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Sustainable Alternatives for Granular Sub Base in Road Construction: A Comprehensive Study on Steel Slag and GBFS

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Abstract:- As the demand for sustainable and eco-friendly infrastructure continues to grow, there is an increasing need to explore alternative materials for road construction. This study investigates the viability of replacing natural aggregates in the granular sub base (GSB) layer with industrial by-products, specifically Steel Slag and Ground Granulated Blast Furnace Slag (GBFS). The primary objective is to assess the suitability of these alternative materials through a series of comprehensive tests, aligning with Indian Standard (IS) codes and Indian Road Congress (IRC) guidelines.

The research encompasses fundamental tests on aggregates as per IS codes, evaluating essential properties such as particle size distribution, specific gravity, and water absorption. Additionally, a critical examination of the Volumetric Expansion of steel slag is performed, following the guidelines outlined in IRC codes, to assess its expansive nature.

The study systematically analyzes the mechanical, physical, and expansive characteristics of Steel Slag and GBFS, comparing them with conventional aggregates typically used in GSB layers. The findings aim to provide insights into the structural performance, durability, and environmental impact of these sustainable alternatives. The results obtained from this research contribute to the broader discourse on incorporating eco-friendly practices in road construction, offering valuable information for decision-makers, engineers, and stakeholders involved in infrastructure.

Keywords*: Aggregates, GBFS, Steel slag, Sub base.*

1. Introduction

Steel slag

Steel Industry in India: India ranks as the fourth-largest steel manufacturer globally, following China, Japan, and the United States. Steel production has been on the rise, with the target to increase production from 99 million tonnes (MT) in 2013 to 125 MT in 2016.Iron and Steel Slag: India generates a significant amount of industrial solid waste, including iron and steel slag. The total generation of industrial solid waste by integrated iron and steel plants is approximately 270 million tones,similar generation in countries such as china[23]. Utilization of Steel Slag: Despite the large generation of steel slag, its utilization rate in India is only around 30-35%. This low utilization leads to issues like open dumping, landfills, environmental pollution, and economic challenges

Suitability as Construction Material: Steel slag is known for its high strength and durability, often making it a superior construction material compared to natural rock materials. It can help reduce the amount of waste sent to landfills.Pozzolanic Potential: Steel slag, including LD slag and EAF slag, has high pozzolanic potential. This means it could be utilised as a raw material or blending component in cement manufacturing and construction activities.

Types of Steel Slag: Depends on the steelmaking process, different varieties of slag are generated, such as high sulfur slag, LD slag (steel furnace slag – SFS), LF slag, and electric arc furnace (EAF) slag. International Use: Steel slag, particularly LD and EAF slag[20], is extensively used for many applications in countries like the USA, the European Union, Brazil, Australia, and China.Blast Furnace Slag: Blast furnace slag, which contains a high amount of SiO2, is widely utilized in the cement and concrete industry[34] as they exhibit cementitious and pozzolanic properties.

Challenges and Opportunities: The steel industry generates substantial quantities of steel slag, and there is high potential for increased utilization, especially in construction and cement manufacturing. Proper management and utilization of steel slag can have economic, environmental, and product quality benefits.Efforts to increase the utilization of steel slag in India might lead to more sustainable and environmentally friendly practices within the steel industry and other related sectors.The generation of slag in industries such as the iron and steel industry is a common by-product of the manufacturing process. Here's an overview of the entire process of slag generation:

Blast Furnace Slag Generation:

Blast furnace slag is primarily produced during the stages of reducing iron ore to produce molten iron (hot metal) in a blast furnace.Iron ore, coke (carbon), and limestone are the main raw materials used widely in the blast furnace.Iron ore is further reduced to molten iron, and the impurities in the ore combine with limestone to form slag.The slag is thus finally separated from the molten iron and tapped from the blast furnace.

Steelmaking Slag Generation:

Steelmaking slag is generated during the refinement of hot metal which was produced by the blast furnace into steel. The sources of steelmaking slag include: Gangue content of iron ore: These are the non-iron minerals and impurities present in the iron ore. Constituents of iron ore other than iron: This includes various elements found in the iron ore. Lime content: Lime is added to adjust the overall composition of the molten slag. Steel slag typically has a very crystalline structure due to slow cooling conditions and the lack of SiO2 (silicon dioxide) in its overall chemical composition, which resulted in weak cementitious properties.

Volume Stability and Water Granulation:

Steel slag can show weak cementitious properties, and its volume stability can vary. Water granulation is a common technique used to improve volume stability. However, steel slag can still possess volumetric instability with the contact of moisture. Utilization: Coarse fractions (gravel sizes) of steel slag are often used as road aggregates.The finer fractions (sand and silt sizes) of steel slag have been less explored in terms of engineering properties and utilization in the construction industry.

Amount of Slag Generation:

The amount of slag generated during the initial , pig iron as well as steel production depends on the over all mineral composition of raw materials and th different type of furnace used.

On average, for every single tonne of steel produced, there is a generation of approximately 130 to 200 kg of slag.

Blast furnace (B.F.) slag generation can vary but typically ranging from300 to 540 kg per tonne of the produced pig or crude iron , with variations based on the specific iron ore's grade and composition.

Substandard-grade iron ores can result in a larger amount of slag, accounting for about 20% by mass of the crude steel output.

Environmental Considerations:

The disposal of abundant amount of locally produced steel slag could have environmental implications. Proper management and utilization of slag can help mitigate environmental harm. Overall, slag generation is an inherent process of the iron and steel production, and its proper handling, utilization, and management are essential for minimizing environmental impact and maximizing its potential as a valuable resource.

Table 1 Plant-wise Capacity in Tonnes of Iron and Steel Slag in India

	Name of Steel Plants	Capacity for Granulation(Ton/YEAR)
1	Bhilai Steel Plant ,Durg,Chattisgarh	2675
2	Bokaro Steel Plant,Bokaro,Jharkand	5000
3	Rourkela Steel Plant, Rourkela, Odisha	600
4	Durgapur Steel Plant,Durgapur,West Bengal	NA
5	IISCO Steel Plant, Bumpur, West Bengal	400
6	Visvesvaraya Iron & Steel Plant,Bhadravati,Karnatka	6.8
7	Rashtriya Ispat Nigam Ltd, Visakhapatnam, Andhra Pradesh	1440
8	IDCOL Kalinga Iron Works Ltd, barbil, Odisha	5.3
9	JSW Steel Ltd, Bellary, Karnataka	NA
10	Tata SteelLtd, Jamshedpur, Jharkhand	2100
11	Visa Steel Ltd,Kalinganagar,Odhisa	175
12	Neelachal Ispat Nigam Ltd, Kalinganagar, Odisha	NA
13	Sona Alloys Pvt Ltd, Satara, Maharashtra	100.8

The amount of iron content can differentiate between Blast Furnace slag and steel slag. Generally, in B.F. slag, the amount of FeO is approximately 0.5%, while total iron content may vary from 16 to 23% in steel slag. The permeability and porosity of Soil can be reduced by using iron and steel slag.

Table 2 Physical Characteristics Of Blast Furnace Slag And Steel Slag

Physical properties	Test Method	Blast furnace slag	Steel slag
Aggregate Impact Value (Percent)	IS 2386(Part 4)-1963	18-24	8-11
Aggregate Crushing Value (Percent)	IS 2386(Part 4)-1963	24-26	15-18
Los Angeles Abrasion (Percent)	IS 2386(Part 4)-1963	28-32	9-10
Water absorption (Percent)	IS 2386(Part 3)-1963	1.5-2.5	1-1.4
Specific gravity	IS 2386(Part 3)-1963	2.65	3.22

Air-cooled blast furnace slag and weathered steel slag can be used instead of stone aggregates in WBM layers for mechanical stabilization. Granulated blast furnace slag, which is pozzolanic material, can be stabilized using Lime and used to construct stabilized layers and lime–GBFS concrete base / sub-base. The addition of a small quantity of gypsum enhances strength. GBFS can be used in place of a granular sub-base if it meets CBR requirements.

1.1. Types of Steel slag and their applications

Steelmaking is a strategic part of the economy of any developing nation like India. As a consequence, many steel plants were set up and are producing millions of tonnes of Iron and steel. This is related with the production of waste materials, like Blast furnace slag, steel slag, granulated blast furnace slag, etc. One ton of steel results in the generation of one ton of solid waste.. Promoting the wide use of iron and steelmaking slags as replacements for aggregates in roads and civil construction represents a feasible solution to the enormous demand for the availability of conventional materials. Slag is helpful as an aggregate as they exhibit high mechanical strength, which exceeds many natural totals. In general, the basic properties of the iron and steel slag aggregates are very much comparable to that of natural aggregate. In some specific cases, slag aggregates are even superior to natural aggregates.

In the steel industry, iron-making slag is processed in three different forms based on the different methods of cooling adopted. Air/water-cooled slags result in large mass blocks and granulated slags similar to Sand.. Slags from such manufacturing plants can be utilised as pavement material in various forms. It can be used as sub-base material in the bound or unbound state. With certain controlled processing conditions, as explained in Table 3, the various types of slag, their characteristics, and applications.

Air-Cooled Slag: Allowing the produced molten slag to cool down slowly in air in an open air pit produces the air-cooled slag. While that of the Air-cooled blast furnace slag is "the material that is resulting from the solidification of molten blast furnace slag under the atmospheric conditions. The slag thus produced is close to the form of large boulders. The air-cooled B.F. slag needs to be crushed and screened and can be used as coarse aggregate for roads and bases[1], asphalt paving, railway ballast, landfills, and concrete aggregate. The solidified slag shows typical vesicular structure with closed pores. The rough typical vesicular texture of slag has a greater surface area than the smoother aggregates of equal volume. It provides a strong bond with cement and exhibits high stability in asphalt mixtures.

Water-Cooled Slag: Water-cooled or Dry pit slag is generated through controlled rapid cooling of molten slag immersing in water or water with a combination of steam. This slow cooling makes the slag foamy and increases the porosity and vesicular nature, resulting in lightweight boulders. This slag's density and compressive strength are lower than the air-cooled slag and do not meet the standard requirement of the concrete aggregates. This type of expanded or foamed slag binds very well with cement and can only be utilised as aggregate for lightweight concrete.

However, with controlled water cooling, dry pit slag can be used as coarse aggregates in non-critical applications such as village roads, construction fills, and skid-resistant aggregates. Since this slag aggregate is a highly vesicular and porous material, water absorption capacity is high

GranulatedSlag: The molten B.F. slag emanating from the blast furnace at high temperatures is directly quenched using very high-pressure water jets. The slag disintegrates and forms into granules, hence the term Granulated B.F. Slag (GBFS). Generally, granulated slag is whitish-grey in color, similar to Sand. Almost 95% of the total slag that is generated in present-day iron-making operations is granulated, and 5% is water-cooled in a dry pit. Rapid quenching that prevents the crystallization of mineral constituents in the slag, thus resulting in a granular, glassy aggregate. This powdered form of B.F. slag is called Ground Granulated Blast Furnace Slag (GBFS). GBFS, as received from Blast Furnace, is very similar to natural river sand in properties and appearance and can be directly used as its replacement in the construction/road-making industry. GBS has been widely used in developed countries in place of natural river sand for all construction/road-making applications. Slag sand can be utilised in many road-based and sub-base applications. It also has marked pozzolanic properties when ground into fine powder.

Some of the basic test results conducted on slag materials are shown in Table 2, which shows the Physical Characteristics of Blast Furnace Slag and Steel Slag. Soundness tests on steel slag and blast furnace slags showed they suit road applications.

Table 3 Characteristics and applications of slags

Slag	Condition	Characteristics	Applications
B.F. Slag obtained during Iron Making	Air/Water Cooled Slag	No alkali-aggregate reaction and self-curing	Coarse aggregate for concrete
		Size, high strength, and Hydraulic property	Coarse aggregate for Roads
		Thermal insulation and sound absorption	Raw materials for rock wool
		Fertilizer component (CaO, SiO2)	Calcium silicate fertilizer
	Granulated slag	Cementitious and Strong latent hydraulic property	Raw materials for Clinker
			Blending material for Slag cement and concrete
		Latent hydraulic property, large angle of internal friction, and large water permeability	Material for civil engineering works and ground improvement material
		It does not contain chlorides and has No alkali-aggregate reaction	Fine aggregate for concrete
		Lightweight and Self-curing	Fine aggregate for Mortar and Plaster
		Fertilizer component (CaO, SiO2)	Calcium silicate fertilizer and Soil Improvement
Slag obtained during the manufacturing of Steel	Air Cooled and Magnetically Separated	Hard, wear-resistant, and Hydraulic property	Aggregate for Asphalt and concrete roads
		Large angle of internal friction and high strength	Aggregates for civil foundations and engineering works, ground improvement material
	Granulated and Magnetically Separated	Suitable Hydraulic properties and contains (CaO, SiO2, MgO, FeO)	Raw material for Clinker
			Blending material for Slag cement
			Performance improver and Colouring agent in cement
		Latent hydraulic property, large angle of internal friction, and large water permeability	Material for civil engineering works and ground improvement material
		It does not contain chlorides and has No alkali-aggregate reaction	Fine aggregate for Roads and concrete and as grit

2. Literature Review

(i) **Ahmed Ebrahim et. al., (2012)** studied the application of steel slag on mixes with crushed limestone mixes for incorporation in Sub-base. Their properties such as maximum dry density, CBR, and resilient modulus were evaluated. The results revealed that the mechanical characteristics resistance factors improved by adding steel slag to crushed limestone. It concluded that 70% steel slag and 30% limestone gave the layer inroads the best density, strength, and failure resistance.

(ii) **Ashok Kumar et. al., (2016)** studied the potential use of steel slags in the pavement sub-base. Gradation and physical properties were investigated, and suggested the inclusion of optimum percentage of slag to satisfy MORTH specifications, that 78% of the percentage of slag along with conventional aggregates. It concluded that slags have excellent strength and properties for road base and sub-base applications.

(iii) **Brajesh Mishra et. al., (2015)** presented a detailed study on the use of different Industrial wastes such as Fly Ash, Blast Furnace slag, Cement Kiln Dust, Phosphogypsum, Waste plastic bags, Foundry sand, and colliery sand. Testing these materials and developing the Methodology and specification to enhance the application of such Industrial wastes on rural roads with low volumes of Traffic. A review of wide range of wastes for their suitability to be used in road construction is presented in this paper.

(iv) **George Wang and Russell Thompson (2011)** showcased the utilization of ferrous and nonferrous slags in civil and highway construction.

(v) **Magdi Zumrawi and Alaa Abdel-Aziz Ali Babikir (2017)** This study investigates the stabilization of expansive soil through the incorporation of Steel Slag (SS). The experimental program aims to assess the impact of Steel Slag on enhancing the engineering characteristics of expansive clay. Various tests were conducted to analyze consistency limits, free swell index, compaction parameters, and unconfined compressive strength for both natural and stabilized soils. The study evaluates the effectiveness of incorporating 0%, 5%, 10%, 15%, 20%, and 30% of SS into the soil. Comparative analysis of the results obtained for natural and stabilized soils indicates a substantial influence of SS on strength parameters, leading to notable improvements in plasticity and swelling properties. The addition of SS to the soil resulted in increased dry density, reduced optimum moisture content, and enhanced unconfined compressive strength. The findings suggest that the utilization of steel slag successfully and beneficially enhances the properties of expansive soil

(vi) **Magdi Zumrawi (2015)**This research explores the potential utilization of Steel Slag Aggregates (SSA), a by-product of the steel industry, as a viable substitute for natural aggregates in the formulation of hot mix asphalt (HMA) for road construction. The study involves a comprehensive laboratory testing program to assess the characteristic properties of SSA and determine its suitability for incorporation into HMA. Four different proportions of SSA (0%, 50%, 75%, and 100%) were employed, and mix designs for HMA were developed following the Marshall mix design guidelines.

The experimental results highlight a substantial enhancement in the properties of HMA with the addition of SSA. Specimens incorporating 100% SSA demonstrated notable improvements in density and stability, coupled with a decrease in flow and air voids values. These findings indicate that SSA can effectively contribute to the improvement of HMA characteristics. Consequently, the study concludes that steel slag stands as a viable and reasonable alternative source of aggregate for the production of concrete asphalt mixtures.

(vii) Ebenezer Akin Oluwasola et al.(2015). This study evaluated the advantage of using Electric Arc Furnace (EAF) steel slag and copper mine tailings (CMT) as substitutions for conventional aggregates used in pavements for roads and highways. Four mix designs containing slags at different proportions were investigated. The findings showed that substituting natural granite aggregates with these slags improved the performance properties of asphalt mixtures. The mixture containing 80% EAF steel slag and 20% CMT was determined to be final optimum.

(viii) Somnath Kumar(2019) In the context of integrated steel plants, the production of steel is accompanied by the generation of various types of waste, including solid, liquid, and gas forms. In India, where approximately 100 million tonnes of steel is produced annually, the resultant by-products amount to around 40 million tonnes of diverse slags. The production of one ton of steel typically yields 200 kg (Electric Arc Furnace - EAF) to 400 kg (Blast Furnace/Basic Oxygen Furnace - BF/BOF) of by-products, encompassing slags, dusts, sludges, and other materials. Globally, more than 400 million tons of iron and steel slag are generated each year.

The contemporary focus in the steel industry is on waste avoidance, recycling, and minimizing the environmental impact of disposal. Among the various solid and liquid wastes, iron and steel slags, generated during the iron and steel-making processes, constitute the largest proportion. The disposal of substantial quantities of slag poses significant environmental challenges for steel manufacturers, necessitating innovative solutions.

In recent years, advancements in process technologies and a deeper understanding of slag properties have led to a substantial reduction in slag volume. Simultaneously, efforts to expand the reuse of iron and steel-making slag have mitigated the environmental impact of these by-products. Despite these improvements, slag generation remains an unavoidable aspect, underscoring the continued importance of recycling efforts.

This paper explores the ongoing developments in the total recycling of slag within the steel industry. The objective is to work towards achieving the vision of producing "clean and green steel with zero waste," ensuring the sustainability and growth of the steel business in the future.

(ix) Qifeng Song (2021) explores the potential of utilizing steel slag, a by-product of the steelmaking process, as an eco-friendly construction material. The disposal of steel slag in landfills is recognized as environmentally harmful, given its abundance of free calcium/magnesium oxide, low cementitious properties, and elevated heavy metal content. The direct use of untreated steel slag poses risks to the mechanical properties and durability of resulting composites.

Recent research has made significant strides in addressing these challenges, particularly through the discovery that accelerated carbonation can enhance the properties of steel slag-derived materials. The review categorizes steel slags based on their chemical/mineral compositions and outlines various physico-chemical properties. It then delves into the advancements related to accelerated carbonation, detailing influencing factors such as temperature, reaction time, CO2 concentration and pressure, moisture, particle size, gradation of steel slag, and the impact of additives.

A central challenge highlighted is understanding the interconnectedness among these influencing factors and their respective contributions to improving the properties of steel slag. The review also discusses practical applications of carbonated steel slag with enhanced qualities. In conclusion, the authors provide new insights into the mechanisms and challenges associated with using accelerated carbonation as a treatment for steel slag, emphasizing its potential for future research and industrial applications in sustainable construction materials.

(x) Jianlong Guo (2018) This Paper reviews examines the treatment, recycling, and management of steel slag in China, a major by-product of the steelmaking process. Despite an annual production exceeding 100 million tons, China's steel slag utilization rate stands at only 29.5%, with over 300 million tons remaining unused as of 2016. This substantial amount of unutilized steel slag contributes to environmental issues in the country.

The literature points to outdated treatment approaches in China, where many steel plants conduct preliminary treatments resembling family workshops. Additionally, inconsistencies in ferrous waste recovery processes and insufficient stability of treated steel slag in 47% of enterprises hinder effective utilization. High costs and policy limitations impede road construction applications, while legal restrictions and a lack of standards hinder agricultural uses.

To address these challenges, the review proposes the concept of gradual utilization, emphasizing the need for new policies to improve steel slag utilization rates in China. This approach aims to promote effective and sustainable steel slag utilization in various applications, emphasizing the importance of a comprehensive and updated approach to treatment and recycling.

(xi) Marina Díaz-Piloneta (2021) This literature summary discusses the potential use of Blast Oxygen Furnace (BOF) slag, a significant byproduct of steelmaking, as an alternative to natural aggregates in road construction. The key issue addressed is the volumetric instability of BOF slag in the presence of water, necessitating stabilization pre-treatments that are both cost-inefficient and environmentally problematic. The paper advocates for the use of untreated BOF slag and explores its technical and environmental viability in comparison to traditional aggregates.

A pilot test is conducted, comparing a mixture with limestone as the coarse aggregate to another with 15% BOF slag. The technical performance of asphalt mixtures is evaluated using the Marshall Quotient, with results indicating improvement when incorporating BOF slag (4.9 vs. 6.6).

Additionally, the study employs Life Cycle Analysis (LCA) to measure the global warming impacts of different asphalt mixtures. The LCA results reveal that the use of BOF slag as a coarse aggregate leads to a carbon emissions reduction rate of over 14% compared to traditional limestone aggregates. The environmental benefits of using BOF slag in road construction are highlighted. Furthermore, a transport sensitivity analysis is conducted, likely exploring the implications of transporting and using BOF slag in different locations. The findings support the feasibility of utilizing BOF slag in road construction, emphasizing both technical advantages and environmental benefits. Overall, the paper advocates for the sustainable utilization of BOF slag as a secondary resource in the construction industry, offering a potential solution to the volumetric instability issue while promoting environmental sustainability in road infrastructure development.

In summary, the findings of these study not only endorse the technical feasibility of using steel slag,GBFS in pavement layers but also emphasize the economic benefits, especially when considering reduced construction costs and strategic material sourcing. The widespread adoption of these industrial by-products in pavement construction [5,21,25,28] has the potential to significantly contribute to sustainable and cost-efficient infrastructure development. Further detailed chemical composition ,micro structural studies and leaching studies[33] can investigate possibility of stabilising steel slag with lime or puzzolonic materials for more effective use of steel slag in different layers of road construction [30,31,32,35] and contribute to the environmental conservation.

3. Present study: Steel slag Investigations for Sub Base

3.1 Materials and Methodology: Granular sub-base layer consisting of Steel slag, GBFS

As shown in Figure 1, steel slag was procured from JSW Plant, Vijaya Nagar, Toranagallu, Karnataka, in a 53 mm down size range. Table 3. 2 shows the details of various Properties of steel Slag.

Figure 1: Steel slag

Investigation for steel slag as coarse and fine aggregates for use in Sub Base were undertaken:

In the present work, different types of tests are conducted on the given samples. Various physical properties are measured by using these tests. The various test conducted on material are listed below:

- Specific gravity
- Water absorption(%)
- Crushing Value(%)
- Impact Value(%)
- Flakiness Index(%)
- Volumetric Expansion
- Soundness Test with sodium sulfate
- SoundnessTest With magnesium sulphate

Steel slag and GBFS are used as Granular Sub Base layer and Granular sub base design as per MORTH and IRC standards .

3.2 Results of testing Steel slag and the laboratory investigation results are explained in Table 4

Table 4 Laboratory Investigations of Steel Slag Properties Aggregate

Grain Size Distribution (%)					Atterberg Limits (%)		Modified Compaction		Specific Gravity (G)	Soaked CBR (%)
> 4.75	4.75 to 2.36	2.36 to 0.425	0.425 to 0.075	0.075 to 0.00	Liquid Limit	Plastic Limit	MDD (g/cc)	OMC (%)		
1.50	0.86	82.58	11.56	3.50	-	NP	1.73	15	3.73	60

	Test Conducted	Steel Slag results	Natural aggregate results	Limits for Sub-Base	CODE
1	Specific gravity	**3.73**	**2.68**		IS:2386 (Part III)-1963
2	Water absorption (%)	**1.86 %**	**0.2%**	<6	IS:2386 (Part III)-1963
3	Crushing Value (%)	**32%**	**20.55%**		IS:2386 (Part IV)-1963
4	Impact Value (%)	**52%**	**17.29%**	>50	IS:2386 (Part IV)-1963
5	Flakiness Index (%)	**16.2%**	**7.81%**	<40	IS:2386 (Part I)-1963
7	Volumetric Expansion	**1.8%**		<2%	
8	**Soundness Test with sodium sulfate**	**1.72%**		Max 12% by mass	IS:2386(part 5)-1963(RA2016)
9	**SoundnessTest With magnesium sulphate**	**2.28%**		Max 18% by mass	

GBFS was obtained from **JSW Bellary, Vidyanagar Plant., and Table 5** shows the basic Properties of Granulated Blast Furnace Steel slag, Graduation, Zone II as per IS:383-2016

Table 5 Chemical Properties of GBFS to be used in Sub-base

Specific Gravity	2.88
Glass Content	93%
Magnesia Content	7.66%
Sulphide	0.5%
Sulphite	0.39%
Manganese	0.11%
Chloride	0.005%
Insoluble	0.41%

Table 5 shows that the principal constituent is glass-like and has minimal magnesia and sulfite content.

Requirements for Granular Sub-base as per MORTH:

As per MORTH section 400, Table 400-1, Table 400-Sub base materials should confirm to

1. Grading V and VI for use in sub-base cum drainage layer
2. Aggregate Impact Value up to Maximum 40

3. Liquid Limit to a maximum of 25
4. Plasticity Index maximum of 6
5. CBR at 98% dry density, a minimum of 30

3.3 Granular Sub Base Design:

Grading of GSB: The Granular Sub-Base (GSB) can have different gradings, but the choice of grading depends on its intended use. Grading III and IV are proposed for use as lower sub-base layers, while Grading V and VI are recommended for use as sub-base-cum-Drainage Layer. Here we are utilizing the available sample of steel aggregate , hence we use the available grade of steel slag for sub base using the mid point method of design

Table 6 Gradation for steel slag aggregates and GBFS

IS SIEVE SIZE (mm)	40mm	20 mm	12.5 mm	Dust	35%	20%	25%	20%	Combined Gradation	Specific limits for GSB as per MORT&H Grading- I	Mid Point
75	100	100	100	100	35.00	20.00	25.00	20.00	100.0	100	100
53	95.2	100	100	100	33.32	20.00	25.00	20.00	98.3		
26.5	12.2	99.7	100	100	4.27	19.94	25.00	20.00	69.2	55 - 75	65
9.5	0.1	0.4	77.9	100	0.04	0.08	19.48	20.00	39.6		
4.75	0	0.2	5.2	99.4	0.00	0.04	1.30	19.88	21.2	10 - 30.	20
2.36	0	0	1.7	93.1	0.0	0.00	0.43	18.62	19.0	…	
0.425	0	0	1.6	36.9	0.0	0.00	0.4	7.38	7.8	…	
0.075	0	0	0.2	3.8	0.0	0.00	0.1	0.76	0.8	<5	2.5

Size	Range		Mid Point	Obtained grading
75	100	100	100	100.0
26.5	55	75	65	69.2
4.75	10	30	20	21.2
0.075	0	5	2.5	0.8

TEST	40mm	20mm	12.5 mm	Dust

GSB DESIGN AS PER MORTH 5TH Revision Table 400-1(Grading –I)

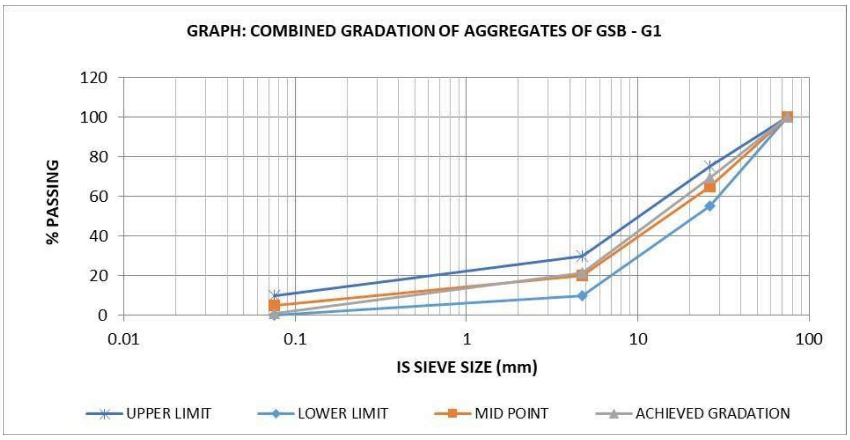

Figure 2 Gradation curve for sub base layers

The gradation o steel slag designed for sub base layer as shown in **Figure 2**. **Table 6** shows the gradation of steel slag and its mix design .Here the gradation designed is classified into Grade – 1 aggregate size as obtained the samples from the source

3.4 Steel slag suitability-Sub base requirements as per IRC codes:

Table 7: Requirements of sub Base as per Codes

	As per SP-20-2002	As per MORD-2014	As per MORTH-2018	IRC-SP-121-2018
Graduation	I, II, III	I, II, III	III,IV(LOWER SUB BASE) V,VI(SUBBASE CUM Drainage)	
Aggregate Impact Value	<50	<50	<40	<50
Water absorption	<6%	<2%	<10%	<2%
Crushing Value	30-45			
Flakiness Index	<40	<30	<35	<30
Volumetric Expansion				2%
Soundness Test- sodium sulfate	<12%	<12%	<12%	<12%
Soundness Test-magnesium sulphate	<18%	<18%	<18%	<18%
Liquid Limit(for 425 micron passing)	<25	<25	<25	
Plasticity Index	<6	<6	<6	
CBR-soaked	>15	>20	>30	

4. Conclusions

Steel slag exhibited favourable properties for use in sub-base including high strength and good drainage. It met the required physical and strength parameters for sub-base layers as GRADE-I aggregates as per MORTH-2018.

In conclusion, the utilization of industrial wastes, steel slag and GBFS, in subbase layers in pavement construction emerges as a feasible and economically attractive alternative. This study demonstrates the versatility of these materials, showcasing their suitability not only for rural roads but also for more demanding applications such as haul roads and industrial areas characterized by heavy vehicle movement

The cost-effectiveness of roads constructed with steel slag is a standout feature, with a substantial reduction in construction costs observed compared to conventional materials. This reduction is primarily attributed to the decreased pavement thickness achievable with these industrial by-products. This cost advantage underscores the potential economic benefits of adopting these materials in pavement construction projects.

The geographic location of material sourcing plays a crucial role in optimizing the economic advantages. The study highlights that it is more economically viable to utilize steel slag in areas proximate to the plants producing these waste materials. This approach minimizes transportation costs and further enhances the overall cost-effectiveness of utilizing industrial wastes in pavement construction.

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Conflicts of interest

The authors declare no conflict of interest.

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