IRC:SP:121-2018

GUIDELINES FOR USE OF IRON, STEEL AND COPPER SLAG IN CONSTRUCTION OF RURAL ROADS

INDIAN ROADS CONGRESS
2018

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Published by:

INDIAN ROADS CONGRESS

Kama Koti Marg,
Sector-6, R.K. Puram,
New Delhi-110 022

NOVEMBER, 2018

Price : ₹ 600/-
(Plus Packing & Postage)

First Published : November, 2018

Printed at India Offset Press, Delhi - 110 064
500 Copies

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GUIDELINES FOR USE OF IRON, STEEL AND COPPER SLAG IN CONSTRUCTION OF RURAL ROADS

PART A : IRON AND STEEL SLAG

1 INTRODUCTION

The challenges related to the utilization of Steel Making Slag (SMS) slag were discussed during the meeting of NITI Aayog and it was decided that Indian Roads Congress (IRC)/ Ministry of Road Transport & Highways (MoRTH) need to look into the matter and include processed SMS slag in Indian standards for road making in line with the practices adopted in other countries. Accordingly,the task of preparation of IRC:SP:121-2018 "Guidelines for Use of Iron, Steel and Copper Slag in Construction of Rural Roads" was taken up by the Rural Roads Committee (H-5). The draft was prepared by the sub-group headed by Dr. I.K. Pateriya, comprising of Prof. (Dr.) U.C. Sahoo, Prof. (Dr.) K. Sudhakar Reddy, Dr. Vasant G. Havanagi, Shri Satish Pandey, Prof. (Dr.) G.J. Joshi and Prof. (Dr.) Mahabir Panda. Further, inputs were received from Shri Sunil Singal (Representative of SAIL), Shri S.M.R. Prasad (Representative of JSW Steel), Shri Ujjal Chakraborty (Representative of Tata Steel) and Shri R.N. Bhattacharya (Representative of Visakhapatnam Steel Plant). This draft was deliberated in several meetings of H-5 Committee and was finalized in its meeting held on 4th October, 2017. The revised draft was considered by the Highways Specifications and Standards Committee (HSS) in its meeting held on 13th October, 2017. The Council in its 213th meeting held on 3rd November, 2017 at Bengaluru considered and authorized Executive Committee to take final call about printing of this document. The Executive Committee deliberated this document in its various meetings and approved the same for printing in its meeting held on 26.06.2018.

The composition of H-5 Committee is as given below:

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Secretary General, Indian Roads Congress	Nirmal, Sanjay Kumar

India is the 3rd largest producer of steel in the world with a production of 101 MT and a capacity of 125 MT in 2017. Iron and steel slags are by-products generated during manufacturing of pig iron and steel respectively. Apart from the iron or Blast Furnace Slag (BFS) that is obtained from the production of pig iron, based on the process of production, the major categories of steel slags produced in India are Basic Oxygen Furnace Slag (BOFS) and Electric Arc Furnace Slag (EAFS). In an integrated steel plant, 2-4 tonnes of wastes are generated for every tonne of steel produced in different forms (i.e. solid, liquid and gas). The amount of slag depends on composition of raw materials and the type of furnace. Typically, ore containing 60 to 65% iron, BF slag production ranges between 300 and 540 kg per tonne of pig iron produced, whereas up to 200 kg of slag is generated per tonne of liquid steel. Lower grade ores yield much higher slag fractions. **Fig. 1** presents a flow diagram of slag production process.

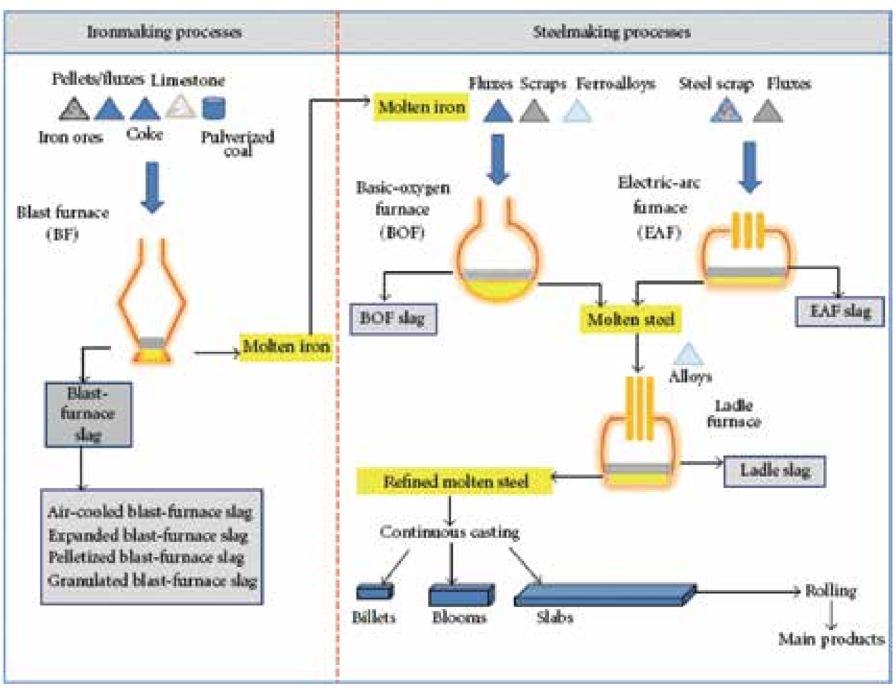

Fig. 1 Typical Slag Production Process (Yildirim and Prezzi, 2011)

For an eco-friendly environment, the major concerns of today are to pay adequate emphasis on minimisation of waste generation, recycling and re-use of waste, and minimise the adverse impact of waste disposals. The amount of slag generated from these plants is so large that its management has become a critical component. With increasing capacities, the mechanism for disposal of large quantities of slag has also gained traction for steel makers. Over the last few years, due to better understanding of various properties of slags, its use in different forms has led to significant reduction in the volume of slag generated. However, slag generation remains inevitable and its utilization remains one of the most serious concerns that need redressal.

1.1 Blast Furnace Slag

The slag produced from the blast furnace during production of pig iron is called blast furnace slag. This is a non-metallic product consisting primarily of silicates, alumina-silicates, and calcium-alumina-silicates. The molten slag comprises about 20 per cent by mass of iron production. In the blast furnace, the slag floating over molten pig iron is flushed out and then cooled. Depending on the cooling process, different types of slags are generated as required for various end-use consumers. Although, the chemical composition of slag may remain unchanged, physical properties vary widely with the changing process of cooling. Three types of slags are generated, namely, air-cooled slag, granulated slag and expanded slag as shown in **Fig. 2**.

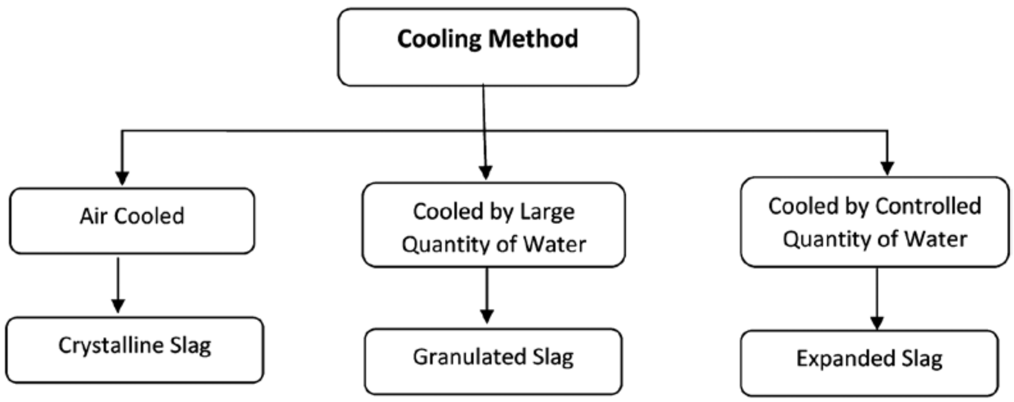

Fig. 2 Production of BF Slag Based on the Cooling Method

1.1.1 *Air-Cooled Blast Furnace Slag (ACBFS)*

ACBFS is produced by cooling the molten slag under atmospheric conditions. Under controlled cooling, the slag tends to be hard and dense and it develops pozzolanic properties, which is suitable for use in granular base, hot mix asphalt, Portland cement concrete, and other applications. Using conventional aggregate processing equipment, this material can be crushed and screened to meet the specified gradation requirements. Special quality control measures may be required to address the lack of consistency in some properties such as gradation, specific gravity, and absorption. ACBFS does not require weathering as it does not contain free lime. **Fig. 3** shows the crushed ACBFS.

Fig. 3 Air Cooled Blast Furnace Slag Aggregates

1.1.2 *Granulated Blast Furnace Slag (GBFS) and Ground Granulated Blast Furnace Slag (GGBFS)*

GBFS is produced by sudden cooling or quenching of the molten slag using high-pressure water jets. This process results in the formation of sand size fragments (as shown in **Fig. 4**), usually with some friable clinker like material. The physical structure and gradation of granulated slag depends on the chemical composition of the slag, its temperature at the time of quenching, and the method of production.

Fig. 4 Granulated Blast Furnace Slag

When crushed or milled to fine powder, it is called ground granulated blast furnace slag (GGBFS), which has cementitious properties that makes it suitable for partial replacement for or additive to Portland cement.

1.1.3 *Expanded Blast Furnace Slag*

Expanded slag is formed through controlled cooling of molten slag in water or water with combination of steam and compressed air. Formation of steam and other gases enhances the porosity and vesicular nature of slag, resulting in light weight aggregate suitable for use in lightweight concrete masonry, lightweight ready-mix concrete and lightweight precast concrete besides cement manufacturing. This type of slag is not usually preferred for road construction.

1.2 Steel Slag

Steel slag is produced from the steel making process. The calcined lime used as flux combines with the silicates, aluminium oxides, magnesium oxides, manganese oxides and ferrites to form the steel slag. This is cooled in a cooling yard with air and sprinkling of water. Depending on the type of furnace used for manufacture of steel, the major categories of steel slag produced in India are Basic Oxygen Furnace (BOF) and Electric Arc Furnace (EAF) slag. Steel slag contains about 10 to 20 per cent by mass of metallic iron, and is recovered by magnetic separation. The metal free slag is crushed and screened to different sizes for use as aggregates. The vesicular nature of surface of slag particles promotes good particle interlock and high shear strength.

1.2.1 *Basic Oxygen Furnace Slag (BOFS)*

In basic oxygen furnace, the carbon-rich molten pig iron is converted into steel by blowing oxygen through the molten pig iron that lowers the carbon content of the alloy and changes into low carbon steel. The steel slags are processed through series of steps involving cooling, metal recovery, crushing, screening, weathering and stockpiling. This is finally referred as "Processed Steel Slag" as shown in **Fig. 5**.

Fig. 5 Processed Basic Oxygen Furnace Slag

Volumetric stability in the BOFS is a major concern, which occurs mainly due to the presence of free magnesium oxide (MgO) and lime (CaO) that hydrates expansively in presence of water. Therefore, before utilizing as road making aggregate, this slag needs to be treated or weathered (natural or accelerated) to decrease the volume instability. In natural weathering process, the steel slag is stockpiled for a period up to six months under normal atmospheric conditions before use as road aggregates.

1.2.2 *Electric Arc Furnace Slag (EAFS)*

EAFS is a strong, dense and non-porous aggregate that is cubical in shape. This type of slag bears good resistance to polishing and has an excellent affinity to bitumen. This makes it an ideal aggregate for bituminous surface materials and road surface treatments as it produces materials that are resistant to deformation (rutting), safe and durable. **Fig. 6** presents an image of processed EAFS.

Fig. 6 Processed Electric Arc Furnace Slag

1.3 Chemical Composition and Engineering Properties

BF slag and steel slag can be primarily differentiated by the iron content. In BF slag, FeO is around 0.70%, whereas in case of steel slag, total iron content varies from 16 to 25%. The chemical composition of GBFS and steel slag generated from various steel plants in India are given in **Table 1**.

Table 1 Chemical Composition of Slag Generated in Steel Plants (Indian Minerals Yearbook 2015)

Name of Plant	Slag	Chemical Composition (%)						
		SiO_2	Al_2O_3	CaO	MgO	MnO	FeO	S
Bhilai Steel Plant Durg Chhattisgarh	BF	34.52	20.66	32.43	10.09	0.23	0.57	0.77
	Steel	14.20	1.40	42.90	9.59	1.69	18.20	1.70
Bokaro Steel Plant Bokaro, Jharkhand	BF	30.06 to 31.85	21.12 to 22.71	32.48 to 34.17	10.12 to 10.39	- -	0.26 to 0.37	- -
	Steel	12.15 to 15.82	1.07 to 1.63	46.52 to 53.52	8.14 To 13.12	-	17.01 to 18.52	-
Rourkela Steel Plant Rourkela, Odisha	BF	33.15	22.33	30.78	10.78	0.18	0.51	0.52
Durgapur Steel Plant, Durgapur West Bengal	BF	32.68	21.23	32.14	-	-	-	-
	Steel	17.9	1.0	49.4	-	-	-	-
Visvesvaraya Iron & Steel Plant, Bhadravati Karnataka	BF	32	18	33	9	-	0.5	-
	Steel	30.35	1.2	35.40	9.11	-	10.15	-
IISCO Steel Plant Burnpur West Bengal	BF	32.60	23.60	33.70	7.60	-	-	-
Rashtriya Ispat Nigam Ltd. Visakhapatnam, Andhra Pradesh	BF	35.33	16.60	36.89	8.48	0.12	0.51	-
	Steel	17.69	1.07	50.70	10.31	1.05	16.50	1.40
IDCOL, Kalinga Iron Works, Ltd. Barbil, Odisha	BF	33 to 34	24 to 25	29.00 to 30.00	8.00 to 9.00	0.50 to 0.60	0.70 to 0.80	1.00
Tata Steel Ltd Jamshedpur, Jharkhand	BF	34.5	20.8	34.3	7.3	0.052	0.6	-
	Steel	12.65	1.16	46.23	1.76	0.45	25.06	0.33
JSW Steel Ltd. Bellary Karnataka Visa Steel Ltd.	BF	35.20	19.00	34.90	8.76	0.14	(Fe) 0.039	- -
Kalinganagar, Odisha	BF	33.8	15.39	35.38	10.25	0.64	0.74	0.92
Neelachal Ispat Nigam Ltd, Kalinganagar, Odisha	BF	32.62	32.62	33.25	9.91	0.40	0.55	0.62 -

Typical physical and engineering properties of ACBFS, BOFS and EAFS, as reported by Stroup-Gardiner & Watterberg-Koams (2013) are given in **Table 2**.

Table 2 Typical Engineering Properties of Iron and Steel Slag (Stroup-Gardiner & Watterberg-Koams, 2013)

Physical Property	Blast Furnace Slag	Steel Slag		Test Method
	ACBFS*	BOFS**	EAFS***	
Open Graded				
Specific Gravity Dry	2.450-2.550	3.300-3.400	3.300	ASTM C124/128: Density, Specific Gravity, and Absorption
SSD	2.550-2.650	3.350-3.475	3.400	
Water Absorption, %	3 to 7	1 to 2 Coarse	1 to 2 Coarse	ASTM C566: Moisture Content by Drying
		2 to 4 Fine	2 to 4 Fine	
Dry Strength, ksi	19.0 to 22.5 (131 to 155 MPa)	61.8 (426 MPa)	56.0 (386 MPa)	AS 1142.22: Australian Test Method for Wet/Dry Strength Variation
Wet Strength, ksi	14.6 to 20.3 (100.7 to 140 MPa)	51.7 to 67.4 (356.5 to 464.7 MPa)	54 to 67.4 (372.3 to 464.7 MPa)	
Wet/Dry Strength Variation, %	10 to 20	5 to 20	5 to 15	
Micro Deval, %	15 to 22	12 to 18	16	ASTM D6928: Degradation by Abrasion
Polished Aggregate Friction Value (PAFV)	53	58 to 63	58 to 63	ASTM D3319: Accelerated Polishing of Aggregates
Sodium Sulphate Soundness, %	5	<4	<4	ASTM C88: Soundness of Aggregates
Dense Graded Aggregate Material				
Maximum Dry Density, lb/ft^3	128.0 to 134.2 (20.1 to 21.1 kN/m^3)	143.6 to 149.8 (22.6 to 23.5 kN/m^3)	143.6 to 149.8 (22.6 to 23.5 kN/m^3)	ASTM D698: Compaction Characteristics of Soils
Optimum Moisture Content, %	8 to 12	8 to 12	8 to 12	

* Air-Cooled Blast Furnace Slag (ACBFS)

** Basic Oxygen Furnace Slag (BOFS)

*** Electric Arc Furnace Slag (EAFS)

Engineering properties of ACBFS produced in India as determined by the Central Road Research Institute (CRRI) under various sponsored research projects are presented in **Table 3**. Abrasion value is found to be marginally higher in some of the samples. However, it is expected to have no adverse effect on performance of road pavement made using ACBFS. Water absorption is found higher than the prescribed limit but ACBFS slag aggregates were found satisfying soundness test requirements.

Table 3 Engineering Properties of Air-Cooled Blast Furnace Slag (ACBFS)

Property Tested	Typical Range Steel Slag in %	MoRD Specification Limits for Aggregates (%)			Test Method
		Surface	Base	Sub-base	
Aggregate Impact Value (Dry Condition)	18-22%	Max. 30 for BM, MSS, OGPC Max. 27 for SDBC	Max.40 WBM and WMM Max. 30 for Crusher Run Macadam	Max. 50	IS2386 (Part IV)
Aggregate Impact Value (After Soaking 3 days)	20-25%	Max. 30 for BM, MSS, OGPC Max. 27 for SDBC and PQC	Max.40 WBM and WMM Max. 30 for Crusher Run Macadam	Max.50	IS 5040
Los Angeles Abrasion Resistance	32-37%	Max. 35 for SDBC and PQC	Not specified	Not Specified	IS 2386 (Part IV)
Water Absorption Test*	Varying from 2 to 4%	Max. 2 for BM and SDBC Max. 1 for MSS, OGPC	Max. 2	Max. 2	IS 2386 (Part III)
Specific Gravity	2.4-2.5	Typical range of natural aggregate 2.4-2.8			IS 2386 (Part III)
Combined Flakiness and Elongation (FI+EI) Index	30-35	Flakiness Index <25 for BM,MSS OGPC Combined FI+EI < 35 for SDBC	Flakiness Index < 25, WBM WMM and Crusher Run Macadam	Flakiness Index< 30	IS 2386 (Part I)
Soundness Test Sodium Sulphate	3-4	< 12	< 12	< 12	IS 2386 (Part V)
Magnesium Sulphate	5-7	< 18	< 18	< 18	
Stripping Value Test (Bitumen coating retention)	95-98	Min. Retained coating 95	NA	NA	IS 6241

* If water absorption value exceeds 2 % then soundness test is required to be carried out

BM: Bituminous Macadam, OGPC: Open Graded Pre Mix Carpet, MSS: Mix Seal Surfacing

SDBC: Semi Dense Bituminous Concrete, WBM: Water Bound Macadam, WMM: Wet Mix Macadam

NA: Not Applicable

Engineering properties of indigenous processed steel slag aggregates (BOFS and EAFS) as determined by CRRI under various sponsored research projects are presented in **Table 4**. Engineering properties of steel slags are found to vary significantly.

Table 4 Engineering Properties of Processed Steel Slag Aggregates

Property Tested	Typical Range for Steel Slag in %		MoRD Specification Limits for Aggregates (%)			Test Method
	BOFS	EAFS	Surface	Base	Sub-base	
Aggregate Impact Value (Dry Condition)	15-22	16-20	Max. 30 for BM, MSS, OGPC Max. 27 for SDBC	Max.40 WBM and WMM Max. 30 for Crusher Run Macadam	Max.50	IS 2386 (Part IV)
Los Angeles Abrasion Resistance	11-18	12-14	Max. 35 for SDBC and PQC	Not specified	Not Specified	IS 2386 (Part IV)
Water Absorption Test*	1-2	0.8-2	Max. 2 for BM and SDBC Max. 1 for MSS, OGPC	Max. 2	Max. 2	IS 2386 (Part III)
Specific Gravity	2.93-3.25	2.92-3.06	Typical range of natural aggregate 2.4-2.8			IS 2386 (Part III)
Combined Flakiness and Elongation (FI+EI) Index	8-22	10-21	Flakiness Index <25 for BM,MSS OGPC Combined FI+EI < 35 for SDBC	Flakiness Index < 25 for WBM WMM and Crusher Run Macadam	Flakiness Index< 30	IS 2386 (Part I)
Soundness Test - • Sodium Sulphate	0.2-1.8	2-4	< 12	< 12	< 12	IS 2386 (Part V)
• Magnesium Sulphate	0.3-2.1	3-5	< 18	< 18	< 18	
Stripping Value Test (Bitumen coating retention)	98-99	99-99.5	Min. Retained coating 95	NA	NA	IS 6241
Volumetric Expansion after Weathering	1-2%	<2%	<2%			IS 383

* If water absorption value exceeds 2 % then soundness test is required to be carried out

BM: Bituminous Macadam, OGPC: Open Graded Pre Mix Carpet, MSS: Mix Seal Surfacing

SDBC: Semi Dense Bituminous Concrete, WBM: Water Bound Macadam, WMM: Wet Mix Macadam

NA: Not Applicable

1.4 Slag Utilization

Slags, based on their types, have a wide scope for use in different areas. The ACBFS is usually crushed, screened and mainly used as aggregate in subbase, base and asphalt layers and as concrete aggregate. GBFS is mainly used in sub-base and base layers as fine aggregates and also as replacement of natural sand on many occasions. GGBFS is mostly used as a pozzolanic material in production of Portland Slag Cement (PSC). In conjunction with lime (as an activator), this can also be used as a soil stabiliser.

2 SLAG AS PAVEMENT MATERIAL

Pavement materials must meet the desired specifications to ensure adequate performance. Unbound materials develop (shear) strength through particle interlock and have no significant tensile strength. The usual distress modes are deformation through shear and densification and also disintegration through particle breakdown. Performance of pavements using slag in unbound layers is highly dependent on the angularity and shear resistance of the constituent particles. Bound materials develop shear strength through chemical bonding as well as particle interlock and have significant tensile strength. For design parameters, refer IRC:37.

Slag in different forms has potential to be used in pavement construction for rural roads. Various slag products may be used in different pavement layers (either bound or unbound) as:

i) Aggregates for Unbound Granular Layers (i.e. Granular Subbase and Base)

ii) Aggregates for Asphalt Layers

iii) Aggregates for Concrete Pavement

iv) Stabiliser for Bound Subbase and Base

Fig. 7 shows the use of slag in different layers of a low volume road pavement.

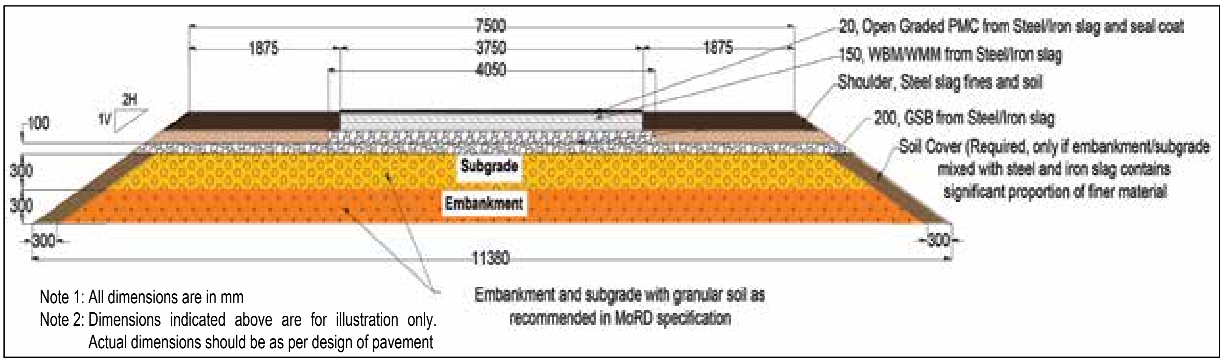

Fig. 7 Typical Cross Section of Rural Road with Steel and Iron Slag in Different Layers

2.1 Slag as Sub-base Material

ACBFS and weathered steel slag can be used as coarse aggregate for the construction of subbase after crushing and screening to meet the gradation requirements. Crushed slag should meet the specifications given in clause 405 of MoRD Specifications. Some industries are now producing processed BOFS, which can be readily used for subbase construction. A typical gradation of the processed steel slag is given in **Fig. 8**.

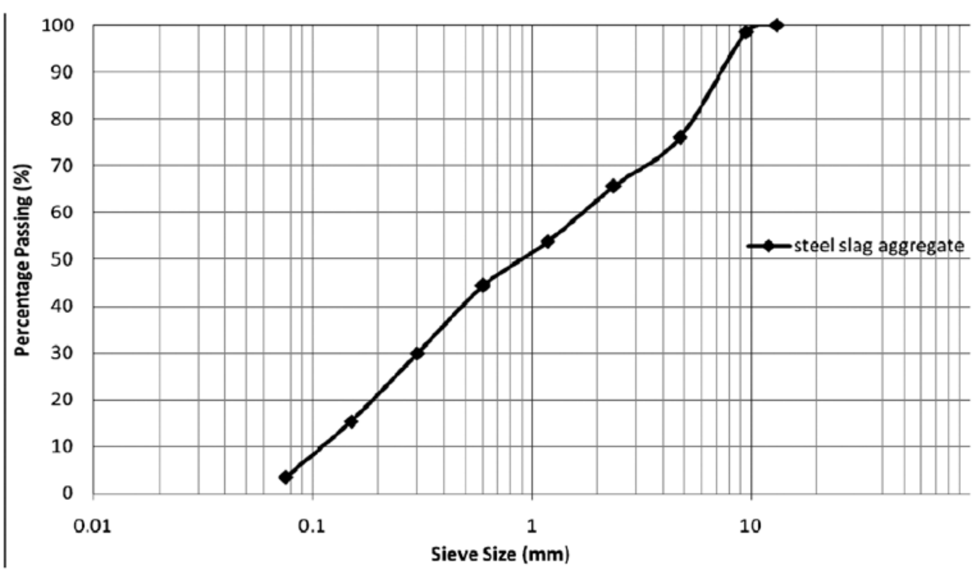

Fig. 8 Particle Size Distribution of a Processed BOFS

GBFS can also partially replace the fine aggregates to meet the specified gradation for sub base construction. GBFS alone can also be used as sub base material provided that it meets the strength requirement. GBFS possesses pozzolanic property and, therefore, can be stabilised along with lime for construction of stabilised subbase layers. **Fig. 9** presents use of slag in subbase layer in a PMGSY road in Odisha, whose performance is found to be very good.

Fig. 9 Use of Steel Slag in Subbase Course in a PMGSY Road

2.2 Slag as a Base Material

For construction of granular base layer, ACBFS can be used as coarse aggregates after crushing, screening and adding fines to meet the specified gradation. Crushed slag usually contains very few fines to meet the particle size distribution specified for dense graded bases, which can be complied by the addition of stone dust from another crushing operation. Alternatively, a blend of 20 mm down crushed ACBFS (80%) and 20% GBFS can be used for base course construction. An activator such as lime (1–3%) or lime/fly ash (1–3%) can be used for a more rapid initial set. Processed steel slag manufactured by some industries can also be used in the base course.

2.3 Slag Materials in Asphalt Construction

Both steel slag and blast furnace slag have been successfully used in asphalt constructions. For low volume roads, slag aggregates satisfy the requirements for use in surface dressing and premix carpet applications. Steel slag is preferred due to its better strength, abrasion and impact resistance compared to blast furnace slags. Some of the important characteristics of slag aggregates are given below:

- Better skid resistance due to a higher friction value
- Higher density of steel slag (typically 20% denser than traditional material)
- Cubical shape and high percentage of fractured faces ensuring good mechanical interlock
- Higher affinity to bitumen and therefore lower stripping value

For materials selection in case of surface dressing reference may be made to the MoRD Specifications. **Table 5** gives a broad indication of the uses of blast furnace, steel slags in construction and maintenance of rural roads.

Table 5 Iron and Steel Slag Applications in Rural Roads

Application	Steel Slag		Iron Slag	
	BOFS	EAFS	ACBFS	GBFS
Bituminous Surfacing				
Open Graded Premix carpet	✓	✓	✓	x
Surface Dressing	✓	✓	✓	x
Bituminous Macadam	✓	✓	✓	x
Semi Dense Bituminous Concrete	✓	✓	✓	x
Cement Concrete Pavement				
PQC	x	x	✓	✓
DLC	x	✓	✓	✓
Granular Base Course				
Water Bound Macadam	✓	✓	✓	x
Wet Mix Macadam	✓	✓	✓	x
Granular Sub- Base				
Unstabilised Granular Base	✓	✓	✓	x
Stabilised Granular Base	✓	x	✓	✓

Iron and steel slag being vesicular material (as shown in **Fig. 10**) requires higher binder content for surface coating. Therefore, whenever it is used for bituminous surfacing, the binder content should be increased by 0.5 % over the normal quantity given in MoRD Specification for different applications.

Fig. 10 Vesicular Nature of Iron and Steel Slag

3 STABILISATION USING SLAG

GBFS and GGBFS can be used as binders for chemical stabilisation of soils, gravel and crushed rock. This may be used for construction of lightly and heavily bound structural layers for the pavements. One of the major benefits of using slag in stabilisation is the slow rate of the cementation process. The pavement material can be reworked up to two days after initial mixing, without much affecting the final strength. This enables the user to go for longer hauling distances and temporary stockpiling of the material before use.

Elastic Modulus and Poisson's Ratio are important input for mechanistic design of the pavements. Modulus for these bound materials is usually determined using a relationship between Unconfined Compressive Strength (UCS) and Modulus as given in IRC:37 (Eq.1).

$$E = 1000 \times UCS \qquad \dots (1)$$

Where, E = Elastic Modulus (MPa), and

UCS = Unconfined Compressive Strength (MPa) after 28 days of curing.

For cementitious sub base and base, the minimum UCS value after 7 days of curing, specified by IRC:SP:72 are 1.7 MPa and 3.0 MPa respectively. Eq. 1 results in a modulus values in the range of 2000 to 3000 MPa for sub base and 4000 to 5000 MPa for base. Since, the sub-base acts as a platform for the heavy construction traffic, low strength cemented sub-base is expected to crack during construction and a design value of 600 MPa is recommended for the stress analysis. For base course, the long term modulus of the cemented layer may be taken as fifty per cent of the initial modulus due to shrinkage cracks and construction traffic. A value of 0.25 may be taken as Poisson's Ratio for such layers. Design of pavements with bound bases and sub bases for rural roads may be done following the guidelines given in IRC:SP:72.

Both GBFS and GGBFS require an activator such as lime or cement to achieve their strength potential. It is observed that UCS value increases with an increase in the lime/GGBFS ratio, increased curing period and temperature. A binder (GGBFS) content of 6% with replacement by lime of 20% or 30% (of the GGBFS content) results in optimum strength. Pavement layers/embankments constructed on floodplains can be made durable with the application of GGBFS activated by lime. BOFS fines are more effective in stabilising the coarser-grained, less hydrophilic soils.

4 SLAGS IN CEMENT CONCRETE PAVEMENTS

ACBFS aggregate is one of the most commonly used reclaimed construction materials, being used as coarse aggregate in cement concrete. It should be kept in mind that slag aggregate should not be directly substituted for conventional aggregate in an existing concrete mix, rather the mix should be specifically designed based on ACBFS's lighter weight and higher water absorption. The higher the density, the higher the suitability of the aggregate for use as an aggregate in paving concrete. It may be added that the Japanese standards sets a minimum oven-dry density of 24 kN/m^3 for BF slag aggregates to be used in normal concrete applications.

4.1 Characteristics of Slag Aggregates

The characteristics of ACBFS in terms of particle shape, density, surface texture, durability, strength and hardness need to be understood for concrete mix design with slag aggregates. It is important to pre-wet the aggregates as it absorbs water and this condition be maintained prior to batching.

IS:383 (2016) guidelines may be referred for use of slag aggregates in cement concrete. Maximum percentage of slag aggregate, which can be used for PCC and lean concrete are given in **Table 6**.

Table 6 Extent of Slag Utilization in Cement Concrete

Sl. No.	Type of Aggregate	Maximum Utilization Percentage	
		Plain Concrete	Lean Concrete (Less than M15 Grade)
(1)	(2)	(3)	(4)
(i)	Coarse Aggregate		
	(a) Iron Slag Aggregate	50	100
	(b) Steel Slag Aggregate (Electric Arc Furnace Slag Aggregate)	25	100
(ii)	Fine Aggregate		
	(a) Iron Slag Aggregate	50	100
	(b) Steel Slag Aggregate (Electric Arc Furnace Slag Aggregate)	25	100

For slag aggregates, following additional tests shall be carried out:

a) Iron unsoundness- When chemical analysis of aggregates shows that the ferrous oxide content is equal to or more than 3 per cent, and sulphur content is equal to or more than 1 per cent, the aggregate shall be tested for iron unsoundness. The iron unsoundness of the slag aggregate when tested as per the procedure given in **Annexure-I**, shall not exceed 1 per cent.

b) Volumetric expansion ratio - It shall not be more than 2 per cent. The procedure shall be as given in **Annexure-I**.

c) Unsoundness due to free lime- Prior to use of iron slag (for production of aggregates) from a new source or when significant changes in furnace chemistry occur in an existing source which may result in the presence of free lime, the potential for pop-out formation shall be assessed by determining the free-lime content of the slag by petrographic examination or quantitative x-ray diffractometry on a representative sample.

Detailed test procedures are provided in **Annexure-I**.

If the number of particles containing free lime exceeds 1 in 20, then weathering of the slag stockpile (in moist condition or at/near saturated surface dry condition) represented by the test sample shall be continued until further testing shows that the level has fallen below 1 in 20.

4.2 Mix Design

Due to the difference in various properties of blast furnace slag compared to conventional aggregates, standard mix design procedure should not be applied directly for slag aggregates. To improve workability of slag aggregate mixes, a larger proportion of fine sand may be incorporated.

5 REFERENCES

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ANNEXURE-I

TEST PROCEDURES AS PER IS:383-2016

A1 DETERMINATION OF IRON UNSOUNDNESS FOR SLAG AGGREGATES

1. Some slags containing more than 3 per cent Ferrous Oxide (FeO) will disintegrate on immersion in water when the Sulphur (S) content of the slag is 1 per cent or more. Aggregates derived from such slags show iron unsoundness.

2. PROCEDURE

Take at random two test samples of not less than 50 pieces each of aggregate passing 40 mm and retained on 20 mm IS sieve. Immerse the pieces of first sample in distilled or deionized water at room temperature for a period of 14 days. Remove the pieces from the water at the end of the 14 days period and examine them.

3. CRITERIA FOR CONFORMITY

If no piece develops the following unsoundness during the storage period, the slag aggregate shall be deemed to be free from iron unsoundness:

a) Cracking (development of a visible crack),
b) Disintegration (physical breakdown of aggregate particle),
c) Shaling (development of fretting or cleavage of the aggregate particle), or
d) Craze cracking at the surface of the aggregate.

The second test sample shall be tested, if any of the pieces (in the above sample) shows cracking, disintegration, shaling or craze cracking at the surface of the aggregate. If not more than one in hundred pieces (1 per cent) of the two test samples tested shows cracking, disintegration, shaling or craze cracking at the surface of the aggregate, the slag shall be regarded as free from iron unsoundness.

A2 DETERMINATION OF VOLUMETRIC EXPANSION RATIO OF SLAG AGGREGATES

1. This test specifies the procedure to calculate the volumetric expansion ratio for the evaluation of the potential expansion of aggregates like steel slag due to hydration reactions. This method can also be used to evaluate the effectiveness of weathering processes for reducing the expansive potential of such aggregate materials.

2. APPARATUS AND TOOLS

a) *Moulds with base plate, stay rod and wing nut, perforated plate*- These shall conform to 4.1, 4.3 and 4.4 of IS 9669.
b) *Metal Rammer*- As specified in 5.1 of IS 9198.
c) *Curing apparatus* - The curing apparatus shall be a thermostat water tank, capable of holding not less than two 15 cm moulds, and able to keep the water temperature at 80° ± 3 °C for 6 h.

d) *Sieves*- These shall be 31.5 mm, 26.5 mm, 13.2 mm, 4.75 mm, 2.36 mm, 500 µm and 75 µm IS sieves.

e) *Expansion measuring apparatus* – The expansion measuring apparatus shall be as shown in **Fig. A1**.

3. SAMPLE

3.1 Preparation of Sample

The samples of slag shall be collected so as to represent the whole lot. The samples shall be prepared to meet the grading requirement given below.

Sl No.	Sieve Size	Percentage Passing
(1)	**(2)**	**(3)**
i)	31.5 mm	100
ii)	26.5 mm	97.5
iii)	13.2 mm	70
iv)	4.75 mm	47.3
v)	2.36 mm	35
vi)	500 µm	20
vii)	75 µm	6

3.2 Adjustment of Sample

The adjustment of sample shall be as follows:

a) Add water to approximately 30 kg of sample so that the difference between the moisture content and the optimum moisture content is within 1 per cent. Mix it well to make moisture content uniform, and keep it for not less than 24h.

b) Reduce the above sample and obtain the sample necessary for making three specimens.

4. TEST PROCEDURE

4.1 Specimen Preparation

The specimens shall be prepared as follows:

a) Attach collar and perforated base plate to the mould, put spacer disc in it, and spread a filter paper on it.

b) The measurement of moisture content shall be conducted on two samples, each sample weighing not less than 500 g. When the measured value of moisture content differs from the value of optimum moisture ratio by not less than 1 per cent, new specimens shall be prepared for curing.

c) Pour the samples prepared as indicated in para 3.2, in the mould with a scoop keeping a falling height of approximately 50 mm and ram the sample into three layers one upon another so that the depth of each layer after ramming is nearly equal to one another.

d) Ram the layer uniformly by free dropping of the rammer 92 times from a height of 450 mm above each rammed surface. The ramming shall be performed on a rigid and flat foundation such as a concrete floor.

e) Rammed surfaces shall be scratched slightly with a sharp ended steel bar for securing adhesion between layers.

f) After finishing the ramming, remove the collar, shave out the excess sample stuck on upper part of the mould with a straight knife carefully. At this time, holes on the surface due to the removing of coarse grade materials shall be filled with fine grade materials, and the top surface shall be reformed.

g) Tum the mould upside down gently pushing the reformed top surface with a lid so that the specimen in the mould does not decay or drop down, then remove the perforated base plate and take out the spacer-disc.

h) Spread a filter paper on the perforated base plate, turn the mould upside down gently again, connect to the perforated base plate again for securing adhesion to the filter paper.

i) Wipe off the materials of the specimen stuck on the outside of the mould and the perforated base plate, and measure the total mass.

j) From the sum of masses of the rammed specimen, the mould and the perforated base plate, subtract the masses of the mould and the perforated base plate, and divide it by the volume of the mould, which gives the wet density of the rammed specimen.

4.2 Curing and Measuring Operation of the Specimen

The curing and measuring operation of the specimen shall be as follows:

a) Place the perforated plate with shaft on the filter paper which is spread on the top surface of the specimen in the mould.

b) Install the dial-gauge and the attaching device (gauge holder) correctly. As shown in **Fig. A1**, dip it in the curing apparatus, and record the first reading of the dial-gauge after the mould reaches equilibrium with respect to the water bath.

c) For curing, keep it at 80° ± 3°C for 6 h, then leave it to cool in the curing apparatus.

d) Repeat the above operation, one time per day for 10 days.

e) On finishing of the curing period, record the last reading of the dial-gauge, remove the gauge holder and the dial-gauge, take out the mould from water, tilt it gently with the perforated plate with shaft on it, and remove the accumulated water. Then, after leaving quietly for 15 min, remove the filter paper and measure the mass.

5 VOLUMETRIC EXPANSION RATIO

The volumetric expansion ratio shall be calculated by the following formula, and rounded off to the first decimal place:

$E = 100 \times (D_f - D_i) / H$

Where E volumetric expansion ratio, per cent,

D_f = last reading of the dial-gauge in mm,

D_i = first reading of the dial-gauge in mm, and

H = initial height of the specimen (125 mm)

The test shall be carried out on three specimens prepared from the sample taken at the same time in accordance with para 3.2, and the average of the three test results shall be taken. The averaged value shall be rounded off to the first decimal place.

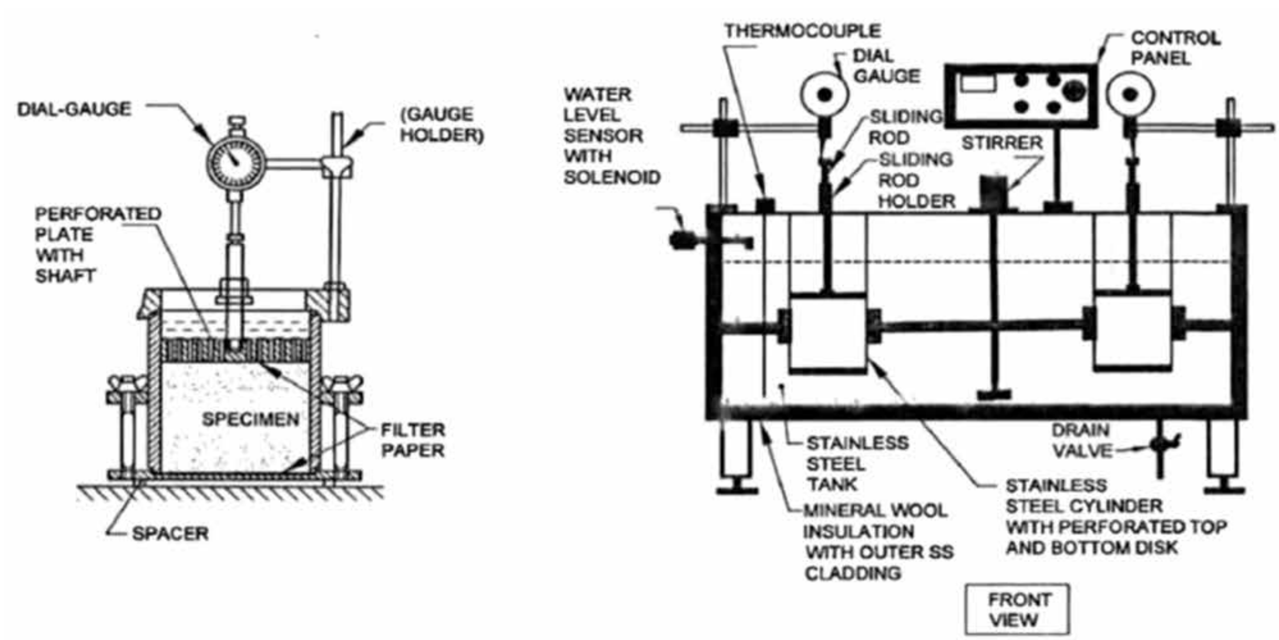

Fig. A1 Test Set up for Volumetric Expansion Test

PART B: COPPER SLAG

1 INTRODUCTION

Similar to Iron and Steel Slag, utilization of Copper Slag in road construction industry is gaining importance in India, considering the disposal, environmental problems and gradually depleting natural resources like aggregates. Copper units located at Dahej (Gujarat) and Tuticorin (Tamil Nadu) generate huge amount of copper slag, during the manufacture of copper. Huge mounds of copper slag are created occupying avoidable land space within or outside the plant premises. (**Fig. 1**).The total amount of the copper slag accumulated till date is about 10 million tonnes and around 2 million tonnes per year is generated currently. Detailed laboratory investigations have been carried out on coarse copper slags collected from Birla copper Industries, Dahej and Sterlite copper Industry, Tuticorin by studying physical, chemical, geotechnical and other engineering characteristics for coming to conclusions regarding its feasibility in Road construction. Fine copper slag from Dahej, Gujarat was also studied in depth to investigate its feasibility in road construction. Experimental test tracks were constructed using coarse copper slag collected from Sterlite industry along NH-45 B (Madurai to Tuticorin). The performance of the same was monitored for a period of two years. Based on the experience gained at the laboratory and field level, these guidelines have been prepared for the benefit of the rural road construction authorities/departments.

Fig.1 View of Copper Mound at Tuticorin, Tamil Nadu

2 SCOPE

1. Typical physical and chemical characteristics.
2. Geotechnical characteristics.
3. Design specifications for construction of embankment.
4. Detailed design of copper slag embankment.
5. Specifications for copper slag in subgrade, shoulder and drainage layer.
6. Specifications for copper slag in granular sub base.
7. Specifications for copper slag in cement stabilised sub base and base.
8. Specifications for copper slag in WBM and WMM base layers.
9. Specifications for copper slag in bituminous mixes.
10. Method statement for road construction.
11. Quality control tests.
12. Environmental aspects.
13. Typical road cross section.
14. Case study.

3 COPPER SLAG

Copper slag is an industrial by-product material produced from the process of manufacturing copper. It is produced by:

(i) **Roasting,** in which Sulphur in the ore is eliminated as Sulphur Dioxide (SO_2);

(ii) **Smelting,** in which the roasted product is melted in a siliceous flux and the metal is reduced; and

(iii) **Converting,** where the melt is de-sulphurized with lime flux, iron ore, or a basic slag and then oxygen lanced to remove other impurities.

The general process diagram of the smelting of copper concentrates in a reverberatory furnace is shown in **Fig. 2**.

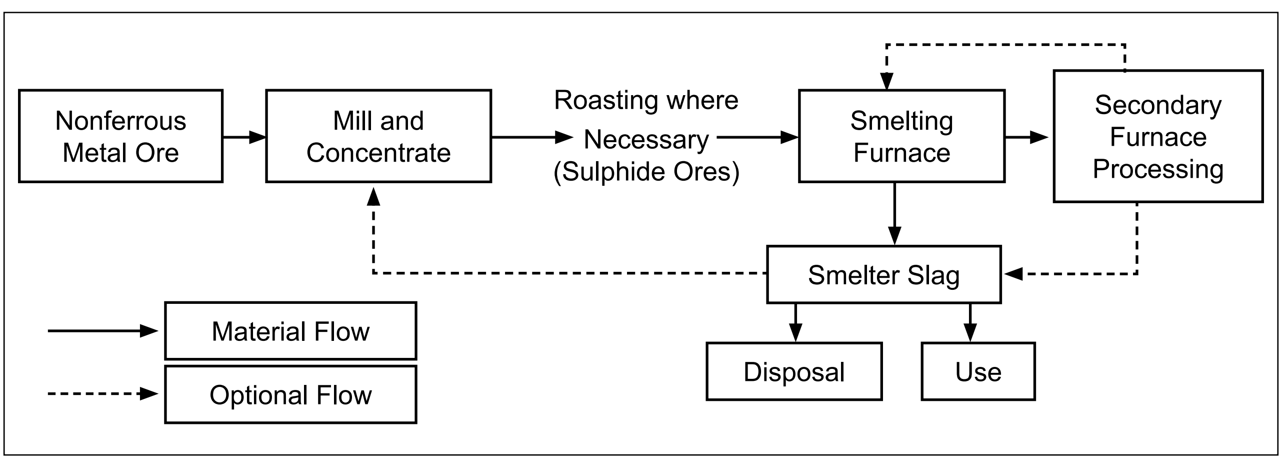

Fig 2. General Process Diagram of Copper Slag Production

3.1 Physical and Chemical Characterisation

Copper slag (coarse and fine) is a blackish material, similar to coarse sand/fine sand (**Fig. 3**). Typical physical properties and chemical composition of copper slag are summarised in **Table 1**.

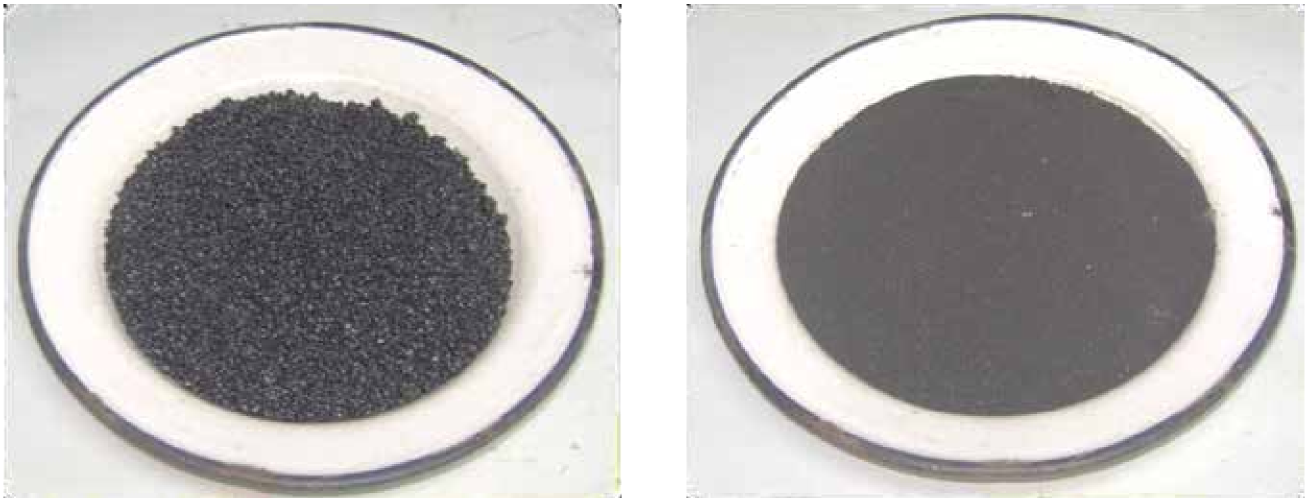

Fig. 3 Close View of Coarse and Fine Copper Slag

Table 1 Typical Physical Properties and Chemical Composition of Copper Slag

Property/Elements	Value
Specific Gravity	3.2 - 3.6
Loss on ignition	Nil
Fe_2O_3	40-45 %
Al_2O_3 (%)	3-5 %
SiO_2 (%)	28-35 %
SO_2 (%)	0.5-1.5 %
CaO (%)	2-5 %
MgO (%)	1-3 %
CuO (%)	0.4-0.5 %

3.2 Geotechnical Characteristics

Detailed geotechnical characteristics need to be studied to investigate its feasibility for embankment construction. Different geotechnical tests which have to be carried out include viz. Grain size analysis, Standard Proctor compaction tests, Direct shear tests, California Bearing Ratio (CBR) tests, Permeability tests as per BIS standards.

3.2.1 *Grain size distribution*

Typical grain size distribution curve of both fine and coarse copper slag is shown in **Fig. 4**. The grain size distribution is summarized in **Table 2**. Coarse copper slag is classified as SP (Poorly graded sand), while Fine slag is classified as ML (Fine sand with silts).

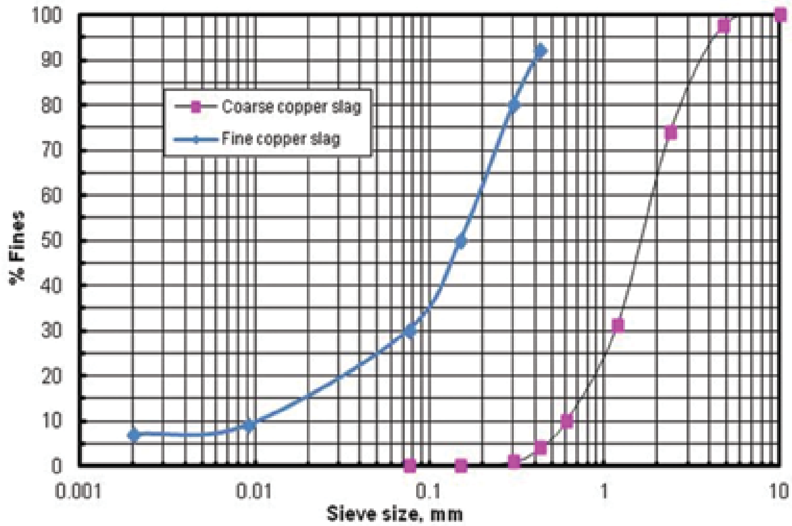

Fig. 4 Typical Grain Size Distribution of Coarse and Fine Copper Slag

3.2.2 *Compaction characteristics*

Typical compaction characteristics of both fine and coarse copper slag in terms of Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) are shown in **Fig. 5** and different range of values is summarized in **Table 2**. Tests indicated insensitiveness of dry density with moisture content which is an added advantage for field construction.

3.2.3 *Shear strength characteristics*

Slope stability of copper slag embankment depends on its shear strength characteristics. Typical values of cohesion and angle of internal friction of both fine and coarse copper slag are given in **Table 2**. High angle of internal friction justifies its suitability in embankment construction.

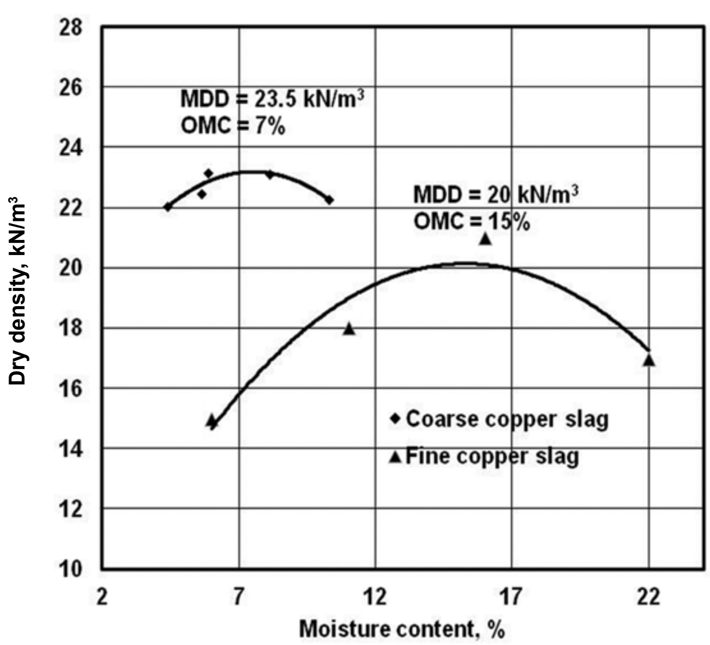

Fig. 5 Typical Compaction Characteristics of Coarse and Fine Copper Slag

3.2.4 *Permeability characteristics*

Permeability characteristics of copper slag play a key role in the development of pore water pressure (pwp) when used in embankment construction. Some of the typical permeability characteristics are shown in **Table 2**. Permeability values indicate the good permeability characteristics similar to conventional sand and the pore water pressure would be dissipated easily when used in embankment construction.

3.2.5 *California Bearing Ratio (CBR)*

High values of California Bearing Ratio (CBR) indicate the suitability of both fine and coarse copper slag in embankment construction. The typical values of CBR for both fine and coarse copper slag are given in **Table 2**.

Table 2 Typical Geotechnical Characteristics of Different Types of Copper Slag*

Property	**Coarse Copper Slag**	**Fine Copper Slag**
Grain size analysis		
Gravel (%)	0-2	0
Sand (%)	98-100	25-65
Silt (%)	0	28-70
Clay (%)	0	5-7
Atterberg Limit test *(PI)*	NP	NP
MDD (kN/m^3)	21-24.5	19-22
OMC (%)	7-11	11-17
Direct shear test (Saturated)		
c (kN/m^2)	0	0
ø (degree)	35-39	20-36
Permeability (m/sec)	1.7×10^{-4}	1.9×10^{-6}
CBR (%)	35-50	14-21

*Data is indicative only, may vary slightly in the range

4 DESIGN SPECIFICATIONS OF COPPER SLAG EMBANKMENT

4.1 Need for Mechanical Stabilisation of Copper Slag

Construction of road embankment using copper slag alone would not be feasible as these materials are cohesionless materials. Copper slag falls under the category of poorly graded coarse/fine sand and it may be difficult to compact in the field. It has therefore to be mixed with local soils or pond ash. It would not only improve the gradation but would also improve its density, shear strength and CBR etc. However, care shall be taken to see that the mixes satisfy the density and plasticity requirements as per MoRD Specifications. As per these Specifications, the embankment fill material shall have Plasticity Index (PI) less than 45 and dry density shall not be less than 14.4 kN/m^3 for use in embankment and should not be less than 16.5 kN/m^3 for use as subgrade soil. Different methods of mechanical stabilisation which may be adopted in the field are given below.

4.1.1 *Mixing of copper slag with fly ash/other wastes*

The feasibility of mixing copper slag (fine/coarse) in different proportions with fly ash/other wastes needs to be studied in the laboratory. Copper slag may be mixed with fly ash in the range 10-75%. The mixing can be optimized based on the results of laboratory geotechnical characteristics satisfying the design criteria as per MoRD Specifications.

4.1.2 *Mixing of copper slag with clayey/other local soils*

Both fine/coarse copper slag may be mixed with clayey (expansive/non expansive) and other local soils in the typical range 10-75%. The mix may be optimized based on their laboratory geotechnical characteristics satisfying the design criteria as per MoRD Specifications.

4.1.3 *Mixing of fine and coarse copper slag*

Depending on the availability of both fine and coarse copper slag in a particular industry, both can be mixed in different proportions for its improvement in gradation, dry density, shear strength and CBR characteristics. Detailed laboratory characterization needs to be carried out for optimizing the mix.

Table 3 summarizes some of the typical geotechnical characteristics of copper slag(fine/coarse)-soil and copper slag(fine/coarse)-fly ash mixes, coarse+fine copper slag mixes.

The plasticity, compaction, shear strength and permeability characteristics indicating their suitability in embankment construction.

Table 3 Typical Geotechnical Characteristics of Copper Slag-Soil/ Fly Ash Mixes, Copper Slag (Coarse+Fine)

Property	**Copper Slag + Soil**	**Copper Slag + Pond Ash**	**Copper Slag (Fine + Coarse)**
Atterberg Limit test (PI)	NP-14*	NP	NP
MDD (kN/m^3)	20-25	15-24	22-25
OMC (%)	6-13	7-30	5-12
Direct shear test (saturated)			
c (kN/m^2)	10*	0	0
ø (degree)	30-34	25-37	30-38
Permeability (m/sec)	2×10^{-6}	7×10^{-6}	1.2×10^{-6}
CBR (%)	10*-80	8-65	22-65

*In case of Black cotton soils

4.2 Earth Cover for Protection of Slopes

Earth cover is needed to prevent erosion of copper slag-soil/fly ash stabilised layer. For embankment upto 3 m height, a 0.3 m thick (measured horizontally) cover of soil is provided. The cover soil used should have maximum dry density not less than 14.4 kN/m^3. For more than 3 m height embankments, side cover thickness shall be increased to 0.5 m (measured horizontally, with min dry density 15.2 kN/m^3). In such embankments, intermediate soil layers of 0.2 m thickness may be provided every 2 m considering the practical feasibility.

5 DETAILED DESIGN OF COPPER SLAG EMBANKMENT

5.1 Site Investigation

The site on which copper slag embankment is to be constructed needs to be investigated for its in-situ characteristics. Apart from in-situ characteristics, additional information may be collected as discussed below.

Availability of local soils/wastes: As discussed in section 4.1, fly ash needs to be mixed with local soil/fly ash/other wastes for its use in embankment construction. The availability, quantity/lead/location details need to be noted.

Topography: Survey of the proposed copper slag alignment need to be carried out by total station to prepare the profile road map which would be beneficial for estimation of quantity of copper slag needed as an embankment fill material.

Hydrological data: The rainfall data and ground water data need to be collected from the alignment of copper slag embankment. This data would be very useful for drainage design and for evaluation of slope stability of copper slag embankment, if required.

Subsoil investigations: The nature and extent of soil and rock strata, at least for a depth of 2 times the height of copper slag embankment below the ground needs to be investigated. The in-situ characteristics viz. Bulk density, shear strength characteristics affect the stability of the embankment.

5.2 Slope Stability Analysis

Slope stability analysis is normally required only when the height of copper slag embankment is more than 3 m height (Slope 2:1). But if the slopes are steeper, it is advisable to carry out the analysis for lower height of embankment also. In the analysis, different types of failure of embankment (a) Toe failure (occurring when foundation soil is stronger than fill material) (b) Slope failure (occurring in a layered embankment when a strong layer limits the extent of development of failure surface and (c) Base failure (occurring when the foundation soils beneath the base of the embankment have low strength).

Stability analysis needs to be carried out by limit equilibrium methods as per IRC:75-2014. Circular failure is assumed in the analysis. The sub soil characteristics, fill characteristics, and the traffic loading conditions need to be considered in the design. The analysis has to be carried out under different moisture conditions and considering the seismic factors. The factor of safety along a critical circle needs to be determined to evaluate the safety of the copper slag in the embankment. The factor of safety shall be more than 1.25.

6 SPECIFICATIONS FOR COPPER SLAG IN SUBGRADE/ SHOULDER/DRAINAGE LAYER

6.1 Slag as Subgrade Material

The typical plasticity (NP), compaction (MDD>16.5 kN/m^3) and CBR characteristics of copper slag-soil, copper slag-fly ash and mixes of fine and coarse copper slag (**Table 2**) indicated their suitability for construction of subgrade. However, these mixes shall be confined with good earth (as discussed in section 4.2) to prevent possible erosion during the monsoon.

6.2 Slag as Shoulder Material

As the shoulder is unconfined and also exposed to the atmosphere, there is every possibility of erosion copper slag- ash mixes of both fine and coarse copper slag. Hence these mixes are not recommended for shoulder construction. However, those copper slag-soil mixes having low plastic characteristics (PI<20, MDD>16.5 kN/m^3) may be used as a shoulder material.

6.3 Slag as Drainage Layer

The permeability characteristics of copper slag-soil, copper slag-fly ash and mixture of fine and coarse aggregates (**Table 3**) indicate their suitability as a drainage layer.

7 SPECIFICATIONS FOR COPPER SLAG IN GRANULAR SUB BASE LAYER

Coarse and fine copper slag can be mixed in a definite proportion with the conventional aggregates (40 mm, 20 mm and 10 mm) to achieve the desired gradation of sub base material as per Table 400.1A & 400.1B of MoRD Specifications. Studies have indicated 30-50% conventional fine aggregates can be replaced by copper slag for use in sub base layer. If fine slag is not available then stone dust shall be used along with coarse slag.

8 SPECIFICATIONS FOR COPPER SLAG IN SUB BASE/BASE LAYER

Cement stabilised coarse copper slag, copper slag-fly ash/soil mixes can be used in sub base/base layer of a rural road. In the case of mixes, studies have indicated copper slag content is about 75%. The amount of cement content varied in the range 3-6%. Laboratory studies need to be undertaken by carrying out 7 day UCS tests on stabilised and cured specimens. As per MoRD Specifications, the achieved design UCS shall be 1.7 MPa for use in sub base and 3 MPa for use in base layer of road pavement (IRC:SP:72).

9 SPECIFICATIONS FOR COPPER SLAG IN WBM AND WMM LAYER

9.1 Water Bound Macadam

In Water Bound Macadam (WBM) layer, coarse copper slag may be mixed by about 50% with 10 mm size aggregates for preparation of ‘Type B’ screenings. However, MoRD Specifications for gradation of screening shall be satisfied.

9.2 Wet Mix Macadam (WMM)

The constituent conventional materials/(aggregates) viz. 40 mm, 20 mm, 10 mm and stone dust can be mixed with copper slag (fine/coarse/fine+coarse) in the proportion 20-30% to arrive at gradation requirements of WMM as given in MoRD Specifications, Table 400.12. If fine slag is not available, stone dust shall be used.

10 SPECIFICATIONS FOR COPPER SLAG IN BITUMINOUS SURFACE COURSES

10.1 Bituminous Macadam

Bituminous Macadam (BM) is sometimes used as a surface course on a Rural road and can be laid over a primed granular base course like Water Bound Macadam (WBM) or Wet Mix Macadam (WMM). This type of mix can also be used in profile correction course and for overlay of existing rural roads.

Studies have indicated that fine copper slag is not suitable for bituminous construction. However, fine aggregates in the conventional mix can be replaced by coarse slag/mixture of fine and coarse slag by about 15- 20%, however shall satisfy the gradation criteria as per Table 500.4 of MoRD Specifications. Bitumen content and grade of bitumen that shall be used as per section 504 of MoRD Specifications.

10.2 Seal Coat

Seal coat can be used for sealing the voids in an Open Graded Premix Carpet/Bituminous Macadam used in rural roads. About 60-70% copper slag can be used as a replacement of conventional aggregates in Type B premixed seal coat, while its per cent utilisation in Type A (liquid seal coat) and Type C seal coat is about 20-25%.

11 METHOD STATEMENT

11.1 Mechanically Stabilised Copper Slag Embankment

As discussed in section 4.1 copper slag needs to be mixed with local soil/fly ash for using it in embankment construction. The stepwise method statement for construction of copper slag embankment is given below.

11.1.1 *Clearing and grubbing*

Clearing and grubbing work shall be undertaken for cutting, removing and disposal of all trees, bushes, roots, rubbish, etc, from the area of road land containing road embankment, drains, cross-drainage structures. It shall include necessary excavation, backfilling of pits resulting from uprooting of trees and stumps to required compaction, handling, salvaging, and disposal of cleared materials. Clearing and grubbing shall be performed in advance of earthwork operations. The site clearance is as per section 201 of MoRD Specifications.

11.1.2 *Setting out*

After the site has been cleared, the limits of embankment shall be set out true to lines, curves, slopes, grades and sections as shown on the drawings or as directed by the Engineer. The limits of the embankment shall be marked by fixing batter pegs on both sides at regular intervals as guides before commencing the earthwork. The embankment shall be built sufficiently wider than the design dimensions so that surplus material may be trimmed, ensuring that the remaining material is to the desired density. The setting out is as per section 301.5.1 of MoRD Specifications.

11.1.3 *Dewatering of foundation of embankment*

In road stretch, where stagnant water is encountered, the vegetation in stagnant water shall be first removed. Stagnant water shall then be bailed out using pumps. Care shall be taken to discharge the drained water so as not to cause damage to adjacent embankment or other private/public property. The foundation shall be kept dry before receiving the first layer of the embankment. Dewatering is as per section 301.5.2 of MoRD Specifications.

11.1.4 *Stripping of top soil*

Before laying first layer of mechanically stabilised copper slag, the top soil should be stripped to specified depth not exceeding 150 mm as per section 301.5.3 of MoRD Specifications.

11.1.5 *Compaction of ground supporting proposed embankment*

The ground shall be levelled, watered if necessary and rolled to a well compacted surface for placement of the embankment. In case where the difference between the top of the subgrade and the ground level is less than 600 mm, the ground shall be loosened to a minimum depth of 150 mm and compacted in accordance with clauses 301.5.5 and 301.5.6 of MoRD Specifications. Any unsuitable material occurring in the embankment foundation shall be removed to the required depth and replaced with suitable soil and compacted as directed by the Engineer.

11.1.6 *Materials for construction of copper slag embankment*

Copper slag needs to be collected from the stacks inside the plant. Soil has to be collected from the quarry already identified during the experimental stretch construction. The soil used for mixing shall have Plasticity Index value between 10-20 and shall also satisfy the requirements as per section 301 of MoRD Specifications. Fly ash collected from the ponds in the thermal power plant shall be dried in the sun till the ash becomes suitable for mixing. The totally dry Fly ash may be conditioned with 1-2% moisture before laying and mixing to avoid air pollution and dust nuisance.

11.1.7 *Spreading of embankment material*

After preparation of the ground supporting the embankment, conditioned fly ash/dry soil shall be spread using dozers/graders to the required loose thickness. The copper slag is then spread over the same to the required loose thickness. The loose thickness of each of the fill materials has to be determined for the specified proportion (by weight) and for a compacted thickness of 150 mm.

11.1.8 *Spreading of side cover soil*

The side soil cover of specified width (as per drawing) and loose thickness shall be spread along with the copper slag-soil/fly ash fill material (core of the embankment). The addition of side earth cover subsequent to the construction of the core is prohibited. The side cover soil shall have Plasticity Index between 10-20, shall also satisfy the requirements as per section 301 of MoRD Specifications. The dry density of the cover soil shall not be less than 14.4 kN/m^3, when used for embankment of height upto 3 m. However, when it forms the subgrade, its dry density shall not be less than 16.5 kN/m^3.

11.1.9 *Mixing/compaction of fill and cover material*

The loose layers of copper slag and soil/Fly ash are then dry mixed using a tractor towed tiller or Rotavator till a uniform mix is achieved. The number of passes of tiller in either direction (perpendicular) may be two to three passes sufficient to achieve uniform mixing. The required amount of water is then added as per the Optimum Moisture Content (OMC) obtained from the Standard Proctor compaction tests. Water shall be sprinkled from a water tanker fitted with a sprinkler capable of applying water uniformly without any flooding. The moisture content may vary within the range of +1% and -2% of OMC. Wet mixing is then carried out using the same equipment. The number of passes shall be the same as in dry mixing. However, the number of passes for both dry and wet mixing shall be determined by an experimental field study or as per the decision of the site engineer. The wet mix material shall then be spread by mechanical means, finished by motor grader. Compaction shall be carried out preferably by vibratory rollers of dead weight of 8 to 10 tonnes to achieve a compacted thickness of 150 mm.

The cover soil has to be simultaneously compacted along with fill material in the embankment. This would provide confinement to copper slag/soil/pond ash mix.

11.1.10 *Earth for intermediate soil layers*

Intermediate soil layers are proposed only for copper slag-Fly ash fill material. The same soil which was used for mixing/cover soil may be used as an intermediate layer. An intermediate layer of compacted thickness 150 mm is proposed, after every 2 m raise in the height of embankment. This has been proposed for ease of construction and to provide adequate confinement for the fill material. This would also protect the copper slag-Fly ash material from erosion during possible rainfall at the time of construction.

11.2 Mechanically Stabilised Copper Slag Subgrade and Sub Base

When copper slag-soil mix is used as an embankment material, the same shall form the subgrade material. Black cotton soil and other expansive soils shall be used in subgrade construction judiciously considering the swelling characteristics of such soils. However, when copper slag-pond ash is used as a fill material a separate subgrade of thickness 300 mm of good earth/copper slag+soil shall be laid. The material shall be the same as used conventionally throughout the road section.

In general, the physical and other requirements of embankment fill material, subgrade shall be constructed as per sections 301 and 303 of MoRD Specifications.

11.3 Mechanically Stabilised GSB and WMM Layers with Copper Slag

The design mix of copper slag with conventional aggregates for use in GSB and WMM may be prepared in the conventional WMM plant. The computer controlled plant shall be adjusted till a uniform mix satisfying the design gradation is achieved. The wet mix (@OMC) is non plastic and needs to be compacted immediately with conventional rollers which would be helpful to achieve the required degree of compaction. Also, addition of water to the dried mix at a later stage may result in segregation of the mix. However, the physical, gradation and other requirements of GSB and WMM shall be as per section 400 of MoRD Specifications.

11.4 Construction Methodology for Bituminous Mixes with Copper Slag

The hot bituminous mix, Bituminous Macadam (BM) may be prepared in conventional drum mix plant (IRC:27). After ensuring the gradation, and physical requirements of aggregates, construction shall be carried out as per section 504 of MoRD Specifications. For mix seal surfacing, section 507 of MoRD Specification shall be referred.

12 QUALITY CONTROL TESTS

12.1 Copper Slag Embankment and Subgrade

The material used as an embankment fill material shall be controlled through periodic checks by carrying out different tests with the required frequency. Compaction control and acceptance criteria are also very essential. Section 1803.2 of MoRD Specifications may be strictly adhered to.

12.2 Copper Slag GSB, Cement Stabilised base/Sub base, WMM and Bituminous Mixes

Quality control tests of coarse aggregates, fine aggregates, filler, bitumen and their testing frequencies should be carried out as per section 1803.3, 1803.5,1803.7,1803.10 and 1803.13 of MoRD Specifications.

13 ENVIRONMENTAL ASPECTS

Leachate characteristics of both coarse and fine copper slag shall be evaluated by Toxicity Characteristic Leaching Procedure (TCLP). Though the research studies, indicated that leachability of toxic heavy metals from the copper slag is below the regulatory limits and is considered non-hazardous, a certificate from the Industry regarding the same shall be obtained before using copper slag (coarse/fine) in road construction.

14 TYPICAL CROSS SECTION OF RURAL ROAD WITH COPPER SLAG

As discussed in different sections, mechanically stabilised copper slag viz. copper slag (fine/coarse)-fly ash, copper slag (fine/coarse)-soil, mixture of coarse and fine slag can be suitably used for construction of embankment, subgrade, shoulders, as a part replacement in GSB, WMM and bituminous mixes. Typical cross section of a rural road with usage in different layers is shown in **Fig. 6**. A case study of using copper slag on a National Highway with brief details as given in **Annexure-II**.

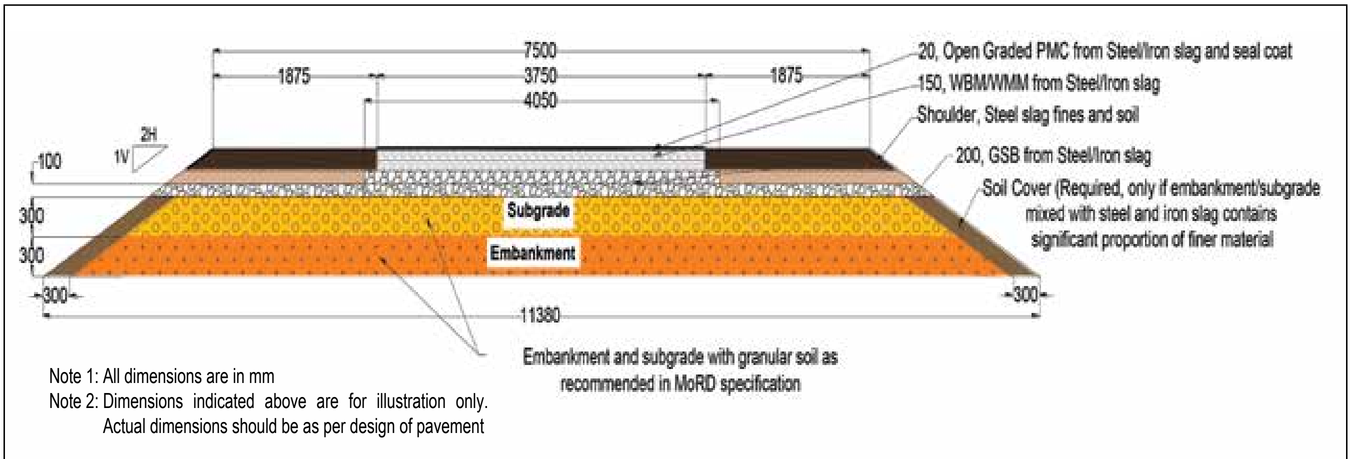

Fig. 6 Typical Cross Section of Rural Road with Copper Slag in Different Layers

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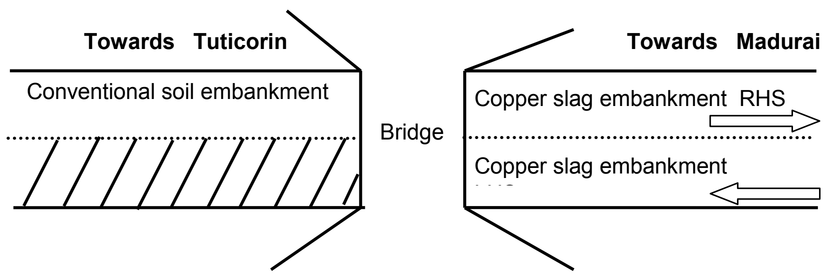
ANNEXURE-II

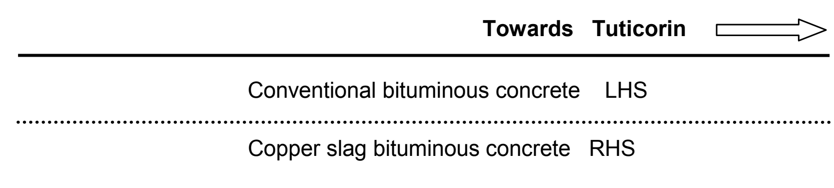
CASE STUDY

CSIR-Central Road Research Institute (CRRI) carried out detailed laboratory and field study to investigate the feasibility of coarse copper slag in the construction of embankment and in bituminous concrete mix. About 0.5 km stretch of bridge approach embankment on Madurai-Tuticorin Highway (NH-45B) (**Fig. A1**) was constructed with coarse copper slag and its performance was monitored for a period of two years. The height of copper slag embankment varied from 1 m to 4 m. As the construction of 100% copper slag was not practically feasible, the material was mixed with locally available pond ash/local soil by 50% (**Fig. A2(a,b), Fig. A3(a,b)**). The slope of the embankment was protected with 2 m thick selected good earth.

Copper slag was also used as a replacement of fine aggregates in bituminous concrete layer (wearing course) and a test section was laid on the same highway for a length of 350 m towards Madurai.



(a)



(b)

Fig. A1 Line Diagram of Experimental Test Sections
(a) Copper Slag Embankment Section (b) Copper Slag Bituminous Concrete Section

(a) **(b)**

Fig. A2 (a) Mixing of Copper Slag + Soil (b) Compacted Surface

(a) (b)

Fig. A3 (a) Mixing of Copper Slag + Fly Ash (b) Compacted Surface

Fig. A4 (a) Dynamic Cone Penetrometer

Fig. A4 (b) Plate Load Test

Copper slag embankment was evaluated during construction by Core cutter/Sand replacement tests, Plate load tests, and Dynamic Cone Penetrometer tests (**Fig. A4**). Pavement performance study on the finished embankment was carried out quarterly for a period of two years by measuring rebound deflection using Benkelman beam (**Fig. A5**), surface roughness using dipstick. To find out the settlement behavior of copper slag embankment, surface level was recorded at different cross sections using auto level. All the results indicated that the copper slag is suitable for construction of embankment and for bituminous concrete mixes.

Fig. A5 Benkelman Beam Studies on Finished Copper Slag Embankment

(The Official amendments to this document would be published by the IRC in its periodical, 'Indian Highways' which shall be considered as effective and as part of the Code/Guidelines/Manual, etc. from the date specified therein)