COMPARISON OF VOLUMETRIC PROPERTIES OF MARSHALL AND SUPERPAVE FOR NHA MIXES

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TO

OUR FAMILIES, TEACHERS AND COLLEAGUES

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ABSTRACT

Roads are the main mode of transportation in Pakistan. The aim of this research is the comparison of volumetric properties between Marshall and Superpave Mix design methods. Marshall Mix design method is in practice for many years. The new design method called the Superpave method has replaced the Marshall method for design of asphalt pavements in the USA. Roads in Pakistan are designed mostly on the basis of Marshall Mix design guidelines. The asphalt mixes made for the roads according to these specifications have failed to handle the traffic and environmental conditions in Pakistan. The impact compaction with Marshall Method does not allow mixture densification as it is commonly found in roads. The Marshall method doesn't stimulate the field compaction, while Superpave design stimulates the field method of compaction. The Ideal condition should be if the mixtures to be tested are prepared and compacted as close to the field condition as possible, so that they can be representative of the mixtures to be produced and put in the field. Margalla hills aggregate was used procured from Taxilla. Binder was procured from Attock refinery. NHA gradation class A was used for the preparation of samples for both Marshall and Superpave Mix design method. Total of 15 samples were prepared for each grade (60/70 and 80/100) of binder using the Marshall method. The samples were prepared at (3, 3.5, 4, 4.5 and 5) percent binder content. Approximately 1200 grams samples were prepared for Marshall Method. The Optimum binder content was estimated for each grade of binder. The volumetric properties were estimated for each binder content and also at the optimum binder content. Similarly total of 9 samples were prepared for each grade of binder using the Superpave Method. Samples were prepared at (3.5,4 and 4.5) percent binder content. Volumetric properties were estimated for the Superpave method at all the binder contents and at the optimum binder content. The volumetric properties of Marshall and Superpave methods were compared graphically and statistically. The outcomes of the findings were.(a) Optimum binder content of the Superpave mix method is less than the Marshall mix method.(b) VMA calculated from the Superpave mix method is lower than that of Marshall Mix method at any binder content.

Chapter 1

1 INRODUCTION

1.1 General

The total population of Pakistan is almost 185 million and is the 6th most populous country of the world with the total area of 796096 km^2.Roads are the major mode of transportation in Pakistan handling 91% of passenger and 96% of freight traffic. The total road network of Pakistan is 260,000 km which contributes 12% to GDP and consumes 35% of total energy. The total network of Pakistan comprising of 10,000Kms National Highways, 102,000Kms of Provincial Highways, 94,000Kms local Government Roads and 55,000Kms Municipal Roads.

Marshall Mix method has been using in the world for many years but due to the improvement in technology and needs of people there are many heavy vehicles and machineries which creates problems for the road designed with the Marshall mix design method .Marshall mix design is not capable of achieving multi purposes of the highways and roads and even it is difficult to know about the Mix voids needed for the future traffics. It also doesn’t examine shear strength, impact of compactness and the loads that are perpendicular to compact axis.

Due to these reasons the Strategic Highway Research Program (SHRP) has come up with the idea of Superior Performance asphalt Pavements (SUPERPAVE) mix design technique.The Superpave techniques were introduced in the USA and that was proved with great achievement. Superpave mix design unlike marshal mix method stimulates the field compaction method and field condition. Superpave technology is the substitute of the Marshall method, which is being used in construction of road for almost fifty years.

1.2 Historical Background

The Engineer Bruce Marshall, with the collaboration of Mississippi State Highway Department, comes up with the idea of Marshall Mix Design Method. The method we are using today of Marshall Mix design technique came from the research of US Corps of Engineer in 1940. **(MS-2 Manual, 1996)**

The Marshall mix design technique is being used for almost 50 years , most of the experts of the transportation engineering believe that the impact compaction with the Marshall method does not allow mixture densification as it is commonly found in roads. Moreover, Marshall Stability does not accurately give the results for the shear strength of HMA. These two conditions make it problematic to insure the rutting resistance of the designed mixture.

With the passage of time and increase in traffic volume and the growing technology and heavier vehicles and loads the Strategic Highway Research Program (SHRP) in 1987 started their research. From 1987 through 1993, SHRP did many experiments and developed many prototypes of the Superpave method for high performance based HMA design. New design methods have replaced the Marshall and Hveem design techniques in the United States and Canada. **(SP-2 Manual, 2001)**

The sole cause of beginning Superpave was to upgrade the field capacity of asphalt pavements. There are many reasons of breakdown of an asphalt pavement the most common of these failures are fatigue cracking, rutting, thermal cracking, loss of friction, moisture susceptibility and low temperature cracking. But rutting and low temperature cracking is the distresses that commonly become the reason for the rapid failure.

Heavier vehicular weights continuously and constantly ruining asphalt pavement create rutting. This usually happens in the summers season's .Low temperature cracking happens at sub-freezing temperatures whenever the asphalt viscosity is more. For a pavement to restrain rutting and low-temperature cracking, it should be good under extreme conditions of environment.

1.3 Problem Statement

Roads in Pakistan are accomplishing badly with pavement and expected life is lesser. The heavier vehicular loads of commercial vehicles, the overloading of heavy vehicles and remarkable difference in day to day and seasonal temperature and extensive rainfall seasons of the pavement of Pakistan have been the reasons for early distress like rutting, fatigue and thermal cracking.

The roads of Pakistan are generally based on Marshall Mix Design guidelines **(ASTM D 1559)**. The asphalt mixes made for the roads according to these specifications have failed to handle the traffic and environmental conditions in Pakistan. Premature rutting is the main cause of failure of asphaltic materials in Pakistan **(M.Irfan et .al, 2013)**. This becomes reason for the huge loss of national investments on maintenance and rehabilitation of highways, to the tax payer, and road user (accidents and vehicle operating costs). The volumetric properties of the mix samples play a great role in the proper design of the pavements. To increase the durability, decrease cracking and permeability of the road the voids in the pavement must be present upto some limit. So a design optimum moisture content is needed for the proper design of the pavement.

1.4 Objective

The aim of this study is to investigate the following properties for the asphalt pavements.

- To Compare between Superpave and Marshal mix design procedures in terms of volumetric properties
- This research was focused to compare the old Marshall method and the state of the art new method to discontinue the premature failures of HMA pavements in the country.

1.5 Scope:

To accomplish the above mentioned research objectives, a research plan was prepared and the following research tasks were outlined:

- Literature review of the previous research finding comparing the volumetric properties of Marshal and the Super-pave Mix design.
- Laboratory characterization of materials including tests on the bitumen and the aggregates.
- Preparation of specimens using NHA class A gradation and two (60/70 and 80/100) penetration grade bitumen. Samples are prepared using both Marshal and Gyratory Compaction Method.
- Calculation and analysis of the volumetric properties of Marshal and Super-pave Mix Design Method.
- Comparison analysis of the volumetric properties of Marshal and Super-pave Mix Design Method.

1.6 ORGANIZATION OF THE THESIS

This research is organized into five chapters

- Chapter 1 includes a brief introduction and historical background of the Marshal and Superpave Mix Design, the problem statement, objectives and the scope of the research.

- Chapter 2 includes a literature review on findings of the previous studies related to the Marshal and Superpave Mix Design, discussion of the volumetric properties of the both procedures.
- Chapter 3 explains the selection of materials used in this research, the bituminous mix preparation procedures and the methodology of the tests performed on the samples.
- Chapter 4 presents the test results, their statistical analysis and the comparison of the result of the Marshal and Superpave Mix Design.
- Chapter 5 is concerned with the conclusions and future recommendations. Conclusions and recommendations are drawn from research findings.

Chapter 2

2 LITERATURE REVIEW

2.1 Introduction:

Transportation plays a vital role in the development of a country. All the develop countries have good transportation system. Road is the first and most important mode of transportation. For the first time Bitumen's road was paved in 600's B.C. in Babylon. In 1873 the first bituminous Hot Mix Asphalt (HMA) pavement was built in Washington D.C, USA **(wrbailey.com)**. From 1940 to 1990 the Marshall and Hveem methods were extensively used for construction of the pavement in the USA and other parts of the world. According to a survey in 1984, about 75% of the State Highway Departments in the United States used the Marshall method with some variation while the remaining 25% used Hveem method with some addition. **(John P. Zaniewski et.al, 2003)**. While in 1995, the Super-pave procedure has been adopted in some states of the United States. After 5 year in 2000 survey shows that Super-pave mix design has been implemented in almost every state in the USA.

In this chapter the Marshall Mix Design and Superpave Mix design and their volumetric comparison in the recent past is being discuss.

2.2 Objective of the Mix Designs:

Various types of mix designs are used for construction of the pavement. Each one of the mix design has the aim to achieve certain properties these are:

- Durability: the mix should contain sufficient asphalt cement to ensure an adequate film thickness around the aggregate particles. The compacted mix should not have very high air voids, which accelerates the aging process.
- Workability: the mix must be capable of being placed and compacted with reasonable effort.
- Resistance to permanent deformation: It should not be displaced when subjected to traffic loads.
- Fatigue resistance: It should not crack when subjected to repeated loads.
- Skid resistance.
- Resistance to moisture-induced damage.
- Resistance to low temperature cracking: This mix property is important in cold regions.

- Low noise and good drainage properties: it should have low noise and good drainage properties if the mix is to be used for the surface (wearing) layer of the pavement structure.

The mix designs which are commonly practice in the world are:

1 Marshall
2 Hveem
3 Superpave

The mix design procedure usually involves selecting the aggregates, asphalt and to be used, testing the asphalt mixtures at different proportions of the ingredients, and choosing the optimum mix design which would give the best anticipated performance in service. The Ideal condition should be if the mixtures to be tested are prepared and compacted to as close to the field condition as possible, so that they can be representative of the mixtures to be produced and put in the field. The properties of the mixtures to be determined should be good indicators of performance of the mixtures in field, so that these properties can be used to determine the acceptability of the mixtures and to select the optimum mix design to be used.

2.3 General Design Procedure:

A design procedure for asphalt mixtures generally involves:

- Preparing and compacting the asphalt mixtures in the laboratory to simulate the field condition
- Characterizing the laboratory compacted specimens.
- Determining the optimum mix design based on the properties of the tested specimens and the set criteria for these properties.

Different design methods generally differ from one another by

- The equipment and method used to prepare and compact the asphalt mixtures,
- The properties of the compacted specimens to be measured.
- The criteria used for selecting acceptable and optimum mix designs.

In the above four methods Marshall Mix design is most extensively practiced all over the world. But now a days a new technique of superpave is introduced which is used in America and other developed countries. Our concerned is only about Marshall and Superpave mix designs.

2.4 Marshall Mix design:

The basic concept of the Marshall Mix design method was originally developed by Bruce Marshall of the Mississippi Highway Department around 1939 and then refined by the U.S. Army. The Marshall method, despite its shortcomings, is probably the most widely used mix design method in the world. It has probably become so widely used because. **(MS-2 manual 1996).**

- It was adopted by the U.S. military all over the world during and after world war II and
- It is simple, compact and inexpensive.

The Marshall method seeks to select the asphalt binder content at a desired density that satisfies minimum stability and range of flow values. It has two main steps:

- Determination of physical properties, size and gradation of aggregates.
- Selection of types of asphalt binder.

The Marshall Mix design procedure as recommended by the Asphalt Institute is described in detail in the Manual "Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types" by the Asphalt Institute [1997].

2.5 Superpave Mix Design:

It stands for Superior Performing Asphalt Pavements. 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**(SP-2 Manual 2001).** 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 Superpave 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.

It has three key components:

a) Performance based asphalt binder specification

b) Volumetric mix design and analysis

c) An improve method of compaction

a) Performance based asphalt binder specification:

Superpave incorporates a new binder specification which classifies 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 pavement design temperature and minimum pavement design temperature.

b) Volumetric mix design and analysis:

Volumetric properties are directly related to performance. It includes:

- Voids in the mineral aggregate VMA
- Voids filled with asphalt VFA
- Air voids.

The volumetric properties like voids or air voids form the bases for aggregate gradation and asphalt content. Super pave aggregate properties are:

- Coarse aggregate angularity
- Fine aggregate angularity
- Flat and elongated particles
- Clay content

Source properties of aggregate are also determined it include:

- toughness
- soundness
- deleterious material

Superpave mix design specifies aggregate gradation control points, through
which aggregate gradations must pass

C) An improve method of compaction:

Super pave mix design uses an improve method of laboratory compaction that reflexes field condition called gyratory compaction. It provides the field condition to the specimen. The compaction data are analysed by calculating the estimated bulk specific gravity, corrected bulk specific gravity, and corrected percentage of maximum theoretical specific gravity (%G_{mm}). From these data points, three graphs are generated: air voids, voids in mineral aggregate (VMA), and voids filled with asphalt (VFA) versus asphalt content.

2.6 Volumetric properties of Marshall Mix and super-pave mix design:

Different volumetric properties of Marshall Mix and superpave mix design are:

i. **Maximum specific gravity (G_{mm}):** Maximum specific gravity is the Specific gravity of an asphalt mixture when there is no air voids. It is also known as theoretical maximum specific gravity. Theoretically, if all the air voids are removed from a sample, the combined specific gravity of the remaining aggregate and asphalt binder would be the theoretical maximum specific gravity. It is a very important parameter because it is used to calculate air voids in a compacted sample. Formula for G_{mm} is : **(AASHTO Designation: T209-05):**

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

A = sample mass in air (g)

D = mass of flask filled with water (g)

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

ii. **Bulk specific gravity (G_{mb}):** The ratio of HMA sample weight to the weight of an equal volume of water is known as bulk specific gravity of the specimen. It is calculated by following formula**: (AASHTO Designation: T166-07):**

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

A= mass of sample in air (g)

B= mass of SSD sample in air (g)

C= mass of sample in water (g)

iii. Air voids:

The small pockets of air that occur between the coated aggregate particles in the final compacted mix are known as air voids. A specific percentage of air voids is necessary in all mixes to allow for some additional compaction of pavement under heavy load of the traffic and to provide spaces into which small amounts of asphalt can flow during this compaction. The allowable percentage of air voids for surface course mixes is between 2.0 to 4.0% of the total mix. The durability of a flexible pavement depends upon the air void content. When the air void content is too high then it provides passageways through the mix for the entrance of damaging air and water. And when the air void content is too low the mixture will be less permeable, also it can lead to flushing, a condition in which excess asphalt squeezes out of the mix to the surface. Density also directly depends on air voids. Higher the air void content lower will be the density and vice versa. It can be found by following formula:

$$\text{Air voids } (V_a) = \frac{Gmm - Gmb}{Gmm} \times 100$$

iv. Percent Voids Filled with Asphalt (VFA):

The percentage of voids in the compacted aggregate mass that are filled with asphalt content is known as VFA. VFA is a very important design property, it affect the durability of the pavement. Most DOT specifications require 70-80 during the design phase. The VFA requirement helps to avoid those mixes that are susceptible to rutting under heavy traffic loading. It is calculated by following formula:

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

v. Voids in the Mineral Aggregate (VMA):

The air void spaces that exist between the aggregate particles in a compacted paving mixture, including spaces filled with asphalt VMA. It is an aggregate property. It represents the space that is available to accommodate the binder and the volume of air voids necessary in the mixture. The more VMA in the dry aggregate, the more space is available for binder to be filled up. It also affect the durability of the pavement, if the voids in mineral aggregate are low then asphalt will not properly adhere and durability become low. Optimum VMA is needed to ensure that adequate amount of asphalt could be added to the mixture without overfilling the voids.

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

2.7 Recent Researches about the topic:

Israa F. Jasim et al. 2012 compared the traditional Marshall Design method and the Superpave system design method in the wearing course mixes in flexible pavements by evaluating the volumetric, mechanical properties and moisture susceptibility. He estimated asphalt content for the Superpave mix design which is found to be lower than that of Marshall Mix Design method which indicates that the Super-pave mix design is more economical. He determined the A.C at 4% air void which was 4.3%, VMA & VFA was 14% & 71.4% respectively, while G_{mm} (@N=9) was 83.55 and G_{mm} (@N=220) was 96.3.

Dr. Ibrahim Asi et al. Oct 2010 conducted a study to find out the adoptability of Superpave mixtures specifications to the Jordan climatic and traffic condition by using the specific materials. He carried out his study on local materials to design the asphalt mixtures using both Marshall and Superpave mixtures. He came to conclusion from his study that the Superpave design procedure required lower bitumen content as compare to that of Marshall Mix design procedure.

KIRAN KUMAR UPPU et al. 2008 performed study to investigate the moisture resistance of Superpave HMA mixtures with varying asphalt content also to investigate effects of voids in mineral aggregate and asphalt film thickness on the performance of the mixes. He conclude from his research that the amount of A.C in the mixture significantly affect the rutting and moisture resistance of HMA mixtures. Also he find out that For SR-9.5A & SR-12.5A mixtures, the number of wheel passes, creep slope, and stripping inflection point was higher at the dry side of OAC. At the other hand For SR-9.5A & SR-12.5A mixtures, the No. of wheel passes, creep slope, & stripping inflection point increased as A.C decreased.

Swami, Mehta and Bose et al. Sept 2004 analysed the design of A.C by Superpave and Marshall Method of mix design for Indian conditions. They studied the properties of Superpave mixes at different numbers of gyrations & different angles. They conclude from their study that Superpave mixes fulfilled all the criteria for easy and good construction at lesser asphalt content than the Marshall mixes (i-e 4.4% versus 5.3%). Also It was also found that Superpave mixes are least affected by water as compare to Marshall Mixes.

Vasavi Kannegantiet al. 2002 performed research work to compare the 19mm Superpave and Base II Marshall Design mixes in West Virginia (WV) to supplement information required for WVDOH to make a suitable decision regarding the implementation of Superpave for low volume roads. He concluded from his study that the statistical analysis did not provide enough evidence to say that there is a difference in the Superpave and Marshall Mix design methodologies. That is the mixes prepared under the Superpave method passed the Marshall criteria also the mixes prepared under the Marshall Mix method passed the Superpave criteria. These results indicate that contractors using Marshall Mix Method to design and construct pavements should not face unusual difficulties with Superpave mix pavements. He also find out that the asphalt contents of Superpave mix designs are higher than that of the Marshall mix design for the same traffic level.

Jian-Neng Wang & Tsair-Yi Luo et al.September 1999 evaluate the pavement performance using the super-pave system on Taiwan's freeway network. They compared Two Superpave mixtures and the Taiwan Freeway Mixture (TFM) on both volumetric and mechanical properties. Their results of Volumetric analyses of specimens showed that the Taiwan Free Way (TFM) mixture hardly meets the Superpave requirements. The TFM mix contains less than 1 percent air voids (0.6 percent) at the number of gyrations for initial compaction. This strongly suggests that the Taiwan Free Way mixture (TFM) might be highly prone to rutting. On the bases of mechanical property test for withstanding permanent deformation of the specimen, the ability of the Taiwan Free Way mixture (TFM) was found not as much as those of the Superpave mixes.

Khaled Ksaibati and Jason Stephen et al. July 1998 performed their research to compare the Superpave mix design to the Marshall Mix design on a typical aggregate source in Wyoming. They concentrated on the comparison of resistance to rutting and low temperature cracking of asphalt mixes prepared using the two design methods. Their results shows that the optimum asphalt content determined by the Marshall and the Superpave mix designs were similar. This shows that in some cases Marshall and Superpave produce nearly identical mix designs when the same materials are used and the aggregate gradations are similar in both designs. They also find out that the Superpave samples tested in the GLWT have been rutted slightly more than the Marshall samples. The Superpave mix samples tested in the TSRST fractured at a slightly higher pressure and lower temperature than the Marshall Mix samples.

James A. Musselman et al. 1996 presented Florida's early experience about the Superpave field. In his study, he reviewed major Superpave projects in different counties of Florida. From his research work he came to conclusion that the compaction of fine graded Marshall mixes is easier than that of the coarse graded Superpave mixes. He also found that coarse-graded Superpave mixes required a higher level of density to reduce the water permeability. This level equate to an in-place asphalt content of (6 - 7 percent). This was significantly lower than that required for existing Marshall Design mixes. Based on Musselman's study, FDOT (the Florida Department of Transportation) made several changes to the existing Superpave design mix specifications.

Habib et al. (1) performed study to analyse the volumetric properties of Superpave and Marshall Mix designs for low volume roads and paved shoulders. The project site he selected was Kansas Route 177 km in northeast Kansas. He selected three different locally available aggregates including crushed limestone, coarse and fine river sands. To design the aggregate structure in this research work three different aggregates were combined together for material selection. He conclude from his work that for design of low-volume roads the Super-pave mix resulted in lower estimated asphalt content compared to the Marshall method, and therefore, Superpave mixtures will be more economical than Marshall mixtures for these applications because of low asphalt content in it.

2.8 Chapter Summary

This chapter provided a brief history and description of currently used Marshall Mix Design and Superpave Mix Design methods. It also provided the volumetric comparison of both Mix Design methods by using different types of aggregate and different environmental condition. Different research work in the recent past has been discussed. The State highway agencies have some discretion in the specific details of how both the methods are implemented.

Chapter 3

3 RESEARCH METHADOLGY

3.1 Introduction

In chapter 3, methods and techniques are discussed which are used in this research project in order to attain the desired goals discussed in chapter 1. Materials used in this project are characterized, tests on individual materials and there results are presented. Bitumen Mix preparation techniques used in lab for both Marshall and Superpave mix design are described in detail. Method used for volumetric and strength tests performed on these samples are described.

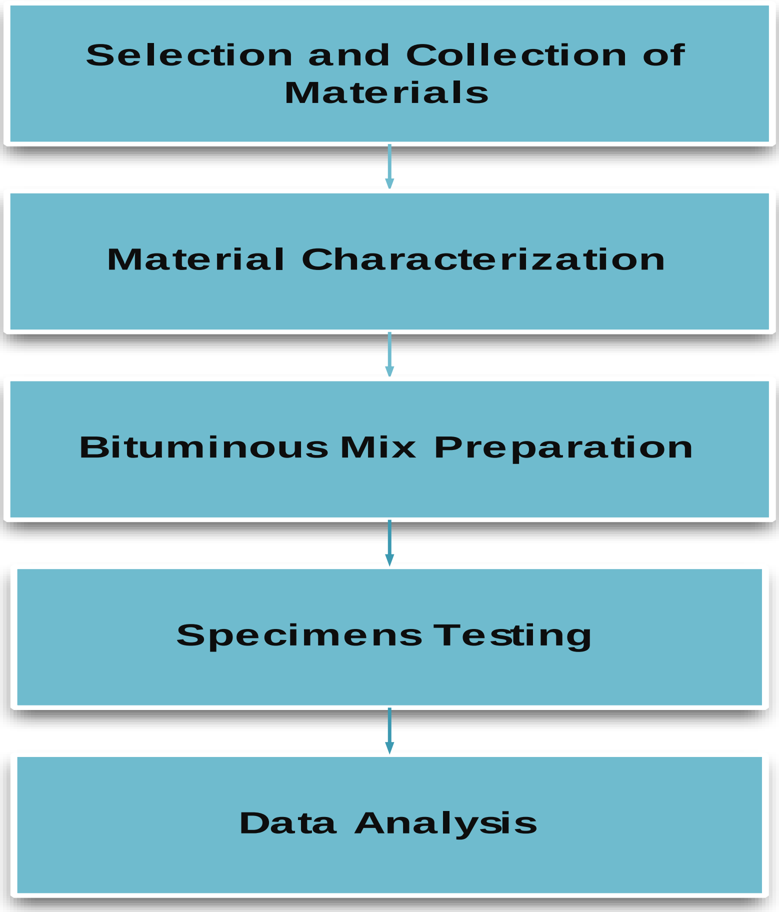

Figure 3-1 Steps of Research Methodology

3.2 Selection of Aggregates

Coarse aggregate, fine aggregate and bitumen used in this research were selected according to the standard specification for hot mixed, hot laid bituminous paving mixtures **(ASTM D3515)**.

3.2.1 Coarse and Fine Material

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). Both coarse and fine aggregate used in our project are from Margalla Hills of Islamabad, Pakistan.

The mix design manual for preparation of bituminous paving mixes **(MS-2 Asphalt Institute)**, recommends that for surface courses, the maximum aggregate size must be 3/8-inch to 3/4-inch. Therefore; in this research, for surface course mixtures the maximum aggregate size of 3/4 -inch (19.0mm) or nominal maximum size of 1/2-inch (12.5mm) was selected.

NHA gradation A is used in this project. Material was sieved according to NHA gradation A in laboratory using standard sieve set. Sieving results are tabulated below:

Figure 3-2 Aggregate sample

Table 3-1 NHA Gradation Class A

Sieve size	%Passing Cumulative	%Passing Cumulative Average	%Retained Cumulative	%Retained Each sieve
1	100	100	0	0
3/4	90-100	95	5	5
3/8	56-70	63	37	32
#4	35-50	42.5	57.5	20.5
#8	23-35	29	71	13.5
#16	5-12	8.5	91.5	20.5
#200	2-8	5	95	3.5
Pan				5

3.2.2 Bitumen

60/70 and 80/100 penetration grade bitumen are used in this project. Both these grades are commonly used in Pakistan. Bitumen is procured from Attock Oil Refinery which is one of the finest oil refinery located in Rawalpindi Pakistan. Bitumen contents of 3%, 3.5%, 4%, 4.5%, 5% for each penetration grade is used. Three specimens of each bitumen content and for both Marshall and Super pave Hot Mix Design are made. So total of 60 specimens are made in this project.

3.3 Material Characterization

For the preparation of bituminous paving mixes, it is necessary to check the acceptability of both aggregates and bitumen. In the light of ASTM standards and specifications for material characterization, tests were performed on aggregate and bitumen. Table 3.2 and Table 3.3 show the test performed on the aggregates and bitumen respectively.

3.3.1 Aggregates Evaluation

In order to prepare a mix by using Marshall Apparatus, 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. Table 2.1 shows the required tests for aggregates. Tests and Specifications for Aggregates

Table 3-2 Tests and Specifications for Aggregates

Test type	Designation		Specifications
Shape test	Flakiness Index Elongation Index	BS 812	<35 % <35 %
Impact test	BS 812		<25 %
Los Angles abrasion test	ASTM D535		<40%
Specific gravity	Coarse aggregate	ASTM C 127	
	Fine aggregate	ASTM C 127	

3.3.2 Bitumen Evaluation

Like aggregates, for preparation of bituminous paving mixes, it is necessary to determine the bitumen acceptability. Different tests must be conducted on the bitumen before bituminous mixture preparation.

Table 3-3 Tests and Specifications for Bitumen

Test type	Designation	Specifications
Penetration @ 25 ° C, mm	ASTM D 5	60-70
Flash and fire point, *°C*	ASTM D 92	232
Specific gravity	ASTM D 70	1.01 – 1.06
Ductility Test	ASTM D113	>100

3.4 Bitumen Mix Preparation

Bitumen mix preparation is important step and much focus has been given on it in this research project. Two different standard techniques are used to make different bitumen mix specimens. Firstly we prepared bitumen mix specimens by using standard procedure and apparatus of Marshall Mix (ASTM D6926). Secondly, super pave mix design standard procedure and apparatus used for preparation of bituminous specimens. Procedure for each method is discussed later in this chapter. These specimens are later gone through number of tests to find volumetric properties.

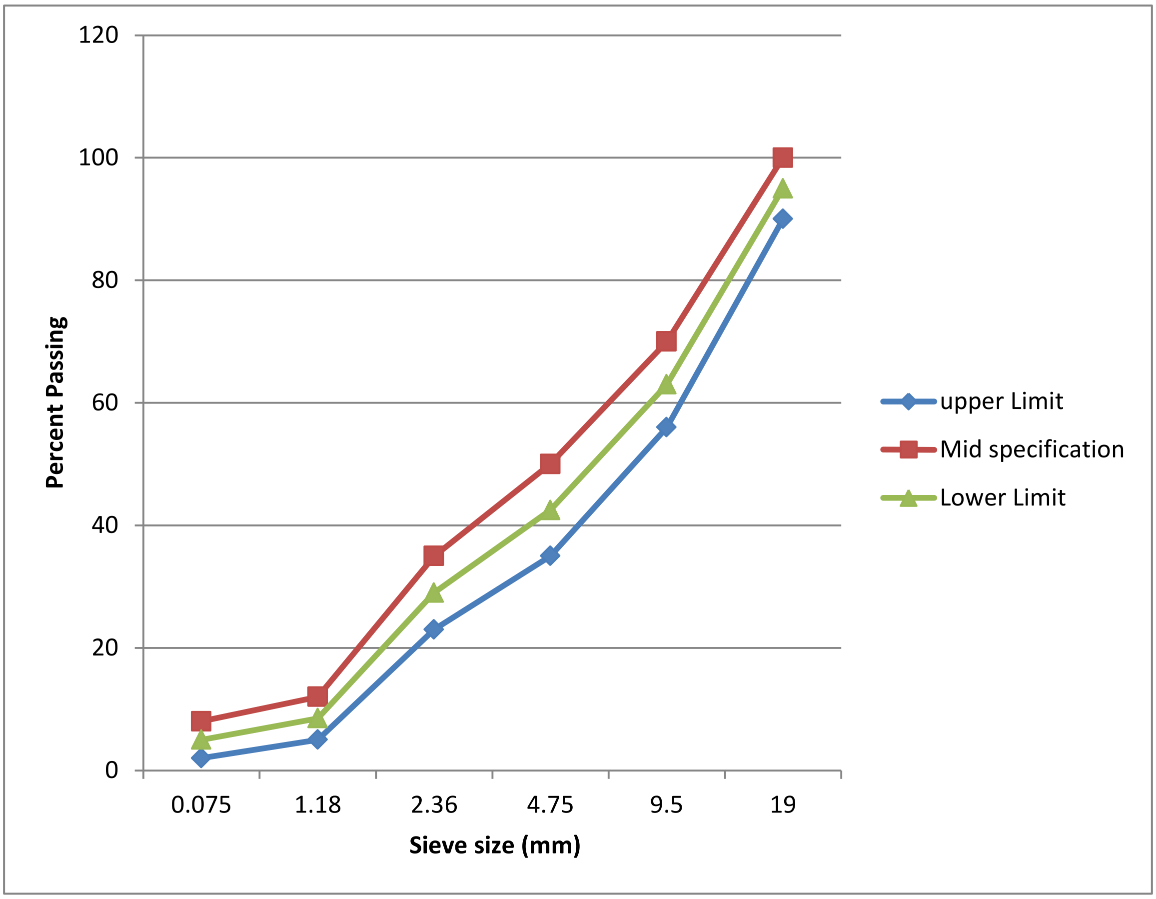

Figure 3-3 Gradation of Aggregate for Bitumen Mix

3.5 Marshall Mix technique

Aggregates were sampled according to NHA gradation A. The Marshall samples of approximately 1200 gm were prepared.

3.5.1 Preparation of Aggregate and Bitumen for mixing

For preparation of Marshall Mix aggregate samples were kept in the oven at a temperature of 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 flow. 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, mould cylinder, and collar extension as shown in Figure 3.4. The mold cylinder has an inside diameter of 4-inch and height of approximately 3-inch.

Figure 3-4 Digital Temperature gun

3.5.2 Mixing of Aggregate and Bitumen

Aggregate and bitumen were mixed in the mechanical mixing apparatus at a temperature of (165-170) °C which corresponds to the temperature during the manufacturing of paving mixes in Pakistan (NHA Specifications). Mixing machine is shown in the Figure 3.5. 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.

3.5.3 Compaction of specimen

The mold and collar were assembled on the base plate and then a paper disk was placed in the bottom of the mold. The approximate 1200 gm mix was added to the mold. The mold assembly was positioned on the mold holder of the triple Marshall Mix compaction 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 paper disk was placed on its top. A 22.5-lb rammer having drop of 18 inches was used (Figure 3.6).

Figure 3-5 Mixer

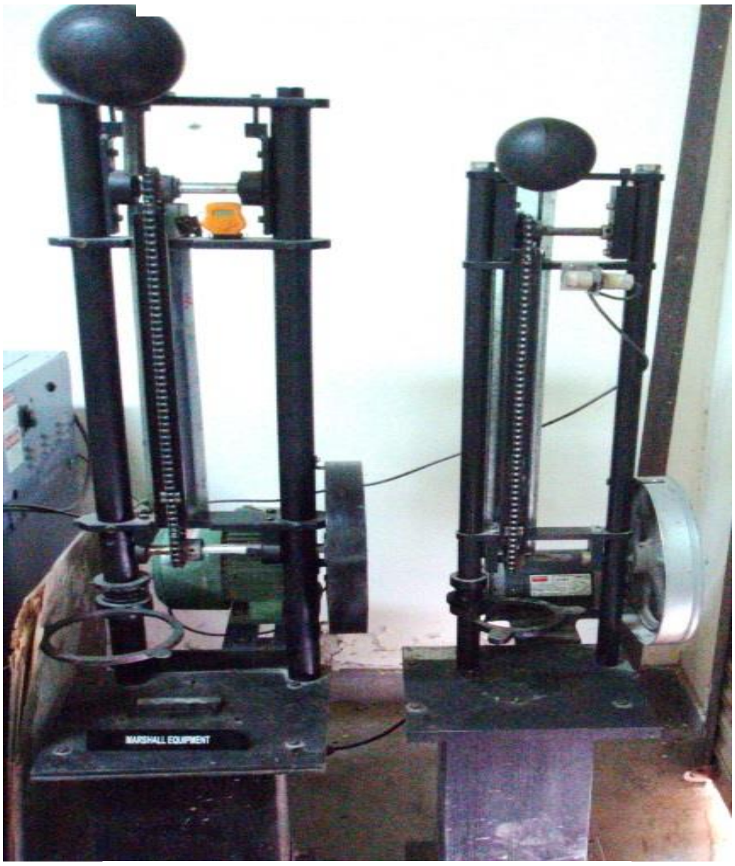

Figure 3-6 Automatic compactors

The rammer was positioned and placed on the top of the mix and 75 blows were provided with the rammer having a free fall of 18”. The base plate and collar were removed and mold was reassembled with the base plate. The 75 blows of 18” free fall were provided to the reverse side. The compaction temperature was kept in range of 135- 155°C.

3.5.4 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.

Figure 3-7 extrusion jack

3.6 Testing on Marshall Mix Sample:

Three tests were performed on Marshall Mix sample.

3.6.1 BULK SPECIFIC GRAVITY OF COMPACTED HOT MIX ASPHALT:

This testing was carried out according to AASHTO T166 and ASTM D1188 or D2726 standards. To perform this test for bulk specific gravity of compacted hot mix asphalt, the specimen was left to be cooled up to 25^0C 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

Figure 3-8 Marshall Samples

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.

<u>Formula</u>:

$$Gmb = \frac{A}{B-C}$$

Where:

A = Mass of dry specimen in air

B = Mass of SSD specimen in air

C = Mass of specimen in water

3.6.2 The Marshall Stability and Flow test:

Marshall Stability of a test specimen is the maximum load required to produce failure when the specimen is preheated to a prescribed temperature placed in a special test head and the load is applied at a constant strain of 50.8 mm/minute (2-inches/minute). The Marshall Stability and flow test provides the performance prediction measure for the Marshall Mix design method.

To perform Marshall Stability and Flow test, the guide rods and the inside surfaces of the test heads were thoroughly cleaned prior to making the test, and the guide rods were lubricated so that the upper test head slide freely over them. Specimens prepared by Marshall mix method were brought to the specified temperature by Immersing in a water bath for 30 minutes. The bath or oven temperature was maintained at 60 ± 1°C for asphalt cement specimens.

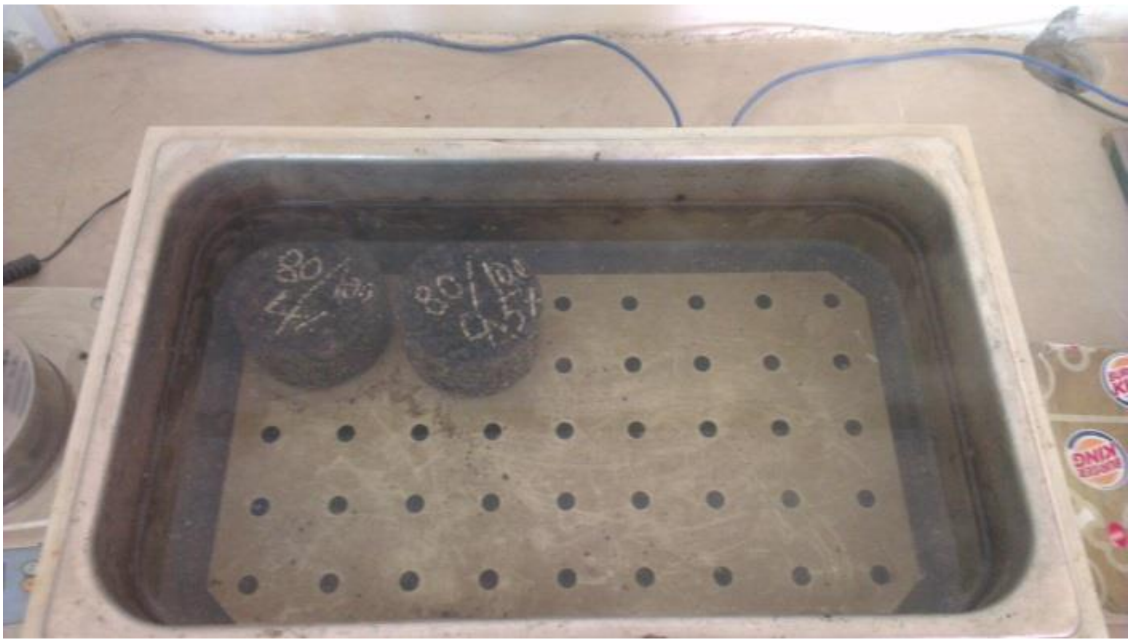

Figure 3-9 Samples in water bath

The specimen was removed from the water bath and placed in the lower segment at the breaking head. 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 to the specimen by means of the constant rate of movement of the testing machine head at speed of 50.8 mm/minute until the maximum load was reached and the load decreased as indicated by the dial.

The maximum load noted on the testing machine 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 micrometre dial for flow measurement.

It was made sure that the elapsed time for the test from removal of the test specimen from the water bath to the maximum load determinations did not exceed 30 seconds.

Figure 3-10 Marshall Apparatus

3.6.3 Determination of Theoretical Maximum Specific Gravity of Mixtures with Different Asphalt Contents (G_{mm})

The specific gravity excluding air voids is known as Theoretical Maximum Specific Gravity (G_{mm}). Theoretically, if all the air voids were eliminated from an HMA sample, the combined specific gravity of the remaining aggregate and asphalt binder would be the theoretical maximum specific gravity. Theoretical maximum specific gravity is used to calculate percent air voids in compacted HMA.

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 not to fracture aggregate.

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 of 27.75 mm Hg (3.7 kPa) to the Pycnometre 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.

Figure 3-11 vacuum container

Formula:

$$Gmm = \frac{A}{A+D-E}$$

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).

3.7 Super pave Mix Technique

It stands for Superior Performing Asphalt Pavements. 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.

It has three key components:

a) Performance based asphalt binder specification

b) Volumetric mix design and analysis

c) An improve method of compaction

3.7.1 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 pavement design temperature and minimum pavement 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 6000 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 170^{o}C. All the implements were also places in oven at the above mentioned temperature. Asphalt was also placed in oven.

3.7.2 Mixing and compaction Procedure performed

- Hot mixing bowl was placed on balance and zero the balance.
- Bowl was charged with heated aggregate and mixed.
- Crater was formed in the blended aggregate and desired weight of asphalt (like 240g 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 disk is placed on top of the base plate.
- Short termed aged mix is than placed in the mold. Paper disk is placed on top of the levelled mixture.
- Mold containing specimen was placed into the gyratory compactor. Mold been centered under the loading arm.
- There are three levels of compaction, namely N_{ini}, N_{des} and N_{max} gyrations. The specimen is compacted to N_{des} gyrations, while the height of specimen is recorded continuously.
- 1.25^{o} angle of gyration was set and gyratory compactor started. Speed is 30 gyrations per minute. Compaction proceeded until N_{des} = 125 had been completed.
- Constant pressure of 600Kpa was maintained by the ram loading system.

- After completion of N_{des} , compaction stopped and angle of gyration released. Loading arm raised.
- Mold was removed from the compactor and after 5 minute cooling period, specimen was extruded from the mold using automatic hydraulic jack.
- Paper disks are removed and specimen is allowed to cool undisturbed.

3.7.3 Data collection and volumetric properties

Computer gave height of specimen and density of specimen at every gyration. After compaction, the specimen bulk specific gravity and %G_{mm} 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:

$$Gmb = \frac{Wm/Vmx}{\gamma w}$$

Where:

Gmb = estimated bulk specific gravity of specimen during compaction

Wm = mass of specimen, grams

♈ w = density of water = 1g/cm^3

V_{mx} = volume of compaction mold

Surface irregularities cause the volume of the specimen to be slightly less than the volume of a smooth-sided cylinder. Therefore, the final estimated G_{mb} at N_{des} is different than the measured G_{mb}. Therefore, the estimated G_{mb} is corrected by a ratio of the measured to estimated bulk specific gravity:

$$C = \frac{Gmb\ (measured)}{Gmb\ (estimated)}$$

Where, C = correction factor

$$Gmb(corrected) = c \times Gmb(estimated)$$

Where, G_{mb} (corrected) = corrected bulk specific gravity of the specimen at any gyration

G_{mb} (estimated) = estimated bulk specific gravity at any gyration.

Percent air voids at N_{des} is determined from the following equation:

$$Va = 100 - \%Gmm\ @\ Ndes$$

Where,

V_a = air voids @ N_{des}, present of total volume

% G_{mm} @ N_{des} = maximum theoretical specific gravity @ N_{des}, percent

The percent voids in mineral aggregate are calculated using:

$$\%VMA = 100 - (\frac{\%Gmm\ @\ Ndes \times Gmm \times Ps}{Gsb})$$

The estimated asphalt content for: N_{des} is calculated using following equation:

$$Pb\ (estimated) = Pbi - (0.4 \times (4 - Va))$$

Where, P_b estimated = estimated asphalt content, percent by mass of mixture

P_{bi} = initial (trail) asphalt content, percent by mass mixture

V_a = percent air voids at N_{des} (trail)

For VMA:

$$\%VMA\ (estimated) = \%VMA\ (initial) + Cx(4 - Va)$$

Where C = constant = 0.1 if V_a is less than 4.0 percent

0.2 if V_a is greater than 4.0 percent

For VFA:

$$\%VFA = 100 \times \frac{(\%VMA\ estimated - 4)}{\%VMA\ estimated}$$

The effective asphalt binder content is calculated using the following equation:

$$Pbe = -(Ps \times Gb) \times \left(\frac{Gse - Gsb}{Gse \times Gsb}\right) + Pb\ estimated$$

Dust proportion is than calculated using the following equation:

$$DP = \frac{P0.075}{Pbe}$$

Where,

$P_{0.075}$ = aggregate content passing the 0.075-mm sieve, percent by mass of aggregate

P_{be} = effective asphalt content, percent by total mass of mixture

NOTE: An acceptable range of dust proportion ranges from 0.6 to 1.2.

3.7.4 Super-pave mix design requirements:

The asphalt mixture design must meet all the following requirements and our project does so:

- The asphalt mixture must have target air voids of 4% when compacted to N_{des} gyrations.
- The VMA of the compacted mixture at N_{des} gyrations must meet the minimum VMA requirements.
- The VFA (Voids Filled with Asphalt) of the compacted mixture at N_{des} gyrations must fall within the range.
- The dust-to-binder ratio, which is the ratio of the weight of the mineral filler to the weight of the binder, must be between 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 compacted to N_{max} must not exceed 98%.

Chapter 4

4 RESULTS AND ANALYSIS

4.1 General

The main objective of the research was to compare the volumetric properties of the Marshall Mix Design Method and the Superpave Mix Design Method for the wearing course. “NHA Class A “gradation with a maximum nominal size of 19mm was selected. The constituents of mix were coarse aggregates, fine aggregates, filler and asphalt. Two types of bitumen that is 60/70 penetration grade and 80/100 penetration grade were used. After a number of trials Optimum Bitumen Content was obtained for Marshall Mixes at standard (75) blows compaction effort of Marshall Hammer. The samples prepared by both types of bitumen were tested for flow and stability and also VA%, VMA% and VFA% were calculated. The obtained values were then compared with the standard specifications.

The samples of both types of bitumen were also prepared by the super-pave procedure. First of all the samples were prepared at optimum bitumen content obtained for the Marshall Mix Design Method. Then different trial mixes were prepared to obtain the optimum bitumen content for the super-pave method at 4% Air Voids. The volumetric properties of Marshall Method were then compared with the volumetric properties of the Super-pave Method.

4.2 Material Characterization

Various tests were performed in the laboratory to determine the physical properties of the aggregate collected from the Margalla Rock Quarry, Taxila and asphalt cement collected from Attock Oil Refinery, Rawalpindi. A summary of laboratory test results for the aggregates and asphalt cement is presented in Table 4.1 and Table 4.2 respectively. The results have been taken from the MS project (Experimental investigation of factors affecting the resilient modulus of bituminous paving mixes using indirect tension test by Afaq khatak 2010 – NUST – MS PhD – Tn – 09).

Table 4-1 Aggregate Tests Results

Test type	Designation		Test Results
Shape test	Flakiness Index	BS 812	14.62%
	Elongation Index		12.31%
Impact test	BS 812		16.68%
Los Angles abrasion test	ASTM C 535		31.15%
Specific gravity	Coarse aggregate	ASTM C 127	2.61
	Fine aggregate	ASTM C 127	2.69

Table 4-2 Bitumen Tests Results for Grade 60/70

Test type	Designation	Test Results
Penetration @ 25 $^\circ$ C, mm	ASTM D 5	62
Flash and fire point, $^\circ C$	ASTM D 92	243
Specific gravity	ASTM D 70	1.022
Ductility Test	ASTM D 113	103

4.3 Marshall Mix Design (Penetration Grade 60/70)

Using Marshall Mix Method, specimens were prepared at 3, 3.5, 4.0, 4.5 and 5.0% asphalt contents. Three specimens were prepared for each asphalt contents and compactive effort (standard) making a total of 15 specimens. The Marshall parameters determined for samples compacted at standard compaction (75 blows) are tabulated in Table 4.3 and graphically illustrated in Fig. 4.1.The optimum asphalt content determined at standard compaction (75 blows) is tabulated in Table 4.4.

Table 4-3 Volumetric Properties for 60/70 Bitumen content

% Asphalt	Gmb (avg)	Gmm	Va %	VMA %	VFA %	FLOW AVG (mm)	STABILITY (KN)
3	2.301	2.495	7.74	15.04	48.52	2.722	7.923
3.5	2.319	2.480	6.49	14.81	56.20	2.765	8.134
4	2.341	2.463	4.97	14.43	65.55	2.828	8.323
4.5	2.352	2.441	3.63	14.41	74.83	2.923	8.520
5	2.361	2.429	2.81	14.51	80.63	3.017	8.35

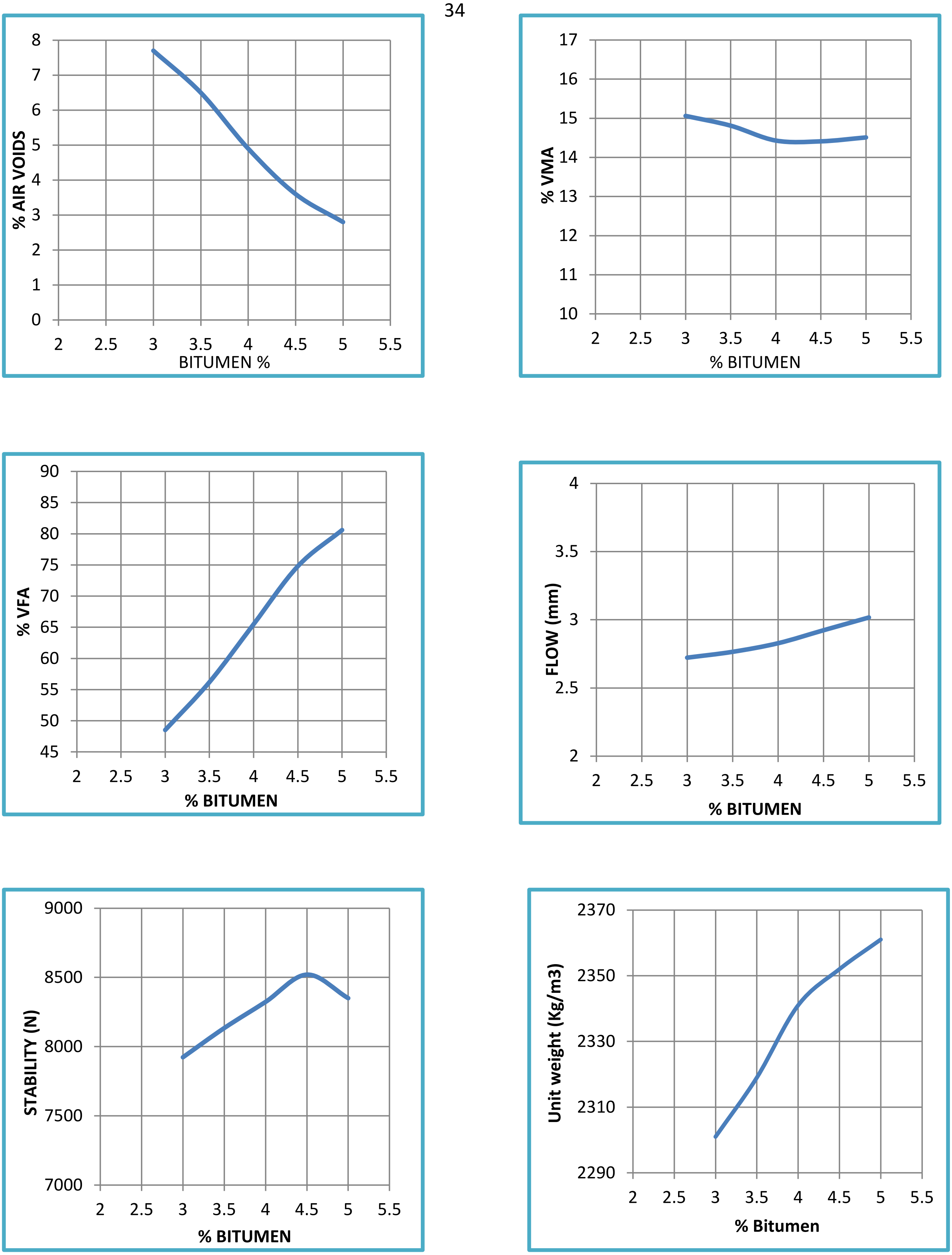

Figure 4-1 Marshall Design Mix Properties (ARL 60/70)

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

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 4-4 Optimum Bitumen Content Results for 60/70 Penetration Grade Bitumen

Optimum Bitumen Content Results for 60/70 Penetration Grade Bitumen	
Optimum Bitumen Content	4.35 %
Air Voids	4 %
VMA	14.4%
VFA	71.1 %
Flow	2.91 mm
Stability	8450 N

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 analysed.

Table 4-5 Criteria for Marshall Mix Volumetric Properties

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*

- % 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 se 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 mixture which is less durable. 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.
- VFB 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 VFB 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 performs 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 are 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 (Penetration Grade 80/100)

Using Marshall Mix Method, specimens were prepared at 3.5, 4.0, 4.5 and 5.0% 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 4-6 Volumetric of Grade 80/100 samples (MARSHALL METHOD)

Asphalt Content %	G_{mb} AVG	G_{mm}	V_a % %	VMA %	VFA % %	FLOW AVG(mm)	STABILITY(KN)
3.5	2.313	2.474	6.50	15.04	56.75	2.897	8.236
4	2.331	2.457	5.13	14.78	65.29	2.957	8.341
4.5	2.345	2.446	4.13	14.68	71.88	3.054	8.408
5	2.362	2.427	2.69	14.47	81.44	3.114	8.365

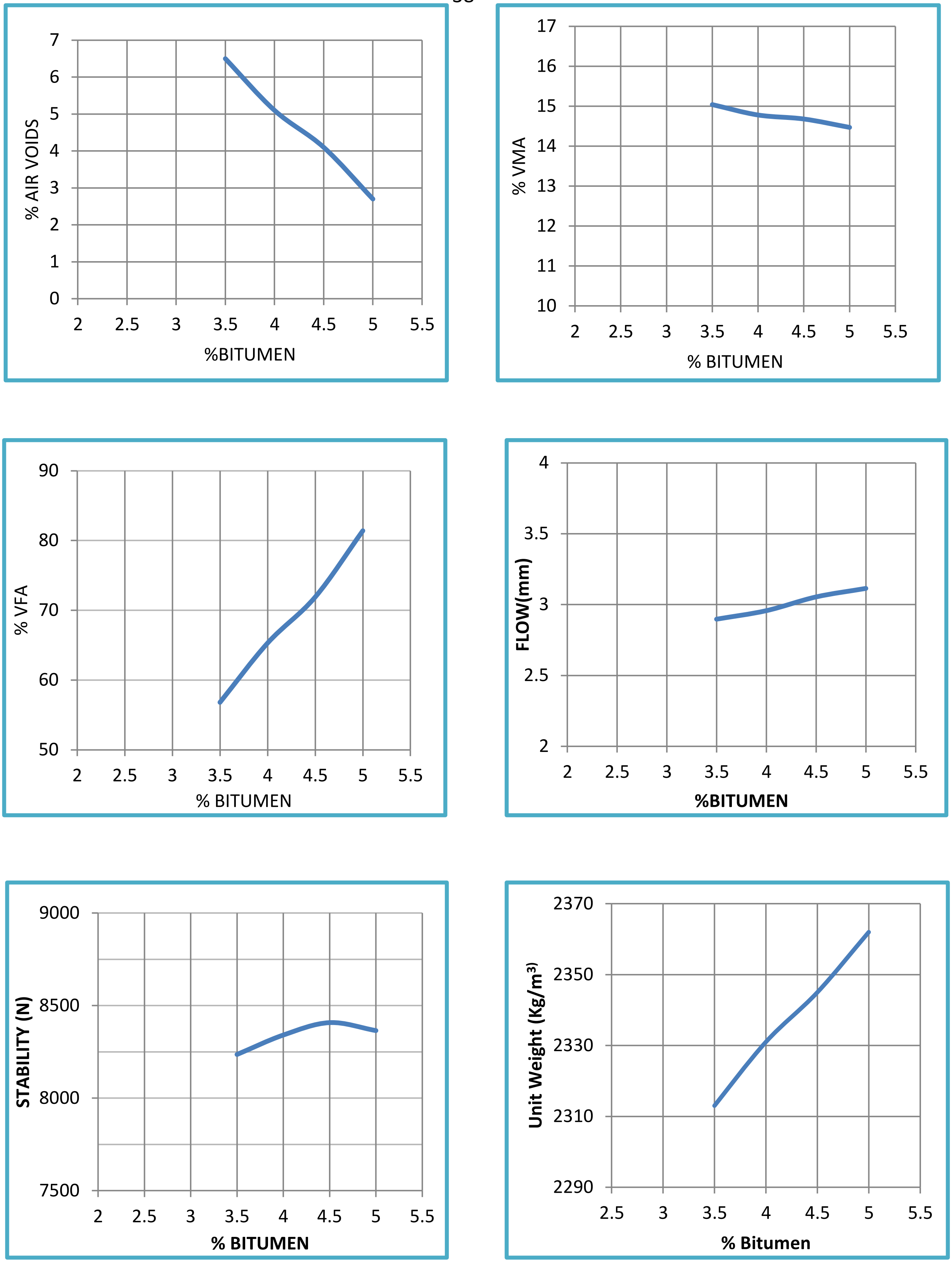

Figure 4-2 Marshall Design Mix Properties (ARL 80/100)

4.4.1 Volumetric Properties at Optimum Bitumen content (Penetration Grade 80/100)

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 4-7 Optimum Bitumen Content Results for 80/100 Penetration Grade Bitumen

Optimum Bitumen Content Results for 80/100 Penetration Grade Bitumen	
Optimium Bitumen Content	4.55 %
Air Voids	4 %
VMA	14.7%
VFA	72.8 %
Flow	3.05 mm
Stability	8410 N

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 se 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

mixture which is less durable. 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 Superpave Mix Design Method (ARL 60/70)

Using Superpave Mix Method, specimens were prepared at 4.35% asphalt content for ARL 60/70. 4.35% was the optimum asphalt content obtained by Marshall mix method. After calculating the % Air voids 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 no of gyrations (Ndes=125). The Superpave parameters determined for samples compacted at standard compaction (75 blows) are tabulated in Table 4.8 to 4.12 and graphically illustrated in Fig. 4.3.

Table 4-8 Superpave Volumetric properties (Grade 60/70)

Bitumen content %	VA %	VMA %	VFA %	Gmm @ N_{des} %	Dust Proportion
3.5	5.9	13.9	70.3	94.15	1.19
4	4	13.7	70.9	95.95	1.25
4.35	3.3	14	71.5	96.75	1.24

4.5.1 Volumetrics at Optimum Bitumen content (ARL 60/70)

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. Then the values were checked against the criteria given in the (SP-2) manual.

Table 4-9 Superpave Optimum Bitumen Content Results (60/70)

Optimum Bitumen Content Results for 60/70 Penetration Grade Bitumen	
Optimum Bitumen Content	4 %
Air Voids	4 %
VMA	13.7%
VFA	70.9 %

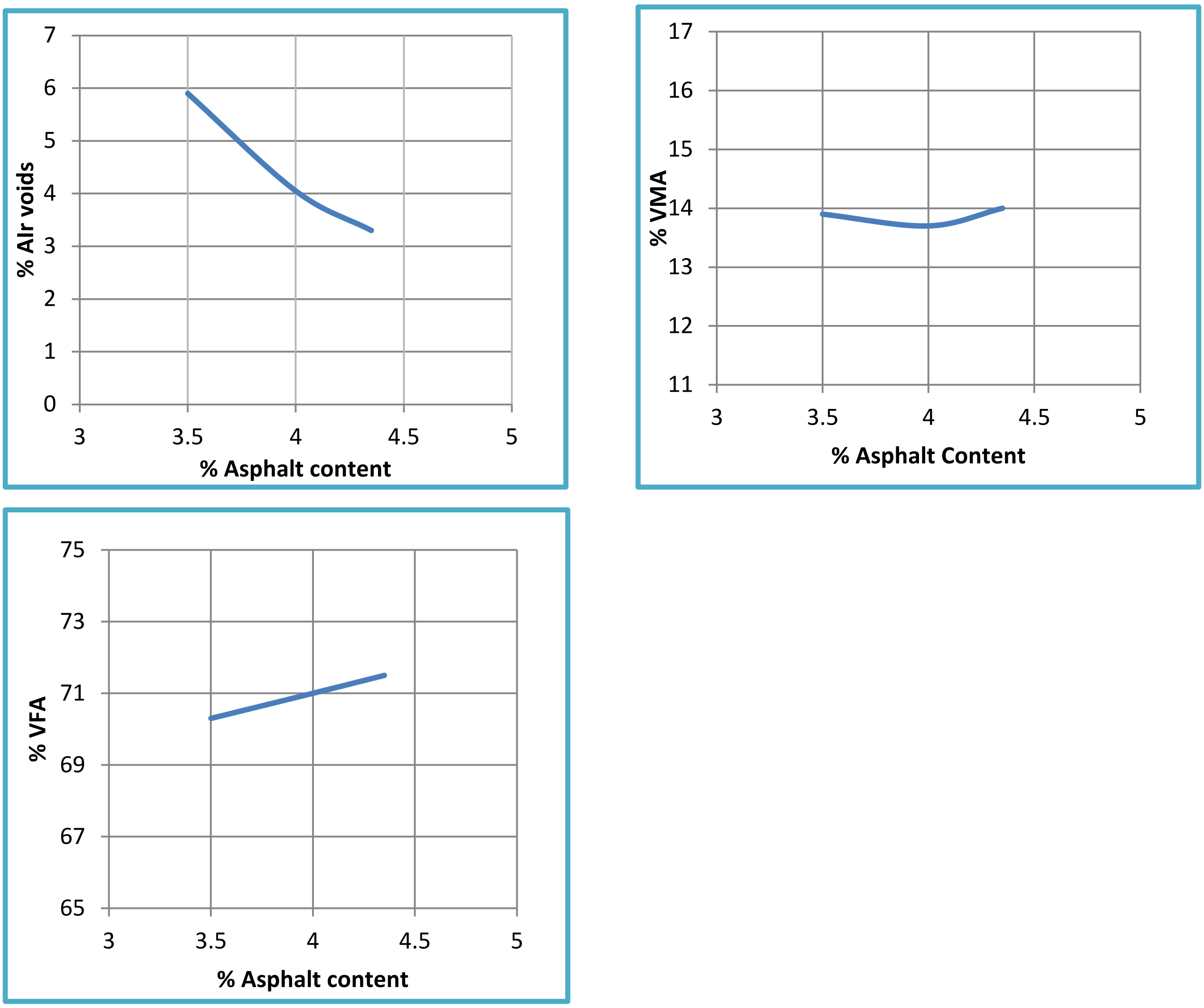

Figure 4-3 Superpave Design Mix Properties (ARL 60/70)

4.5.2 Analysis of Superpave Results (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 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.

Table 4-10 Criteria For Volumetric Properties Of Superpave

Design air voids				4.0%
Fines to effective asphalt ratio				0.6 - 1.2
Tensile strength ratio				80% minimum
VMA, %	Nominal maximum size			
37.5 mm	25 mm	19mm	12.5 mm	9.5 mm
11.0	12.0	13.0	14.0	15.0
Design ESALs (millions)	% Theoretical maximum specific gravity			Percent voids filled with asphalt (VFA)
	N_i	N_d	N_{max}	
<0.3	91.5	96.0	98.0	70-80
0.3 < 3	90.5	96.0	98.0	65-78
3 < 10	89.0	96.0	98.0	65-75
10 < 30	89.0	96.0	98.0	65-75
≥ 30	89.0	96.0	98.0	65-75

- % 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.
- The trend in the % VMA is that it first decreases with the increase of bitumen content, and once the bitumen content reaches a limit it then starts to increase. The values of VMA in the table 4-11 are within the range according to the criteria given in SP-2 manual so the design of VMA is acceptable.
- % G_{mm} values at Nini and Ndes are checked. All the values at Nini are witin the range ie<89%. So after checking the values of G_{mm} at Ndes, those values are selected which are equal or nearly equal to 96%.

- The VFA values increase with the increase of the bitumen content. The values for VFA are within the range for all the samples. Hence the values of VFA are acceptable in our results.
- The dust to binder ratio has the range of (0.6-1.2).In the results in table 4-11 all the values are above the range of 1.2. According to the Superpave manual (SP-2), if the gradation passes below the restricted zone as explained in SP-2, then the Dust to binder ratio can go upto 1.8. since our gradation passes below the restricted zone so the values of dust to binder ratio are above 1.2. Since the values of dust to binder ratio are also within the range, so our design is acceptable.

4.6 Superpave Mix Design Method (ARL 80/100)

Using Superpave Mix Method, specimens were prepared at 4.55% asphalt content for ARL 80/100. 4.55% was the optimum asphalt content obtained by Marshall Mix method After calculating the % Air voids at 4.55% asphalt content 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 content with the design no of gyrations (Ndes=125). The Superpave parameters determined for samples compacted at standard compaction (75 blows) are tabulated in Table 4.14 to 4.17 and graphically illustrated in Fig. 4.4. The optimum asphalt content determined at standard compaction (75 blows) is tabulated in Table 4.18.

Table 4-11 Superpave Volumetric Properties Results

Bitumen content %	VA %	VMA %	VFA %	Gmm @ Ndesign %	Dust Proportion
3.5	6.0	14.4	71	94.0	1.26
4	4.2	14	71.5	95.82	1.22
4.55	3.1	14.1	72	96.92	1.20

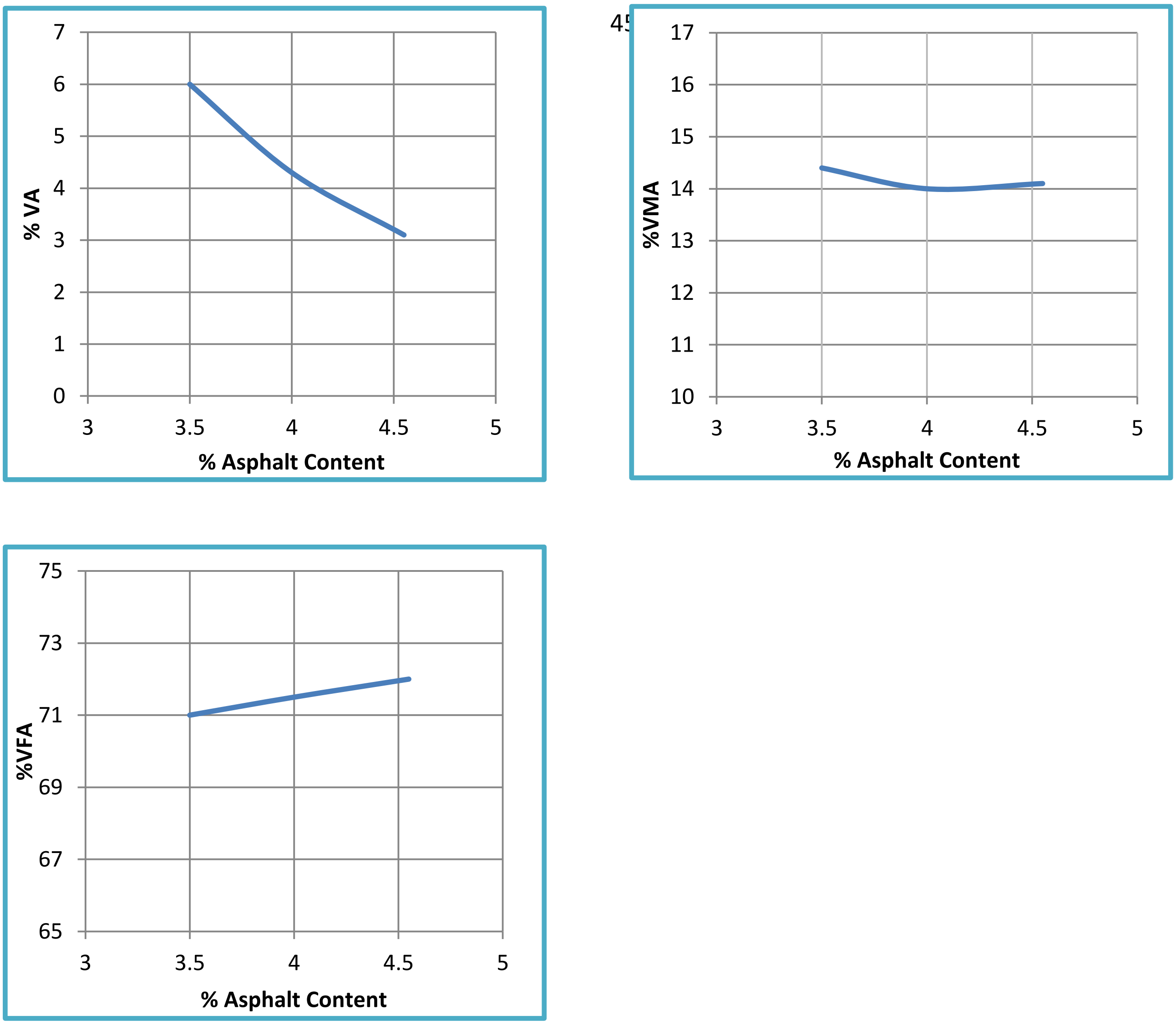

Figure 4-4 Superpave Design Mix Properties (80/100)

4.6.1 Volumetrics at Optimum Bitumen content (Penetration Grade 80/100)

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. Then the values were checked against the criteria given in the (SP-2) manual.

Table 4-12 Superpave Optimum Bitumen Content Results (80/100)

Optimum Bitumen Content Results for 80/100 Penetration Grade Bitumen	
Optimium Bitumen Content	4.1 %
Air Voids	4 %
VMA	14.0%
VFA	71.6%

4.6.2 Analysis of Superpave Results (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 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.
- The trend in the % VMA is that it first decreases with the increase of bitumen content, and once the bitumen content reaches a limit it then starts to increase. The values of VMA in the table 4-11 are within the range according to the criteria given in SP-2 manual so the design of VMA is acceptable.
- % G_{mm} values at Nini and Ndes are checked. All the values at Nini are witin the range ie<89%. So after checking the values of G_{mm} at Ndes, those values are selected which are equal or nearly equal to 96%.
- The VFA values increase with the increase of the bitumen content. The values for VFA are within the range for all the samples. Hence the values of VFA are acceptable in our results.

- The dust to binder ratio has the range of (0.6-1.2).In the results in table 4-11 all the values are above the range of 1.2. According to the Superpave manual (SP-2), if the gradation passes below the restricted zone as explained in SP-2, then the Dust to binder ratio can go upto 1.8. since our gradation passes below the restricted zone so the values of dust to binder ratio are above 1.2. Since the values of dust to binder ratio are also within the range, so our design is acceptable.

4.7 Comparison of the volumetric properties of Marshall and Superpave Mix Method:

The results of Marshall Mix design Method and the Superpave Mix design method have been compared in the tabular form and also graphically for both the (60/70 and 80/100) Penetration grade bitumen in the following section.

4.7.1 Comparison of Superpave and Marshall (60/70)

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 procedures in Fig 4.5.

Table 4-13 Comparison of Superpave and Marshall Mix (60/70)

Asphalt Content %	% VA		% VMA		%VFA	
	Marshall	Superpave	Marshall	Superpave	Marshall	Superpave
3.5	6.5	5.9	14.8	13.9	56.2	70.3
4	5	4	14.5	13.7	65.5	70.9
4.35	4	3.5	14.4	14.0	71.1	72

Table 4-14 Comparison of Superpave and Marshall Mix at OBC (60/70)

Volumetric Properties	Marshall Method	Superpave Method
%Optimum Asphalt Content	4.35	4
%Va	4	4
%VMA	14.4	13.72
%VFA	71.1	70.9

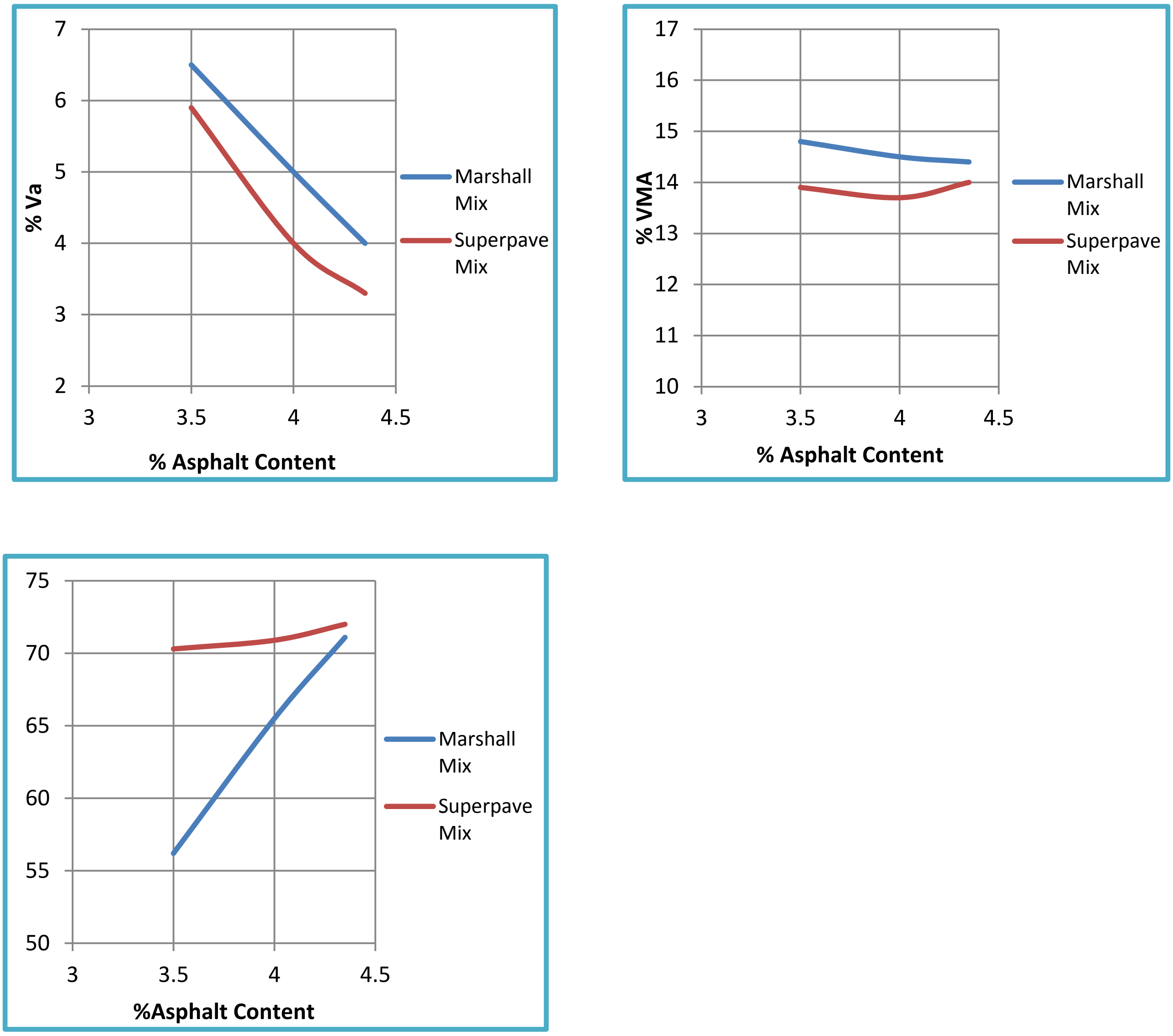

Figure 4-5 Graphical comparison of Superpave and Marshall Mix (60/70)

4.7.1.1 Analysis:

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

4.7.2 Comparison of Superpave and Marshall Mix (80/100)

The comparison of the volumetric properties is shown below in the table 4.21 and 4.20. The volumetric properties are compared at the optimum bitumen content. The results have also been shown graphically showing the variations of the two procedures in Fig 4.6.

Table 4-15 Comparison of Superpave and Marshall Mix (80/100)

Asphalt Content %	% VA		% VMA		%VFA	
	Marshall	Superpave	Marshall	Superpave	Marshall	Superpave
3.5	6.5	6	15	14.4	56.8	70.9
4	5.1	4.2	14.8	14.0	65.3	71.5
4.55	4	3.3	14.7	14.1	72.8	72

Table 4-16 Comparison of Superpave and Marshall Mix at OBC (80/100)

Volumetric Properties	Marshall Method	Superpave Method
%Optimum Asphalt Content	4.55	4.1
%Va	4	4
%VMA	14.7	14.0
%VFA	72.8	71.6

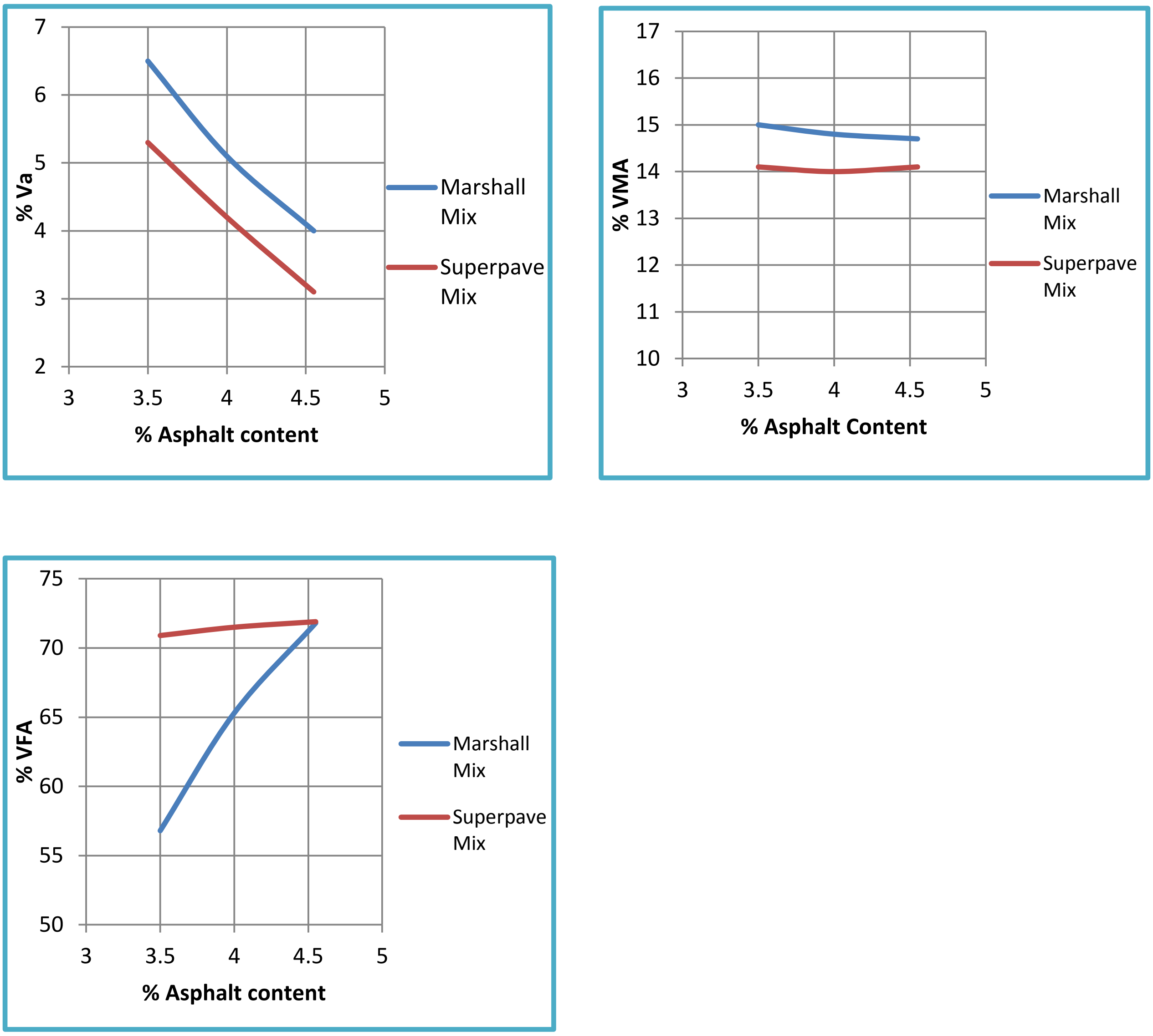

Figure 4 6 Graphical comparison of Superpave and Marshall Mix (80/100)

4.7.2.1 Analysis:

The results the penetration grade 60/70 bitumen are also compared in the same manner in the following section.

1. In the below 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.
2. VMA calculated from the Superpave mix method is lower than that of Marshall Mix method at any asphalt content. It means Superpave provides good compaction compared to the Marshall Mix procedure.
3. The values of VFA for Marshall mix method increase 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.
4. Optimum bitumen content of the Superpave mix method is less than the Marshall mix method.
5. 4% air voids for Superpave Method are obtained at less asphalt content compared to the Marshall Method.

Chapter 5

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 General

This research was primarily aimed at studying the Marshall Mix Design Method and the Superpave Mix Design Method and then to calculate and compare the volumetric properties of the two procedures at the optimum asphalt content. To simulate the heavy loading conditions in Pakistan, Marshall Tests were performed with standard procedure of sample preparation with 75 blows per side of the sample. Samples were prepared at five different asphalt contents for Marshall Mix to find the optimum asphalt content. Samples were prepared for superpave at optimum asphalt content of Marshall and at lower asphalt contents. The Superpave samples were prepared at design no of gyrations (N_{des}=125). Aggregate for wearing course were taken according to NHA (Class A) gradation having 19 mm nominal max size aggregate. Mixes were prepared by using 60/70 and 80/100 penetration grade asphalt.

5.2 Conclusions

Based on the results obtained from the lab testing and analysis of the experimental data following conclusions are drawn.

- 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 .2-.3 % higher than the optimum asphalt binder content of Superpave mix design.
- The Superpave system provides the estimation of dust to binder ratio while Marshall Method doesn’t provide any estimation about dust to binder ratio.
- The Superpave mix method investigated the compactability of the sample at early stages by estimating %G_{mm} at N_{ini} , while no early investigation about the compaction of sample was investigated by the Marshall mix method.
- 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.
- Superpave mixes fulfilled all the criteria for easy and construction at lower asphalt binder content compared to the Marshall mix method.

- Air voids (4%) criteria was achieved at lower asphalt content for Superpave mix compared to Marshall mix.
- VMA values for Superpave mix are lower than that of the Marshall mix design, these results could be attributed due to higher compactive effort of superpave gyratory compactor.

5.3 Future Work and Recommendations

The following can be the recommendations for the future work.

- NHA Gradation class B can be used to evaluate the results.
- Results can be evaluated for light and medium traffic. So it means a different compaction effort will be required for both the Marshall and the Superpave Mix design method.
- Performance testing can be performed on the same samples for the Superpave Mix design method.
- Modifiers can be added to the binder to check the change in behaviour of the binder.

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7 APPENDIX

7.1 Aggregate Testing:

1. Bulk Specific Gravity of Coarse Aggregates

Mass of oven-dry test sample in air = A = 1000gm

Mass of saturated-surface-dry test sample in air = B = 1039 gm
Mass of saturated test sample in water = C= 656 gm

Bulk specific gravity of coarse aggregates = $\frac{A}{B-C} = \frac{1000}{(1039-656)} = 2.61$

2. Bulk Specific Gravity of Fine Aggregates

Mass of dry aggregates = A = 1000 gm

Mass of pycnometer filled with water = B = 667 gm

Mass of aggregates + water + pycnometer = C = 795.25 gm

Bulk specific gravity of fine aggregates =

$$\left[\frac{A}{B+500-C}\right] = \left[\frac{1000}{667+500-795.25}\right] = 2.69$$

3. Bulk Specific Gravity of Aggregates

Percentage of coarse aggregate = P_1= 40 %

Percentage of fine aggregate = P_2= 60%

Specific gravity of coarse aggregate = G_{CA}=2.61

Specific gravity of coarse aggregate = G_{FA}=2.69

$$G_{sb} = \frac{100}{\frac{P_1}{G_{CA}} + \frac{P_2}{G_{FA}}} = \frac{100}{\frac{40}{2.61} + \frac{60}{2.69}} = 2.63$$

4. Los Angeles Abrasion Test

Initial mass of aggregate = 5000 gm

Final mass of aggregate (retained 1.75 mm sieve) = 3367 gm, 3518gm

- % loss = $\frac{A-B}{A} = \left(\frac{5000-3367}{5000}\right) \times 100 = 32.66\%$
- % loss = $\frac{A-B}{A} = \left(\frac{5000-3518}{5000}\right) \times 100 = 29.64\%$

Average % loss = $\frac{32.66+29.64}{2} = 31.15\%$

5. Impact Value Test

Weight of container = 712gm

Weight of aggregate= A = 315gm
Weight of aggregate after impact test = B = 51gm, 56gm

- Impact value = $\frac{B}{A} = \left(\frac{51}{315}\right) \times 100 = 16.19\%$
- Impact value = $\frac{B}{A} = \left(\frac{56}{315}\right) \times 100 = 17.17\%$

Average Impact value = $\frac{16.19+17.17}{2} = 16.68$

7.2 Marshall Mix design Results:

GRADE 60/70

% Asphalt	wt air gm	water gm	SSD WT gm	Gmb	gmb avg	Gmm	Va %	VMA %	VFA %
3	1163.4	671.1	1177.1	2.299	2.301	2.495	7.74	15.04	48.52
	1165.2	673.4	1179.2	2.304					
	1164.3	672.3	1178.2	2.301					
3.5	1168.2	679.5	1182.3	2.323	2.319	2.480	6.49	14.81	56.20
	1169.1	680.1	1185.2	2.315					
	1168.65	679.8	1183.75	2.319					
4	1171.8	685.3	1185.1	2.345	2.341	2.463	4.97	14.43	65.55
	1170.2	684.2	1185	2.337					
	1171	684.75	1185.05	2.341					
4.5	1173.5	686.2	1184.1	2.357	2.352	2.441	3.63	14.41	74.83
	1178.2	690.2	1192.1	2.347					
	1175.85	688.2	1188.1	2.352					
5	1178.1	691.2	1191.5	2.355	2.361	2.429	2.81	14.51	80.63

% Asphalt		FLOW	FLOW AVG mm	STABILITY KN	STABILITY KN
3		2.736	2.722	7.913	7.923
		2.707		7.933	
		2.722		7.923	
3.5		2.777	2.765	8.104	8.134
		2.753		8.164	
		2.765		8.134	
4		2.875	2.828	8.319	8.323
		2.781		8.326	
		2.828		8.323	
4.5		2.893	2.923	8.542	8.520
		2.953		8.498	
		2.923		8.520	
5		3.051	3.017	8.305	8.35
		2.983		8.395	
		3.017		8.350	

GRADE (80/100):

% Asphalt	WT IN AIR (gm)	WT IN WATER(gm)	SSD WT (gm)	Gmb	Gmb AVG	Gmm	Va % %	VMA %	VFA % %
3.5	1172.3	687.8	1193.4	2.319					
	1170.7	684.7	1192.2	2.307	2.313	2.474	6.50	15.04	56.75
	1171.5	686.25	1192.8	2.313					
4	1173.4	683.8	1188.5	2.325					
	1164.1	683.4	1181.5	2.337	2.331	2.457	5.13	14.78	65.29
	1168.75	683.6	1185	2.331					
4.5	1162.2	673.6	1170.5	2.339					
	1168.2	686.3	1183.2	2.351	2.345	2.446	4.13	14.68	71.88
	1165.2	680.0	1176.9	2.345					
5	1170.5	690.2	1185.2	2.365					
	1172.5	690.5	1187.5	2.359	2.362	2.427	2.69	14.47	81.44
	1171.5	690.4	1186.35	2.362					

% Asphalt	FLOW (mm)	FLOW AV(mm)	STABILITY(KN)	STABILITY(KN)
3.5	2.962		7.703	
	2.832	2.897	8.769	8.236
	2.897		8.236	
4	2.931		8.325	
	2.982	2.957	8.356	8.341
	2.957		8.341	
4.5	2.985		8.364	
	3.123	3.054	8.452	8.408
	3.054		8.408	
5	3.235		8.352	
	2.993	3.114	8.378	8.365
	3.114		8.365	

7.3 Superpave Results:

Grade (60/70):

Bitumen Content= 3.5 %	
Specimen Weight (grams)	6218
No of Gyrations	125
G_{sb}	2.63
G_{se}	2.6307
Compaction Angle (mrad)	22
G_{mb} (measured)	2.347
G_{mm} (measured)	2.48
VA %	5.86
VMA %	13.9
VFA %	70.4
Dust Proportion	1.19

Bitumen Content= 4 %	
Specimen Weight (grams)	6250
No of Gyrations	125
G_{sb}	2.63
G_{se}	2.631
Compaction Angle (mrad)	22
Gmb (measured)	2.363
Gmm (measured)	2.463
VA %	4
VMA %	13.7
VFA %	70.9
Dust Proportion	1.25

Bitumen Content= 4.35 %	
Specimen Weight (grams)	6273
No of Gyrations	125
G_{sb}	2.63
G_{se}	2.631
Compaction Angle (mrad)	22
G_{mb} (measured)	2.363
G_{mm} (measured)	2.446
VA %	3.3
VMA %	14.0
VFA %	71.5
Dust Proportion	1.24

Grade (80/100):

Bitumen Content= 3.5 %	
Specimen Weight (grams)	6218
No of Gyrations	125
G_{sb}	2.63
G_{se}	2.6307
Compaction Angle (mrad)	22
G_{mb} (measured)	2.335
G_{mm} (measured)	2.474
VA %	6.0
VMA %	14.4
VFA %	71
Dust Proportion	1.26

Bitumen Content= 4 %	
Specimen Weight (grams)	6250
No of Gyrations	125
G_{sb}	2.63
G_{se}	2.631
Compaction Angle (mrad)	22
G_{mb} (measured)	2.353
G_{mm} (measured)	2.457
VA %	4.30
VMA %	14.1
VFA %	71.5
Dust Proportion	1.21

Bitumen Content= 4.55 %	
Specimen Weight (grams)	6286
No of Gyrations	125
G_{sb}	2.63
G_{se}	2.631
Compaction Angle (mrad)	22
G_{mb} (measured)	2.367
G_{mm} (measured)	2.441
VA %	3.1
VMA %	14.0
VFA %	72
Dust Proportion	1.20