Evaluation of Fibre Reinforced Flexible Pavement with Partial Replacement of Coarse Aggregates by Steel Slag

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[4](Under Guidance of) (Professor); [5;6;7](With Help of) [6](Professor)

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Abstract: Bituminous mixtures are widely used in flexible pavement construction worldwide, combining bitumen as a binder with mineral aggregates. However, these pavements often underperform in hilly areas. Research has explored additives and bitumen modifications, with Fibre additions to asphalt enhancing strength and cohesion between aggregates and the binder.

Meanwhile, industrial steel slag, an environmental concern, is a byproduct of steel manufacturing. It can replace natural aggregates in concrete, addressing scarcity and environmental concerns. This report presents key studies on steel slag's use as coarse aggregate and its impact on concrete strength, durability, density, and workability. It also discusses steel slag properties and potential applications, along with the advantages of adding various fibers to bituminous concrete.

In the context of this research, we have examined bitumen contents at 5%, 6%, and 7% of the total specimen weight. Additionally, we have substituted steel slag for aggregates at levels of 20%, 40%, and 60%, and incorporated glass Fibre at proportions of 0.4%, 0.7%, and 1% relative to the total specimen weight. We tested Conventional Specimen (B1), Fiber-reinforced Specimen(B2), Specimen with steel slag (B3) & Fiber-reinforced concrete with steel slag (B4).

Keywords: *Bituminous Concrete, Steel Slag, Aggregates, Lime Powder, Glass Fibre, Marshall Mix Design.*

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I. INTRODUCTION

This article presents a detailed, sequential guide to working with bituminous concrete while also examining the consequences of substituting traditional aggregates with steel slag and introducing glass Fibre as a supplementary component to the mix. Also, inclusion of Lime powder. Making the Conventional Specimen, specimen with addition of Glass Fibre by percentage of weight of specimen, specimen with substituting Aggregates with Steel slag.

II. METHODOLOGY

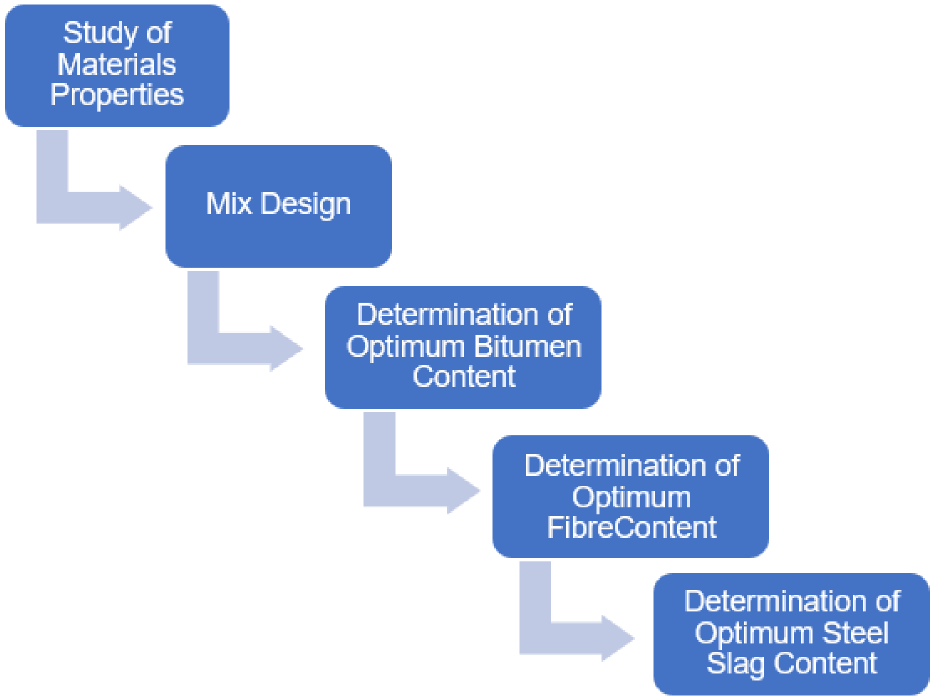

Fig 1 Methodology Flow

III. MATERIALS AND THEIR PROPERTIES

Within the scope of this research study, various materials were employed, specifically VG30-grade bitumen, stone aggregates, Lime, steel slag, and glass fiber.

Table 1 Properties of VG 30 Bitumen

Property	Test results	Remarks
Penetration value	65	Satisfactory
Softening point	55.5°C	Unsatisfactory
Specific Gravity	1	Satisfactory
Viscosity of bitumen	5.3 sec@120°C	Satisfactory

Table 2 Properties of Aggregates

Property	Test results	Remarks
Impact value	11.6%	Satisfactory
Crushing value	21.65%	Satisfactory
Abrasion value	17.10%	Satisfactory
Specific Gravity	2.78	Satisfactory
Water Absorption	1.01%	Satisfactory
Flakiness index	16.18	Satisfactory
Elongation index	15.46	Satisfactory
Specific Grav. of Crushed sand	2.96	Satisfactory

Table 3 Properties of Steel Slag

Property	Test results	Remarks
Impact value	13.00%	Satisfactory
Crushing value	25.18%	Satisfactory
Abrasion value	20.69%	Satisfactory
Specific Gravity	3	Satisfactory
Water Absorption	2.46%	Satisfactory
Flakiness index	17.14	Satisfactory
Elongation index	16.21	Satisfactory

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Table 4 Properties of Glass Fibre

Property	Specification
Chop Lengths (mm)	6mm
Filament (μm)	11 to 17
Tensile Strength (Mpa)	915
Elastic Modulus (Gpa)	72
Moisture Content (%)	<0.2%
Specific Gravity	2.63
Thermal Conductivity (W/m°K)	1.0~1.5
Alkaline Resistance Stability	Good
UV Stability	Good

IV. MIX DESIGN

The mix design (wet mix) determines the optimum bitumen content [1]. The Marshall stability and flow test provides the performance prediction measure for the Marshall mix design method [1]. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute [1]. Load is applied to the specimen till failure, and the maximum load is designated as stability [1]. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) due to the loading [1]. The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time when the maximum load is recorded [1].

➢ *Blending of Aggregates:*

- Aggregate: 0.37
- Crushed Sand: 0.53
- Lime Powder: 0.10

➢ *Optimum Bitumen Content*

For Determining of Optimum Bitumen content, we selected Bitumen content of 4%,5% & 6% and tested three specimens for each percentage of Bitumen.

Table 5 Optimum Bitumen Content (Conventional Specimen)

Optimum Bitumen Content (Conventional Specimen)							
Sp. no	**Bitumen content %**	**Bulk density**	**Marshall Stability (Kg)**	**Flow (mm)**	**% Air voids**	**%Air voids in mineral Aggregate (VMA)**	**% Voids filled by Bitumen (VFB)**
			Corrected Load				
1	5	2.32	1589.05	3.15	9.99	20.690	51.712
2		2.23	1095.04	4.4	13.71	23.965	42.802
3		2.38	1376.27	2.8	7.60	18.585	59.098
Average		**2.31**	**1353.45**	**3.45**	**10.43**	**21.080**	**51.200**
1	6	2.42	1548.67	5.5	4.39	18.006	75.608
2		2.42	1603.85	3.93	4.68	18.254	74.356
3		2.41	1592.18	3	4.79	18.351	73.873
Average		**2.42**	**1581.56**	**4.14**	**4.62**	**18.200**	**74.610**
1	7	2.39	1555.08	3.7	4.06	19.906	79.602
2		2.43	1563.00	4.3	2.47	18.581	86.686
3		2.47	1468.13	5.25	1.01	17.361	94.171
Average		**2.43**	**1528.74**	**4.42**	**2.52**	**18.620**	**86.820**

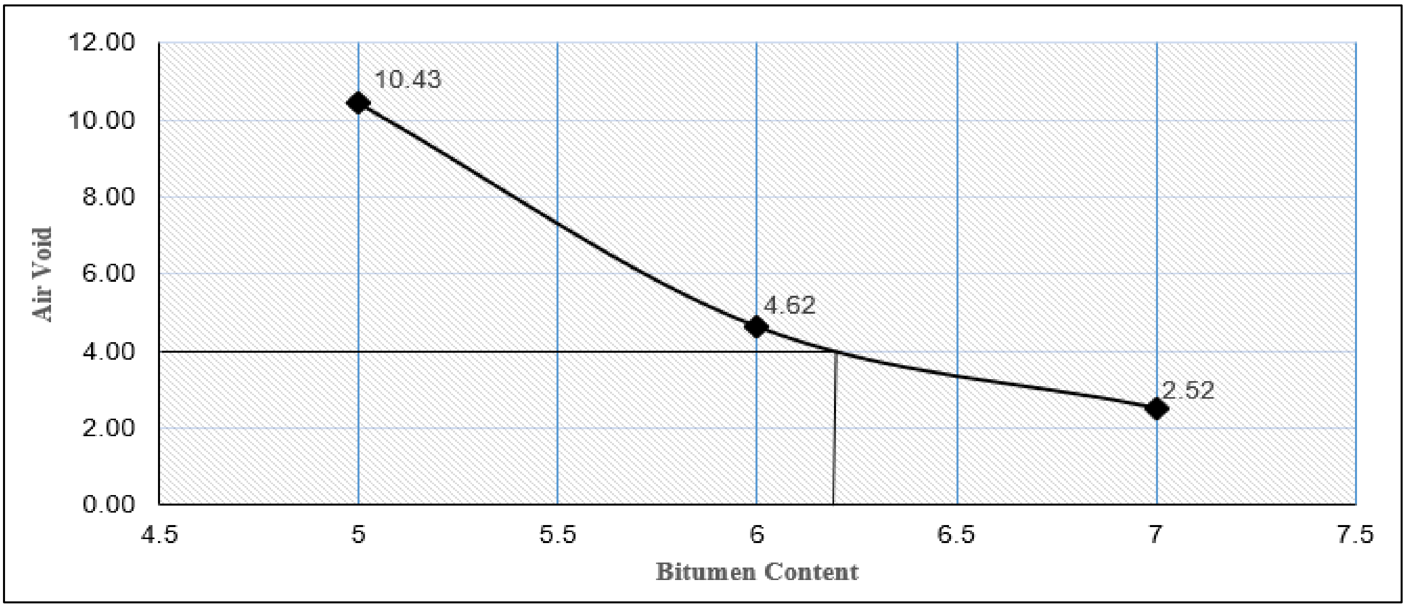

Fig 2 Air Void v/s Bitumen Content

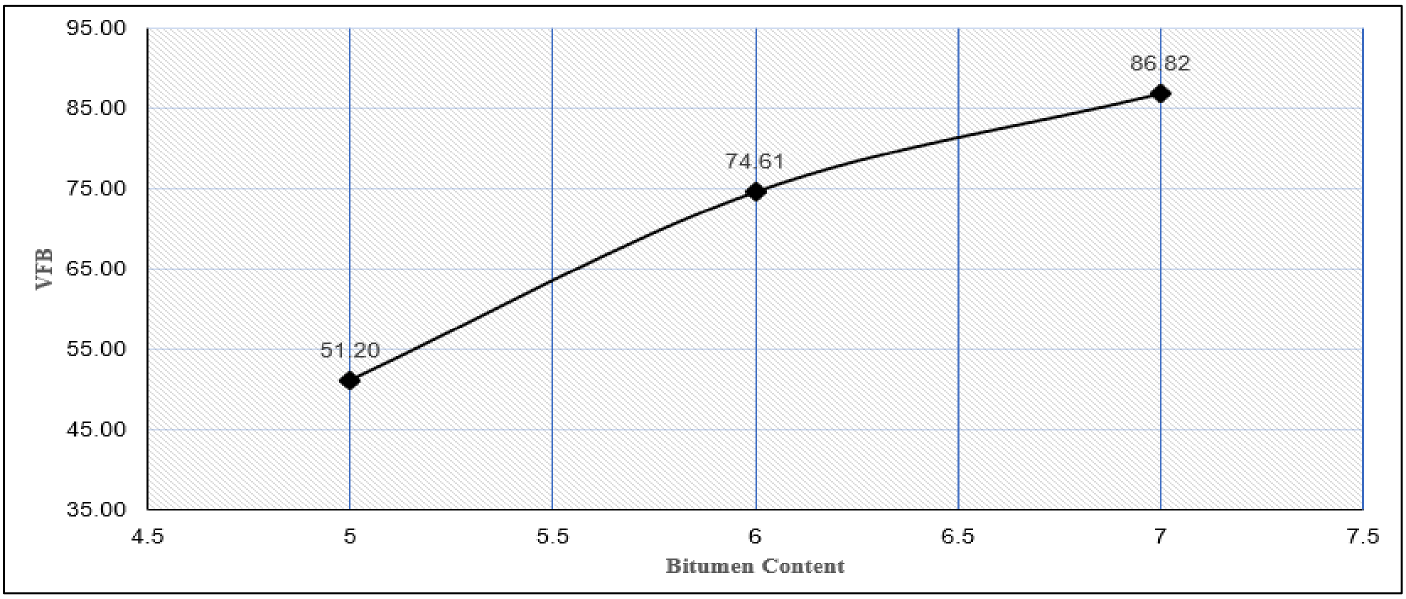

Fig 3 VTB v/s Bitumen Content

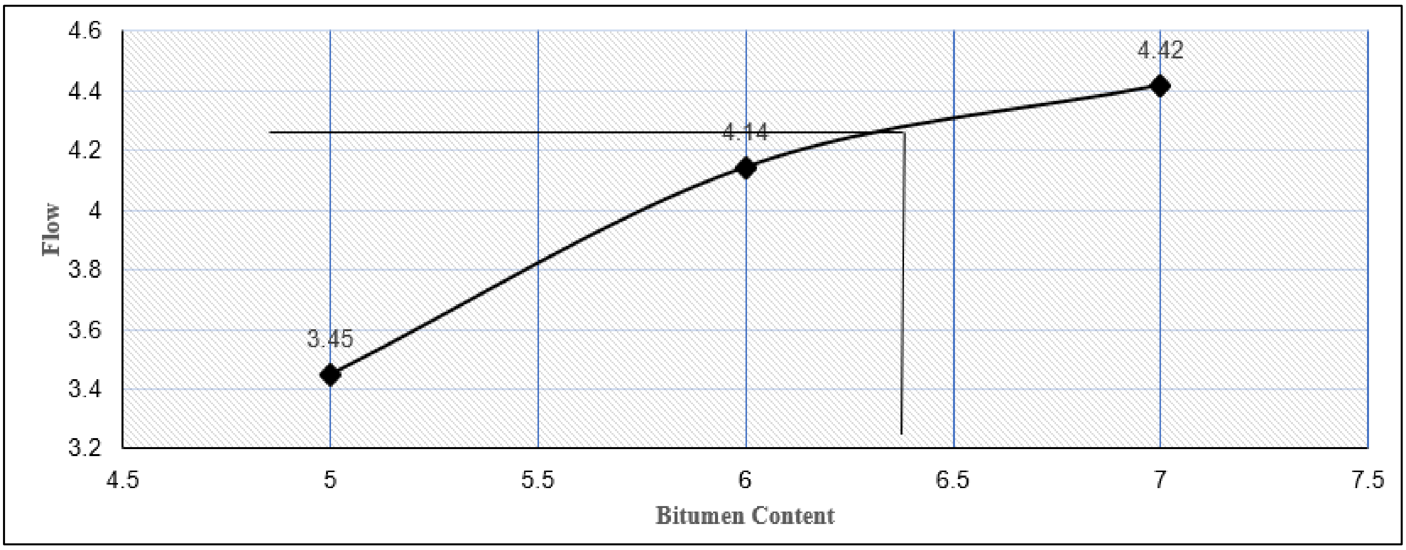

Fig 4 Flow v/s Bitumen Content

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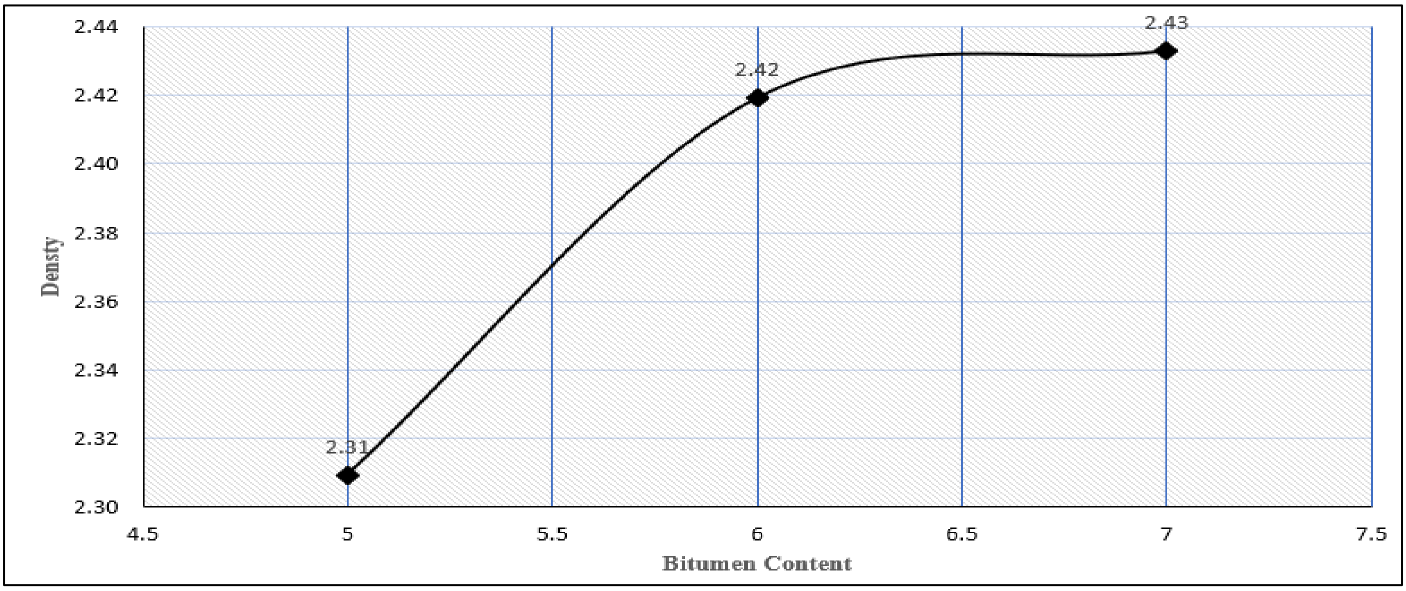

Fig 5 Density v/s Bitumen Content

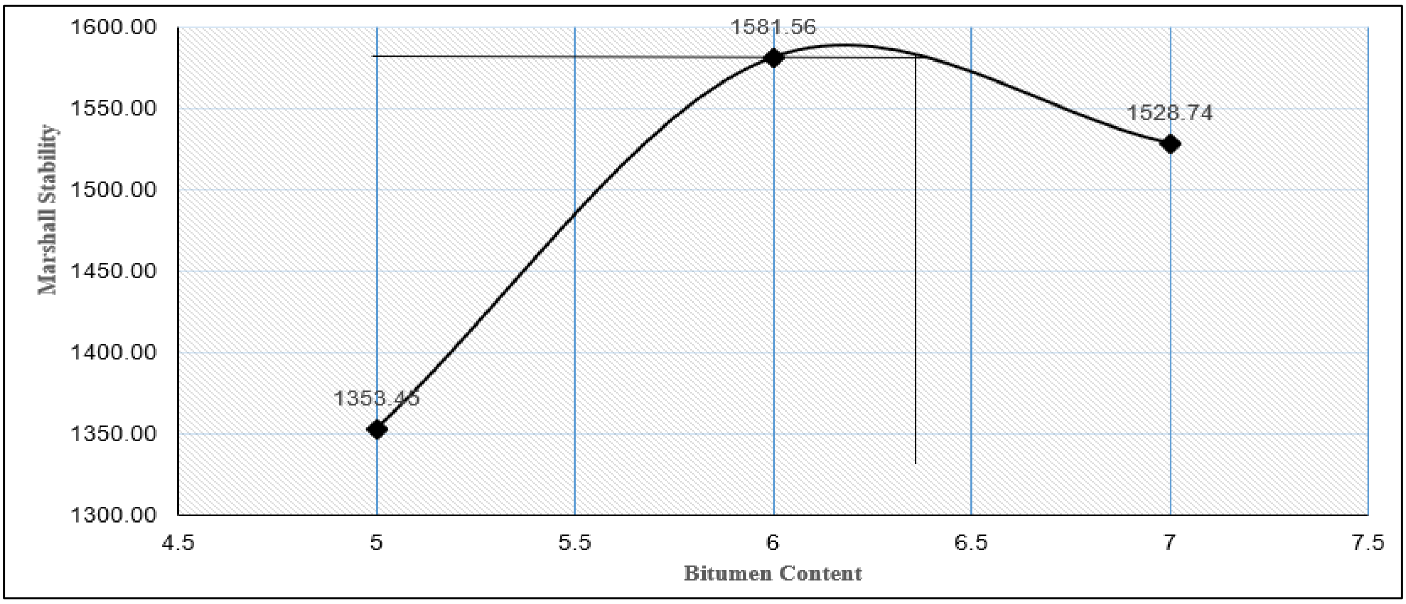

Fig 6 Marshall Stability v/s Bitumen Content

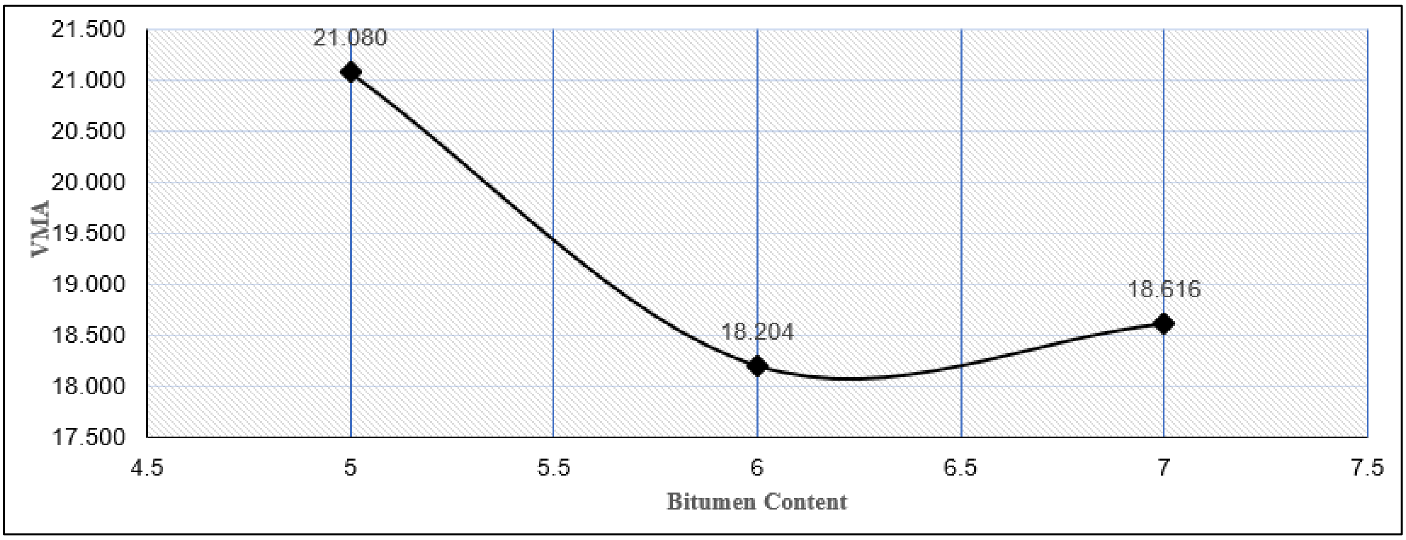

Fig 7 VMA v/s Bitumen Content

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Our primary objective was to enhance stability, and we achieved this by determining the optimal bitumen content through analysis of Marshall Stability, Air Void, and Flow. We established the optimum bitumen content to be **6.3%.**

➢ *Optimum Fibre Conte*

For Determining of Optimum Fibre content, we selected Glass Fibre content of 0.4%,0.7% & 1% by weight of total specimen i.e., 1200gms, Fibre is used as an additive in total mass and tested three specimens for each percentage of Glass Fiber.

Table 6 Optimum Fibre Content (Glass Fibre Specimen)

Optimum Fibre Content (Glass fibre Specimen)							
Sp. no	Glass Fibre content %	Bulk density	Marshall Stability (Kg) Corrected Load	Flow (mm)	% Air voids	%Air voids in mineral Aggregate (VMA)	% Voids filled by Bitumen (VFB)
1	0.4	2.38	833.60	3.6	5.86	19.646	70.170
2		2.38	937.80	4.4	5.65	19.470	70.959
3		2.37	894.04	4	6.16	19.905	69.036
Average		**2.38**	**888.48**	**4**	**5.89**	**19.67**	**70.05**
1	0.7	2.33	948.22	3.4	7.53	21.058	64.264
2		2.35	807.55	4.2	6.94	20.562	66.225
3		2.34	963.85	5.5	7.36	20.917	64.812
Average		**2.34**	**906.54**	**4.37**	**7.28**	**20.85**	**65.10**
1	1	2.41	1563.00	5	4.37	18.619	76.504
2		2.37	1250.40	4.6	6.06	20.054	69.778
3		2.35	1616.14	4.9	7.04	20.883	**66.312**
Average		**2.38**	**1476.51**	**4.83**	**5.82**	**19.85**	70.86

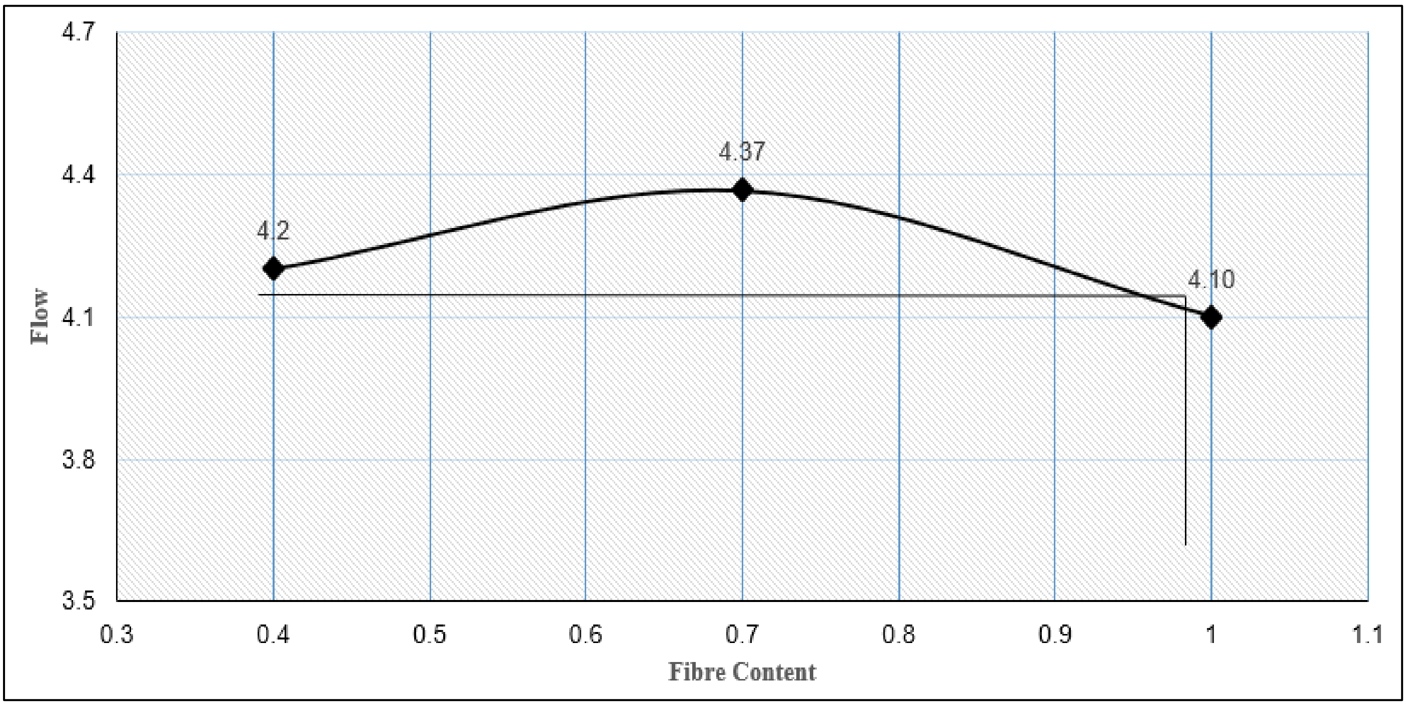

Fig 8 Flow v/s Fibre Content

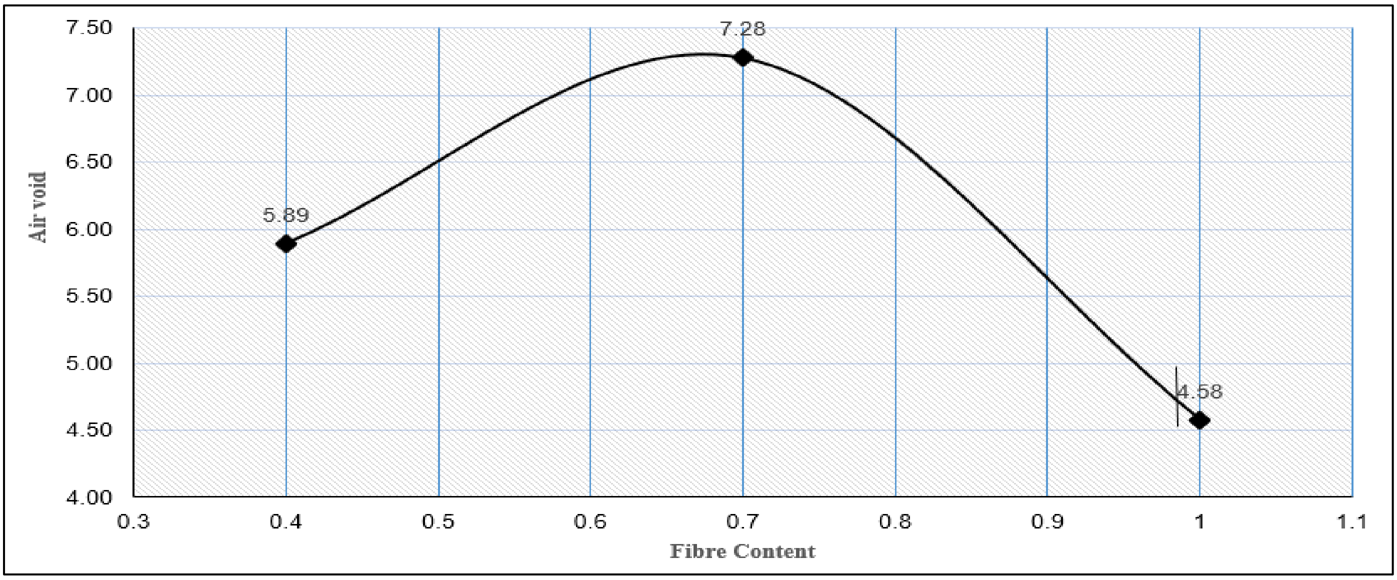

Fig 9 Air Void v/s Fibre Content

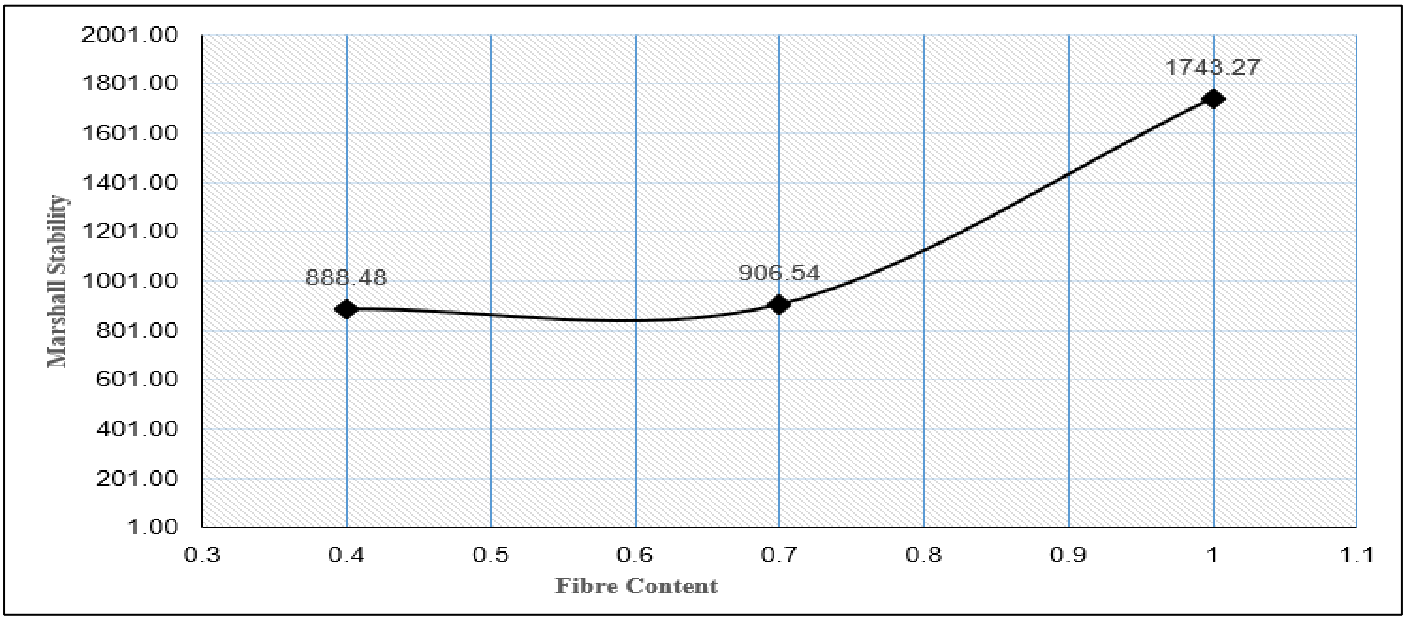

Fig 10 Marhsall stability v/s Fibre Content

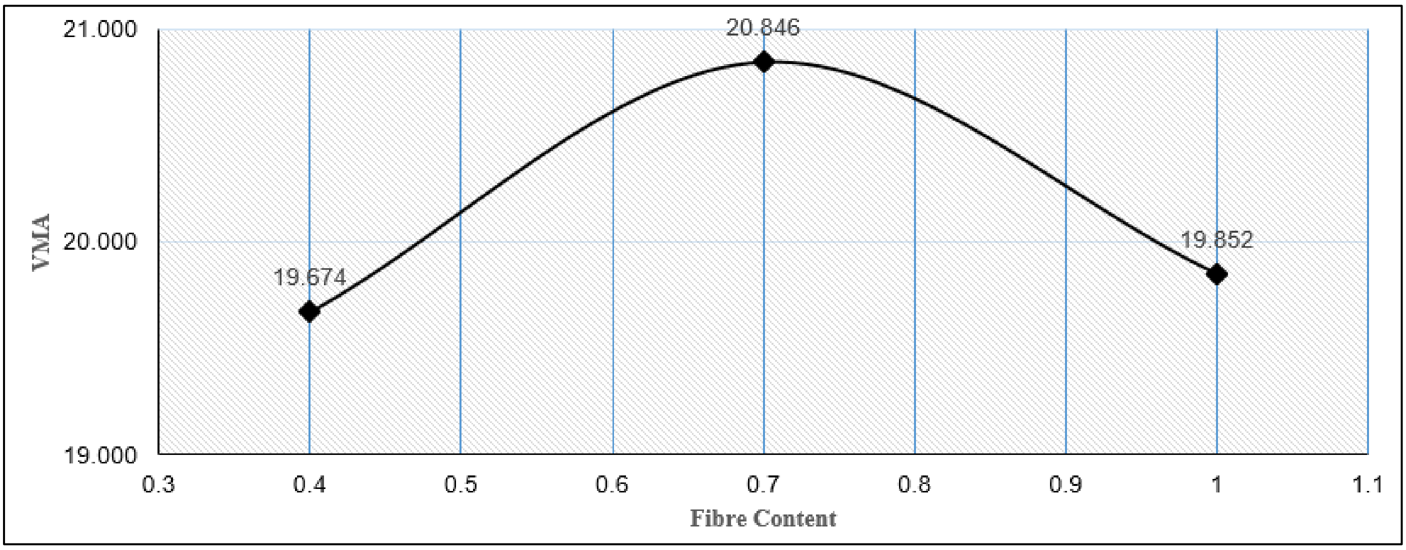

Fig 11 VMA v/s Fibre Content

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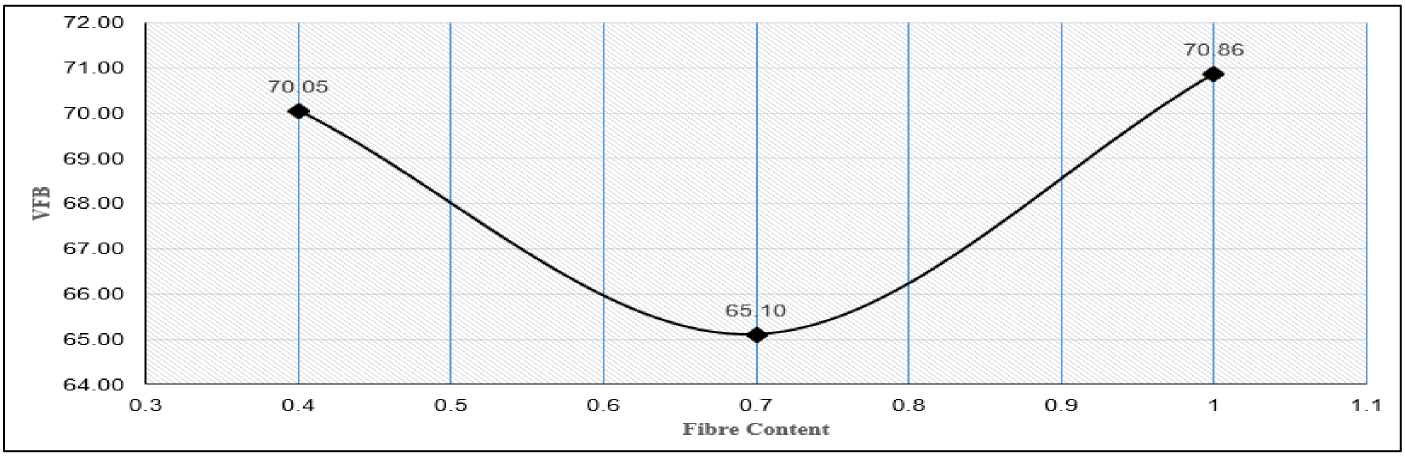

Fig 12 VFB v/s Fibre Content

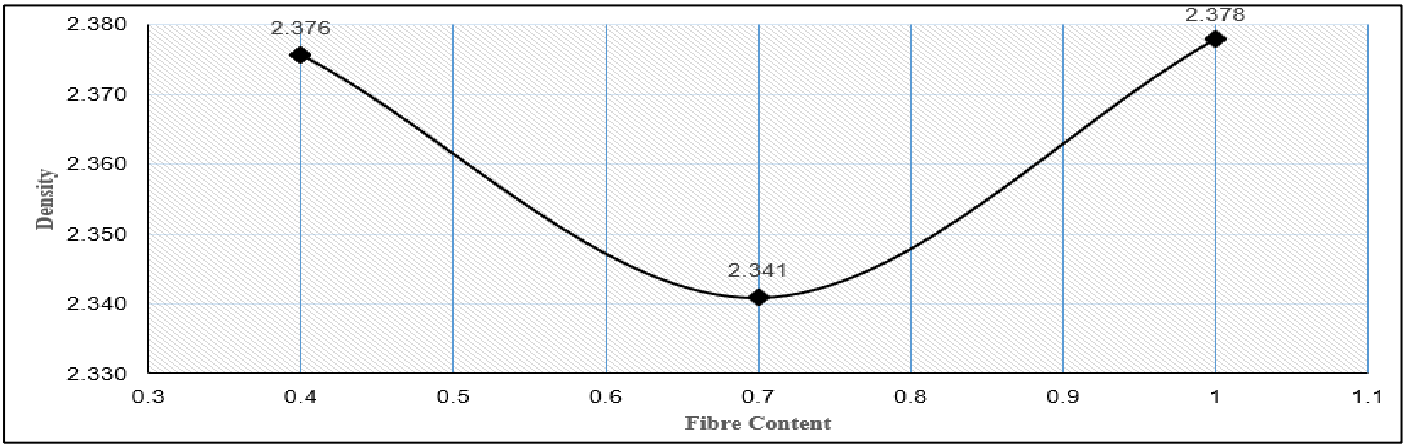

Fig 13 Density vs Fibre Content

Our primary objective was to enhance stability, and we achieved this by determining the optimal Fibre content through analysis of Marshall Stability, Air Void, and Flow. We established the optimum Fibre content to be **1%.**

➢ *Optimum Steel Slag Content*

For Determining of Optimum Steel Slag content, we selected Steel slag content of 20%,40% & 60% and replaced it with aggregate, also tested three specimens for each percentage of Steel Slag.

Table 7 Optimum Steel Slag Content (Steel Slag Specimen)

Optimum Steel Slag Content (Steel Slag Specimen)							
Sp. no	**Steel Slag content %**	**Bulk density**	**Marshall Stability (Kg)**	**Flow (mm)**	**% Air voids**	**%Air voids in mineral Aggregate (VMA)**	**% Voids filled by Bitumen (VFB)**
			Corrected Load				
1	20	2.35	987.95	4	6.63	21.309	68.892
2		2.33	995.11	3.5	7.58	22.107	65.733
3		2.35	980.31	3.4	6.81	21.458	68.286
Average		**2.34**	**987.79**	**3.63**	**7.00**	**21.62**	**67.64**
1	40	2.31	881.53	2.6	8.02	22.625	64.556
2		2.31	920.29	3.8	8.03	22.631	64.532
3		2.36	1094.10	3.6	6.09	21.002	71.004
Average		**2.33**	**965.31**	**3.33**	**7.38**	**22.09**	**66.70**
1	60	2.37	1146.20	4.5	5.40	20.573	73.730
2		2.37	1114.94	4.4	5.65	20.782	72.796
3		2.37	1544.24	4.8	5.49	20.642	73.421
Average		**2.37**	**1268.46**	**4.57**	**5.51**	**20.67**	**73.32**

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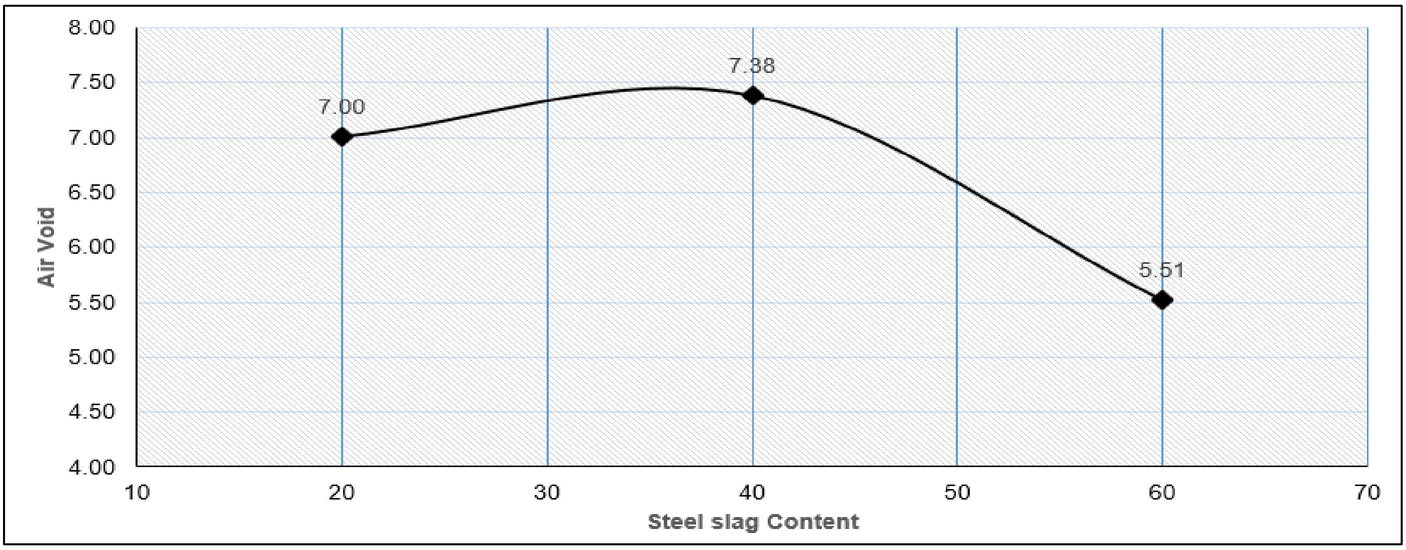

Fig 14 Air Void v/s Steel Slag Content

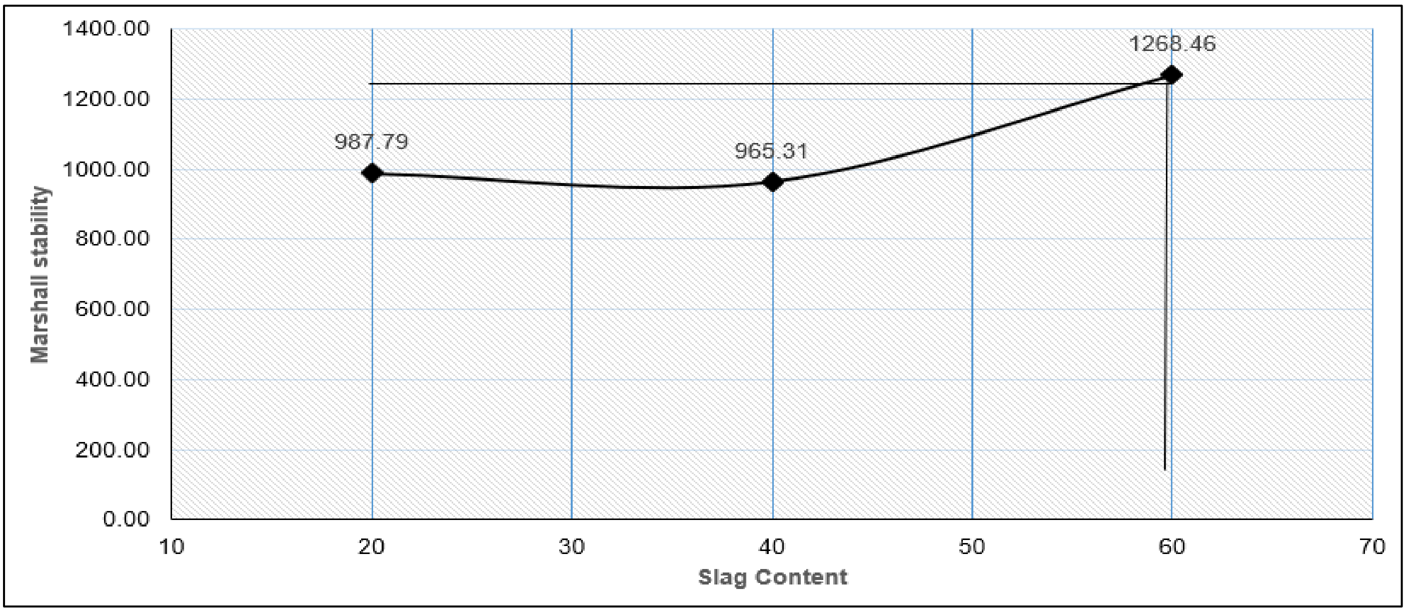

Fig 15 Marhsall Stability v/s Slag Content

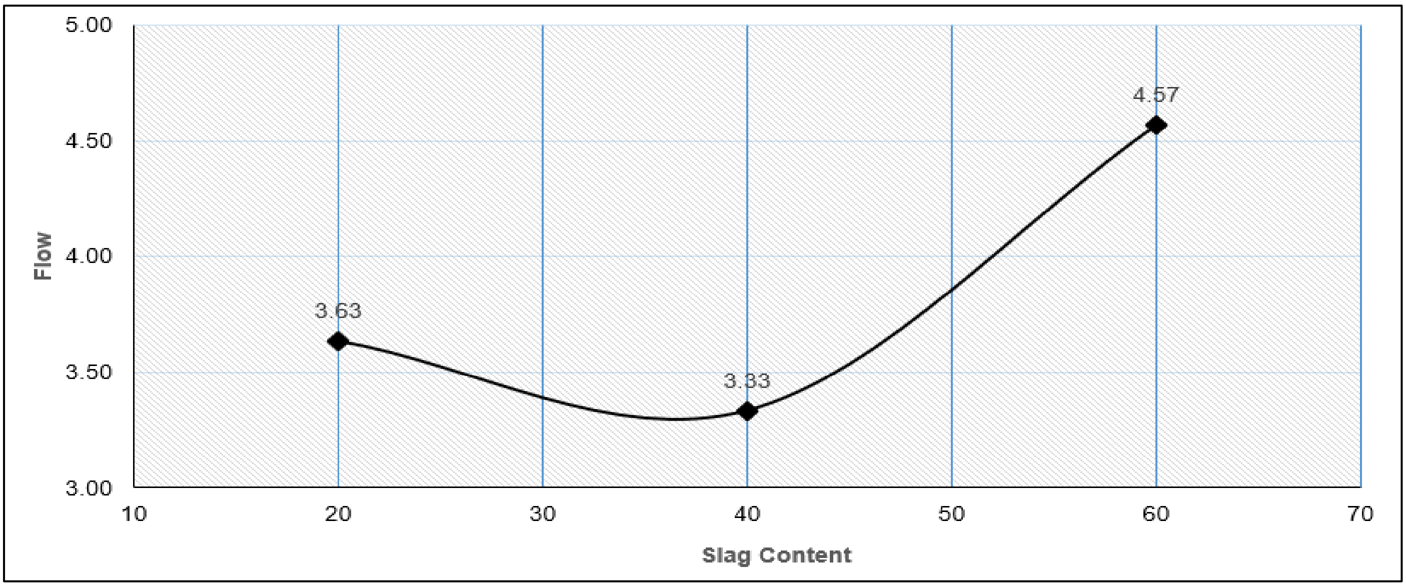

Fig 16 Flow v/s Slag Content

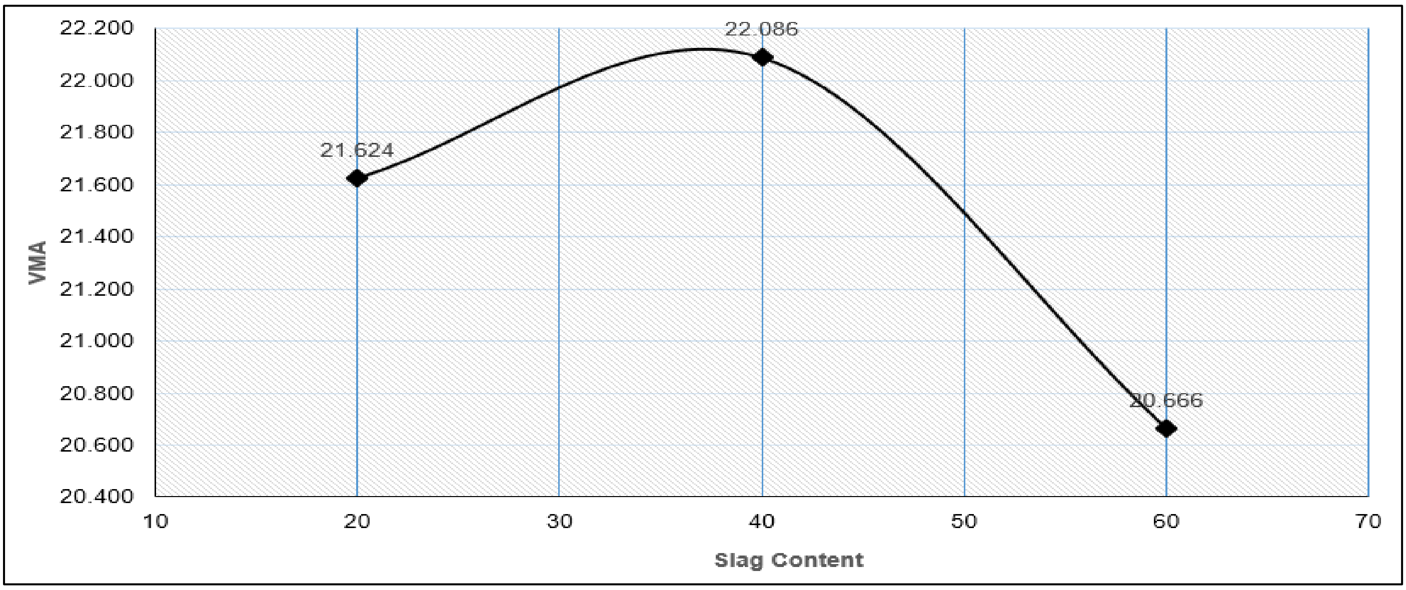

Fig 17 VMA v/s Slag Content

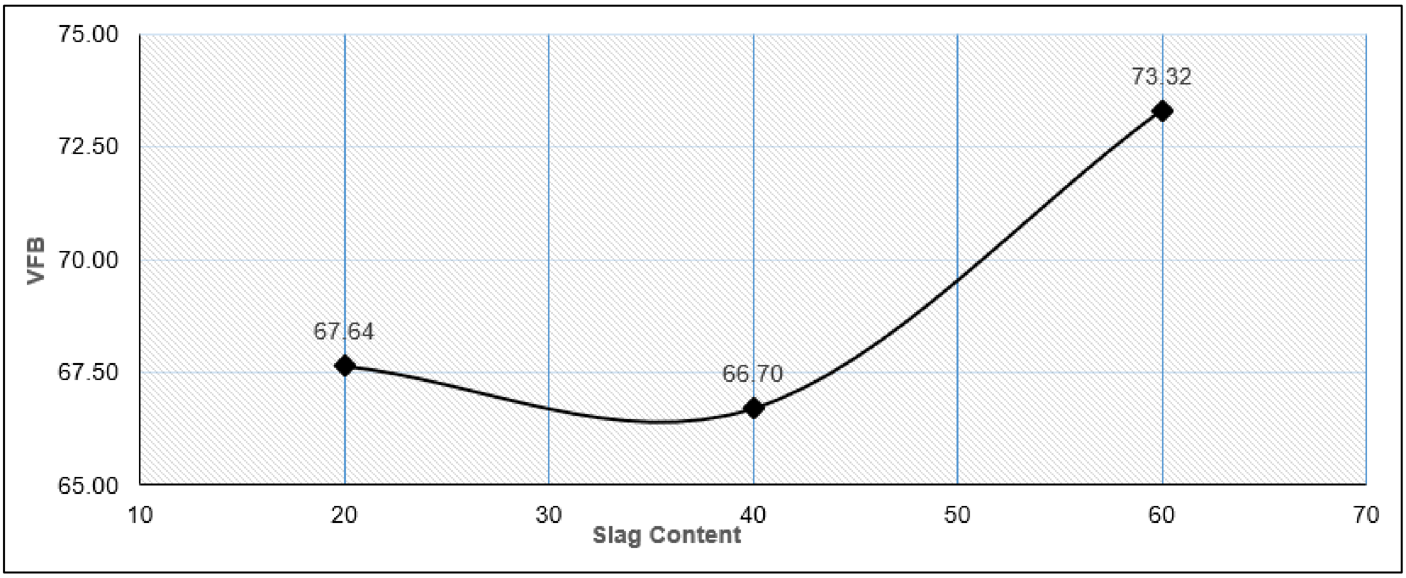

Fig 18 VFB v/s Slag Content

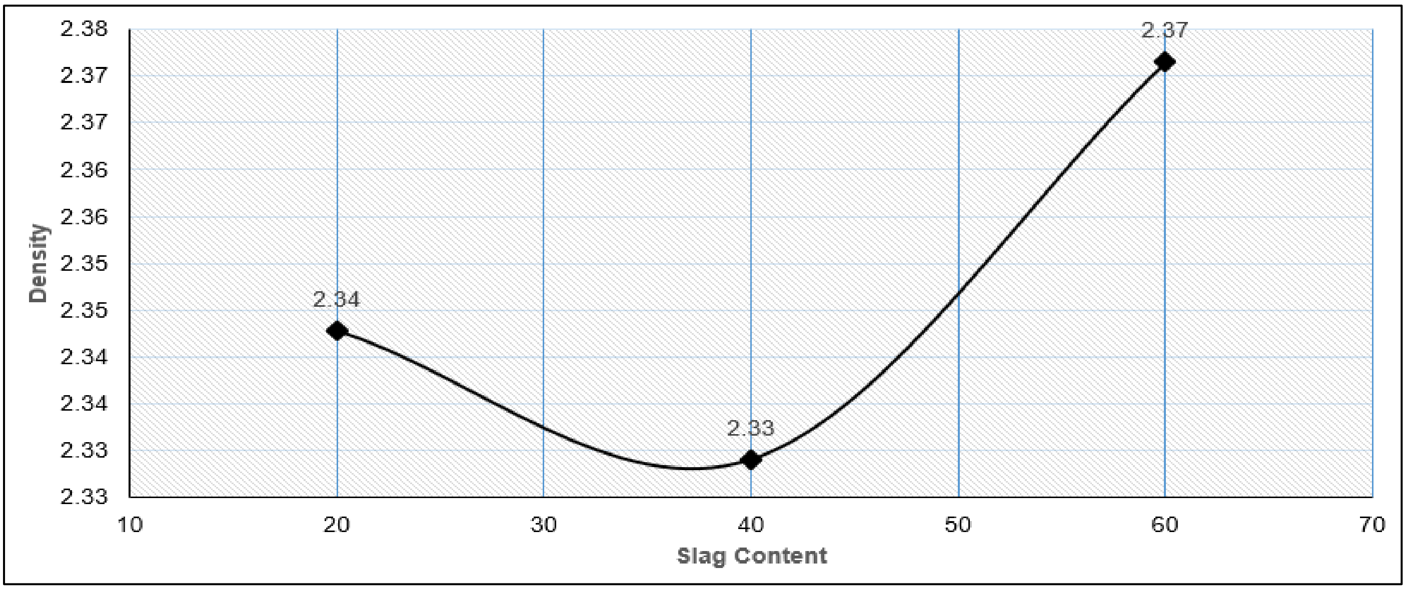

Fig 19 Density v/s Slag Content

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Our primary objective was to enhance stability, and we achieved this by determining the optimal Fibre content through analysis of Marshall Stability, Air Void, and Flow. We established the optimum Steel Slag content to be **60%.**

➢ *Bituminous Concrete with Optimum Fibre and Replacing Optimum Steel Slag with Coarse Aggregates*

Following the determination of the ideal proportions of bitumen (6.3%), glass Fibre (1%), and steel slag (60%), we meticulously crafted a specimen embodying these optimized components. Subsequently, we subjected it to a Marshall stability test, yielding the subsequent strength results.

Table 8 Enhanced Bitumen Concrete using Optimum Contents (Bitumen + GlassFibre + Steel Slag)

Enhanced bitumenous Concrete using optimum contents.							
Sp. no	Bitumen content %	Bulk density	Marshall Stability (Kg) Corrected Load	Flow (mm)	% Air voids	%Air voids in mineral Aggregate (VMA)	% Voids filled by Bitumen (VFB)
1	6.3	2.39	1471.18	4	4.79	19.158	75.018
2		2.42	1684.71	4.1	3.74	18.268	79.533
3		2.40	2050.66	4.3	4.41	18.836	76.604
Average		**2.40**	**1735.51**	**4.13**	**4.31**	**18.75**	**77.05**

V. RESULTS AND COMPARISON

➢ *Annotations;*

- BC1= Bituminous Concrete
- BC2= Bituminous Concrete with Glass Fibre
- BC3= Bituminous Concrete with steel slag
- BC4= Bituminous Concrete with Glass Fibre & Steel Slag

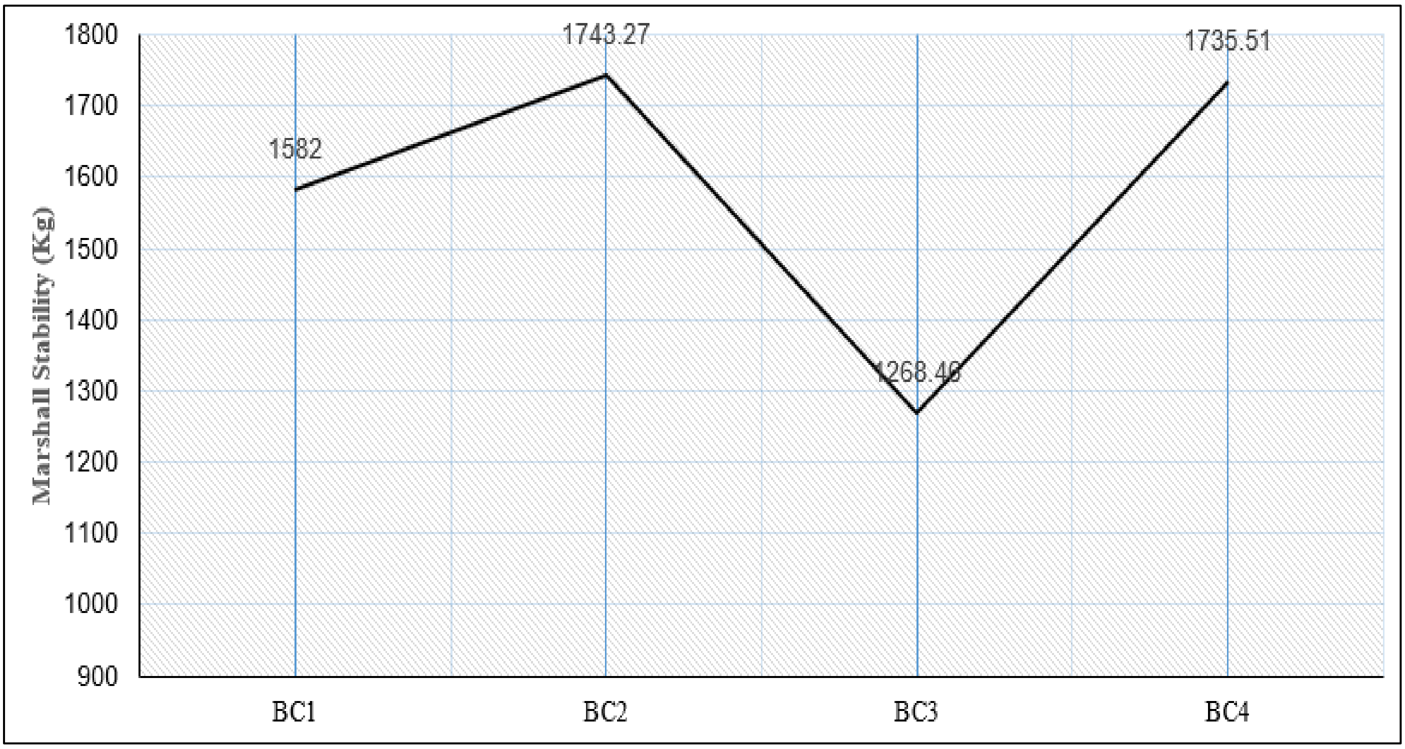

Fig 20 Comparison of Marshall Stability

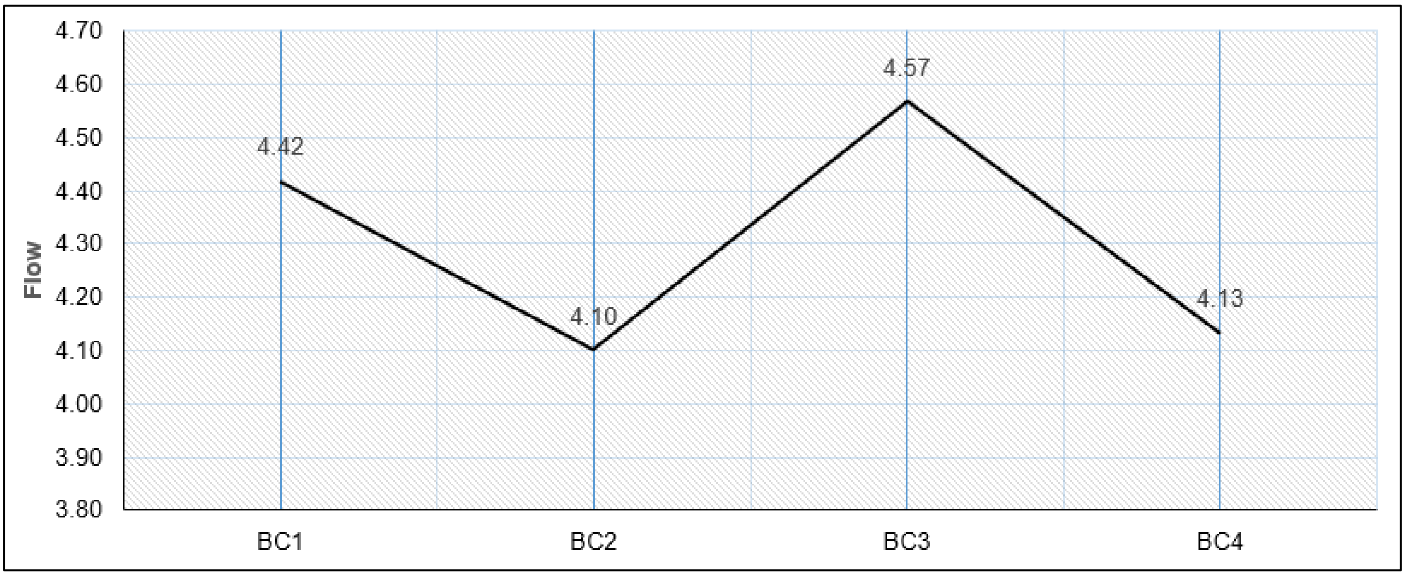

Fig 21 Comparison of Flow

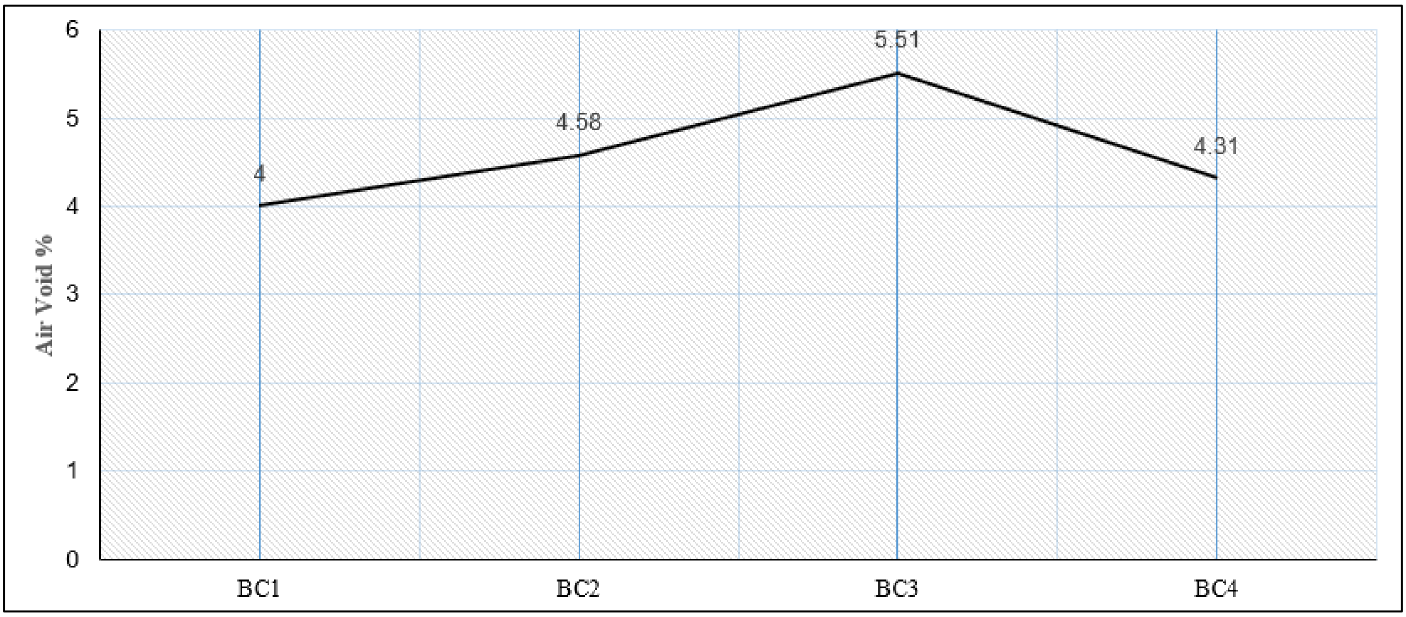

Fig 22 Comparison of Air Void

BC1 exhibited a stability of 1582kg, while BC2 showed superior stability at 1743.27kg. Incorporating steel slag lowered stability to 1268.46kg, compared to BC1 and BC2. BC4 yielded a high stability of 1735.51kg, close to BC2 and surpassing BC1 and BC3. BC1 displayed the lowest air void percentage at 4%, while BC2 and BC3 had 4.58% and 5.51%, respectively. BC4 had a slightly higher air void content at 4.31%. BC2 demonstrated the optimal flow of 4.10mm, which was lower than BC1, BC3, and BC4. The bituminous concrete with glass Fibre and steel slag remained within acceptable limits, with 2.5-4 for hot climates and 3.5-5 for cold climates.

VI. CONCLUSION

In conclusion, the environmental community is deeply concerned about industrial waste slag, with a specific focus on steel slag—an abundant byproduct from Electric Arc Furnace steel production. the evaluation of Fibre Reinforced Flexible Pavement with partial replacement of coarse aggregates by Steel Slag has yielded significant findings. The optimum bitumen content of 6.3% and 1% Fibre content have been determined as key parameters. A 60% replacement of coarse aggregates with Steel Slag has proven to enhance stability and volumetric properties, while impact and crushing value tests showed favorable results for Steel Slag aggregate. Furthermore, Steel Slag aggregate's water absorption falls within IS 2386-1963 limits. To further enhance mix design and aggregate interlocking, shape and texture improvements for Steel Slag are recommended. The inclusion of 6mm length Glass Fibre has shown promising outcomes in various aspects, and the addition of lime has contributed to the stability of bitumen specimens, particularly in nominal mixes. Given the scarcity and logistical challenges of natural aggregate production and transportation, exploring steel slag's viability as a concrete aggregate replacement offers significant environmental advantages. The substantial volume of concrete consists of

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aggregates, and replacing natural aggregates with 60% steel slag presents a promising avenue for substantial environmental benefits. Enhanced replacement of steel slag can prove effective when the material undergoes processing to attain a texture and shape similar to conventional coarse aggregates. Additionally, the incorporation of glass Fibre has demonstrated its capacity to reduce air voids, resulting in a well-balanced end product—Bituminous concrete with the inclusion of Fibre and steel slag as a substitute for coarse aggregate.

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