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USE OF LOCALLY AVAILABLE MATERIALS IN PAVEMENT SUB-BASE

Pappu Yadav[1], Shivam Singh Patel[2],
[1]M.Tech (Highway Engineering) Scholar, Maharishi University of Information Technology, Lucknow
[2]Assistant Professor (Civil Engineering Department), Maharishi University of Information Technology, Lucknow
Uttar Pradesh, India

***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.**

***Index Terms*— Slag, Moorum, XRD analysis, Toxicity, Unconfined Compressive Strength.**

I. INTRODUCTION

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)].

A. 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).

II. LITERATURE REVIEW

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.

A. 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)].

B. 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.

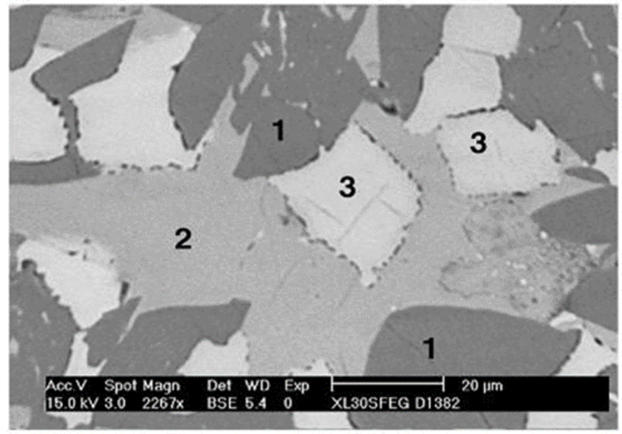

Figure 2.1 SEM photography of a polished section (grains> 2 mm) [P. Chaurand., et al. (2006)]

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)].

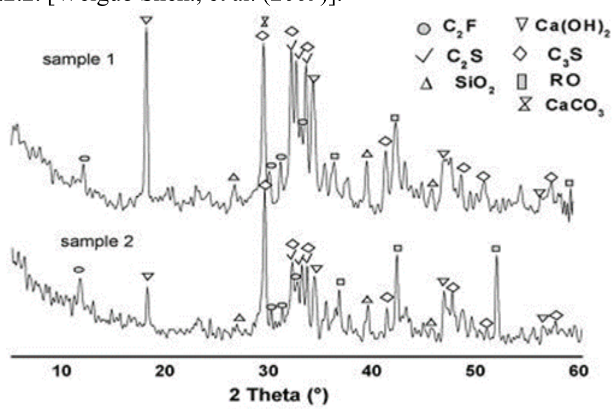

Figure 2. 2 XRD patterns of steel slag samples [Weiguo Shen., et al. (2009)]

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)].

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The hydration products of steel slag can be mineralogically determined by X-ray diffraction. TTR ||| diffractometer was used having nickel-filtered Cu Kα1 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.

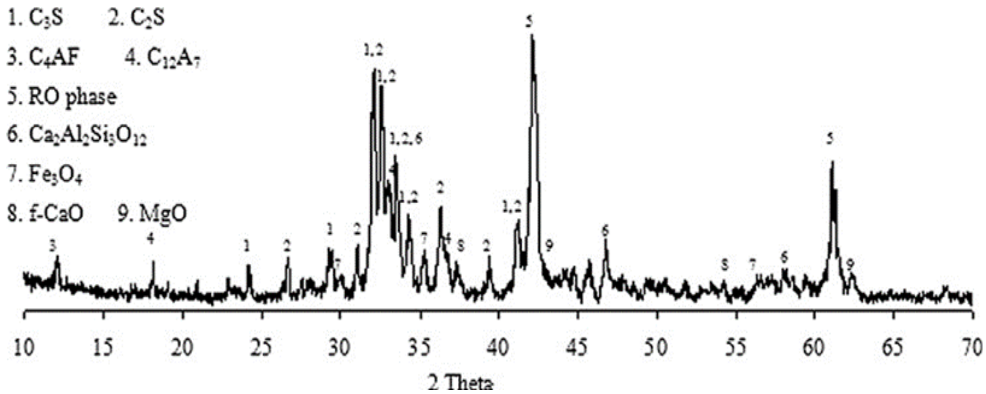

Figure 2.3. X-ray diffraction of steel slag [Wang and Yan (2010)]

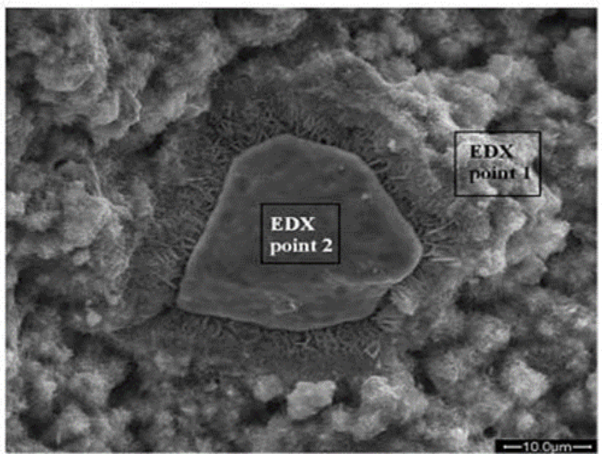

Figure 2.4 (a) SEM morphologies and EDX analysis of hydration products at the age of 28 days- SEM picture [Wang and Yan (2010)]

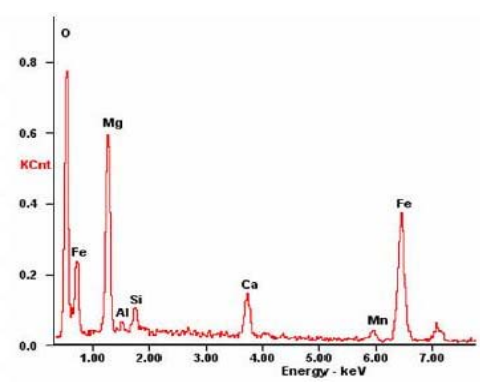

Figure 2.4 (b) EDX result of point 1

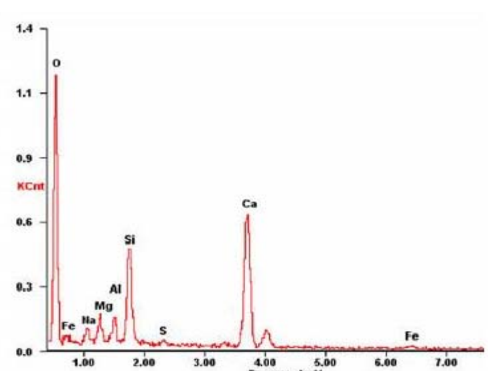

Figure 2.4 (c) EDX result of point 2

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 ($K\alpha$=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).

III. EXPERIMENTAL METHODOLOGY

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.

A. 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.

B. 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 SiO2, which defines the chemical composition and metallurgical properties of slag.

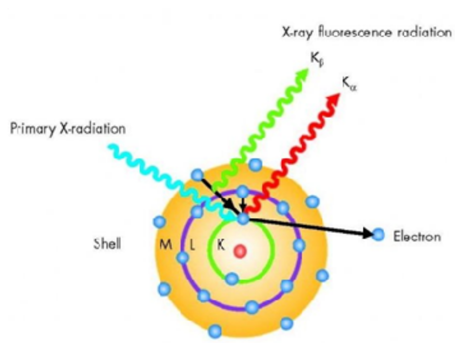

Figure 3.1 (a) Principle of XRF

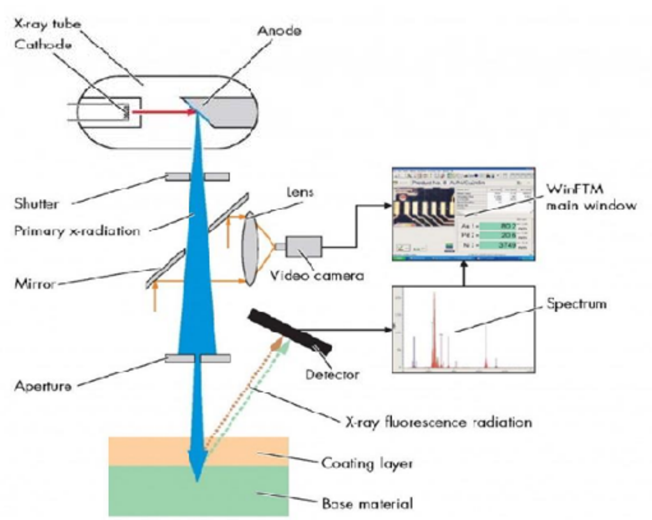

Figure 3.1 (b) XRF Instrument

C. 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

D. 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 (A1). 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.

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

E. 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.

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

F. 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.

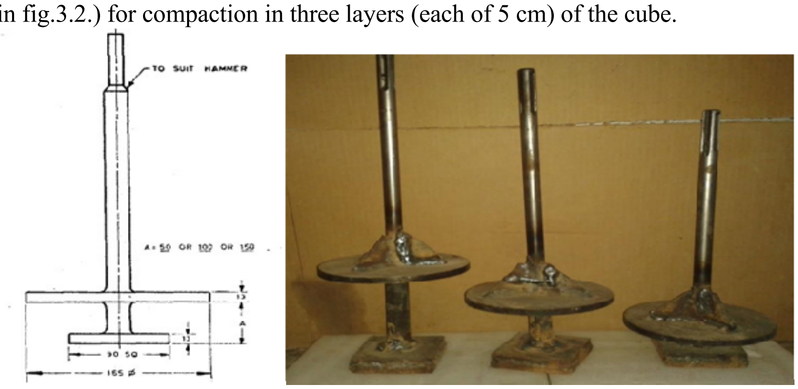

Figure 3.2. Tampers for use with a vibrating hammer for Unconfined Compressive Strength test [IS: 4332 (Part V) -1970

IV. RESULTS AND DISCUSSIONS

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

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

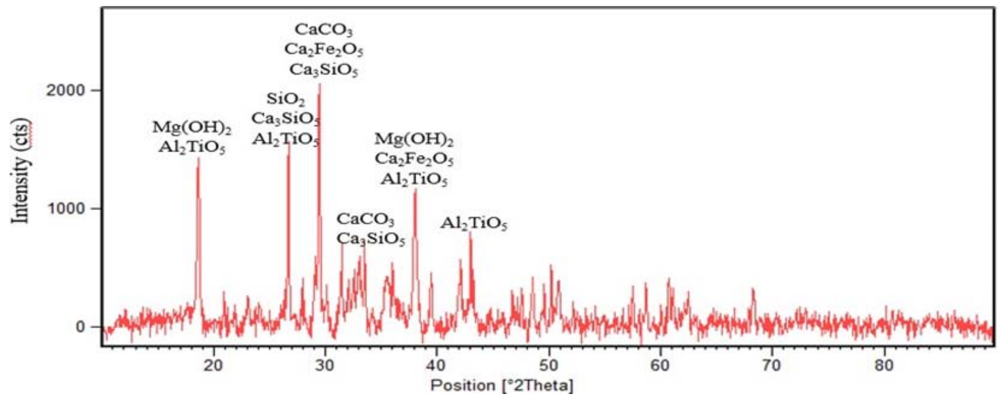

Figure 4.1 (a) Position (2θ) ~Intensity variation of slag sample no.1

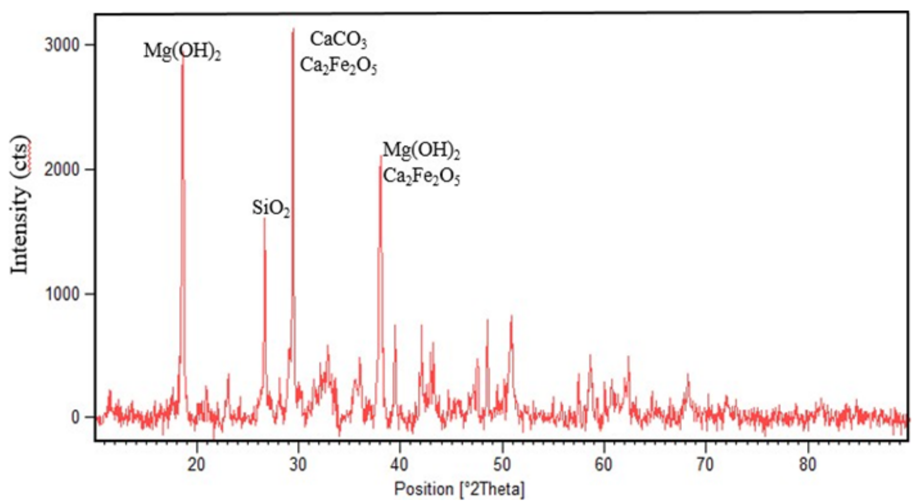

Figure 4.1 (b) Position (2θ) ~Intensity variation of slag sample no.2

V. SUMMARY AND FUTURE SCOPE

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.

A. Characterisation of Slag

- The slag sample used in this work contains about 30% by weight of both CaO, SiO2 and 20% by weight of FeO and some amount of Al2O3 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.

B. 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.

C. 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.

D. 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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