Proceedings of IOE Graduate Conference, 2019-Winter
Peer Reviewed
Year: 2019 Month: December Volume: 7
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Utilization of Steel Slag as a Replacement for Filler Material in the Asphalt Concrete

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Abstract

Asphalt Concrete comprises of Aggregate, filler and Bitumen. Generally in practice, cement, limestone and stone dust filler materials are used in Asphalt Pavement Construction work in Nepal. Steel slag, a by-product of Steel making industry, can also be used as filler material in Asphalt mix. In this study, the Marshall Properties of Asphalt mix with stone dust filler is compared with that of Asphalt mix with steel slag filler. Total 63 numbers of Marshall Specimens were prepared with four different steel slag content (2%, 4%, 6% and 8%) and total 15 number of them were prepared with Stone dust filler. The results indicate that the use of steel slag in Asphalt Concrete mixtures can enhance the Marshall properties of mixtures. Steel slag as a filler material can be used in the ranges from 2% to 8% content in Asphalt Concrete mixes, since its properties meet the Departmental Specifications of Department of Roads. For 4% steel slag content, all the Marshall properties have shown the best result.

Keywords

Asphalt, Filler, Marshall Properties, Steel Slag, Stone Dust

1. Introduction

Marshall Mix Method is adopted by Standard Specifications for Road and Bridge, 2073, Department of Roads for construction of Asphalt Concrete road. Different researches are performed worldwide to standardize and economize the asphalt technology. As per Standard Specifications of Roads and Bridges, 2073, the standard followed by DOR, only stone dust, hydrated lime and cement have been introduced as mineral filler materials. The major purpose of this study is to explore the effect on Marshall Properties of Asphalt mix with steel slag as a filler material for the construction of Asphalt Concrete. In this research study, steel slag, a waste material produced from steel industries will be used as mineral filler material instead of stone dust as a filler material. Marshall Properties of the Asphalt concrete mix and financial analysis of the asphalt concrete mix with various proportions of the proposed material will be tested to identify the best proportion for field application.

Steel Slag

Steel slags are by-products from steel industries which can be used for the construction of roads and highways. Most of the physical and mechanical properties of steel slags are similar or better compared to conventional crushed stone aggregates. Steel slag has been successfully used as aggregate in wearing course hot mix asphalt and in surface treatments in the United States and internationally. Some of the mix properties that are of interest when steel slag is used in asphalt concrete mixes include stability, stripping resistance, and rutting resistance. (U.S. Department of Transportation, 2019)

The history of slag use in road building dates back to the time of the Roman Empire, some 2000 years ago, when broken slag from the crude iron-making forges of that era were used in base construction.(D. W. Lewis, 1982).

The air-cooled BF slag is crushed, screened and used mainly as road metal and bases, asphalt paving, track ballast, landfills and concrete aggregate. Global Slag production was 250 Mt from 1.6 billion tons of steel production in 2014and Asia alone contributes 60% of steel slag production. Production of Steel slag in India is 17.263 Million tpy (Indian Minerals Yearbook 2018).

2. Scope of Research

Main Objective

- To find out the range of Steel slag as a filler material in Asphalt Concrete mixes as per Standard Specifications for Roads and Bridges, Department of Roads.

Specific Objectives

- To find out Optimum Bitumen Content in the Asphalt concrete mix with Steel slag as a filler material with various filler content.
- To compare the Marshall Properties of asphalt concrete mix with Stone Dust filler material and that with Steel slag as a filler material.
- To find out the optimum steel slag content as a filler in asphalt concrete mix.
- To compare the cost of construction of asphalt concrete mix with stone dust as filler and asphalt concrete with steel slag as a filler material.
- To find out the Marshall Retained Stability Index for the Optimum Steel Slag Content.

3. Literature Review

(Khodary, 2015) adopted different percentages of bitumen 4.0% 4.5% 5.0% 5.5% 6.0% to find the optimal ratio of bitumen for asphalt concrete mixtures. The study obtained an optimum bitumen content of 5.02% for asphalt concrete mixtures using crushed limestone and an optimum bitumen content of 5.60% for asphalt concrete mixtures using steel slag aggregate. The Marshall stability of asphalt concrete mixtures using steel slag aggregate was 1.50 higher than mixtures with crushed limestone aggregate. The results of the study also showed that using steel slag aggregate is useful to resist rutting and suitable for pavement in hot climate area.

(Maharaj et al., 2017) investigated the influence of electric arc furnace steel slag (0–20% by weight of 3/4 inch sized aggregates) using the Marshall stability of blends to determine the optimal slag content. Results revealed that, a slag content of 15% by mass of 3/4 inch sized aggregates (or 2.25% of the total mass of aggregate) was optimal within Marshall Stability and air void acceptability.

(Zumrawi et al., 2015) evaluated the use of Steel Slag Aggregates (SSA) as a substitute for natural aggregates in the production of Hot Mix Asphalt (HMA) for road construction. The experiment results revealed that the addition of SSA has a significant improvement on the properties of HMA. An increase in density and stability and a reduction in flow and air voids values were clearly observed in specimens prepared with 100% SSA. is the study concluded that the steel slag can be considered reasonable alternative source of aggregate for concrete asphalt mixture production.

(Arun et al., 2018) performed a comparative study of steel slag with coarse aggregate and testing its binding properties with bitumen. The Marshall properties were satisfied for 20% steel slag proportion. Economically the steel slag may be cheaper if utilized in urban roads but it would be expensive for rural roads due to the transportation charges.

(Asi et al., 2007) evaluated the use of steel slag aggregate in asphalt concrete mixes. This research was intended to study the effectiveness of using steel slag aggregate (SSA) in improving the engineering properties of locally produced asphalt concrete (AC) mixes. The research started by evaluating the toxicity and chemical and physical properties of the steel slag. Then 0%, 25%, 50%, 75%, and 100% of the limestone coarse aggregate in the AC mixes was replaced by SSA. It was found that replacing up to 75% of the limestone coarse aggregate by SSA improved the mechanical properties of the AC mixes. The results also showed that the 25% replacement was the optimal replacement level.

The replacement of fine or coarse aggregate fraction with steel slag in asphalt pavement mixes provides satisfactory results. Moreover, the use of 100% steel slag requires higher amounts of bitumen binder because of its high porosity and also results in volume expansion owing to free lime and magnesium (Aziz et al., 2014).

The various literatures available about the use of Steel Slag mainly focuses on the partial replacement of either coarser portion or finer portion along with filler of the Asphalt Concrete Pavement. In my research work, the major research objective is to evaluate the Marshal Properties of the Asphalt mix by fully replacing the conventional filler material only and to find out the range of the Steel slag filler usage.

4. Methodology of Research

Various Marshall Specimens were prepared by using standard procedure and with 75 blows on each side of the specimen considering the heavy traffic condition. The test was performed on Department of Roads, Trade Road Improvement Project office Laboratory, Butwal- Belahiya.

Aggregates confirming to the gradation requirement provided by Standard Specification for Road and Bridge Works, 2073 of Nepal have been collected from Chamunda Crusher Udhyog, materials collected from Tinau River, Butwal. The aggregates such collected were sieved with standard sieves and then collected as the Aggregate-1 (13.2 mm down), Aggregate-2 (10 mm down) and Aggregate-3 (5 mm down). After combined gradation, the aggregate mix of aggregate 1, 2 and 3 was used for the control mix. Furthermore, those aggregate were again sieved to separate the filler size (0.075mm) particle from each aggregate type and say Aggregate-1' (13.2mm-0.075mm), Aggregate-2 (10mm-0.075mm) and Aggregate-3' (5mm-0.075 mm), which will be used for Asphalt mix with steel slag (0.075mm -0 mm) as a filler . Various trial and mix were done to find out the appropriate proportion of each aggregate type to prepare the aggregate mix of appropriate combined gradation according to the Standard Specifications for Roads and Bridge and the appropriate mix proportion is given in Table 1. The Combined gradation for Asphalt mix with Stone dust filler (AMFSD) is given in Table 2, which is graphically represented in Figure 1.

In this research study, only VG-30 grade Bitumen is considered.

Table 1: Mix Proportion for Asphalt Mix

	Aggregate 1	Aggregate 2	Aggregate 3	Steel Slag
AMFSD	20%	35%	45%	0%
	Aggregate 1'	Aggregate 2'	Aggregate 3'	Steel Slag'
AMFSS2	20%	35%	43%	2%
AMFSS4	20%	35%	41%	4%
AMFSS6	20%	35%	39%	6%
AMFSS8	20%	35%	37%	8%

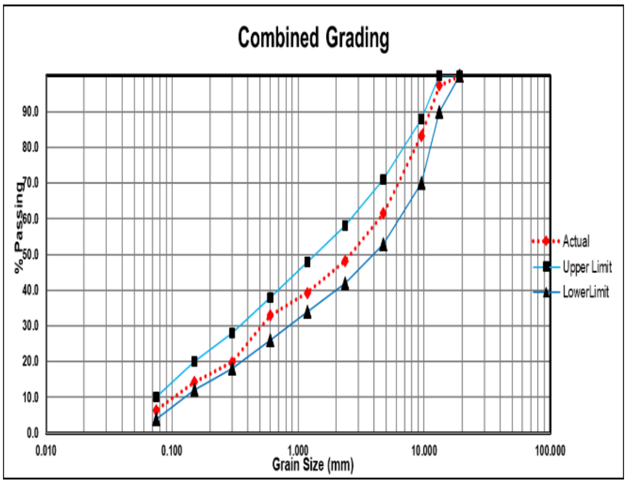

Figure 1: Combined Gradation for AMFSD

Table 2: Combined Gradation for AMFSD

Sieve Size (mm)	Individual Grading Percent Passing (%)			16 mm down	10 mm down	5 mm down	All-in Agg	Dor. Spec. Limit	
	16 mm down	1 mm down	5 mm down	20%	35%	45%		Lower	Upper
19	100	100	100	20.00	35.00	45.00	100.00	100	100
13.2	86.36	100	100	17.27	35.00	45.00	97.27	90	100
9.5	19.52	98.02	100	3.90	34.31	45.00	83.21	70	88
4.75	25.56	37.89	95.9	5.11	13.26	43.16	61.53	53	71
2.36	24.33	24.66	77.05	4.87	8.63	34.67	48.17	42	58
1.18	14.38	23.58	62.47	2.88	8.25	28.11	39.24	34	48
0.6	14.28	33.22	40.86	2.86	11.63	18.39	32.87	26	38
0.3	10.35	9.71	32	2.07	3.40	14.40	19.87	18	28
0.15	10.85	17.25	13.59	2.17	6.04	6.12	14.32	12	20
0.075	0	0	14.27	0.00	0.00	6.42	6.42	4	10

The Gradation of the Marshall Specimen for AMFSS2, AMFSS4, AMFSS6 and AMFSS8 were same as per AMFSD, except that, the filler (0.075mm-0mm) type and content are different. The Specific Gravity of Steel Slag and Stone dust were found to be 2.89 and 2.684 respectively.

4.1 Marshall Test

Step 1: To conduct the test, previously calibrated probing ring by Nepal Bureau of Standards and Metrology was used. Marshall Tests were performed in laboratory set up at Trade Route Improvement Project.

A. Control Sample

Different bitumen content using stone aggregate, stone dust filler 6.42% and different bitumen content

(4.5%, 5%, 5.5%, 6%, and 6.5%). (3 no of samples for each)

Total number of Control Marshall Specimen (5 types of binder content, 3 samples in each=5*3=15 numbers of sample)

B. Test Marshall Specimen

Different filler content (2%, 4%, 6% and 8%) and different Bitumen content (4.5%, 5%, 5.5%, 6%, and 6.5%) and for 8% filler content, additional samples for bitumen content 7% was also prepared. (3 no of samples for each type)

Total no of Test Marshall Specimen =63 no's of Test samples)

Total no of Marshall Specimen = Total number of Control Marshall Specimen + Total no of Test Marshall Specimen = 15+63=78 no's of sample

Step 2: Marshall Test was conducted as per standard.

Step 3: Preparation of Test specimens for measuring Effect of water on cohesion of compacted bituminous mixtures as per ASTM Designation: D 1075-81.

Total number of samples = 4

Step 4: Conduct test for Effect of water on cohesion of compacted bituminous mixtures as per CRD-C 652-95 and ASTM Designation: D 1075-81.

5. Result and Analysis

5.1 Marshall Test Summary

The results of the experiments are expressed in following terms;

a. Marshall stability – kN

b. Flow value – in mm

c. Percentage of air voids – %

d. Voids in Mineral Aggregate (VMA) – %

e. Voids Filled with Bitumen (VFB) – %

f. Unit weight of specimen (G) – gm/cm^3

The various results obtained from Marshall Test in tabular as well as graphical form is represented as follows.

Table 3: Marshall Test Summary I

	Bitumen at max. Stability	Bitumen at max. Density	Bitumen at 4% air Voids	OBC
AMFSD	5.00%	5.50%	6.50%	5.67%
AMFSS2	4.50%	6.50%	6.00%	5.67%
AMFSS4	5.50%	6.50%	5.60%	5.87%
AMFSS6	5.50%	6.50%	6.25%	6.08%
AMFSS8	6.50%	7.00%	6.65%	6.72%

Table 4: Marshall Test Summary II

	Stability (KN)	OBC	Flow (mm)	VFB (%)	VTM (%)	Density (t/cum)
AMFSD	11.55	5.67%	3.05	75.00	4.10	2.35
AMFSS2	12.55	5.67%	2.80	70.00	5.00	2.31
AMFSS4	18.00	5.87%	3.60	78.00	3.40	2.35
AMFSS6	14.50	6.08%	3.50	75.00	4.50	2.33
AMFSS8	14.00	6.72%	3.05	80.00	3.70	2.33

Table 5: Variation of Stability with Bitumen Content

	4.50%	**5%**	**5.50%**	**6%**	**6.50%**	**7%**
AMFSD	12.2	14	12.4	11.3	10.6	
AMFSS2	18	15.1	13.4	11.6	10	
AMFSS4	18.9	20	20.9	16.9	15.3	
AMFSS6	12.8	13.9	16.8	14.7	13.8	
AMFSS8	11.7	13.1	13.5	14	14.9	12.724

Table 6: Variation of % Air voids with Bitumen content

	4.50%	**5%**	**5.50%**	**6%**	**6.50%**	**7%**
AMFSD	6.2	5.3	4.2	4.1	3.7	
AMFSS2	7.2	6.3	5.4	4	2.7	
AMFSS4	8.7	6.5	4.4	3.1	2.1	
AMFSS6	9.6	8.5	6.6	4.9	3.4	
AMFSS8	10	7.6	5.7	5.1	4.3	3.3

Table 7: Marshall Flow Value Summary

	4.50%	**5%**	**5.50%**	**6%**	**6.50%**	**7%**
AMFSD	2.48	2.82	3.02	3.15	3.37	
AMFSS2	2.57	2.67	2.77	2.83	2.83	
AMFSS4	2.57	2.8	3.83	3.47	3.27	
AMFSS6	2.4	2.78	3.97	3.6	3.15	
AMFSS8	3.02	3.22	3.45	3.3	3.1	3

Table 8: Unit wt Vs Bitumen Content

	4.50%	**5%**	**5.50%**	**6%**	**6.50%**	**7%**
AMFSD	2.331	2.337	2.347	2.333	2.325	
AMFSS2	2.29	2.295	2.303	2.318	2.334	
AMFSS4	2.258	2.295	2.33	2.347	2.353	
AMFSS6	2.255	2.267	2.296	2.322	2.342	
AMFSS8	2.248	2.292	2.321	2.32	2.323	2.331

Table 9: VFB vs Bitumen Content

	4.50%	**5%**	**5.50%**	**6%**	**6.50%**	**7%**
AMFSD	61.9	67.9	74.7	76.6	79.7	
AMFSS2	57.9	63.6	69.2	76.9	84.4	
AMFSS4	52.8	62.9	73.7	81.3	87.5	
AMFSS6	50.4	56.1	64.7	73.2	81.1	
AMFSS8	49.3	59.1	68.2	72.4	77.1	82.6

5.2 Marshall Retained Stability Test

Marshall Retained Stability Test is conducted on the Marshall samples for 4% Steel Slag Content and OBC

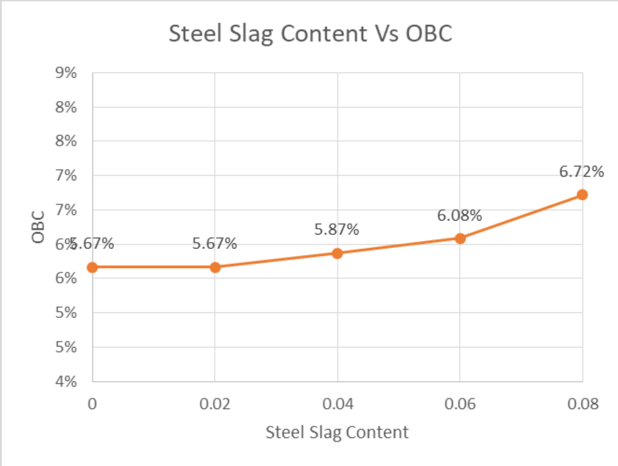

Figure 2: Steel Slag Content vs OBC

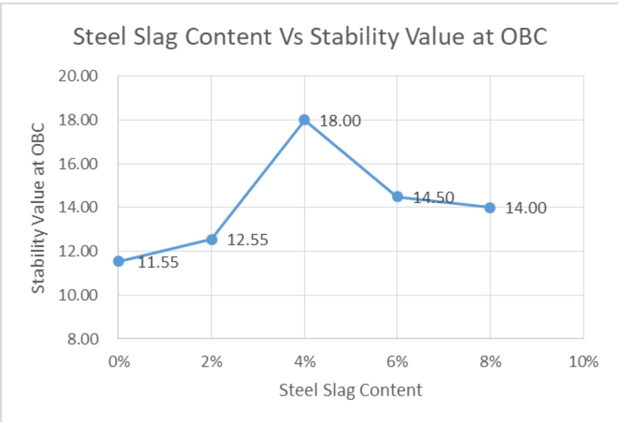

Figure 3: Steel Slag Content vs Stability value at OBC

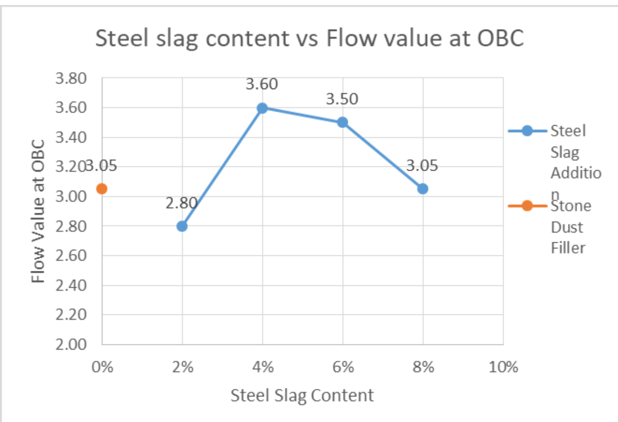

Figure 4: Steel Slag Content vs Flow Value at OBC

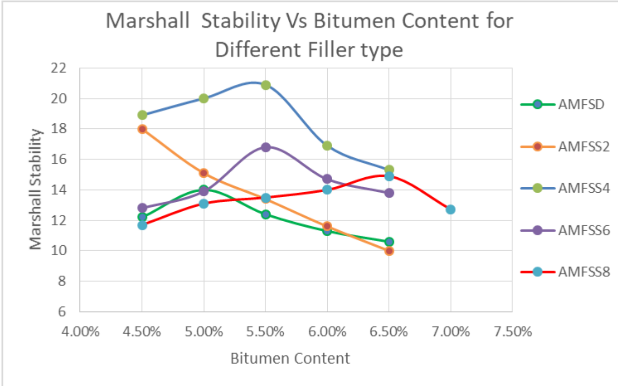

Figure 5: Marshall Stability vs Bitumen Content

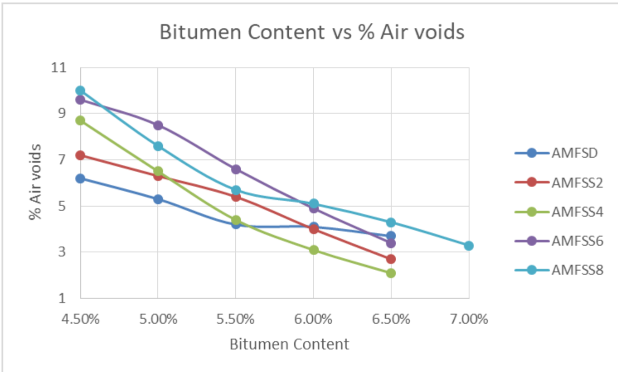

Figure 6: Air Voids vs Bitumen Content

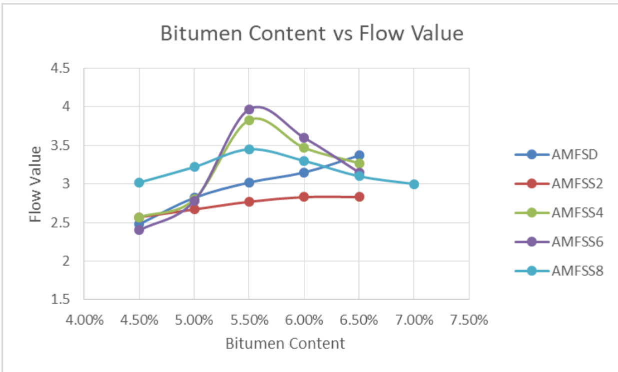

Figure 7: Bitumen Content Vs Flow Value

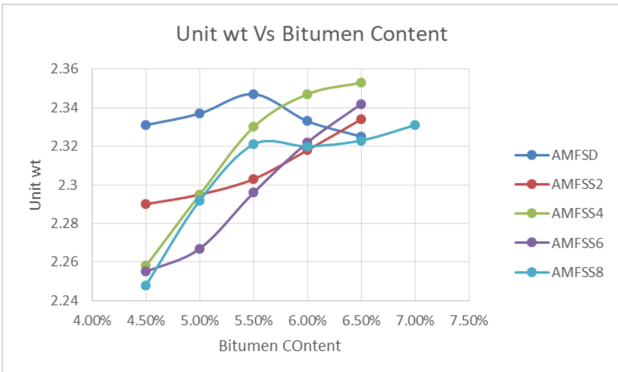

Figure 8: Unit wt. vs Bitumen Content

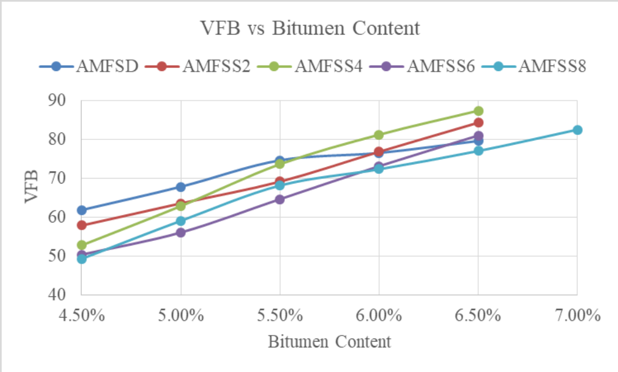

Figure 9: VFB vs Bitumen Content

of 5.87% mixture to measure the resistance towards the moisture. The stability was determined after placing the samples in room temperature for 4 hours (for samples B1 & B2) and 60°C for 24 hours and followed by storing at room temperature for 2 hours (for samples B3 & B4). Table 10 shows the summary of Retained Marshall Stability test results.

Table 10: Retained Marshall Stability test Summary

Sample	Stability	Flow	Density
B1	19.1	2.38	2.346
B2	19.2	2.43	2.346
B3	16.3	1.97	2.332
B4	16.6	2.07	2.336

Index of Retained Strength (%)

$$= (16.3 + 16.6)/(19.1 + 19.2)$$

$$= 85.90\%$$

5.3 Financial Analysis

The financial analysis is done according to the Norms for Rate analysis of Road and Bridge works, Department of Roads. District Rate of Rupandehi district was used for labor and material rate. The equipment rate was taken from Department of Roads. Steel slag rate was taken from Indian Minerals Yearbook 2018 (Part- II: Metals and Alloys) and Indian Minerals Yearbook 2017 (Part-II: Metals and Alloys). Rate of fuel was taken from Nepal oil Corporation.

In Scenario-I, the rate of slag is taken considering that Granulated slag is taken from Steel factory located in Nepal i.e. Future case scenario.

In scenario-II, the rate of slag is taken considering that Granulated Slag is taken from Indian market i.e. Present Case scenario.

Table 11: Materials in ton (per cum of Asphalt mix)

	Aggregate	Steel Slag	Bitumen
AMFSD	2.2242	0.0000	0.1258
AMFSS2	2.1423	0.0437	0.1239
AMFSS4	2.1264	0.0886	0.1300
AMFSS6	2.0641	0.1317	0.1322
AMFSS8	2.0069	0.1745	0.1466

Considering Case I (Steel slag is taken from Steel factory located in Nepal) i.e. Future case scenario, the rate analysis of material is given in Table 11.

Table 12: Rate Analysis for Material Cost, Case I

	Aggregate	Steel Slag	Bitumen	Total Material Cost
AMFSD	2353.17	0.00	9059.55	11412.73
AMFSS2	2266.59	22.04	8924.33	11212.95
AMFSS4	2249.71	44.65	9361.39	11655.76
AMFSS6	2183.78	66.40	9517.53	11767.71
AMFSS8	2123.30	87.95	10554.53	12765.78

Considering Case II (Steel Slag is taken from Indian market) i.e. Present Case scenario, the rate analysis of material is given in Table 12.

Table 13: Rate Analysis for Material Cost, Case II

	Aggregate	Steel Slag	Bitumen	Total Material Cost
AMFSD	2353.17	0.00	9059.55	11412.73
AMFSS2	2266.59	218.61	8924.33	11409.52
AMFSS4	2249.71	443.00	9361.39	12054.10
AMFSS6	2183.78	658.74	9517.53	12360.05
AMFSS8	2123.30	872.56	10554.53	13550.39

6. Conclusions

Steel slag as a filler material can be used in the ranges from 2% to 8% content in Asphalt Concrete mixes, since its properties meet the Departmental Specifications of Department of Roads.

Stability value of the Asphalt concrete mix with 4% steel slag content as filler is found to be 1.55 times higher than that of asphalt concrete mix with stone dust as a filler at Optimum Bitumen content. Also, the stability values of Asphalt concrete mix with 2%, 6% & 8% steel slag content as filler is found to be 1.08, 1.558, 1.225 and 1.212 times respectively higher than that of asphalt concrete mix with stone dust as a filler at Optimum Bitumen content. This indicates that the Asphalt concrete mix with steel slag filler will have higher rutting resistance.

The Optimum Bitumen content has been found to be increasing as we increase the steel slag content as filler.

The value of Optimum Bitumen Content for Asphalt mix with stone dust filler was found to be 5.67% and that of Asphalt mix with steel slag as filler with 2%, 4%, 6% & 8% was found to be 5.67%, 5.87%, 6.08% and 6.72% respectively.

The Marshall Flow Value at Optimum Bitumen Content obtained from test was found to be within the range of 2 to 4 as per DOR standard.

The Marshall Properties for 4% Steel Slag filler content shows the best results.

Retained Stability Value of more than 70% is suggested as a criterion for a mixture to be resistant to moisture induced damage. As the value of Index of Retained Stability has been found to be 85.90%, the Asphalt mix with 4% Steel slag content shows the better result towards the moisture susceptibility.

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