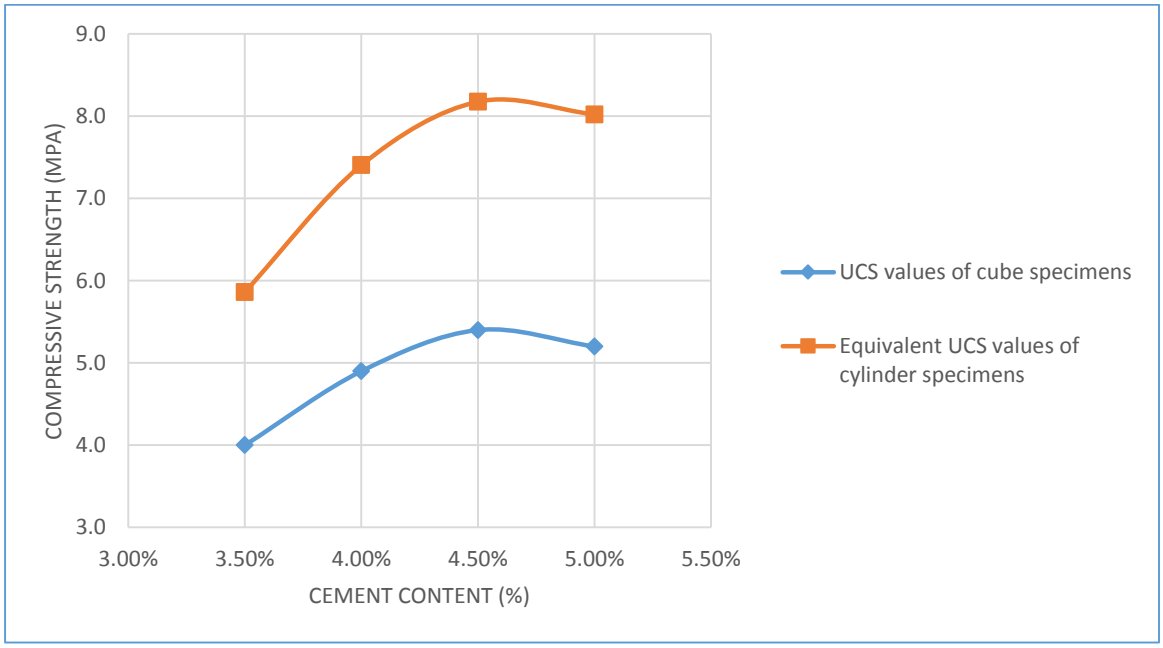


Figure 4.8 (b) Comparison of the UCS values of cube specimens with the equivalent UCS values of cylinder specimens for use in the cement treated base [Moorum=50%+ A10=15% +A6=35%]

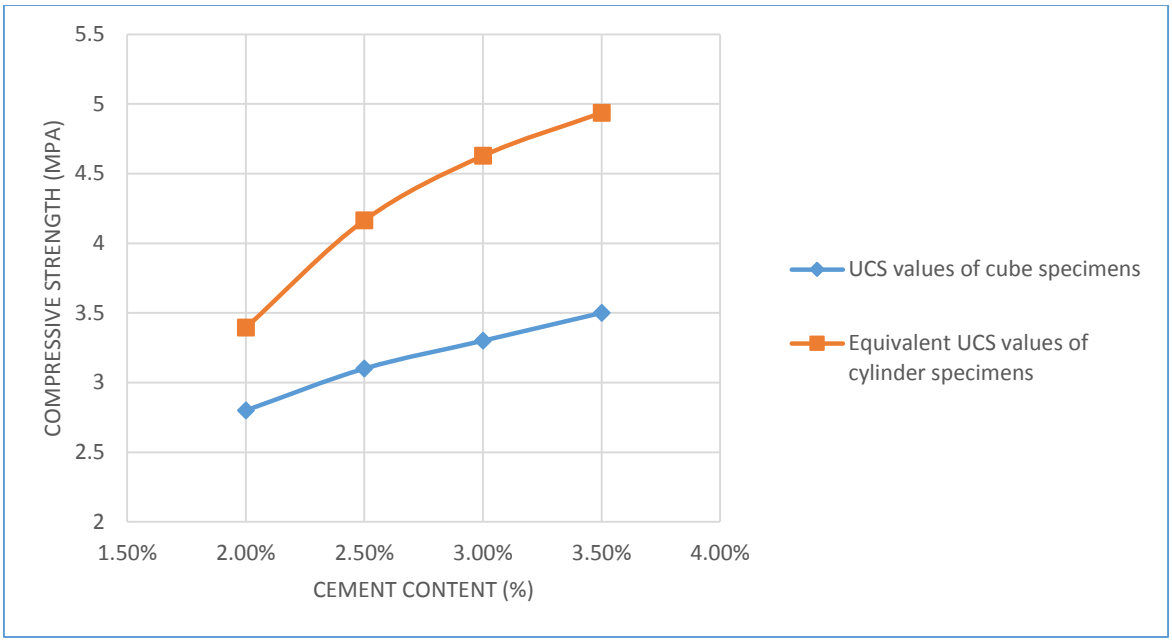


Figure 4.8 (c) Comparison of UCS values of cube specimens with equivalent UCS values of cylinder specimens for use in the filter layer of cement treated sub-base [Moorum=50%+ A10=15% +A6=35%]

The UCS value of the combination of moorum and crushed aggregates was found to be more as compared to that of the combination of crushed aggregates only for a particular cement content. The equivalent UCS values of the cylinder specimens were found to be more as compared to those of the cube specimens. The 7 days UCS values for cement bound materials should be between 4.5 to 7 MPa for use in the base and between 1.5 to 3 MPa for use in sub-base (drainage or filter layer) as per IRC SP: 89(2010). So depending on the required UCS value for construction of a particular layer the corresponding cement content can be taken to satisfy the requirements.

CHAPTER-5

SUMMARY AND FUTURE SCOPE

5.1. General

From the experiments conducted on the slag samples and locally available hard moorum, and from the analysis of results, the conclusions drawn are summarized below.

5.1.1. Characterisation of Slag

- The slag sample used in this work contains about 30% by weight of both CaO, SiO_2 and 20% by weight of FeO and some amount of Al_2O_3 and MgO, confirms the slag as steel slag.
- The phases present in the slag are in carbonate, hydroxide or silicate form rather than oxide form making it suitable for construction purposes.
- The heavy and toxic metals present in the slag and its leachate water are either zero or negligible. Hence, the potential for environmental hazards is very low.

5.1.2. Physical Properties

- The slag samples are well graded which require less amount of crushed (conventional) aggregates for blending to meet the desired grading for use in different layers of sub-base. For filter layer a maximum up to 76% slag and for drainage layer a maximum up to 80% slag can be used to satisfy the desired grading (GSB grading II and grading IV respectively as per the MoRTH specifications).

- The finer material content in the moorum used for this work is very high. Hence, the amount of moorum that can be used for base and sub-base is limited to 50% in the total aggregate blend.
- The impact values of the slag, crushed aggregates and wet impact value of moorum are within the maximum limits for road base or sub-base applications.
- The specific gravity of the slag aggregates is much higher than that of the crushed aggregates. Hence, the MDD and CBR values of the slag and aggregate blends are very high.
- The specific gravity of moorum is comparatively more than that of the crushed aggregates. Hence, the MDD values are also higher in the moorum aggregate blend.
- Cement is used as a binder for stabilization of moorum because of its high plasticity (PI= 20). The UCS values of the combination of moorum and crushed aggregates specimens satisfy the desired lower limits for use in the cement treated base or sub-base layers.
- The UCS value of cement treated moorum-crushed aggregates blend is more as compared to that of crushed aggregates blend for a particular cement content.

5.2. Summary

In this work, an attempt has been made to use the slag and locally available hard moorum in different layers of road base and sub-base. The slag used in the study is well graded and can be used as a major aggregate constituent (up to 80% of total aggregates) in the road sub-base applications (both filter and drainage layer). Results have shown that it not only has excellent physical properties and desired strength for use in road sub-base and but is also environmentally safe. Locally available hard moorum used in this study contains more fine materials and can be

suitable for closed or dense grading applications (base or filter layer of sub-base) which can replace the conventional aggregates up to a maximum of 50% by weight. The physical properties satisfy the desired requirements. The minimum desired strength value for use in a particular layer can be achieved by using a small amount of binder (cement). For a particular content of binder, moorum has shown better strength than that of the conventional crushed aggregates.

5.3. Future scope of work

- The strength parameters considered in the study are CBR and UCS. Apart from these tests the repeated load triaxial test can also be performed to find out the effect of dynamic loading in different layers, and the realistic resilient modulus values may be determined.
- The permeability of the slag and crushed aggregate mixture can be determined especially in the drainage layer of the sub-base by using suitable tests.

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