EFFECT OF AGGREGATE GRADATION & COMPACTIVE EFFORT ON MARSHALL PROPERTIES OF DENSE BITUMINOUS MACADAM MIX GRADE-II

A Dissertation Submitted
In Partial Fulfillment of the Requirements
for the degree of

MASTERS OF ENGINEERING
IN
INFRASTRUCTURE ENGINEERING

Submitted by:
HARJINDER KAUR
(ROLL NO. 801423004)

UNDER THE SUPERVISION OF

Er. TANUJ CHOPRA
Assistant Professor
Department of Civil Engineering
Thapar University, Patiala

DEPARTMENT OF CIVIL ENGINEERING
THAPAR UNIVERSITY,
PATIALA-147004
JULY 2016

DECLARATION

I, Harjinder Kaur, hereby declare that this dissertation titled **"Effect of Aggregate Gradation & Compactive Effort on Marshall Properties of Dense Bituminous Macadam Mix Grade-II"** is an authentic record of my study carried out as requirements for the award of degree of **Master of Engineering** in **Infrastructure Engineering** in the Civil Engineering Department, Thapar University, Patiala under the supervision of **Mr. Tanuj Chopra, Assistant Professor,** Department of Civil Engineering, Thapar University, Patiala during July 2015 to July 2016 . This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

Date: 15/7/2016

Harjinder Kaur
(Harjinder Kaur)
Roll No. :801423004

CERTIFICATE

This is to certify that above statement made by the student concerned is correct and true to the best of my knowledge and belief.

Mr. Tanuj Chopra
Assistant Professor
Department of Civil Engineering
Thapar University, Patiala

Countersigned by

Dr. Naveen Kwatra
~~*Associate*~~ *Professor & Head*
Department of Civil Engineering
Thapar University, Patiala- 147004

Dr. S.S.Bhatia
Dean of Academic Affairs
Thapar University, Patiala-147004

ACKNOWLEDGMENT

A thesis cannot be completed without the help of many people who contribute directly or indirectly through their constructive criticism in the evolution and preparation of this work. It would not be fair on my part, if I don't say a word of thanks to all those whose sincere advice made this period a real educative, enlightening, pleasurable and memorable one.

First of all, a special debt of gratitude is owned to my supervisor, **Mr. Tanuj Chopra, Assistant Professor,** Department of Civil Engineering, Thapar University, Patiala for his gracious efforts and keen pursuits, which has remained as a valuable asset for the successful completion of research work. His dynamism and diligent enthusiasm has been highly instrumental in keeping my spirit high. His flawless and forthright suggestions blended with an innate intelligent application have crowned my task. I would like to express my gratitude to **Dr. Naveen Kwatra, Head of department of Civil Engineering**, Thapar University, Patiala for his kind cooperation and encouragement which helped in the completion of work.

I am extremely thankful **to Mr. Amarjit Singh** for helping me carry out experimental work.

I would also like to thank my parents and my friends for their constant encouragement during the entire course of my thesis work.

Harjinder Kaur

ABSTRACT

India has a road network of over 4.69 million kilometers, second large roadways in the world. The road transport carries close to 5% of passenger traffic and 70% of freight transport. The bituminous mix design aims to determine the proportion of bitumen, filler, fine aggregates, and coarse aggregates to produce a mix which is workable, strong, durable and economical. An aggregate’s particle size distribution, or gradation, is one of its most influential characteristics. In hot-mix asphalt, gradation helps to determine almost every important property including stiffness, stability, durability, permeability, workability, fatigue resistance, and resistance to moisture damage. Gradation is usually measured by a sieve analysis.

Dense Bituminous Macadam is a binder course in the highway pavement. Bituminous mixes are most commonly used in flexible pavement construction. Marshall properties of bituminous mix vary from binder to binder. DBM. mix is a heterogeneous material that consists of aggregate, filler, bitumen binder, stone dust and air voids. Marshall mix design method is used to decide the optimum bitumen content (OBC) and Marshall properties were determined at optimum bitumen content.

Gradation is one of most important factors influencing the Marshall Properties of DBM mix, so it is required to select best aggregates gradation. The optimum gradation is the one that which gives the highest density. When fine particles are properly packed between coarser particles, this reduces the voids space between to specified limit. Thus improves the density and is called the optimum gradation.

The present study aims to determine the Marshall properties of DBM mix, such as Stability, Flow, density, Voids in mineral aggregate, Voids filled with bitumen and Air voids percentage by using three types of aggregate gradation (MORTH, ASTM and Kandhal gradation) and three types of compactive effort (50 blows, 75 blows and 100 blows) for each gradation according to low, medium and high traffic at 4%, 4.5%, 5% and 5.5%. It is important to analyze that how the variation in aggregate gradation can affect the Marshall Mix properties of DBM without affecting the durability of pavement. The Maximum Marshall Stability is 27.44 obtained at 5% of bitumen content at 100 blows of MORTH Gradation. For the ASTM Gradation the maximum Marshall Stability is 18.43 at 5% of bitumen at 50 blows.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER – 1

INTRODUCTION

1.1 General

Earlier due to scarcity of cement, it was trend and convention to adopt the bituminous pavement as flexible pavement. Therefore, bituminous pavements are adopted over cement concrete roads. A good bituminous mix design is required to produce a mix which is supposed to be sufficient, long-lasting and resistive. And also effective compaction is an essential pre-requisite foe obtaining the best performance bituminous mixes for greater load spreading ability, improved resistance to deformation and fatigue cracking. The purpose of bituminous mix design is to determine the proportion of bitumen, filler, fine aggregate and coarse aggregate to produce a mix which is workable, strong, durable and economical. Coarse and fine aggregate acts as the structural skeleton of pavement while asphalt function as the binder for the mixture.

1.2 Flexible Pavement

Flexible pavements are so named because the total pavement structure deflects, or flexes under loading. A flexible pavement structure is typically composed of several layers of material. Each layer receives the loads from the above layer, spreads them out and then passes loads to the next layer below. Typically flexible pavement structure shown in Figure 1.1 consisting of: -

Figure 1.1: Components of Flexible Pavement Section

a. **Surface Course:** This is the top layer that comes in contact with traffic. It may be composed of one or several different hot mix asphalt sub-layers. HMA is a mixture of coarse and fine aggregates and asphalt binders with or without additives.
b. **Base Course:** This is the layer directly below hot mix asphalt and generally consists of aggregate.
c. **Sub-base Course:** This is the layer (or layers) under the base layer. A sub-base is not always required.
d. **Sub-grade Course:** The sub-grade is the material upon which the pavement structure is placed. Although there is a tendency to look at pavement performance in terms of pavement crust structure material, mix design and thickness but the sub-grade can often be the overriding factor in the overall pavement performance. The CBR value of the sub-grade material is generally used to design the total pavement crust thickness as per IRC: 37-2012 guidelines.

A flexible pavement structure is typically composed of several layers (as shown in figure 1.1) of material with better quality materials on top where the intensity of stress from traffic loads. Flexible pavements can be analyzed as a multilayer system under loading and are constructed by using different layers such as Bituminous concrete (BC), Dense Bituminous Macadam (DBM), Bituminous Macadam (BM), Wet Mix Macadam (WMM) and Granular sub-base (GSB) as per the MORTH Specifications with the designed thickness as per the IRC: 37-2012 .

1.3 Bituminous Mixes for Flexible Pavement Layers

Bituminous mixes are composite materials that consist of a binder mixed with filler/fines and aggregates. The mixes of asphalt pavements consist of bituminous binder that connect between the filler together and the aggregates. In India, MORTH Specifications provides different mix specifications foe base courses, binder courses and for wearing courses. The major properties in bituminous paving mixtures are stability, flow, durability, flexibility and skid resistance (in case of wearing surface). Traditional mix design methods are established to determine the optimum bitumen content that would perform satisfactorily, particularly with respect to stability and flow values. Selection of the components and their relative proportions are influenced by the pavement section in which the mix is to be incorporated. Design of bitumen-aggregate mixes for the different layers broadly consists of the following steps:

- Selection of the type and gradation of the mineral aggregates.
- Selection of the type and grade of binder.
- Selection of the amount of binder to satisfy the project specific requirements for mix properties.

The Marshall properties of bituminous mixes of DBM can be determined (or compared) while using different types of aggregate gradation (MORTH, ASTM and KANDHAL gradation) and different types of compacted effort (50 blows, 75 blows and 100 blows).

1.4 Dense Bituminous Macadam Mix

Dense Bituminous macadam is mainly used as binder course for roads having much higher number of heavy commercial vehicles. In DBM mix there is a wide scope of varying the gradation to obtain the good mix without affecting the durability of pavement. Achieve adequate compaction of bituminous mixes is crucial to the performance of flexible pavement. Normally Marshall Mix design method is adopted for mix design of Dense Graded Bituminous Macadam. DBM is also intended for use as road base material. The construction work of DBM consists of construction in a single layer of DBM on a previously prepared base or sub-base layer.

1.5 Material Specifications for DBM Mix

1.5.1 Bitumen

The bitumen for the DBM is the paving bitumen of Penetration Grade complying with Indian Standard Specifications for "Paving Bitumen" IS: 73 and of the penetration specified by MOSRT&H Specification for Road and Bridge works (IV Revision) Reprint March 2007 for Dense Bituminous Macadam.

1.5.2 Coarse Aggregates

The coarse aggregates for the DBM mix consists of crushed rock, crushed gravel or other hard material retained on the 2.36 mm sieve. Aggregate should be clean, hard, and durable, of cubical shape, free from dust and soft or friable matter, organic or other deleterious substances. Where crushed gravel is proposed for use as aggregate, not less than 90% by weight of the crushed material retained on the 4.75 mm sieve should have at least two fractured faces. The aggregates should satisfy the physical requirements as specified in Table 1.1 (Ref: MORTH Specifications for Road and Bridge Works (IV Revision) for Dense Bituminous Macadam.).

Table 1.1: Physical Requirements of Coarse Aggregate for DBM (MORTH, Clause 507.2.2)

Property	Test	Specification
Cleanliness(dust)	Grain Size Analysis	Max. 5% passing 0.075mm sieve
Particle Shape	Flakiness and Elongation Index	Max.30%
Strength	Los Angeles Abrasion Value Aggregate Impact Value	Max.35% Max.27%
Durability	Soundness Sodium Sulphate Magnesium Sulphate	 Max.12% Max.18%
Water Absorption	Water Absorption	Max.2%
Stripping	Coating and Stripping Bitumen Aggregate Mixtures	Minimum retained coating 95%
Water Sensitivity	Retained Tensile Strength	Minimum 80%

1.5.3 Fine Aggregates

Fine aggregates for DBM consists of crushed or naturally occurring mineral material or a combination of the two, passing the 2.36mm sieve and retained on the 75 micron sieve. Aggregate should be clean, hard, durable, dry and free from dust, and soft or friable matter, organic or other deleterious matter.

1.5.4 Filler

Filler for DBM consists of finely divided mineral matter such as rock dust, hydrated lime or cement. The filler should be free from organic impurities. The filler should be graded within the limits.

1.5.5 Aggregate Grading and Binder Content as per MORTH

When tested in accordance with IS:2386 Part 1 (wet sieving method), the combined grading of the coarse and fine aggregates and added filler for the particular mixture should fall within the limits shown in Table 1.2, for DBM grading 1 or 2. The type and quantity of bitumen, and appropriate thickness, are also indicated for each mixture type.

Table 1.2: Gradation of Dense Bituminous Macadam (MORTH, Clause 505.2.5)

Grading	1	2
Nominal aggregate size	37.5 mm	26.5 mm
Layer Thickness	75-100 mm	50-75 mm
IS Sieve (mm)	Cumulative % Passing	Cumulative % Passing
45	100	
37.5	95-100	100
26.5	63-93	90-100
19	-	71-95
13.2	55-75	56-80
9.5	-	-
4.75	38-54	38-54
2.36	28-42	28-42
1.18	-	-
0.6	-	-
0.3	7-21	7-21
0.075	2-8	2-8
Bitumen content %	Min4.0	Min4.5

1.5.6 Mixture Design

Apart from conformity with the grading and quality requirements for individual ingredients, the mixture shall meet the requirements set out in Table 1.3

Table 1.3: Requirements for DBM Mix (MORTH, Clause 505.3.1)

Minimum stability (KN at 60°C)	9
Minimum flow (mm)	2
Maximum flow (mm)	4
Compaction level (Number of blows)	75 blows on each of the two faces of the specimen
Per cent air voids	3-5
Per cent voids filled with bitumen (VFB)	65-75

The requirements for minimum per cent voids in mineral aggregate (VMA) should be

as per Table 1.4.

Table 1.4: Minimum Percent Voids in Mineral Aggregate (MORTH, Clause 507.3.1)

Nominal Maximum Particle Size (mm)	**Minimum VMA , Percent Related to Design Air Voids, Percent**		
	3%	4%	5%
9.5	14	15	16
12.5	13	14	15
19	12	13	14
25	11	12	13
37.5	10	11	12

1.5.7 Binder Content

The binder content should be optimized to achieve the requirements of the mixture set out in

Table 500-11 and the traffic volume specified in the Contract. The Marshall method for determining the optimum binder content has been adopted as described in The Asphalt Institute Manual MS-2, replacing the aggregates retained on the 26.5 mm sieve by the aggregates passing the 26.5 mm sieve and retained on the 22.4 mm sieve, where approved by the Engineer. Where 40 mm dense bituminous macadam mixture is specified, the modified Marshall method described in MS-2 shall be used. This method requires modified equipment and procedures; particularly the minimum stability values in Table 500-11 shall be multiplied by 2.25 and the minimum flow should be 3 mm.

1.6 Aggregate Gradation for DBM Mix as per ASTM D 5581

Along with MORTH gradation two types of aggregate gradation followings: -

1.6.1 American Society for Testing and Materials (ASTM) D 5581: -

The aggregate nominal size 37.5mm is used in ASTM aggregate gradation. Aggregates must consist of crushed stone, crushed gravel, crushed slag, screenings, natural sand and mineral filler, as required.

1.6.2 Coarse Aggregate

The portion of material retained on the 4.75mm sieve is coarse aggregate. Coarse aggregate must consist of clean, sound, tough, durable particles, free from films of material that would prevent thorough coating and organic matter and other deleterious substances.

1.6.2 Fine Aggregate

The portion of material passing the 4.75mm sieve and retained on the 0.075mm sieve is fine aggregate. Fine aggregate must consist of clean, sound, tough, durable particles. The aggregate particles must be free from coatings of clay, silt or any objectionable material and must contain no clay balls.

1.6.3 Mineral Filler

The portion passing the 0.075mm sieve is defined as miner filler. Mineral filler must be non-plastic material. Grain size must conform to table 1.5.

Table 1.5: Grain Size Vs Percent Finer

Grain Size	Percent Finer
0.05mm	70-100%
0.02mm	35-65%
0.005mm	10-20%

1.6.3 Aggregate Gradation

Combined Aggregate Gradation must not vary from the low limit on one sieve to the high limit on the adjacent sieve, or vice-versa, but grade uniformly from coarse to fine. The combined aggregate gradation must conform to gradations specified in table.

Table 1.6: Aggregate Gradation

Sieve size	Percent by weight Passing
37.5 mm	100
25 mm	81-93
19 mm	73-95
12.5 mm	63-77
9.5 mm	56-70
4.75 mm	44-58
2.36 mm	35-49

1.18 mm	27-41
0.60 mm	19-33
0.30 mm	13-25
0.15 mm	9-17
0.075 mm	3-6

1.6.4 Mix Design

The asphalt mix must be composed of a mixture of well-graded aggregate, mineral filler (if required) and asphalt material. The aggregate fractions must be sized, handled in separate size groups and combined in such a proportions that the resulting mixture meets the grading requirements of JMF (Job mix formula) and tolerance for aggregate showing in Table 1.7 and large aggregate asphalt concrete mixture properties showing in Table 1.8 as follows: -

Table 1.7: Job Mix Tolerances

Mix Design Element	**Tolerance**
Aggregate passing 4.75 mm or larger sieves	±4%
Aggregate passing 2.36, 1.18, 0.60 & 0.30 mm sieves	±3%
Aggregate passing 0.15 & 0.075mm sieves	±1%
Asphalt binder content	±0.25
Mixing temperature	±14°C

Table 1.8: Large Aggregate Asphalt Concrete Mixture Properties

Mixture Property	Criteria
Stability (minimum)	17.8 KN
Flow (maximum), 0.25 mm	24
Voids total mix	3-5%
Voids filled with asphalt	70-80%

1.7 Aggregate Gradation as per Kandhal Aggregate Gradation

Prithvi Singh Kandhal is a civil engineer who has been recognized internationally for his work in asphalt road construction technology. Kandhal was inducted in August 2011 on the "Wall of Honor" established at the National Center for Asphalt Technology (NCAT) which is the largest asphalt road research center in the world. In 2012 he became an Honorary Member of the Association of Asphalt Paving Technolists (AAPT). Prof. Prithvi S. Kandhal gives the aggregate gradation for Marshall Mix design to determine the Marshall properties as follows: -

Table 1.9: Kandhal Aggregate Gradation

Sieve size (mm)	Gradation of Aggregate Percent passing
45	100
37.5	97
26.5	79
13.2	50

4.75	30
2.36	28
0.30	11
0.075	5

1.8 Organization of Thesis

Chapter 1. Introduction: A brief background about the bituminous mix, Marshall Properties of DBM mix, Aggregate Gradation and their classification.

Chapter 2. Review of literature: Deals with works carried to determine the effect of aggregate gradation and comparative effort on Marshall Properties of DBM.

Chapter 3. Methodology& Experimental Plan: Describes the experimental programme wherein all test procedures are explained in detail.

Chapter 4. Experimental results and discussions: Deals with the analysis of results obtained from experimental work in laboratory.

Chapter 5. Conclusion: Deals with the conclusions observed from the study.

CHAPTER- 02
LITERATURE REVIEW

2.1 Literature Review on Aggregate Gradation & Compactive Effort

R. Sridhar, C.Kamaraj, Sunil Bose, P.K Nanda and Manvinder Singh (2006), adopted Marshall Mix design method using Marshall Hammer and Hugo hammer for compaction of DBM mix. Effective compaction in an essential pre-requisite for obtaining the best performance bituminous mixes for greater load spreading ability and improved resistance to deformation and fatigue cracking. In this study two types of compaction efforts (Marshall Hammer and Hugo hammer) and three types of aggregate grading (Kandhal, maximum density and MORTH mid grading) were used for designing dense bituminous macadam mix. From the results, it was observed that Hugo hammer showed lower bitumen content compared to Marshall Compaction. Maximum density grading can be adopted as the best grading with Hugo hammer compaction simulating the field conditions by increasing the binder content, which fulfils the film thickness and durability criteria of the DBM mix. Kandhal Grading and Maximum Density grading using Hugo hammer compaction efforts give rise to a stiff mix. MORTH mid grading, which gives rise a mix resistant to permanent deformation even higher temperatures, can be used for roads where heavy commercial vehicles are more in number to avoid rutting of roads.

Haider Habeeb Aodah, Yassir N.A. Kaeem and Satish Chandra (2012), Studied the performance of bituminous mixes with different Aggregate Gradation and binder Content. This study is conducted to determine the effect of aggregate gradation on indirect tensile strength, shear strength and rutting behavior of bituminous mixes. In this work, one type of aggregate and two types of binders (VG -30 & PMB -40) and two types of mixes (Bituminous concrete & dense Bituminous Macadam) were used. Three type of aggregate gradation were used such as Upper limit (Nominal size for BC is 9.5mm for & 19mm for DBM), Midpoint (Nominal size for BC is 13mm and 26.5mm for DBM) and Lower limit (Nominal size for BC 9.5mm and 19mm for DBM). The results indicate that the performance of mixes made with PMB-40 is better than that of the mixes made with VG-30. In term of indirect tensile strength (ITS), horizontal tensile strain (HTS) and the compressive strength, while DBM mix is better in terms of shear strength &

rut resistance. The tensile strain at failure determined from ITS test is useful in predicting the cracking potential of mixes. The results indicates that the tensile strength of BC mixes is higher than DBM mix and mixes made with PMB-40 is higher than that of mixes made with VG-30. It is primarily due to higher viscosity of PMB-40 compared to VG-30. The horizontal tensile strain for DBM mixes higher than BC mixes.

Darshna B. Joshi, Prof A.K. Patel, Highlights the variability involved in the asphalt mix design process and develop a procedure to find out Optimum bitumen content. Laboratory Compacted specimens were used for volumetric and mechanical testing in order to predict flow and stability of mix. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute. The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time when the maximum load is recorded. Table 2.1 & 2.2 represents the summary of DBM Mix Design and the result of Marshall Stability test respectively.

Table 2.1: Summary of DBM Mix Design

Bitumen Grade	**60-70**	**Required limit as per MORTH**
Proportion(20mm:10mm:6mm:stone dust)	35:20:20:30	-
Bitumen %age By weight of aggregate	4.9	-
Bitumen %age By weight of Mix	4.7	-
No. of Blows on each side of sample	75	75
Stability (KN)	17.626	9.0
Flow (mm)	3.78	2-4
Voids in Mix (VIM)	5.150	3-6
Voids in mineral aggregate (VMA)	16.242	Table 500-12
Voids filled with Bitumen (VFB)	68.29	65-75
Density (gm/cc)	2.452	-
Specific gravity of Bitumen	1.03	-

Table 2.2: Marshal Stability Calculation

% of Bitumen	VMA (voids in mineral aggregate)	VIM (air voids in mineral)	VFB (voids filled with bitumen)
4.30	17.514	7.478	57.30
4.48	16.659	6.071	63.56
4.66	16.242	5.150	68.29
4.84	16.589	5.095	69.29
5.02	17.096	5.227	69.43

This paper focuses on the Marshall Mix design for DBM with various bitumen proportions. The Marshall Stability and flow test provides the performance prediction measure for the Marshall Mix design method.

***Prithvi S. Kandhal and E.R. Brown (NCAT Report*)**, conducted Marshall test to compare the mix properties such as Marshall stability and flow, Indirect tensile strength and permanent deformation obtained on 4-inch(101.6 mm) and 6-inch(152.4 mm) diameters specimens. The maximum aggregate size ranged from 12.5 mm to 38.1 mm. The data indicates increased co-efficient of variation when testing 4-inch (101.6 mm) specimens of the mix containing aggregate larger than one inch (25.4 mm) compared to 6-inch specimens. Results of two test series which involved the comparative evaluation of 4-inch (101.6 mm) and 6-inch (152.4 mm) diameter specimens in testing large stone asphalt mixes were reported in this paper.

In the test Series-I, a dense graded binder course asphalt mix meeting the Pennsylvania Department of Transportation (PennDOT)'s specifications for ID-2 Binder Course Mix was used. The maximum aggregate size was 38. 1 mm used in this study. And AC-20 asphalt cement was used in the mix. **Nine** 4-inch (101.6 mm) diameter specimens were compacted using a standard Marshall mould in accordance with ASTM D1559. Compaction was achieved with a mechanical hammer by applying 50 blows on each face of the specimen. And ten 6-inch (152.4 mm) diameter specimens were compacted using the modified Marshall test.

Table 2.3: Summary of Stability and Flow Ratios for Large Stone Mixes

Agency (Year data obtained)	**No. of Blows**		**Ratio**	
	4”	**6”**	**Stability**	**Flow**
Penn. DOT(1969)	50	75	2.12	1.62
Penn. DOT(1970)	50	75	2.81	1.15
Penn. DOT(1988)	50	75	1.95	1.39
Penn. DOT(1988)	50	75	2.17	1.58
Penn. DOT(1989)	50	75	1.68	1.40
Jamestown Macadam(1989)	50	75	1.89	1.24
Kentucky DOH(1988)	75	112	2.08	1.34
American Asphalt Paving (1989)	75	112	2.37	1.63
American Asphalt Paving (1989)	75	112	2.58	1.52
American Asphalt Paving (1989)	75	112	1.98	1.68
American Asphalt Paving (1989)	75	112	2.40	1.27
No. of Mixes (N)			11	11
Mean			2.18	L44
Std. Dev.			0.33	0.18

The average Stability and Flow ratio for these five mixes compacted with 75/112 blows are 2.28 and 1.49, respectively. It is recommended that the minimum Marshall Stability requirement for 6-inch (152.4 mm) diameter specimens should be 2.25 times the requirement for 4-inch (101.6 mm) diameter specimens. The Test Series-II was a part of a research project which evaluated the effects of maximum aggregate size on rutting potential of HMA pavements as reported by Brown and Bassett@. In this series crushed limestone aggregate was used to prepare five different mixtures that contained maximum aggregate sizes of 3/8-inch (9.5 mm), %-inch (12.5 mm), 3A-inch (19.0 mm), l-inch (25.4 mm), and l% inch (38.1 mm). AC-20 asphalt cement was used. The asphalt content for all mixes was selected to provide an air voids content of 4 percent under a compactive effort in the Gyratory Testing Machine (GTM) equivalent of 75 blows of a Marshall hammer. Mix gradations and optimum asphalt contents are given in Table 2.4. Four-inch (101.6 mm) diameter specimens of all five mixes were compacted in GTM using 30 revolutions at a pressure of 200 psi (1,379 kPa) and 1° gyratory angle. Six-inch (152.4 mm) diameter specimens of all five mixes were also compacted in GTM using 30 revolutions, 200 psi (1,379 kPa) and 1° gyratory angle. A comparison of the densities obtained in the 4-inch (101.6 mm) and 6-inch (152.4 mm) samples showed almost equal densities.

Indirect tensile test in accordance with ASTM D4123-82 was conducted on both 4-inch (101.6 mm) and 6-inch (152.4 mm) diameter specimens of all five mixes. This test was conducted at 77°F (25°C) using a standard loading rate of 2-inches per minute (50.8 mm/min). Unconfined static creep tests were also conducted on all specimens. A load of approximately 50 psi (345 kPa) was applied at room temperature for one hour followed by unloading for one hour.

Table 2.4: Mix Gradation and Optimum Asphalt Content

Sieve	3/8 Inch	1/2 Inch	3/4 Inch	1 Inch	1-1/2 Inch
1 ½”					100
1” = 25.4mm				100	83
¾”			100	87	73
½”		100	83	73	61
3/8”	100	87	72	63	54
#4	72	62	52	46	39
#8	51	44	37	33	29
#16	36	31	26	23	21
#30	26	21	19	17	15
#50	18	14	12	12	11
#100	12	9	8	8	8
#200	8.2	5.8	5.2	5.5	6.1
Optimum Asphalt Content	4.5	5.0	4.3	3.8	3.4

Comparative evaluation of 4-inch (101.6 mm) and 6-inch (152.4 mm) diameter specimens in this study has indicated that the test results for large stone asphalt mixes obtained with 6-inch (152.4

mm) specimens had better repeatability, and were more meaningful compared to 4-inch (101.6 mm) specimens.

Nitinprasad.R1, M.S.Nagakumar (2013), used the Marshall test with increased compaction level to evaluate the Marshall properties and Secondary compaction, that is the state; where the pavement which is compacted with the conventional compaction has been further compacted due to the movement of traffic and which corresponds to the ultimate density which can be attained on the bituminous pavement called as "Refusal density" of the pavement. It is understood that the 75 blows of the Marshall test does not determine the actual field circumstances. The Marshall design actually in the field will not simulate the field condition. Hence an attempt has been made to study the air void content at Refusal density. Also the Bulk Density, Air voids (Va), Voids in mineral aggregate (VMA), Voids filled with Bitumen (VFB) of the mix at the Refusal density are also studied. For the simulation of the field density in the laboratory a Hugo hammer is used. The experimental investigation showed an increase in the compaction energy shows a corresponding increase in the bulk density and decrease in the air voids level. For various blows the Marshall properties at OBC for 50 blows, 75 blows, 100 Blows, 150 Blows 200 Blows and 600 blows.

Table 2.5: Marshall Properties of DBM-II at Optimum Binder Content (OBC)

Properties	50 Blows	75 Blows	100 Blows	150 Blows	200 Blows	600 Blows
Bulk Density, gm/cc	2.286	2.359	2.35	2.375	2.372	2.427
Air Voids, %	7.176	4.1214	4.63	3.43	3.76	1.497
VMA, %	19.78	16.41	17.25	16.48	16.5	14.522
VFB, %	63.73	75.54	73.2	77.58	77.47	89.816
Marshall Stability. Kgs	1445	1821.2	2127.5	2144.25	1926.33	3418.5
Marshall Flow, mm	4.96	4.85	4.9	3.52	4.125	3.7

The 600 blows of compaction were done to evaluate the min Va% at maximum secondary Compaction. The bitumen content at the maximum bulk density is lesser than that for specimen compacted using Marshall Hammer. The stability of the mix prepared with Hugo hammer has increased when compared to that of the Conventional Marshall hammer. The binder content of the specimen casted by Hugo hammer has lower values when compared to that of the conventional Marshall Hammer.

Ganapati Naidu.P and S.Adiseshu (2013-2014), adopted Marshall Stability test to determine the strength serviceability requirements of Bitumen mixes such as stability, flow, voids in mineral aggregate (VMA), voids filled with bitumen (VFB) and air voids are highly depend on the physical properties of aggregate. Dense bituminous macadam (DBM) mixes were analyzed with different proportions (10%, 20%, 30%, 40%, 50%) of different shape of aggregates were studied. Aggregate particles can be defined in terms of three independent shape properties: shape (or form), angularity, and surface texture (Barrett, 1980). Aggregate shape properties are known to influence Bitumen pavement performance. Angularity and texture govern the frictional properties and dilation of the aggregate structure. Aggregate texture plays a major role in influencing the adhesive bond between the aggregate and the binder, while aggregate form influences the anisotropic response of Bitumen mixes. Mixes with cubical and rod shape aggregates has been showed good results on stability. Particle shape can be described as cubical, blade, disk and rod.

Table 2.6: Marshall Properties of Different Shape of Aggregates

CUBE					
Properties	10	20	30	40	50
Stability	1580.03	1677.23	1619.06	1632.61	1638.58
Flow	2.63	2.83	2.07	2.03	1.90
Air voids	3.32	3.66	3.65	3.89	4.10
Density	2.473	2.470	2.475	2.474	2.473
VFB	76.51	74.63	74.69	73.40	72.28
VMA	14.14	14.42	14.41	14.61	14.79

DBM					
Stability	**Flow**	**Air voids**	**Density**	**VFB**	**VMA**
1405.73	2.9	4.01	2.47	71.95	14.30

BLADE					
Properties	10	20	30	40	50
Stability	1105.14	1026.16	1027.08	1048.97	1037.03
Flow	1.97	1.67	1.73	2.07	2.13
Air voids	3.35	3.52	3.54	3.56	3.80
Density	2.472	2.472	2.477	2.482	2.480
VFB	76.37	75.44	75.31	75.21	73.94
VMA	14.17	14.32	14.34	14.35	14.58

DBM					
Stability	**Flow**	**Air voids**	**Density**	**VFB**	**VMA**
1405.73	2.9	4.01	2.47	71.95	14.30

From results, Higher Marshall Stability values were obtained from the mixes prepared with cubical shape aggregates i.e. 16.77kN. Cubical shape aggregates attains the maximum percentage VMA, and blade shape aggregates attains the lower values because of the aggregates tend to break down excessively during compaction. The stability of mix with different type of aggregates is shown good results, against satisfying the minimum requirement of 9kN. The parameters such as air voids and voids in mineral aggregate increases with increase in proportion of blade type of aggregates in DBM mixes, because the same type of particles will not replace the gaps between the bitumen mixes.

Mohammed Naim Mansuri, Dr. V.M. Patel & Prof. H.K. Daue (2014), investigated the influence of shape of coarse aggregate on DBM Mix. In this study dense bituminous macadam mixes were analyzed with different properties of different shape of aggregate. The shape of aggregate particle has significant influence on performance of the Bitumen pavement. Test sample were prepared as per MORTH specifications. The aggregate used in this study were 16-25 mm, 7-16mm, 4-7mm and 0-4 mm. Bitumen of penetration grade 60/70 was used. The aggregate gradation for DBM mix was selected from MORTH specifications. The proportion of aggregate sizes was determined by trial & error method to achieve the combined gradation as per the requirement.

Table 2.7: Optimum Binder Content

Sr. No.	Test Properties	Bitumen Content By wt. of mix (%)			Optimum Bitumen Content By wt. of mix (%)		
		cube	pyramid	sphere	cube	pyramid	sphere
1	Max. Bulk density (gm/cc)	4.56	4.77	4.78	4.51%	4.66%	4.71%
2	4.5 % VIM	4.39	4.81	4.73			
3	70% VFB	4.37	4.81	4.73			
4	Max. Marshall Stability	4.55	4.57	4.65			
5	3mm Flow	4.70	4.49	4.60			

Experimental study indicates that, of the various shape of aggregates used in mix, the mix with cubical aggregates has minimum value of OBC = 4.51%. For spherical and pyramidal aggregates it is 4.71% and 4.66% respectively. As per MORTH specification (cl. no. 507.3.1) permissible value for Voids Fill with Bitumen = 65% to 75%. Observed experimental value for cubical, spherical and pyramidal shaped aggregate are 74.88%, 70.12% & 71.21% respectively which is indicative of the fact that all types of shape are meeting the MORTH requirements initially under sample preparation condition(after 75 no. of blows).

As per MORTH specification (cl. no. 507.3.1) permissible value for Marshall Flow is 2mm to 4mm. Observed experimental value for cubical, spherical and pyramidal shaped aggregate are 2.70mm, 3.45mm & 3.60mm respectively which is indicative of

the fact that all types of shape are meeting the MORTH requirements but mix with cubical aggregate give closer value to the mid limit of flow value. As per MORTH specification (cl. no. 507.3.1) minimum Marshall Stability is 9KN. Observed Maximum Stability value for cubical, spherical and pyramidal shaped aggregate are 12.95KN, 11.95KN & 12.40KN respectively which is indicative of the fact that all types of shape are meeting the MORTH requirements but mix with cubical aggregate give maximum stability compare to other.

SK. Wasim Anwar (2014), conducted the study to compares the mix properties of Marshall such as stability, Flow and indirect tensile strength obtained on 100 mm and 150 mm diameter specimens. In this study Marshall and Modified Marshall Method of mix design were used to compact the specimens. The aggregate gradation adopted was DBM grade-I. The max aggregate size used in this study is 37.5 mm and aggregate gradation is adopted as per MORTH (IV) specification.

Binder used this study is CRMB – 55 (Crumb Rubber Modified bitumen), and for mix design, Marshall Method mix design for 100 mm diameter specimen and MS-2 guidelines were used for 150 mm diameter specimen which is called Modified Marshall Method. It was observed that the Modified Marshall Method satisfies the mix properties such as Marshall Stability, flow and indirect tensile strength and can be used for testing the large stone Aggregate mixes. Laboratory studies on the behavior of Marshall and Modified Marshall specimen were carried out in terms of optimum bitumen content.

Table 2.8: Marshall Properties of DBM-I mix for Marshall Method (100mm diameter) Specimen using CRMB-55

Bitumen Content (%)	Marshall Stability Kg	Flow mm	Bulk density gm/cc	Total air voids (%)	Voids filled by bitumen (%)	Voids in miner aggregate (%)
3.50	1013.33	1.55	2.34	5.68	58.84	13.80
4.00	1120.00	2.42	2.36	4.40	69.22	13.55
4.50	1301.33	2.98	2.38	3.80	76.48	13.36
5.00	1205.33	3.52	2.37	3.50	82.56	14.29
5.50	1152.00	3.90	2.36	3.15	85.73	15.02

Table 2.9: Marshall Properties of DBM-I mix for Modified Marshall Method (150mm diameter) Specimen using CRMB-55

Bitumen Content (%)	Marshall Stability Kg	Flow mm	Bulk density gm/cc	Total air voids (%)	Voids filled by bitumen (%)	Voids in miner aggregate (%)
3.50	2560.00	5.07	2.33	6.00	57.41	14.08
4.00	2720.00	6.09	2.35	4.58	67.15	13.88
4.50	3146.67	6.09	2.37	3.88	75.74	13.92
5.00	3093.33	7.02	2.36	3.08	79.25	14.75
5.50	2848.00	7.26	2.35	2.65	83.03	15.46

It is concluded that specimen prepared by modified Marshall method of mix design give very good result than Marshall Specimen and it can be used in flexible pavement.

Lokesh Gupta, Ashutosh Patil and Avinash Ojha (2016), In this research an effort has been ended to evaluate the Marshall properties of dense bituminous macadam prepared using VG-30 and CRMB-55(crumb rubber modified bitumen) as binder material. Marshall Method of bituminous mix design is adopted to determine the optimum bitumen content and Marshall Properties. The main objectives of the analysis are to ensure the properties of aggregates by conducting the test in the laboratory as per MORT&H (IV Revision) Specification and to conduct tests on bitumen content. There is a reduction in optimum bitumen content of about 0.78% in the specimens prepared using CRMB- 55 as binder material when compared to specimens prepared using VG-30 as binder material. There is % increase in Marshall stability value of about 15.10% in the specimens prepared using CRMB-55 as binder material when compared to specimens prepared using VG-30 as binder material. There is no variation in bulk density value of specimens prepared using CRMB-55 as binder material when compared to specimens prepared using VG-30 as binder material. There is increase in percentage air voids value of about 1.10% in the specimens prepared using CRMB- 55 as binder material when compared to specimens prepared using VG-30 as binder material. There is marginal increase in flow value of about 2.70% in the specimens prepared using CRMB-55 as binder material when compared to specimens prepared using VG-30 as binder material. There is a reduction in VMA value of about 0.29% in the specimens prepared using CRMB-55 as binder material when compared to specimens prepared using VG-30 as binder material. The reduction in VFB value of about 0.35% in the specimens prepared using CRMB-55 as binder material when compared to specimen prepared using VG-30.

Deepesh Kumar Singh Lodhi and R.K Yadav (2016), Performed the Marshall Stability test to determine the strength serviceability requirements of bitumen mixes such as stability, flow, voids in mineral aggregate, voids filled with bitumen and air voids which are highly dependent on the physical properties of aggregate. Viscosity grade bitumen V-30 used as binder in this research for preparation of mix. It is important property as per Indian Standard Code Specification for paving bituminous IS: 73(2007) was used. In this investigation, five gradations were used such as lower grade, lower middle grade, middle grade, higher middle grade and higher grade. Marshall Test specimen were prepared for each aggregate gradation at 4%, 4.5%, 5% and 5.5% bitumen content to study the effect of aggregate gradation on the Marshall properties of DBM.

Optimum binder content is minimum in middle grade which is more economical for design mix DBM in this gradation. Most of the Marshall properties are superior at middle grade. So DBM mix is design at this gradation.

Table 2.10: Dense Bituminous Macadam Gradation

Sieve Size	L.G	L.M.G	M.G	H.M.G	H.G	MORTH Range
26.5 mm	90	92.5	95	97.5	100	90-100
19 mm	71	77	83	89	95	71-95
4.75 mm	56	62	68	74	80	56-80
2.36 mm	38	42	46	50	54	38-54
0.3 mm	7	10.5	14	17.5	21	7-21
0.075 mm	2	3.5	5	6.5	8	2-8

Table 2.11: Dense Bituminous Macadam Marshall Properties

Properties	**L.G.**	**L.M.G**	**M.G.**	**H.M.G.**	**H.G.**
O.B.C. %	4.46	4.46	4.42	4.57	4.46
Stability	9.9	10.6	11.5	9.85	9.7
Flow	2.8	3.3	3	3.1	2.7
Density	2.346	2.348	2.356	2.336	2.342
V.F.B.	72	74.8	74	65	72.2
Air Voids V_V	3.84	3.86	3.62	4.2	3.88

Various laboratory tests on D.B.M. mixes results concluded that Marshall values of Stability is maximum in Middle Grade (M.G.) and Optimum Binder Content (O.B.C.) is also minimum in Middle Grade (M.G.) which is more economical for design D.B.M. mix in this gradation. The Density value is maximum in Middle Grade (M.G.) and minimum at High Middle Grade (H.M.G.) Flow is highest in Middle Grade (L.M.G.) and minimum at Higher Middle Grade (H.G.). Air voids is maximum in Higher Middle Grade (M.G.) and minimum at Middle Grade

(M.G.). V.F.B. is maximum in Lower Middle Grade (L.M.G.) and minimum at Higher Middle Grade (H.M.G.). From the above points it can be concluded that in the design of D.B.M. mix most of the Marshall properties are superior at Middle Gradation of MORTH specifications so D.B.M. mix is design at this gradation.

CHAPTER-3

EXPERIMENTAL PROGRAMME

3.1 Marshall Stability Test for DBM Grade-II

Marshall Mix design is adopted worldwide for determining and reporting the stability and flow characteristics of bituminous mixes. In India, it is a very popular method for characterization of bituminous mixes. In this study, the Marshall Stability method was used to determine the Optimum Binder Content (OBC) for the different mixes and to study other Marshall properties such as Marshall Stability, flow value, air voids in a mixture, voids filled with bitumen and voids in mineral aggregate. These properties were calculated to determine the Optimum Binder Content (OBC).

3.2 Equipment Used in Work

The following is a brief overview of the major equipments used in experimental work

a. **Compaction Mould Assembly**: **-** This consists of compaction mould of cylindrical shape of diameter 101.6mm, thickness 63.5mm and height 75mm, a collar extension and a base plate. Both the ends of the cylindrical mould are interchangeable and may be placed on the base plate showing in Figure 3.1.

Figure 3.1: Mould Assembly of Marshall Test

b. **Compaction Hammer: -** It is a Compaction hammer with a flat circular plate of diameter 98.4 mm and a hammer of weight 17 kg which can be lifted and released to obtain a drop of 457mm.

c. Oven for heating bituminous mixtures and specimen mould assemblies to required temperature.

d. Thermometer for determining the temperature of bituminous mixtures. Armoured glass thermometers or dial-type with metals with arrange of 10 to 200^0C are generally recommended. Thermometers shall have increments of not greater than 2.8^0C.

e. A balance or scale capable of measuring the maximum weight to be determined. The sensitivity of any balance or scale utilized shall be least one gram.

f. Large spoon for placing mixtures in specimen moulds.

g. A specimen extractor showing in Figure 3.3 suitably fitted with a jack or compression machine shall be used for extruding the compacted specimen form the mould.

Figure 3.2: Sample Extractor for Marshall Specimen

h. Marshall stability and flow was determined by using the following apparatus:

- Breaking head consisting of upper and lower cylindrical segment shortest heads. The lower segment shall be mounted on a base having two perpendicular guide rods or posts extending upward. Guide sleeves in the upper segment shall be in such a position as to direct the two segments together when a 152.4 ±3.1 mm diameter by 100 mm thick metal block is placed between the two segments. The Marshall Stability testing machine consists of a motorised loading unit provided with a gear system to lift the base plate upward at the specified rate. A calibrated proving ring of 10 ton capacity with a dial gauge or a load cell with a digital load display unit is fixed on the upper end of the machine to measure the load applied. The testing head with the specimen inside is placed in position between the proving ring and the base plate.
- Water bath of sufficient depth to provide for the complete immersion of sample and thermostatically controlled so as to maintain the bath at 59 to 61^0C.
- Marshall Stability and flow testing apparatus capable of applying a strain controlled load at a rate of 48.3 to 53.3 mm per minute.
- Height gauge capable of measuring the height of samples.

3.3 Preparation of Test Samples:-

- Approximately 1200gm aggregates were weighted and heated up to 154-160°C to prepare each mould of the DBM mix. The Bitumen is also heated 160°C.
- The weight of the mix was taken in such a manner that compacted samples of DBM should have height in between 88.9 to 101.6mm.
- Aggregate and bitumen are mixed thoroughly until a uniform grey colour is obtained. The mix was then transferred into the mould assembly of diameter 101.6 & height 63.5 mm in two layers.
- Compaction is done with Marshall Hammer by varying the blows for every bitumen content 50, 75 and 100 blows were used to simulate the effect of according to the low, medium and heavy traffic respectively.
- After 90 minute mould is taken out & kept under normal Laboratory temperature for 12hours.
- The sample is immersed in water bath maintained at a constant temperature of 60°C for

30 minutes. Then sample is tested for obtaining Marshall Properties such as stability value and flow value. The following properties should be determine such as theoretical and bulk specific gravity, Air voids(V_v%), percent volume of bitumen(V_b%),voids in mineral aggregate(VMA%), voids filled with bitumen(VFB%).

3.4 Prepared Bituminous Samples: -

3.4.1 MORTH Gradation: - A total of 12 samples are prepared for bitumen content. These bituminous samples are prepared by varying the compactive effort as 50, 75 and 100 blows at varying bitumen content like 4%, 4.5%, 5%, and 5.5%.

Figures of 50 blows compactive effort for all bitumen content can be shown in MORTH gradation

Figure 3.3: Bituminous Samples of MORTH gradation for 50 blows

Figure 3.4: Bituminous Samples of MORTH gradation for 75 blows

Figure 3.5: Bituminous Samples of MORTH gradation for 100 blows

3.4.2 ASTM Gradation: - Similar to MORTH gradation a total of 12 bituminous samples are prepared by varying the bitumen content(4%, 4.5%, 5%, and 5.5%) with varying compactive effort (50 blows, 75 blows and 100 blows). Followings are the figures:

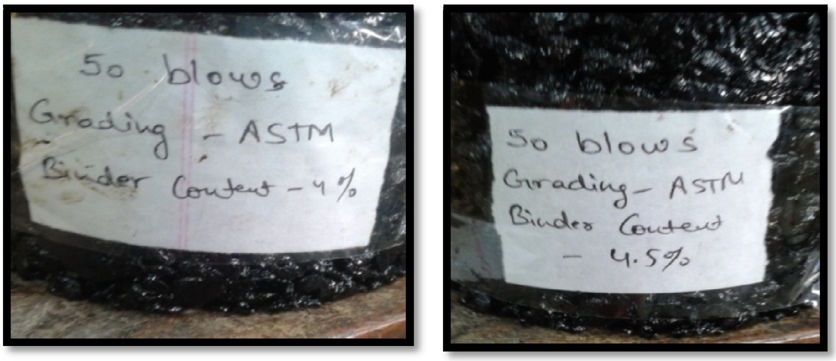

Figure 3.6: Bituminous Samples of ASTM gradation for 50 blows

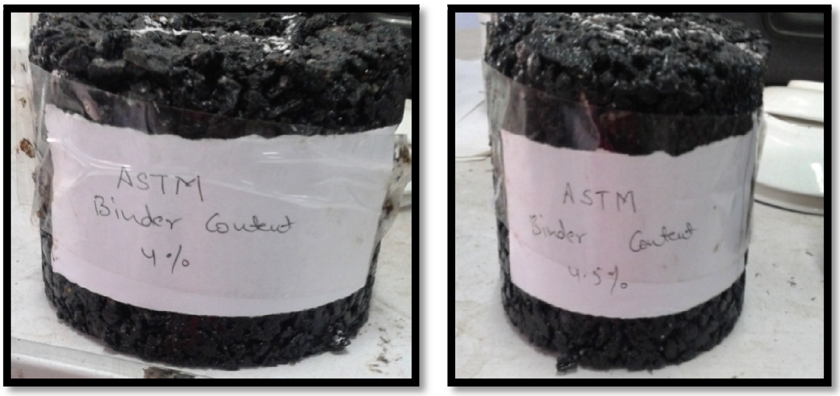

Figure 3.7: Bituminous Samples of ASTM gradation for 75 blows

Figure 3.8: Bituminous Samples of ASTM gradation for 100 blows

3.4.3 Kandhal Gradation: - Similar to ASTM gradation, a total of 12 bituminous samples are prepared by varying the bitumen content (4%, 4.5%, 5%, and 5.5%) with varying compactive effort (50 blows, 75 blows and 100 blows). Followings are the figures:

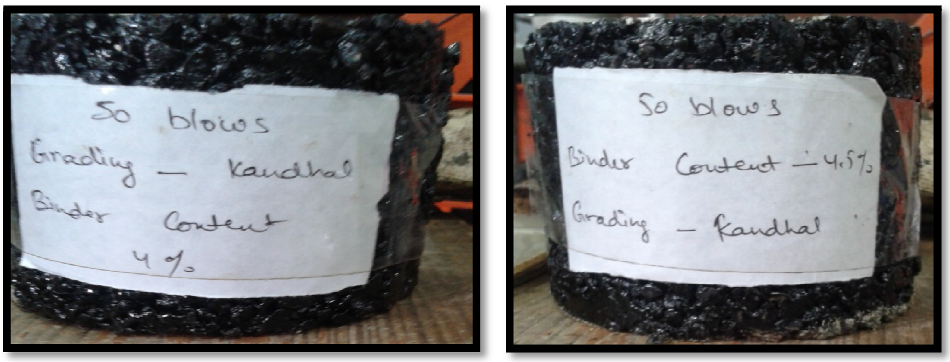

Figure 3.9: Bituminous Samples of Kandhal gradation for 50 blows

Figure 3.10: Bituminous Samples of Kandhal gradation for 75 blows

Figure 3.11: Bituminous Samples of Kandhal gradation for 100 blows

3.5 Volumetric Analysis (Manual of Transportation Engineering.)

In the Marshall Stability method each compacted sample was subjected to the following analysis:

- Theoretical Density or Specific Gravity of Sample
- Bulk Specific Gravity of Sample
- Air voids in the Mix, % (V_v %
- Volume of Bitumen (V_b %)
- Voids in Mineral Aggregate (VMA %)
- Voids Filled with Bitumen (VFB %)

3.5.1 Theoretical Density or Specific Gravity Analysis

The specific gravity (G_t) values for the different aggregates and the bituminous binder used are determined before conducting the Marshall Stability test on the bituminous mix.

$$G_t = 100/ (W_1/G_1+W_2/ G_2 +W_3/G_3+W_4 /G_4)$$

Where,

W_1 = percent by weight of coarse aggregate in total mix

W_2 = percent by weight of fine aggregate

W_3 = percent by weight of filler

W_4 = percent by weight of bituminous binder in total mix

G_1 = Specific gravity of Coarse aggregate

G_2 = Specific gravity of Fine aggregate

G_3 = Specific gravity of Filler

G_4 = Specific gravity of Bituminous binder

3.5.2 Bulk Density or Specific Gravity Analysis

The bulk density or specific gravity (G_m) of compacted sample is determined by using following equation: -

$$G_m = W/V$$

Where,

W = weight of the compacted sample of bituminous mix (weight in air) gm

V = volume of the compacted sample determined by two methods,

The volume V can be calculated by either measuring the mean dimension of sample or by weighing in water and thus finding the volume of water displaced (cm^3).

3.5.3 Air voids in the Mix, % (V_v %)

Air voids in the mix are defined as void volume between the aggregates coated by bitumen. It is determined by the following equation: -

$$V_v\% = 100\ (G_t - G_m / G_t)$$

Where,

G_t = Theoretical specific gravity of bituminous sample

G_m = Bulk specific gravity of bituminous sample

3.5.4 Volume of Bitumen (V_b %)

The following equation is used to determine the Volume of Bitumen.

$$V_b\ \% = (W_4 / G_4) / (W_1 + W_2 + W_3 + W_4/G_m)$$

Where,

W_1 = percent by weight of coarse aggregate in total mix

W_2 = percent by weight of fine aggregate

W_3 = percent by weight of filler

W_4 = percent by weight of bituminous binder in total mix

G_m = Bulk specific gravity of bituminous sample

G_4 = Specific gravity of bituminous binder

3.5.5 Voids in Mineral Aggregate (VMA %)

It is the volume of inter granular void space between the aggregate particles of a compacted paving mixture. It includes the air voids and the volume of the asphalt not absorbed into the aggregate. VMA describes the portion of space in a compacted sample which is not occupied by the aggregate. Following equation is used to determine the VMA.

$$VMA = V_v + V_b$$

Where,

$V_v\%$ = Percentage of air voids in the mix

$V_b\%$ = Percentage Volume of Bitumen

3.5.6 Voids Filled with Bitumen (VFB %)

A void filled with binder is voids in the mineral aggregate that are filled with binder expressed as a percent of the Volume of the voids in the mineral aggregate. Equation for the VFB, as follows: -

$$VFB = 100^* V_b / VMA$$

Where,

V_b = Percentage Volume of Bitumen

VMA = Percentage of voids in mineral aggregate

3.6 Tests on Bitumen

There are number of tests to determine the properties of bituminous materials. The following tests were conducted to evaluate the different properties of binder to be used. Table 3.1 shows IS code reference of various tests on bitumen sample.

3.6.1 Specific Gravity Test (IS: 1202-1978)

The specific gravity is defined as the ratio of the mass of a given volume of the bituminous material to the mass of an equal volume of water at 27^0C. This value is required to convert the weight of bitumen to volume for use with aggregate. The specific gravity is influenced by the chemical composition of binders.

The specific gravity is evaluated as per IS: 1202-1978 procedure. There are two methods to determine the specific gravity of bitumen: -

i) Pycnometer method

ii) Balance method

In this study Balance method is used for determining the specific gravity of bitumen. The specific gravity of bitumen is varies from 0.97 to 1.02. If bitumen contains mineral impurity, the specific gravity will be higher.

3.6.2 Softening point test (IS: 1205-1978)

As the temperature increases, bitumen gradually becomes softer till it flows readily. Softening Point is essentially the temperature at which the bituminous binders have an equal viscosity. Softening Point gives the idea of the temperature at which the bituminous materials attains a certain viscosity.

The test for estimating the softening point is conducted as per IS: 1205-1978. The test is conducted by ring and ball apparatus. A brass ring containing test sample of bitumen is suspended in liquid like water or glycerin at a given temperature. A steel ball is placed upon the bitumen sample and the liquid medium is heated at a rate of 5^0C per minute. Temperature is noted when the softened bitumen touches the metal plate which is at a specified distance below. For material whose softening point is above 80^0C, Glycerin is used as a heating medium and the starting temperature is 35^0 C instead of 5^0C. Bitumen with higher softening point may be preferred in warmer place. Softening Point is also sometimes used to specify hard bitumen and pitches.

3.6.3 Ductility Test (IS: 1208-1978)

In the flexible pavement construction, it is desirable that the bitumen binders used in the bituminous mixes form ductile thin films around the aggregates. Ductility is the property of bitumen that permits it to undergo great deformation or elongation. The ductility value of bitumen binder is expressed as the distances in centimeters to which a standard briquette of bitumen can be stretched before the thread breaks.

This test has been standardized as per IS: 1208-1978. The bitumen sample is heated and poured into the mould and the plate assembly along with the samples is cooled in the air and then water bath at 27^0C. The excess material is cut off by leveling the surface using the hot knife. Then the mould assembly containing sample is kept in water bath at 27^0C for 85 to 95 minutes. The sides of the mould are removed and the clips are carefully hooked on the machine without causing any initial strain and the machine is operated. The distance to the point of breaking of thread is the ductility value which is reported in cm. The ductility value is affected by factors such as pouring temperature, test temperature, rate of pulling etc. The ductility values of bitumen vary from 5cm to over 100cm. The minimum ductility as specified by codal recommendations in 50-75cm for use in flexible pavement.

3.6.4 Viscosity Test (IS:1206-1978)

Viscosity denotes the fluidity of bituminous material and it is a measure of resistance to flow. The degree of fluidity of a bituminous binder at the application temperature influences the ability of the binder to spread, penetrate into the voids and also to coat the aggregates and hence affects the characteristics of the resulting paving mixes. Low or high viscosity during compaction or mixing have been observed to result in lower stability values. At high viscosity, the bituminous binder will not be able to coat the entire surface of aggregates and it offers higher resistance to compaction resulting in lower density and stability of the bituminous mix. A low viscosity, the bitumen binder simply 'lubricates' the aggregate particles instead of providing a uniform film over aggregates, it will lubricate the aggregate.

3.6.5 Penetration Test (IS: 1203-1978)

Penetration test is the most commonly adopted test on bitumen to determine the grade of the material in terms of its hardness because of its simplicity. The penetration values are measured as per IS: 1203-1978. This test measures the hardness or softness of bitumen by measuring the depth in tenths of a mille meter to which a standard loaded needle will penetrate vertically in 5 seconds. The penetro-meter consists of a needle assembly with a total weight of 100gm and a device for releasing and locking in any position. The bitumen is softened to a pouring consistency, stirred thoroughly and poured into containers at a depth at least 15 mm in excess of the expected penetration. The test should be conducted at a specified temperature of 25^0C.The penetration grades of bitumen binders are generally denoted as 80/100, 60/70 or 30/40 grade bitumen. 80/100 bitumen denotes that the penetration value of the binder ranges between 80mm to 100mm. Harder grade of bitumen binder with lower penetration value is generally chosen in warm regions. In colder regions bitumen with higher penetration values are generally used. The penetration value is greatly influenced by any inaccuracy with regards to pouring temperature, size of the needle, weight placed on the needle and the test temperature.

3.6.6 Flash and Fire Point Test (IS: 1209-1978)

When a bituminous binder is heated continuously, it starts emitting volatile vapours above a certain temperature and these volatile vapours can momentarily catch fire causing the flash, though the binder itself does not catch fire and burn at this temperature. This temperature is referred to as the flash point of bitumen based binders. The temperature at which such behavior occurs is found to differ for different types and grades of bituminous binders. Flash point test gives an indication of the critical temperature at and above which suitable precautions should be taken while heating the bitumen.

When the bituminous binder is further heated to a temperature higher than the flash point, the binder material itself catches fire and continues to burn. The lowest temperature causing this condition is called the fire point. The fire point is thus defined as the lowest temperature under specified test conditions at which the bituminous material gets ignited and burns.

3.7 Aggregate Testing

Aggregate are the principal material in pavement construction. Aggregates should posses good shear and compressive strength; This results in better interlocking properties of aggregate .To assess the properties of aggregates i.e. strength, hardness, toughness, specific gravity and shape, the following tests were conducted on aggregates in the laboratory as follows: -

- Aggregate Crushing Value Test

$$\text{Aggregate Crushing Value} = 100\ W_2/W_1\ \%$$

Where,

W_1 = Total weight of dry sample of aggregate taken (gm)

W_2 = Weight of the portion of crushed material passing 2.36 mm test sieve (gm)

- Los Angeles Abrasion Test

$$\text{Los Angeles Abrasion Value} = 100*(W_1 - W_2)/\ W_1$$

Where,

W_1 = Weight of Specimen (gm)

W_2 = Weight of Specimen after Abrasion test, Retained on 1.70mm test sieve (gm)

Table 3.1: Maximum Allowable Los Angles Abrasion Value of Aggregates in Different Types of Pavement Layers

Sl. No.	Types of pavement layer	Los Angles abrasion value, maximum %
1.	WBM Sub-base, WBM, WMM and CRM base course	40
	Bituminous Macadam base/binder course	
	Bituminous Penetration Macadam, Built-up spray grout base course	
2.	Dense graded Bituminous Macadam binder course	35
	Cement Concrete Pavement	
3.	Bituminous carpet surface course	40
	Bituminous surface dressing, 1 or 2 coats	
	Close graded Bituminous Surfacing /Mixed Seal Surfacing	
4.	Bituminous concrete surface course	30

- Aggregate Impact Test

$$\text{Aggregate Impact Value (AIV)} = 100\ W_2 / W_1\ (\%)$$

Where,

W_1 = Total weight of aggregate sample filling the cylindrical measure (gm)

W_2 = Weight of aggregate passing 2.36mm sieve after the test (gm)

Table: 3.2: Properties of Aggregate Impact Value

Aggregate Impact Value, %	Toughness Property
Less than 10	Exceptionally tough / strong
10 to 20	Very tough / strong
20 to 30	Good for pavement surface course
Above 35	Weak for pavement surface course

- Blending to achieve required gradation for DBM grade-II

CHAPTER-4

RESULT AND DISCUSSION

4.1 General

In this chapter, the results of various laboratory tests of the DBM mixes with Marshall Stability Method by three types of aggregate gradation and three types of compactive effort are presented and discussed. The results obtained were used to determine the Optimum Binder Content (OBC) by performing Marshall Stability-Flow Analysis and volumetric analysis for the prepared samples.

4.2 Sieve Analysis

Sieve analysis test was used to determine the aggregate sizes for a sample taken from quarry. Through the sieve test, the proportion of coarse aggregates, fine aggregate and filler was determined. It was ensured that the aggregate were well blended within the gradation limit as specified in MORTH for DBM Grade-II. The sieve analysis test results are presented in Table 4.1. The MORTH gradations of DBM are shown in Table 4.2. The blending selected for the gradation of DBM Grade-II is shown in Table 4.3.

Table 4.1 Results of Sieve Analysis of Aggregates

Sieve Size	Percentage Passing 20mm	Percentage Passing 10mm	Percentage Passing 2.36mm(retained)	Percentage Passing Stone dust
37.5mm	100	100	100	100
26.5mm	100	100	100	100
19mm	74	100	100	100
13.2mm	10.5	98.5	99.4	100

4.75mm	0	14.9	16	100
2.36mm	0	0	38.5	96
0.300mm	0	0	4.5	45
0.075mm	0	0	0	3.5

4.3 Aggregate Testing

Aggregate were tested for the various specified properties such as Aggregate Crushing Value (%), Los Angles Abrasion (%), Aggregate Impact Value (%), Water Absorption and Specific gravity. The obtained results so obtained were compared with the allowable values as per the MORTH Specifications as shown in Table 4.4.

Table 4.2: Gradation of Dense Bituminous Macadam (MORTH, Clause 505.2.5)

Existing MORTH Gradation for Dense Bituminous Macadam		
Grading	1	2
Nominal aggregate size	37.5mm	26.5 mm
Layer Thickness	75-100 mm	50-75 mm
IS Sieve (mm)	% passing	% passing
45	100	
37.5	95-100	100
26.5	63-93	90-100
19	-	71-95
13.2	55-75	56-80
9.5	-	-
4.75	38-54	38-54
2.36	28-42	28-42
1.18	-	-
0.6	-	-

0.3	7-21	7-21
0.15	-	-
0.075	2-8	2-8
Bitumen content %	Min4.0	Min4.5

Table 4.3: Percentage of Aggregate Size Retained

Calculated Blending For MORTH Gradation Grade-II				
20mm	**10mm**	**2.36 retaining**	**Stone dust**	**Total**
25%	35%	30%	10%	100%

Calculated Blending For ASTM Gradation				
20mm	**10mm**	**2.36 retaining**	**Stone dust**	**Total**
25%	30%	30%	15%	100%

Calculated Blending For Kandhal Gradation				
20mm	**10mm**	**2.36 retaining**	**Stone dust**	**Total**
25%	30%	30%	15%	100%

Table 4.4 Test Results of Ingredient Aggregates

Description of Test	**Specification as per MORTHTable-500-18**	**Test Result**
Aggregate Crushing Value (%)	Max. 10-25	17.23 %
Loss Angles Abrasion (%)	Max. 30%	20.23 %
Aggregate Impact Value (%)	Max. 24%	9.66 %
Water Absorption	Max. 2%	0.75 %
Specific gravity	Max. 2.5-3	2.65

4.4 Bitumen Testing

The bitumen Samples were tested for the tests shown in Table 4.5. In these tests, the penetration and viscosity test was performed to obtain consistency of bitumen at some specified temperature and designate grade of bitumen. The softening point test is to obtain the temperature for bitumen melt.

Table 4.5 Test results of Ingredient Bitumen Sample

Property	**Specification as per IS: 73 (2007)**	**Test Results**
Penetration Value, mm	50-70 mm	56
Softening Point, ^{0}C	>47^{0}C	74.5
Ductility, cm	Min. 40 cm	90
Specific Gravity	Min. 0.99	1.025

4.5 Stability-Flow Analysis of DBM Grade-II with MORTH Gradation

To determine the Marshall Properties of DBM Mix and Optimum Binder Content (OBC), Marshall Samples were prepared by MORTH gradation and varying no. of blows as 50, 75 and 100. Marshall Stability Test was carried out for prepared bituminous Samples with varying bitumen content from 4% to 5.5%. All the result values of Marshall Properties of DBM Mix obtained are plotted graphically and in the form of table 4.6 to 4.8 as follows: -

Table 4.6: Marshall Test Results for MORTH Gradation &50 No. of Blows

Marshall Properties of Bituminous Mix for No. of Blows – 50	**Gradation – MORTH, Grade-II Varying Bitumen Content**			
	4%	**4.5%**	**5%**	**5.5%**
Corrected Stability (KN)	10.78	12	13	9
Flow Value (mm)	3.5	4.8	4.9	4.98

Air Voids (%)V_v	7.48	5.95	5.24	4.43
VMA(%)	16.42	16.18	16.37	16.66
VFB(%)	54.44	63.22	68.23	74.40

Figure 4.1 shows the variation in corrected stability at different bitumen content. The maximum Stability is 13KN at 5% of bitumen content.

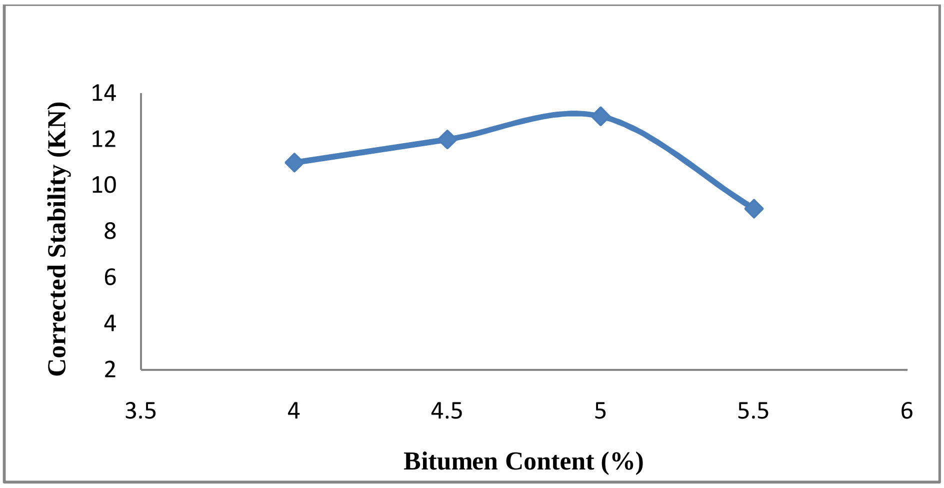

Figure 4.1: Corrected Stability Vs Bitumen Content Curve for 50 blows

Figure 4.2 represents the increment of flow value with respect to increasing the bitumen content. The maximum flow value is 4.98 mm at 5.5% of bitumen content for 50 blows.

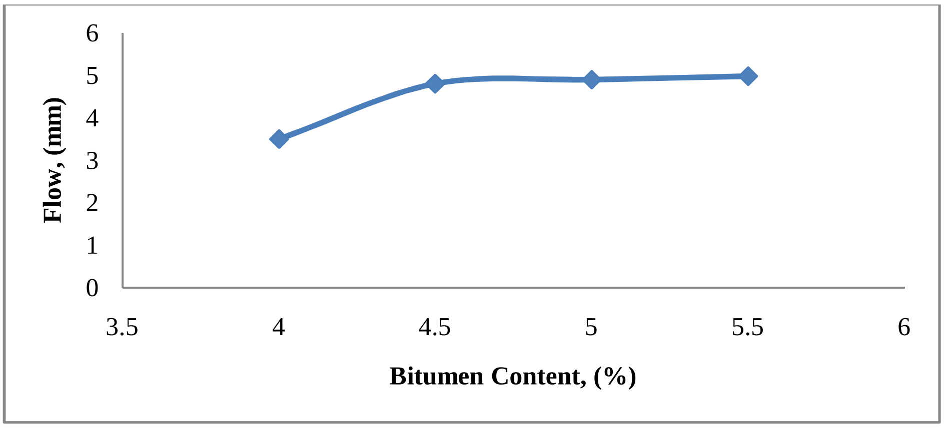

Figure 4.2: Flow Vs Bitumen Content curve for 50 blows

Figure 4.3 shows the percentage of air voids in the mix, which vary with bitumen content. Percentage of air voids in the mix is 7.48 % at 4% of bitumen content.

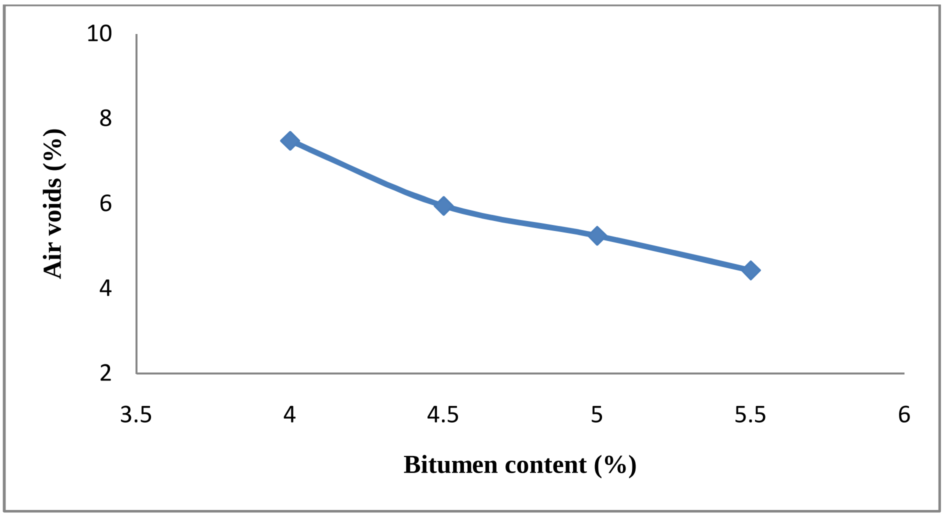

Figure 4.3: Air voids Vs Bitumen Content curve for 50 blows

Figure 4.4 shows the variation in percentage of voids in mineral aggregate at different bitumen content. The maximum percentage of VMA is 16.66% at 5.5% of bitumen content.

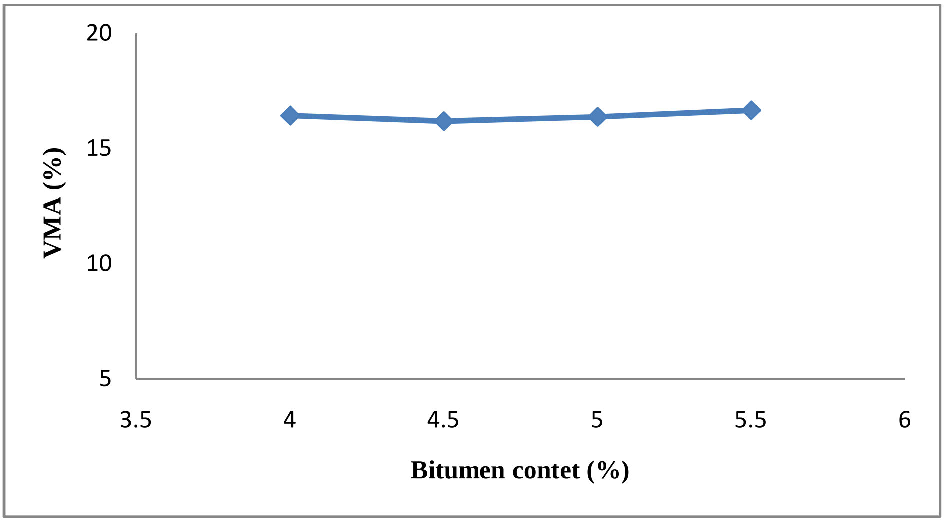

Figure 4.4: VMA Vs Bitumen Content curve for 50 blows

Figure 4.5 indicates the variation in percentage of voids filled with bitumen with different bitumen content. The Maximum VFB is 74.40 %at 5.5% of bitumen content.

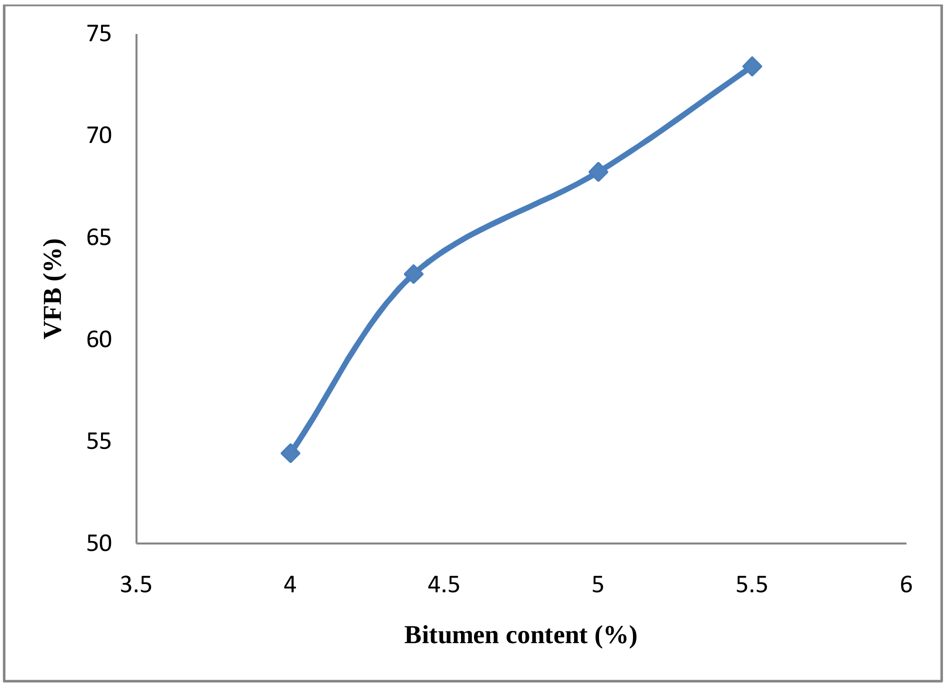

Figure 4.5: VFB Vs Bitumen Content curve for 50 blows

Discussion of Results of MORTH Gradation

4.5.1 Effect of MORTH Grade-II Aggregate Gradation for 50 Blows on Marshall Properties of DBM Mix:

Marshall Stability test is conducted to determine the Marshall Properties of Dense Bituminous Macadam Mix. Table 4.6 and figure 4.1 to 4.5 shows the variation in the Properties of DBM mix for MORTH Grade-II Gradation with the 50 blows of compaction effort and using different percentage such as 4%, 4.5%, 5% and 5.5% of bitumen content. The optimum bitumen content is calculated by adding the three terms such as Max. Stability, Max. Bulk Specific Gravity and Bitumen content for air voids @ 4% and then dividing by 3. The average value of these three is the Optimum Binder Content (O.B.C) for the Mix with MORTH Gradation. For this gradation the obtained optimum binder content is 4.5.

Table 4.7: Marshall Test Results for MORTH Gradation &75 No. of Blows

Marshall Properties of Bituminous Mix for No. of Blows – 75	**Gradation – MORTH, Grade-II Varying Bitumen Content**			
	4%	**4.5%**	**5%**	**5.5%**
Corrected Stability(KN)	12.74	14.55	16.49	12
Flow Value (mm)	2.3	4.5	4.78	4.80
Air Voids (%)Vv	10.62	6.74	6	5.64
VMA(%)	19.32	16.75	17	18
VFB(%)	44.74	59.76	65	67

Figure 4.6 shows the variation in corrected stability with different bitumen content. The Maximum Marshall Stability is 16.49 KN at 5% of bitumen content.

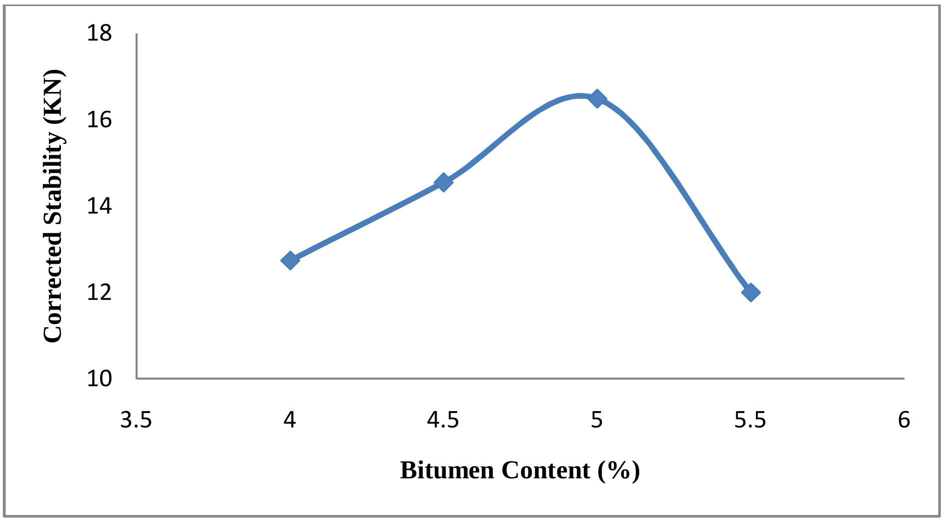

Figure 4.6: Corrected Stability Vs Bitumen Content curve for 75 blows

Figure 4.7 represents the increment of flow value with respect to increasing the bitumen content. The maximum flow value is 4.80 mm at 5.5% of bitumen content for 75 blows.

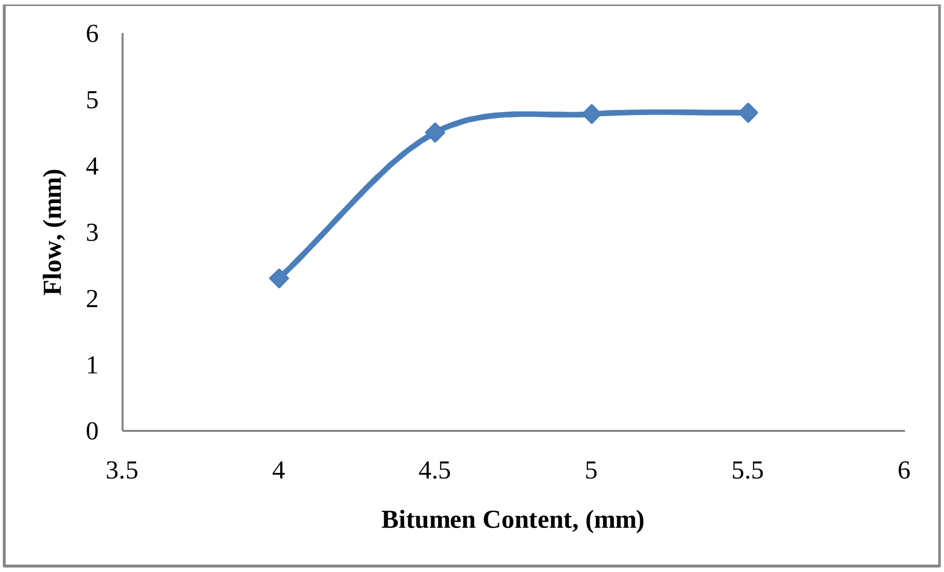

Figure 4.7: Flow Vs Bitumen Content curve for 75 blows

Figure 4.8 shows the percentage of air voids in the mix, which vary with bitumen content. Percentage of air voids in the mix is 10.62 % at 4% of bitumen content.

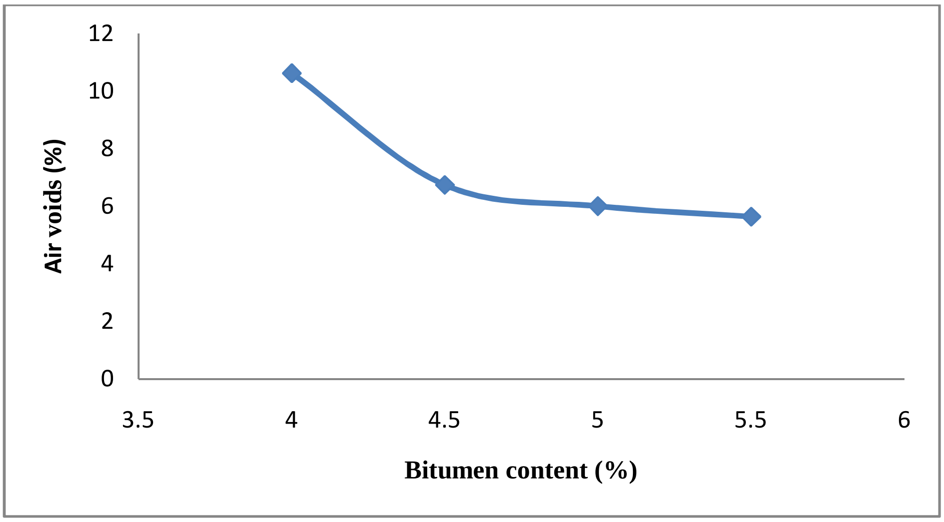

Figure 4.8: Air voids Vs Bitumen Content curve for75 blows

Figure 4.9 shows the percentage increases, voids in mineral aggregate at different bitumen content. Maximum VMA is 19.32% @ 4% bitumen content.

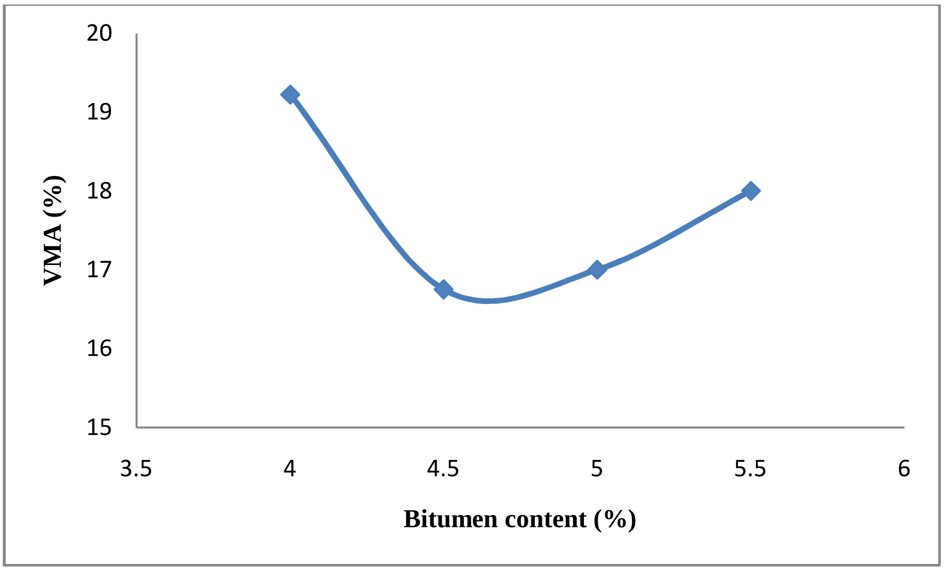

Figure 4.9: VMA Vs Bitumen Content curve for 75 blows

Figure 4.10 shows the variation in percentage of voids filled with bitumen at different bitumen content. The maximum VFB is 59.76 % at 4.5% of bitumen content.

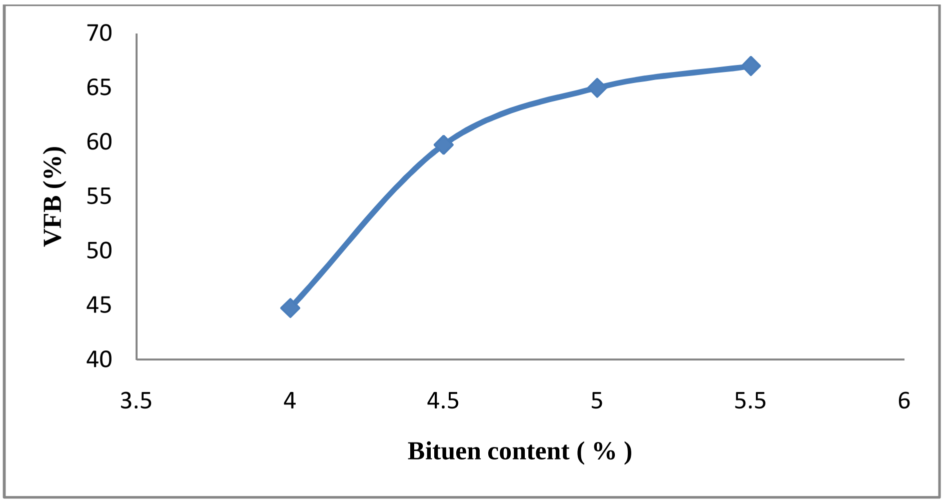

Figure 4.10: VFB Vs Bitumen Content curve for 75 blows

4.5.2 Effect of MORTH Grade-II Aggregate Gradation for 75 Blows on Marshall Properties of DBM Mix:

The Optimum Bitumen Content is determining from different percentage of bitumen used with 75 blows of compaction effort, which affects the Marshall Stability and Marshall Flow value. Table 4.7 and figure 4.6 to 4.10 shows the variation in the Marshall Properties of DBM mix for MORTH Gradation. In these figures, the Marshall Stability is more than the required range of Marshall Stability as per MORTH Specifications i.e 9 KN and obtained Marshall Stability is 16.49 KN. And the Marshall Flow value is also in specified range i.e 2 to 6 and obtained max. Flow value is 4.80. Increasing the percentage of bitumen content decreases the air voids percentage. And increasing the compaction effort as well increases the Marshall Stability value.

Table 4.8: Marshall Test Results for MORTH Gradation & 100 No. of blows

Marshall Properties of Bituminous Mix for No. of Blows–100	**Gradation – MORTH, Grade-II Varying Bitumen Content**			
	4%	**4.5%**	**5%**	**5.5%**
Corrected Stability (KN)	19.6	23.52	27.44	25.22
Flow Value (mm)	4.5	4.1	4.5	4.7
Air Voids (%)Vv	5.91	6.34	2.0	4.8
Voids in Mineral Aggregate (%) VMA	15.01	16.4	14.0	17.0
VFB(%)	60.62	61.34	83.0	72.0

Figure 4.11 shows the variation in corrected stability at different bitumen content. The Marshall Stability is maximum at 5% of bitumen content is 27.22 KN.

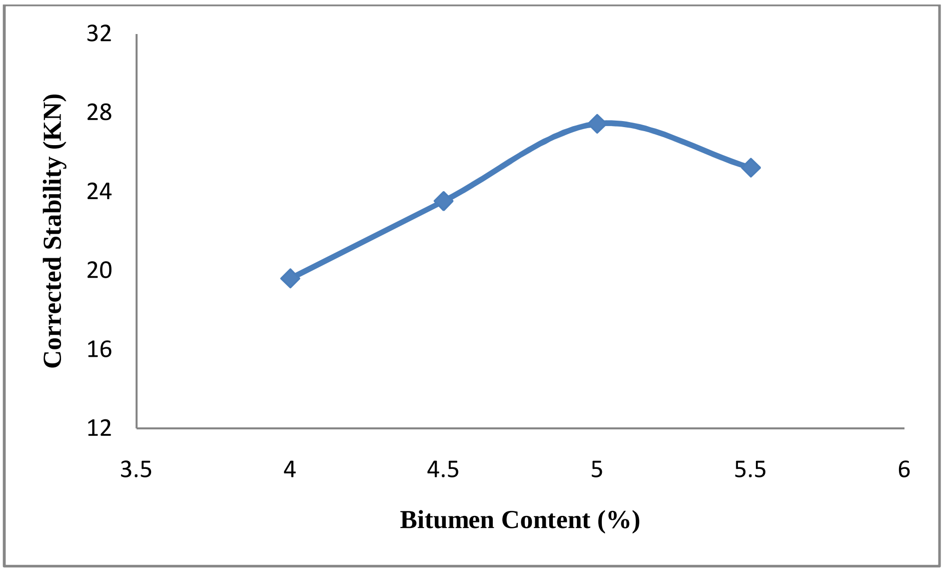

Figure 4.11: Corrected Stability Vs Bitumen Content curve for 100 blows

Figure 4.12 represents the increment of flow value with respect to increasing the bitumen content. The maximum flow value is 4.7 mm at 5.5% of bitumen content for 100 blows.

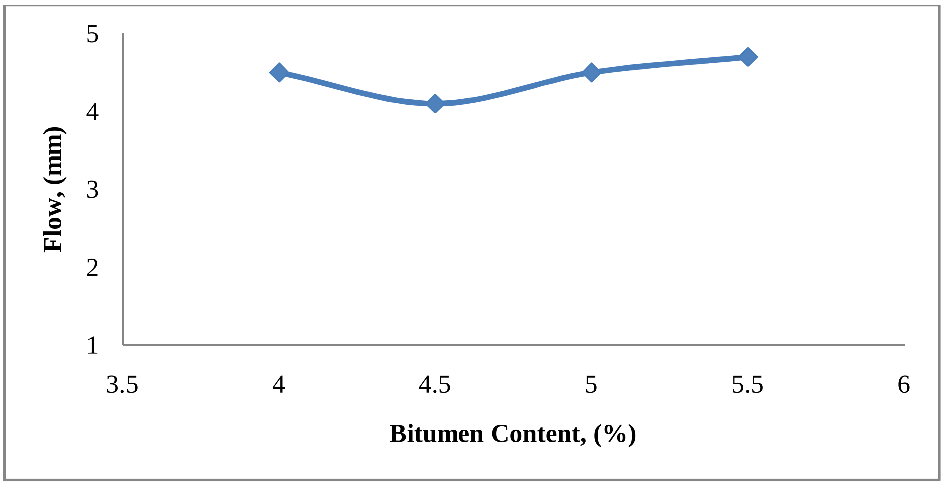

Figure 4.12: Flow Vs Bitumen Content curve for 100 blows

Figure 4.13 shows the percentage of air voids in the mix, which vary with bitumen content. Percentage of air voids in the mix is 6.34 % at 4.5% of bitumen content.

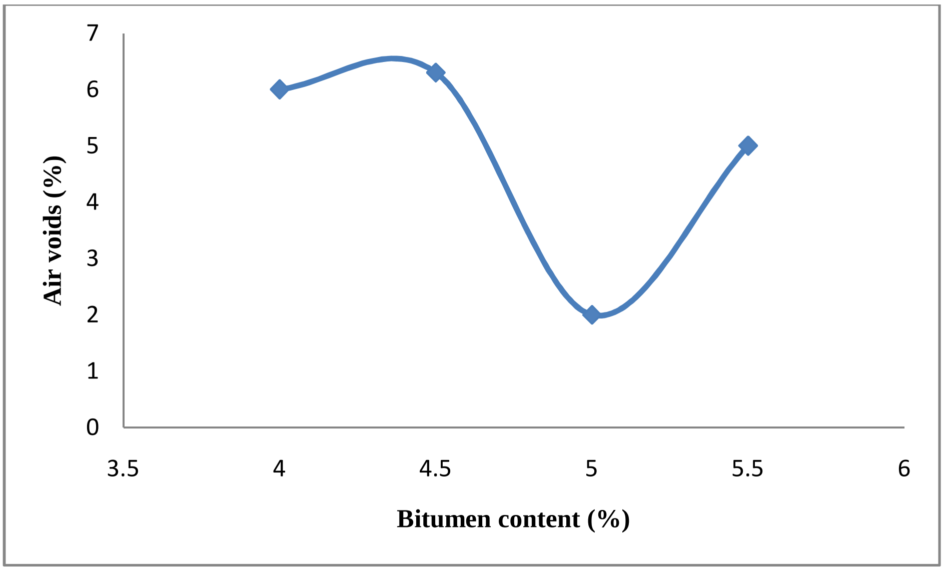

Figure 4.13: Air voids Vs Bitumen Content curve for 100 blows

Figure 4.14 shows the variation in percentage of voids in mineral aggregate at different bitumen content. The maximum percentage of VMA is 17% at 5.5% of bitumen content.

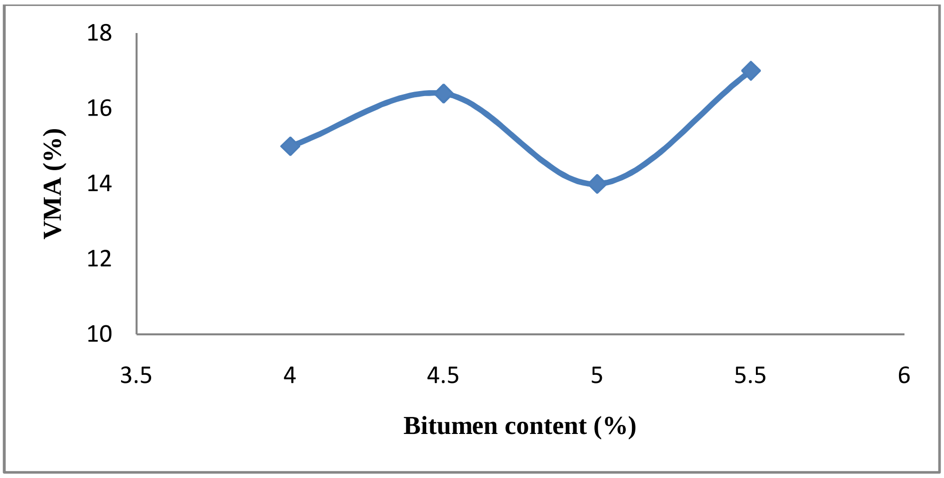

Figure 4.14: VMA Vs Bitumen Content curve for 100 blows

Figure 4.15 indicates the variation in percentage of voids filled with bitumen with different bitumen content. The Maximum VFB is 83% at 5% of bitumen content.

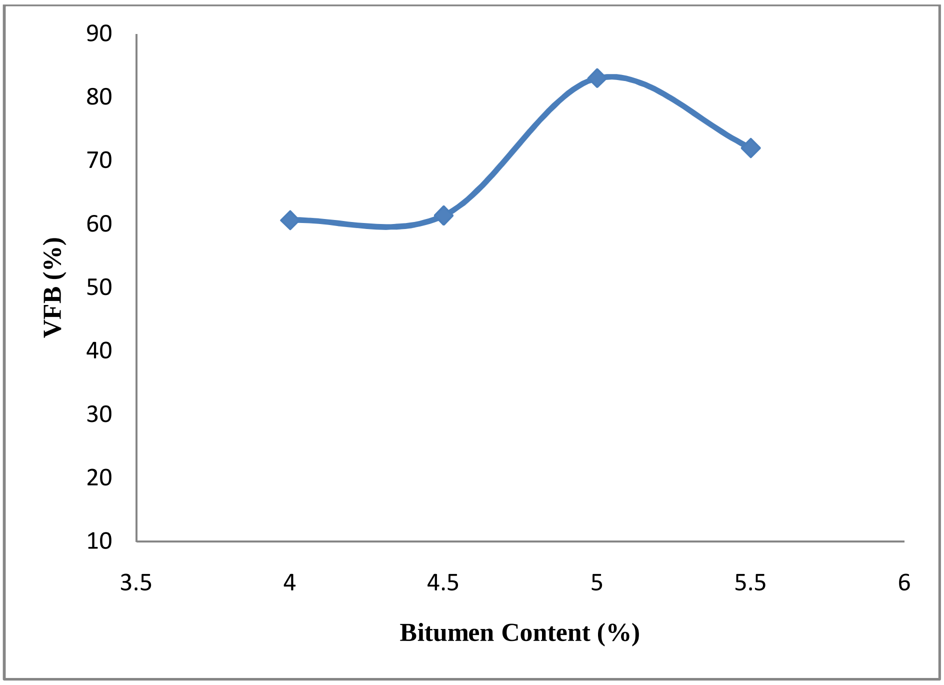

Figure 4.15: VFB Vs Bitumen Content curve for 100 blows

4.5.3 Effect of MORTH Grade-II Aggregate Gradation for 100 Blows on Marshall Properties of DBM Mix:

Table 4.8 shows the Marshall Properties of Dense Bituminous Macadam Mix for MORTH Gradation with the 100 blows of compaction effort. A figure from 4.11 to 4.12 shows the variation in Marshall Stability and flow value. The Marshall Stability value by 100 blows of compaction effort is more than the other two compaction effort (50 and 75). Figure from 4.13 to 4.15 shows the variation in percentage with increment of bitumen content in air voids %, voids filled with bitumen % and voids in mineral aggregate. The maximum percentage of air void is 6.34%, VMA is 17% and VFB is 83% @ 5% of bitumen content. Increasing the bitumen content thus decreases the voids in the specimen which gives the more stability. And also more the blows increase the Marshall Stability. The optimum binder content for this gradation and compactive effort is 4.83.

4.6 Stability-Flow Analysis of DBM Grade-II with American Society for Testing and Materials (ASTM) Gradation

Marshall Samples were prepared by American Society for Testing and Materials (ASTM) gradation, varying no. of blows 50, 75 and 100. Marshall Stability Test was carried out for prepared bituminous Samples with varying bitumen content from 4% to 5.5%. Optimum Bitumen Content for ASTM Gradation, 4.56, 4.66 and 4.67 for 50, 75 and 100 are respectively.

The specimens prepared as per ASTM Gradation were tested to determine the Marshall Properties of DBM Mix such as Bulk density or Bulk Specific Gravity, Marshall Stability, Flow value, percentage of Air Voids in the mix, Voids in Mineral Aggregate and Voids Filled with Bitumen and Optimum Binder Content (OBC).

All the result values obtained are presented in Tables 4.9 to 4.11.

Table 4.9: Marshall Test Results for ASTM Gradation & 50 No. of Blows

Marshall Properties of Bituminous Mix for No. of Blows – 50	**Gradation – ASTM Varying Bitumen Content**			
	4%	**4.5%**	**5%**	**5.5%**
Corrected Stability (KN)	16	17.836	18.43	13
Flow Value (mm)	5	4.3	4.6	4.8
Air Voids (%)Vv	9.1	8.5	5	2.40
VMA (%)	18	18.6	16.31	15
VFB (%)	49	54.30	69.34	83.46

Figure 4.16 shows the variation in corrected stability at different bitumen content. The maximum Stability is 18.43KN at 5% of bitumen content.

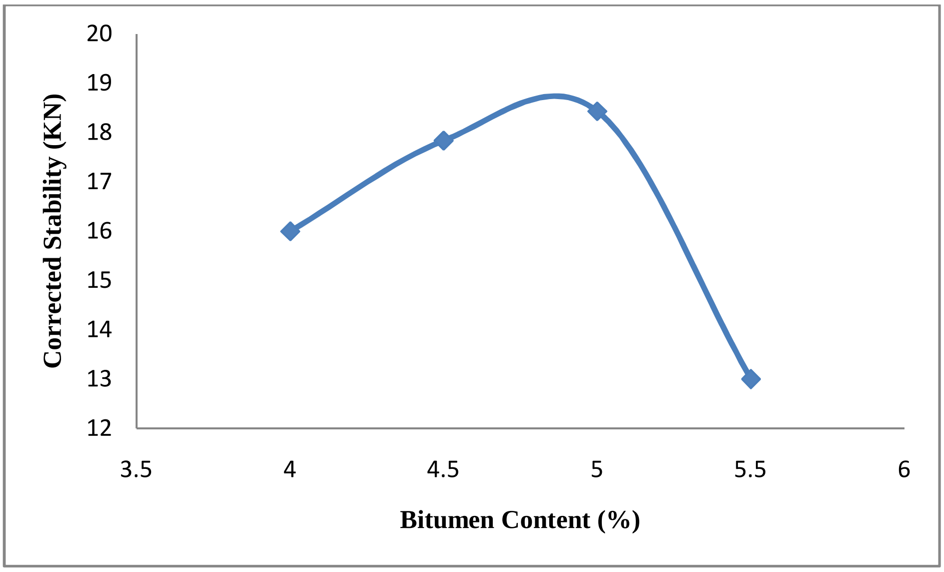

Figure 4.16: Corrected Stability Vs Bitumen Content curve for 50 blows

Figure 4.17 represents the increment of flow value with respect to increasing the bitumen content. The maximum flow value is 4.8mm at 5.5% of bitumen content for 50 blows.

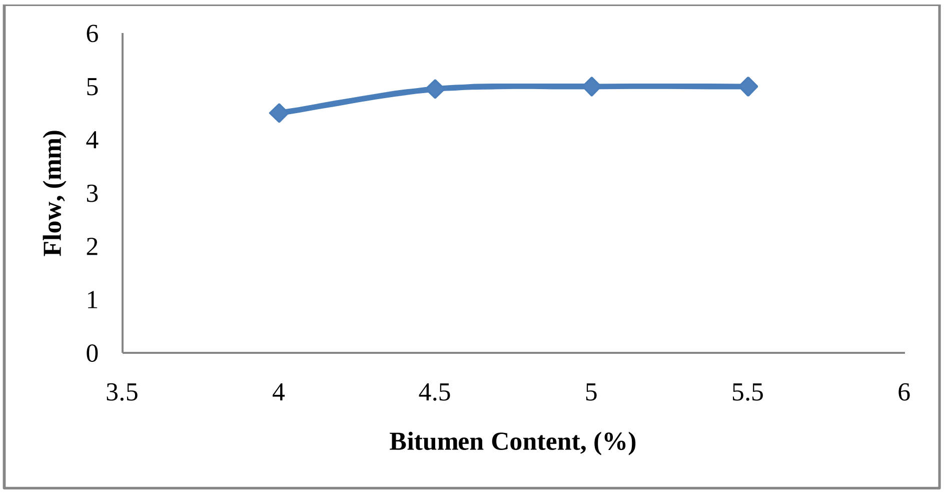

Figure 4.17: Flow Vs Bitumen Content curve for 50 blows

Figure 4.18 shows the percentage of air voids in the mix, which vary with bitumen content. Percentage of air voids in the mix is 9.1 % at 4% of bitumen content.

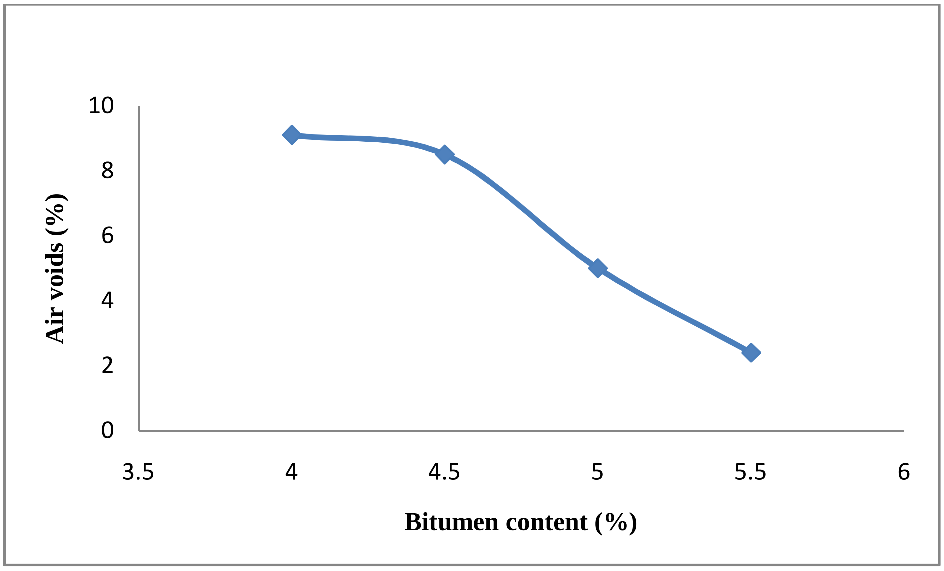

Figure 4.18: Air voids Vs Bitumen Content curve for 50 blows

Figure 4.19 shows the variation in percentage of voids in mineral aggregate at different bitumen content. The maximum percentage of VMA is 18.6% at 4.5% of bitumen content.

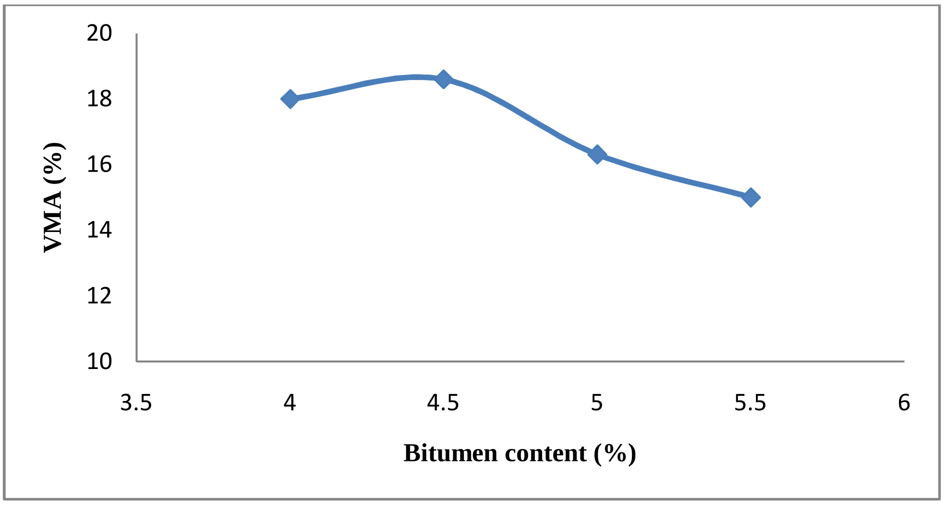

Figure 4.19: VMA Vs Bitumen Content curve for 50 blows

Figure 4.20 indicates the variation in percentage of voids filled with bitumen with different bitumen content. The Maximum VFB is 83.46% at 5.5% of bitumen content.

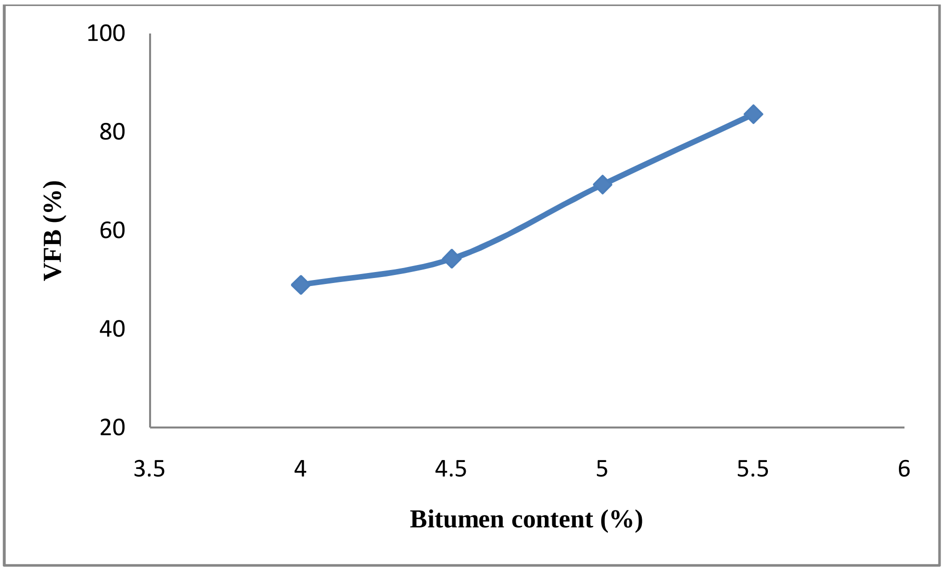

Figure 4.20: VFB Vs Bitumen Content curve for 50 blows

4.6.1 Effect of American Society for Testing & Materials (ASTM) Aggregate Gradation for 50 Blows on Marshall Properties of DBM Mix:

The Optimum Bitumen Content Calculated from different percentage of bitumen such as 4%, 4.5%, 5% and 5.5% used with the 50 blows of compaction effort which affects the Stability and flow value. Table 4.9 and figure 4.16 to 4.20 shows the variation in the Properties of DBM mix for MORTH Gradation. In this type of gradation aggregate size is larger than the MORTH Grade-II gradation. Larger size of aggregate are more compact and take more load. The optimum binder content is calculated from three maximum values of Marshall Stability-Flow analysis i.e the maximum bulk specific gravity, maximum stability and bitumen content @4%. These values are added and then divided by 3, The average value of these three is called the optimum binder content. For 50 blows the O.B.C obtained is 4.67. The Maximum Marshall Stability is 18.43@ 5% of bitumen content and Maximum Marshall Flow value is 4.8@ 5.5 of bitumen content.

Table 4.10: ASTM Aggregate Gradation & 75 No. of blows

Marshall Properties of Bituminous Mix for No. of Blows – 75	**Gradation – ASTM Varying Bitumen Content**			
	4%	**4.5%**	**5%**	**5.5%**
Corrected Stability (KN)	16.5	17.9	18.5	17.9
Flow Value (mm)	4.5	4.9	4.92	4.99
Air Voids (%)Vv	24	6.9	2.39	3.61
Voids in Mineral Aggregate (%) VMA	31.2	11.7	13.98	15.99
Voids Filled with Bitumen (%) VFB	23.07	59.81	82.90	77.42

Figure 4.21 indicates the variation in corrected stability at different bitumen content. The maximum Stability is 18.5 KN at 5% of bitumen content.

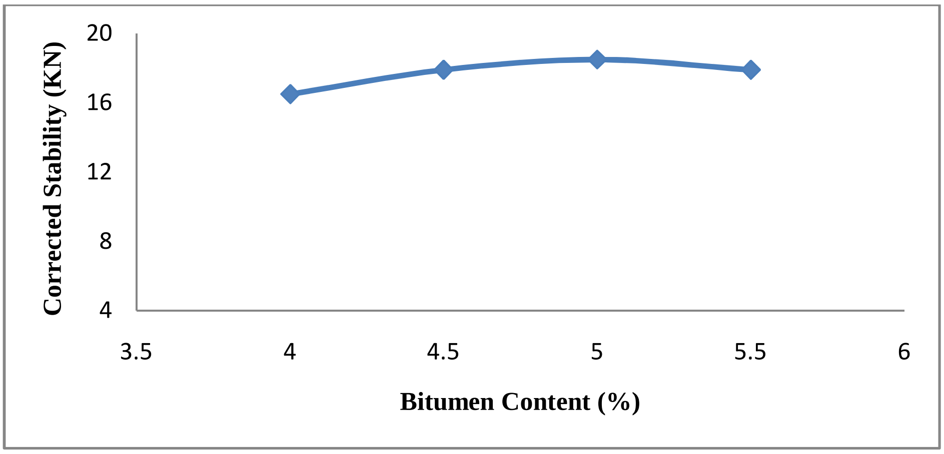

Figure 4.21: Corrected Stability Vs Bitumen Content curve for75 blows

Figure 4.22 represents the increment of flow value with respect to increasing the bitumen content. The maximum flow value is 4.99 mm at 5.5% of bitumen content for 75 blows.

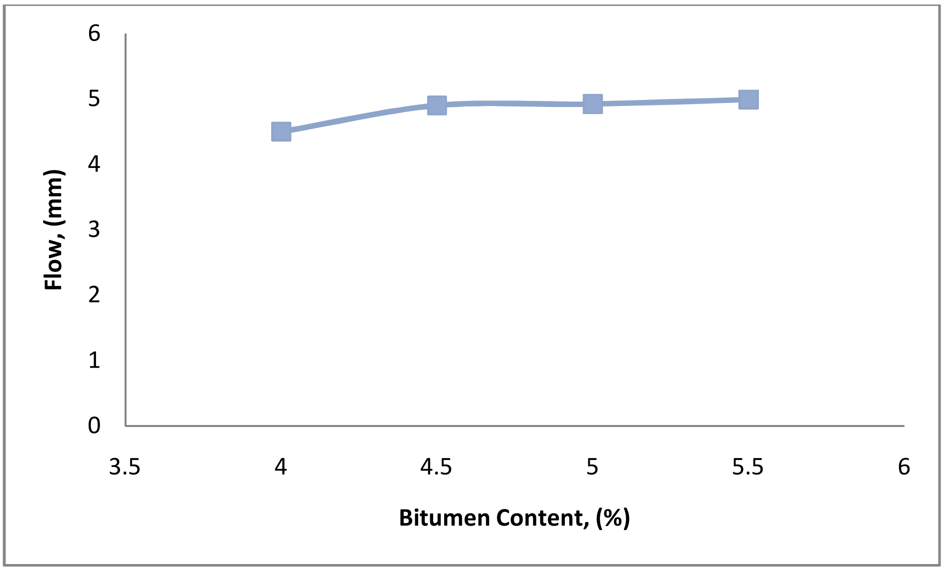

Figure 4.22: Flow Vs Bitumen Content curve for 75 blows

Figure 4.23 shows the percentage of air voids in the mix, which vary with bitumen content. Percentage of air voids in the mix is 24 % at 4% of bitumen content.

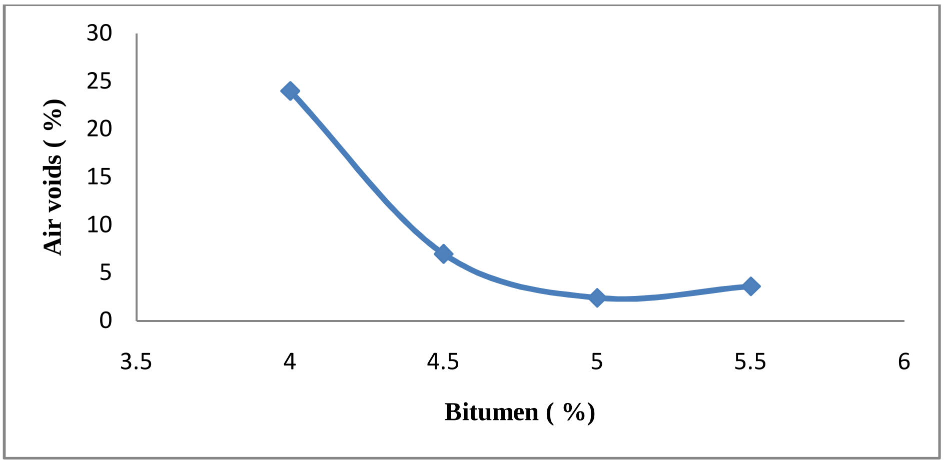

Figure 4.23: Air voids Vs Bitumen Content curve for75 blows

Figure 4.24 indicates the variation in percentage of voids in mineral aggregate at different bitumen content. The maximum percentage of VMA is 31.2 % at 5.5% of bitumen content.

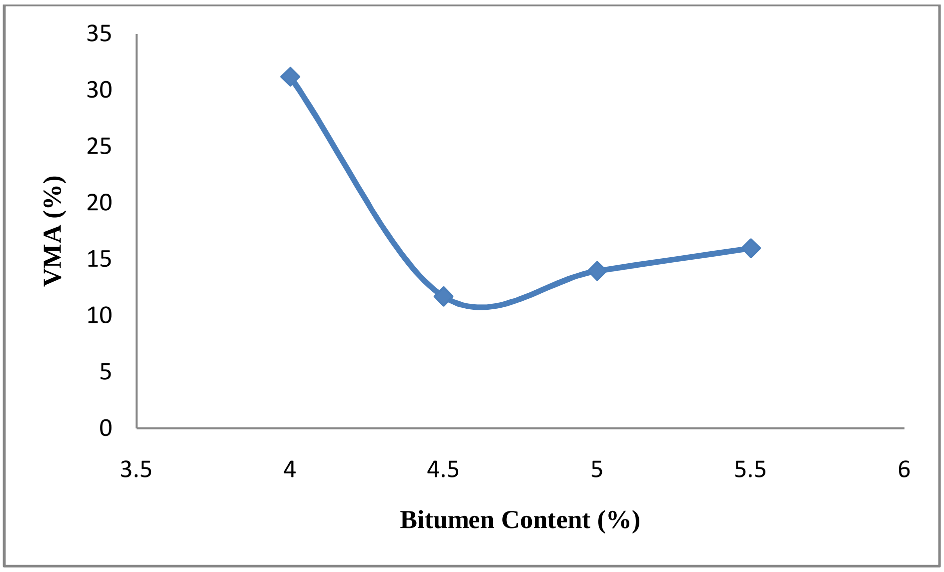

Figure 4.24: VMA Vs Bitumen Content curve for75 blows

Figure 4.25 shows the variation in percentage of voids filled with bitumen with different bitumen content. The Maximum VFB is 82.90 at 5% of bitumen content.

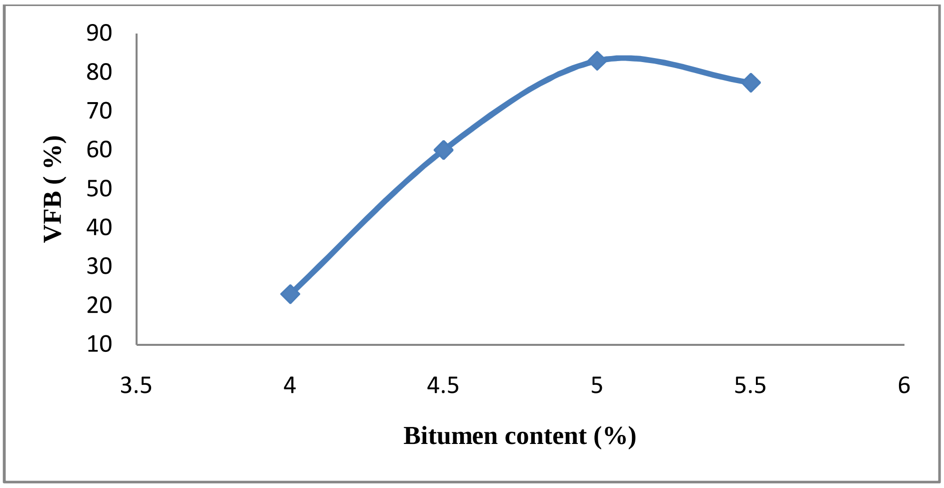

Figure 4.25: VFB Vs Bitumen Content curve for75 blows

4.6.2 Effect of American Society for Testing & Materials (ASTM) Aggregate Gradation for 75 Blows on Marshall Properties of DBM Mix:

Table 4.10 shows the Marshall Properties of Dense Bituminous Macadam Mix for MORTH Gradation with the 75 blows of compaction effort. A figure from 4.21 to 4.22 shows the variation in Marshall Stability and flow value. The Marshall Stability value by 75 blows of compaction effort is not very much varying from 50 blows of compaction effort. Figure from 4.23 to 4.25 shows the variation in air voids %, voids filled with bitumen % and voids in mineral aggregate %. The Maximum stability and flow values 18.5 and 4.99 are respectively.

Table 4.11: ASTM Aggregate Gradation &100 No. of blows

Marshall Properties of Bituminous Mix for No. of Blows–100	**Gradation – ASTM Varying Bitumen Content**			
	4%	**4.5%**	**5%**	**5.5%**
Corrected Stability (KN)	17	17.95	18.9	18
Flow Value (mm)	4.5	4.95	5	5
Air Voids (%)Vv	8.3	7.3	1.91	6.02
Voids in Mineral Aggregate (%) VMA	17	17.53	14	18
Voids Filled with Bitumen (%) VFB	50	58.35	85.71	66.66

Figure 4.26 shows the variation in corrected stability at different bitumen content. The Maximum Stability is 18.9 KN at 5% of bitumen content.

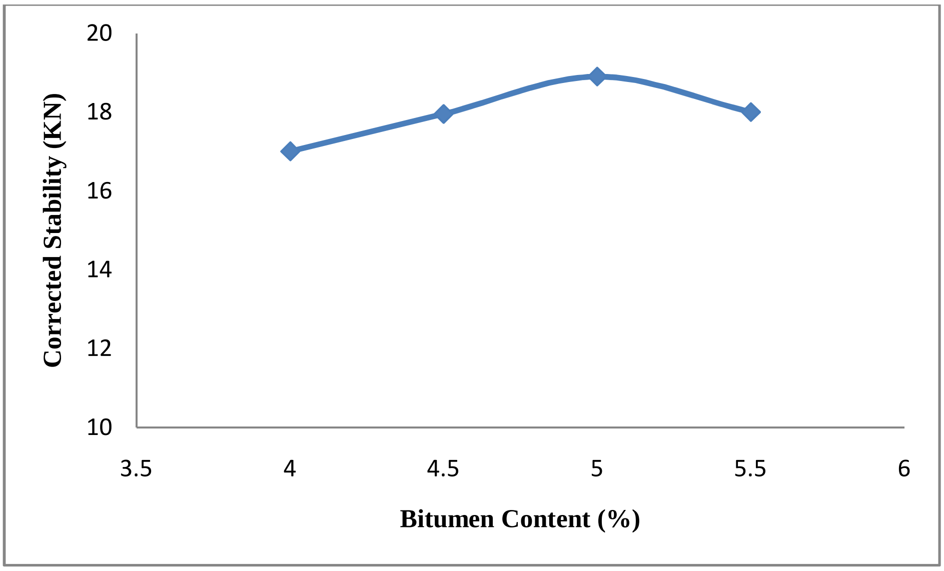

Figure 4.26: Corrected Stability Vs Bitumen Content curve for100 blows

Figure 4.27 represents the increment of flow value with respect to increasing the bitumen content. The maximum flow value is 5mm at 5% and 5.5% of bitumen content for 100 blows.

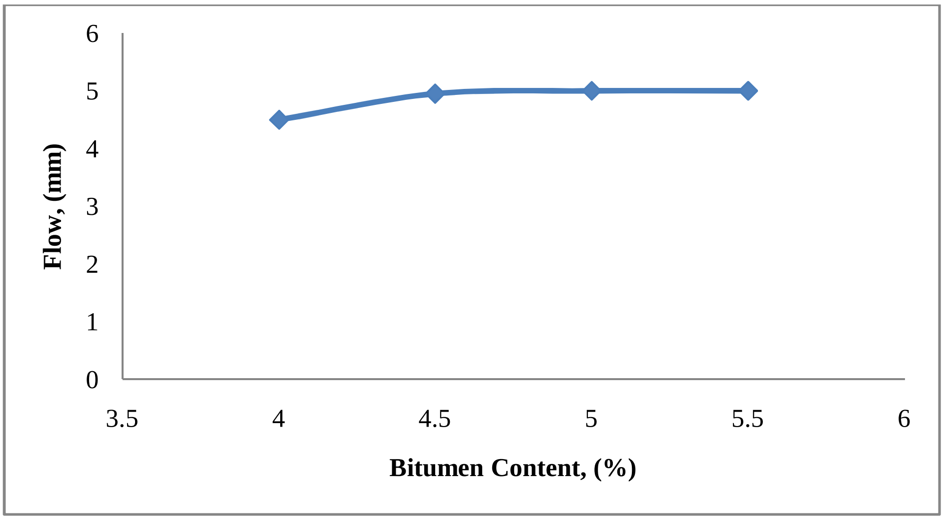

Figure 4.27: Flow Vs Bitumen Content curve for 100 blows

Figure 4.28 shows the percentage of air voids in the mix, which vary with bitumen content. Percentage of air voids in the mix is 8.3 % at 4% of bitumen content.

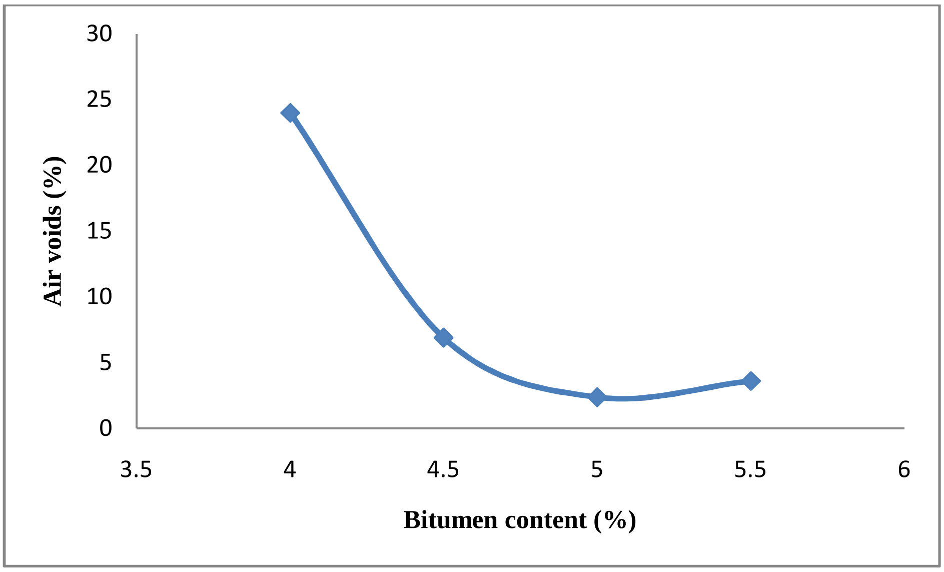

Figure 4.28: Air voids Vs Bitumen Content curve for 100 blows

Figure 4.29 shows the variation in percentage of voids in mineral aggregate at different bitumen content. The maximum percentage of VMA is 18% at 5.5% of bitumen content.

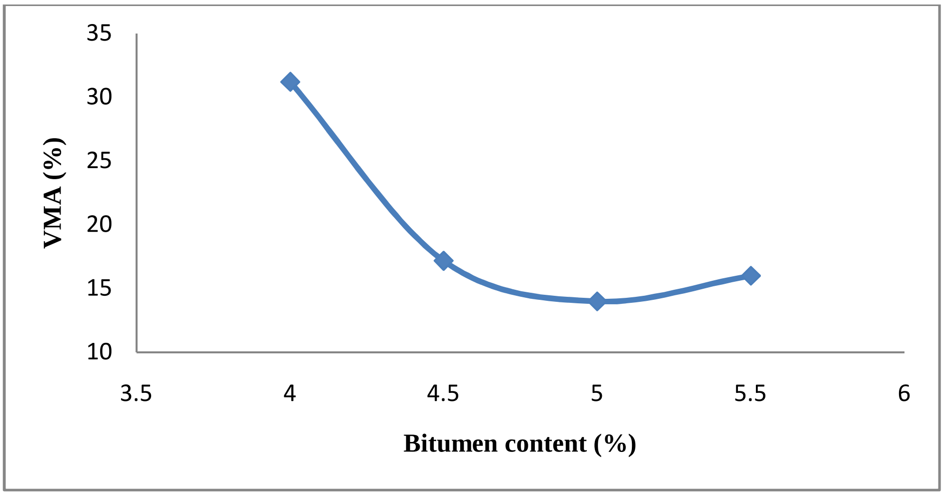

Figure 4.29: VMA Vs Bitumen Content curve for100 blows

Figure 4.30 indicates the variation in percentage of voids filled with bitumen with different bitumen content. The Maximum VFB is 85.71% at 5% of bitumen content.

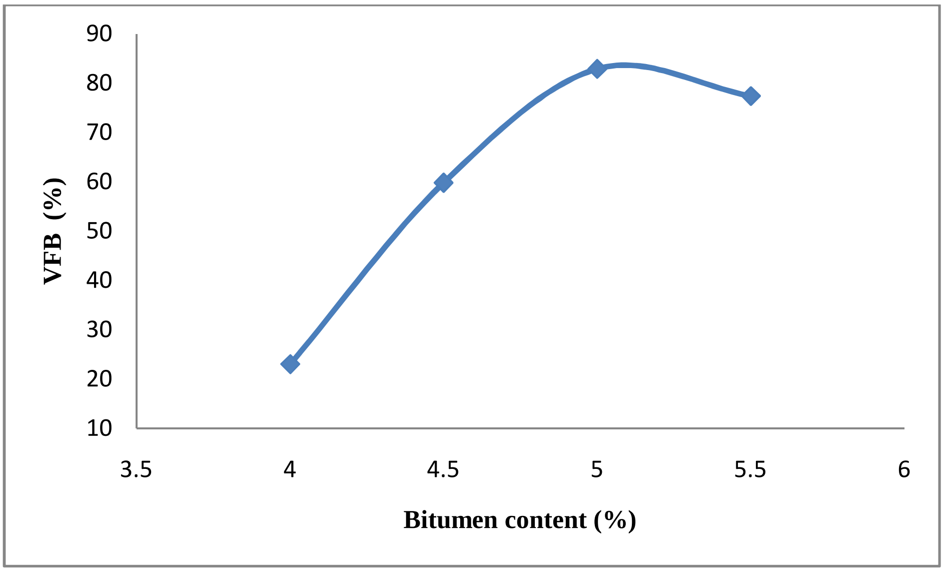

Figure 4.30: VFB Vs Bitumen Content curve for100 blows

4.6.3 Effect of American Society for Testing & Materials (ASTM) Aggregate Gradation for 100 Blows on Marshall Properties of DBM Mix:

Different percentage such as 4%, 4.5%, 5% and 5.5% of bitumen content was used to determine the optimum bitumen or binder content for the American Society for Testing & Materials (ASTM) gradation. Table 4.12 and figure 4.26 to 4.27 shows the variation in Marshall Stability and flow value for different percentage of bitumen content. It is found that the flow criteria for DBM were satisfied for the entire range of mixes. Marshall Stability test is conducted to determine the Marshall Properties of Dense Bituminous Macadam Mix shows in table 4.28 to 4.30. The stability value is higher than then the minimum specified value as per MS2 and MORTH specifications. The optimum binder content from the three maximum values of Marshall Properties obtained as 4.67 for 100 blows of compaction effort using Marshall Stability-Flow analysis method. The maximum Stability and Flow values i.e 18.9@ 5% of bitumen content and 5@ 5.5% of bitumen content are respectively. The maximum percentages obtained of air voids, VMA and VFB are 8.3@ 4%, 18@ 5.5% and 85.71@ 5% of bitumen content.

4.7 Stability-Flow Analysis of DBM Grade-II with Kandhal Gradation

Marshall Samples were prepared by Kandhal gradation, varying no. of blows 50, 75 and 100. Marshall Stability Test was carried out for prepared bituminous Samples with varying bitumen content from 4% to 5.5%. Optimum Bitumen Content for ASTM Gradation, 4.65, 4.66 and 4.7 for 50, 75 and 100 blows are respectively.To determine the Marshall Properties of DBM Mix such as Bulk density or Bulk Specific Gravity, Marshall Stability, Flow value, percentage of Air Voids in the mix, Voids in Mineral Aggregate and Voids Filled with Bitumen and Optimum Binder Content (OBC). All the result values obtained are shown in form of Tables 4.12 to 4.14

Table 4.12: Kandhal Aggregate Gradation & 50 No. of blows

Marshall Properties of Bituminous Mix for No. of Blows–50	**Gradation – Kandhal Varying Bitumen Content**			
	4%	**4.5%**	**5%**	**5.5%**
Corrected Stability (KN)	13.58	17.95	18.62	13
Flow Value (mm)	4.5	4.89	4.90	4.96
Air Voids (%)Vv	7.87	7.33	3.98	6.02
Voids in Mineral Aggregate (%) VMA	16.78	17.56	15.34	18.09
Voids Filled with Bitumen (%) VFB	53.09	58.25	74.05	66.72

Figure 4.31 shows the variation in corrected stability at different bitumen content. The Maximum Marshall Stability is 18.62 KN at 5% of bitumen content.

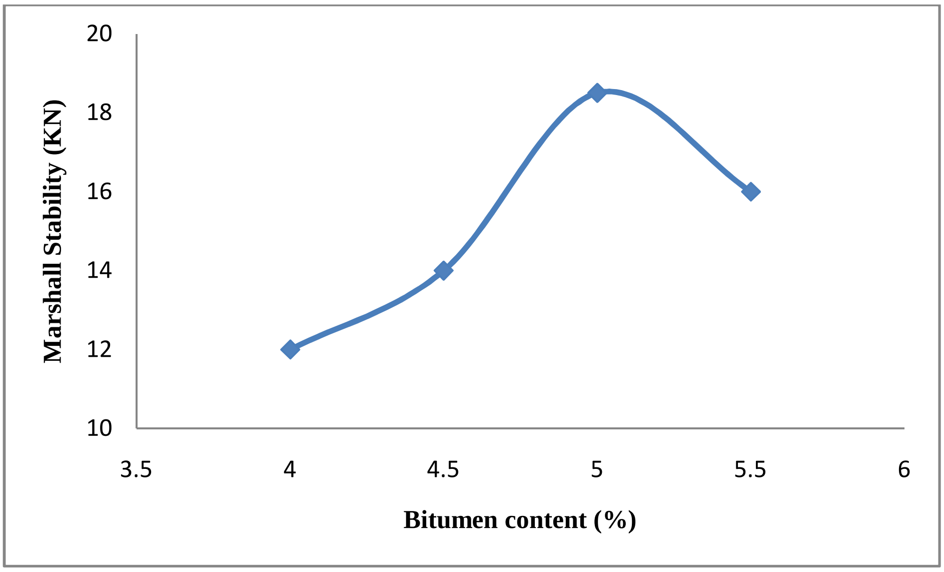

Figure 4.31: Corrected Stability Vs Bitumen Content curve for 50 blows

Figure 4.32 represents the increment of flow value with respect to increasing the bitumen content. The maximum flow value is 4.96 mm at 5.5% of bitumen content for 50 blows.

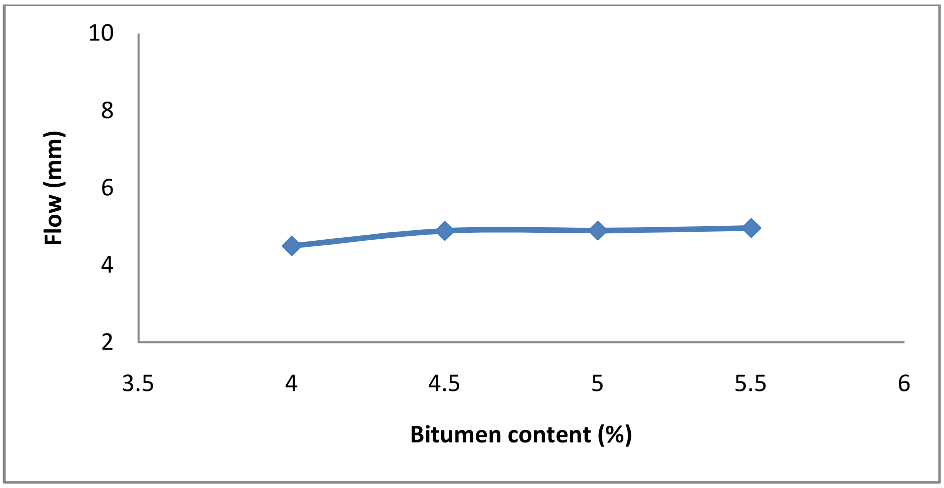

Figure 4.32: Flow Vs Bitumen Content curve for 50 blows

Figure 4.33 shows the percentage of air voids in the mix, which vary with bitumen content. Percentage of air voids in the mix is 7.87 % at 4% of bitumen content.

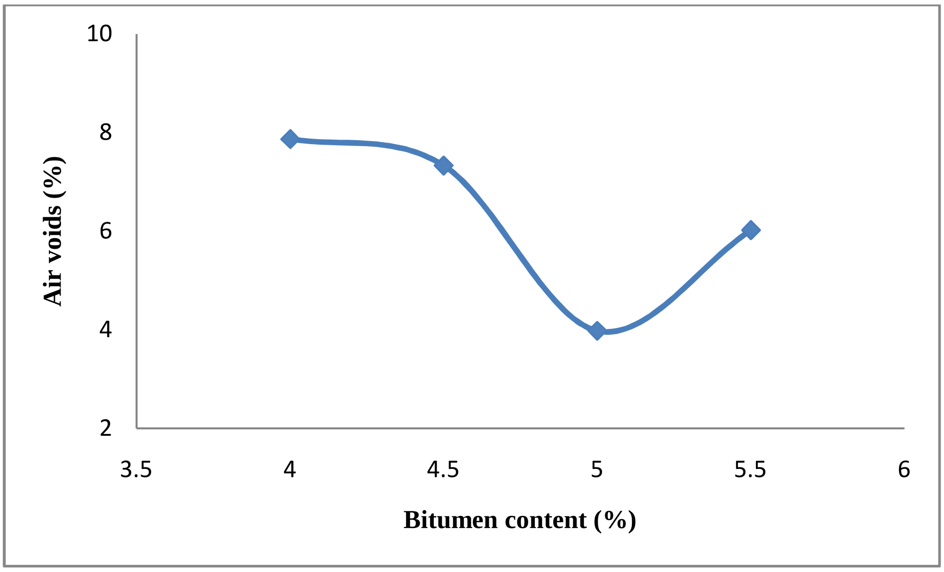

Figure 4.33: Air voids Vs Bitumen Content curve for 50 blows

Figure 4.34 shows the variation in percentage of voids in mineral aggregate at different bitumen content. The maximum percentage of VMA is 18.09% at 5.5% of bitumen content.

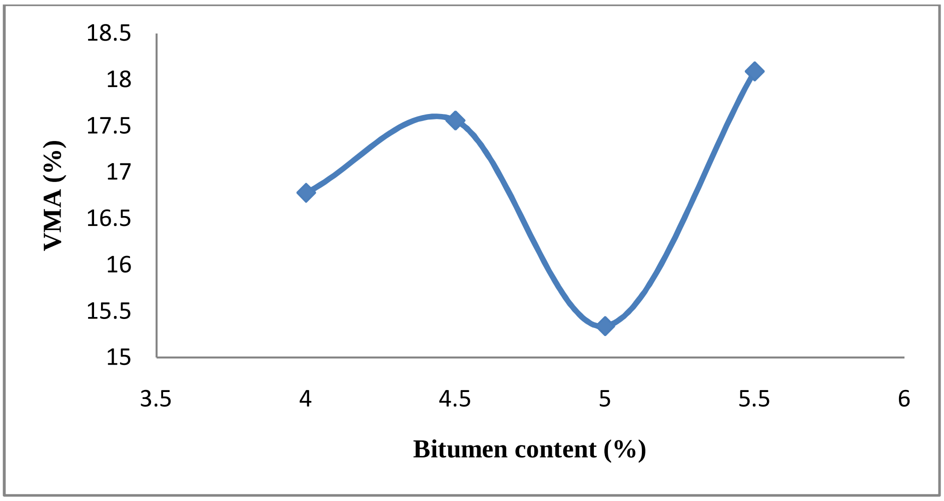

Figure 4.34: VMA Vs Bitumen Content curve for 50 blows

Figure 4.35 indicates the variation in percentage of voids filled with bitumen with different bitumen content. The Maximum VFB is 74.05% at 5% of bitumen content.

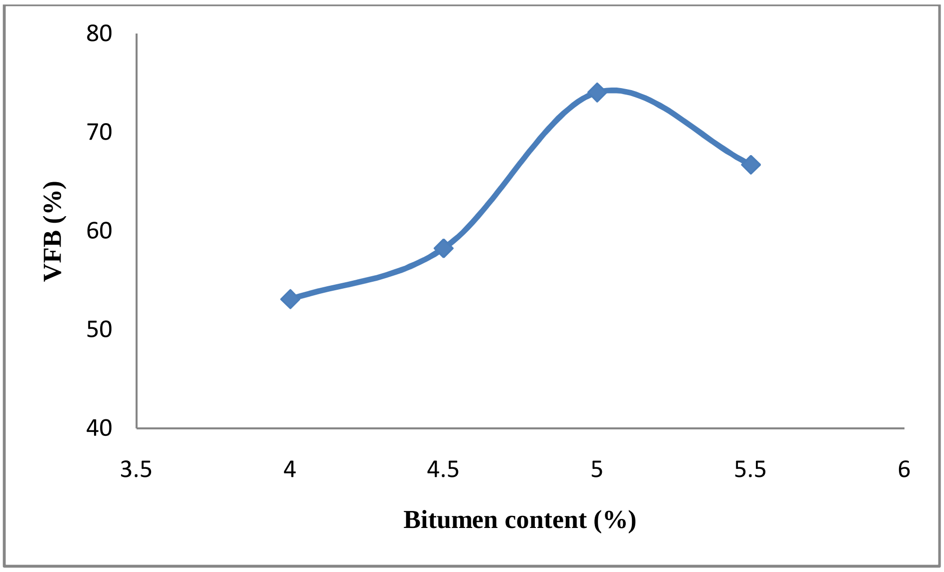

Figure 4.35: VFB Vs Bitumen Content curve for 50 blows

4.7.1 Effect of Kandhal Aggregate Gradation for 50 Blows on Marshall Properties of DBM Mix:

Table 4.13 shows the Marshall Properties of Dense Bituminous Macadam Mix for Kandhal Gradation with the 50 blows of compaction effort. A figure from 4.31 to 4.32 shows the variation in Marshall Stability and flow value. Figure from 4.33 to 4.35 shows the variation in air voids %, voids filled with bitumen % and voids in mineral aggregate %, which all are in specific range as per MORTH specification. This aggregate gradation works same as ASTM gradation, due to large aggregate used in this gradation. Marshall Stability value is not very much varying from a gradation ASTM's Marshall Stability value. The optimum binder content for this gradation and @ of 50 blows of compaction effort is 4.67. The Maximum percentage of air voids, voids in mineral aggregate and voids filled with bitumen are obtained as 7.87@ 4%, 18.09@ 5.5% and

74.05 at 5% of bitumen content. The maximum Marshall Stability and Flow values i.e 18.62 and 4.96 at 5.5% &5.5% of bitumen content are respectively.

Table 4.13: Kandhal   Aggregate Gradation & 75 No. of blows

Marshall Properties of Bituminous Mix by No. of Blows–75	**Gradation – Kandhal Varying Bitumen Content**			
	4%	**4.5%**	**5%**	**5.5%**
Corrected Stability (KN)	14.5	18	18.80	17.5
Flow Value (mm)	4.8	4.9	4.95	4.98
Air Voids (%)V_v	5.9	7.33	2.7	4.81
Voids in Mineral Aggregate (%) VMA	12.5	14.81	14.2	17.4
Voids Filled with Bitumen (%) VFB	74.88	71.37	81	71.77

Figure 4.36 shows the variation in corrected stability at different bitumen content. The Maximum Stability is18.80 KN at 5% of bitumen content.

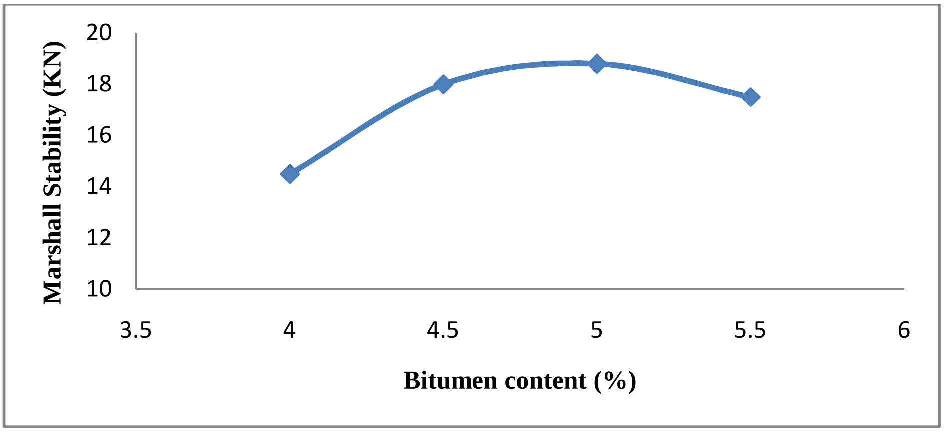

Figure 4.36: Corrected Stability Vs Bitumen Content curve for 75 blows

Figure 4.37 represents the increment of flow value with respect to increasing the bitumen content. The maximum flow value is 4.98 mm at 5.5% of bitumen content for 75 blows.

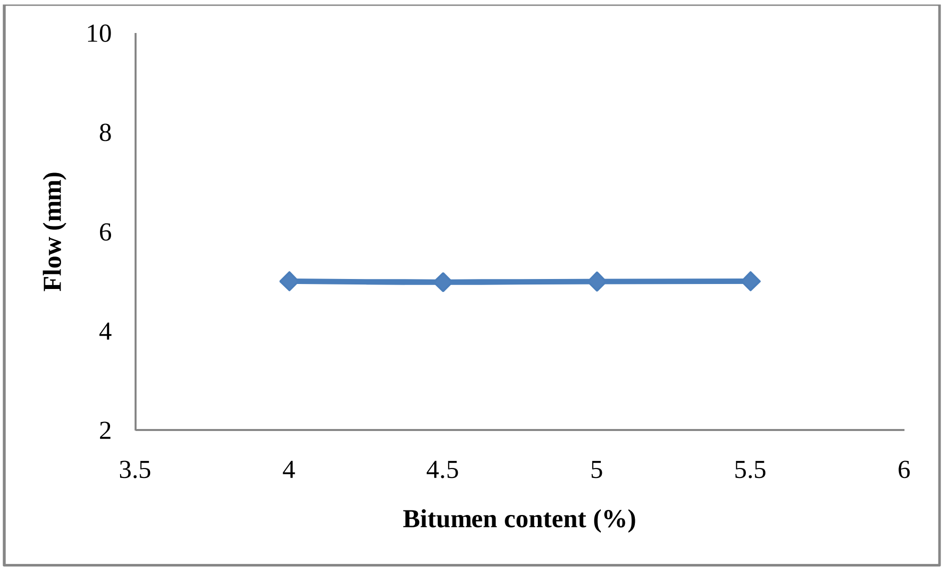

Figure 4.37: Flow Vs Bitumen Content curve for 75 blows

Figure 4.38 shows the percentage of air voids in the mix, which vary with bitumen content. Percentage of air voids in the mix is 5.9 % at 4% of bitumen content.

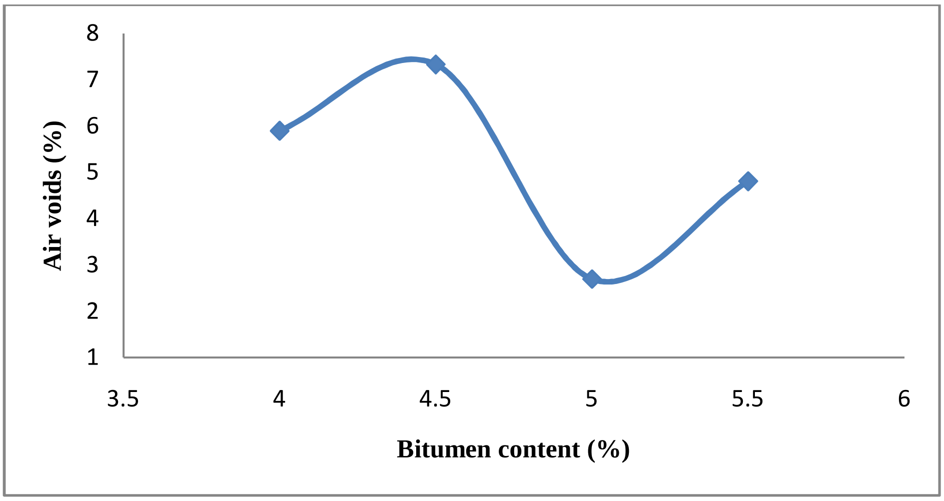

Figure 4.38: Air voids Vs Bitumen Content curve for 75 blows

Figure 4.39 shows the variation in percentage of voids in mineral aggregate at different bitumen content. The maximum percentage of VMA is 17.4% at 5.5% of bitumen content.

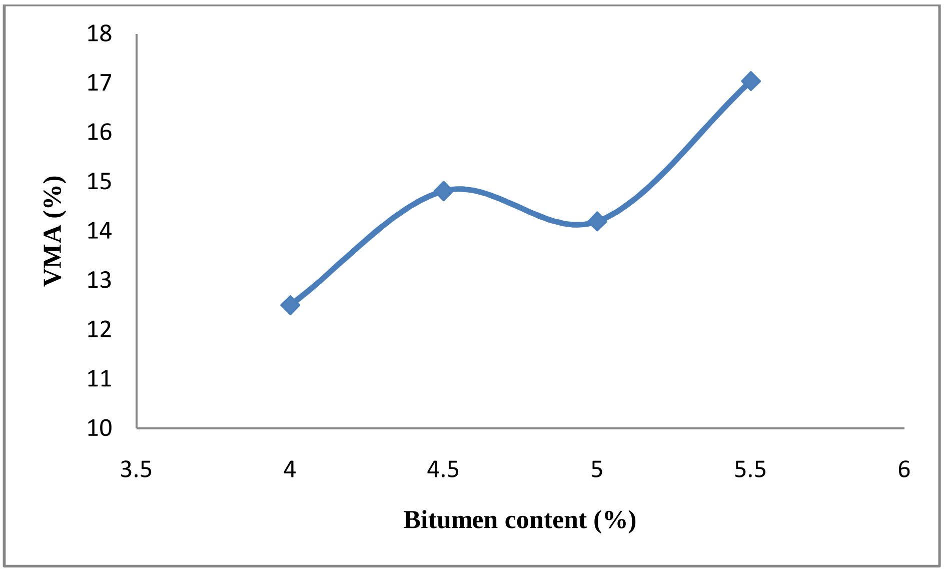

Figure 4.39: VMA Vs Bitumen Content curve for 75 blows

Figure 4.40 indicates the variation in percentage of voids filled with bitumen with different bitumen content. The Maximum VFB is 74.88% at 4% of bitumen content.

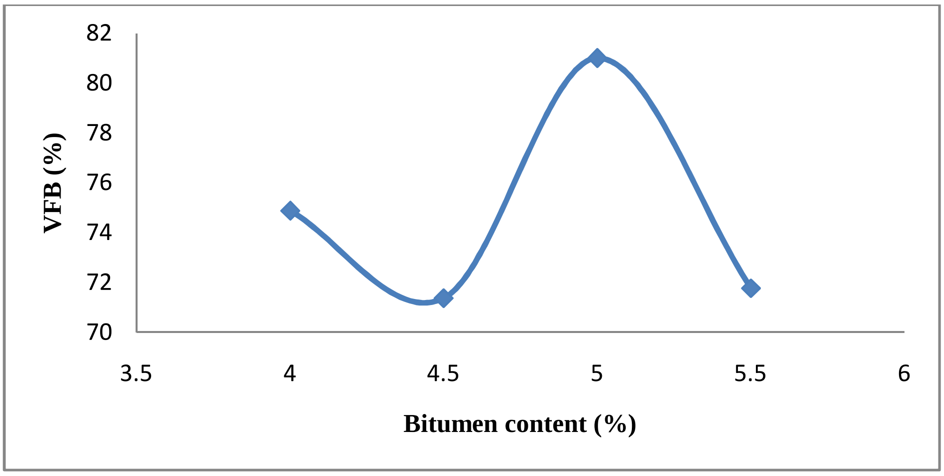

Figure 4.40: VFB Vs Bitumen Content curve for 75 blows

4.7.2 Effect of Kandhal Aggregate Gradation for 75 Blows on Marshall Properties of DBM Mix:

Different percentage such as 4%, 4.5%, 5% and 5.5% of bitumen content was used to determine the optimum bitumen or binder content for the Kandhal gradation. Table 4.14 and figure 4.36 to 4.37 shows the variation in Marshall Stability and flow value for different percentage of bitumen content. It is found that the flow criteria for DBM were satisfied for the entire range of mixes. Marshall Stability test is conducted to determine the Marshall Properties of Dense Bituminous Macadam Mix showing in table 4.38 to 4.40. The stability value is higher than then the minimum specified value as per MS2 and MORTH specifications. Maximum Marshall Stability is found at 5% of bitumen content. The optimum binder content for this aggregate gradation and for 75 blows of compactive effort is 4.83. The Maximum Marshall Stability for 75 blows of compactive effort is 18.80 KN@ 5% and Marshall Flow is 4.98@5.5%.

Table 4.14: Kandhal Aggregate Gradation and 100 No. of blows

Marshall Properties of Bituminous Mix by No. of Blows–100	**Gradation – Kandhal Varying Bitumen Content**			
	4%	**4.5%**	**5%**	**5.5%**
Corrected Stability (KN)	15	18.266	18.751	17.7
Flow Value (mm)	5	4.98	4.99	5
Air Voids (%)Vv	9.44	7.34	2	3.61
Voids in Mineral Aggregate (%) VMA	18.22	17.65	14	16
Voids Filled with Bitumen (%) VFB	48.18	58.25	82.78	77.37

Figure 4.41 shows the variation in corrected stability at different bitumen content. The Maximum Marshall Stability is 18.7 KN@ 5% of bitumen content.

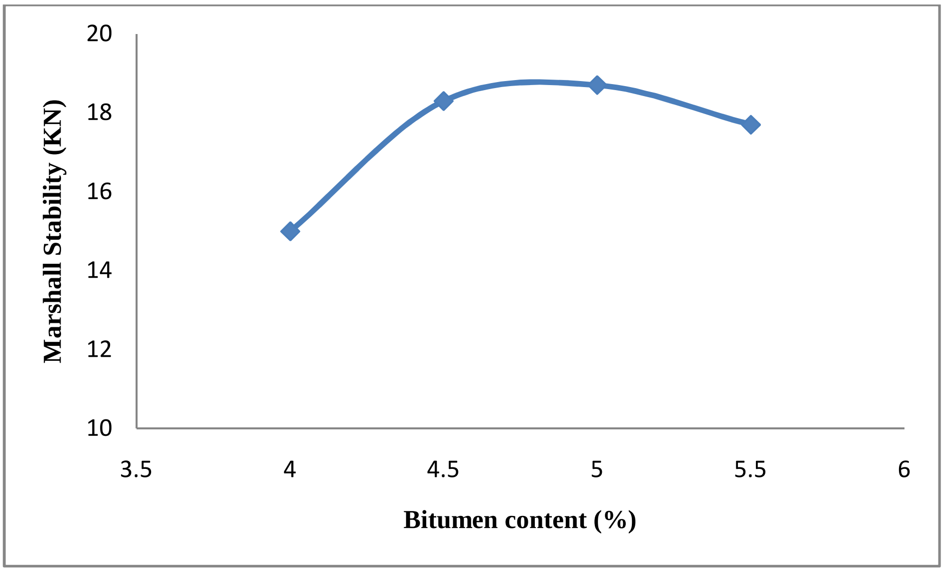

Figure 4.41: Corrected Stability Vs Bitumen Content curve for100 blows

Figure 4.42 represents the increment of flow value with respect to increasing the bitumen content. The maximum flow value is 5 mm at 5.5% of bitumen content for 100 blows.

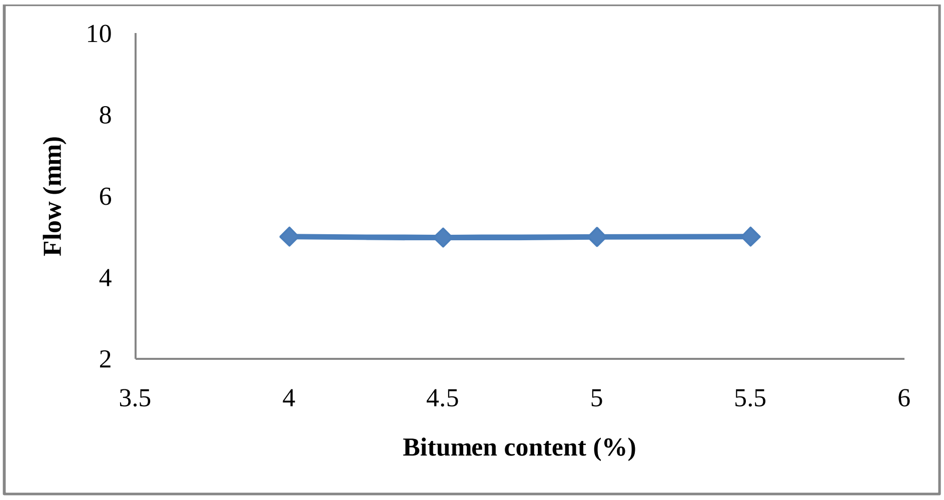

Figure 4.42: Flow Vs Bitumen Content curve for100 blows

Figure 4.43 shows the percentage of air voids in the mix, which vary with bitumen content. Percentage of air voids in the mix is 9.44 % at 4% of bitumen content.

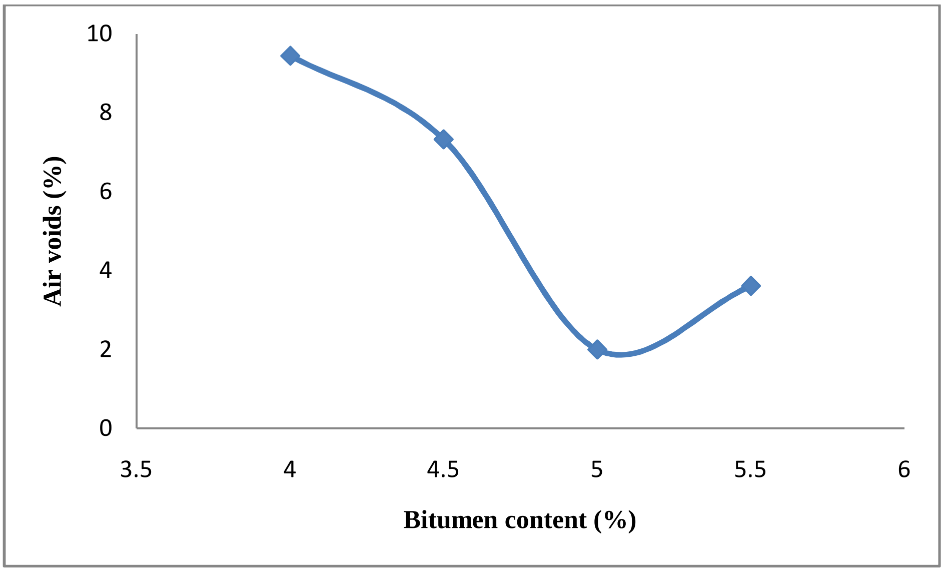

Figure 4.43: Air voids Vs Bitumen Content curve for100 blows

Figure 4.44 shows the variation in percentage of voids in mineral aggregate at different bitumen content. The maximum percentage of VMA is 18.2% at 4% of bitumen content.

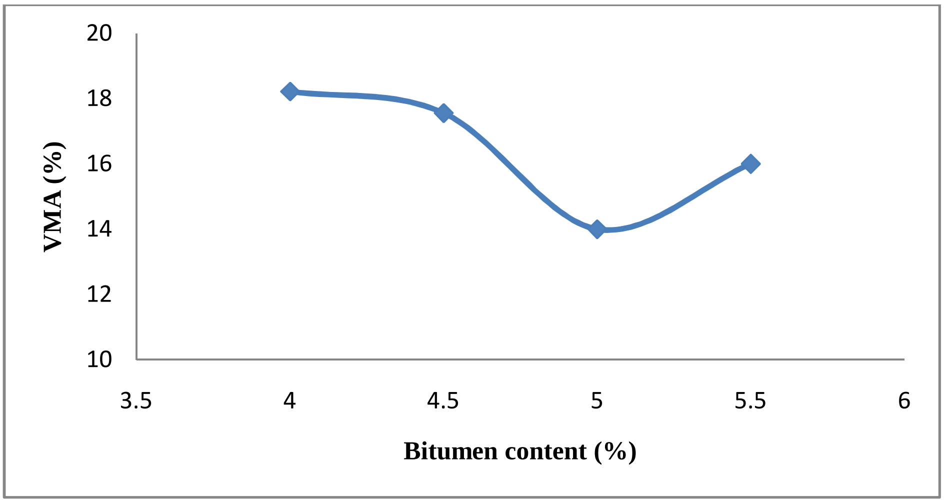

Figure 4.44: VMA Vs Bitumen Content curve for 100 blows

Figure 4.45 indicates the variation in percentage of voids filled with bitumen with different bitumen content. The Maximum VFB is 82.78% at 5% of bitumen content.

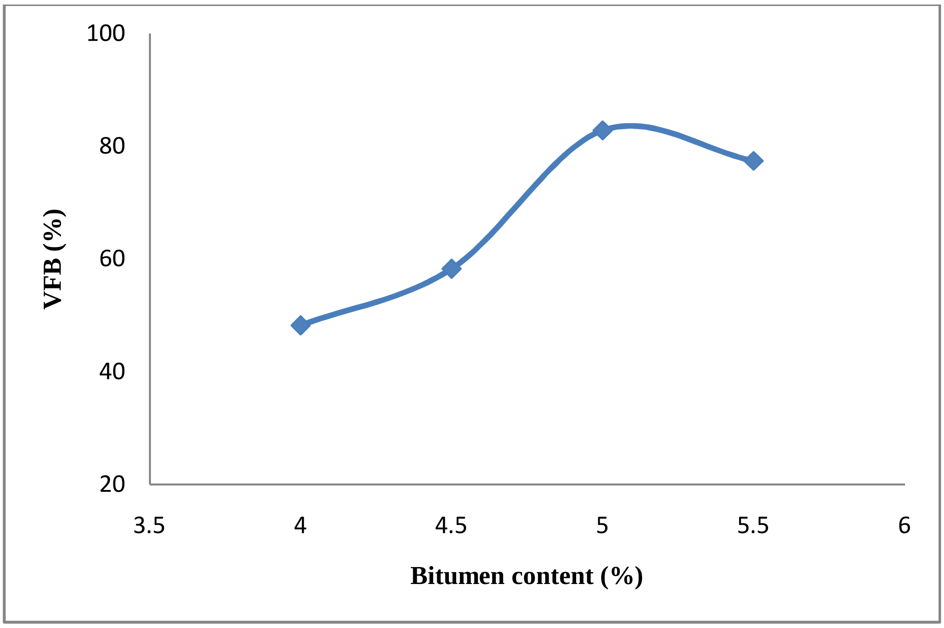

Figure 4.45: VFB Vs Bitumen Content curve for 100 blows

4.7.3 Effect of Kandhal Aggregate Gradation for 100 Blows on Marshall Properties of DBM Mix:

The Optimum Bitumen Content determining from different percentage of bitumen i.e 4%, to 5.5% used with the 100 blows of compactive effort which affects the Stability and flow value. Table 4.15 and figure 4.41 to 4.45 shows the variation in the Marshall Properties of DBM mix for Kandhal Gradation. The Maximum Stability is 18.751 determined for the 100 blows of compaction effort. The three values of Marshall Properties taken i.e Marshall Stability, Maximum Bulk Specific Gravity and bitumen content @4% for determining the optimum binder content. Add the three values then divide by 3 and this average value is called the optimum binder content. For this gradation and compactive effort the O.B.C. is 4.67. For this gradation and 100 blows of compactive efforts the Maximum Flow is 5@ 5.5% of bitumen content. Also the maximum percentage of air voids, voids in mineral aggregate (VMA) and voids filled with bitumen (VFB), 9.44@4%, 18.22 @4% and 82.78 are respectively.

4.8 Comparison between Aggregate Gradation and Compactive Effort

Figure 4.46 to 4.49 represents the variation in Marshall Stability values for three types of aggregate gradation i.e MORTH, ASTM and Kandhal and for three types of compactive efforts i.e 50, 75 & 100 blows@4%,4.5%,5% & 5.5% of bitumen content.

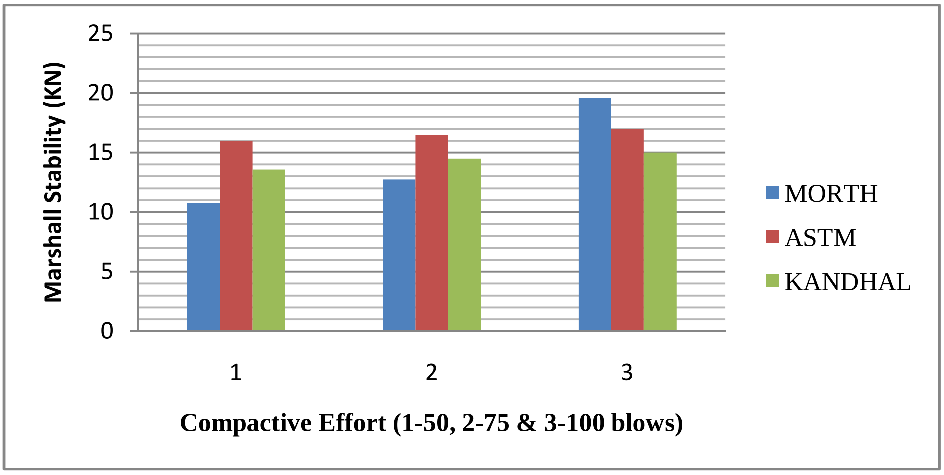

Figure 4.46: Marshall Stability Vs Aggregate Gradation &Compactive Effort @ 4% of bitumen content

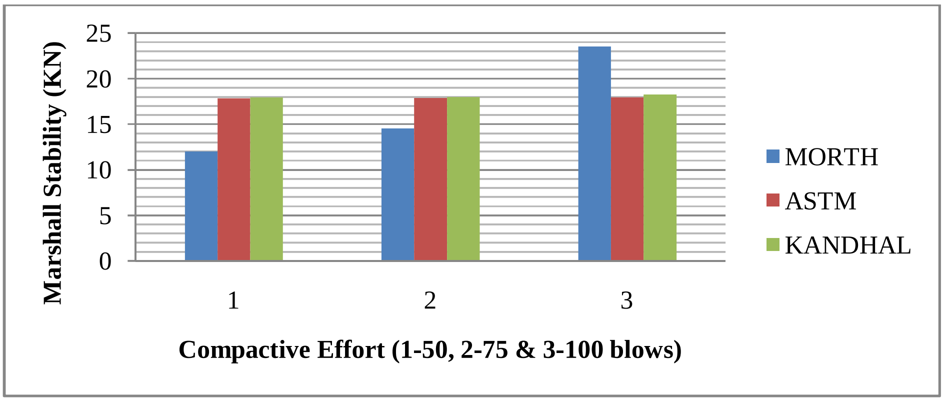

Figure 4.47: Marshall Stability Vs Aggregate Gradation &Compactive Effort @ 4.5% of bitumen content

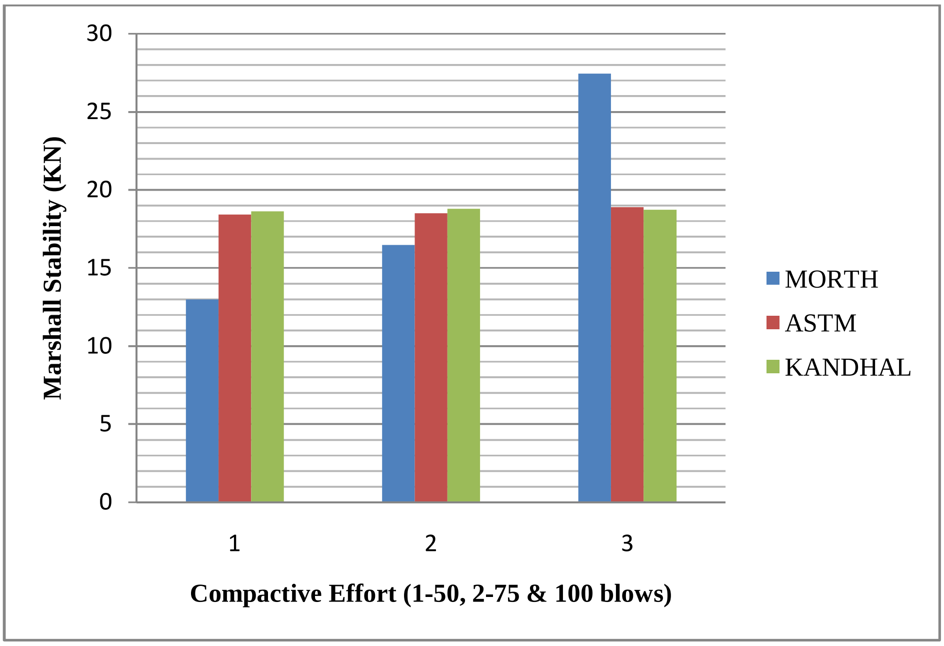

Figure 4.48: Marshall Stability Vs Aggregate Gradation &Compactive Effort @ 5% of bitumen content

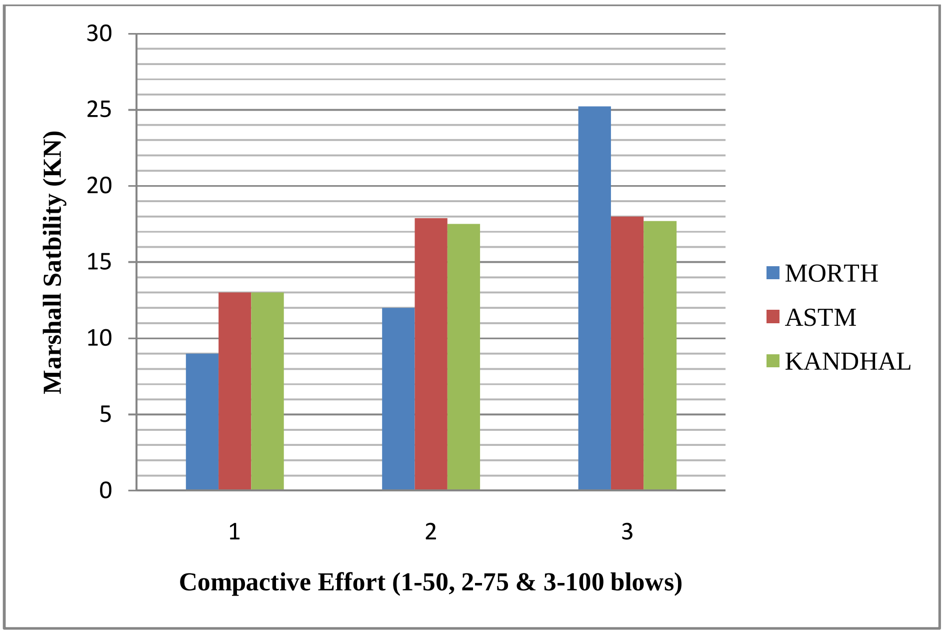

Figure 4.49: Marshall Stability Vs Aggregate Gradation &Compactive Effort @ 5.5% of bitumen content

Figure 4.50 to 4.53 represents the variation in Marshall Stability values for three types of aggregate gradation i.e MORTH, ASTM and Kandhal and for three types of compactive efforts i.e 50, 75 & 100 blows@4%,4.5%,5% & 5.5% of bitumen content.

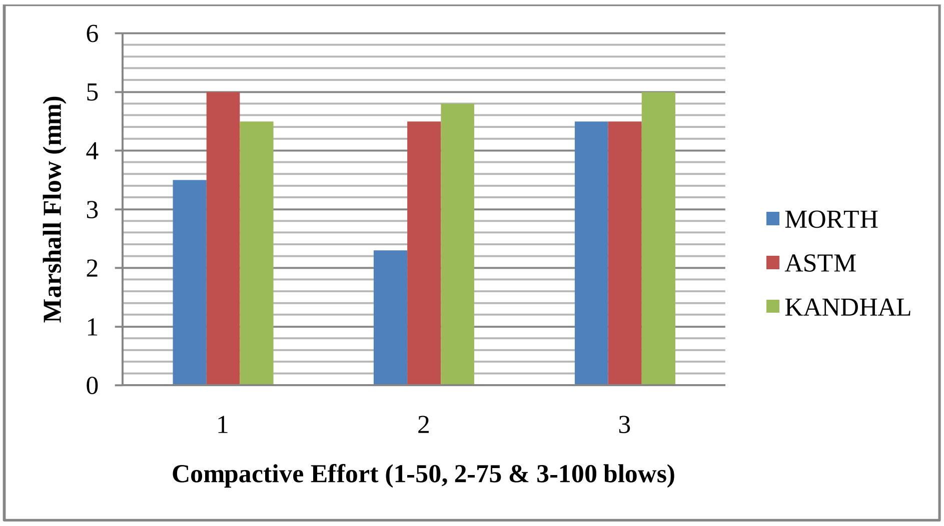

Figure 4.50: Marshall Flow Vs Aggregate Gradation &Compactive Effort @ 4% of bitumen content

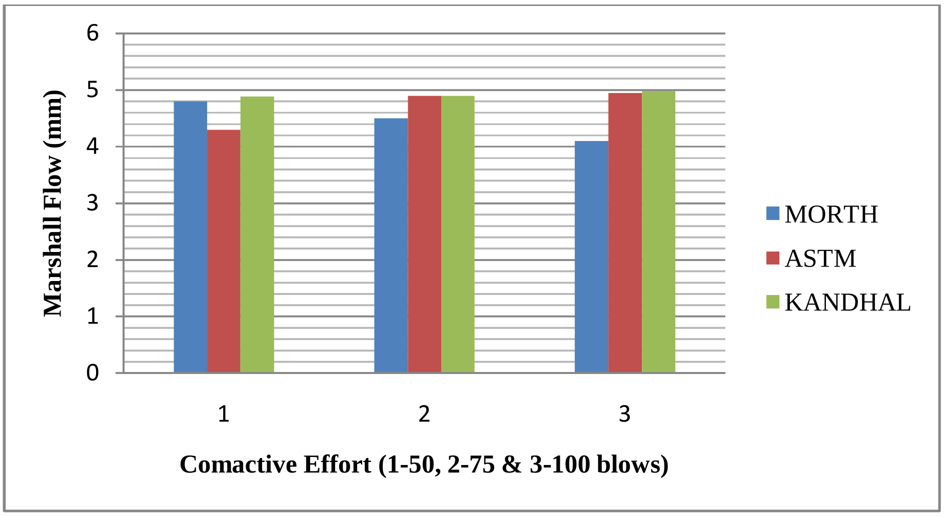

Figure 4.51: Marshall Flow Vs Aggregate Gradation &Compactive Effort @ 4.5% of bitumen content

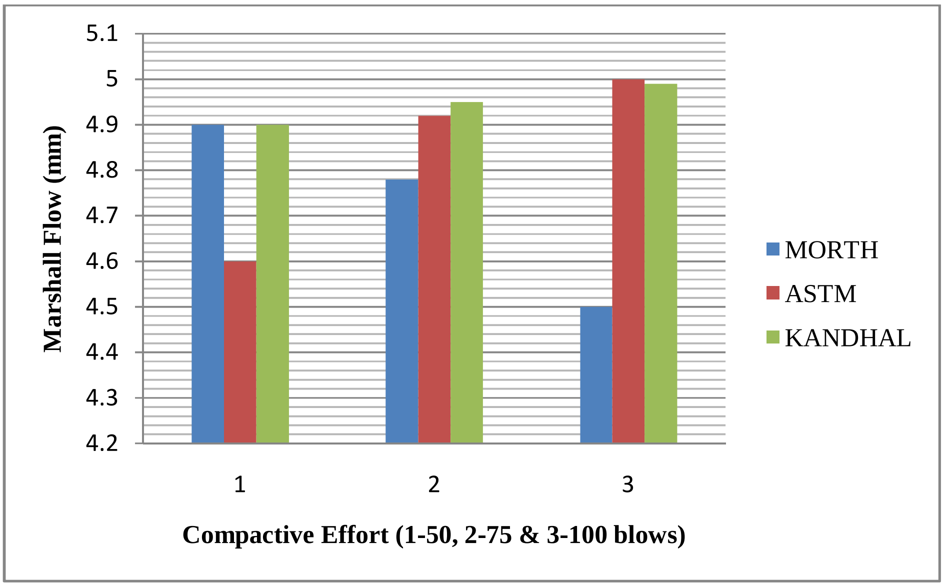

Figure 4.52: Marshall Flow Vs Aggregate Gradation &Compactive Effort @ 5% of bitumen content

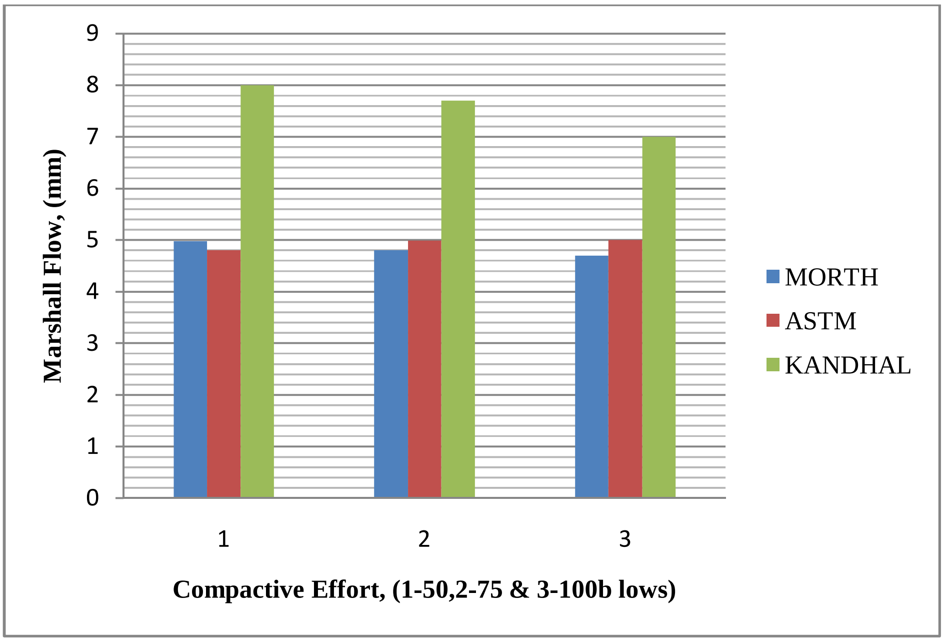

Figure 4.53: Marshall Flow Vs Aggregate Gradation &Compactive Effort @ 5.5% of bitumen content

4.9 Comparison for O.B.C between Aggregate Gradation and Compactive Effort

Figure 4.50 represents the different optimum binder content for three types of aggregate gradation i.e MORTH, ASTM and Kandhal and for three types of compactive efforts i.e 50, 75 & 100 blows@4%,4.5%,5% & 5.5% of bitumen content.

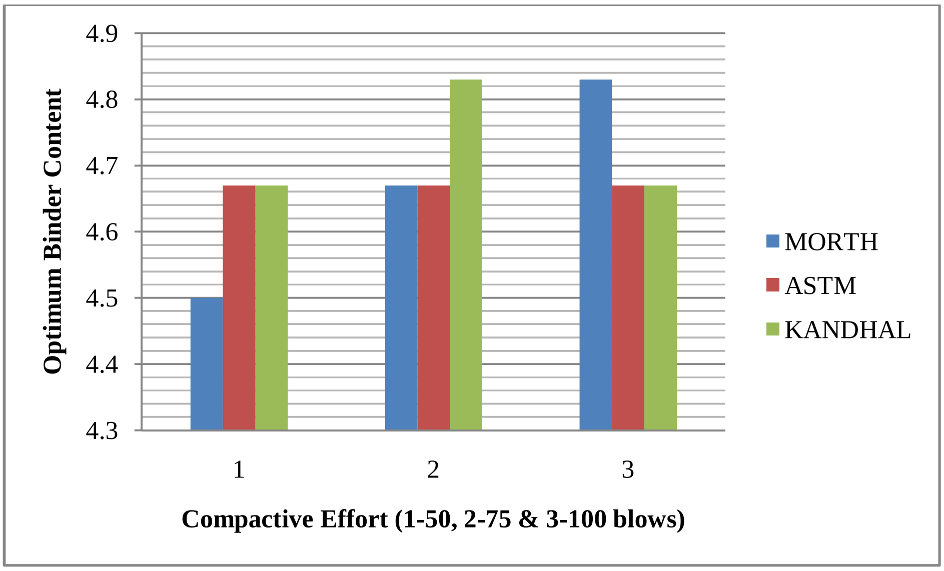

Figure 4.54: O.B.C Vs Aggregate Gradation &Compactive Effort

CHAPTER-5

CONCLUSIONS

- The stability of mix with different type of aggregates shows good results, against satisfying the minimum requirement of 9 KN. The maximum stability is observed at 5% of bitumen content for all three types of aggregate gradation of the bituminous mixes of DBM grade-II. The Maximum Stability is 27.44KN at 5% bitumen content for the MORTH Gradation for 100 blows. The corresponding maximum stability for ASTM Gradation is 18.9 KN at 5% bitumen content for 100 blows.

- The Maximum Marshall Flow values for MORTH, ASTM and Kandhal Gradation are 9mm at bitumen content 5.5% for 100 blows, 4.98 mm at bitumen content 5.5% for 50 blows and 5 mm at 5 % bitumen content for 75 blows and 5 mm at 5.5 % bitumen content for 100 blows.

- The highest percentage of air voids is observed at 4% bitumen content. With the increment of bitumen content void content decreases. The Maximum air voids for the three aggregate gradation and for three types of compactive effort are 10.62 % for MORTH at 4% bitumen content for 75 blows, 24% for ASTM at bitumen content 4% for 75 blows, 9.44 % for Kandhal at 4% bitumen content for 100 blows.

- The Maximum percentage of voids in mineral aggregate for MORTH, ASTM and Kandhal gradation are 19.32% at 4% bitumen content for 75 blows, 31.2% at 4% for 75 blows and18.22% at 4% bitumen content for 100 blows are respectively.

- The Optimum Binder Content for MORTH gradation is 4.83% at 100 blows, for ASTM gradation 4.67% and for Kandhal gradation 4.83% at 75 blows. The Marshall Stability value is observed to increase in every type of aggregate gradation with the increase in the compaction effort.

Singh, Deepesh Kumar., Lodhi and Yadav, R.K., (2016), "Effect of Gradation of Aggregates on Marshall Properties of DBM Mix Design" International Journal of Engineering Research and science & Technology, Vol.5, No.2, pp. 23-24

Gupta, L., Patil, Ashutosh. and Ojha, Avinash., (2016), "A Study on the Marshall Properties of DBM Mix prepared using VG-30 and CRMB-55 as Binder Materials" International Journal of Research Engineering and Technology, Vol.5, Issue.3.22, pp. 22 to 23.

Aodah, H.H., Kareem, Y.N.A. and Chandra, S., (2012), "Performance of Bituminous Mixes with Different Gradations and Binders" International Journal of Research Engineering and Technology, Vol.2, No.11, pp. 12 to 13.

Mansuri, M.N., Dr. Patel V.M. and Prof. Dave, H.K., (2014), "T o Study the Influence of Shape of Coarse Aggregate on DBM Mix" Journal of International Academic Research for Multidisciplinary, Impact factor1.393, Vol.2, Issue 5, pp. 20 to 21.

Anwar, S.K.W., (2014), "Studies on Marshall and Modified Marshall Specimens by using CRMB" International Journal of Structural and Civil Engineering and Research, Vol.3, No.4. pp. 21 to 22.

R,N., Nagakumar.,M.S., (2013),"Performance Evaluation of Dense Bituminous Macadam Mix-A Refusal Density Approach" International Journal of Research in Engineering and Technology, IC-RICE Conference Issue, pp. 17 to 18.

MORT&H Specifications for the Road and Bridge Works (Fourth & Fifth Revision), pp. 4 to 7.

Kandhal, P.K. and Brown, E.R.,(NCAT Report) "Comparative Evaluation of 4-inch and 6-inch diameter Specimens for Testing Large Stone Asphalt Mixes", National Center for Asphalt Technology, NCAT: Report No.90-5, pp. 14 to17.

IRC-94-1986, “Specifications of Dense Bituminous Macadam” IRC, New Delhi.
Joshi, D.B., Prof. Patel, A.K., “Optimum Bitumen Content by Marshall Mix Design DBM” Journal of Information, Knowledge and Research Civil Engineering” ISSN:0975-6744,Nov 12 to Oct 13, Vol.2, Issue.2, pp. 13 to 14.

P, Ganapatinaidu. and Adiseshu, S., (2013) “Influence of Coarse Aggregate Shape factors on Bituminous Mixtures” International Journal of Engineering Research and Application, ISSN: 2248-9622, Vol.1, Issue.4, pp, pp. 18 to 20.

Sridhar, R., Kamaraj, C., Bose, Sunil., Nanda, P.K. and Singh, Manvinder., (2007), “ Effect of Gradation and Compactive Effort on the Properties of Dense Bituminous Macadam Mixes” Journal of Scientific & Industrial Research,Vol.66, pp-56-59.pp. 12.

Dr. G.Ahmed, N.G and Er. M.Ismail (2009),“ Comparative Evaluation for Mix Design of Marshall and Super pave Methods” Journal of Engineering and Development,Vol.13,No.2

Kandhal, P.S., Veeraragavan. A. and Jain, R.K., (2010), “Guidelines for Long Lasting Bituminous Pavements in India” Journal of the Indian Roads Congress, Paper No.564.

Guidance Notes (1996), “Mix Design of Bituminous Materials” Research and Development Division, RD/GN/022.

Kandhal, P.S and Cross, S.A., (1993), “Effect of Aggregate Gradation on Measured Asphalt Content” NCAT Report 93-01.

Budiati, A., (2013), “Effect of 19 mm as Aggregate’s Maximum Size to Marshall Properties of Asphalt Concrete” Academic Research International,Vol.4,No. 5.

Banerji, A.K., Das, A., Monalal, A., Biswas, R. and Md.Obaidullah (2014), “A Comparative Evaluation on the Properties of HMA with Variations in Aggregate Gradation of Laboratory and

Field produced Mixes” International Journal of Research in Engineering and Technology,Vol.3, Issue 9