COPYRIGHT

TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

DEPARTMENT OF CIVIL ENGINEERING

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "**Utilization of Steel Slag as a Replacement of Filler Material in the Asphalt Concrete**" submitted by Bishow KC in partial fulfillment of the requirements for the degree of Master in Civil Engineering.

Supervisor

____
Gautam Bir Singh Tamrakar
Professor
Institute of Engineering

External Examiner

____
Dr. Biswa Ranjan Shahi
Consultant

Programme Coordinator

____
Anil Marasini
M.Sc. Program in Transportation Engineering
Department of Civil Engineering
Pulchowk Campus, Nepal
November, 2019

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to Department of Civil Engineering, Pulchowk Campus for allowing me to undertake this work.

I am grateful to my Supervisor Professor Dr. Gautam Bir Singh Tamrakar Department of Civil Engineering for his continuous guidance, advice, effort and invertible suggestion throughout the research. I would also like to express my profound gratitude to the coordinator of Transportation Engineering Mr. Anil Marsani for providing me the opportunity to carry out the research work.

I am also grateful to Project Manager SDE Jibendra Mishra, Er Megh Bahadur KC, Er Prakriti Pokharel, Er Arun Khatri and whole laboratory team member of Trade Road Improvement Project, Butwal- Belahiya, Department of Roads, for providing me the laboratory setup for my research work and their valuable suggestion to carry out my research successfully.

My utmost gratitude to Er. Shivu Khatri, Er. Shailesh Das, Er. Sharmila Desar, Er. Sudip Bikram Bhatta and whole classmates of MSc in Transportation Engineering, 2072 Batch of Pulchowk Campus for their help throughout the study.

I would also like to thank Project Manager SDE Sunil Babu Pant and my colleagues Er. Mahendra Majhi, Er. Dhruba Bahadur Chand and all team members of Bridge Project, Sector No. 3, Nepalgunj, Department of Roads, for their continuous encouragement and providing me the necessary time to complete my thesis work.

I would also like to thank Mr. Roshan Karki and Mr Thaman Khadka, Lecturer Pulchowk Campus, and Er Dhruba Gyawali for encouraging me to carry out this thesis work.

Lastly, I would like to express my sincere appreciation to my family for encouraging and supporting me throughout the study.

Bishow KC

ABSTRACT

Asphalt 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 66 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.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF GRAPHS

ABBREVIATIONS AND ACRONYMS

ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
Cum	Cubic meter
DoR	Department of Road
G	Specific gravity/Unit weight
LAA	Los Angeles Abrasion
SMA	Stone Mastic Asphalt
Min	Minimum
MQ	Marshall Quotient
OBC	Optimum bitumen content
SSRBW	Standard Specification for Road and Bridge Works
VFB	Voids Filled with Bitumen
VMA	Voids in Mineral Aggregate
AMFSD	Asphalt Mix with Stone Dust Filler
AMFSS2	Asphalt Mix with 2% Steel slag Filler
AMFSS4	Asphalt Mix with 4% Steel slag Filler
AMFSS6	Asphalt Mix with 6% Steel slag Filler
AMFSS8	Asphalt Mix with 8% Steel slag Filler
SSRBW	Standard Specifications for Roads and Bridges works, 2073

CHAPTER 1: INTRODUCTION

In Asphalt Technology, Marshall Mix Method is adopted by Standard Specifications for Road and Bridge, 2073, Department of Roads. Different researches are performed worldwide to standardize and economize the asphalt technology. In our country, Nepal, Asphalt Technology have been adopted by Department of Roads (DOR), Department of Urban Development and Building Construction (DUDBC) and also by some of the local level authorities, however, only few researches have been performed so far in this area. As per Standard Specifications of Roads and Bridges, 2073, the standard followed by DOR and other institutions involved in the construction of road, only stone dust, hydrated lime and cement have been introduced as mineral filler materials; and stone aggregate is introduced as aggregate. Many researches have been undertaken in this area to investigate the more acceptable method of construction of road.

In this research study, steel slag, a waste material produced from steel industries will be used as a replacement of 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.

1.1 Background

Asphalt concrete is a composite material commonly used in construction projects such as road surfaces, airports and parking lots. It is the dense graded premixed bituminous mixture consisting of carefully proportioned mixture of dry coarse aggregates, fine aggregates, mineral filler and bitumen. When properly designed with appropriate proportion of ingredients, it has a potential to result a surfacing with exceptional durability and capability to carry significant traffic load. It is one of the highest quality of construction among the group of black top pavement.

Fillers in asphalt concrete play an important role on engineering properties of the bituminous paving mixes. Conventionally, cement, lime and stone dust were used as fillers. In this study, an attempt has been made to assess the effects of different types of fillers (e.g. non-conventional and conventional) on the Marshall properties of bituminous paving mixes. For this purpose, non-conventional filler such as brick dust, Sand and conventional fillers such as cement and stone dust were used (Behnood & Ameri, 2012)

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. Most of the developed countries have successfully incorporating steel slags as an aggregate in hot mix asphalt, road base, and sub-base and soil stabilization in road works. Steel slag is one of the industrial waste materials containing significant amounts of iron which makes it sufficiently hard, dense and abrasion resistant. Asi et al. 6 reported that partial replacement of limestone coarse aggregates with steel slag of about 30–75% provides high skid resistance and improves mechanical properties of the asphalt mix design. 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).

“Steel slag can be processed into a coarse or fine aggregate material for use in dense- and open-graded hot mix asphalt concrete pavements and in cold mix or surface treatment applications. Proper processing of steel slag and special quality-control procedures are extremely important in selecting steel slag for use in asphalt paving mixes. Of particular importance is the potential for expansion because of free lime or magnesia in the slag, which could result in pavement cracking if ignored. Steel slag use in paving mixes should be limited to replacement of either the fine or coarse aggregate fraction, but not both, because hot mix asphalt containing 100 percent steel slag is susceptible to high void space and bulking problems due to the angular shape of steel slag aggregate. Mixes with high void space (100 percent steel slag aggregate mixes) are susceptible to over-asphalting during production and subsequent flushing due to in-service traffic compaction. Steel slag has been successfully used as aggregate in wearing course hot mix asphalt and in surface treatments in the United States and internationally. Its use requires proper selection, processing, aging, and testing to ensure that it will perform in accordance with intended design specifications.

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.

Stability: Steel slag aggregate mixes combine very high stabilities (1.5 to 3 times higher than conventional mixes) with good flow properties.

Stripping Resistance: Steel slag mixes typically exhibit excellent resistance to stripping of asphalt cement from the steel slag aggregate particles. Resistance to stripping is most probably enhanced because of the presence of free lime in the slag.

Rutting Resistance: The high stability (1.5 to 3 times higher than conventional mixes) with good flow properties results in a mix that resists rutting after cooling, but is still compactable. Rutting resistance is advantageous for highways, industrial roads, and parking areas subjected to heavy axle loads." – (U.S. Department of Transportation, 2019)

1.2 Research Objective

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 Steel Slag filler content.
- To compare the 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 Retained Stability Index for the optimum steel slag content.

CHAPTER 2: LITERATURE REVIEW

Steel slag is a by-product of the steel industry and can be used potentially as aggregate in the asphalt mixture (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. Based on intensive laboratory testing program, the characteristic properties of SSA were assessed to determine its suitability to be used in HMA. Four different percentages (0, 50, 75, and 100%) of SSA were used, and the proposed mix designs for HMA were conducted in accordance with Marshall Mix design. 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. The study concluded that the steel slag can be considered reasonable alternative source of aggregate for concrete asphalt mixture production.

(Behnood and Ameri, 2012) performed in-direct tensile strength and resilient modulus tests. The study showed that the mixtures with steel slag had encouraging results in comparison with those containing limestone. Also, replacing the coarse portion of limestone aggregate with steel slag were observed to yield better results in comparison with mixtures that contain steel slag as the fine portion. SMA mixtures with steel slag used had increased Marshall Stability value and decreased flow values. Hence, mixtures with steel slag coarse aggregate were observed to have higher full Marshall Quotient values, which is an indicator of high stiffness and resistance to permanent deformation. (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 ¾ 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 ¾ inch sized aggregates (or 2.25% of the total mass of aggregate) was optimal within Marshall Stability and air void acceptability.

(Patil and Patil, 2013) evaluated the cost effectiveness of different non-conventional materials for the maintenance of flexible road pavement. They examined the effectiveness of foundry sand and steel slag as fine aggregate and granulated steel slag as filler material in different combination. From the result and analysis of various properties of steel slag and foundry sand it is found that these materials can be used as fine aggregates as replacement for natural sand and ground granulated blast furnace slag can be used as filler material as replacement for cement in bituminous mix.

(Arun et al., 2018) performed a comparative study of steel slag with coarse aggregate and testing its binding properties with bitumen. They found that the physical Properties like AIV, LAA, Specific Gravity and water absorption were as per IS code requirements. Also, 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.

(Shreemanth et al., 2015) examined the effect of replacement of fine aggregate by steel slag aggregates in concrete. They evaluated the use of waste steel slag as a fine aggregate for M20, M30 and M40 grade of concrete and recommended the approval percentage level for use of concrete in replacement of fine aggregates. They found that compressive strength at 7 days was increased by 10% to 15% at 28 days in all the mixes. Optimum strength was found the replacement level in-between 30 to 50%. Strength reduction was observed at 100% replacements of fine aggregate with granular slag and the reduction in the strength is by 7% to 10%.

(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.

(Vahora et al., 2017) studied the Retained Stability on warm bituminous mixes. The Marshall test was performed to the measure the resistance of mix towards the moisture using VG-30 Bitumen and VG30+0.3% Evotherm J1. The study found that the Retained stability for Marshall Mix with VG-30 Bitumen and VG30+0.3% Evotherm J1 to be 88.17% and 89.4% respectively.

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.

CHAPTER 3: RESEARCH METHODOLOGY

The methodology starts with the listing of problems with respect to the relevant literatures followed by the setting of objectives. The work proceeded with three months plan for collection of material, sample preparations and data collections. Before the sample preparations all the equipment's were prepared and validated. During the report writing, all data, results and graphs were collected and discussed along with literature references. Literature were reviewed during different phases of researches.

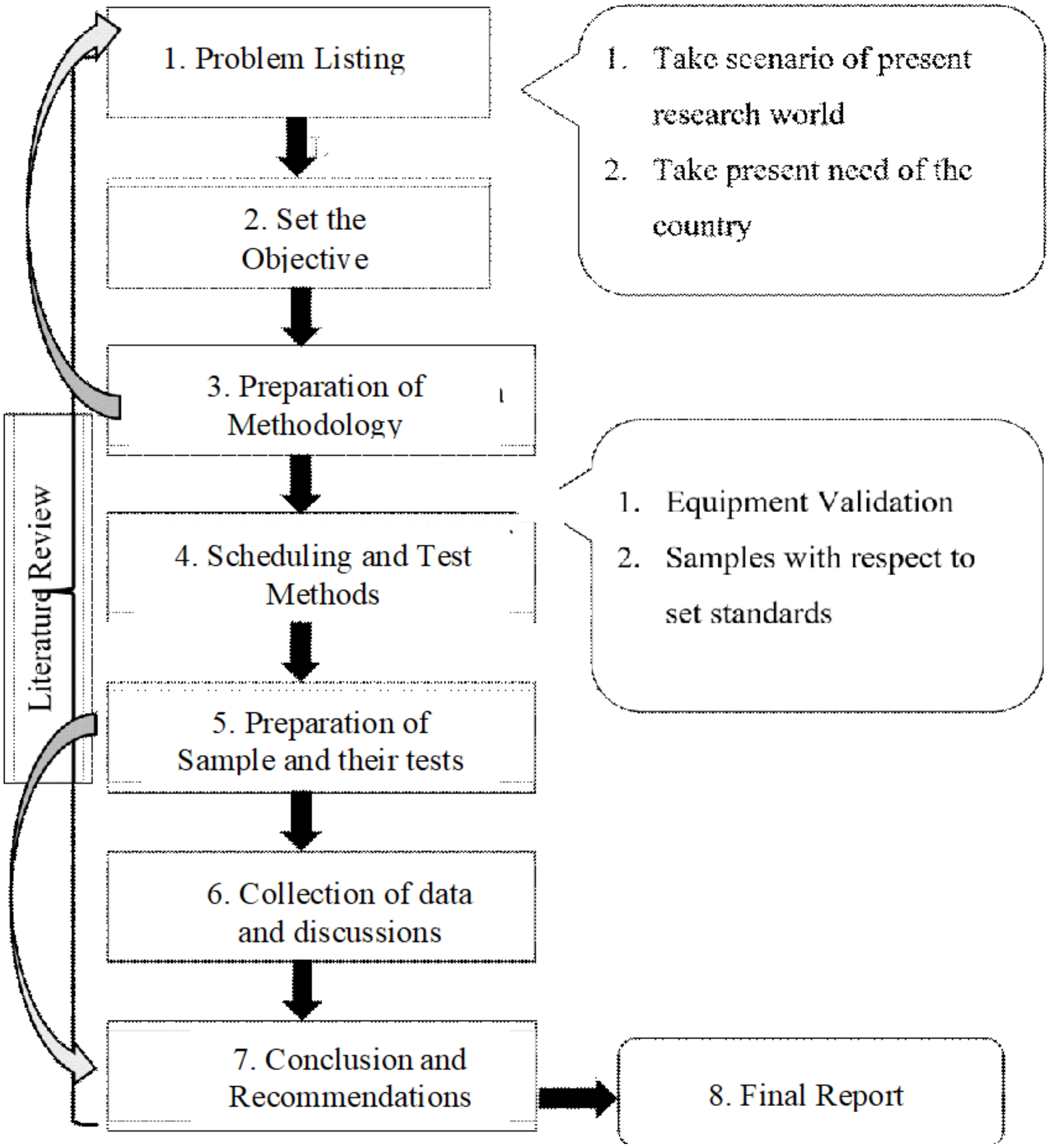


Figure 1 Network Schematic Diagram

3.1 Sample preparation

Sample preparation followed a standard procedure and included steps are discussed below as:

3.1.1 Aggregate selection

Coarse aggregate 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 (16 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' (16 mm-0.075 mm), Aggregate-2 (10 mm-0.075 mm) and Aggregate- 3' (5 mm-0.075 mm), which will be used for Asphalt mix with steel slag 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 Bridges.

Figure 2 Aggregates used in Marshall Test

The gradation requirement (as shown in Table 3.1 for 30-40 mm layer thickness) is fulfilled by suitably proportioning aggregates. Respective proportions of aggregates are: Aggregate 1 – 20% (16 mm down)

Aggregate 2 – 35% (10 mm down)

Aggregate 3 – 45% (5 mm down), (Includes filler (0.075 mm down) particle also).

The resulting gradation curve which satisfies the limit of gradation is given in the following figure

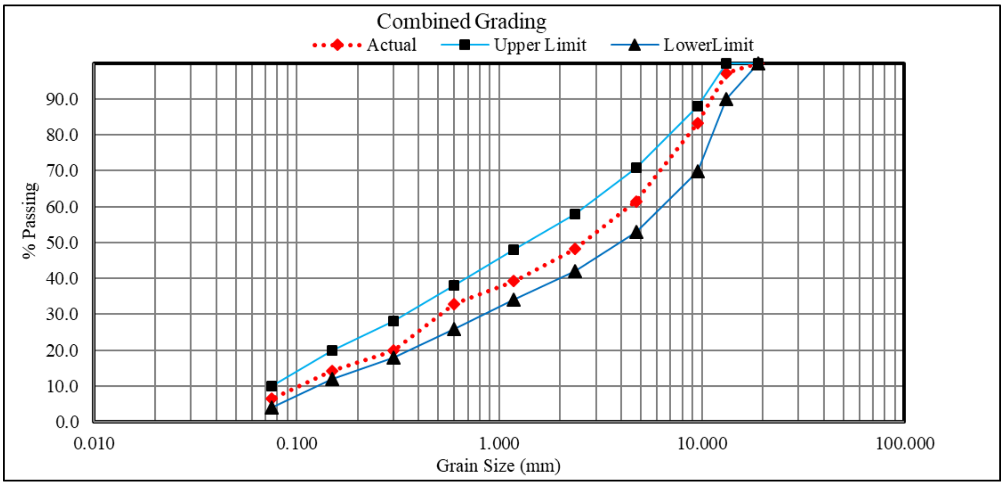


Figure 3 Combined gradation curve

Table 1 Gradation limit as per Standard Specification for Road and Bridge Works

Grading	2
Nominal aggregate size*	**13.2 mm**
Layer thickness	**30-40 mm**
IS Sieve[1] (mm)	
45	
37.5	
26.5	
19	100
13.2	90-100
9.5	70-88
4.75	53-71
2.36	42-58
1.18	34-48
0.6	26-38
0.3	18-28
0.15	12-20
0.075	4-10
Bitumen content % by mass of total mix	Min 5.4**

Table 2 Combined Gradation of Aggregate

Sieve Size (mm)	Individual Grading Percent Passing (%)			16 mm down	10 mm down	5 mm down	ALL-IN AGG	DOR SPEC. LIMIT	
	16mm down	10mm 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

Table 3 Physical tests for Aggregate

Test	Limiting Value	Result	Standard
Los Angeles Abrasion Test	Maximum 30%	29%	IS 2386 Part IV
Aggregate Impact Test	Maximum 24%	21%	
Aggregate Crushing Value Test		20%	

Specific gravity tests for aggregates can be summed up as:

Aggregate 1 – 2.678

Aggregate 2 – 2.614

Aggregate 3 – 2.684

3.1.2 Bitumen selection

Bitumen was collected from Biruwa Nirman Sewa and was tested for its penetration value, specific gravity, ductility test, viscosity test and specific gravity. With the available sets of properties of bitumen, bitumen can be classified as VG 30 as per SSRBW, 2073.

3.1.3 Filler selection

Two different filler materials i.e. steel slag and stone dust were used. Since, the research objective is to provide a guide to the design of filler with Steel slag, higher amount of the Steel slag was required to produce samples with its varying proportion. Steel slag was collected from Jagdamba Cement factory, Birgunj which previously was imported from India. For stone dust, crushed stone dust sieved from 75µ sieve was used. Figure 3.5 and Figure 3.6 shows Steel slag and stone dust respectively used in Marshall Test.

Sieve analysis of collected Steel slag yielded following results:

Table 4 Sieve analysis result of Steel slag

Sieve size (mm)	Percentage passing
0.3	100%
0.15	100%
0.075	100%

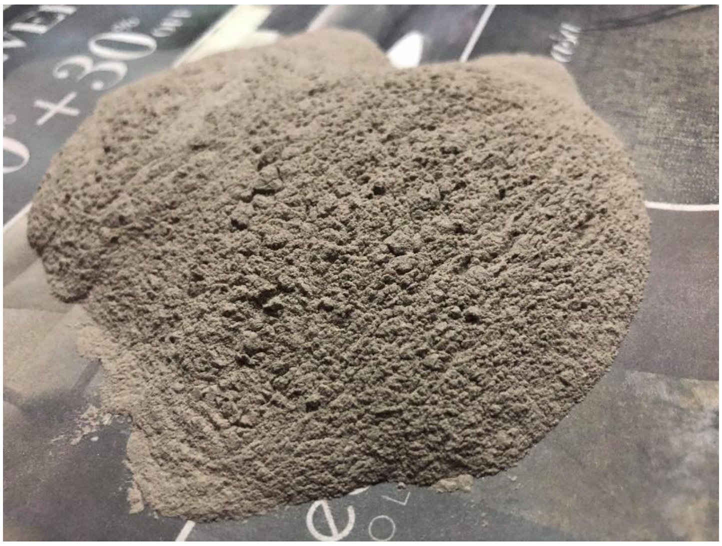


Figure 4 Steel Slag, 75mm down

SSRBW, 2073, (DoR, 2016) as mentioned, does not identify Steel slag as filler material. Thus, the specification provided by DoR could not be satisfied in terms of passing percentage of 75µ sieve.

Figure 5 Stone dust, 75mm down

Specific gravity of filler materials is summed up as below:

Steel Slag: 2.89

Stone Dust: 2.684

3.1.4 Mix proportion

All together 81 number of samples were prepared to study about the variation in the properties of the specimen with the varying proportion of steel slag. The variation of the Steel slag as the filler and the bitumen content is shown as following table.

Table 5 Mix Proportion of different types of aggregate

	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%

Table 6 Marshall Specimen mix variation with respect to Steel slag content and bitumen content

SN	Variation of Filler (% by wt of total aggregate)	Variation of Bitumen Content (% by wt. of mix)	Sample Id
1.	2% Steel slag	4.5%	4.5-1,4.5-2,4.5-3
2.		5%	5-1,5-2,5-3
3.		5.5%	5.5-1,5.5-2,5.5-3
4.		6%	6-1,6-2,6-3
5.		6.5%	6.5-1,4.6-2,6.5-3
6.	4% steel slag		
7.		4.5%	4.5-1,4.5-2,4.5-3
8.		5%	5-1,5-2,5-3
9.		5.5%	5.5-1,5.5-2,5.5-3
10.		6%	6-1,6-2,6-3
11.		6.5%	6.5-1,4.6-2,6.5-3

12	6% Steel slag	4.5%	4.5-1,4.5-2,4.5-3
13		5%	5-1,5-2,5-3
14		5.5%	5.5-1,5.5-2,5.5-3
15		6%	6-1,6-2,6-3
16		6.5%	6.5-1,4.6-2,6.5-3
17	8% steel slag	4.5%	4.5-1,4.5-2,4.5-3
18		5%	5-1,5-2,5-3
19		5.5%	5.5-1,5.5-2,5.5-3
20		6%	6-1,6-2,6-3
21		6.5%	6.5-1,4.6-2,6.5-3
22		7%	7-1,7-2,7-3
23	Stone Dust 6.2%	4.5%	4.5-1,4.5-2,4.5-3
24		5%	5-1,5-2,5-3
25		5.5%	5.5-1,5.5-2,5.5-3
26		6%	6-1,6-2,6-3
27		6.5%	6.5-1,4.6-2,6.5-3

3.2 Marshall Test

The Marshall Test methodology is adopted by Department of Roads and other organizations involved in Asphalt Road construction in Nepal. To conduct the test, previously calibrated probing ring by Nepal Bureau of Standards and Metrology was used.

Figure 6 Marshall Stability test setup

Marshall Tests were performed in laboratory set up at Trade Route Improvement Project, Butwal-Belhiya road. To perform the test, specimens with total weight of the mix, bitumen, filler and aggregates were prepared confirming to standard specified by Standard Specification for Roads and Bridges Work (SSRBW), 2073 (DoR, 2016). For the control mix, stone filler of 6.2% by weight of aggregate and varying percentage of bitumen content for one set (15) samples were prepared.

As the mixing temperature and compaction temperature are the major part of the specimen preparation, aggregate (aggregate 1, aggregate 2, aggregate 3 and filler) and bitumen were heated separately till mixing temperature of 160° C was reached. Samples were given 75 number of blows on both sides as specified by Standard Specification for Road and Bridge Work (SSRBW), 2073 (DoR, 2016). Three numbers of specimen for each proportion of the filler and bitumen content were prepared for the test.

Each time one set (15 to 18 numbers) of samples were prepared and tested after 24 hours of its preparation. Before testing the sample, it was kept in hot water bath of 60°C temperature for 30 minutes. All tests were carried out as per Standard Specification for Roads and Bridges Work (SSRBW), 2073 (DoR, 2016). 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 minimum requirement of these parameters for the mix design is provided in the SSRBW, 2073 under clause 1308 (3). These parameters are taken as reference for giving recommendations for design mix.

3.3 Laboratory Working Procedure

i) The required materials were collected and the standard tests of samples were done.

ii) Preparation of sample

a. Control Sample

Marshall Test specimens were prepared considering different bitumen content using stone aggregate, stone dust filler 6.2% and VG 30 Grade Bitumen (3 no of samples for each)

Total number of samples (5 types of binder content (4.5%, 5%, 5.5%, 6%, 6.5%), 3 samples in each=5*3=15 numbers of sample)

b. Test samples

Marshall Test specimens were prepared considering different bitumen content using different filler content (2%, 4%, 6% and 8%), stone aggregate and VG 30 Grade Bitumen (4.5%, 5%, 5.5%, 6%, 6.5%) and for 2% filler content, additional samples for bitumen content 4% was also prepared and also for 8% filler content, additional samples for bitumen content 7% was also prepared. (3 no of samples for each type)

Total no of samples (2 types of aggregate mix, 5 types of binder content, 3 samples in each=2*5*3=30 plus 2 type of aggregate mix, 6 type of binder content, 3 samples in each combination) = 2*6*3=36

Total no of samples=66 nos of Test samples)

Total no of samples = Total no of control Sample + Total no of Test sample

= 15+66

= 81 nos of sample

iii) Conduct Marshall Test as per specifications.

The test was performed on Department of Roads, Trade Road Improvement Project office Laboratory, Butwal- Belahiya. The test of the sample was done minimum after 24 hrs of the preparation of sample.

iv) 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

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

Two test specimens were brought to room temperature and after storing the specimen in 4 hrs, the Marshall Test were performed as per standards.

Another two test specimens were immersed in water for 24 hrs at 60° C and then transferred to second water bath which was maintained at room and were stored for 2 hrs. After then, Marshall Test were performed as per standard.

vi) Result, Analysis and Comparison of result.

3.4 Performance of Marshall test in Laboratory

Figure 9 Mixing of steel slag on aggregate mix

Figure 8 Measuring temperature of Asphalt mix

Figure 7 Prepared Asphalt specimens for 8% steel slag filler content

Figure 10 Weighing of specimen before Marshall test

Figure 11 Samples at Hot water bath at 60 Degree Celcius for 30 min before Marshall Test

Figure 12 Performing Marshall test

Figure 13 Marshall Sample for Retained Stability Test


Figure 14 Water Bath for Retained Stability Test

CHAPTER 4: RESULTS AND ANALYSIS

The Marshall Stability Value of the base sample was 11.55 with Optimum Bitumen Content 5.67%. The maximum Marshall Stability value was found in the asphalt mix with 4% steel slag filler content and the value of Marshall Stability was 18, which is 1.55 times higher than that of the base sample. The Marshall Stability value was found to be increased by using the steel slag filler in place of stone dust filler. The Marshall Stability value was initially increased up to 4% steel slag content, and after then, the value starts decreasing. The satisfactory result was obtained to use steel slag filler in the range of 2% to 8%.

The Optimum Bitumen Content (OBC) value was found to be increased from 5.67% to 6.72%, as we increase the slag content from 2% to 8%. As we increase the slag content, value of optimum bitumen content is also increasing.

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 Quotient Value will also comply with DOR standard for all ranges of slag content.

Table 7 Marshall Test Result Summary-I

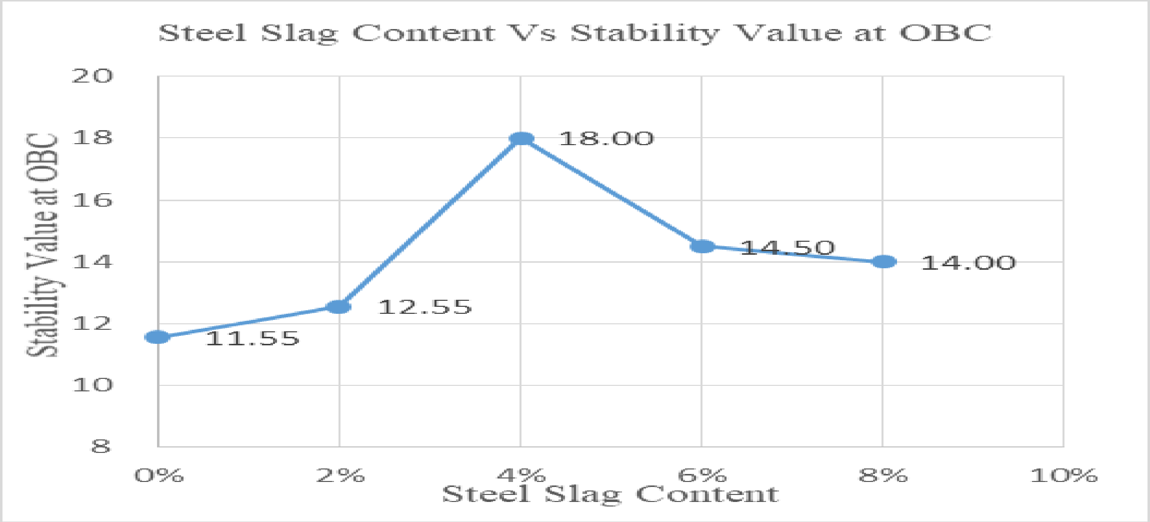
Filler type	AMFSD	AMFSS2	AMFSS4	AMFSS6	AMFSS8
Bitumen at max. Stability	5.00%	4.50%	5.50%	5.50%	6.50%
Bitumen at max. Density	5.50%	6.50%	6.50%	6.50%	7.00%
Bitumen at 4% air Voids	6.50%	6.00%	5.60%	6.25%	6.65%
Optimum Bitumen Content	**5.67%**	**5.67%**	**5.87%**	**6.08%**	**6.72%**

Table 8 Marshall Test Result Summary-II

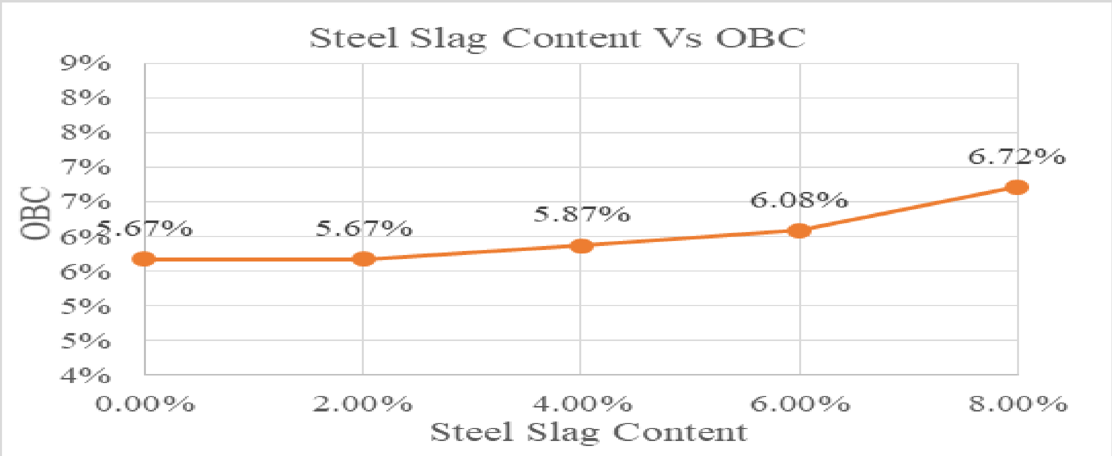
Steel Slag Content	AMFSD	AMFSS2	AMFSS4	AMFSS6	AMFSS8	DoR Standard
OBC	5.67%	5.67%	5.87%	6.08%	6.72%	
Unit wt.(gm./cc)	2.35	2.31	2.35	2.33	2.33	
% Air voids	4.10	5.00	3.40	4.50	3.70	3 to 5
VFB	75.00	70.00	78.00	75.00	80.00	65 to 75
Marshall Stability(KN)	11.55	12.55	18.00	14.50	14.00	Minimum 9.00
Flow Value(mm)	3.05	2.80	3.60	3.50	3.05	2 to 4
Marshall Quotient(KN/mm)	3.79	4.48	5.00	4.14	4.59	2 to 5

Graphical Analysis

Graph 1 Variation of Stability value (KN) according to Slag content at Optimum Bitumen Content



Graph 2 Variation of Optimum Bitumen Content with respect to Steel Slag Content



Graph 3 Variation of Flow value (mm) with respect to slag content

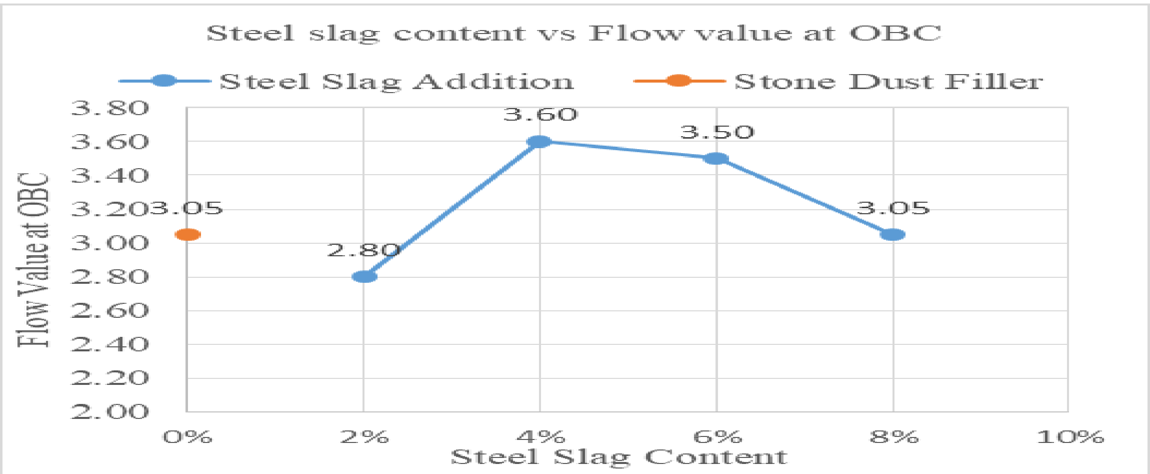


Table 9 Variation of Stability (KN) with Bitumen Content

	4%	4.50%	5%	5.50%	6%	6.50%	7%
AMFSD		12.2	14	12.4	11.3	10.6	
AMFSS2	16.9	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	12.7

Table 10 Variation of Air voids with Bitumen content

	4%	4.50%	5%	5.50%	6%	6.50%	7%
AMFSD		6.2	5.3	4.2	4.1	3.7	
AMFSS2	8	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 11 Variation of Marshall Flow Value (mm) with Bitumen Content

	4%	4.50%	5%	5.50%	6%	6.50%	7%
AMFSD		2.48	2.82	3.02	3.15	3.37	
AMFSS2	2.5	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

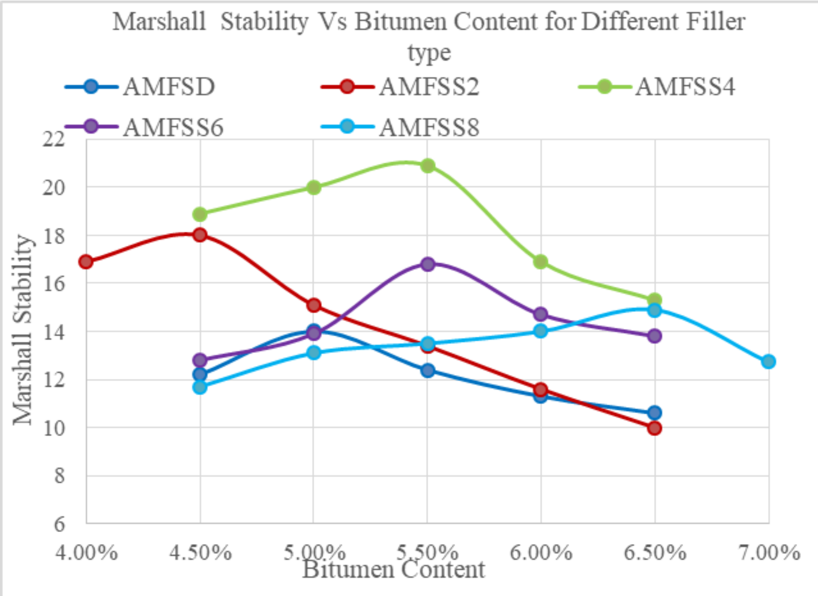
Table 12 Variation of Unit wt (gm/cm3) with Bitumen content

	4%	4.50%	5%	5.50%	6%	6.50%	7%
AMFSD		2.33	2.34	2.35	2.33	2.33	
AMFSS2	2.29	2.29	2.30	2.30	2.32	2.33	
AMFSS4		2.26	2.30	2.33	2.35	2.35	
AMFSS6		2.26	2.27	2.30	2.32	2.34	
AMFSS8		2.25	2.29	2.32	2.32	2.32	2.33

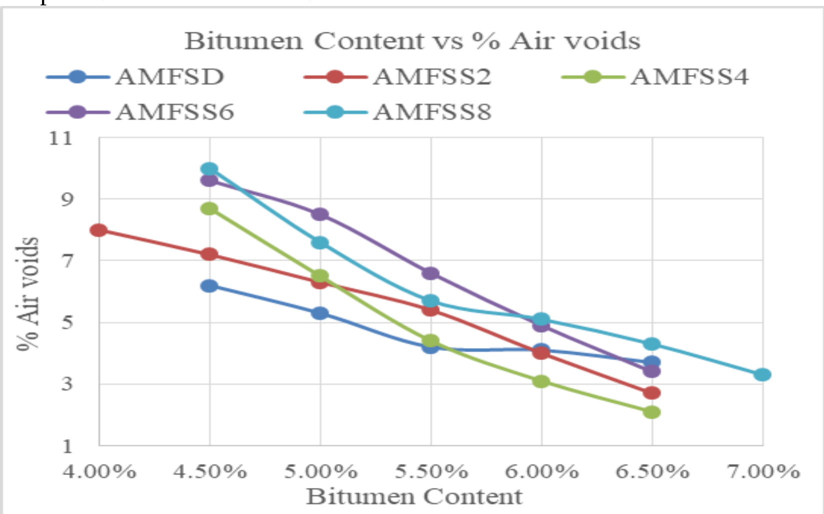
Table 13 Variation of VFB with Bitumen Content

	4%	4.50%	5%	5.50%	6%	6.50%	7%
AMFSD		61.9	67.9	74.7	76.6	79.7	
AMFSS2	52.3	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

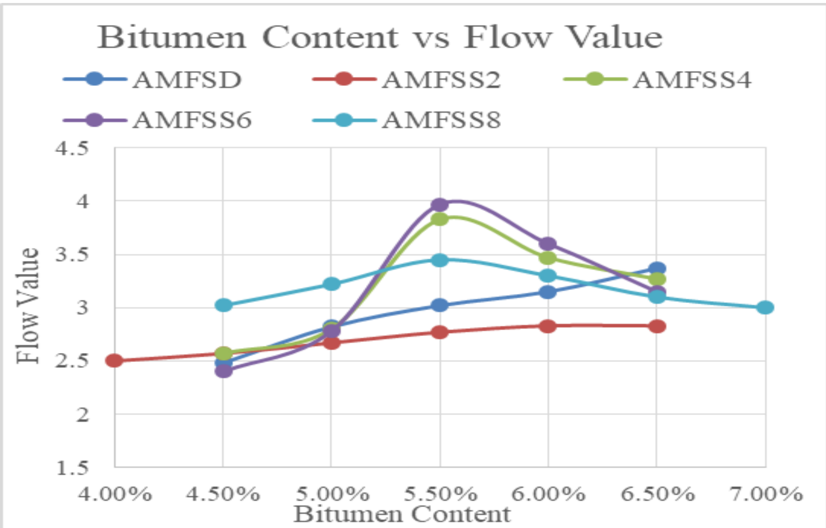
Graph 4 Variation of Stability Value (KN) with Bitumen Content



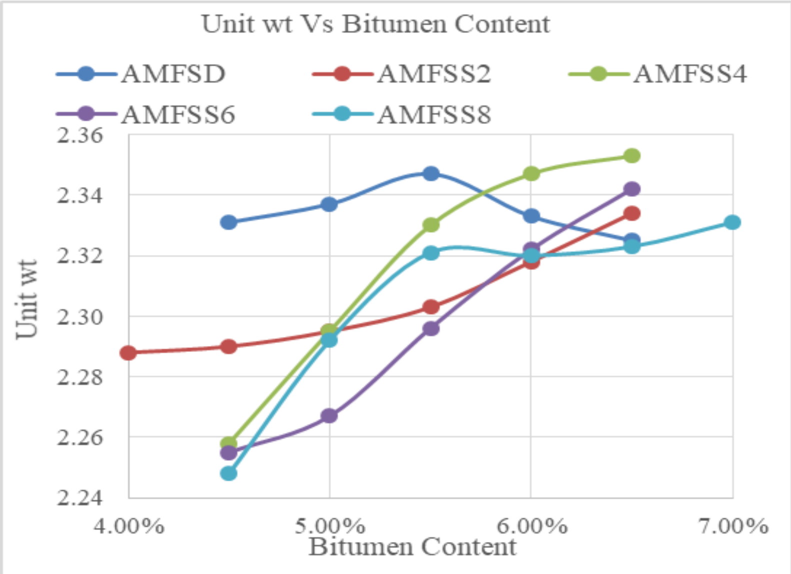
Graph 5 Variation of % Air Voids with Bitumen Content



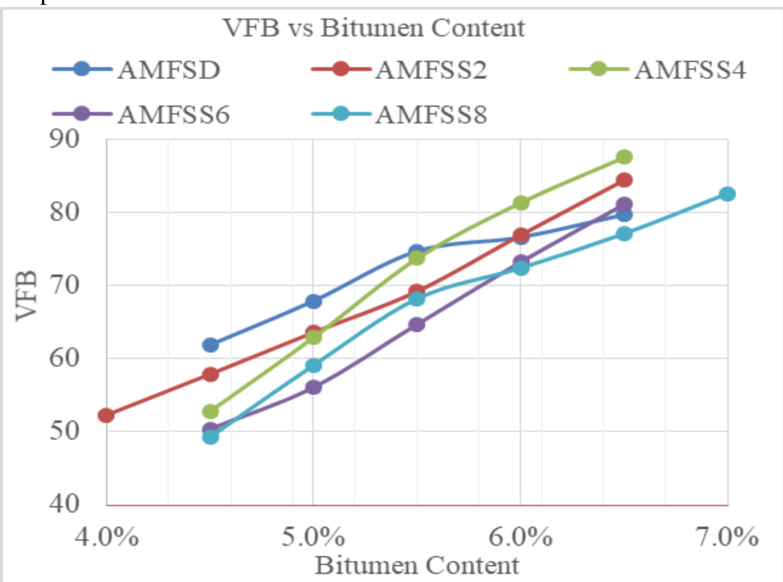
Graph 6 Variation of Flow Value (mm) with Bitumen Content



Graph 7 Variation of Unit wt(gm/cm3) with Bitumen Content



Graph 8 Variation of VFB with Bitumen Content



The result of Marshall Test is enlisted as follows:

A. Control Sample (AMFSD)

The base sample was prepared by following standard Marshall Mix design methodology, using 6.2% stone dust filler, as per the Standard Specifications for Roads and Bridges, 2073, Department of Roads. Total 15 number of samples were prepared. The Marshall Stability Value, Flow Value, Measured density, Voids in total mix, Volume of Bitumen in the mix, VMA and VFB values were obtained from the calculation of datas collected from laboratory work. The detail calculation is shown in the appendix.

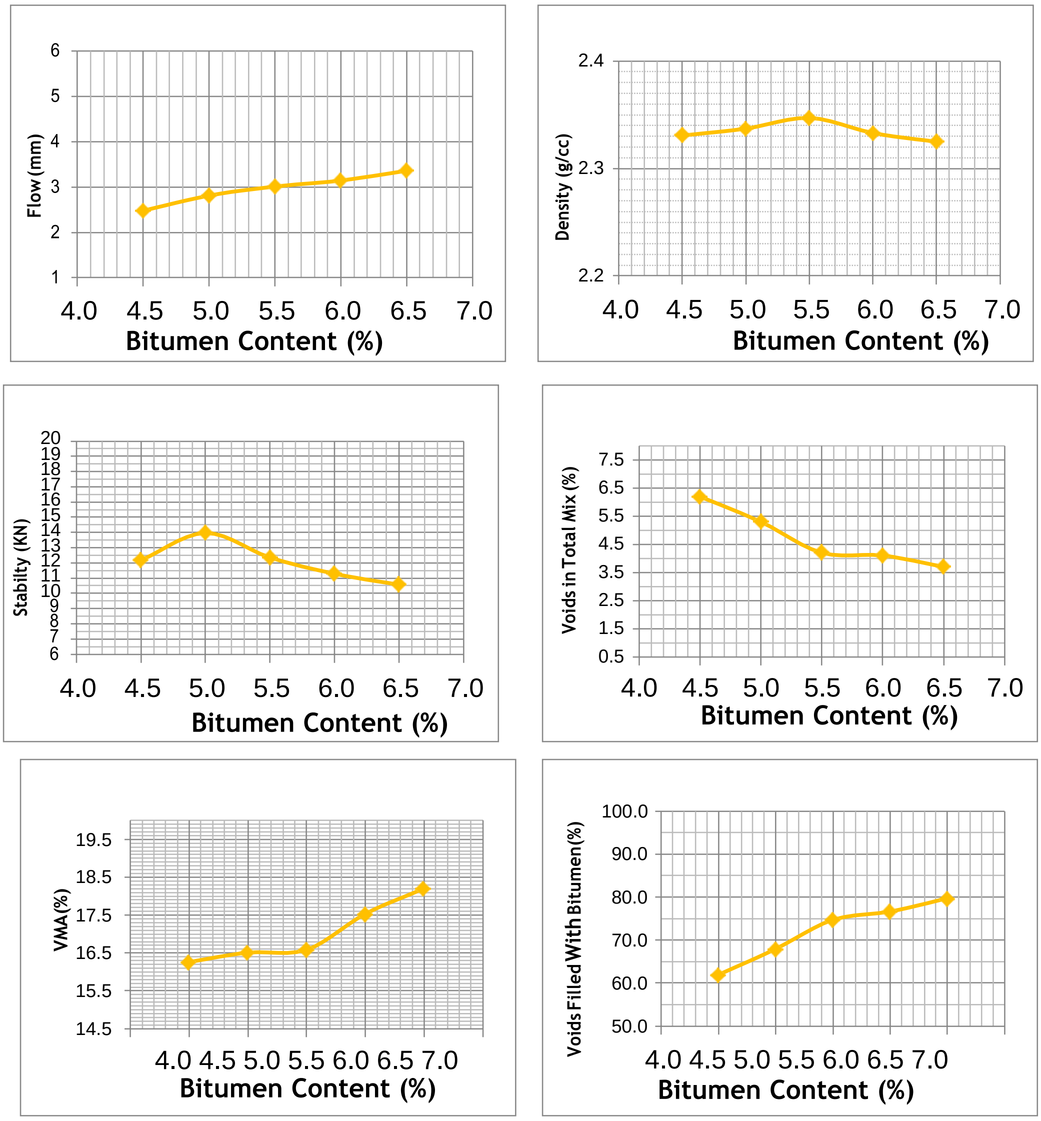
The Optimum Bitumen Content value has been calculated to be 5.67%. The Stability value at OBC is found to be 11.55 KN and corresponding flow value of 3.05 mm is obtained.

The result of Marshall Test is shown in table below.

Table 14 Marshall Result Summary AMFSD

S. No.	DESCRIPTION	UNIT	BITUMEN CONTENT, P x 100				
			4.5	5.0	5.5	6.0	6.5
1	MARSHALL STABILITY	KN	12.2	14.0	12.4	11.3	10.6
2	FLOW VALUE	mm	2.48	2.82	3.02	3.15	3.37
3	MEASURED DENSITY, g'	gm/cm^3	2.331	2.337	2.347	2.333	2.325
4	THEORETICAL DENSITY, g	gm/cm^3	2.484	2.467	2.449	2.432	2.415
5	VOIDS IN TOTAL MIX, V_m	%	6.20	5.30	4.20	4.10	3.70
6	VOLUME OF ASPHALT IN THE MIX, V_b	%	10.07	11.21	12.39	13.43	14.50
7	VOIDS IN MINERAL AGG; VMA	%	16.3	16.5	16.6	17.5	18.2
8	VOIDS FILLED WITH BITUMEN, VFB	%	61.9	67.9	74.7	76.6	79.7

Graph 9 Graphical Analysis of Marshall Test Result for Control Sample (AMFSD)



B. 2 % Steel Slag Filler (AMFSS2)

The sample was prepared by following standard Marshall Mix design methodology, using 2% Steel Slag filler, as per the Standard Specifications for Roads and Bridges, 2073, Department of Roads. Total 18 number of samples were prepared. The Marshall Stability Value, Flow Value, Measured density, Voids in total mix, Volume of Bitumen in the mix, VMA and VFB values were obtained from the calculation of data's collected from laboratory work. The detail calculation is shown in the appendix.

The Optimum Bitumen Content value has been calculated to be 5.67%. The Stability value at OBC is found to be 12.55 KN and corresponding flow value of 2.80 mm is obtained.

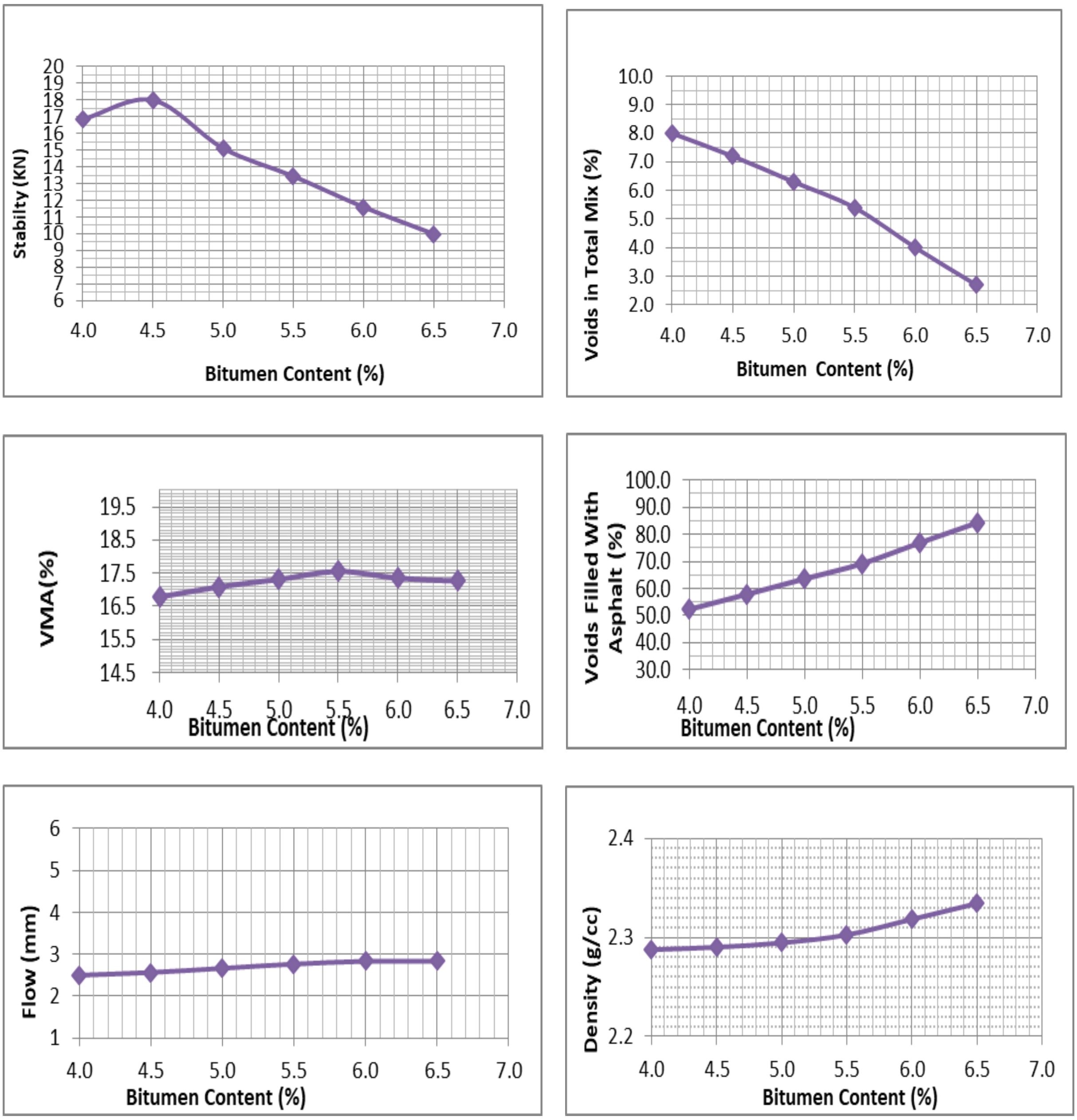
The result of Marshall Test is shown in table below.

Table 15 Marshall Result Summary AMFSS2

S. No.	DESCRIPTION	UNIT	BITUMEN CONTENT, P x 100					
			4.0	4.5	5.0	5.5	6.0	6.5
1	MARSHALL STABILITY	KN	16.9	18.0	15.1	13.4	11.6	10.0
2	FLOW VALUE	mm	2.50	2.57	2.67	2.77	2.83	2.83
3	MEASURED DENSITY, g'	gm/cm^3	2.288	2.290	2.295	2.303	2.318	2.334
4	THEORETICAL DENSITY, g	gm/cm^3	2.486	2.468	2.450	2.433	2.416	2.399
5	VOIDS IN TOTAL MIX, V_m	%	8.00	7.20	6.30	5.40	4.00	2.70
6	VOLUME OF ASPHALT IN THE MIX, V_b	%	8.78	9.89	11.01	12.15	13.35	14.56
7	VOIDS IN MINERAL AGG; VMA	%	16.8	17.1	17.3	17.6	17.3	17.3
8	VOIDS FILLED WITH ASPHALT, V_a	%	52.3	57.9	63.6	69.2	76.9	84.4

Graphical Analysis

Graph 10 Graphical Analysis of Marshall Test Result for 2 % Steel Slag Filler



C. 4% Steel Slag

The sample was prepared by following standard Marshall Mix design methodology, using 4% Steel Slag filler, as per the Standard Specifications for Roads and Bridges, 2073, Department of Roads. Total 15 number of samples were prepared. The Marshall Stability Value, Flow Value, Measured density, Voids in total mix, Volume of Bitumen in the mix, VMA and VFB values were obtained from the calculation of datas collected from laboratory work. The detail calculation is shown in the appendix.

The Optimum Bitumen Content value has been calculated to be 5.87%. The Stability value at OBC is found to be 18 KN and corresponding flow value of 3.6 mm is obtained.

The Stability value obtained is found to be 1.55 times greater than that of base sample.

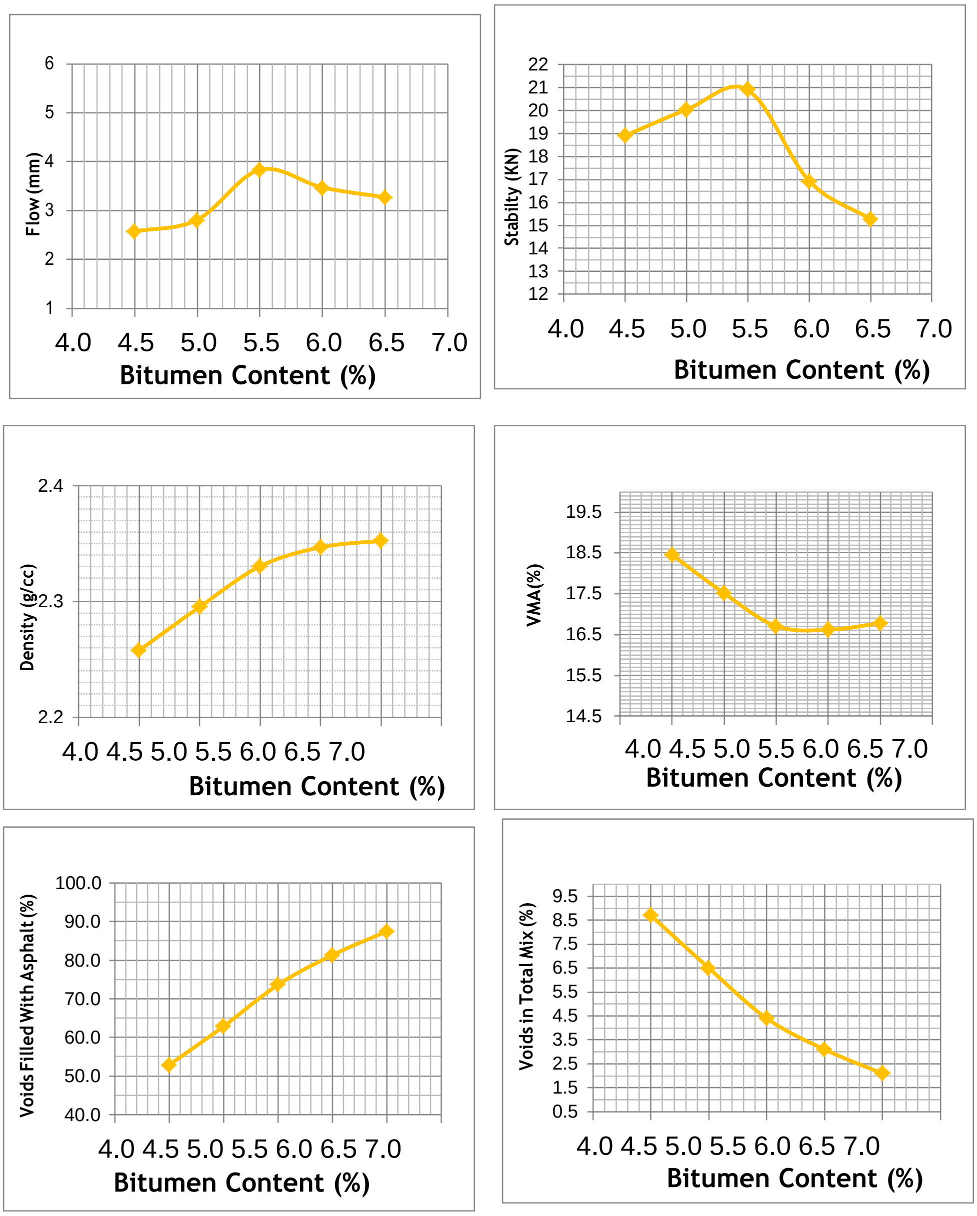
The result of Marshall Test is shown in table below.

Table 16 Marshall Test Result Summary for 4 % Steel Slag Filler (AMFSS4)

S. No.	DESCRIPTION	UNIT	BITUMEN CONTENT, P x 100				
			4.5	5.0	5.5	6.0	6.5
1	MARSHALL STABILITY	KN	18.9	20.0	20.9	16.9	15.3
2	FLOW VALUE	mm	2.57	2.80	3.83	3.47	3.27
3	MEASURED DENSITY, g'	gm/cm^3	2.258	2.295	2.330	2.347	2.353
4	THEORETICAL DENSITY, g	gm/cm^3	2.473	2.456	2.438	2.421	2.404
5	VOIDS IN TOTAL MIX, V_m	%	8.70	6.50	4.40	3.10	2.10
6	VOLUME OF ASPHALT IN THE MIX, V_b	%	9.75	11.01	12.30	13.51	14.68
7	VOIDS IN MINERAL AGG; VMA	%	18.5	17.5	16.7	16.6	16.8
8	VOIDS FILLED WITH ASPHALT, V_a	%	52.8	62.9	73.7	81.3	87.5

Graphical Analysis

Graph 11 Graphical Analysis of Marshall Test Result for 4 % Steel Slag Filler (AMFSS4)



D. 6% Steel Slag

The sample was prepared by following standard Marshall Mix design methodology, using 8% Steel Slag filler, as per the Standard Specifications for Roads and Bridges, 2073, Department of Roads. Total 15 number of samples were prepared. The Marshall Stability Value, Flow Value, Measured density, Voids in total mix, Volume of Bitumen in the mix, VMA and VFB values were obtained from the calculation of data's collected from laboratory work. The detail calculation is shown in the appendix.

The Optimum Bitumen Content value has been calculated to be 6.08%. The Stability value at OBC is found to be 14.5 KN and corresponding flow value of 3.5 mm is obtained.

The Stability value obtained is found to be 1.255 times greater than that of base sample.

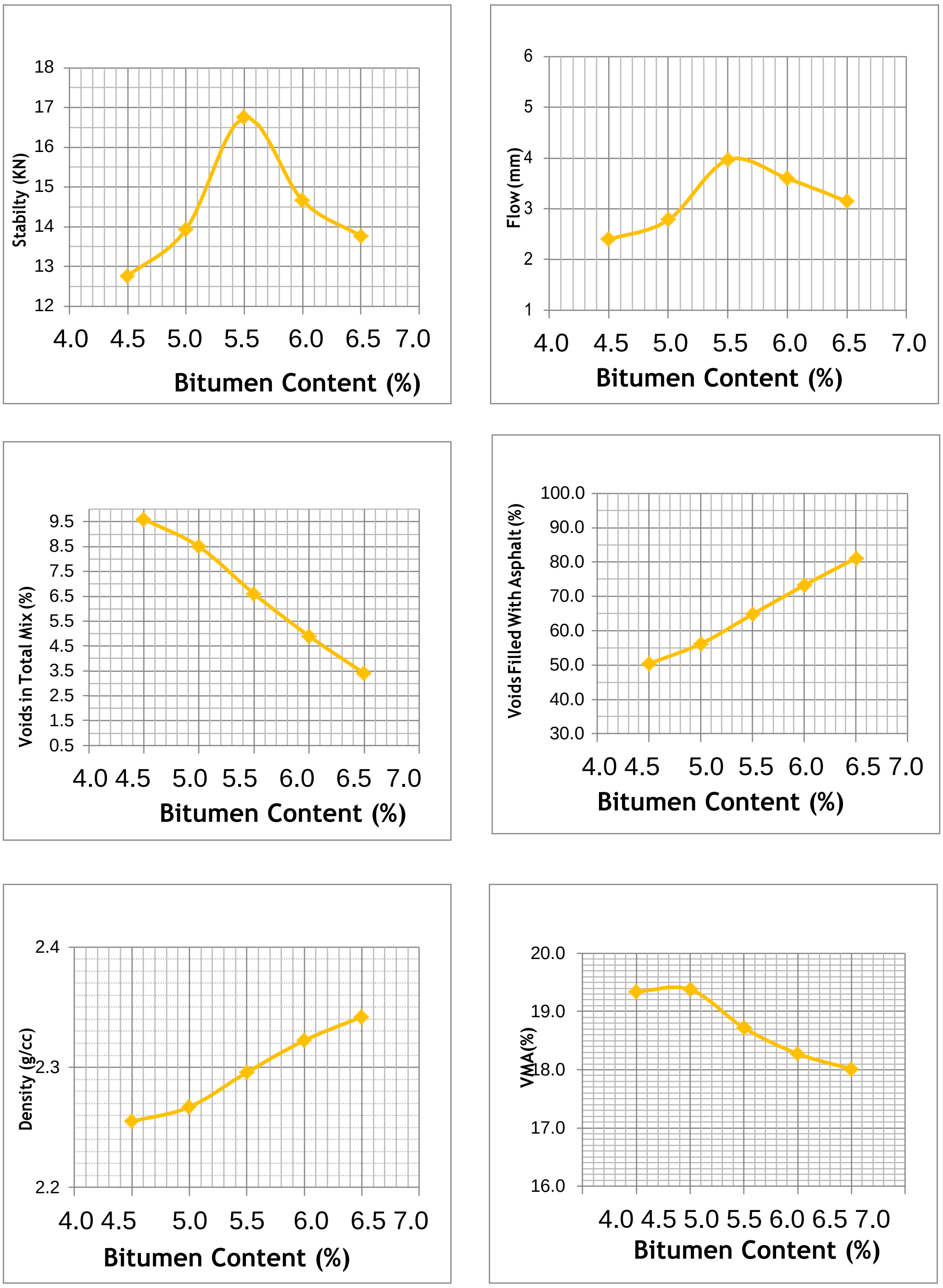
The result of Marshall Test is shown in table below.

Table 17 Marshall Test Result Summary for 6 % Steel Slag Filler (AMFSS6)

S. No.	DESCRIPTION	UNIT	BITUMEN CONTENT, P x 100				
			4.5	5.0	5.5	6.0	6.5
1	MARSHALL STABILITY	KN	12.8	13.9	16.8	14.7	13.8
2	FLOW VALUE	mm	2.40	2.78	3.97	3.60	3.15
3	MEASURED DENSITY, g'	gm/cm^3	2.255	2.267	2.296	2.322	2.342
4	THEORETICAL DENSITY, g	gm/cm^3	2.495	2.477	2.459	2.441	2.424
5	VOIDS IN TOTAL MIX, V_m	%	9.60	8.50	6.60	4.90	3.40
6	VOLUME OF ASPHALT IN THE MIX, V_b	%	9.74	10.88	12.12	13.37	14.61
7	VOIDS IN MINERAL AGG; VMA	%	19.3	19.4	18.7	18.3	18.0
8	VOIDS FILLED WITH ASPHALT, V_a	%	50.4	56.1	64.7	73.2	81.1

Graphical Analysis

Graph 12 Graphical Analysis of Marshall Test Result for 6 % Steel Slag Filler (AMFSS6)



E. 8% Steel Slag

The sample was prepared by following standard Marshall Mix design methodology, using 8% Steel Slag filler, as per the Standard Specifications for Roads and Bridges, 2073, Department of Roads. Total 18 number of samples were prepared. The Marshall Stability Value, Flow Value, Measured density, Voids in total mix, Volume of Bitumen in the mix, VMA and VFB values were obtained from the calculation of datas collected from laboratory work. The detail calculation is shown in the appendix.

The Optimum Bitumen Content value has been calculated to be 5.87%. The Stability value at OBC is found to be 14 KN and corresponding flow value of 3.05 mm is obtained.

The Stability value obtained is found to be 1.212 times greater than that of base sample.

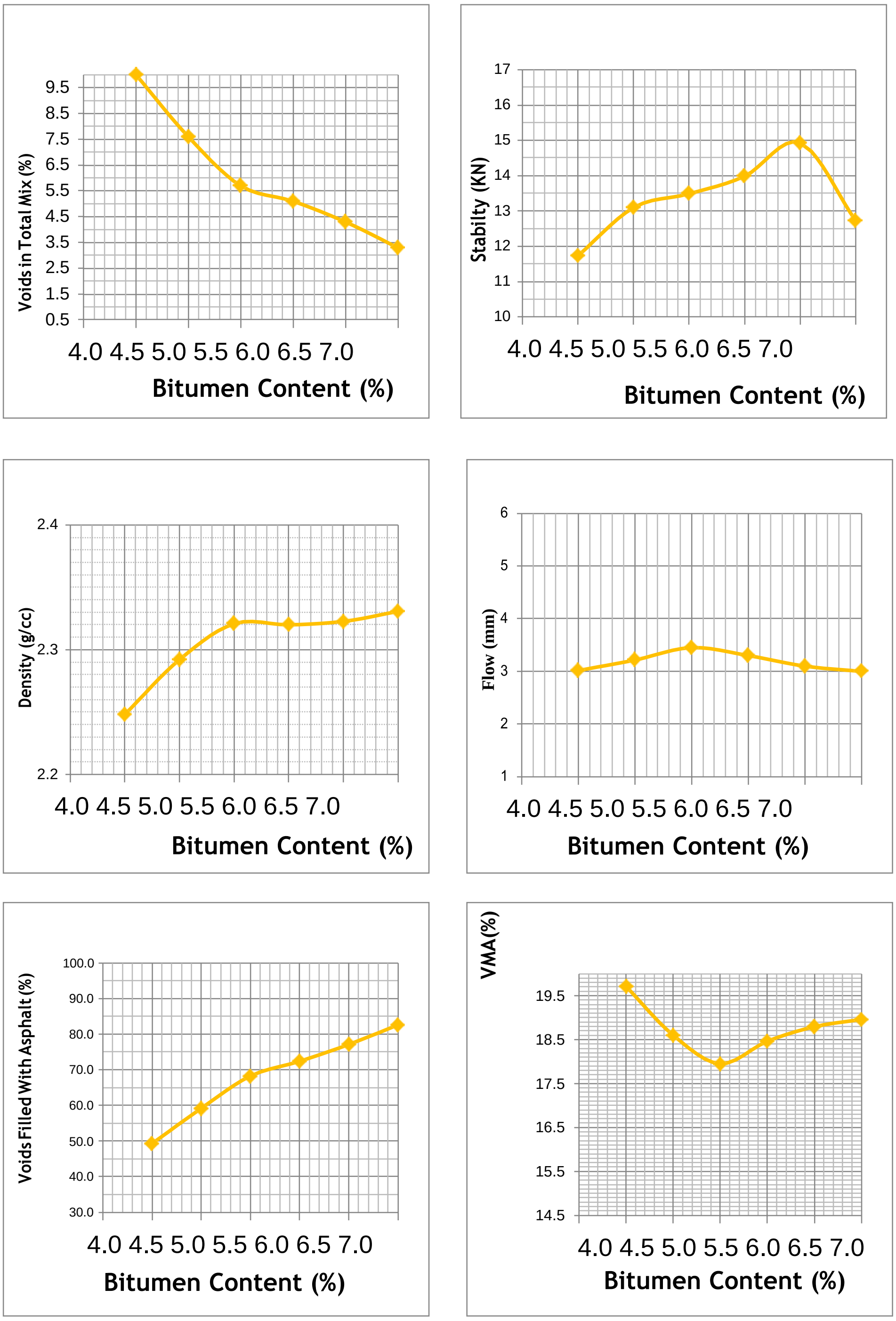
The result of Marshall Test is shown in table below.

Table 18 Marshall Test Result Summary for 8 % Steel Slag Filler (AMFSS8)

S. No.	DESCRIPTION	UNIT	BITUMEN CONTENT, P x 100					
			4.5	5.0	5.5	6.0	6.5	7.0
1	MARSHALL STABILITY	KN	11.7	13.1	13.5	14.0	14.9	12.724
2	FLOW VALUE	mm	3.02	3.22	3.45	3.30	3.10	3.000
3	MEASURED DENSITY, g'	gm/cm^3	2.248	2.292	2.321	2.320	2.323	2.331
4	THEORETICAL DENSITY, g	gm/cm^3	2.499	2.480	2.462	2.445	2.427	2.410
5	VOIDS IN TOTAL MIX, V_m	%	10.00	7.60	5.70	5.10	4.30	3.30
6	VOLUME OF ASPHALT IN THE MIX, V_b	%	9.71	11.00	12.25	13.36	14.49	15.66
7	VOIDS IN MINERAL AGG; VMA	%	19.7	18.6	17.9	18.5	18.8	19.0
8	VOIDS FILLED WITH ASPHALT, V_a	%	49.3	59.1	68.2	72.4	77.1	82.6

Graphical Analysis

Graph 13 Graphical Analysis of Marshall Test Result for 8 % Steel Slag Filler (AMFSS8)



4.1 Retained Strength of Asphalt Concrete

Marshall Retained Stability Test is conducted on the Marshall samples for 4% Steel Slag Filler content and OBC of 5.87% mixture to measure the resistance of mix 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 19 shows the summary of Retained Marshall Stability test results.

Table 19 Summary of Retained Strength of Asphalt mix

Specimen No	Thickness	wt in air, gm	wt in water,gm	wt of SSD Sample, gm	Stability	Flow	Density of Specimen
B1	63.70	1201.3	691.5	1203.5	19.1	2.38	2.346
B2	62.87	1183.5	680.3	1184.7	19.2	2.43	2.346
B3	65.50	1198.3	680.9	1194.8	16.3	1.97	2.332
B4	64.37	1189.8	683.1	1192.4	16.6	2.07	2.336

Index of Retained Strength, %= (16.3+16.6)/ (19.1+19.2) = 85.90%

4.2 Financial Analysis

The Rate analysis was done according to the Norms for Rate analysis of Road and Bridge works, Department of Roads. The financial analysis was done by using the District Rate of Rupandehi district for labor and material, Equipment rate was taken from Department of Roads, Equipment hire rate and 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) and the rate of fuel was taken from Nepal oil Corporation.

There is very little production of steel slag in Nepal and all the Steel slag quantity required for Slag Cement Production is currently importing from India. There is the possibility of establishment of Steel Industry in our country very soon. So, in the financial analysis section, 2 scenarios could be assumed. 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, whereas in scenario-II, the rate of slag is taken considering that Granulated Slag is taken from Indian market i.e. Present Case scenario.

Table 20 Material Cost, Scenario I (without lead)

	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

Table 21 Material Cost, Scenario II (without lead)

	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

Table 22 Financial Analysis of Asphalt mix with different filler proportion

		per m3	0%	2%	4%	6%	8%
Labour	Skilled	0.03	26.55	26.55	26.55	26.55	26.55
	Unskilled	0.13	81.90	81.90	81.90	81.90	81.90
Material (Case -1)			11412.73	11212.95	11655.76	11767.71	12765.78
Material (Case -2)			11412.73	11409.52	12054.10	12360.05	13550.39
Equipment	Batch Mix HMP	0.044	303.215	303.215	303.215	303.215	303.215
	Paver finisher	0.220	325.875	325.875	325.875	325.875	325.875
	Steel tyred roller	0.550	319.688	319.688	319.688	319.688	319.688
	Wheeled loader	0.660	1188.000	1188.000	1188.000	1188.000	1188.000
	Tripper/Trucks	0.320	243.600	243.600	243.600	243.600	243.600
	Pneumatic roller	0.550	418.688	418.688	418.688	418.688	418.688
Total Cost (Scenario-I)			14320.241	14120.470	14563.275	14675.223	15673.297
Total Cost (Scenario-II)			14320.241	14317.039	14961.617	15267.566	16457.906

4.3 Discussion and Conclusion

This study presents and discusses the results of using steel slag filler instead of Stone dust filler, to evaluate the probability and effectiveness of using steel slag filler in construction of Asphalt Concrete Pavement. The results indicate that the use of steel slag in Asphalt Concrete mixtures can enhance the Marshall properties of mixtures.

The Asphalt Concrete mix with Stone dust as a filler had the Marshall Stability value of 11.55 KN at the Optimum Bitumen Content. However, the use of steel slag Asphalt Concrete mix with Steel slag filler resulted in higher value of Marshall Stability than 11.55 KN in each of the steel slag filler content used (i.e. 2%, 4%, 6%, 8%).Marshall Stability value of Asphalt Concrete mixes with Steel slag filler content 2%, 4%, 6% &

8% has been found to be 1.08, 1.558, 1.225 and 1.212 times respectively higher than that of AC mix with Stone filler. This indicates that the Asphalt concrete mix with steel slag filler will have higher rutting resistance.

The flow value for asphalt concrete mixtures with Steel slag filler content of 2%, 4%, 6% & 8% was found to be 2.80 mm, 3.60 mm, 3.50 mm and 3.05 mm, whereas the flow value for asphalt concrete mixtures with stone dust filler was found to be 3.05 mm. These all mixes follows the range (2 to 4 mm) given by Standard Specifications for Roads and Bridges, 2073.

The Marshall Quotient values increased in Asphalt concrete mixtures that contained steel slag. The use of steel slag as filler in Asphalt Concrete mix for 2%, 4%, 6% & 8% slag content resulted in an increase in MQ values by 1.182, 1.319, 1.092 & 1.211 times respectively compared to samples that contained stone dust as a filler. Marshall Quotient is an indicator of the resistance against the deformation of the asphalt concrete. Higher Marshall Quotient value indicates a high stiffness mixture with a great ability to resist creep deformation. The use of steel slag in Asphalt concrete mixes therefore makes a positive contribution to asphalt pavements' overall performance.

Retained stability value of more than 70% is suggested as a criterion for a mixture to be resistant to moisture induced damages. As the value of Index of Retained Stability has been found to be 85.90%, the AMFSS4 have shown the better result towards the moisture susceptibility.

4.3.1 Conclusions

In this research, the effectiveness of using steel slag as a filler was judged by the Marshall Test methodology. The following conclusions can be drawn:

i. 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.

ii. The 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 higher than that of asphalt concrete mix with stone dust as a filler at Optimum Bitumen content.

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

iv. 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.

v. The value of Index of Restrained Strength was found to be 85.90%.

vi. For present case scenario, i.e. Steel slag to be imported from India, the construction cost of Asphalt Concrete Pavement with Stone dust filler will be equal to that of Asphalt Concrete Pavement with 2% Steel slag filler content. Whereas, construction cost of Asphalt Concrete Pavement with 4%, 6% & 8% steel slag content will become costlier.

vii. For future case scenario, i.e. steel slag is taken from local steel factory, the construction cost of Asphalt Concrete Pavement with 2% Steel slag filler content will lesser than that of Asphalt Concrete Pavement with Stone dust filler. Whereas, construction cost of Asphalt Concrete Pavement with 4%, 6% & 8% steel slag content will become costlier.

LITERATURE CITED:

Arun, K.R., S. Narayanan, M.S. Thangapandiyan and R. R Venkateshwaran. 2018. Comparative Study of Steel Slag with Coarse Aggregate and Testing Its Binding Properties with Bitumen.

Asi, I.M., H.Y. Qasrawi and F.I. Shalabi. 2007. Use of Steel Slag Aggregate in Asphalt Concrete Mixes. **Canadian Journal of Civil Engineering**. 34(8): 902-911.

ASTM D1075-81, "Standard Method of Test for Effect of Water on Cohesion of Compacted Bituminous Mixtures"

Aziz, M.M.A., M.R. Hainin, H. Yaacob, Z. Ali, F.L. Chang and A.M. Adnan. 2014. Characterisation and Utilisation of Steel Slag for the Construction of Roads and Highways. **Materials Research Innovations**. 18(sup6): S6-255-S256- 259.

Behnood, A. and M. Ameri. 2012. Experimental Investigation of Stone Matrix Asphalt Mixtures Containing Steel Slag. **Scientia Iranica**. 19(5): 1214-1219.

CRD-C 652-95 (1995), "Standard Test Method for Measurement of Reduction in Marshall Stability of Bituminous Mixtures Caused by Immersion in Water"

Khodary, F. 2015. Comparative Study of Using Steel Slag Aggregate and Crushed Limestone in Asphalt Concrete Mixtures. 6(3): 73-82.

Maharaj, C., D. White, R. Maharaj and C. Morin. 2017. Re-Use of Steel Slag as an Aggregate to Asphaltic Road Pavement Surface. **Cogent Engineering**. 4(1): 1416889.

Patil, S.B. and D.S. Patil. 2013. Evaluation of Cost Effective Material for Maintenance of Flexible Pavement. 4(72-78).

Shreemanth, M., K.P. Shivananda and J.K. Dattattreya3. 2015. Effect of Replacement of Fine Aggregate by Steel Slag Aggregates in Concrete. **Journal of Civil Engineering and Environmental Technology**.

U.S. Department of Transportation, F.H.A.N.J.A., SE Washington, DC 20590 202-366-4000. 2019. **User Guidelines for Waste and Byproduct Materials in Pavement Construction.**

Vahora and Mishra. 2017. Study of Retained Stability on Warm Bituminous Mix. International Conference on Research and Innovations in Science, Engineering &Technology. Selected papers in Civil Engineering. (144-149)

Zumrawi, M.M., F.O.J.W.A.o.S. Khalill, Engineering, I.J.o.C. Technology, Environmental, Structural, Construction and A. Engineering. 2015. Experimental Study of Steel Slag Used as Aggregate in Asphalt Mixture. 9(6): 753-758.