EVALUATION OF CONVENTIONAL AND SUPERPAVE MIX DESIGN USING NEAT AND MODIFIED BINDER

FINAL YEAR PROJECT UG-2012

By

M. Naveed Ashraf	2012-BE-CE-393
Mubashir Islam	2012-BE-CE-404
Masood Hadi	2012-BE-CE-357
Khurram Shahzad	2012-BE-CE-473

Project Advisor: Dr. Arshad Hussain

National Institute of Transportation (NIT)

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology, Islamabad, Pakistan

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This is to certify that the Final Year Project Titled

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Khurram Shahzad	2012-BE-CE-473

has been accepted towards the requirements
for the undergraduate degree

in

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Dr. Arshad Hussain

Assistant Professor
National Institute of Transportation
School of Civil and Environmental Engineering
National University of Sciences and Technology, Islamabad, Pakistan

DEDICATED TO OUR PARENTS

& TEACHERS

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ABSTRACT

Traditionally Marshall Mix Design is used to find out volumetric properties and optimum bitumen content but it does not represent the actual field conditions faced by asphalt pavement. So a new method known as Superpave (Superior Performance Asphalt Pavements) was introduced by Strategic Highway Research Program (SHRP) established in 1987 in USA. The ideal condition will be if the samples prepared and compacted in laboratory are close enough to represent field conditions.

There are several additives to improve the behavior of bitumen in severe climatic conditions (especially in warm climate-70% of Pakistan Area) and under over loading (common case in Pakistan) where use of neat bitumen (only bitumen) makes pavement susceptible to pavement failures like rutting etc. Additive usage may have some negative effects on bitumen properties with their positive effects so it is really important to study the impact of modifier addition before using it. Our project aims to compare the volumetric properties of Marshall Mix Design and Superpave Mix Design using Neat Bitumen and Modified Bitumen (Bitumen and DuPont Elvaloy 4170) and compare the impact of modification of bitumen on volumetric.

The materials used in our study are, aggregate procured from Margalla Hills Taxila, bitumen of grade 60/70 from Attock Refinery Limited (ARL) and DuPont Elvaloy 4170 Reactive Ethylene Terpolymer (RET) as a modifier/additive. Performance testing of aggregate and bitumen was conducted in the laboratory and test results were compared to standard values. Bitumen was modified using modifier (1.5% DuPont Elvaloy 4170 Reactive Ethylene Terpolymer (RET)) according to standard procedure of mixing. The bitumen contents used to prepare samples were 4%, 4.5%, 5% and 5.5%.For each bitumen content 3 samples were prepared for Marshall Mix Design as well as Superpave Mix Design using and modified binders, thus resulting in total of 48 samples. After the preparation, samples were tested and volumetric properties were found out. Optimum bitumen contents for Marshall Mix Design using Neat Bitumen, Marshall Mix Design using Modified Bitumen, Superpave Mix Design using Neat Bitumen and Superpave Mix Design using Modified Bitumen were found out and stated. At last volumetric properties of above mentioned mix designs were compared and conclusion were made.

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CHAPTER 1

INTRODUCTION

1.1 General

Transportation is the movement of goods and people from one location to the other. Most of the Road networks were built during British Raj before 1947.Roads carry almost 83% of Pakistan total traffic. Transportation contribute 12% of the Pakistan total GDP. According to World Bank report, road transport provide 7% employment in the country. During 1990s Pakistan began to rebuild all the National Highways in the country to important mass centers. Motorways were built, Construction of M-2 motorway connecting Islamabad to Lahore had done, it has length of 375 km.M-3 was constructed in early 2000s which connects Pindi Bhattian and Faisalabad. Later M-4 Motorway which connects Faisalabad and Multan was constructed. Gojra to Faisalabad section is completed and is open for traffic however other sections are to be built soon.

Marshall Mix Design was introduced by Bruce Marshall in 1939, a former bituminous Engineer with the Mississippi State Highway Department. Later, US Army Corps of Engineers improved the method and added some features. Marshall Mix Design has been proposed for aggregate with maximum size up to 1.5 inch. Marshall Method implemented throughout the world for almost half a century.it didn’t take into account the traffic and environmental issues, therefore after introduction of Super-Pave Mix Design this method is not used today in USA.

Super-Pave Mix Design was introduced in 1990s with the help of Strategic Highway Research Program (SHRP).Super-Pave stands for Superior Performing Asphaltic Pavements.it introduced the new design system which accounts for the aggregate and binder requirements and compactive effort related to the traffic.

Asphalt can be modified with different Binders like SBS, Elvaloy, Glass, Rubber etc. to encounter flexible pavement distresses like rutting, thermal cracking, stripping, raveling and damage due to accidental fuel spillage.in 1902 first Rubber modifier was used in France. Later in 1930 UK and France found the importance of these rubber modifiers. From 1946 to 1985, different other modifiers were introduced like SBS, SBR, and Neoprene etc. These modifiers improve the road system but these modifiers also create issues for the environment and needed a specific mixing temperature to react with Bitumen as it may disturb the properties of Bitumen. Elvaloy RET which is the product of DuPont is widely used in the world. Elvaloy increases both the stiffness and elasticity of the mix which is good against rutting and cracking in the flexible pavements.

***Table 1.1*: Pakistan Transport Sector Key Statistics (World Bank; 2007)**

Particulars	Units	As of 2007
Length of Roads	Km	259,758
National Highway and Motorway	Km	10,525
Paved Roads	%	63
Unpaved Roads	%	37
Road Density	Km/1000 Sq. Km	335

1.2 Problem Statement

One of the major problem Pakistan roads are facing is the rutting. Main reasons are worse climatic conditions (especially temperature boost in summers) and overloading.Pakistan can be divided into six temperatures zones requiring the PG 70-10 as the most important binder that covers more than 70 percent of the Pakistan. At present, commonly available grades are A-60/70, A-80/100, A-PMB and K-40/50, K-60/70, K-80/100 and commonly used binder grades A-60/70 and K-60/70 in Pakistan. The corresponding performance grades are PG 58-22 and PG 64-22. These softer binders, especially at high temperatures are likely to rut in areas requiring PG 70-10.One of the solutions to increase rutting resistance and to achieve PG 70-10 properties is the modification of bitumen (i.e. using Polymer as additive to neat bitumen). The main aim of our research is to find out the impact of bitumen modification on the volumetric properties of Marshall Mix Design as well as Superpave Mix Design. Additionally volumetric properties of Marshall Mix Design are compared with the volumetric properties of Superpave Mix Design.

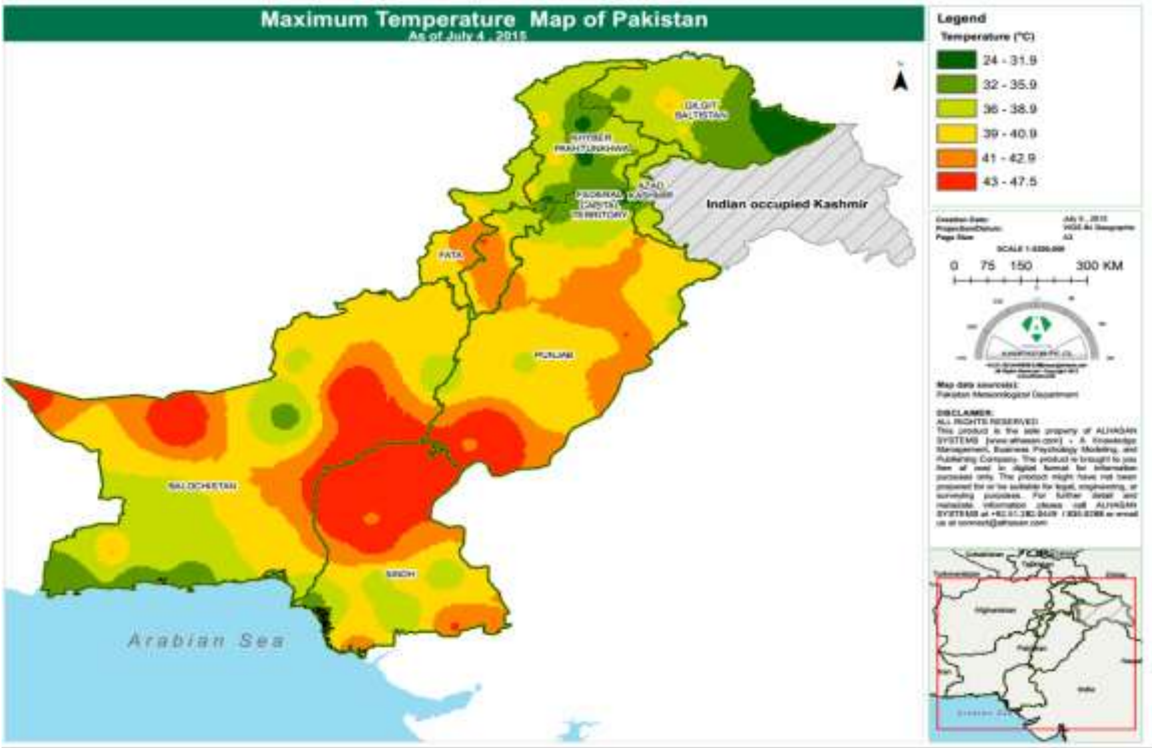


Figure 1.1: Temperature Distribution of Pakistan

1.3 Objective

The objective of this research is to accomplish following properties.

- Effects of binder modification on volumetric properties of Marshall and Super-Pave Mix Design
- A comparison between HMA samples prepared with neat binder (A-60/70) and modified binder (A-60/70 + 1.5 % Elvaloy) for both mix designs (Marshall Mix Design and Super-Pave Mix Design)
- A comparison between Marshall Mix Design and Superpave Mix Design.

1.4 Scope of Research

To accomplish above mentioned Objectives, a comprehensive research plan was made and various research tasks were outlined

- Intensive research review based on previous research comparing the Marshall and Super-Pave Mix Design
- Laboratory characterization of materials included bitumen and aggregate tests
- Preparations of specimens using NHA Class-A Gradation. samples are prepared

by Marshall and Gyratory compaction method

- Preparation of job mix formula and evaluation of volumetric properties like VMA, VFA, Air voids, Stability and Flow values for modified and unmodified samples
- Comparison analysis of volumetric properties of Marshall and Super-Pave Mix Design
- Comparison effects of binder modification on volumetric properties of Marshall and Super-Pave Mix Design

1.5 Thesis Organization

This research is organized into five chapters

- Chapter 1 includes a brief introduction of the Marshall and Super pave Mix Design, and different Modifiers use for the road construction, the problem statement, objectives and the scope of the research.
- Chapter 2 is related to the Literature Review of the previous studies related to Marshall Mix Design, Super-Pave Mix Design and Modifiers used in pavements.
- Chapter 3 includes the selection of the material for performing the tests, methodologies related to Bituminous and Aggregate test are also discussed
- Chapter 4 presents the results of Marshall and Super-Pave Mix Design and a brief comparison between HMA prepared with neat and modified binder is shown with results.
- Chapter 5 concerned with the conclusions and future recommendation. Conclusion and recommendations are derived from the research findings.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The Transportation system is the backbone of country development. All the developed countries have a good Transportation system, however Pakistan Transportation System is old but certain changes are done by National Highway Authority (NHA). Pakistan Officials say that CPEC would create more than 700,000 Jobs in 2015-2028. It'll contribute 2.5%-3% to the country annual economic growth. CPEC projects related to Road works are Karakoram Highway Reconstruction, Eastern Alignment of the roads of province Punjab and Sindh, Western Alignment include expanded and up-gradation of road networks in Baluchistan, KPK and Punjab Province. Therefore new methods should be introduced to meet the ongoing requirements, old methods like Marshall Mix design should replace with super-pave mix design method that gives more accurate results. Marshall Method of mix design doesn't count the traffic and environment for its design.

Modifiers such as SBS, Elvaloy, Rubber and Glass are used in some parts of a country that gives good results when modified with Bitumen. Elvaloy RET is reactive ethylene Glyceryl (EGA) acrylate Terpolymer product, manufactured by DuPont Company. Elvaloy is a free flowing pellet that melts into hot bitumen and produces permanently modified bitumen that cannot be separated. When ARL 60/70 is modified with Bitumen the corresponding Performance Grade achieved is 70-10 almost that is Stiffer and gives the mix more Stability.

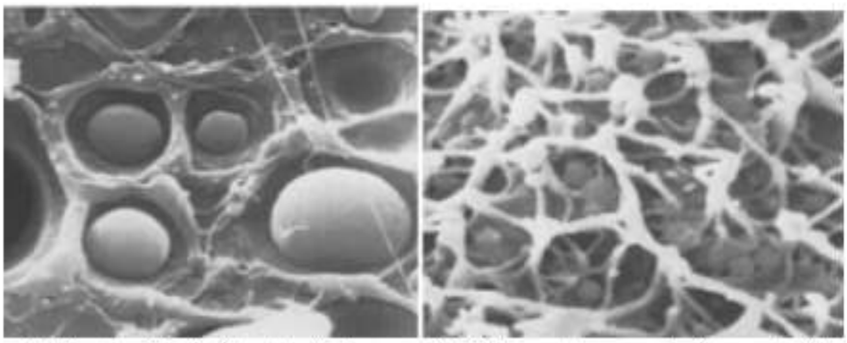
Figure 2.1: Elvaloy RET 4170 Grains

Table 2. 1: **Elvaloy RET 4170 Properties**

Typical Characteristics			
Features	Bulk Density 0.58 g/cubic cm		
Applications	Asphalt (Bitumen) Modification		
Typical Properties			
Physical	Nominal Values	Test Method(s)	
* Density ()	0.94 g/cm³	ASTM D792	ISO 1183
* Melt Flow Rate (190°C/2.16kg)	12 g/10 min	ASTM D1238	ISO 1133
Thermal	Nominal Values	Test Method(s)	
* Melting Point (DSC)	72°C (162°F)	ASTM D3418	ISO 3146
Processing Information			
General			
* Maximum Processing Temperature	280°C (536°F)		

2.2 Reaction with Asphalt

Reaction of Asphalting with RET causes increase in stiffness and elasticity and reduces problems (separation) during storage and transportation. Elvaloy is also resistant to fuel exposure.



(a) Elvaloy Chain into Asphalt (b) Other polymers mix into asphalt

Figure 2.2: Elvaloy Structure as Compared to other Polymers in Asphalt

2.3 Objectives of Mix Design

Different types of mix design are used in construction industry. Each mix design has its own objectives and properties. Some of them are:

- To achieve higher durability.

- To achieve certain amount of workability so that it can be compacted and placed with little effort.
- To resist the higher traffic loads. It should not deform.
- When repeated loads are applied it should resist the cracking.
- To resist moisture and skid.

To achieve certain objectives there are three types of mix designs are in common practice.

- Marshall Mix design.
- Haveem Mix design.
- Super-pave Mix design.

All these mix design generally involves selection of aggregate and asphalt, preparation of samples, testing and then selecting optimum mix design based on good and economical services.

2.4 General Design Procedure

In general each mix design involves:

- Selection of Aggregate and sieving to get required gradation.
- Selection of Asphalt and modifier, depending upon the Temperature zones and problem focused
- Preparation of Samples and testing based on real field conditions.
- Finding out the OBC and different parameters relative to OBC.

These mix design are different from each other on the basis of equipment used, procedure and criteria for the selection of OBC. Our project's scope is only the evaluation of Marshall and Super-pave Mix design using neat and modified binder.

Figure 2.3: Marshall Stability and Flow Apparatus

2.5 Marshall Mix Design

Marshall Mix design was 1st developed by Bruce Marshall in 1939 and then it is redefined by US Army. It is the mostly used mix design around the world. The reason to be most widely used is:

- It is used by US Army after world war-II around the world.
- It is very easy to use and compact.
- The equipment used in this method is inexpensive and simple to operate.

2.6 Superpave Mix Design

Super-pave comprises of three words “Su= Superior, Per= Performance and Pave= Pavements”. It is basically a superior performance asphalt pavement. It is discovered by strategic highway research program (SHRP). SHRP was 1st developed in 1993. In Marshall Mix design we are not able to consider the real traffic loads and climatic conditions so this disadvantage of Marshall Method is replaced by Super-pave Mix design. Under SHRP it was an idea of selecting material by developing:

- A new mix design that consider the realistic approach.
- A method of binder evaluation.

- New methods of mix Evaluation.

The procedure for super-pave mix design comprises of 7 steps:

- Selection of aggregate.
- Selection of Asphalt.
- Preparation of samples.
- Performance tests.
- Calculations of voids and density.
- Selection of OBC (Optimum Bitumen Content)
- Evaluation of moisture susceptibility

2.7 Volumetric Properties

Some volumetric properties of Marshall and Super-pave mix design are:

2.7.1 Bulk Specific Gravity (Gmb)

It is the ratio of HMA sample weight to the weight of an equal volume of water. It is an important parameter used to determine the different volumetric properties like air voids and voids in mineral aggregate (VMA). It can be found by the formula:

$$G_{mb} = \frac{A}{B-C}$$

A= mass of sample in air (g)

B= mass of SSD sample in air (g)

C= mass of sample in water (g)

2.7.2 Maximum Mix Specific Gravity (Gmm)

It can also be called as theoretical specific gravity or Asphalt-voids ratio. It is used to calculate other volumetric properties like voids filled with asphalt (VFA). It can be found by formula:

$$G_{mm} = \frac{A}{A+D-E}$$

A = sample mass in air (g)

D = mass of flask filled with water (g)

E = mass of flask and sample filled with water (g)

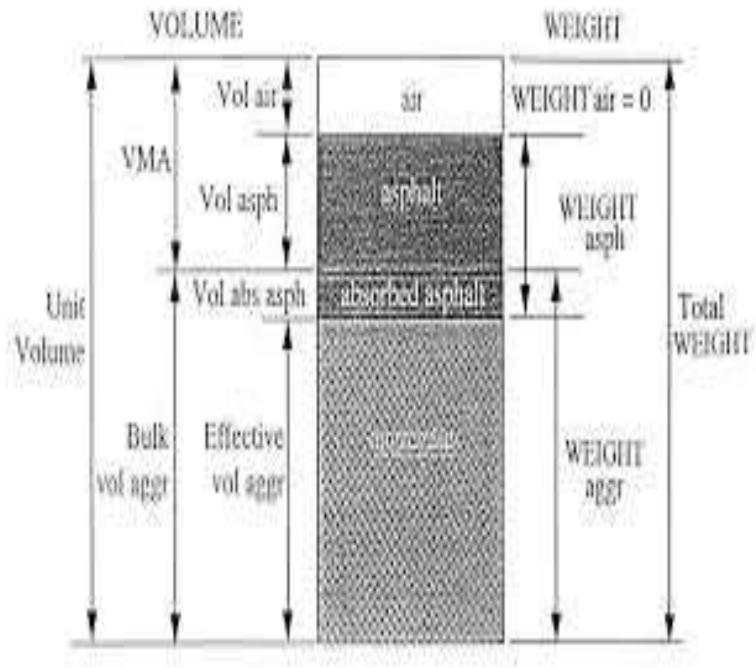


Figure 2 1: Constitutes of a HMA Mix

2.7.3 Air Voids (VA)

Small spaces that occurs between the coated particles when sample is finally compacted. A certain amount of air voids are important in pavements because they provide elasticity/flexibility to the pavements normal range according to ASTM standard is 3%-5%. It can be calculated by using Gmm and Gmb.

2.7.4 Voids Filled with Asphalt (VFA)

It is the percentage of Asphalt filled voids in compacted sample. Its range is 65%-75% under heavy traffic volume. It helps in improving sustainability and flow. It can be calculated as:

VFA (Voids Filled with Asphalt)

$$\frac{(Vol.of\ eff.asphalt)}{(Vol.of\ eff.asphalt + air)}$$

$$\frac{Vbe}{Va + Vbe} \times 100\%$$

V_{be} = volume of effective asphalt

2.7.5 Voids in Mineral Aggregate (VMA)

It represents the air voids spaces between the intra-granular particles of paving mixture. If the value of VMA is more then more bitumen is required to fill the spaces. It corresponds to the durability of pavement. If the voids are low then durability will be low. Formula for VMA is:

$$VMA = (1 - \frac{Gmb(1-Pb)}{Gsb} \times 100)$$

CHAPTER 3

METHODOLOGY

3.1 General

In chapter 3, methods and techniques used in our project are discussed in details. Our projects involves the materials; aggregate, bitumen and modifier. It involves following steps:

1. Selection of materials
2. Acquisition of Materials
3. Characterization of Materials
4. Performance Testing of Materials
5. Preparation of Modified Bitumen (Mixing of modifier and neat bitumen)
6. Sample Preparation (Marshall HMA and Superpave HMA)
7. Testing of Samples
8. Results reporting and analysis

Materials used in this project are selected on the basis of the literature. After the selection, they were acquired and characterized accordingly. The performance test on each type of materials was carried out except modifier. In case of modifier we rely on the literature provided by manufacturer. The modifier was mixed in neat bitumen according to standard procedure to prepare modified bitumen. After this the most tough stage has come which was preparation of samples. Lastly tests on prepared samples were carried out and results were reported. Now each of the steps will be discussed in details.

3.2 Selection of Materials

The properties of materials being used in Hot Mix Asphalt are one of the main factors on which behavior of Hot Mix Asphalt depends throughout its service life. Therefore it is very important and critical stage to select the appropriate materials. Following points are considered in selection of materials:

1. Traffic Factors (Traffic Level and Layer Depth)
2. Environmental Factors (Air Temperature)
3. Traffic Speed

3.2.1 Aggregate Selection

Aggregate selection is depending upon layer location, traffic level of area and prevailing traffic speed. Aggregates used in pavement are primarily responsible for the strength of the pavement. So much importance is given to select the aggregates according to specification (NHA specifications). Results of performance testing of aggregate dictate, either to select the aggregate or it should be replaced by other aggregate sources. Both coarse and fine aggregate used in our project were acquired from Margalla Hills of Islamabad, Pakistan as they meet the specification and lower transportation cost was incurred.

***Table 3.1*: NHA Class-A Specification and Selected Gradation**

Sieve Size(mm)	Required Percent Passing By Weight	Selected Percent Passing By Weight
25	100	100
19	90-100	95
12.5		75
9.5	56-70	60
4.75	35-50	40
2.38	23-35	25
0.3	5-12	10
0.075	2-8	5

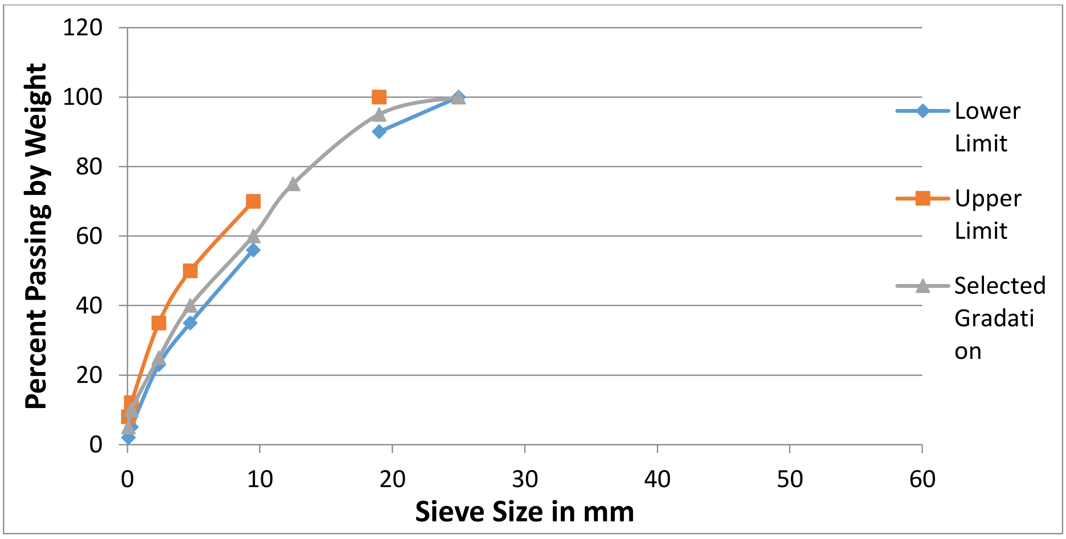


***Figure 3.1*: NHA Class-A Specification and Selected Gradation**

Table 3.2: **Superpave Mix Design Gradation Criteria and Selected Gradation of Wearing Course for NMAS-19mm**

Sieve Size(mm)	Percent Passing by Weight	Restricted Zone	Selected Percent Passing by Weight
25	100		100
19	90-100		95
12.5			75
9.5			60
4.75			40
2.36	23-49	34.6	25
1.18		22.3-28.3	14
0.6		16.7-20.7	10
0.3		13.7	6
0.075	2-8		3

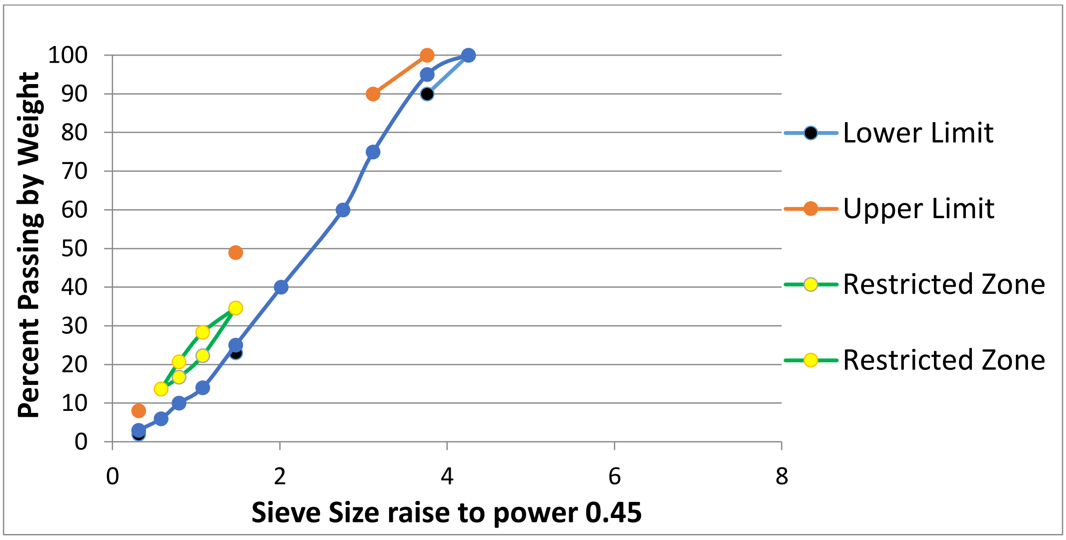


Figure 3.2: **Superpave Mix Design Gradation Criteria and Selected Gradation of Wearing Course for NMAS-19mm**

3.2.2 Bitumen and Modifier Selection

Binder selection is based on environmental data, traffic level and traffic speed. Pakistan can be divided into six temperature zones requiring the PG 70-10 .this binder cover the 70% of total area of Pakistan. The use of 98% reliability provides extra safety margin against high traffic levels of pavement and uncontrolled loadings situations. No additional bumping of binder grade is needed as recommended by AASHTO MP1 specifications, because it provide excessively stiff binder. Presently A-60/70 and K-60/70 are widely used in Pakistan. The corresponding performance grades are PG 58-22 and PG 64-22. These softer binders, especially at high temperature are likely to rut in areas requiring PG 70-10. We selected A-60/70 (PG 58-22) as it is widely used in Pakistan and easily available.

Modifier was required to enhance the stiffness to resist rutting phenomenon in the area requiring PG 70-10. Previous studies reveals that polymer modified binders show consistently better rutting performance than those with other binder types. Hence we selected DuPont Elvaloy 4170 Reactive Ethylene Terpolymer (RET) as a modifier.

3.3 Acquisition of Materials

After the selection process, acquisition stage came. We went to the Margalla Hill quarries and selected the aggregate by visual inspection so that it exhibits the required properties. The bitumen and modifier was already present in National Institute of Transportation Laboratory and they were used after verifying properties by performance tests.

3.4 Characterization of Materials

After the acquisition, characterization stage started. It was mainly related to the aggregate only. Gradation curves for both method Marshall Mix Design and Superpave Mix Design were selected according to the criteria provided in **NHA Specifications and Superpave Series No. 2 (SP-2) by Asphalt Institute** respectively. Criteria and selected gradation are shown below.

3.5 Performance Testing of Materials

Performance testing is done to check the coherence of properties of a material to the specification of the job/standard. Performance testing of both materials (aggregate and bitumen) was carried out in laboratory according to the standard procedure and results were checked out against standard requirements.

3.5.1 Aggregate Performance Testing

In order to prepare a mix by using Marshall Apparatus and Superpave Mix design, it is necessary to determine the aggregate acceptability. The tests often performed include Los Angeles abrasion, impact test, crushing value test and shape tests. In case if material satisfy the specification of these test results, then other tests including gradation, specific gravity and absorption must be performed. The table given below shown the tests and their results.

***Table 3.3*: Aggregate Performance Test Results**

Test	Standard	Permissible Value	Results
Impact Value	ASTM D5874	30%	21.75%
LA Abrasion Value	ASTM C535-12	40%	26.20%
Crushing Value	BS 812	25%	21.40%
Specific Gravity	ASTM C127-88		
Gsb			2.51
Gssd			2.54
Gsa			2.59
Absorption Value	ASTM C127		1.43%

3.5.2 Bitumen Performance Testing

Likewise aggregate we have performed number of performance tests on bitumen. It was necessary to determine the different aspects of bitumen for use in Marshall Mix as well as Superpave mix design.

***Table 3.4*: Neat Bitumen Performance Test Results**

Test	Standard	Permissible Value	Result	Remarks
Flash Point	ASTM D3143	Min. 250	279 °C	Grade 60/70
Fire Point	ASTM D3143 M-13		302 °C	Grade 60/70
Penetration Value	ASTM D5/D5M	60-70	64.5	Grade 60/70

Softening Point	ASTM D36-06	49-56 °C	50.8 °C	Grade 60/70
Viscosity Test	ASTM D4402	0.22-0.45 pascal-sec	0.2625 pascal-sec	Grade 60/70
Ductility Test	ASTM D113-99	Min. 100	123 cm	Grade 60/70

***Table 3.5*: Performance Test Results of Modified Bitumen**

Test	Standard	Permissible Value	Result	Remarks
Flash Point	ASTM D3143	Min. 250	296 °C	More than A-60/70
Fire Point	ASTM D3143 M-13		312 °C	Less than A-60/70
Penetration Value	ASTM D5/D5M	60-70	60.5	More than A-60/70
Softening Point	ASTM D36-06	49-56 °C	52°C	More than A-60/70
Viscosity Test	ASTM D4402	0.22-0.45 pascal-sec	0.44 pascal-sec	More than A-60/70
Ductility Test	ASTM D113-99	Min. 100	150 cm	More than A-60/70

3.6 Modification of Bitumen

An asphalt neat modified to enhance the following properties:

- The stiffness of the bitumen at field construction temperature.
- If the stiffness is higher than during summer rutting would be reduced.
- Low stiffness is also help in cracking problems in the roads.it may be especially beneficial for higher temperature zones like Pakistan.
- Elvaloy addition help in reducing stripping in the pavement.

It is important to note that every modifier is not suited for every situation, some modifier may improve the pavement properties in particular situation but at the same time it can disturb the pavement properties for another area where it is applied.

Now there is a question need to be addressed in modification of bitumen. What is the modification method used to modify neat bitumen?

3.6.1 Modification Method of Neat Bitumen

The mixing procedure of Elvaloy was performed as per prescribed manual in Technical Bulletin RET 1.1 of DuPont Elvaloy RET. There are two type of reactions of Elvaloy RET with bitumen.

- Speeding up of reaction with the addition of some acid apart from speeding up of reaction also brings some other modifications like raising high temperature range etc. Attock Oil Refinery use PPT as a catalyst.
- The second method is mixing without using any catalyst. However in this method the mixing time was too long.

The 2nd method was followed for formation of PMB in lab for our project. Bitumen was heated up to pouring temperature and poured in laboratory mixer. The heating temperature of bitumen was 190 ^{O}C and kept constant at the same temperature for about 10 minutes. Elvaloy RET 4170 was mixed asphalt at the rate of 10g/minutes in neat asphalt. After complete addition of desired percentage of modifier, the mixing procedure continue for 2 hrs. at 170 ^{O}C. The polymer modified bitumen were placed in the laboratory steel containers and then cured for 14 hours in oven at 165 ^{O}C.

3.7 Samples Preparation

A total of 48 samples were made out of which 24 were Marshall Samples and rest of 24 were Superpave Samples. There were four type of samples as

- Marshall Mix Design Using Neat Bitumen
- Marshall Mix Design Using Modified Bitumen
- Superpave Mix Design Using Neat Bitumen
- Superpave Mix Design Using Modified Bitumen

For each type, samples were made of 4 different bitumen contents (i.e. 4%, 4.5%, 5% and 5.5%) and for each bitumen content 3 samples were made. So it gave rise to a total of 48 samples.

3.8 Marshall Mix Design

NHA Class A gradation was used in Marshall Sample preparation .the weight of sample was 1200 g. These are following steps followed in Marshall Mix design.

- Preparation of Aggregate and Bitumen for mixing
- Mixing of bitumen with aggregate
- Compaction of specimen
- Extraction of specimen

3.8.1 Preparation of Aggregate and Bitumen for Mixing

For preparation of Marshall Mix design sample aggregate was kept in oven about 105° to 110°, so that the aggregates got dried. Bitumen was kept in the oven at a temperature of 100°C, after an hour solid bitumen was able to use for sample preparation. The molds were cleaned and then placed in the oven at a temperature of (93-149) °C. The specimen mold assembly consists of a base plate, mold cylinder, and collar extension as shown in Figure. The mold cylinder has an internal diameter of 4-inch and height of 2.5-inch.

3.8.2 Mixing of Bitumen with Aggregate

In this step aggregate and bitumen were mixed in mechanical mixer at temperature 140-160 °C which corresponds to the temperature during the manufacturing of paving mixes in Marshall Mix design. Mixing machine is shown in the Figure Mixing temperature is the temperature at which the aggregate can be sufficiently and uniformly coated. Enough material was mixed so that it resulted in a compacted sample of approximately 3-inch height which resulted in approximately 1200 gm sample.

3.8.3 Compaction of Specimen

The compaction operation is performed by automatic compactor. The mold and collar were placed on the base plate and then a paper was placed in the bottom of the mold. The approximate 1200 gm mix was added to the mold. The mold assembly was placed on the mold holder of the Marshall Mix machine. Spading of mixture vigorously with a heated spatula was carried out about 10 times in the Centre and 15 times around the perimeter. The top of the mix was formed into a smooth rounded shape and a piece of filter paper was placed on its top. A 22.5-lb rammer having drop of 18 inches was used. The compaction temperature was kept in range of 135- 155°C.

3.8.4 Extraction of specimen

After completion of compaction procedure, the rammer was removed. After rammer, the base plate and the paper disk were removed and the sample was allowed to cool. The mold was placed in the extrusion jack and sample was removed from the mold. The extrusion jack is shown in Figure **3.5**. The sample was kept on a smooth surface and was allowed to cool overnight before testing.

3.9 Marshall Samples Testing

Three type of different tests carried out on Marshall Mixture.

3.9.1 Theoretical Maximum Specific Gravity of Mixtures using Different Bitumen Contents (G_{mm})

The maximum value of specific gravity, true representation of total air voids can be present in a mixture. The specific gravity excluding air voids is known as Theoretical Maximum Specific Gravity (G_{mm}). Theoretically, if all the void removed from mixture the combined specific gravity of aggregate and bitumen is known as theoretical maximum specific gravity. Theoretical maximum specific gravity is used to calculate percent air voids in compacted hot mix asphalt.

While performing the test, first of all the mixture was loosened and broken up so that the fine aggregate was separated into particles taking care, that no aggregate particle would be fractured. Then the loose sample was placed at room temperature into a vacuum container and the dry mass was recorded. Sample was completely covered by adding water at approximately 77^0F (25^0C) to the container. By applying a vacuum pressure of 27.75 mm Hg (3.7 KPa) to the Pycnometer for 15 minutes, entrapped air was removed. It was made sure that the container agitated continuously by mechanical means. Then the vacuum was slowly released and the sample was weighed in the water.

Formula:

$$Theoretical\ Maximum\ Specific\ Gravity = G_{mm} = \frac{A}{(A + D - E)}$$

Where:

A = sample mass in air (g)

D= mass of flask filled with water (g)

E= mass of flask and sample filled with water (g).

3.9.2 Flow and Stability Test

Marshall Stability of a specimen is the maximum load required to produce failure when the specimen is preheated to a required temperature placed in a special test head and the load is applied at a constant strain of 2-inches/minute. The Marshall Stability provide us about load taking capacity of pavement using this method.

Specimen were placed at water bath keeping temperature 60 ± 1°C for approximately 30 mints. Samples taken out from water bath then put into Marshall Stability machine within 30 sec, if the temperature of specimen becomes low than prescribed temperature ,results would be unsatisfied.

The upper segment of the breaking head was placed on the specimen and complete assembly was placed in position on testing machine. The flow meter was placed, where used, in position over one of the guide rods and the flow meter was adjusted to zero while holding the sleeve firmly against the upper segment of the breaking head. While the test load was being applied, the flow meter sleeve was firmly held against the upper segment of the breaking head.

Load was applied with constant rate of 2-inch/minute until the maximum load was reached and then sample will fail and corresponding reading shown on dial. This is the standard practice for flow and stability test.

The maximum value of load was recorded. The flow meter sleeve was released; the instant the maximum load began to decrease. The indicated flow value was noted and recorded. And equivalent units in mm were used in case of using micrometer dial for flow measurement.

3.9.3 Bulk specific gravity of compacted sample of Marshall Mix

This test was performed according to AASHTO T166 and ASTM D1188 or D2726 Standards. To perform this test for bulk specific gravity of compacted sample of asphalt, the specimen was left to be cooled up to 25^{0}C in air. Dry sample was placed on a balance and its weight noted. A water bath was taken as shown in the Figure. The water bath was then filled more than its half capacity and was left for a while, so that its temperature became 25 degree Celsius. An immersion apparatus was attached to the balance in such a way that the sample was completely immersed in water after placing it in immersion apparatus. Care was taken that the immersion apparatus did not touch the walls of the water bath on either sides.

The weight showed by the balance became zero by pressing the tare button. Specimen was immersed and shacked to remove air bubbles, then was putted in the immersion apparatus. After waiting for five minutes, reading on the balance was noted and written down. Then sample was removed from the water bath and dried with a towel. Balance was tarred again. Reading was noted from the balance after placing the dried sample on it. In the end its bulk specific gravity was calculated using the following formula.

3.10 Superpave Bitumen Mix

It is Superior Performing Asphalt Pavement which is emerging mix design methods. It is a mix Design system for the Next century. It is one of the results of strategic highway research program (SHRP) which was first introduced in 1993. This new mix design system was not an evolution in mix design but a revolution. It replaces the common Marshall Mix Design Method. The volumetric analysis of Marshall Mix method provides basis for the Super-pave mix design method. This new system ties asphalt binder and aggregate selection into the mix design process, and considers traffic and climate condition as well. The common compaction devices from Marshall Procedure have been replaced by a gyratory compactor and the compaction effort in mix design is tied to expected traffic. Gyratory compaction test compatibility assessment is considered one of the best methods of laboratory compaction for the preparation of samples.

It has three key components:

1. Performance based asphalt binder specification

2. Volumetric mix design and analysis
3. An improve method of compaction

Compaction is achieved by the end of the application of a vertical stress (normally 600KPa) through the platens to a known mass of a 100 to 150MM internal Ø mold the asphaltic mix. Longitudinal axis of the mold platens is rotated (gyrated) at a fixed angle to the vertical is placed in parallel and horizontal.

3.10.1 Performance based asphalt binder specification

Super pave incorporate a new binder specification which classify asphalt binder into performance grades. It bases on a range of climate and temperature. It also incorporates the traffic flow condition. Super pave binder are classified by performances graded rating the grading contain two numbers indicating high and low temperature of the pavement. For example a "PG 65 -25" binder used in a pavement means it can resist rutting as high as 65*C temperature of the Pavement and also resist the cracking as low as -25*C temperature of the pavement. To select a super pave binder first of all we determine the average 7 day maximum and minimum design temperature.

NHA gradation A is used for preparing HMA test specimens using the Superpave gyratory compactor. Gyratory compactor gave field conditions to the specimen and work. The specimen used has dimension 150mm (diameter) by 115mm (height). Aggregate weight of 4500 g is used. Mixing temperature of 160^{o}C and compaction temperature of 120^{o}C is maintained. Pan containing aggregate is places in oven for about 2 hours at temperature 135 ^{o}C. All the implements were also places in oven at the above mentioned temperature. Asphalt was also placed in oven.

3.10.2 Sample preparation procedure of Superpave Mix

These are following steps which are performed in Superpave sample preparation.

- Hot mixing bowl was placed on balance and zero the balance.
- Bowl was charged with heated aggregate (at least for two hour at 170 ^{o}C) and mixed.
- Crater was formed in the blended aggregate and desired weight of bitumen (like 180g for 4%) was added to aggregate.

- Mechanical mixer is used to mix the asphalt with aggregate. Mixing continue till aggregate get thoroughly coated (about 15 min)
- Mix is than placed in flat pan at even thickness (25mm to 50mm)
- Mix and pan is than placed in conditioning oven for 2 hours at 160^{o}C. Hence specimen is shot term aged for 2 hours.
- Mold and base plates are removed from the oven. Base plate is fixed with mold and paper is placed on upper side of the base plate.
- Short termed aged mix is than placed in the mold. Paper disk is placed on top and bottom of the levelled mixture. Specimen containing mold was placed into the gyratory compactor gently. Mold should be at center under the loading arm.
- There are three different steps in compaction namely N_{ini}, N_{des} and N_{max} gyrations. But the specimen would be compacted to N_{des} gyrations, while the changing height of specimen calculated automatically.
- 1.25^{o} angle of gyration was set and gyratory compactor started. Speed is 30 gyrations per minute. Compaction proceeded until N_{des} = 100 had been completed.
- Constant pressure of 600Kpa was maintained by the ram loading system.

3.10.3 Data collection and volumetric properties

Data was automatically collected in computer. Computer gave height of specimen and density of specimen at every gyration. After compaction, bulk specific gravity and %G_{mm} of sample is determined. This data is used to calculate the following volumetric properties. G_{mb} at any value of gyration is calculated by dividing the mass of the mixture by the volume of the compaction mold of super pave.

Surface irregularities introduced errors in volume of sample as compared to smooth surface cylinder. The volume would be less in irregular surface as compared to smooth surface. Therefore, the final predicted results of Gmb at Ndes is different than the measured Gmb. Therefore, the predicted Gmb is corrected by using a ratio of the measured to predict bulk specific gravity.

3.10.4 Design Requirements of Superpave Mix

These are essential requirements for Superpave mix sample.

- The air voids should be of 4% when sample compacted to N_{des} gyrations.
- The VMA value must meet to require VMA at Ndes gyrations.it should be more than 13.
- The VFA (Voids Filled with Asphalt) of the compacted mixture specimen at N_{des} gyrations must fall within the range. It should be 65 to 75.
- The dust-to-binder ratio, which is the ratio of the weight of the mineral filler to the weight of the binder, its value must be within 0.6 and 1.2.
- The %Gmm of the asphalt mixture compacted to N_{ini} must not exceed the limits. The %Gmm of the mixture should not be more than 98%.

CHAPTER 4

RESULTS AND ANALYSIS

4.1 General

The main objective of the research was to compare the volumetric properties of the Hot Mix Asphalt (HMA) using neat and modified binder for Marshall Mix Design Method as well as Superpave Mix Design Method for the wearing course. "NHA Class-A "gradation with a maximum nominal aggregate size (MNAS) of 19mm was selected for Marshall Mix Design Method and aggregate gradation with same maximum nominal aggregate size but with slightly different percentages of fine aggregate and mineral filler was selected for Superpave Mix Design. Each sample contains coarse aggregate, fine aggregate, mineral filler and asphalt. Bitumen of penetration grade A-60/70 was used as a neat binder while DuPont Elvaloy RET 4170 in A-60/70 to yield modified binder. Technical Bulletin DuPont Elvaloy RET 4170 suggests its usage of 0.8%-1.8% but it can be used up to 3%.We used 1.5% of DuPont Elvaloy RET 4170 by weight of bitumen in our project. After a number of trials, Optimum Bitumen Content (against 4% VA %) of HMA prepared with neat bitumen and Optimum Bitumen Content (against 4% VA %) of HMA prepared with modified bitumen was obtained for Marshall Mixes as well as Superpave Mixes. The samples prepared by both types of bitumen were tested for flow and stability and also VA%, VMA% and VFA% were calculated for Marshall as well as Superpave Mixes. The obtained values were then compared with the standard specifications.

The values of VA%, VMA% and VFA% of HMA prepared with neat bitumen and prepared with modified bitumen were compared for Marshall as well as Superpave Mix Design. On the basis of comparison conclusion was made and recommendations were drawn.

4.2 Material Characterization

Aggregate was acquired from Margalla Rock Quarry while bitumen and DuPont Elvaloy RET 4170 were already present in NIT laboratory. Performance tests of aggregate and bitumen were carried and results were compared with the standard values. All values were according to requirements imposed by standards so they passed the criteria and hence selected for further use in project. A summary of laboratory test results for the aggregates, neat bitumen and modified bitumen with their standards is presented in Table 4.1, Table 4.2 and Table 4.3 respectively.

***Table 4. 1*: Aggregate Performance Test Results**

Test	Standard	Permissible Value	Results
Impact Value	ASTM D5874	30%	21.75%
LA Abrasion Value	ASTM C535-12	40%	26.20%
Crushing Value	BS 812	25%	21.40%
Specific Gravity	ASTM C127-88		
Gsb			2.51
Gssd			2.54
Gsa			2.59
Absorption Value	ASTM C127		1.43%

***Table 4. 2*: Neat Bitumen Performance Test**

Test	Standard	Permissible Value	Result	Remarks
Flash Point	ASTM D3143	Min. 250	279 °C	Grade 60/70
Fire Point	ASTM D3143 M-13		302 °C	Grade 60/70
Penetration Value	ASTM D5/D5M	60-70	64.5	Grade 60/70
Softening Point	ASTM D36-06	49-56 °C	50.8 °C	Grade 60/70
Viscosity Test	ASTM D4402	0.22-0.45 pascal-sec	0.2625 pascal-sec	Grade 60/70
Ductility Test	ASTM D113-99	Min. 100	123 cm	Grade 60/70

Table 4. 3: Modified Bitumen Performance Test Results

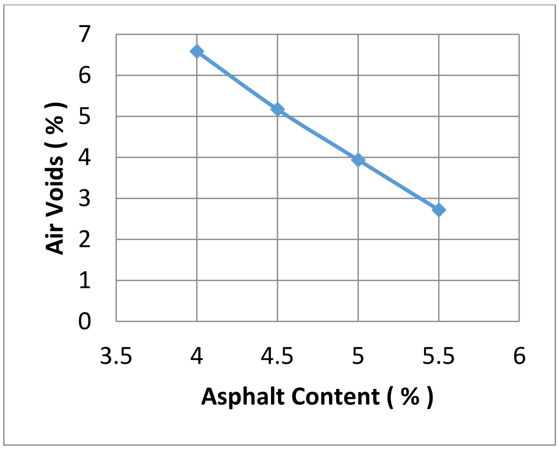
Test	Standard	Permissible Value	Result	Remarks
Flash Point	ASTM D3143	Min. 250	296 °C	More than A-60/70
Fire Point	ASTM D3143 M-13		312 °C	Less than A-60/70
Penetration Value	ASTM D5/D5M	60-70	60.5	More than A-60/70
Softening Point	ASTM D36-06	49-56 °C	52°C	More than A-60/70
Viscosity Test	ASTM D4402	0.22-0.45 pascal-sec	0.44 pascal-sec	More than A-60/70
Ductility Test	ASTM D113-99	Min. 100	150 cm	More than A-60/70

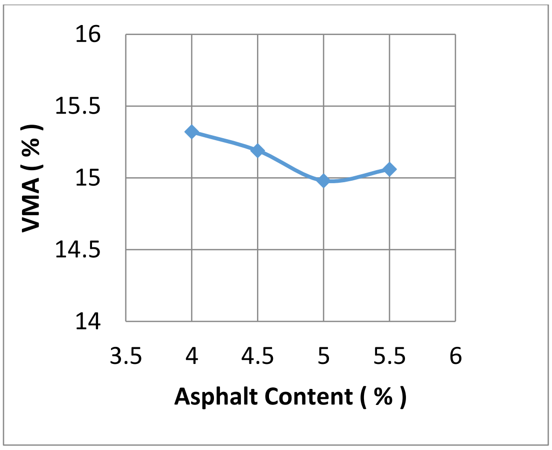
4.3 Marshall Mix Design (Penetration Grade 60/70)

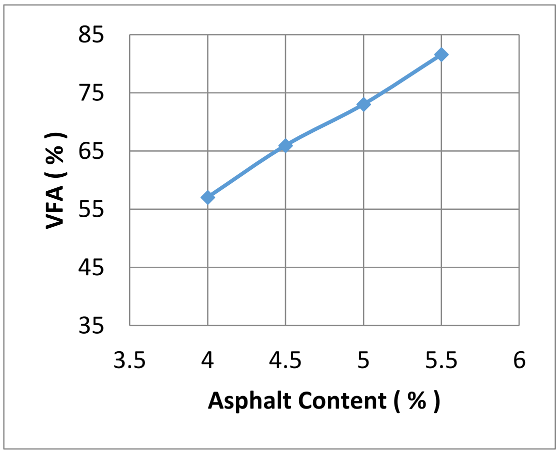
Using Marshall Mix Method, specimens were prepared at 4.0, 4.5, 5.0% and 5.5 % asphalt contents. Three specimens were prepared for each asphalt contents, two of which were used in bulk specific gravity of the mix (G_{mb}) calculation and one was used to find out maximum theoretical specific gravity of the mix (G_{mm}). It results to a total of 24 Marshall Mix Design samples, out of which 12 samples were prepared using neat bitumen and rest of 12 samples were prepared using modified binder. Marshall parameters determined for samples compacted at standard compaction (75 blows) are tabulated in Table 4.4 and graphically illustrated in Fig. 4.1.The optimum asphalt content determined at standard compaction (75 blows) is tabulated in Table 4.5.

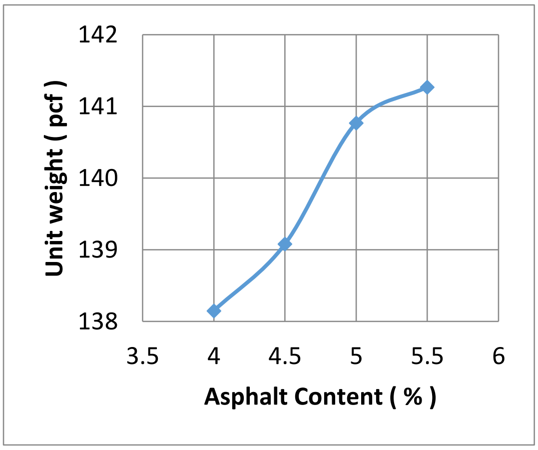
Table 4. 4: **Volumetric Properties of Marshall Mix Design Using Neat Bitumen**

% Asphalt	G mb	Gmm	VA %	VMA %	VFA %	FLOW AVG	STABILITY
4	2.214	2.370	6.58	15.32	57.04	2.935	8.149
4.5	2.229	2.351	5.17	15.19	65.96	3.372	8.62
5	2.256	2.347	3.94	14.98	73.03	3.914	8.435
5.5	2.264	2.327	2.72	15.06	81.57	4.468	8.427









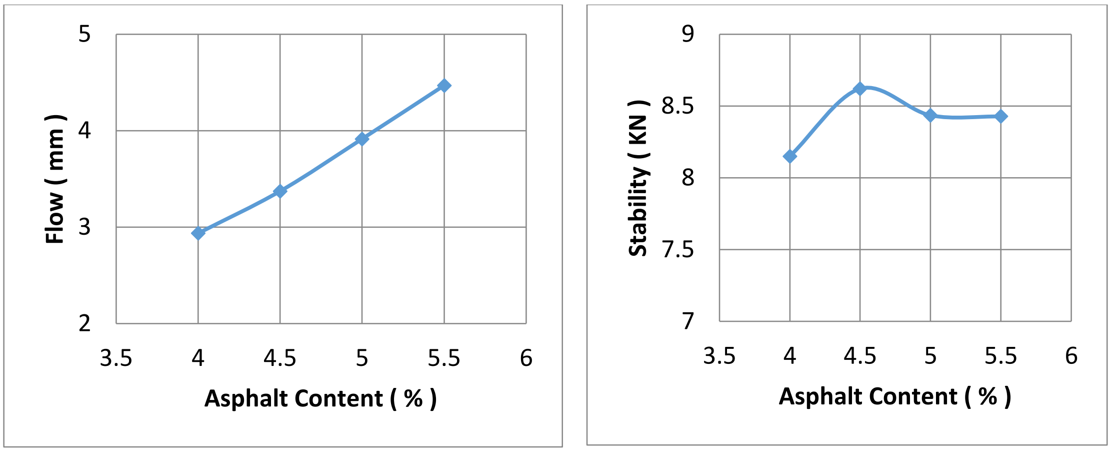


Figure 4.1: Volumetric Properties of Marshall Mix Design Using Neat Bitumen

4.3.1 Volumetric Properties at Optimum Bitumen Content (Penetration Grade 60/70)

The optimum bitumen content was determined from the graph against 4% air voids. After calculating the optimum bitumen content the values of VMA, VFA, Flow and Stability were calculated from the graph. Then the values were checked against the criteria given in the (MS-2) manual. Analyzing the above results in the table we see the following trend for the Marshall Mix specimens of 60/70 Penetration Grade Bitumen. All the analysis is done on the basis of criteria given in the table 4-6. Keeping in view the limits of the volumetric properties the results have been analyzed.

***Table 4.5*: Volumetric Properties of Marshall Mix Design using Neat Bitumen at OBC**

Optimum Bitumen Content	4.98 %
Air Voids	4 %
VMA	14.93%
VFA	72.6 %
Flow	3.902 mm
Stability	8450 N

4.3.2 Analysis

Analyzing the above results in the table we see the following trend for the Marshall Mix specimens of 60/70 Penetration Grade Bitumen. All the analysis is done on the basis of criteria given in the table 4-5. Keeping in view the limits of the volumetric properties the results have been analyzed.

Table 4.6: **Design Criteria of Marshall Mix Design**

Design Criteria	Medium traffic design	Heavy traffic design
Compaction, number of blows per side	50	75
Stability (Newton)	5300	8000
Flow (0.25 mm)	8-16	8-14
Air voids (%)	3-5	3-5
VFA, %	65-78	65-75
VMA, %	13*	13*

Analyzing the above results in the table we see the following trend for the Marshall Mix specimens of Penetration Grade 80/100 Bitumen.

- % VA is the total volume of the small pockets of air between the coated aggregate particles. The amount of air voids in a mixture is extremely important and it is related to stability and durability of the mixture. % VA must be within the specified range. If the % VA is too low the pavement is susceptible to bleeding specially in the summer season. If the % VA is too large the pavement is susceptible to cracking, that's why 4% VA criteria is considered for the selection of optimum asphalt binder content. In the above results a trend is noticed, % VA decrease with the increase of bitumen content because you increase the bitumen content more of the air voids are filled with bitumen.
- The total volume of voids in the aggregate mix when there is no bitumen is called voids in mineral aggregates (VMA). It includes the air voids and volume of the bitumen not absorbed in the aggregate particles. If the VMA is too low there is not enough room in the mixture to add sufficient binder content to coat the aggregate particles. If VMA is too large it will cause unacceptably low mixture stability and less durable mixture. So VMA must be within a specific range as specified by the MS-2 Manual. All the values in the above result are within the range so our design is acceptable to be implemented.
- VFA is the void in mineral aggregate framework filled with bitumen binder. The bitumen content is called as the effective bitumen content. It can also be described as the percent of the volume of VMA filled with bitumen. VFB is inversely related to VA, as VFA increases VA decreases. The lower VFA results in the decreased bitumen film thickness. Thus lower bitumen film thickness

results in less durable pavements. Lower film thickness also causes low temperature cracking as bitumen perform the filling and healing effects to improve the flexibility of the mixture. Very low or very high VA may not meet the VFA criteria but the criteria is well met at the 4% VA. So the design is acceptable as VFA at optimum asphalt content is within the specified range. The general trend with VFA is that it increases consistently with the increase in bitumen content.

- Strength is measured in terms of Stability. Stability is the maximum load sustained by the specimen before failure at 60°C. The temperature 60°C represents the weakest condition of pavement. The load is applied to the specimen at the deformation rate of 50.8mm/min. The trend seen above is that stability first increases with the increase of bitumen content and then decreases after the bitumen content has exceeded a certain limit. The reason is that the % VA decreases due to increase of bitumen content the one to one content of the aggregate particles decrease. So the load is transmitted through hydrostatic pressure by bitumen and hence the strength of the mix decreases. The Stability of the sample must be within the range as specified by the MS-2 Manual. In the above results we see that the stability values are within the specified range so hence the design asphalt content meets the criteria.
- Flow is the deformation at the maximum load. Flexibility is measured in terms of flow rate. Flow value is measured by change in diameter of the sample in the direction of load application between the start of loading and at the time of maximum load. The trend seen in this research is that the values of flow increase with the increase in the asphalt content.

4.4 Marshal Mix Design (A-60/70 + 1.5% Elvaloy)

Using Marshall Mix Method, specimens were prepared at 4.0, 4.5, 5.0 and 5.5% asphalt contents. Three specimens were prepared for each asphalt contents and compactive effort (standard) making a total of 12 specimens. The Marshall parameters determined for samples compacted at standard compaction (75 blows) are tabulated in Table 4.6 and graphically illustrated in Fig. 4.2. The optimum asphalt content determined at standard compaction (75 blows) is tabulated in Table 4.7.

Table 4.7: **Volumetric Properties of Marshall Mix Design Using Modified Binder**

Asphalt	Gmb	Gmm	Va %	VMA %	VFA %	FLOW AVG(mm)	STABILITY AVG(KN)
4	2.221	2.355	5.73	15.05	61.92	2.714	9.369
4.5	2.234	2.349	4.91	14.99	67.24	3.153	10.173
5	2.246	2.330	3.64	14.91	75.58	3.769	8.835
5.5	2.259	2.312	2.31	14.95	84.54	4.186	8.742

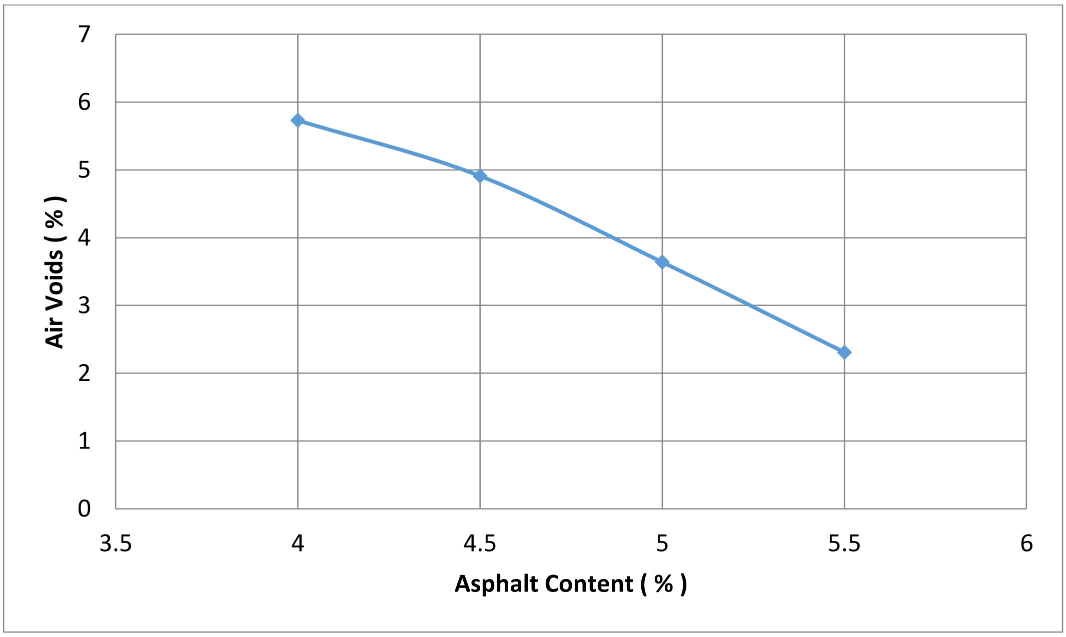


Figure 4.2*: %VA vs %AC of Marshall Mix Design using Modified Bitumen*

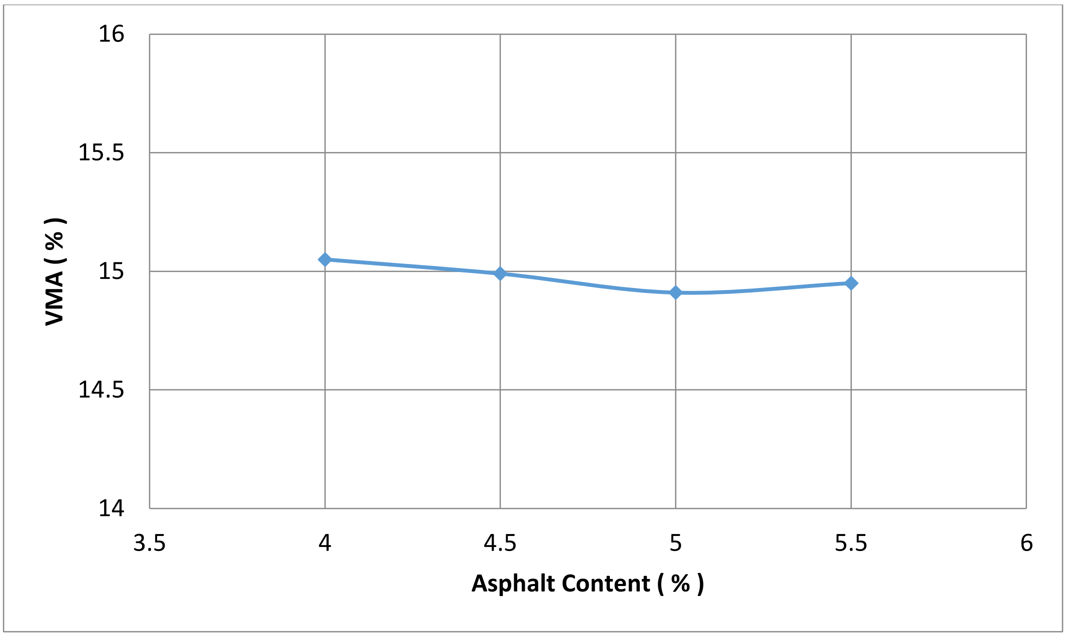


Figure 4.3: %VMA vs %AC of Marshall Mix Design using Modified Bitumen

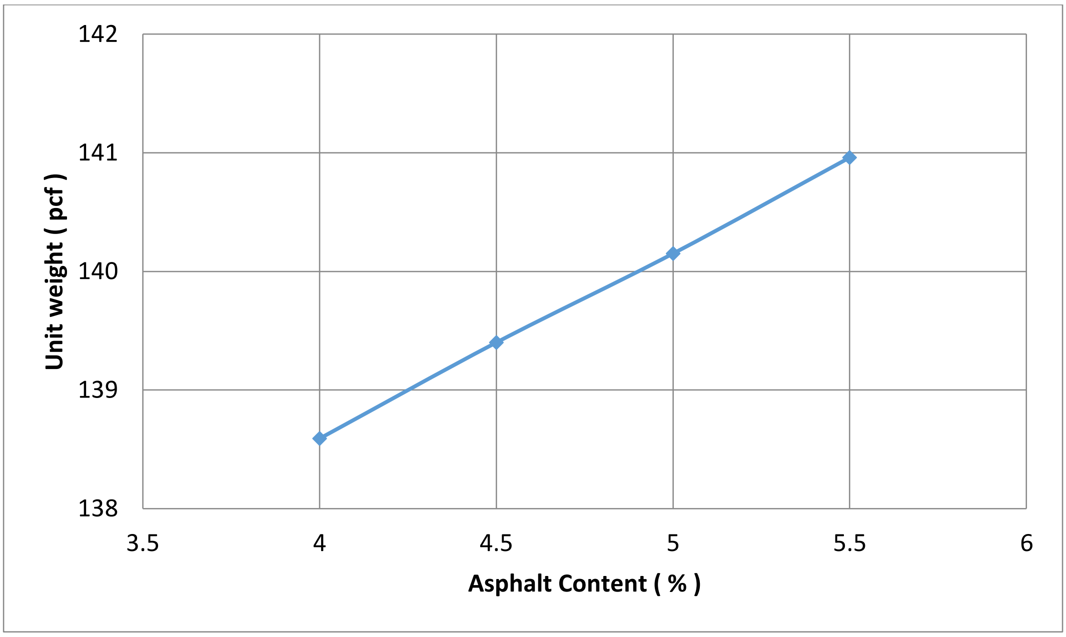


***Figure 4.4*: Unit Weight vs %AC of Marshall Mix Design using Modified Bitumen**

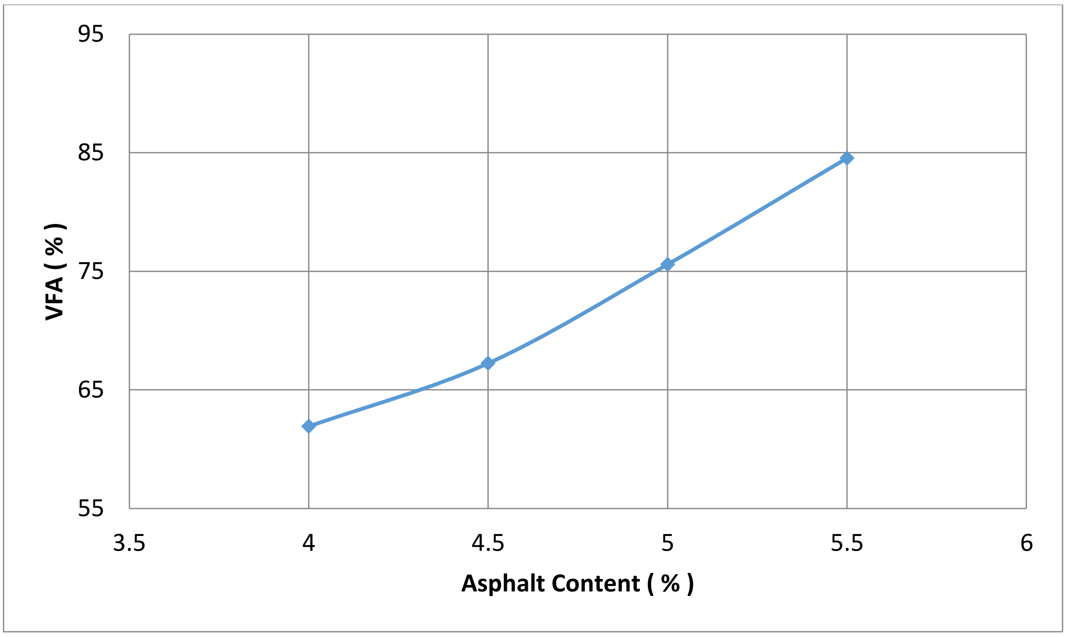


Figure 4.5**: %VFA vs %AC of Marshall Mix Design using Modified Bitumen**

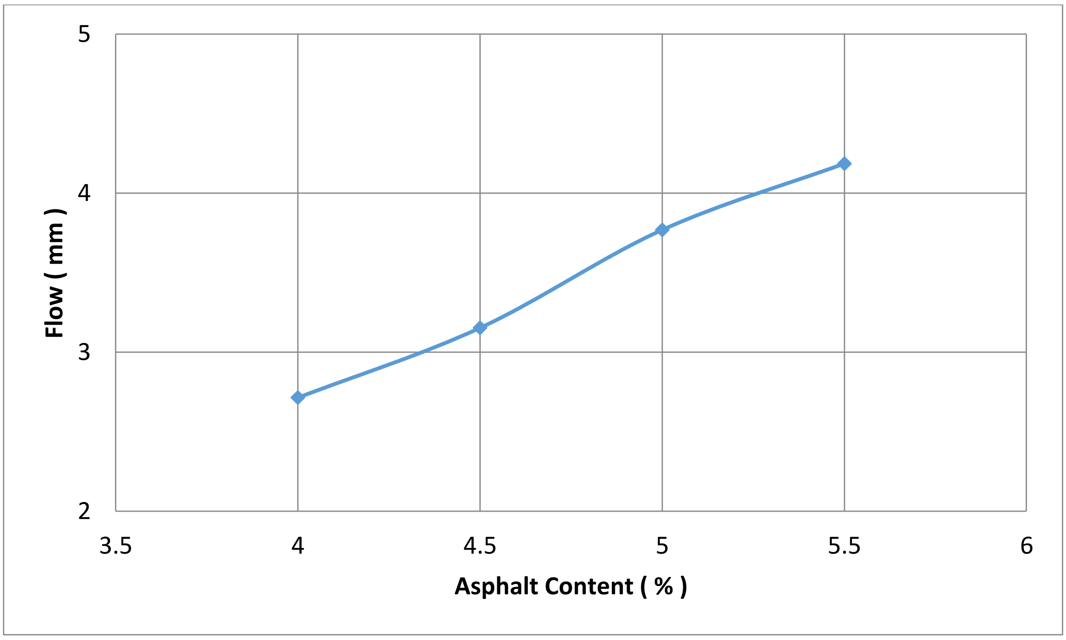


Figure 4.6**: Flow vs %AC of Marshall Mix Design using Modified Bitumen**

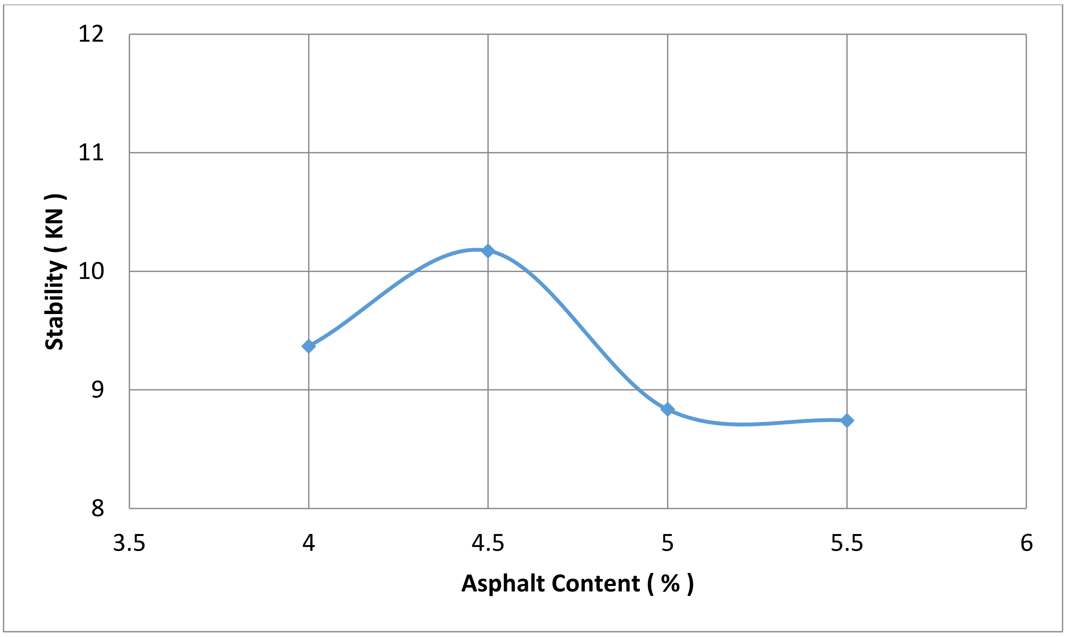


Figure 4.7: **Stability vs %AC of Marshall Mix Design using Modified Bitumen**

4.4.1 Volumetric Properties at Optimum Bitumen Content (Penetration Grade 60/70 + 1.5% Elvaloy)

The optimum bitumen content was determined from the graph at 4% air voids. After calculating the optimum bitumen content the values of VMA, VFA, Flow and Stability were calculated from the graph. Then the values were checked against the criteria given in the (MS-2) manual.

Table 4.8: **Volumetric Properties of Marshall Mix Design using Modified Bitumen at OBC**

Optimum Bitumen Content	4.82 %
Air Voids	4 %
VMA	14.62%
VFA	73 %
Flow	3.641 mm
Stability	9000 N

4.4.2 Analysis

Analyzing the above results in the table we see the following trend for the Marshall Mix specimens of Penetration Grade 80/100 Bitumen.

- % VA is the total volume of the small pockets of air between the coated aggregate particles. The amount of air voids in a mixture is extremely important and it is related to stability and durability of the mixture. % VA must be within the specified range. If the % VA is too low the pavement is susceptible to bleeding specially in the summer season. If the % VA is too large the pavement is susceptible to cracking, that's why 4% VA criteria is considered for the selection of optimum asphalt binder content. In the above results a trend is noticed, % VA decrease with the increase of bitumen content because you increase the bitumen content more of the air voids are filled with bitumen.
- The total volume of voids in the aggregate mix when there is no bitumen is called voids in mineral aggregates (VMA). It includes the air voids and volume of the bitumen not absorbed in the aggregate particles. If the VMA is too low there is not enough room in the mixture to add sufficient binder content to coat the aggregate particles. If VMA is too large it will cause unacceptably low mixture stability and less durable mixture. So VMA must be within a specific range as specified by the MS-2 Manual. All the values in the above result are within the range so our design is acceptable to be implemented.
- VFA is the void in mineral aggregate framework filled with bitumen binder. The bitumen content is called as the effective bitumen content. It can also be described as the percent of the volume of VMA filled with bitumen. VFB is inversely related to VA, as VFA increases VA decreases. The lower VFA results in the decreased bitumen film thickness. Thus lower bitumen film thickness results in less durable pavements. Lower film thickness also causes low temperature cracking as bitumen perform the filling and healing effects to improve the flexibility of the mixture. Very low or very high VA may not meet the VFA criteria but the criteria is well met at the 4% VA. So the design is acceptable as VFA at optimum asphalt content is within the specified range. The general trend with VFA is that it increases consistently with the increase in bitumen content.
  - Strength is measured in terms of Stability. Stability is the maximum load sustained by the specimen before failure at 60°C. The temperature 60°C

represents the weakest condition of pavement. The load is applied to the specimen at the deformation rate of 50.8mm/min. The trend seen above is that stability first increases with the increase of bitumen content and then decreases after the bitumen content has exceeded a certain limit. The reason is that the % VA decreases due to increase of bitumen content the one to one content of the aggregate particles decrease. So the load is transmitted through hydrostatic pressure by bitumen and hence the strength of the mix decreases. The Stability of the sample must be within the range as specified by the MS-2 Manual. In the above results we see that the stability values are within the specified range so hence the design asphalt content meets the criteria.

- Flow is the deformation at the maximum load. Flexibility is measured in terms of flow rate. Flow value is measured by change in diameter of the sample in the direction of load application between the start of loading and at the time of maximum load. The trend seen in this research is that the values of flow increase with the increase in the asphalt content.

4.5 Comparison between Neat Binder HMA and Modified Binder HMA (Marshall Mix Design)

The results of Marshall Mix Design Method with neat and modified binder have been compared in the tabular form as well as graphically. It follows the analysis done on basis of comparison. The comparison of the volumetric properties is shown below in the table 4.19 and table 4.20. The volumetric properties are compared at the optimum bitumen content and all other bitumen contents. The results have also been shown graphically showing the variations of the two types of bitumen in Fig 4.5

***Table 4.9*: Volumetric Properties Comparison of Marshall Mix Design using Neat and Modified Bitumen**

Asphalt Content %	% VA		% VMA		%VFA	
	Neat	Modified	Neat	Modified	Neat	Modified
4	6.58	5.73	15.32	15.05	57.04	61.92

4.5	5.17	4.91	15.19	14.99	65.96	67.24
5	3.94	3.64	14.98	14.91	73.03	75.58
5.5	2.72	2.31	15.06	14.95	81.57	84.54

***Table 4. 10*: Comparison of Volumetric Properties of Marshall Mix Design using Neat and Modified Bitumen at OBC**

Volumetric Properties	Neat Bitumen	Modified Bitumen
%Optimum Asphalt Content	4.98	4.82
%Va	4	4
%VMA	14.93	14.62
%VFA	72.6	73

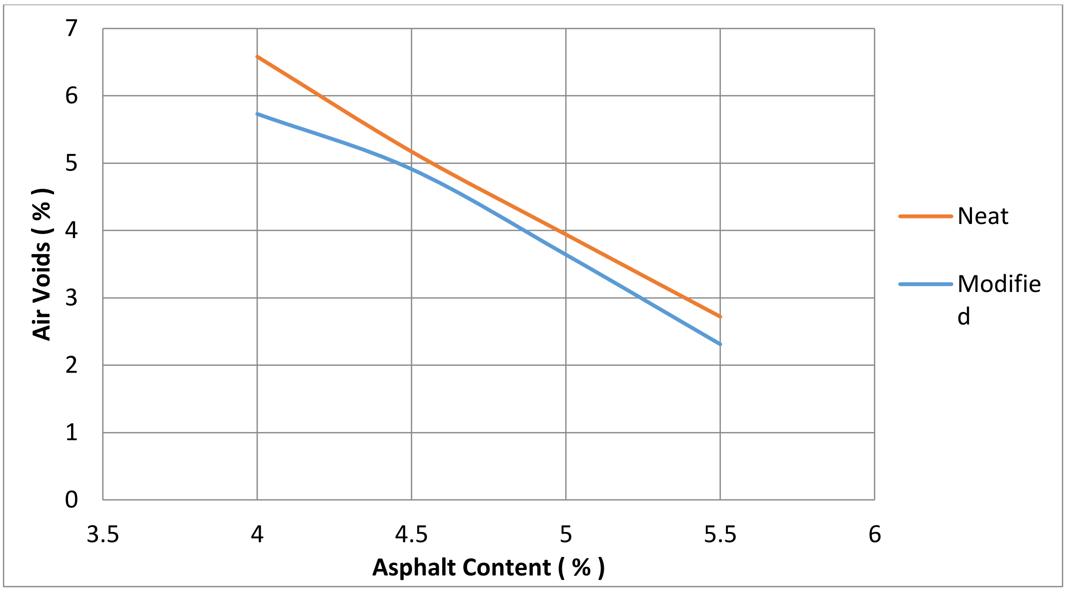


Figure 4.9: **Comparison of %VA vs %AC for Marshall Mix Design using Neat and Modified Binder**

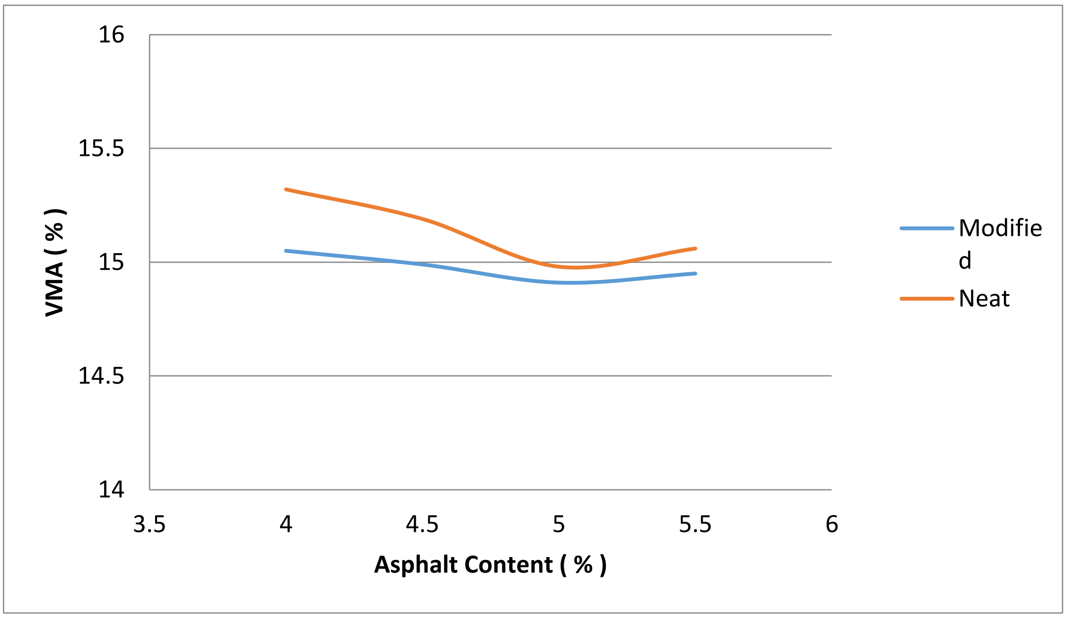


Figure 4.8: **Comparison of %VMA vs %AC for Marshall Mix Design using Neat and Modified Bitumen**

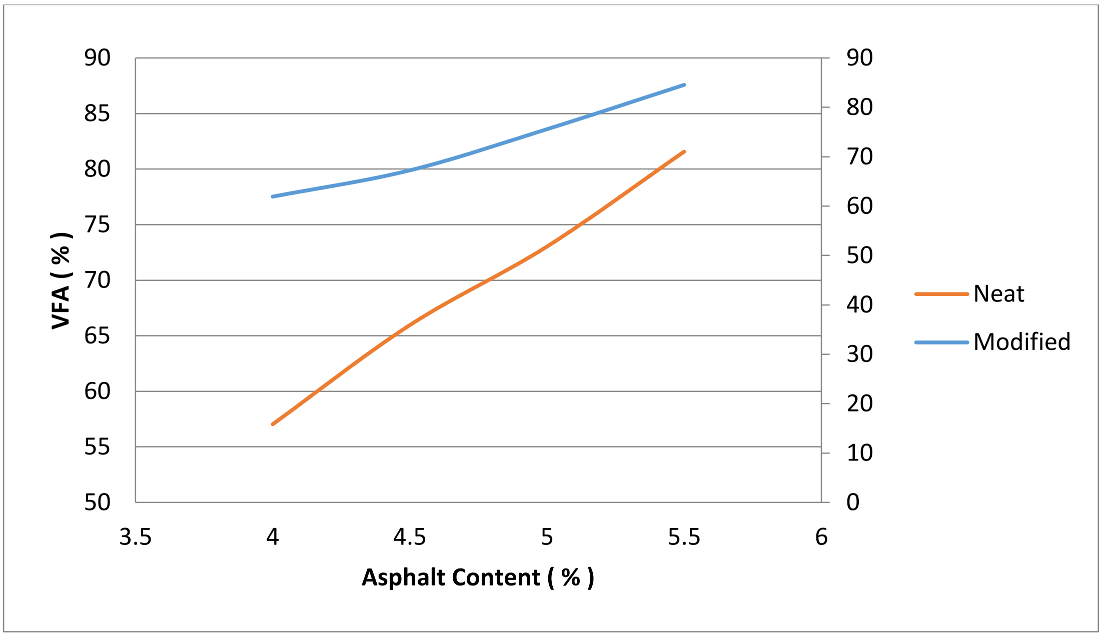


***Figure 4.10*: Comparison %VFA vs %AC for Marshall Mix Design using Neat and Modified Bitumen**

4.5.1 Analysis

The results of the Superpave and the Marshall Mix design method for the 60/70 penetration grade bitumen have been analyzed and compared as follows.

- In the above table we notice that for the same bitumen content, % air voids for Superpave mix are lower than that for Marshall Mix. The air voids estimated by Superpave are more accurate as it stimulates the field compaction method.
- VMA calculated from the Superpave mix method is lower than that of Marshall Mix method at any asphalt content. It was found that the decreased VMA values, as compared to Marshall VMA values, while designing under Superpave could be attributed to the higher compactive effort of the Superpave gyratory compactor as compared to the Marshall Compaction hammer. This problem in the Superpave mixes can be solved by using the coarser mixes.
- The values of VFA for Marshall Mix method increases rapidly with increase in asphalt content and doesn't necessarily satisfy criteria at all asphalt contents. While for Superpave mix method the values increase gradually and satisfy the criteria at all the asphalt contents.
- In the Superpave Mix method Gmm can be estimated at every compaction level, so it gives information about the compaction of the sample throughout the

compaction procedure. While Marshall Mix method can only measure the Gmm once the sample has been compacted completely.

4.6 Superpave Mix Design Method (A-60/70)

Using Superpave Mix Method, specimens were prepared at 4%, 4.5%, 5% and 5.5% asphalt content using A-60/70. Trial specimens were prepared at different asphalt contents to estimate the optimum asphalt content at 4% air voids. Three specimens were prepared for each asphalt contents with the design number of gyrations (N_{des}=100), two of which were compacted in gyratory compaction machine and further used for G_{mb} calculations while third one was used in G_{mm} test in loose form. Volumetric parameters determined for Superpave Mix Design using A-60/70 at compaction effort of N_{des}=100 are tabulated in Table 4.9 and graphically shown in Figure

***Table 4.11*: Volumetric of Superpave Mix Design using Neat Bitumen**

Bitumen content %	VA %	VMA %	VFA %	Ave. G_{mb}	Gmm @ N_{des}	Dust Proportion
4	7.35	14.07	47.76	2.27	92.65	0.988
4.5	5.34	13.78	60	2.3	94.66	0.838
5	2.92	12.84	76.89	2.33	97.08	0.698
5.5	1.68	12.68	86.75	2.34	98.32	0.620

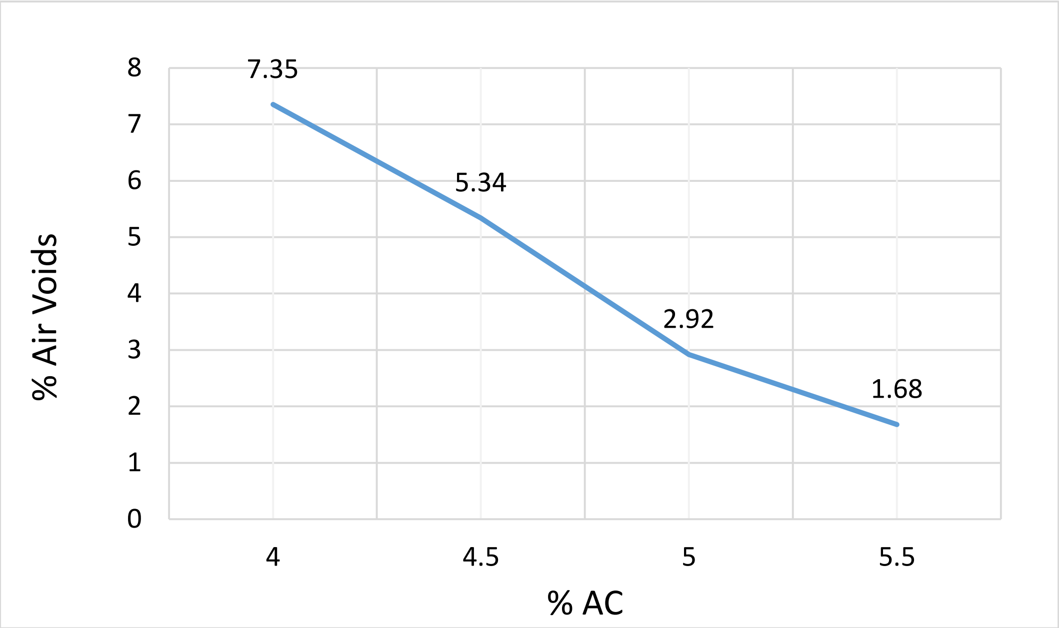


***Figure 4.11*: %VA vs % AC of Superpave Mix Design using Neat Bitumen**

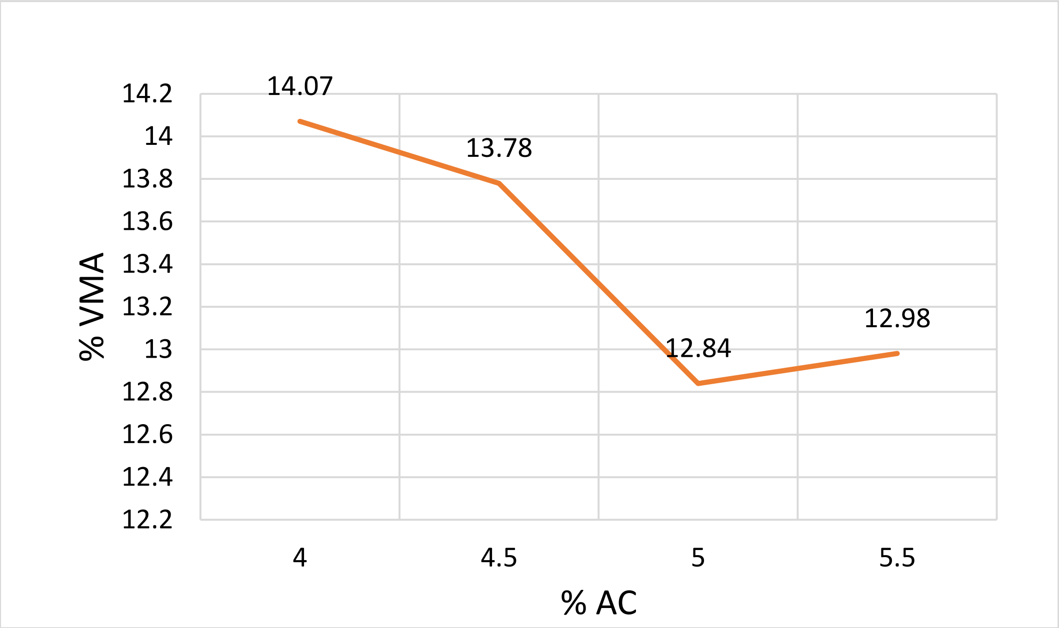


***Figure 4. 12*: %VMA vs %AC of Superpave Mix Design using Neat Bitumen**

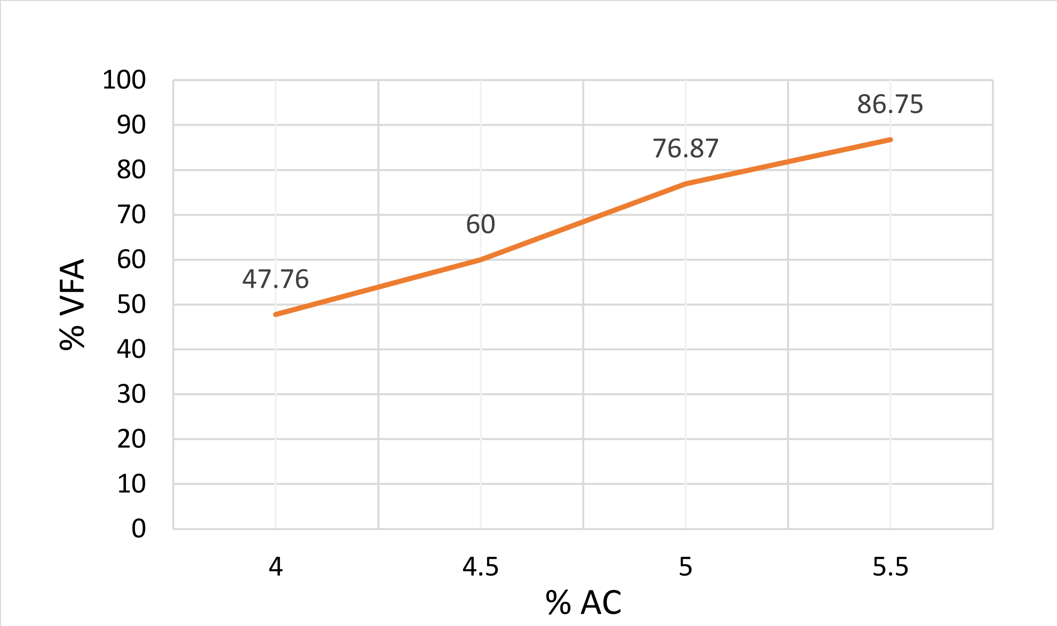


Figure 4.13: %VFA vs %AC of Superpave Mix Design using Neat Bitumen

4.6.1 Volumetric at Optimum Bitumen Content (A- 60/70)

The optimum bitumen content was determined from the graph against 4% air voids. After calculating the optimum bitumen content the values of VMA and VFA were determined from the graph. The value of Dust Proportion was determined by interpolation. Then these values were checked against the criteria given in the (SP-2) manual.

***Table 4.12*: Volumetric Properties of Superpave Mix Design using Neat Bitumen at OBC**

Optimum Bitumen Content	4.77 %
Air Voids	4 %
VMA	13.31%
VFA	69.12 %
Dust Proportion	0.83

4.6.2 Analysis of Superpave Results (A-60/70)

The results in the table 4-8 to 4-12 and figure 4-3 are analyzed in the following paragraph. Analysis is done on the basis of Superpave Mix Design criteria shown in Table 4-13. The results have been compared and analyzed keeping in mind the maximum and minimum ranges of volumetric properties given in the Table 4-13. After the comparison it is analyzed whether our results satisfy the design criteria or not.

- % VA decreases with the increase of the bitumen content. As the bitumen content increases more air voids are filled with bitumen so ultimately VA% reduces. The results are checked at the 4% VA criteria.
- Firstly %VMA decreases with the increase of bitumen content and then it starts to increase. Decrease in %VMA is due to the reason that asphalt occupies the voids as its content increases. After a certain value of bitumen content, any further bitumen addition becomes the reason of slippage of aggregate as most of the voids are already filled with bitumen. Therefore bitumen is now unable to hold the aggregate particles together hence %VMA increases. %VMA at Optimum Bitumen Content was determined and checked against requirement. It meet the criteria stated in SP-2.
- % G_{mm} values at N_{ini} and N_{des} are checked. All the values at N_{ini} are within the range.
- Densification curves showing the densification of Superpave samples with respect to loading (i.e. number of gyration) are shown in Annex-A.
- The VFA values increase with the increase of the bitumen content. It is because with increasing asphalt content the void filled with bitumen will increase. VFA values are within the range for all the samples especially for optimum bitumen content. Hence the values of VFA are acceptable in our results.
- The dust to binder ratio should be in the range of (0.6-1.2). Dust to Binder ratio (DB) values for all Superpave Mix Design samples prepared with A-60/70 are within the above stated range. Since the values of dust to binder ratio are also within the range, so our design is acceptable.

4.7 Superpave Mix Design Method with Modified Binder (A-60/70 + 1.5% Elvaloy)

Using Superpave Mix Method, specimens were prepared at 4%, 4.5%, 5% and 5.5% asphalt content using modified binder. Trial specimens were prepared at above stated asphalt contents to estimate the optimum asphalt content against 4% air voids. Three specimens were prepared for each asphalt content, out of which two were compacted in gyratory compaction machine with the design no of gyrations

(N_{des}=100) and third one was used in loose form for G_{mm} test. The volumetric properties and dust proportion was determined for each asphalt content. The results are tabulated in Table 4.14 to 4.17 and graphically illustrated in Fig. 4.4

***Table 4.13*: Volumetric of Superpave Mix Design using Modified Bitumen**

Bitumen content %	VA %	VMA %	VFA %	Average G_{mb}	%Gmm @ N_{dsign}	Dust Proportion
4	6.45	13.58	53	2.30	93.55	1.20
4.5	3.67	13.10	70.6	2.32	96.33	0.93
5	2.06	12.52	80.8	2.33	97.94	0.79
5 .	1.24	12.59	88.5	2.35	98.76	0.78

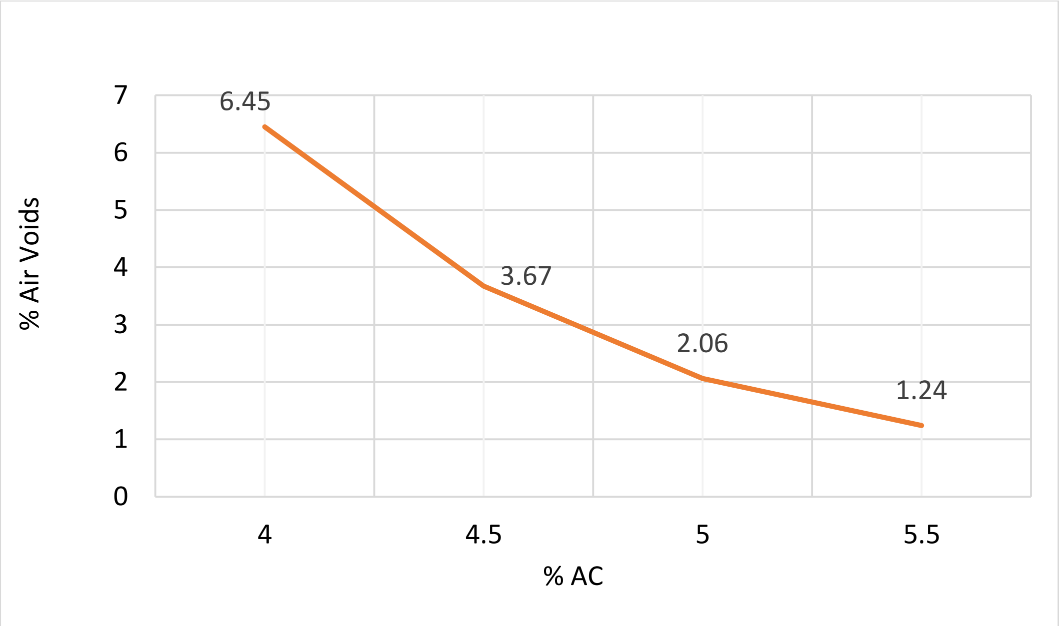


***Figure 4.14*: %VA vs %AC**

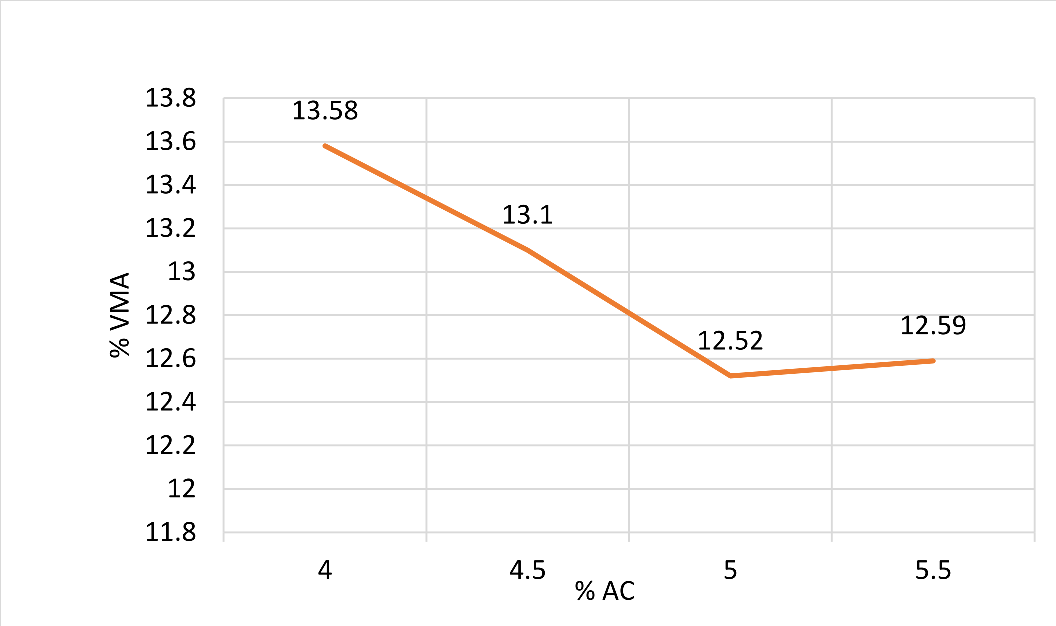


***Figure 4.15*: %VMA vs %AC of Superpave Mix Design using Modified Bitumen**

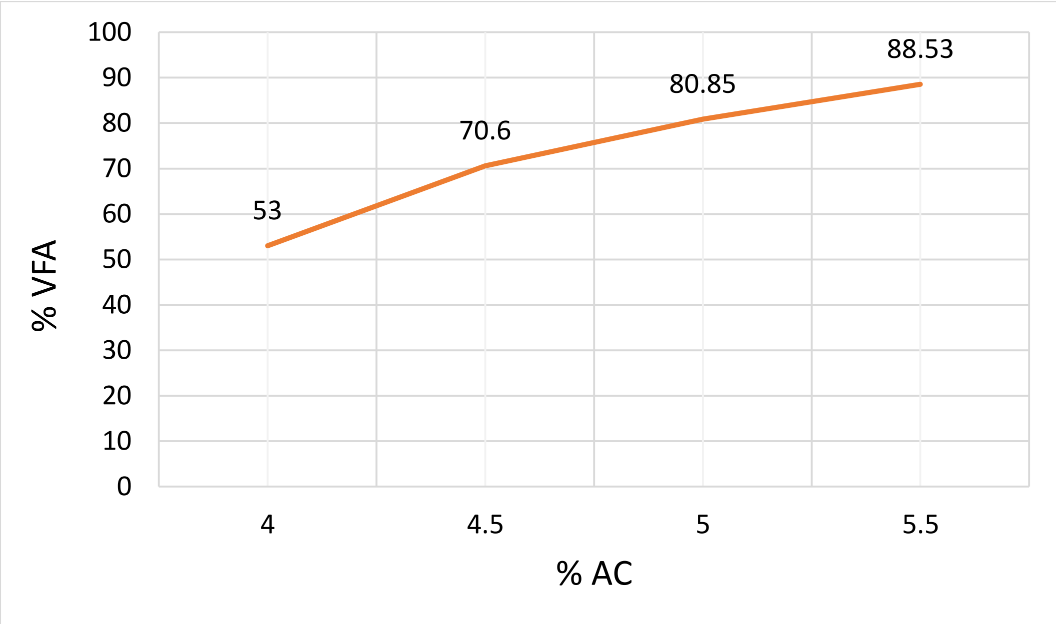


***Figure 4. 16*: %VFA vs %AC of Superpave Mix Design using Modified Bitumen**

4.7.1 Volumetric at Optimum Bitumen Content (A-60/70 + 1.5% Elvaloy)

The optimum bitumen content was determined from the graph at 4% air voids. After calculating the optimum bitumen content the values of VMA, VFA were calculated from the graph. Dust Proportion was determined by interpolation. The values were checked against the criteria given in the (SP-2) manual.

***Table 4.14*: Volumetric Properties of Superpave Mix Design using Modified Bitumen at OBC**

Optimum Bitumen Content	4.44 %
Air Voids	4 %
VMA	13.20%
VFA	66.2%
Dust Proportion	0.933

4.7.2 Analysis of Superpave Results (A-60/70 + 1.5% Elvaloy)

The results in the table 4-8 to 4-12 and figure 4-3 are analyzed in the following paragraph. Analysis is done on the basis of the criteria given in table 4-13. The results have been compared and analyzed keeping in mind the maximum and minimum ranges of volumetric properties given in the table 4-13. After the comparison it is analyzed whether our results satisfy the design criteria or not.

- % VA decreases with the increase of the bitumen content. As the bitumen content increases more of the air voids are filled with bitumen. The results are checked at the 4% VA criteria.
- Firstly %VMA decreases with the increase of bitumen content and then it starts to increase. Decrease in %VMA is due to the reason that asphalt occupies the voids as its content increases. After a certain value of bitumen content, any further bitumen addition becomes the reason of slippage of aggregate as most of the voids are already filled with bitumen. Therefore bitumen is now unable to hold the aggregate particles together hence %VMA increases. %VMA at Optimum Bitumen Content was determined and checked against requirement. It meet the criteria stated in SP-2.
- % G_{mm} values at N_{ini} and N_{des} are checked. All the values at N_{ini} are within the range.
- Densification curves showing the densification of Superpave samples with respect to loading (i.e. number of gyration) are shown in Annex-A.
- The VFA values increase with the increase of the bitumen content. It is because with increasing asphalt content the void filled with bitumen will increase. VFA values are within the range for all the samples especially for optimum bitumen

content. Hence the values of VFA are acceptable in our results.

- The dust to binder ratio should be in the range of (0.6-1.2). Dust to Binder ratio (DB) values for all Superpave Mix Design samples prepared with A-60/70 are within the above stated range. Since the values of dust to binder ratio are also within the range, so our design is acceptable.

4.8 Comparison between Neat Binder HMA and Modified Binder HMA (Superpave Mix Design)

The comparison of the volumetric properties is shown below in the Table 4.21 and Table 4.20. The volumetric properties are compared at the optimum bitumen content. The results have also been shown graphically showing the variations of two type of bitumen usage in Superpave Mix Design in Fig 4.6.

***Table 4.15*: Volumetric Comparison of Superpave Mix Design using Neat and Modified Binder**

Asphalt Content %	% VA		% VMA		%VFA	
	Neat	Modified	Neat	Modified	Neat	Modified
4	7.35	6.45	14.07	13.58	47.76	53
4.55	5.34	3.67	13.78	13.10	60	70.6
5	2.92	2.06	12.84	12.52	76.89	80.85
5.5	1.68	1.24	12.98	12.59	86.75	88.53

***Table 4.16*: Volumetric Comparison of Superpave Mix Design using Neat and Modified Binder at OBC**

Volumetric Properties	Neat Bitumen	Modified Bitumen
%Optimum Asphalt Content	4.77	4.44

%VA	4	4
%VMA	13.31	13.2
%VFA	69.12	66.20
Dust Proportion	0.83	0.933

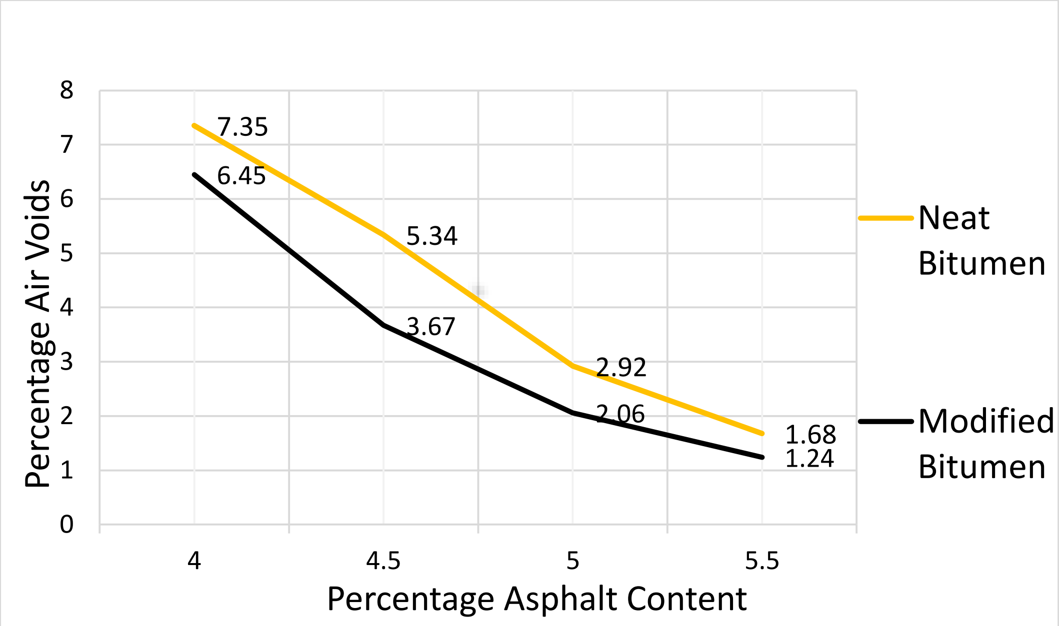


***Figure 4.17*: %VA vs %AC of Superpave Mix Design using Neat and Modified Binder**

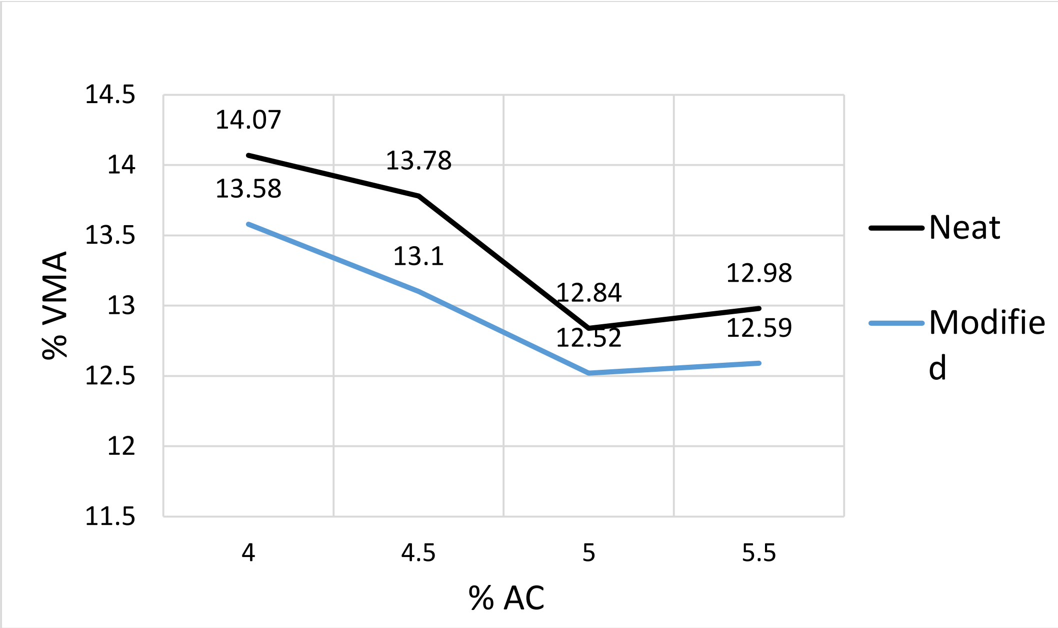


***Figure 4. 18*: %VMA vs %AC of Superpave Mix Design using Neat and Modified Binder**

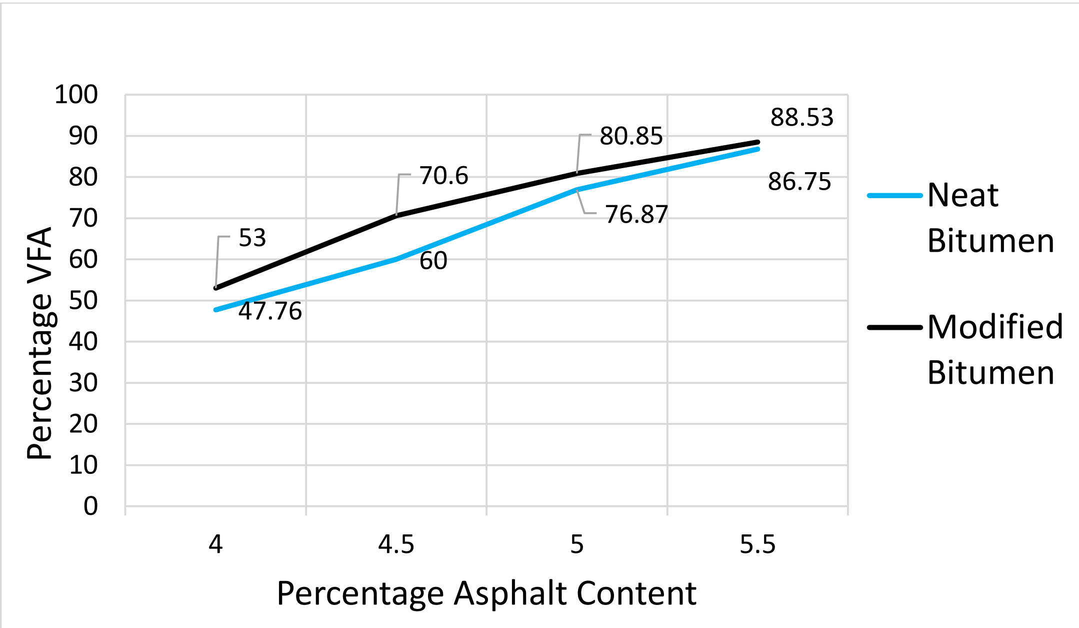


***Figure 4.19*: %VFA vs %AC of Superpave Mix Design using Neat and Modified Binder**

4.8.1 Analysis:

- Excessive Air Voids (VA) in case of Neat Bitumen as compared to Modified Bitumen at a typical bitumen content will cause pavement more susceptible to Air and Moisture Entrance and hence pavement will be prone to cracking.

- Excessive Voids in Mineral Aggregate (VMA) in case of Neat Bitumen as compared to Modified Bitumen will reduce Stability of the mixture.
- Excessive Void Filled with Asphalt (VFA) in case of Neat binder as compared to Modified binder can cause bleeding in High Temperature Zone areas.
    - OR
- At particular Air Voids (e.g. VA = 4%), HMA with Neat binder shows more bitumen content as compared to HMA prepared with Modified bitumen. Excessive asphalt content can cause bleeding.
- Less Optimum Bitumen Content (OBC) in case of Modified binder (OBC = 4.44%) can save a lot of expenses as compared to Neat bitumen (OBC = 4.77%).
- Performance testing of modified bitumen shows that it is stiffer than neat modifier so it can be used in warm areas requiring PG 70-10.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The materials used in our study are, aggregate procured from Margalla Hills Taxila, bitumen of grade 60/70 from Attock Refinery Limited (ARL) and DuPont Elvaloy 4170 Reactive Ethylene Terpolymer (RET) as a modifier/additive. Performance testing of aggregate and bitumen was conducted in the laboratory and test results were compared to standard values. Bitumen was modified using modifier (1.5% DuPont Elvaloy 4170 Reactive Ethylene Terpolymer (RET)) according to standard procedure of mixing. The bitumen contents used to prepare samples were 4%, 4.5%, 5% and 5.5%.For each bitumen content 3 samples were prepared for Marshall Mix Design as well as Superpave Mix Design using and modified binders, thus resulting in total of 48 samples. After the preparation, samples were tested and volumetric properties were found out. Optimum bitumen contents for Marshall Mix Design using Neat Bitumen, Marshall Mix Design using Modified Bitumen, Superpave Mix Design using Neat Bitumen and Superpave Mix Design using Modified Bitumen were found out and stated. At last volumetric properties of above mentioned mix designs were compared and conclusion were made.

5.2 Conclusions

On basis of the experiments and result found following conclusions were made

- Modification of bitumen does not affect the volumetric properties in a way that it crosses the limits and hence Modifier (Elvaloy) can be used.
- The optimum asphalt binder content obtained using Marshall Mix design method is higher than the optimum asphalt binder content obtained from the Superpave mix design method.
- The optimum asphalt binder content of the Marshall Mix design was 0.21% greater than the optimum asphalt binder content of Superpave mix design using neat binder (A-60/70).
- The optimum asphalt binder content of the Marshall Mix design was 0.38% greater than the optimum asphalt binder content of Superpave mix design using modified binder (A-60/70 + 1.5% Elvaloy).

- The Superpave system provides the estimation of dust to binder ratio while Marshall Mix Deign doesn’t provide any estimation about dust to binder ratio.
- The bulk specific gravity (G_{mb}) values for Superpave mix design are greater than those for the Marshall Mix design at the same asphalt content so it can be used for heavy loads
- .Modifier can be used for the area of high temperatures without affecting volumetric properties.
- The best mix design found was Superpave Mix Design with Modified Binder i.e. OBC=4.44%.It saves a lot bitumen and hence reduces the cost.

5.3 Recommendations

- A group may work on the performance testing of pavement using modified binder and observe the improvement in pavement properties.
- A group may work with different percentages of modifier to find out the optimum concentration.

BIBLOGRAPHY

- Habib, Affan, Et Al. "Comparison Of Superpave And Marshall Mixtures For Low- Volume Roads And Shoulders." Transportation Research Record: Journal Of The Transportation Research Board 1609.1 (1998): 44-50.
- Musselman, James A., Et Al. "Superpave Field Implementation: Florida's Early Experience." Transportation Research Record: Journal Of The Transportation Research Board 1609.1 (1998): 51-60.
- B. L. Swami Y. A. Mehta And S. Bose, A Comparison Of Marshall And Superpave Design For Materials Sourced In India. The International Journal of Pavement Engineering (Ijpe), Vol. 5 (3), September 2004, Pp. 163–173.
- J. P. Zaniewski And V. Kanneganti, Comparison Of 19mm Superpave And Marshall Base Ii Mixes In West Virginia, Final Report, Prepared For The West Virginia, June 2003.
- ASI, Ibrahim M. "Performance Evaluation of Superpave and Marshall Asphalt Mix Designs To Suite Jordan Climatic And Traffic Conditions." Construction and Building Materials 21.8 (2007): 1732-1740.
- The Asphalt Institute (AI) Manual Series No. 2 (MS-2), Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types, 1996.
- The Asphalt Institute (Ai) Handbook Sp-2, Superpave Mix Design, 2001.
- Tia, Mang. "Fundamentals and Practice of Asphalt Mixture Design Procedures To Assure Adequate Performance." 13th Conference on Pavement Engineering, Hsin Chu, Taiwan. 2005.
- Marshall Mix And Design Analysis Chapter 4, School Of Engineering, Cochin University Of Science And Technology
- Bruce A Chadbourn, Benita L Crow, Smantha Spindler ,"The Effect of Voids in Mineral Aggregate on HOT Mix Asphalt Pavements", University of Minnesota, Department of Civil Engineering.
- Tom V. Mathew and K V Krishna Rao, "Introduction to Transportation Engineering, Ch.23: Pavement Materials: Bitumen" NPTEL May 24, 2006.
- Israa F. Jasim, Comparison Between Marshall And Superpave Mixture Design, Al- Qadisiya Journal For Engineering Sciences, Vol. 5, No. 4, 394-406, Year 2012

- Jian-Neng Wang, Evaluation of Pavement Performance on Taiwan's Freeways Network Using Superpave System, September, 1999.
- Irfan, M., Et Al. "Determining The Contribution Of Different Structural Layers Of Asphalt Pavement System To Rutting Using Transverse Profile Analysis." American Journal of Civil Engineering and Architecture 1.6 (2013): 174-180.
- John P. Zaniewski, Vasavi Kanneganti, Comparison of 19 Mm Superpave and Marshall Base II Mixes in West Virginia. Asphalt Technology Program Department Of Civil And Environmental Engineering, Morgantown, West Virginia, June, 2003
- MS Thesis By Afaq Khattak "Experimental Investigation Of Factors Affecting The Resilient Modulus Of Bituminous Paving Mixes Using Indirect Tension Test", NUST. Islamabad. Pakistan (2010).
- Pavement Interactive .Org , Volumetric Comparison Of Marshall And Superpave Mix Design
- AASHTO Designation (T209-05) Standard Method Of Test For "Theoretical Maximum Specific Gravity And Density Of Hot Mix Asphalt Paving Mixtures"
- AASHTO Designation (T166-07) Standard Method Of Test For "Bulk Specific Gravity Of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface Dry Specimens"
- ASTM D3515 (2001). "Standard Specification for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures." ASTM International, West Conshohocken, PA.