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ASSESSMENT OF THE POTENTIAL USE OF STEEL SLAG IN HOT BITUMINOUS CONCRETE

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Abstract: The utilization of aggregates in road construction is a conventional global practice. In developing countries like India, the rapid growth of population and traffic necessitates constant highway upgrades to accommodate heterogeneous traffic and the heavy loads of commercial vehicles. This increased demand has led to the depletion of natural aggregate sources. As high-quality aggregates become scarce and expensive, alternative materials are being investigated. One such material is steel slag, a byproduct of steel manufacturing that, if improperly managed, creates environmental concerns. Steel slag is now increasingly used as a substitute material in road construction due to its favorable mechanical properties.

In this study, natural aggregates in Grade-2 bituminous concrete are replaced with steel slag at varying percentages (10%, 20%, 30%, and 40%). The mix design was developed using the Job Mix Formula, and Marshall specimens were prepared according to the specified gradation. Marshall Stability and Indirect Tensile Strength tests were conducted. The results demonstrate that steel slag can effectively replace natural aggregates in bituminous concrete without compromising performance, supporting its use in sustainable pavement construction.

Keywords: Natural Aggregates, Steel Slag, Bituminous Concrete, Job Mix Formula, Marshall Stability, Indirect Tensile Strength

I Introduction

Road transport plays a crucial role in the movement of passengers and freight. The continuous development of road infrastructure demands the use of high-quality construction materials. However, due to prolonged and extensive usage over the years, natural aggregates are depleting at an alarming rate across the globe. This situation has compelled construction engineers to explore alternative materials that can match the strength and performance characteristics of conventional aggregates. One such promising alternative is steel slag, a by-product generated during the steel-making process when molten steel is separated from impurities in the furnace. Traditionally treated as industrial waste, the disposal of steel slag has posed environmental and economic challenges. However, due to its favorable physical and chemical properties, steel slag is now being recognized as a valuable material in construction applications. Steel slag exhibits a pH range of 8 to 10, enabling it to bond effectively with bitumen and contribute to stronger, more durable mixtures. When incorporated into asphalt, it improves the strength, bonding characteristics, and resistance to wear of the bituminous mix. Additionally, replacing natural aggregates with steel slag helps reduce the burden on landfills, as its hardness and durability are comparable to those of conventional aggregates. Thus, its use not only addresses the scarcity of natural materials but also promotes sustainable and environmentally responsible construction practices. The application of steel slag in road construction offers the dual benefits of conserving natural resources and producing high-performance pavement surfaces capable of withstanding heavy traffic loads.

II. Literature Review

In India, approximately 70% of roads are paved, comprising flexible, rigid, and composite pavements. Natural aggregates are widely used in various pavement layers; however, their depletion has driven the search for sustainable alternatives. One promising substitute is steel slag, an industrial by-product that has gained traction in road construction due to its strength, durability, and environmental advantages.

Several studies have evaluated the incorporation of steel slag in asphalt mixes. Ahmed et al. [1] investigated rutting resistance and concluded that steel slag enhances the structural integrity of pavements. Aziz et al. [2] showed that replacing 30% of natural aggregates with steel slag significantly improves mechanical performance and load-bearing capacity, while their earlier study [3] demonstrated the material's durability and hydrophobic characteristics. Deshmukh and Patil [4] compared steel slag with basalt aggregates, confirming its competitive performance in bituminous mixes. Gao et al. [5] proposed microwave de-icing techniques for steel slag asphalt, contributing to greater sustainability. In the Indian context, Magadi et al. [6] performed Marshall Stability tests confirming the suitability of steel slag under local conditions. Hainin et al. [7] reported the successful integration of steel slag in Malaysian hot mix asphalt, aligning with international performance specifications. Kumar et al. [8] emphasized the environmental benefits of steel slag reuse in asphalt pavement. Mladenovic et al. [9] found that steel slag enhances stiffness and resistance to deformation in asphalt layers, while Pasetto and Baldo [10] highlighted structural benefits and long-term performance. Studies by Sharma and Kumar [11] analyzed the economic feasibility of steel slag for Indian roads, supporting its use in cost-effective construction. Singh and Jain [12] noted improved bitumen bonding due to the slag's surface texture. Thomas et al. [13] evaluated hybrid bituminous mixes combining steel slag with other waste materials. Tsantilis and Anagnostopoulos [14] observed a significant increase in fatigue life when slag was used in asphalt mixes. Xue et al. [15] further highlighted excellent skid resistance and long-term durability on highways.

These comprehensive findings support the viability of steel slag as a partial or full replacement for natural aggregates in bituminous concrete. Consequently, the present study investigates its application at replacement levels of 10%, 20%, 30%, and 40% for both coarse and fine aggregates to evaluate its influence on the strength and performance characteristics of hot bituminous concrete.

III. Objectives of the Research

- To evaluate the strength characteristics of bituminous mixes incorporating varying proportions of steel slag as a replacement for natural aggregates.
- To compare the Marshall Stability and performance characteristics of conventional bituminous mixes with those modified using steel slag.

IV. Materials and Methodology

This section outlines the approach and methodology adopted in the study. It includes sample selection, material sources, key parameters, and the analytical framework. The methodology is presented in the form of a flow chart shown below.

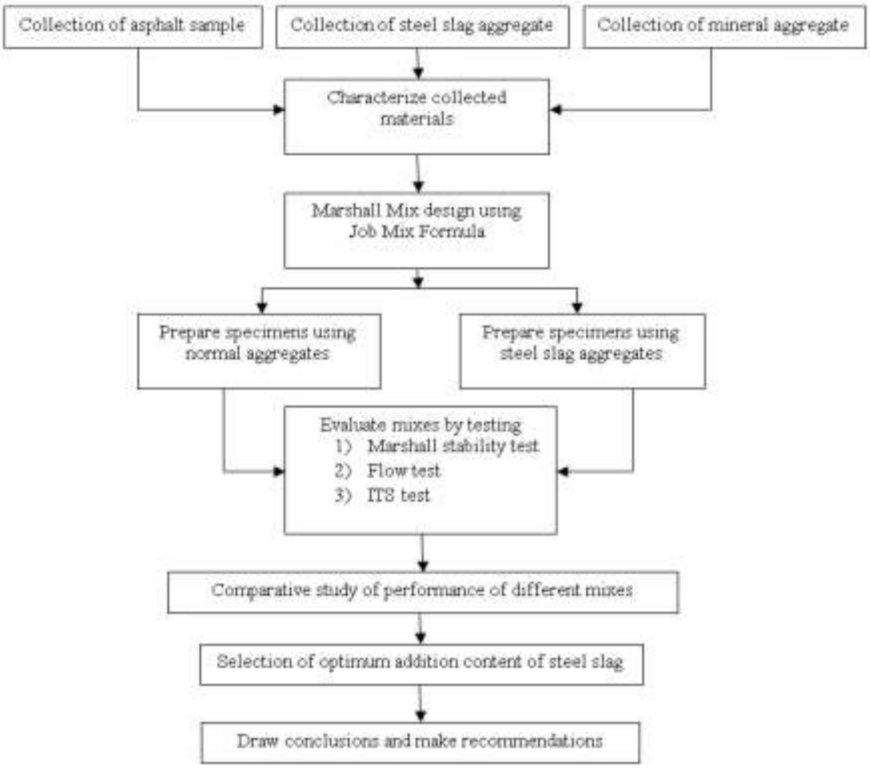


Figure 1: Flow chart of Methodology

4.1 Materials Characterization

4.1.1 Natural aggregates: Natural aggregates commonly used in road construction include stone dust and graded aggregates of sizes 20 mm, 12.5 mm, 6.3 mm, and 2.36 mm. These aggregates form the primary load-bearing component in flexible pavements and play a critical role in transferring vehicular loads to the underlying layers through grain-to-grain contact. In this investigation, all these aggregate sizes were utilized, and their physical properties were evaluated as per the specifications provided by the Ministry of Road Transport and Highways (MORTH). Table 1 shows the physical properties of collected natural aggregates with MORTH specification.

Table 1: Physical properties of collected natural aggregates with MORTH specification

Sl. No.	Tests	20mm down-size	12.5mm down-size	6.3mm down-size	2.36mm down-size	Stone dust	MORTH specification
1	Specific gravity	2.71	2.72	2.74	2.75	2.68	2.5-3.2
2	Aggregate crushing value (%)	23.84	24.22	24.83	-	-	≤ 30
3	Aggregate impact value (%)	20.82	21.21	21.60	-	-	≤ 24
4	Los Angeles abrasion value (%)	28.45	29.51	29.25	-	-	≤ 30
5	Combined indices (%)	24.45			-	-	≤ 30
6	Water absorption (%)	0.15	0.20	0.30	0.35	0.38	≤ 2

4.1.2 Bitumen: Bitumen, also referred to as asphalt, is a black, sticky, and highly viscous material that exists in either a semi-solid or liquid state. It is derived from the distillation of petroleum and may also occur naturally. Approximately 70% of the bitumen produced globally is utilized in road construction, where it functions as a binder that holds the mineral aggregates together to form bituminous concrete. In this study, the bitumen used was tested to ensure its conformity with Indian Standards (IS) specifications. Its physical properties were evaluated through standard tests including ductility, penetration, softening point, flash point, fire point, and specific gravity. These properties are critical in determining the suitability of bitumen for use in flexible pavements. Table 2 presents the test results of the bitumen used in this study, compared with the IS specification limits.

Table 2: Properties of Bitumen used for the study with IS specifications

Sl. No.	Tests	Results	IS specifications
1	Ductility test, cm	73.50	≥ 40
2	Penetration test, cm	67.00	≥ 45
3	Specific gravity	1.01	0.97-1.02
4	Softening point, ^{0}C	52	≥ 45
5	Flash and fire point ^{0}C	320	≥ 175
6	Fire point ^{0}C	365	≥ 180

4.1.3 Steel slag: Steel slag is a byproduct generated during the smelting of ores and recycling of scrap metals in steel manufacturing. In this study, steel slag was procured from Jindal Steel Works (JSW), located in Bellary District, Karnataka. The physical properties of the steel slag aggregates were evaluated and found to conform to the standards specified by the Ministry of Road Transport and Highways (MORTH). Table 3 presents the physical characteristics of the steel slag.

Table 3: Physical properties of the steel slag with MORTH specification

Sl. No.	Tests	20mm down-size	12.5mm down-size	6.3mm down-size	2.36mm down-size	Stone dust	MORTH specification
1	Specific gravity	3.25	3.25	3.26	3.14	3.11	2.5-3.2
2	Aggregate crushing value (%)	18.42	18.44	18.62	-	-	≤ 30%
3	Aggregate impact value (%)	14.22	14.12	13.62	-	-	≤ 24%

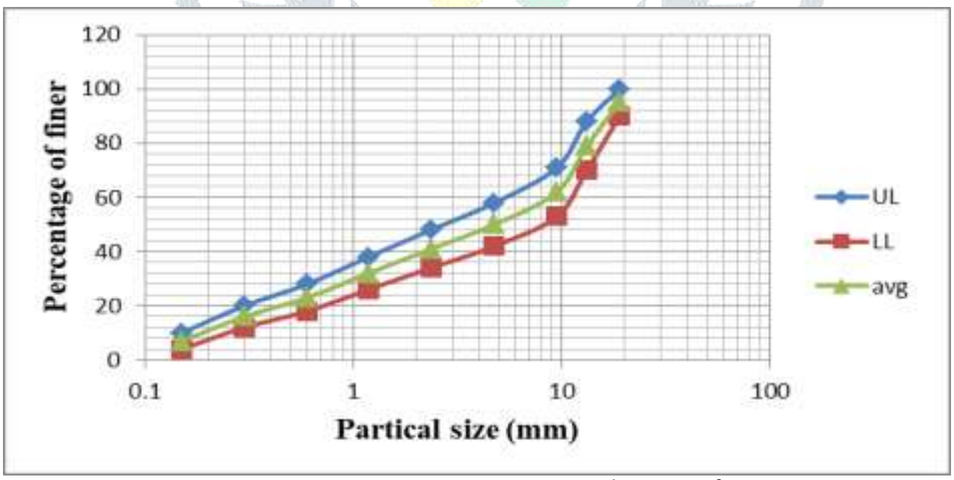
4	Los Angeles abrasion value (%)	17.46	17.52	17.26	-	-	≤ 30%
5	Combined indices (%)	20.58			-	-	≤ 30%
6	Water absorption (%)	0.15	0.24	0.32	0.39	0.39	≤ 2%

4.2 Methodology

To evaluate the suitability of steel slag aggregate (SSA) as a partial replacement for natural aggregates in bituminous concrete, Marshall specimens were prepared with varying bitumen contents of 5%, 5.5%, 6.0%, 6.5%, and 7% by weight of the total mix. For each bitumen content, separate batches were produced by replacing natural aggregates with steel slag at 10%, 20%, 30%, and 40% by weight. The Marshall specimens were prepared and tested in accordance with ASTM D1559 specifications. Key performance parameters including bulk specific gravity, air voids (Va), voids in mineral aggregates (VMA), voids filled with bitumen (VFB), stability, and flow were measured. The weight of each specimen was recorded in air and after immersion in water at 60°C for 30 minutes to determine specific gravity. Marshall Stability and Flow tests were conducted to assess strength and deformation characteristics, while Indirect Tensile Strength (ITS) tests were performed at the respective optimum binder content (OBC) to evaluate tensile resistance. The data obtained provided a comparative analysis of the mechanical performance of conventional and slag-modified mixes.

4.2.1 Combined gradation

To achieve a dense, stable, and economical bituminous mixture, it is essential to select an appropriate combination of aggregate sizes. In this study, individual aggregate fractions were blended based on a combined grading approach. Using the Job Mix Formula (JMF), the ideal mix proportions were identified to meet the gradation requirements for Grade-2 bituminous concrete, as outlined in MORTH (2013). The aim was to produce a well-graded aggregate mix that meets the upper and lower gradation limits while maximizing workability and mechanical performance. The resulting gradation curve, shown in Figure 2, illustrates the aggregate distribution and confirms compliance with the specified grading envelope.



*UL – Upper Limit, *LL – Lower Limit, *avg – Average gradation

Figure 2: Gradation curve of the bituminous concrete as per MORTH (2013) specifications.

V Results and Discussion

The incorporation of steel slag as a partial replacement for natural aggregates in bituminous concrete significantly enhanced the mix performance. An increase in bulk density was clearly observed with the addition of steel slag, accompanied by a progressive improvement in Marshall Stability and other strength parameters compared to the conventional mix. The replacement of natural aggregates with steel slag contributed to higher pavement strength, enabling the mix to withstand greater loads.

Tables 4 to 8 present the Marshall Stability test results for the conventional mix and modified mixes incorporating 10%, 20%, 30%, and 40% steel slag, respectively. Corresponding graphs (Figures 3 to 8) were plotted to determine the Optimum Bitumen Content (OBC) for each mix. Table 9 summarizes the OBC values obtained, while Table 10 provides the Indirect Tensile Strength (ITS) results under both conditioned and unconditioned scenarios, along with the Tensile Strength Ratio (TSR). Figures 9 and 10 illustrate the variation in OBC and ITS test results across different mixes.

The optimum steel slag content was found to significantly enhance the mechanical performance of the mix. The OBC for the conventional mix was observed to be 6.2%, which decreased to 5.7% for the modified mix with 40% steel slag. This reduction is attributed to the higher specific gravity of steel slag, which increased the overall mix density, thereby reducing the binder requirement. At 40% replacement level, a 14.74% increase in stability and a 24% reduction in flow values were recorded, indicating improved load-carrying capacity and stiffness. Moreover, the ITS results at respective OBCs confirmed enhanced tensile strength and durability, validating the effectiveness of steel slag as a sustainable and performance-enhancing substitute in hot bituminous mixtures.

Table 4: Marshall Stability Test results of conventional bituminous mixes

Sl. No	Bitumen content (%)	Unit weight, kN/m^3	V_a (%)	VMA (%)	VFB (%)	Stability (kN)	Flow (mm)
1	5.0	2.47	6.12	16.24	62.28	27.62	4.41
2	5.5	2.47	5.42	16.57	67.38	29.80	4.52
3	6.0	2.52	4.66	16.88	72.48	37.51	4.86
4	6.5	2.36	4.08	17.35	77.28	32.22	5.16
5	7.0	2.28	3.84	18.08	78.91	21.93	5.46

Table 5: Marshall Stability TEST results of modified bituminous mixes with 10% steel slag

Sl. No	Bitumen content (%)	Unit weight, kN/m^3	Va (%)	VMA (%)	VFB (%)	Stability (kN)	Flow (mm)
1	5.0	2.54	6.22	15.73	63.26	29.62	4.30
2	5.5	2.56	5.75	16.11	67.36	31.81	4.41
3	6.0	2.58	4.64	16.84	73.48	38.04	4.66
4	6.5	2.41	4.13	17.31	79.96	34.41	5.02
5	7.0	2.39	3.95	17.84	81.91	23.51	5.26

Table 6: Marshall Stability TEST results of modified bituminous mixes with 20% steel slag

Sl No	Bitumen content (%)	Unit weight, kN/m^3	Va (%)	VMA (%)	VFB (%)	Stability (kN)	Flow (mm)
1	5.0	5.93	2.58	65.72	15.32	29.71	4.13
2	5.5	5.01	2.62	71.34	15.97	33.24	4.23
3	6.0	4.12	2.67	75.94	16.34	38.01	4.56
4	6.5	3.63	2.51	79.97	16.86	30.93	4.82
5	7.0	3.52	2.40	82.22	17.23	24.29	5.03

Table 7: Marshall Stability TEST results of modified bituminous mixes with 30% steel slag

Sl. No	Bitumen content (%)	Unit weight, kN/m^3	Va (%)	VMA (%)	VFB (%)	Stability (kN)	Flow (mm)
1	5.0	5.56	2.61	66.73	14.86	30.13	3.73
2	5.5	4.72	2.68	72.21	15.37	37.94	3.97
3	6.0	3.91	2.73	74.33	15.55	39.46	4.19
4	6.5	3.54	2.64	79.67	16.28	32.89	4.63
5	7.0	3.47	2.53	82.51	16.79	27.50	4.83

Table 8: Marshall Stability TEST results of modified bituminous mixes with 40% steel slag

Sl. No	Bitumen content (%)	Unit weight, kN/m^3	Va (%)	VMA (%)	VFB (%)	Stability (kN)	Flow (mm)
1	5.0	5.32	2.65	67.72	14.23	36.72	3.53
2	5.5	4.53	2.71	74.36	14.67	43.03	3.86
3	6.0	3.70	2.78	77.21	15.42	40.72	4.03
4	6.5	3.44	2.72	81.56	15.85	35.24	4.17
5	7.0	3.31	2.61	83.14	16.20	28.54	4.42

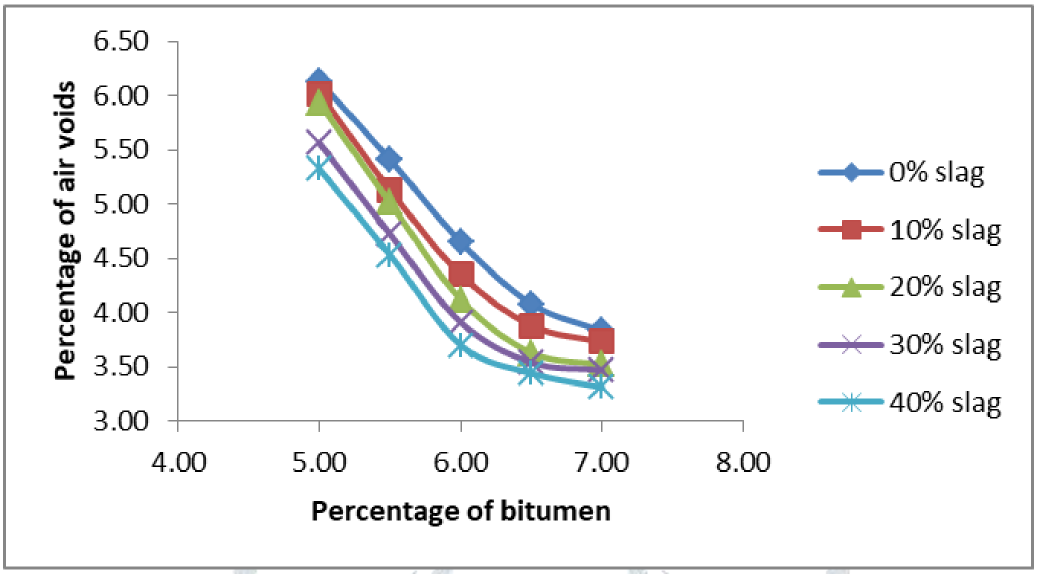


Figure 3: Relationship of percentage of air voids V/S bitumen content for different bitumen mixtures

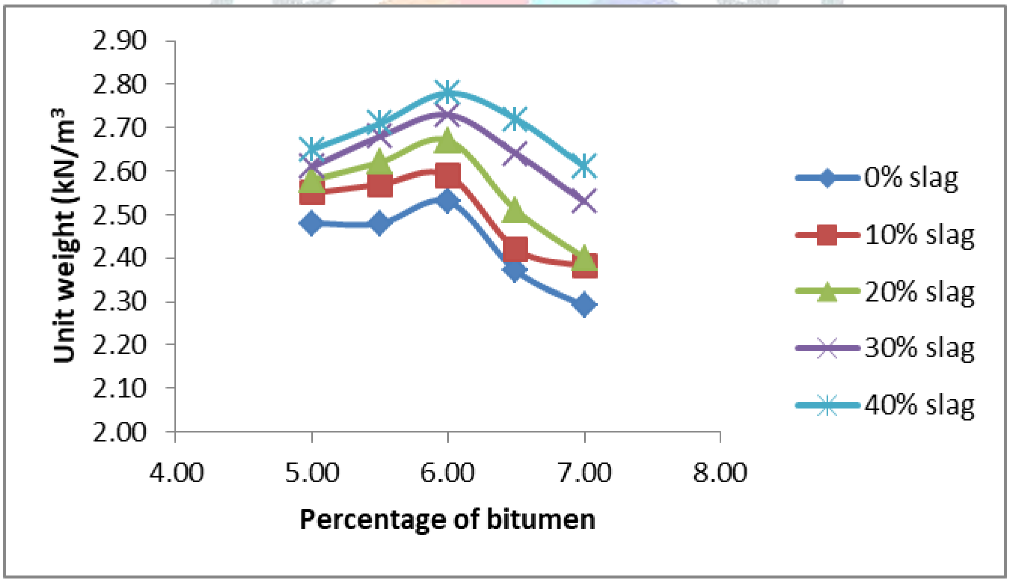


Figure 4: Relation between Unit weight and bitumen content for different bituminous mixtures

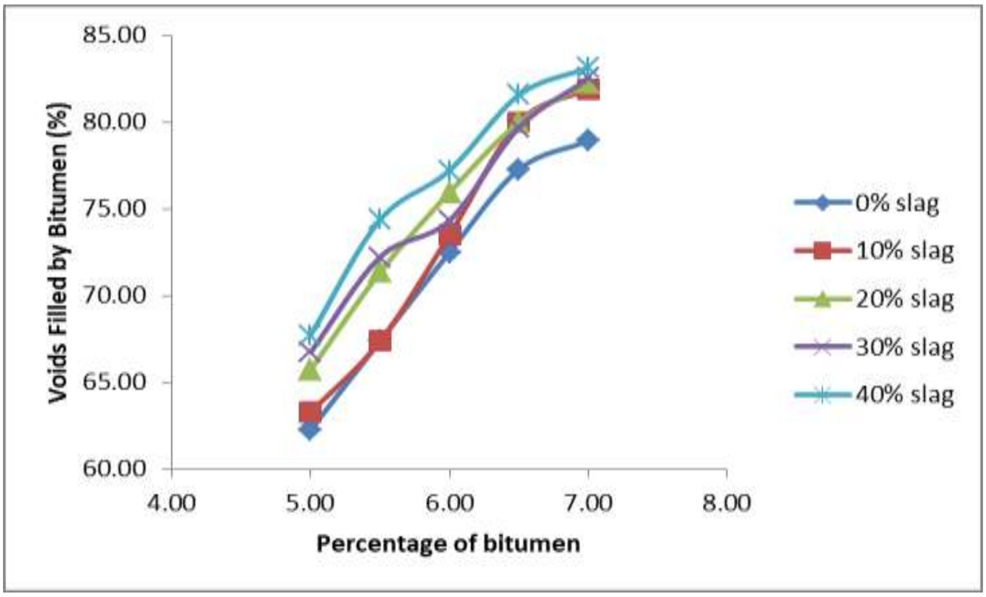


Figure 5: Relation between voids filled with bitumen for different bitumen content and mixtures

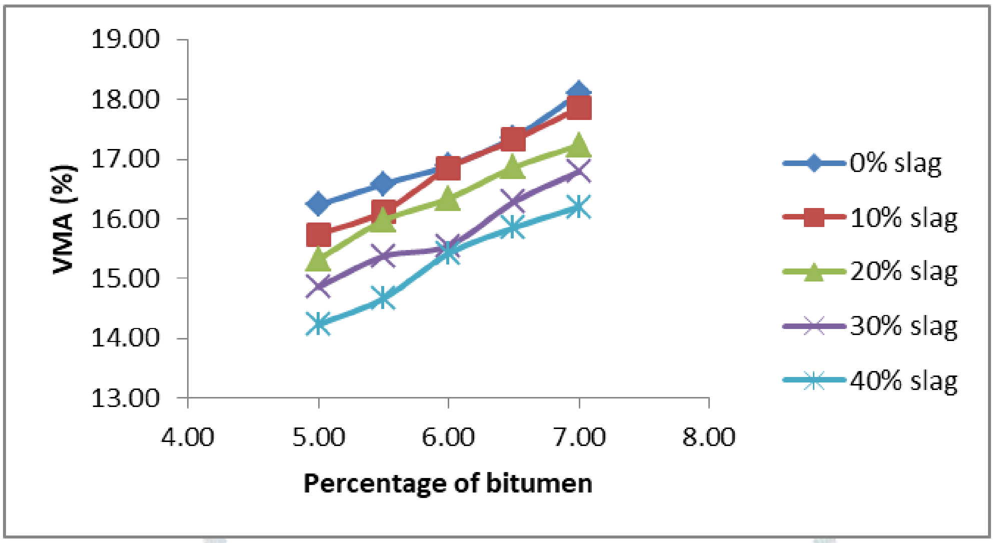


Figure 6: Different bitumen content and mixture for Voids in mineral aggregate.

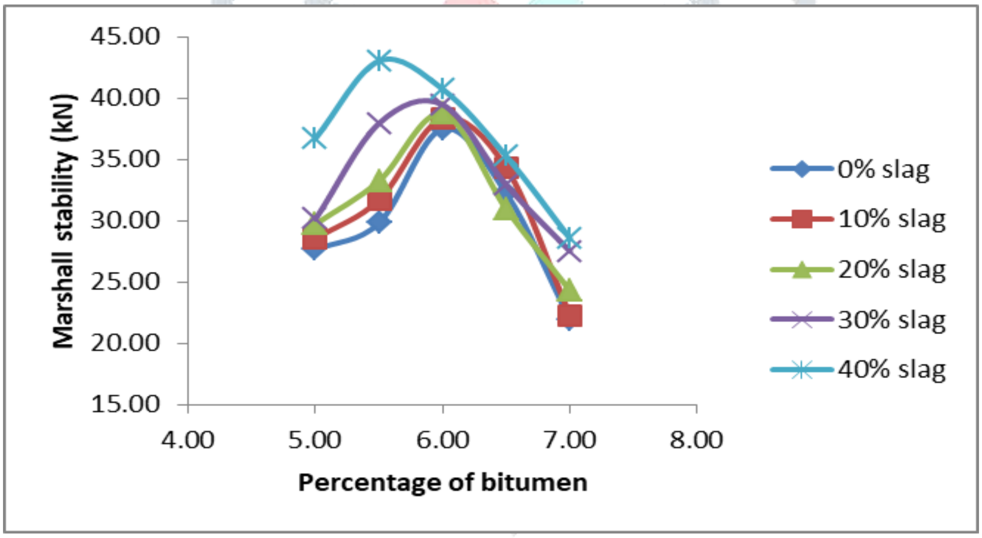


Figure 7: Stability curves for different bitumen content and mixtures

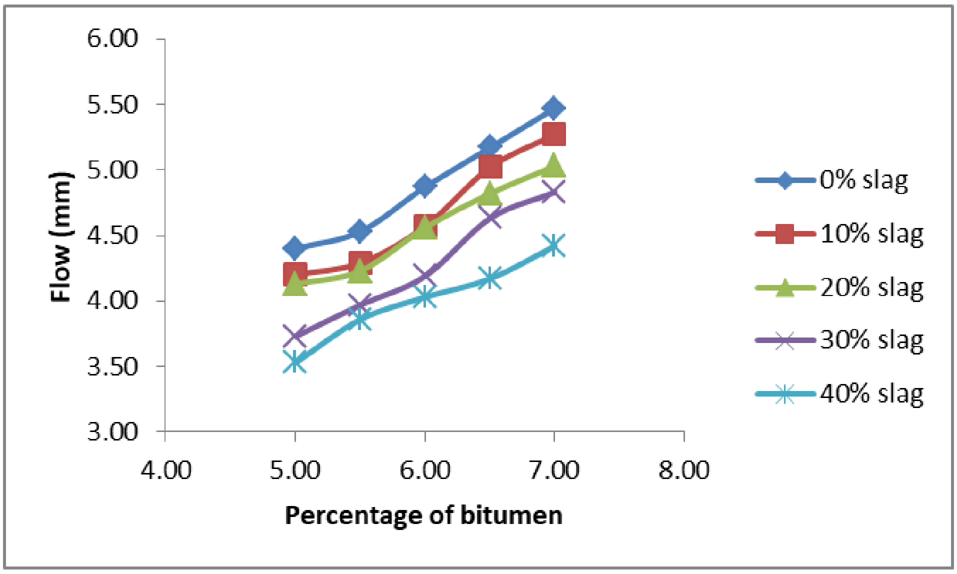


Fig 8: For different bitumen content and mixtures flow curves

Table 9: Optimum binder content for different bituminous mixes

Percentage of steel slag	0	10	20	30	40
Binder content at 4% air voids (%)	6.5	6.3	6.1	5.8	5.7
Binder content at max density (%)	6.2	5.9	5.9	5.9	5.9
Binder content at max Stability (%)	5.9	5.9	5.8	5.8	5.5
Average (%)	6.2	6.03	5.93	5.83	5.7

Table 10: Combined unconditioned and conditioned ITS test results with TSR

Sl. No	Percentage of slag (%)	Indirect tensile strength		Tensile strength ratio (%)
		Unconditioned	Conditioned	
1	0	1.26	1.04	82.54
2	10	2.23	1.87	83.85
3	20	2.65	2.28	86.03
4	30	3.28	2.95	89.93
5	40	3.58	3.38	94.41

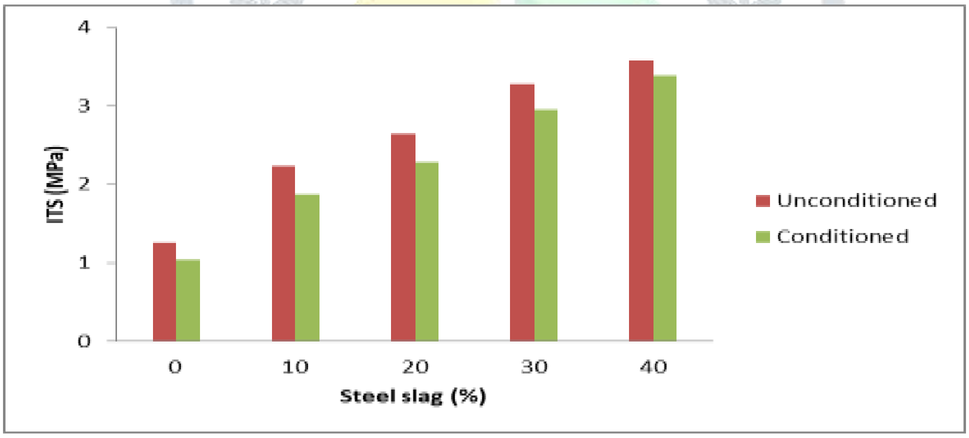


Figure 9: Combined ITS results for different percentage of steel slag for conditioned and unconditioned tests

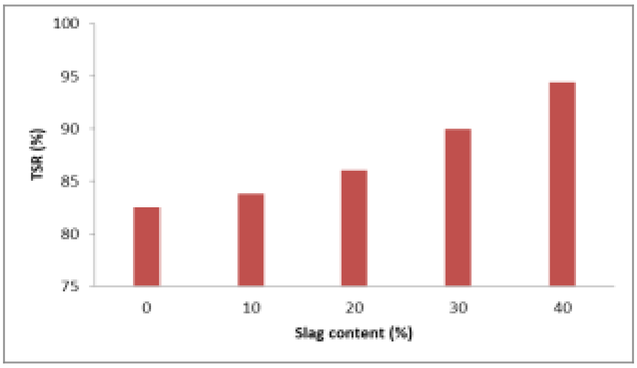


Figure 10: TSR for different percentage of steel slag

6. CONCLUSION

The strength characteristics of modified bituminous concrete improved significantly with the inclusion of steel slag, when compared to conventional mixes at their respective Optimum Binder Contents (OBCs). A consistent increase in Marshall Stability, flow values, and Indirect Tensile Strength (ITS) was observed with increasing steel slag content, up to 40%. Concurrently, there was a noticeable reduction in Voids in Mineral Aggregate (VMA) and air voids, accompanied by an increase in unit weight, indicating better compaction and densification of the mix.

These findings highlight the effectiveness of steel slag as a partial replacement for natural aggregates in bituminous concrete. Beyond enhancing structural performance and durability, the utilization of steel slag contributes to sustainable pavement construction by mitigating the environmental impacts associated with excessive extraction of natural aggregates and the disposal of industrial waste. Thus, the integration of steel slag offers both engineering and ecological advantages, aligning with green construction practices.

REFERENCES

[1] Ahmed, S., et al. (2020). "Rutting Performance of Bituminous Mixtures Containing Steel Slag." Road Materials and Pavement Design, 21(7), 1771–1786.
[2] Aziz, M. M. A., et al. (2020). "Performance Evaluation of Steel Slag in Bituminous Mixes." Construction and Building Materials, 243, 118-130.
[3] Aziz, M. M. A., et al. (2014). "Durability Assessment of Steel Slag in Asphalt Mixes." Procedia - Social and Behavioral Sciences, 195, 2286-2294.
[4] Deshmukh, A., and Patil, R. (2022). "Comparative Analysis of Steel Slag and Basalt Aggregates in Asphalt Mixes." Civil Engineering Journal, 8(5), 981–990.
[5] Gao, J., et al. (2017). "Microwave De-Icing of Steel Slag Asphalt Pavements." Journal of Cleaner Production, 142, 2483-2491.
[6] Hainin, M. R., et al. (2012). "Steel Slag as an Aggregate Replacement in Malaysian Hot Mix Asphalt." International Journal of Pavement Engineering, 13(3), 223–232.
[7] Kumar, R., et al. (2020). "Environmental Benefits of Steel Slag Reuse in Asphalt Pavement." Environmental Science and Pollution Research, 27(12), 13840–13849.
[8] Magadi, M. B., et al. (2016). "Marshall Properties of Bituminous Mixes Using Steel Slag." International Journal of Pavement Engineering, 17(6), 502–510.
[9] Mladenovic, A., et al. (2004). "Performance of Steel Slag Asphalt Mixtures." Journal of Materials in Civil Engineering, 16(6), 509–516.
[10] Pasetto, M., and Baldo, N. (2010). "Experimental Evaluation of the Use of Steel Slag in Bituminous Mixes." Construction and Building Materials, 24(8), 1458–1469.
[11] Sharma, R., and Kumar, A. (2019). "Economic Viability of Steel Slag in Indian Road Construction." Transportation Infrastructure Geotechnology, 6(1), 83–94.
[12] Singh, J., and Jain, P. K. (2018). "Effect of Steel Slag on the Bonding of Bitumen." International Journal of Pavement Research and Technology, 11(5), 453–460.
[13] Thomas, J., et al. (2021). "Evaluation of Hybrid Bituminous Mixes with Steel Slag and Waste Materials." Materials Today: Proceedings, 46, 7019–7024.
[14] Tsantilis, L. and Anagnostopoulos, C. (2014). "Effect of Steel Slag on the Fatigue Life of Asphalt Mixtures." Journal of Testing and Evaluation, 42(1), 131–138.
[15] Xue, Y., et al. (2006). "Utilization of Steel Slag as Aggregate in Asphalt Mixtures." Building and Environment, 41(8), 1353-1357.