COMPARATIVE EVALUATION OF MARSHALL AND SUPEPRAVE MIX DESIGN METHODS USING NHA ASPHALTIC CONCRETE MIXTURES

By
Gulrez Farooq
(Registration No: 00000330550)

Supervisor
Dr. Arshad Hussain

Department of Transportation Engineering
School of Civil and Environmental Engineering (SCEE)
National University of Sciences & Technology (NUST)
Islamabad, Pakistan
(2023)

COMPARATIVE EVALUATION OF MARSHALL AND SUPEPRAVE MIX DESIGN METHODS USING NHA ASPHALTIC CONCRETE MIXTURES

By
Gulrez Farooq
(Registration No: 00000330550)

A thesis submitted to the National University of Sciences and Technology, Islamabad, in partial fulfillment of the requirements for the degree of

Master of Science In
Transportation Engineering

Supervisor
Dr. Arshad Hussain

School of Civil and Environmental Engineering (SCEE)
National University of Sciences & Technology (NUST)
Islamabad, Pakistan
(2023)

THESIS ACCEPTANCE CERTIFICATE

It is certified that final copy of MS thesis written by Mr. Gulrez Farooq, Registration No. 00000330550, of MS Transportation Engineering batch 2020 (NICE), has been vetted by undersigned, found completed in all respects as per NUST Statutes/Regulations, is free of plagiarism, errors, and mistakes and is accepted as partial fulfilment for award of MS degree.

Dr. Arshad Hussain
Associate Professor
Head of Transportation Engineering Department
School of Civil & Environmental Engineering
NUST, Sector H-12, Islamabad

Signature: ______________

Name of Supervisor: Dr. ARSHAD HUSSAIN

Date: 27 - 07 - 2023

Signature (HOD): ______________

HoD Transportation Engineering
NUST Institute of Civil Engineering
School of Civil & Environmental Engineering
National University of Sciences and Technology

Date: 27 - 07 - 2023

Signature (Principal and Dean): ______________

PROF DR MUHAMMAD IRFAN
Principal & Dean
SCEE, NUST

Date: 08 AUG 2023

AUTHOR'S DECLARATION

I, Gulrez Farooq, hereby affirm that my thesis titled "Comparative Evaluation of Marshall and Superpave Mix Design Methods using NHA Asphaltic Concrete Mixtures" is entirely my original work. I have not submitted it previously for taking any degree from this university "National University of Sciences and Technology (NUST), Islamabad" or any other educational institution within in the country / abroad.

At any time if my statement is found to be incorrect even after my graduation, the university retains the authority to revoke my MS degree.

Name of student: Gulrez Farooq

Date: July, 2023

PLAGIARISM UNDERTAKING

I solemnly declare that research work presented in the thesis titled "Comparative Evaluation of Marshall and Superpave Mix Design Methods using NHA Asphaltic Concrete Mixtures” is solely my research work with no significant contribution from any other individual. I confirm that while writing the thesis, I have acknowledged any minor contributions or assistance received and I affirm that I have authored the complete thesis independently. I am fully aware of the strict anti-plagiarism policies of Higher Education Commission (HEC) and National University of Science and Technology (NUST). Therefore, I as an author of the above titled thesis, declare that no part of it has been plagiarized and any material used from external sources has been appropriately referenced and cited. I undertake that if I am found guilty of any formal plagiarism in the above titled thesis even after award of MS degree, the University reserves the rights to withdraw/revoke my MS degree and that HEC and the University has the right to publish my name on the HEC/University website on which names of students are placed who submitted plagiarized thesis.

Student / Author signature:_____________

Name of student: Gulrez Farooq

DEDICATION

This thesis is dedicated to my teachers who shaped my mind with their wisdom and inspiration, to my beloved parents and siblings who are pillars of my strength and unwavering source of encouragement throughout my academic career.

ACKNOWLEDGEMENT

All the acclamation and appreciations for Allah the Almighty, the most Gracious and the most Compassionate. Praises are also addressed to our Holy Prophet Muhammad (S.A.W.W) who guided us towards righteous path and enlightened our sight.

I am obliged to my beloved and respected parents for their unwavering moral support and encouragement during my whole academic career. I am deeply indebted to my parents for being a source of affection, motivation and guidance for me.

Many thanks to my mentor and research supervisor Dr. Arshad Hussain for valuable insights and kind supervision of my research work. His guidance and direction helped me in exploration and writing of this thesis. This research has not been possible without his motivation and intellectual input. Thanks are also extended to my friends, work colleagues and lab staff who have always been there for me whenever I faced any problem whether personally, academically or technically. I am also grateful to the teachers and staff members of NICE for their kind support in my academic program.

ABSTRACT

The primary objective of any asphalt mix design method is to establish an economically efficient combination of bitumen and aggregates in an appropriate proportion such that it yields a paving mix with sufficient amount of asphalt binder, desirable percentage of air voids, VMA, VFA, suitable workability and satisfactory performance. Moreover, the asphalt mix composition, i.e. proportion of asphalt cements (Optimum Asphalt Content), aggregate and mineral filler has a substantial impact on its resistance against pavement distresses. With the advancement in technology, the traditional Marshall mix design method which was introduced in 1939 has become obsolete and outdated. The impact compaction technique implemented in Marshall method is considered a poor reflection of actual field compaction due to the fact that pavements are subjected to gradually applied compressive loads by compaction rollers and traffic. On the other hand, Superpave mix design technique, which was established in 1993, is gaining attraction of many state highway departments due to its better simulation of field compaction characteristics and incorporation of environmental conditions, heavy traffic loading etc. In general, asphalt concrete mix is designed in such a way that it possesses enough stiffness to prevent major deformations without compromising its flexibility. Since the Indirect Tensile Strength (ITS) and Resilient Modulus (M_R) are reliable indicators of asphaltic pavements' stiffness, both these parameters (M_R and ITS) are considered in this research work to characterize the permanent deformation behavior of asphaltic mixtures. This comparative study is aimed to analyze both design methods on the basis of volumetric properties and performance evaluation by using the materials procured from same source and adopting identical aggregates' gradation complying with NHA specifications which are most commonly used all across Pakistan for pavements design. The results of performance testing were quite propitious and the implementation of Superpave mix design approach is strongly recommended.

Keywords: Asphalt mix design, Marshall mix design, Superpave mix design, Indirect Tensile Strength, Moisture Susceptibility, Resilient Modulus

TABLE OF CONTENTS

List of Figures

List of Tables

CHAPTER 1: INTRODUCTION

1.1 Introduction

Developing countries prioritize the advancement of infrastructure, particularly in the realm of transportation systems. In Pakistan, there is a 263,775 km long network of roads and motorways. Among the three main modes of transportation including roadways, railways, and air, road transportation vastly outperforms the other two. The country's economy mainly relies on road transportation which facilitates 90 % of total passenger traffic and 95 % of total freight movement. This underscores the critical role of roads in the economic development of our country. According to a report by the Asian Development Bank (ADB) published in 2018, approximately 85 % of Pakistan's total road network is paved, and, of that, around 97 % is surfaced with asphalt. Therefore, it can be estimated that asphaltic pavements constitute 82.45 % of the total pavements in Pakistan.

Although the highways in Pakistan are intended to have a lifespan of 20 years, their performance is below par, with pavement life being considerably shorter than anticipated design life. This is primarily due to high traffic intensity, particularly the overloading of trucks on national and provincial highways as well as the significant fluctuations in daily and seasonal temperatures that cause distresses like fatigue cracking, rutting and thermal cracking of pavements. A major contributing factor leading to the premature deterioration of roads and highways is the inadequate design practices regarding pavement materials and aggregate-asphalt mixture.

The fundamental aim of an asphaltic concrete mixture design is to define a blend of asphalt binder with aggregates in such a way that it assures optimal performance of pavements. Like other engineering materials design, asphaltic concrete design is mainly a matter of selecting the most appropriate materials, followed by most favorable apportioning of materials to achieve the intended attributes. Basic objectives for the design of paving mixes include obtaining a desirable gradation along with sufficient content of asphalt cement to ensure durability, sufficient air voids to allow for secondary compaction, sufficient stability of asphalt concrete mix to satisfy requisite traffic demand without distortion, adequate workability to allow efficient placement of paving mix without any risk of constituents’ segregation and stability loss (Asphalt Institute, 2014). In Pakistan, the state agency responsible for providing specifications of asphalt mix design conforming to local conditions is National Highway Authority (NHA). The asphalt-aggregate blend is manufactured for highway projects in conformity with job mix formula that has been standardized by NHA (NHA, 1998).

The Marshall method is a commonly used test procedure for designing and assessing the bituminous mixes. It is frequently incorporated in routine testing programs for paving projects. This technique involves measuring the potential of a compacted cylindrical specimen to sustain plastic deformation when loading is applied diametrically while the rate of strain is 50.8 mm/min. These samples are made using specified process that includes heating, mixing and then using Marshall impact hammer for compacting the bituminous mixture. The Marshall method of designing mixes includes two major features which are density-voids analysis followed by stability - flow tests which are performed with the help of Marshall stability machine.

A major change in asphalt mix design was brought about by Strategic Highway Research Program (SHRP) with the introduction of Superpave (Superior Performing Asphalt Pavements) system in 1993. The Superpave system included a novel laboratory equipment, the Superpave Gyratory Compactor, to accomplish the compaction of paving mixes in the laboratory. Furthermore, it introduced specific requirements for aggregates and binders, and established the compactive effort of mixtures based on their anticipated traffic levels. To predict the lifespans of pavements, testing methodologies and performance models have been developed, revised and continuously improved.

1.2 Problem statement

Pakistan has a large national highways network spanning over 12,000 km and a provincial highway network of more than 50,000 km. Unfortunately, due to increase in traffic volume, rise in axle load levels and inadequate maintenance, this large investment is undergoing a rapid and severe decline. Since majority of Pakistani roads are flexible pavements composed of asphaltic concrete, the need of the hour is to carry out pavement materials design by using modern methods in order to enhance the life of pavements. The commonly used methods of asphalt design are outdated because of immense increase in traffic loading and temperature changes. Therefore, the research being undertaken is an attempt to improve the method of materials design of pavements.

Previous literature illustrates that Superpave method of asphaltic concrete design is more economical as compared to traditionally used Marshall method, therefore its use must be promoted. Since Superpave mix design method provides lower Optimum Binder Content, it can fulfill the criteria for convenient and high quality construction at low budget. Moreover, the lower optimum binder obtained via Superpave mechanism is an indicator of better rutting resistance which will ultimately lead to strong and durable pavements. Being a developing country with struggling economy, it is necessary for us to make economical roads with long service lives since the budget is limited.

1.3 Research objectives

The fundamental objectives of the research are enlisted below:

- To design asphalt mixtures using the Superpave as well as Marshall mix design mechanisms and make a comparative evaluation on the basis of volumetric properties and performance tests.
- To carry out a volumetrics based analysis for both mix design strategies in terms of air voids, voids in mineral aggregates (VMA), voids filled with asphalt (VFA) and optimum bitumen content (OBC).
- To evaluate the performance of Marshall mix samples as well as Superpave mix specimens and compare them by means of Indirect Tensile Strength Test, Moisture Susceptibility Test and Resilient Modulus Test.

1.4 Scope of research

To achieve the aforementioned research objectives, an elaborate research framework was devised encompassing the following activities:

- Intensive literature review comprising the findings of previous researches about comparison of Marshall and Superpave design techniques.
- Deep insight into the codes and standards being followed for aggregates testing, bitumen testing and performance tests.

- Testing of materials i.e. aggregate and asphalt binder to examine their physical properties and check their suitability according to specifications.
- Selection of an exactly same aggregates gradation to be used for both kinds of mix design samples.
- Determination of optimum bitumen content by preparing samples at different percentages of bitumen.
- Preparation of samples for both mix designs at their respective optimum asphalt content.
- Performance evaluation with the help of ITS test, TSR test and M_R test.
- Reporting the results, drawing the conclusions and suggesting the recommendations.

1.5 Thesis organization

The entire research work has been structured into five (05) chapters.

Chapter 1 incorporates the background of asphaltic concrete design methods along with brief introduction of Pakistan's road networks, technical problems associated with flexible pavements, research objectives and domain of the study.

Chapter 2 covers a detailed overview of similar research works and findings of the researchers about comparative analyses of both these design methodologies. The significance of various performance tests and their procedures are also included in this chapter.

Chapter 3 comprises the methodology chosen to achieve the desired objectives including selection of most suitable aggregates' configuration, determination of optimum bitumen content and evaluating the performance.

Chapter 4 elaborates the results of volumetric properties, performance tests and a comparison of all the results on the basis of air voids, VMA, VFA, OBC, ITS, TSR M_R and cost analysis.

Chapter 5 summarizes the conclusions, explains the findings and outlines the recommendations for further exploration.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

During the past three decades, several researchers have conducted studies on the comparison between Superpave and Marshall methods of Hot Mix Asphalt design using various parameters. Most of them evaluated these methods on the basis of volumetrics as well as performance. Basic differences between these methods can be classified in terms of materials characterization, compaction strategy and performance evaluation. Research findings of some renowned researchers have been discussed in the following sub-section.

2.2 Previous research-work

Tarek Ghonemi Ibrahim Kassab et al. (2021) carried out a study to compare the Hot Mix Asphalt properties designed by the above-mentioned methods. The researchers performed Flow Number and Dynamic Modulus tests on the samples prepared using both methods and analyzed the results to establish a correlation between them. The study concluded that Superpave mixtures exhibited greater stability and consequently increased resistance against rutting and fatigue compared to Marshall mixes. Additionally, the application of Superpave's aggregate gradation limits and control points to Marshall mix design method enhanced the HMA properties by increasing its stability and improving its ability to resist rutting and fatigue. The study also found a direct correlation between the results of stability and the results of both Dynamic Modulus and Flow Number tests.

Derya Kaya Ozdemir et al. (2019) conducted a comprehensive study to highlight the main differences between Marshall and Superpave Asphalt Pavement Design Methods on the basis of previous literature and research findings of researchers. The author concluded that grading system of bitumen differs between these methods, with penetration grade (PG) used for the former and performance grade for latter. Unlike Marshall method, Superpave method considers the climate and traffic conditions as well. Moreover, Superpave method has specific requirements for aggregate gradation i.e., control points and prohibited zones. Both Marshall and Superpave methods have a 4 % air void ratio as a main criterion for selection of optimum bitumen content, but other factors such as VMA, VFA, flow and stability values should also be considered to find out the optimum bitumen content in the Marshall design approach.

Varma et al. (2019) experimentally investigated the Superpave and Marshall mix design methods to find their resistance to rutting. The primary goal of this experimental study was to make a measurement and comparison of air voids at Marshall refusal density (applying 400 blows on each face) and Superpave maximum gyrations (Nmax of 205) for asphaltic concrete mixtures most commonly used in Qatar State. They found that both, refusal density acquired by means of Marshall compaction at 400 blows and density at Nmax gyrations (205 gyrations of Superpave gyratory compactor) can be used as a mix design criterion to characterize rut resistance for unmodified PG 64-10 asphalt mixtures. The Marshall refusal density does not account for aggregate breakage and the temperature drop during compaction renders the test inappropriate for evaluating mixtures, particularly those with modified binders.

Magdi M. E. Zumrawi et al. (2016) performed Marshall and Superpave mix design techniques using same source of bitumen and aggregate. The researchers determined the optimum bitumen content (OBC) for both methods and analyzed their performance. Results showed that Superpave mix design yielded lower asphalt content than Marshall mix design for heavy traffic conditions and hot climate. Moreover, Superpave mixes had lower values for VMA and VFB compared to Marshall mixes. At the OBC, the specimens produced using Superpave mix design attained higher densities than those produced using Marshall mix design. The higher density achieved in Superpave was mainly due to the compactive effort of the gyratory compactor.

Javier Loma Lozano et al. (2013) carried out a study to determine the equivalent energy required to produce test specimens with a gyratory compactor (using the rotation angle of 0.82 °) to achieve the same density as those produced with an impact compactor for commonly used bituminous mixtures in Spain, with aggregate sizes of 11 mm, 16 mm, 22 mm and 32 mm. The study found that different types and gradation of mixes required varying number of gyrations or Marshall blows for equivalent compaction. For example, AC32, 160 gyrations are equivalent to 75 Marshall blows, while for SMA11, 160 gyrations are equivalent to 50 Marshall blows. The study also found that samples taken from asphalt plants during regular operations verified the satisfactory equivalence between the compaction systems for various types and gradation of mixes.

Israa F. Jasim (2012) conducted a study that involved assessing the mechanical properties and volumetrics of wearing course using both the Superpave design approach and the Marshall design mechanism. The primary goal of the study was to make a comparison with regard to effectiveness of these methods. Materials used for experimental investigation included bitumen, mineral filler and aggregate. The Optimum Asphalt Content for Superpave mixes came to be lesser in comparison with Marshall mixes. He suggested that the Superpave mix design is economically efficient process.

Kamran Muzaffar Khan et al. (2012) performed laboratory tests on three different kinds of asphalt mixes including the Marshall Mix, Superpave mix and Stone Mastic Asphalt (SMA). They evaluated the physical characteristics of aggregates and bitumen, as well as the mechanical properties of the HMA mixtures using creep test, indirect tensile strength test and dynamic modulus test. They found that Superpave mix had lower permanent deformation strains and higher resilient and dynamic moduli than the other two mixes. SMA and Marshall mixes indicated a higher rate of accumulated strain especially at higher temperatures, while Superpave mixes showed superior resistance to accumulated strain even at 55 ° C. Indirect tensile strength testing revealed higher values of resilient modulus for Superpave bituminous mixtures and their dynamic modulus was also significantly higher than other mixes at different stress levels.

Dr. Ghazi G. Al-Khateeb et al. [16] conducted a research to compare these design methods based on several factors, such as the assessment of materials before mixture design, determination of asphalt content in the design process and the relationship between asphaltic concrete design and performance of pavement. Materials used in the research included bitumen and limestone aggregate. The penetration grade of the bitumen used in this study was 60/70 (performance grade PG 64). The researchers utilized one aggregate gradation that met the criteria for both Superpave and Marshall methods. The study concluded that the differences in terms of optimum asphalt content between these mechanisms were influenced by the aggregates gradation used in the design of bituminous mix. In contrast to Marshall mix design method, the Superpave process assessed the compactability and tenderness of the paving mix by estimating the % Gmm at Nini, providing an early-stage evaluation of mixture performance.

Arshad Hussain (2019) performed an experimental investigation to study the effect of different kinds of aggregates configuration on permanent deformation behavior and moisture sensitivity of paving mixes. Five different wearing course gradations were adopted namely NHA-A, NHA-B0, SP-1, SP-2 and MS-2, along with two types of asphalt binder having grade 40/50 and 60/70. The Hamburg wheel tracking test (HWTT) and modified Lottman test were utilized for performance evaluation of asphalt mixtures. Results indicated that NHA-A with a coarser stone structure outperformed the NHA-B, SP-1, SP-2 and MS-2 gradations in the Hamburg Wheel Tracking test while the finer MS-2 and SP-1 gradation couldn’t pass the test which shows their incapacity to withstand heavy traffic volumes. The study demonstrated that higher resistance to rutting can be achieved with a greater nominal maximum size (NMAS) and less moisture damage with higher amounts of fines passing through sieve no. 4. Therefore, it is recommended to use NHA A class as well as B class gradations to ensure satisfactory results regarding higher rut resistance and moisture susceptibility. A well balanced mixture of fine and coarse aggregate is necessary to achieve a mix with resistance to both rutting and moisture damage.

2.3 Marshall mix design method

The Marshall mix design strategy was established by Bruce Marshall who worked for the Mississippi Department of Highways in the late 1930s to early 1940s. During World War II, the corps adopted Marshall’s system to be used for on airfield pavements, and it was further adapted for use by various state highway departments. Marshall used a drop hammer to accomplish the standardization of compaction energy. Marshall and Hveem mix designs were the primary methods used for designing dense mixtures until Superpave mechanism was introduced in the mid-90s (G. Huber, 2013). But there arises a major drawback in the Marshall mix design in terms of compaction method. The Marshall hammer compaction technique is not an accurate simulation of actual field compaction due to absence of kneading action during the compaction process. This lack of correlation is likely due to the mechanical version of the Marshall hammer applying a uniform load (A. Consuegra, 1989).

The Marshall method of designing mixes includes two major features which are density-voids analysis followed by stability - flow tests which are performed with the help of Marshall stability machine. The strength of the mix is measured with regard to Marshall’s stability in accordance with ASTM D 1559 (2004), which refers to the ultimate load a compacted cylindrical specimen can sustain at a temperature of 60˚C before breaking. Sample is subjected to compressive load until it fails. On the other hand, flexibility is assessed by the measurement of flow value. It reveals the change in sample’s diameter along the direction in which loading is applied, from the time when loading starts and the time of peak loading. During application of load, a dial gauge is attached to compute the strain in the sample. The magnitude of plastic deformation that occurs upon specimen’s failure is referred to as flow value.

The Marshall mix design method involves preparing three compacted samples at certain asphalt contents and testing at least four asphalt contents to determine the design content. The volumetric properties of the bituminous mix are utilized to carry out density-voids analysis which includes calculating various mix properties such as bulk specific gravity, theoretical maximum specific gravity, percentage of air voids, percentage of bitumen, voids in mineral aggregate, and voids filled with asphalt. To determine the optimum binder content, the mean values of bulk specific gravity, stability, flow, Va, VMA and VFA are measured and their average values are plotted against asphalt content. A smooth curve is drawn with the help of these values. The bitumen content that corresponds to 4 % air voids is considered to be optimum bitumen content. By examining these smooth curves, the stability and flow values corresponding to optimum asphalt content can be calculated. These values must meet the design parameters specified by Asphalt Institute. Various levels of compaction achieved through impact hammer blows as per designated traffic loads are mentioned below:

Table 1.1. Marshall mix design compaction criteria

Traffic level	**ESALs**	**Blows / side**
Light	> 10000	35
Medium	10000 – 1 million	50
Heavy	> 1 million	75

2.4 Superpave mix design method

Superpave mix design approach is a product of the Asphalt Research Program, which was conducted between 1987 and 1993 under the auspices of Strategic Highway Research Program (SHRP). The principal focus of the program was to devise a mix design system, a performance based asphalt binder specification and performance based asphalt mixture specifications (G. Huber, 2013). The Superpave gyratory compactor was introduced to compact the asphalt mix samples through kneading action. These samples are highly representative of the engineering properties of core samples taken from field.

The Superpave design mechanism retained the criteria of fundamental volumetric properties used in the Marshall design approach but more precise aggregate requirements that were linked to traffic loads. To achieve optimal design, specific criteria are set for all the volumetric properties. Va must be fixed at 4 % for Ndes. The criteria for VMA vary depending upon the nominal maximum aggregates size (NMAS) used. Additionally, the criteria of voids filled with asphalt vary according to expected traffic volume. The Superpave system has two new significant features, laboratory compaction and mixture performance testing. The Superpave Gyratory Compactor (SGC) is used to compact the test specimens and provides significant insight about the compactibility of the mixture. It facilitates the design of mixtures that won’t show tender mix behavior or undergo undesirable densification to minimal air void contents when exposed to traffic. To predict the lifespans of pavements, testing methodologies and performance models have been developed, revised and continuously improved.

Superpave system of asphaltic mixtures design and analysis provides guidelines for three levels of design traffic with each level increasingly rigorous and providing more details on mixture performance. The first level, known as Superpave volumetric mix design is an enhanced process of selecting materials and designing a volumetric mix that is suitable for projects with expected traffic of up to 1 million (1,000,000) ESALs. The second level, originally called level 2 mix design or Superpave abbreviated mix analysis, builds upon the volumetric mix design by using a series of SST and IDT tests to predict in-field performance of bituminous mix. This level corresponds to traffic levels ranging from 1,000,000 ESALs to 10,000,000 ESALs. The third level of mix analysis, which is also called Superpave mix analysis or the original level 3 design, incorporates an extensive range of Superpave Shear Test (SST) and Indirect Tensile Test (IDT) and their outcomes to establish a higher level of accuracy in performance prediction scenario. This level of analysis is recommended for projects that have high traffic levels exceeding 10,000,000 ESALs.

Table 1.2. Gyratory compactive efforts in Superpave volumetric mix design

20 year design ESALs (millions)	**Compaction parameter**		
	N_{ini}	**N_{des}**	**N_{max}**
< 0.3	6	50	75
0.3 - < 3	7	75	115
3 - < 30	8	100	160
> 30	9	125	205

2.5 Volumetrics based analysis

Volumetrics based analysis of asphalt mix involves studying and analyzing the volume-related characteristics of asphalt mixture used in road construction. This type of analysis is crucial for ensuring the performance and durability of asphalt pavements. The volumetric properties of the asphalt mix directly influence its mechanical properties and ability to withstand traffic loads, temperature changes and environmental stresses. Some key aspects of volumetric properties based analysis include the following:

2.5.1 Air voids

The amount of entrapped air in an asphalt layer that has been placed on-site is represented by the term “field air voids”. Asphalt mix should have sufficient amount of entrapped air voids to permit additional compaction under heavy traffic loading besides thermal flushing, loss of stability and bleeding. Moreover, voids also accommodate the volume of binder that could provide adequate cohesion between aggregate particles (J. G. Speight, 2016).If air voids are more than the design limit (3 – 5 %) of Asphalt Institute, the asphalt roadways will acquire enhanced permeability to moisture and air which leads to reduced service life because of moisture susceptibility and intense oxidative hardening (Pavetrend, 2022). If there is lack of air voids in paving mix, the asphalt becomes rutted and deformed when subjected to traffic. It also makes the HMA stiffer and causes fatigue cracking (H. Von Quintus, 2019).

Without adequate entrapped air in the layer, the asphalt becomes vulnerable to deformation and results into to a rough and uneven surface. Reduced compaction leads to higher air voids, which increases the risk of moisture penetration, early oxidation as well as premature raveling that diminishes the structural performance regarding stiffness and fatigue resistance of paving mix (Pavetrend, 2022). For every 1 percent increase in air voids (above a base level of 7 percent), there is 10 % reduction in service life of pavement approximately (or about 1 year less) (Robert N Linden, 1989). Voids in total mix (VTM) are calculated as a percentage of total volume of compacted mixture that is not taken up by aggregate or asphalt. The percent voids filled with asphalt (VFA), also known as asphalt-void ratio, refers to the percentage of air voids which are filled with bitumen within the compacted aggregate mass. If the voids filled with asphalt (VFA) are too low, the mix will lack durability and ability to over densify under loading. For this reason, VFA is a very critical property. The air spaces that are present between the aggregate particles in a compacted asphalt mixture are called Voids in mineral aggregate (VMA). VMA are the representative of the air voids and space available to accommodate the binder within mixture. If the voids in mineral aggregate (VMA) are in excess, more space will be available for asphalt which leads to thicker asphalt film and hence more durability is achieved (J. G. Speight, 2016).

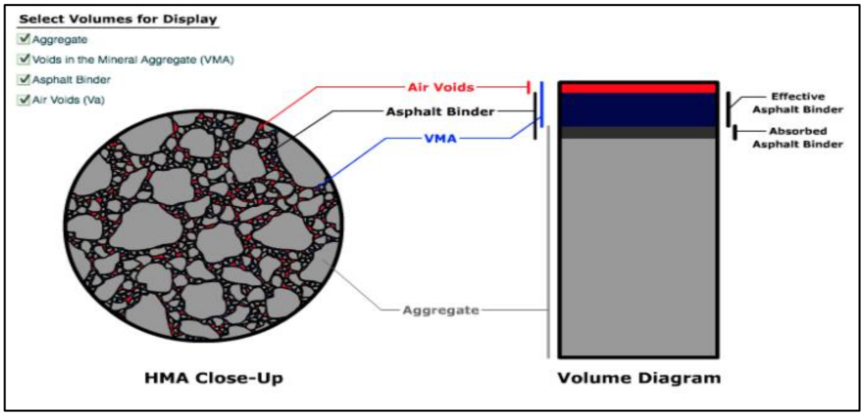


Figure 2.1. Volumetric properties diagram (www.waqtc.org)

2.5.2 Optimum asphalt content

The selection of appropriate asphalt content for the design of asphalt mix is crucial in optimizing the desirable properties including stability, strength, durability, impermeability, stiffness, flexibility, fatigue resistance and rutting resistance (J. G. Speight 2016).

The optimum bitumen content (OBC) is chosen on the basis of achieving the desired pavement characteristics for the target climatic and environmental conditions along with expected traffic loads (Asphalt Institute, 2014). On the basis of volumetric parameters, the process to select optimum binder content is accomplished through mixing and compacting various blends of asphalt cement and job aggregate at different percentages and testing them against standard methods for determination of ideal job mix formula that meets standardized volumetric properties. The criteria for dense graded mixes requires them to have 4 % air voids. The National Asphalt Pavement Association suggests that asphalt content determined against 4 % air voids level is recognized as optimum asphalt content (OAC) (Audrey Copeland, 2019). The Asphalt Institute also recommends choosing the optimum asphalt content at 4 % air voids (Asphalt Institute, 2014). Rutting is influenced by aggregate properties (fine aggregate and coarse aggregate angularity) and volumetric properties (air voids, VFA etc.). On the other hand, fatigue cracking is governed by bitumen content. Indeed this is the most vital characteristic of asphalt mix for fatigue. Moisture damage is controlled by asphalt content, bond strength of asphalt-aggregate interface (G. Huber, 2013).

Figure 2.2. Asphaltic concrete mix (www.pavingorleans.com)

2.6 Performance tests

Performance tests are critical for determination of quality of asphalt mix. Moreover, they provide valuable insights into its durability, suitability and cost effectiveness. Asphalt mix commonly used for constructing roads and highways, needs to meet specific standards and performance requirements to ensure its longevity and safety. The detailed description of the performance tests used in this research is given below:

2.6.1 Resilient modulus test

Resilient modulus is a useful parameter generally used to assess the quality of materials and act as input for the structural design of pavements, analysis and performance evaluation. This method can also be used to explore the effect of load and temperature on resilient modulus (ASTM, 2020). Resilient modulus (M_R) is considered to be an essential property for characterization of unbound pavement materials. It is regarded as an indicator of material stiffness and enables to estimate the stiffness under different levels of stress, moisture and density. Furthermore, it is necessary input parameter for mechanistic-empirical design approach of roads and pavements. M_R is determined by means of laboratory tests by taking into account the stiffness of a cylindrical specimen when a cyclic axle load is applied on it. Generally, it refers to the ratio between applied axle deviator stress and axle recoverable strain (Shongtao Dai, 2009). Resilient modulus is frequently used in the evaluation of materials quality.

Benefits of M_R testing have been summarized below:

- Quantification of fundamental characteristics of material
- Dynamic load testing exactly similar to traffic-induced loading
- A critical factor of mechanistic-empirical pavement design

The Resilient modulus test is considered as indirect tension test under repeated loading and performed according to ASTM D7369. The test sample prepared for the MR test is a cylindrical specimen with a diameter of 100-millimeter (4-inch) and a thickness of 63.5-millimeter (2.5-inch). The process of MR testing involves loading the asphalt mix sample to a stress level ranging between 5 – 20 % of indirect tensile strength with a repeated pulse load and rest period, usually 0.1-second loading with either 2.9, 1.9 or 0.9 seconds. The resulting strain is observed and the values of strain and the applied stress are used for the calculation of resilient modulus of asphalt mix. Typically, the M_R test results are used as input in design processes of layered elastic thickness and also to find out the structural coefficient utilized for pavement's thickness design procedures (Asphalt Institute, 2014).

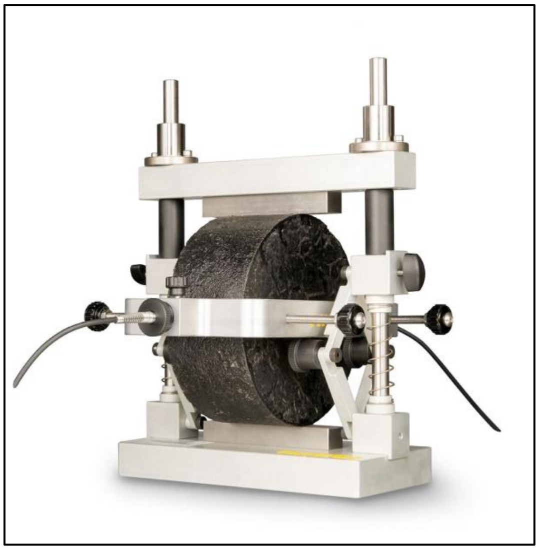


Figure 2.3. Resilient modulus test assembly (www.jetmaterials.com)

2.6.2 Indirect tensile strength test

Prolonged exposure to traffic loads can have a detrimental impact on the strength of paving mixes, resulting in fatigue cracks or rutting. The indirect tensile strength (ITS) test is frequently used for assessing the level of damage caused by this phenomenon. The ITS values play a significant role in evaluating the relative quality of paving mixtures, particularly when used together with laboratory testing of mix design. These values care quite useful while predicting the likelihood of rutting or fatigue cracking. Moreover, the ITS test outcomes can assist in estimating the moisture damage of pavements when the test is performed on both conditioned and unconditioned specimens (ASTM D 6931, 2017). This test involves measuring the maximum tensile stresses experienced by cylindrical specimens as they break under compression when tested in universal testing machine. For determination of indirect tensile strength, the test specimen should be placed between the loading strips of compression testing machine and loading is applied diametrically along the axis of the cylindrical specimen until it fractures. The displacement rate is kept constant meanwhile. The maximum tensile stress is calculated using the equation provided below, taking into consideration the dimensions of test specimen and the peak load at which sample gets fractured.

$$ITS = \frac{2P}{\pi DH}$$

Where;

ITS is the indirect tensile strength expressed in kilopascals (kPa)

P is the peak load (kN)

D is the diameter of sample (mm)

H is the height of sample (mm)

The results of ITS can also be used to assess the probability of moisture-induced deterioration of pavements by using moisture-conditioned and unconditioned specimens.

Figure 2.4. ITS test assembly (www.innopave.com)

The Indirect tensile strength ratio (ITSR) refers to the relationship between the strength measurements taken before and after the material has been exposed to moisture-conditioning (R. Veropalumbo et al., 2019). Tensile strength ratio is figured out according to according to UNI EN 12697-12 standard. TITSR is calculated with the help of following equation:

$$ITSR = \frac{ITS\ (wet)}{ITS\ (dry)}$$

Where;

$ITSR$ is the indirect tensile strength ratio in percent (%)

ITS (wet) is the average indirect tensile strength of the wet group (kPa)

ITS (dry) is the average indirect tensile strength of the dry group (kPa)

2.7 Summary

This chapter describes the procedure of Marshall and Superpave design methods which differs in terms of criteria for materials selection and compaction technique as well as performance evaluation. The significance of volumetric properties and standard test specifications conforming to indirect tensile strength test and resilient modulus test have been discussed in detail. Moreover, the factors influencing the major pavement distresses have also been outlined.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter comprises the technical approach for the execution of desired research activities and the methodology adopted for the implementation of conceived approach. In order to accomplish our research objectives, all the activities were carried out in a sequence. These mainly comprise the following steps:

- Selection and characterization of materials including bitumen and aggregate
- Performing tests on these materials to manipulate their physical properties
- Selection of most appropriate gradation
- Preparation of specimens for determination of volumetrics and optimum asphalt content (OAC)
- Making samples at OAC
- Performance tests on these samples

This comparative analysis was aimed to make an evaluation of mix designs using the specifications most commonly used all across Pakistan in conformity with NHA codes and standards. Superpave design system has revolutionized the binder selection by performing Bending Beam Rheometer and Dynamic Shear Rheometer on bitumen during materials selection process. The bitumen used for this experimental study was Parco 60/70. Its corresponding performance grade varies between PG 58-22 to PG 64-22. For selection of aggregate gradation, NHA B class gradation was adopted. Since our goal was to choose the same design mechanism and same materials, we selected the gradation in such a way that it fulfilled the criteria of NHA and Superpave specifications simultaneously. The gradation similar to NHA B class is regarded as Superpave 12.5 mm (SP 12.5). The restricted points revealed in Superpave gradation-selection codes were avoided and control points were also considered.

The schematic diagram for the intended methodology has been shown below:

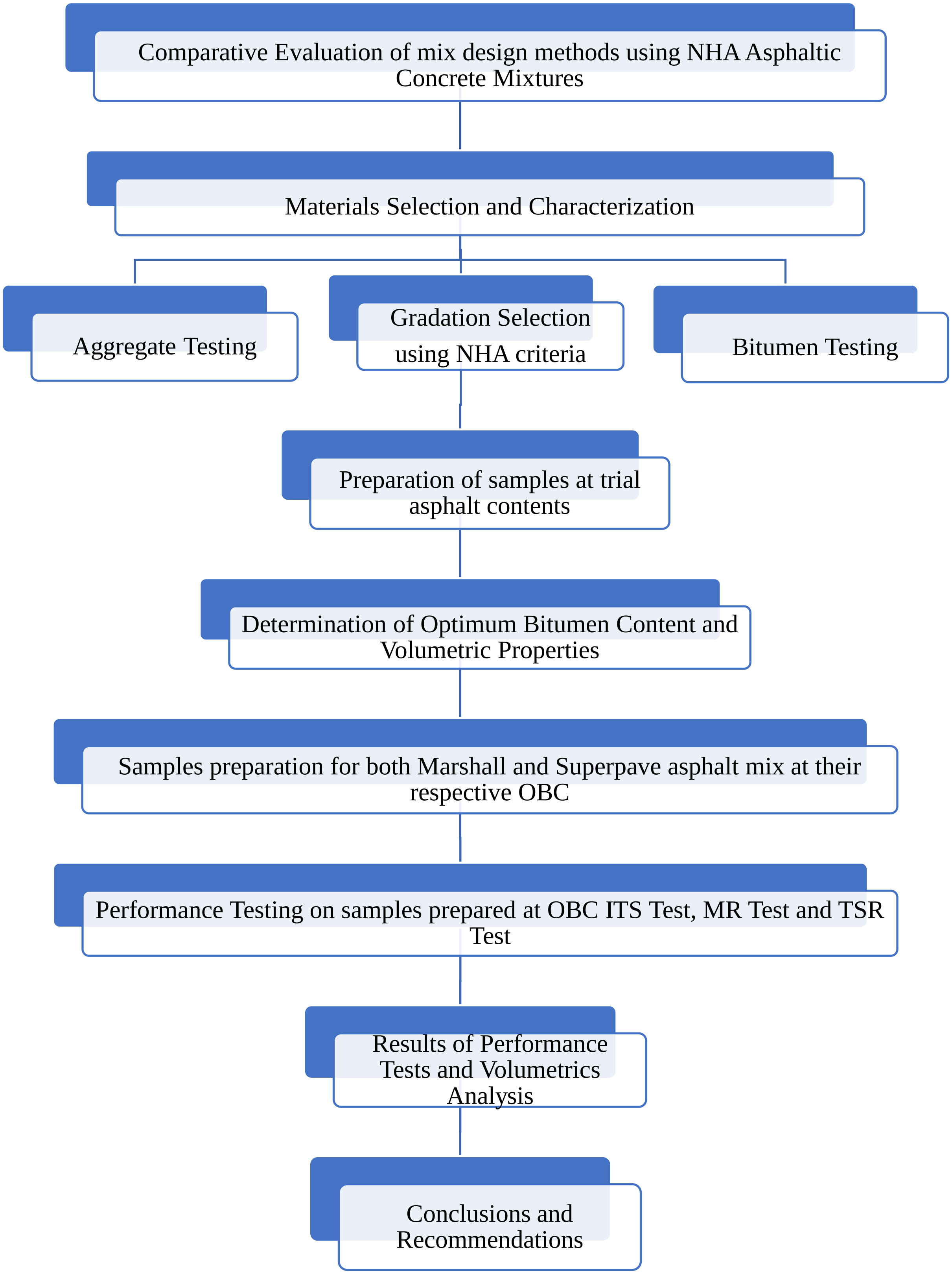


Figure 3.1. Schematic diagram of research methodology

3.2 Materials selection and characterization

Bitumen of grade 60/70 used for this study was procured from Pak Arab Refinery Company (PARCO). The source of aggregate was Khan Pur quarry near Islamabad. Before preparation of asphalt mixtures, various tests complying with ASTM standards were performed on the materials to determine their physical properties. Tests conducted on asphalt binder include penetration, softening point, flash and fire point, ductility and rotational viscosity tests. Whereas aggregate were also tested to check whether they fulfill the requisite criteria of physical characteristics. The results of aggregate and bitumen testing have been tabulated in the subsequent sections.

Figure 3.2. Materials procurement from Khan Pur quarry

3.2.1 Aggregate testing

Since the strength of asphaltic concrete is largely dependent on the aggregate properties i.e. toughness, durability and ability to withstand heavy loads, it implies that aggregate testing is an important step of materials characterization to check their suitability. Physical properties of aggregates were found out through several tests such as impact value test, crushing strength test, Los Angeles abrasion test, flakiness and elongation test, specific gravity and water absorption tests. Some other tests were also performed including sand equivalent test, fine and coarse aggregate angularity test. These are additional requirements for Superpave mix design (AASHTO, 2022). The results of aggregates testing have been summarized in table 3.2.

3.2.1.1 Aggregate impact value test

Aggregate impact value represents the capacity to resist sudden impact. The aggregates used in roads and pavements must possess sufficient hardness and toughness to resist the impact loading of moving traffic without showing any disintegration. The apparatus used for determining the impact value comprise an impact testing machine, a hammer of weight 14 kg approximately, a cylindrical steel cup of 75 mm diameter and 102 mm height, a larger cylindrical mold of 102 mm diameter and 50 mm height, sieves of sizes ½ inch, 3/8 inch and sieve # 8 and a tamping road of 10 mm diameter and 230 mm length. The impact strength test was performed according to BS 812. About 350 grams of aggregate (W1) passing through ½ inch (12.5 mm) sieve and retaining on 3/8 inch (10 mm) were taken to perform the test. Afterwards, the aggregate was filled in steel cup of 75 mm diameter in three consecutive layers. Tamping rod was used to tamp each layer 25 times. Then the aggregate was transferred to larger mold and given 15 blows with the help of a metal hammer having weight of 14 kg which falls freely from a height of 38 cm. The crushed aggregate was further sieved through sieve # 8 (having openings of 2.36 mm). The mass of material retained on sieve # 8 was measured (W2) and impact strength was estimated using the formula below:

Aggregate impact value = (W2 / W1) * 100

Figure 3.3. Impact strength test

3.2.1.2 Aggregate crushing value test

This test evaluates the ability of aggregates used in the construction of highways constructions to withstand compressive loads and the resulting stresses. Aggregates must be able to sustain the crushing phenomenon under rollers during compaction stage and traffic loads during service life of pavements. The apparatus required for this test consists of a steel cylinder of diameter 150 mm with both ends open, plunger with a piston diameter of 150 mm, a square base plate, a cylindrical measure of diameter 115 mm and height 180 mm, a tamping rod of 16 mm diameter and its length ranging between 450 mm to 600 mm, a balance and a compression testing machine. The test was conducted as per BS 812. Approximately 2500 grams of surface-dry aggregates were taken which were passing through ½ inch (12.5 mm) sieve and retained on 3/8 inch (10 mm) sieve. The initial weight (W1) of aggregates was noted down. The sample of aggregates was then added into cylindrical measure in a total of three layers, with each layer being tamped for 25 times. Afterwards, sample was transferred to steel cylinder with a base plate at bottom. The whole assembly was then shifted to compression testing machine. Crushing load was applied through the plunger uniformly whereas the loading rate was kept 4 tonnes / min until it reached a magnitude of 40 tonnes. Aggregates being crushed in the machine were then removed from the cylinder and further sieved with the help of sieve # 8 (2.36 mm). The weight of the material passing through sieve # 8 was noted as W2. Aggregate crushing value was calculated using the formula;

Aggregate crushing value = (W2 / W1) * 100

Figure 3.4. Crushing value test

3.2.1.3 Los Angeles abrasion test

The Los Angeles abrasion test refers to aggregates hardness, toughness and ability to resist abrasion. The aggregates used in highways pavements must be durable and have the ability to resist disintegration, degradation and wear caused due to traffic loading. The apparatus required for this test include Los Angeles machine which consists of a rotating drum, steel balls which provide abrasive charge, sieves of size 12.5 mm, 10 mm and 1.7 mm, weighing balance and a metallic tray. The test was performed according to ASTM C 131. B grading was selected to carry out the test. A total of 5000 grams (W1) aggregates were used which comprised 2500 grams of materials that fulfilled the criteria of passing through ½ inch (12.5 mm) sieve and retained on 3/8 inch (10 mm) sieve and 2500 grams of materials which were passing through 3/8 inch (10 mm) sieve and retained on 1/4 inch (6.3 mm) sieve. All the collected material was shifted to Los Angeles Abrasion machine along with 11 spherical balls. The rotating drum of machine was subjected to 500 revolutions at the rate of 30 to 33 revolutions per minute. After completing the required number of revolutions, the entire quantity of material was emptied into a tray and sieved again using 1.7 mm sieve. Mass of material (W2) passing through 1.7 mm sieve was noted down.

The abrasion value is calculated by using the formula;

abrasion Value = (W2 / W1) * 100

Figure 3.5. Los Angeles abrasion test

3.2.1.4 Flakiness and elongation test

The purpose of this test is to assess the appearance and configuration of coarse aggregates. Particles are said to be flaky if their least dimension is less than 0.6 times of their mean dimension. While elongated particles are having greatest dimension greater than 1.8 times of their mean dimensions. If the flaky and elongated particles are in excess, they will negatively affect the workability and stability of asphalt concrete mixes. The shape test is generally performed as per ASTM D 4791. Three aggregate sizes were chosen, which were 20 mm → 14 mm, 14 mm → 10 mm and 10 mm → 6.3 mm. 200 pieces of aggregate were selected for each category size. Weight of each fraction was observed and total weight was also noted. For determining the flakiness index, each aggregate particle was gauged on thickness gauge and the particles that pass through gauge are separated as flaky particles. Then weight of flaky particles was divided by the total weight of aggregates to obtain the value of flakiness index. Similarly, length gauge was used to determine the elongation index. The aggregate fractions were gauged individually and the particles retained on the gauge were collected separately as elongated particles. The weight of elongated particles was recorded and divided by the total weight of aggregate taken initially to calculate the elongation index. The results of flakiness and elongation tests are reported in the table.

Figure 3.6. Flakiness and elongation index test

3.2.1.5 Sand equivalent test

This test is in indicative of relative proportions of plastic fines or clay sized particles and proportion of dust in fine aggregates and granular soils that pass through the sieve # 4 (4.75 mm). A measured volume of fine aggregate was placed into a graduated plastic cylinder and followed by agitation to loosen the claylike coatings or clay size particles from the test sample. Then, an extra flocculating solution is added to the specimen to irrigate it meanwhile generating suspension in the claylike or clay size material above the sand. Once the sedimentation period is finished, the height of flocculated material is measured while the height of sandy particles in the cylinder is also noted. The sand equivalent value is computed by dividing the height of sand by the height of flocculated material and multiplying it by 100.

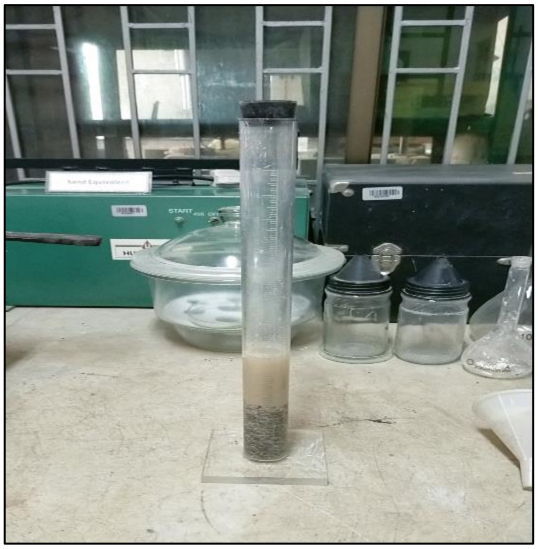


Figure 3.7. Sand equivalent test

3.2.1.6 Specific gravity and water absorption test (Coarse aggregates)

The weight of given volume of aggregate to the weight of an equal volume of water is termed as specific gravity of aggregate. The value of specific gravity is used by HMA design engineers in determining all the volumetric properties such as air voids, VMA and VFA. Water absorption is indicative of water holding capacity. A high water absorption shows that aggregates are porous in nature and not suitable for roads construction.

The specific gravity of coarse aggregates was determined according to ASTM C 127. An aggregates' sample of 2 kg was taken which retained on sieve # 4 (4.75 mm). The coarse aggregates’ sample was submerged in water for 24 hours approximately. Then the sample was taken out of the water container and rolled up into the absorbent cloth until no free water was left on the surface of aggregates. Mass of sample (B) in the saturated surface dry state was noted down. After that, the sample was immersed in water with the help of a wire basket. The weight of aggregates’ sample (C) under submerged condition was measured. Then the aggregates were shifted to an oven and dried to a constant weight at 110 ˚ C. The weight of sample (A) was again noted. The specific gravity and percentage water absorption were calculated by using these weights and reported in the table.

Specific gravity = $A / (B - C)$

Water absorption (%) = $[(B - A) / A] * 100$

Figure 3.8. Specific gravity and water absorption test (Coarse aggregate)

3.2.1.7 Specific gravity and water absorption test (Fine aggregates)

The specific gravity of fine aggregates was measured in accordance with ASTM C 128. Almost 1000 grams of fine aggregates, i.e. passing sieve no. 4 (4.75 mm) were taken. Fine aggregate sample was heated to a temperature of 110˚ C until it reached a constant mass. Moisture was added to it @ 6 % by total weight of fine aggregates after which it was permitted to stand for almost 24 hours. The sample was spread on an absorbent cloth and stirred frequently until it attained saturated surface dry condition.

Afterwards, a portion of water was added to the pycnometer and 500 grams of fine aggregates (S) were introduced into it. Further water was added up to 90 % capacity of pycnometer and agitated it manually. Afterwards, the level of water was elevated up to its calibrated capacity. The total weight of pycnometer, test sample and water (C) was recorded. The fine aggregates were removed and heated to a temperature of 110 ˚ C in an oven. The oven dried weight (A) was measured. The weight of pycnometer that was filled with water up to its calibrated mark (B) was also determined. The specific gravity and water absorption of the sample was computed by using following formula:

Specific gravity = S / (B + S – C)

Water absorption (%) = (S – A) / A

Figure 3.9. Specific gravity and water absorption test (Fine aggregate)

3.1.1.8 Coarse aggregate angularity test

This testing procedure involves measuring the mean density of a given amount of fine aggregate particles (excluding the volume of air spaces that exist between the particles). It also includes determining the relative density (specific gravity) and water absorption capacity of coarse aggregate. The specimen was dried enough to ensure a clean separation between coarse and fine material during sieving process. The sample was sieved using the sieve no. 4 (4.75 mm). Sample was washed to eliminate any residual fine particles and was subsequently dried to constant weight. The weight of the test sample was measured, and further weight determinations were made with an accuracy of 0.1 % of the original dry weight of sample taken initially. Upon drying, the test sample was spread on a clean level surface with ample space so that careful inspection of can be made. In order to confirm whether a particle fulfills the requisite criteria, each of the particles was held such that the face was observed clearly. A particle was considered to have a fractured face if its exposed surface constituted at least one quarter of its maximum cross sectional area. The weight or number of particles that were regarded as fractured particles was measured. Conversely, the weight or number of the particles that did not meet the criteria of fractured particles was also recorded. Mass of particles belonging to fractured particles category was used to calculate their total percentage with the given formula:

$P = (F / F + N) * 100$

Where;

P = Percentage of particles that fulfill the criteria of fractured faces

F = Mass of particles that fulfill the specified criteria of fractured faces

N = Mass of particles that did not meet the fractured particle criteria.

Figure 3.10. Coarse aggregate angularity test

3.2.1.9 Fine aggregate angularity test

Fine aggregate angularity was calculated by measuring the loose uncompacted void proportion of fine aggregate sample. This test was performed according to AASHTO T 304. The value of fine aggregate angularity is an indicative of particle shape when test is conducted on an aggregate specimen of a known standard grading, categorized as Method A. The Superpave asphalt mix design method has provided guidelines regarding minimum requirements for void content that depend on various factors such as traffic loads as well as depth from the surface of the asphalt pavements.

In this method, the sample being tested was allowed to fall freely through a funnel of standard size having pre-determined diameter, from a specified height into a small calibrated cylinder. The volume of calibrated cylinder was already known i.e., 100 mL. Upon leveling the material with the top of the cylinder, it was weighed with precision. Since the mass and volume of the cylinder were known already, the mass of the sample within the cylinder was calculated.

The volume of the material inside the cylinder was calculated by using the bulk specific gravity which had been evaluated as per AASHTO T 84. The volume of voids was calculated by subtraction of calculated volume of material from volume of the graduated cylinder as follows:

Uncompacted voids content: $U = (V - (F / G)) / V) * 100$

Where;

V = Volume of calibrated cylinder in mL (cubic centimeters)

F = Net weight of sample in cylinder (gross weight minus weight of empty cylinder)

G = Bulk dry specific gravity as determined by AASHTO T 84

U = Uncompacted voids in percent (reported to nearest 0.1%)

Table 3.1. Test results of aggregates

Sr. no.	Test Description	Results	Specification	Standards
1	Aggregate impact value	24.36 %	30 % (Max.)	BS 812
2	Crushing strength	19.78 %	30 % (Max.)	BS 812
5	Los Angeles abrasion	21.41 %	45 % (Max.)	ASTM C 131
6	Specific gravity of coarse aggregate	2.69	-	ASTM C 127
7	Water absorption of coarse aggregate	0.85 %	3 % (Max.)	ASTM C 127
8	Specific gravity of fine aggregate	2.65	-	ASTM C 128
9	Water absorption of fine aggregate	2.69 %	3 % (Max.)	ASTM C 128

Table 3.2. Superpave aggregates consensus properties

Sr. No.	Test Description	Results	Specification	Standard
1	Flakiness index	5.13%	10% (Max.)	ASTM D 4791
2	Elongation index	3.06%	10% (Max.)	ASTM D 4791
3	Combined flakiness and elongation index	8.19%	10% (Max.)	ASTM D 4791
4	Sand equivalent	90%	50% (Min.)	ASTM D 2419
5	Fine aggregate angularity (by uncompacted void content method)	46	45 – 47	AASHTO T 304
6	Coarse aggregate angularity	100	100 (Min.)	ASTM D 5821

3.2.2 Asphalt binder testing

Bitumen is used as a binder in flexible pavements worldwide. It is blackish or dark brownish in color and is produced from residues distillation of petroleum. It occurs naturally is asphalt lakes or produced in petroleum refineries from residue of crude oil. Consistency, safety and purity of bitumen are the properties which are necessary for engineering and construction purposes. These properties chiefly affect the asphalt mixture performance. A variety of tests were performed to check the suitability of binder for asphaltic concrete mix. Tests on binders are usually performed at 25˚C temperature to compare consistencies of asphalt binders as consistency changes with temperature. For the whole of research, the penetration grade used was Parco 60/70.

3.2.2.1 Penetration test

This test was conducted to determine the consistency of bitumen. A standard needle was penetrated vertically in the sample of asphalt binder whereas the specified conditions of loading, time, and temperature had been met simultaneously. The penetration distance of needle was measured in tenths of a millimeter. This test is used to classify the bitumen into different grades. It provides a way to classify the asphalt binder and measure its quality. Greater values of penetration represent softer consistency of specimen. Bitumen of higher grades is generally recommended for regions of cold climate and bitumen with smaller grades is preferred for high temperature areas. For penetration test, standard requirement of temperature is 25°C but this test can also be conducted at some other temperatures such as 0°C, 4°C and 46°C by changing the load of needle and penetration. ASTM D5 & AASHTO T 49-93 were the test standards followed for this test. Bitumen samples of PARCO 60/70 were conditioned in a thermostatically controlled water bath, for duration of 60 to 90 while the temperature was kept 25°C meanwhile. These were further tested to calculate their penetration values by using a needle load of 100±0.1 grams and specified time period of 5 seconds.

Figure 3.11. Penetration test

3.1.2.2 Flash and fire point test

This test was performed as per ASTM D 92 by using Cleveland Open Cup (COC) apparatus. Flash point is that temperature at which fumes of bitumen sample in COC ignites spontaneously upon exposure to an open flame. While fire point is the temperature at which surface of binder catches fire and give flames for at least 5 seconds. A brass cup was filled with bitumen up to a certain volume. It was then heated at a constant rate and a test flare 30 was passed above it at definite intervals. When the above mentioned conditions were attained, the temperature at which flash and fire occurred was noted. Three different trials were carried out to note these temperatures for each of the binder. It has been recommended in specifications that flash point should be higher than 232°C. These results are also given in Table 3.2.

Figure 3.12. Flash and fire point test

3.1.2.3 Softening point test

Bitumen is a material with visco-elastic property, but as the temperature go higher it progressively becomes softer and its viscosity reduces. The temperature at which standard sized sample of asphalt binder cannot support the weight of 3.5 g steel ball is called the softening point of bitumen sample. Hence softening point refers to the mean temperature at which the two disks of bitumen soften in such a way that the steel balls can fall a distance of 25 mm. For determination of softening point complying with

AASHTO-T-53 specifications, ring and ball apparatus was used. The results of softening point test have been presented in table 3.2.

Figure 3.13. Softening Point test

3.1.2.4 Viscosity test

The viscosity of bitumen was found in conformity with standard procedure of AASHTO T-316 through rotational viscometer at raised temperatures. The viscosity at high temperature is significant since it directly influences the workability, pumping and. It can be performed at a range of temperatures but for Performance Graded bitumen, it is better to perform at 135°C and 160°C because of similar production temperature, regardless of the environmental conditions. For this purpose, Brookfield RV apparatus was used as per ASTM D 4402 and AASHTO T 316. First of all, the sample chamber, the spindle and the environmental chamber was heated to 135°C and 160°C. The bitumen sample was then heated to such extent that it can flow easily. Then it was poured appropriately in the sample chamber after stirring it so that all the air bubbles are removed from it. The sample was then shifted to the temperature controlled unit and a spindle No. 27 was carefully lowered into sample. It was then brought to the chosen temperature (135°C or 160°C) within thirty minutes and then allowed to equilibrate at that temperature for ten minutes. Spindle was rotated at 20 rev/min, so that percent torque remained between 2 and 98 percent. Three readings were taken when the sample had reached temperature and equilibrated, with a gap of one minute between each reading. The average of three readings was reported as viscosity. The results are shown in tables.

Figure 3.14. Viscosity test

3.1.2.5 Ductility Test

Ductility is an important property of asphalt binder and a necessary feature to depict the in-field performance of HMA mixture. Ductility of bitumen shows its behavior of bitumen under varying temperature conditions. Generally it refers to the maximum distance that a sample of asphalt binder can stretch without fracturing when subjected to a specific rate of tension while the temperature is maintained at 25°C. The results of ductility testing have been tabulated in Table 3.2. All the samples satisfied the minimum criteria of ductility i.e., 100 cm.

Figure 3.15. Ductility test

Table 3.3. Test results of bitumen

Sr. No.	Test Description	Results	Specification	Standard
1	Penetration	62	60 – 70	ASTM D5
2	Flash point	362 ℃	> 232 ℃	ASTM D 92
3	Fire point	388 ℃	-	ASTM D 92
4	Softening point	51 ℃	49 - 56 ℃	ASTM D 36 – 06
5	Viscosity	2.28 Pa.sec	≤ 3 Pa.sec	ASTM D 4402
6	Ductility	124 cm	> 100 cm	ASTM D 113 – 99

3.1.2.6 Theoretical maximum specific gravity test

The purpose of this test is to evaluate the theoretical maximum specific gravity and density of uncompacted asphalt mixtures at a temperature of 25°C. To perform the test, an oven-dried sample of loose mix was placed in a vacuum vessel and water was added to submerge the sample thoroughly at 25±4°C. The vacuum pressure in the vessel was gradually decreased to 30 mm Hg or less over for a duration of 5 to 15 minutes. After the vacuum period, the pressure was systematically decreased and the sample's volume was measured by filling the vacuum container to its top level with water and weighing it in the air.

The weight and volume of sample were used for the calculation of specific gravity at temperature of 25°C.

Theoretical maximum specific gravity = A / (A + D - E)

Where;

A = mass of oven dry sample in air, g

D = mass of container filled with water at 25 °C

E = mass of container filled with sample and water at 25 °C

Figure 3.16. Theoretical maximum specific gravity test

3.1.2.7 Bulk specific gravity test

This testing method is used for calculation of bulk specific gravity (Gmb) of compacted asphalt through the utilization of suspension method. The specimen whose bulk specific gravity was to be measured was cooled in air to a temperature of 25 ±5°C and its dry weight (A) was recorded to the nearest 0.1 g. Water was added in water bath up to top level at 25 ±1°C and it was left to stabilize. The balance was tared with the immersion apparatus attached. Afterwards, the specimen was placed in the suspension apparatus for 4 ±1 minutes. The submerged weight (C) was recorded to the nearest 0.1 g. The sample was removed from the water and immediately surface dried promptly using a damp cloth towel within a time period of 5 seconds. The balance was reset to zero again. The weight of the saturated surface-dry sample (B) was measured to nearest 0.1 g immediately. Bulk specific gravity and percentage of water absorption are calculated as following:

$Gmb = A / (B – C)$

Percent water absorbed (by volume) = $((B – A) / (B – C)) * 100$

Where;

A = mass of oven dried sample in air

B = mass of saturated surface-dry sample

C = mass of sample submerged in water

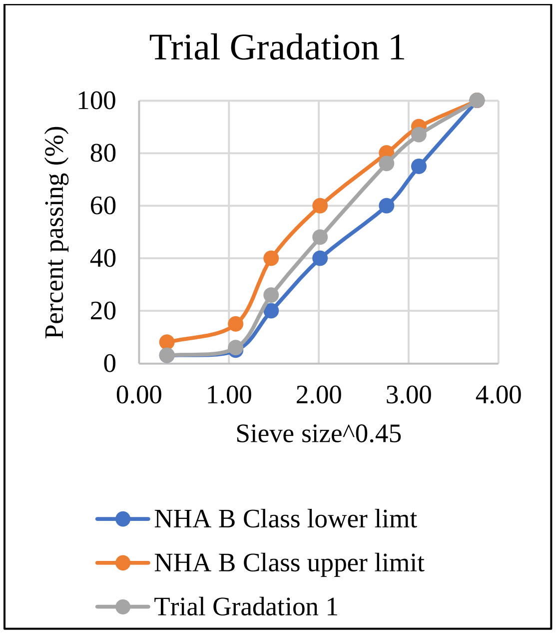
Figure 3.17. Bulk specific gravity test

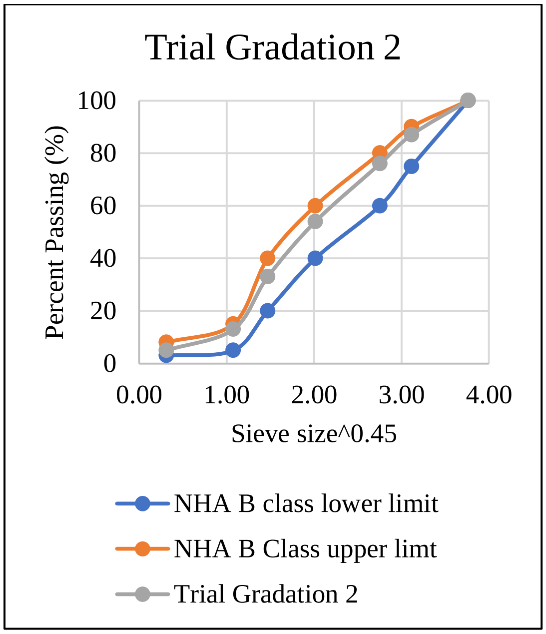
3.3 Gradation selection

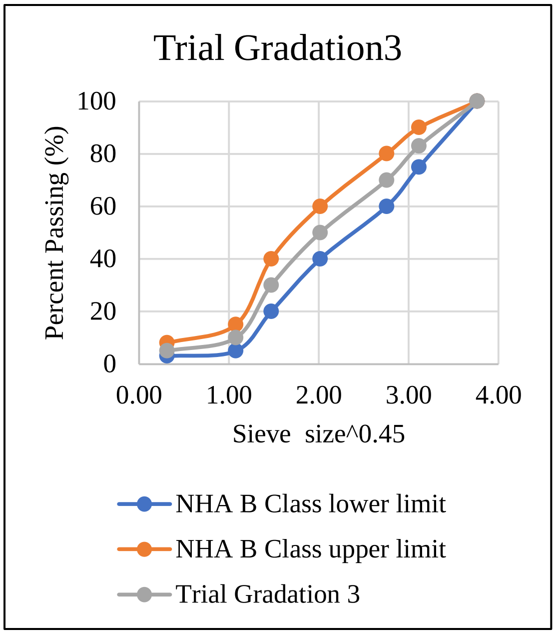
Since our primary objective was to make a comparison of both mix design methods by following same mechanism, we adopted similar aggregates gradation for preparation of both kinds of specimens. In Pakistan, there are two basic gradations specified by National Highway Authority (NHA), which are classified as A class and B class. NHA A class gradation is a finer gradation and generally used for design of base course as well as subbase course. NHA B class gradation is coarser one and mostly used for the design of wearing courses (NHA 1998). In addition, use of NHA B class gradations is recommended in Pakistan because of higher resistance against rutting and favorable outcomes of moisture susceptibility tests (M. K. Khan 2019). The corresponding gradation of NHA B class gradation was “SP-12.5 mm”. Since Superpave design system makes use of control points and restricted zone while choosing gradation (M. Hossain et al. 2017), we selected gradation in such a way that it conformed to both Marshall and Superpave criteria simultaneously. Initially, three different trial blend gradations were used to prepare Superpave samples using Gyratory compactor. Trial asphalt binder content was taken as 4.5%. The gradation that yielded most suitable results in terms of air voids, VMA and VFA .i.e. third one was finally chosen for the whole research work.

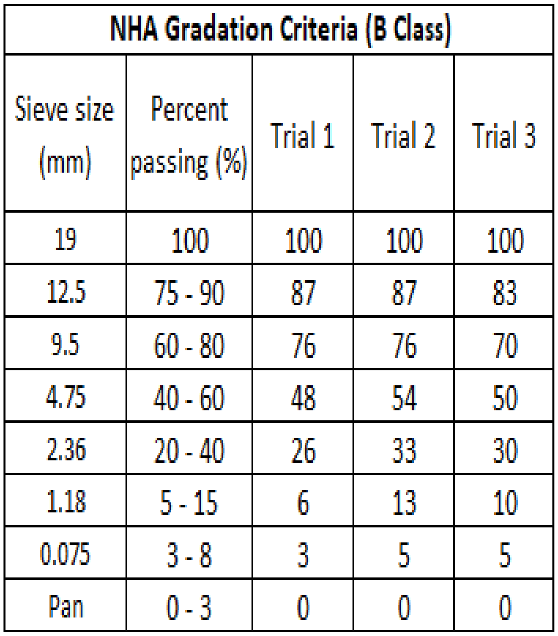
Table 3.4. NHA B class gradation criteria

Sieve size (mm)	**Min. (Passing %)**	**Max. (Passing %)**
19	100	-
12.5	75	90
9.5	60	80
4.75	40	60
2.36	20	40
1.18	5	15
0.075	3	8
Pan	0	3









NHA Gradation Criteria (B Class)				
Sieve size (mm)	Percent passing (%)	Trial 1	Trial 2	Trial 3
19	100	100	100	100
12.5	75 - 90	87	87	83
9.5	60 - 80	76	76	70
4.75	40 - 60	48	54	50
2.36	20 - 40	26	33	30
1.18	5 - 15	6	13	10
0.075	3 - 8	3	5	5
Pan	0 - 3	0	0	0

Figure 3.18. Trial gradations curves

Table 3.5. Superpave trial blends compaction data

Property	**Trial 1**	**Trial 2**	**Trial 3**	**Superpave Criteria**
Asphalt content (Pbi)	4.5	4.5	4.5	-
Average bulk specific gravity (Gmb)	2.372	2.378	2.38	-
Theoretical maximum specific gravity (Gmm)	2.54	2.51	2.49	-
Air voids (%)	6.61	5.26	4.42	4%
Voids in mineral aggregate (%)	15.159	14.944	14.872	> 13 %
Voids filled with asphalt (%)	56.395	65	70.279	65 - 75 %
% Gmm @ Nini	82.79	85.18	87.952	< 89 %
% Gmm @ Ndes	93.39	94.74	95.58	< 96 %

The purpose of making trial gradations was to check the volumetric properties at different aggregates blends. Since our aim was to make a comparative evaluation of Marshall and Superpave Mix Design methods using similar aggregates' gradation, we had to select the most suitable one among these three gradations which we could adopt for both mix design methods.

It is evident from the tables that the trial gradation 3 fulfills all the requirements of Superpave mix design regarding air voids, voids filled with asphalt (VFA) and voids in mineral aggregates (VMA). Therefore it was selected to make Superpave samples as well as Marshall samples.

Table 3.6. Volumetric properties at expected optimum asphalt content

Property	**Value**	**Superpave Criteria**
Asphalt content (Pb.est)	4.67%	-
VMA	14.79%	> 13 %
VFA	70.11%	65 - 75 %
% Gmm @ Nini	88.37%	< 89 %
Asphalt Ratio	1.07	0.6 - 1.2

3.4 Preparation of Samples

For preparation of Superpave specimens, according to AASHTO T 283, the aggregates were heated to mixing temperature i.e. 160 ℃ for two hours. Asphalt binder was also heated to 160 ℃ for one hour approximately. Afterwards, the aggregates and the binder were combined together and mixed thoroughly by a mechanical mixer at the mixing temperature. The hot asphaltic mixture was immediately shifted to an oven and heated to compaction temperature of 135 ℃. Asphalt mix was conditioned for a period of two hours and then it was transferred from oven to Superpave mold and compacted using Superpave Gyratory Compactor at N_{des} (125) gyrations. During compaction, the loading pressure was kept 600 kPa and the gyratory internal angle was set to be 1.18˚. After completion of required number of gyrations, the sample was then extracted using sample extractor.

For preparation of Marshall specimens, heating of aggregates and bitumen was done in a similar manner followed by thorough mixing as well as conditioning of asphalt mix in oven for two hours. Then the paving mix was shifted to a pre-heated Marshall mold of 2.5” height and 4” diameter, fixed with a collar and placed in Automatic Marshall Compactor. The sample was then subjected to 75 blows on both sides by using Marshall hammer of weight 10 lb falling from a height of 18”. The collar was removed and sample was extracted gently. The temperature was continuously noted during mixing and compaction processes by means of a temperature gun to ensure heating to desirable temperature.

3.5 Superpave optimum bitumen content

Once the design aggregate structure had been decided upon, trial blend properties were estimated using following formula;

$$Va = \frac{(Gmm - Gmb) * 100}{Gmm}$$

$$VMA = 100 - [\frac{Gmb * Ps}{Gsb}]$$

$$VFA = VMA - Va$$

Where;

Va is the air void content (%)

Gmb is bulk specific gravity (g/cm^3)

Gmm is the maximum theoretical specific gravity (g/cm^3)

Ps is the percent of aggregate by total weight of mixture

Gsb is the bulk specific gravity of aggregate.

Following equation was used for calculation of estimated optimum bitumen content;

$$Pb\ (est.) = Pbi - [0.4 * (4 - Va)]$$

The estimated bitumen content was found to be 4.7. Where Pbi is the trial asphalt content (4.5%) and Va was found to be 4.42 at trial asphalt content for the selected aggregate structure. Eventually, estimated bitumen content was found to be 4.7% approximately. The next requirement was to evaluate the optimum binder contentwhich involved preparation of two specimens at each of the following asphalt contents:

- Estimated asphalt content - 0.5 %
- Estimated asphalt content
- Estimated asphalt content + 0.5 %
- Estimated asphalt content + 1 %

The Superpave compaction criteria are based on three specific stages of compaction effort: an initial (N_{ini}), design (N_{des}) and maximum (N_{max}) number of gyrations. The design asphalt content that satisfies the volumetric criteria at N_{ini}, N_{des} and N_{max} in the most suitable manner is selected as the optimum asphalt content (R. J. Cominsky et al. 1994). Number of gyrations are chosen on the basis of anticipated project traffic level. All the samples are subjected to N_{des} gyrations (125) using Superpave Gyratory Compactor and their volumetric properties at N_{ini} and N_{des} are evaluated (M. Hossain 2017). The bulk specific gravity (Gmb) of these samples was found as per AASHTO T 166. Two loose samples of asphalt mix are also required at each of the above mentioned bitumen contents to find out theoretical maximum specific gravity (Gmm). These data are used to manipulate the percentage of air voids (Va), VMA and VFA in the compacted paving mixture. These data points are used to plot graphical curves of percent air voids, VMA and VFA versus bitumen content. The optimum bitumen content is established at 4 % air voids or 96 % of theoretical maximum specific gravity. Moreover, all other mix properties are checked at optimum bitumen content either they fulfill the volumetric criteria or not (R. J. Cominsky et al. 1994).

Figure 3.19. Specimens preparation for Superpave asphaltic concrete mixture

3.6 Marshall optimum bitumen content:

For the selected design gradation, three samples were prepared at each of the following asphalt binder contents: 3.5 % , 4 % , 4.5 % , 5 % and 5.5 %. For density-voids analysis, bulk specific gravity (Gmb) of each specimen was found out in accordance with AASHTO T 166 after cooling of freshly compacted Marshall samples to room temperature. Loose asphalt mix samples were also prepared at each asphalt content to estimate theoretical maximum specific gravity (Gmm) as per AASHTO T 209. Furthermore, all the specimens were tested in Marshall Stability Machine for determining their stability and flow values in conformity with ASTM D 1559. To demonstrate the relationship between asphalt content and above mentioned variables, graphical curves were plotted between the average values of air voids, voids in mineral aggregates, voids filled with asphalt, Gmb, Marshall stability and flow against the asphalt content separately. In order to illustrate the trend between asphalt content and each of these key properties, a smooth curve was traced along the plotted data points.

The mean value of asphalt content that corresponds to air voids of 4% is deemed to be the optimum bitumen content. Stability and Flow values were then computed through graphical interpretation at the optimum asphalt content and checked whether they comply with the design sepecifications of AASHTO. On verifying all these parameters and controls, the asphalt content is ultimately regarded as design asphalt content (J. G. Speight 2016).

Figure 3.20. Marshall asphalt mix samples and Marshall stability machine

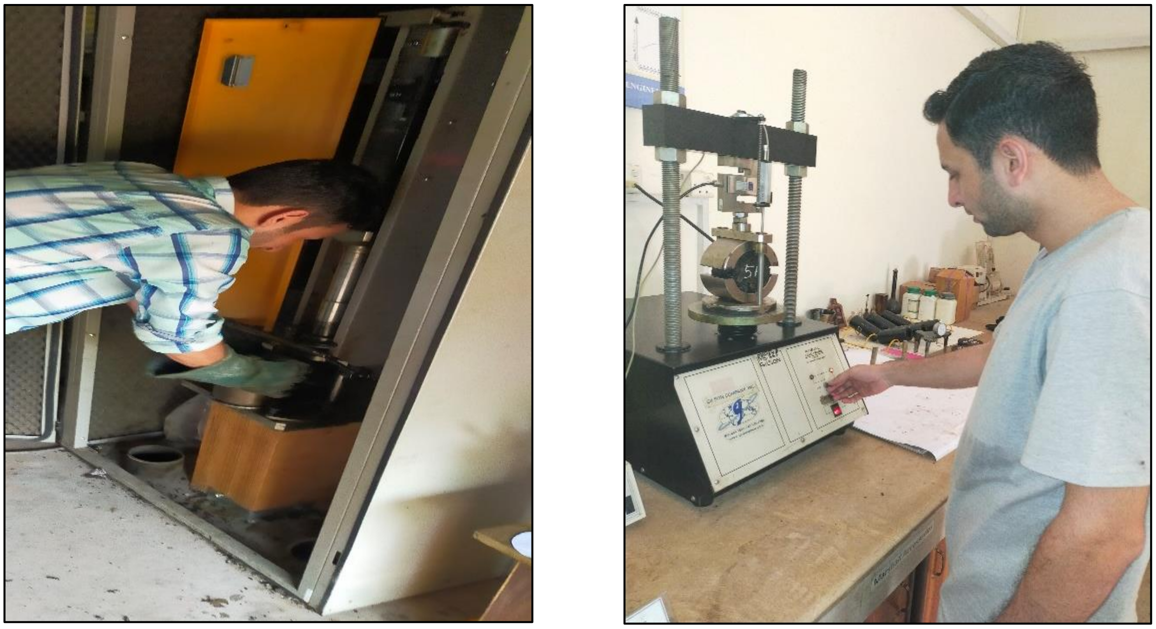


Figure 3.21. Preparation of Marshall samples and testing

3.7 Performance tests

To carry out performance testing, Marshall and Superpave samples were prepared at their respective optimum asphalt content i.e. 4.54 % for former and 4.41 % for latter. Samples' height requirement was fulfilled according to ASTM D 6931. Core cutting technique was used to reduce the height of Superpave samples to the required height. The procedure for both tests has been described below:

Figure 3.22. Core cutting of compacted asphalt sample

3.7.1 Indirect tensile strength testing

In order to perform ITS test, ASTM D 6931 was used which involved application of compressive load using compression testing machine (UTM-25) of 25kN loading capacity. All the samples were tested in UTM at a deformation rate of 50 mm per minute while maintaining a temperature of 25°C. For each mix design, six replicates were required including three unconditioned samples and three conditioned ones. A total of 12 samples were used for ITS evaluation. Samples' height requirement was fulfilled according to ASTM D 6931.

- For Marshall mix design, cylindrical specimens having diameter of 4" (101.6mm) and height 2.5" (63.5mm) were tested.

- For Superpave mix design, specimens of diameter 6” (150mm) and height 3” (75mm) were required. Therefore, Superpave samples of height 115±5 mm were reduced to a height of 75 mm by means of a saw cutter.

The conditioned samples were immersed in water bath at 60°C for a period of 24 hours and then transferred to a thermostatically controlled chamber at 25°C for a duration of 4 hours. The unconditioned specimens were placed in temperature controlled air chamber for 4 hours at 25°C. After achieving the desired conditions, specimens were placed onto the lower loading strip of UTM.

The top loading strip was slightly lowered such that it made a light contact with the sample. The loading strips were aligned in a parallel position and placed at the center along the vertical diametral plane. The time elaspsed from removing the test samples from the water bath to the determination of final load did not exceed 2 minutes. A vertical compressive ramp load was applied in a ramp-like pattern until the load attained the maximum value. This peak load at which sample ruptured, was recorded and used in above mentioned equation to get a measure of indirect tensile strength.

Figure 3.23. Indirect tensile strength and tensile strength ratio test

3.7.2 Resilient modulus testing

The repeated-load indirect tension resilient modulus tests (M_R) on Marshall and Superpave samples were conducted in conformity with ASTM D 7369. test of asphalt mixtures incorporates repeated application of compressive loads in a haversine waveform pattern. The heights of both kinds of samples were selected as suggested by ASTM D 7369.

- For Marshall mix design, cylindrical specimens with a diameter of 4” (101.6mm) and height 2.5” (63.5mm) were tested.
- For Superpave mix design, specimens of diameter 6” (150mm) and height 3” (75mm) were required as suggested by ASTM D 6931. Therefore, Superpave samples of height 115±5 mm were reduced to a height of 63.5 mm by means of a saw cutter.

The peak force was taken as 20% of the ITS test failure. The Poisson’s ratio had been calculated already and it was estimated to be 0.40. Cylindrical samples of asphalt concrete were subjected to a compressive load along a vertical diametral plane. Subsequently, the deformations in both the horizontal and vertical directions were then measured. Afterwards, the resilient modulus of these samples was determined by measuring the total recoverable deformation, which included the instantaneous recoverable and time-dependent continuing recoverable deformation that occurred during the unloading or rest period of a single cycle.

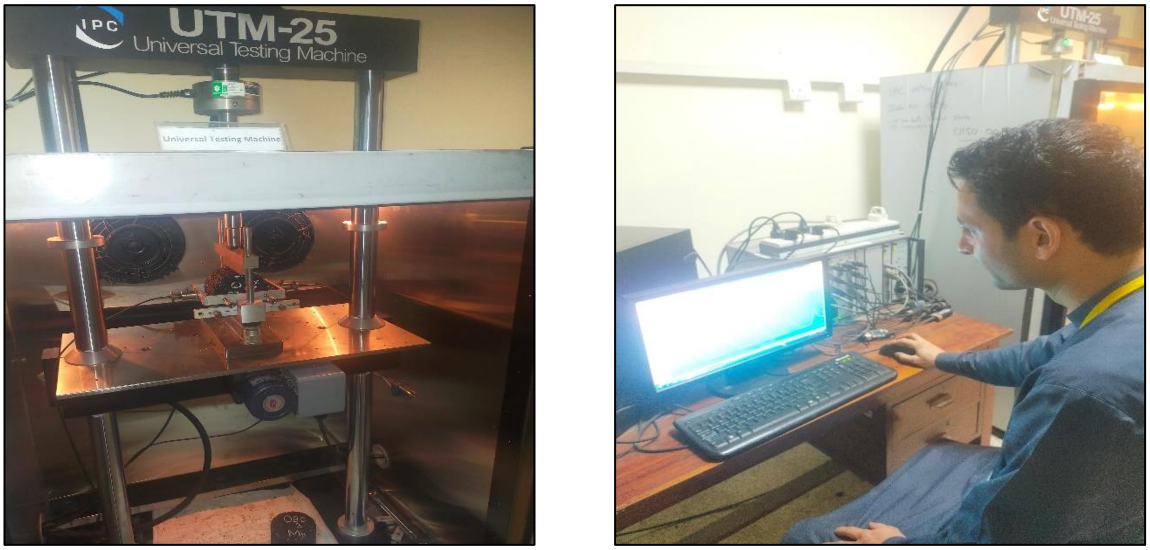


Figure 3.24. Resilient modulus test

3.8 Test matrix

Test matrix formulated for preparation of Marshall as well as Superpave specimens has been shown belown. 6 samples were prepared for selection of gradation. 23 samples were prepared for determination of optimum bitumen content and 18 samples were prepared to accomplish performance based tests.

Table 3.7. Test matrix for gradation selection

Compaction technique	Aggregate Structure	Bitumen Content (%)	No. of samples
Superpave	Trial Gradation 1	4.5	2
	Trial Gradation 2	4.5	2
	Trial Gradation 3	4.5	2
Total			6

Table 3.8. Test matrix for determination of OBC

Sr. No.	Mix Design	Bitumen Content (%)	No. of samples
1	Marshall	3.5	3
		4	3
		4.5	3
		5	3
		5.5	3
2	Superpave	4.2	2
		4.7	2
		5.2	2
		5.7	2
Total			23

Table 3.9. Test matrix for performance evaluation

Sr. No.	Mix design	Tensile strength ratio test		Resilient modulus Test	Total No. of Samples
		Conditioned	Unconditioned		
1	Marshall	3	3	3	9
2	Superpave	3	3	3	9
Total					18

3.9 Summary

This chapter covers the tests used to characterize the physical properties of aggregates and bitumen. Moreover, the gradation selection mechanism was discussed in detail. Afterwards, the procedure to determine OBC was described for both design methods was described. Later sections provide information about the specifications regarding performance testing and the test matrix for the preparation of specimens of both kinds.

CHAPTER 4: RESULTS AND ANALYSIS

4.1 Introduction

This chapter outlines all the results of volumetrics-based analysis and performance evaluation. Optimum asphalt content was evaluated for these design methods and volumetric properties corresponding to optimum asphalt content were manipulated with the help of graphical curves. Moreover, samples were prepared for both mix design at their respective optimum content. Results of Marshall and Superpave mix design methods encompassing volumetric properties and the performance based results are outlined subsequently in separate sections.

4.2 Volumetric properties and optimum asphalt content

The procedure of determining the optimum asphalt content for both these design methods differs a lot. Superpave takes into account the aggregate configuration and predicts an expected optimum bitumen content while assessing the optimum bitumen content. In order to find out the optimum asphalt content of Superpave, an expected design content was suggested by using certain equations followed by preparation of samples at trial asphalt contents as told mentioned previously. The samples were subjected to Ndes (125) gyrations and optimum design content was established at 96 % theoretical maximum specific gravity (% G mm). The volumetric properties of all the Superpave samples have been reported in the table.

Table 4.1. Superpave asphalt mix volumetric properties

% AC	Gmb (avg.)	Gmm	Va (%)	VMA (%)	VFA (%)
4.2	2.378	2.493	4.61	14.68	68.57
4.7	2.393	2.474	3.27	14.59	77.55
5.2	2.402	2.463	2.48	14.72	83.17
5.7	2.407	2.452	1.84	14.99	87.76

Graphical curves were plotted for asphalt content versus % Gmm, VMA, VFA and unit weight. The asphalt content corresponding to 96 % of Gmm was regarded as optimum bitumen content (OBC). The values of VMA, VFA and density corresponding to OBC were manipulated and reported in table.

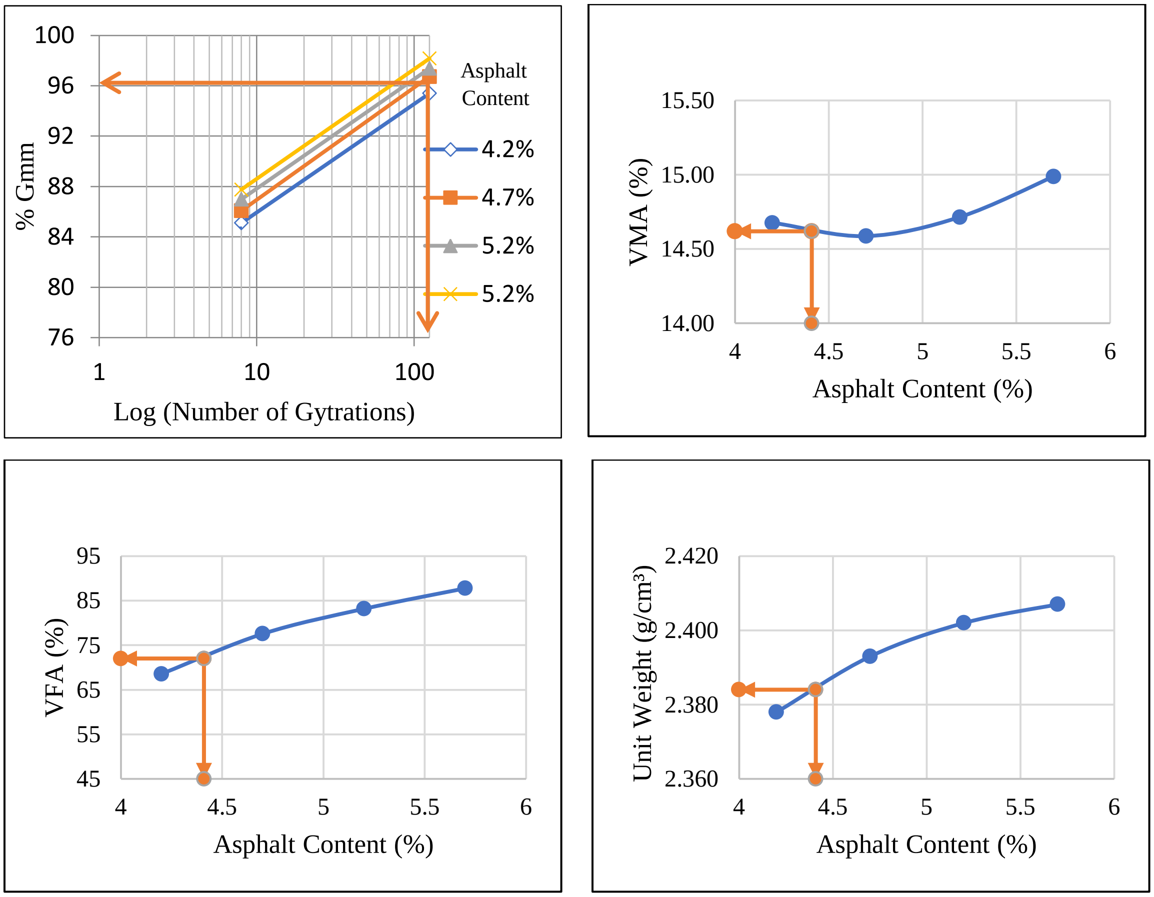


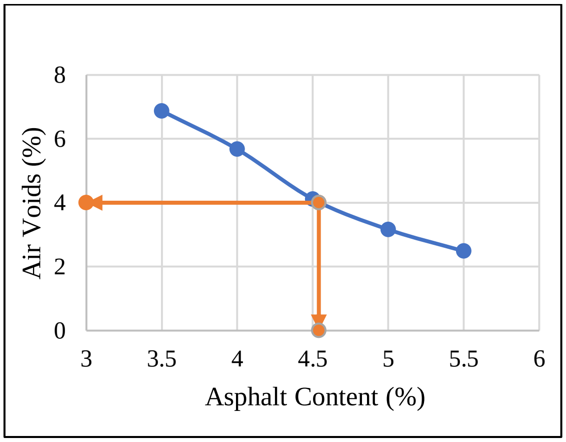
Figure 4.1. Volumetric properties of Superpave mix

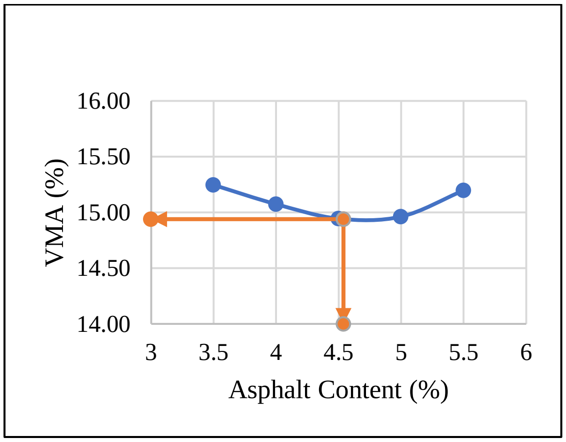
For determination of optimum bitumen content according to Marshall design method, three samples were prepared at each trial asphalt content. The mean values of air voids, voids in mineral aggregates and voids filled with asphalt have been shown in table. Moreover, Marshall stability machine was used to evaluate the Marshall stability and flow values.

Table 4.2. Marshall asphalt mix volumetric properties

% AC	**Gmb**	**Gmm**	**Va (%)**	**VMA (%)**	**VFA (%)**	**Stability (kN)**	**Flow (mm)**
3.5	2.345	2.518	6.871	15.25	54.94	8.113	2.152
4	2.362	2.504	5.671	15.07	62.38	10.321	2.421
4.5	2.378	2.48	4.113	14.94	72.48	12.842	2.894
5	2.39	2.468	3.16	14.96	78.88	11.733	3.192
5.5	2.396	2.457	2.483	15.2	83.66	9.726	3.602

For determining the OBC and corresponding volumetrics, smooth curves were drawn for asphalt content versus air voids, VMA, VFA, unit weight, stability and flow values. All these results have been summarized in the subsequent sections.





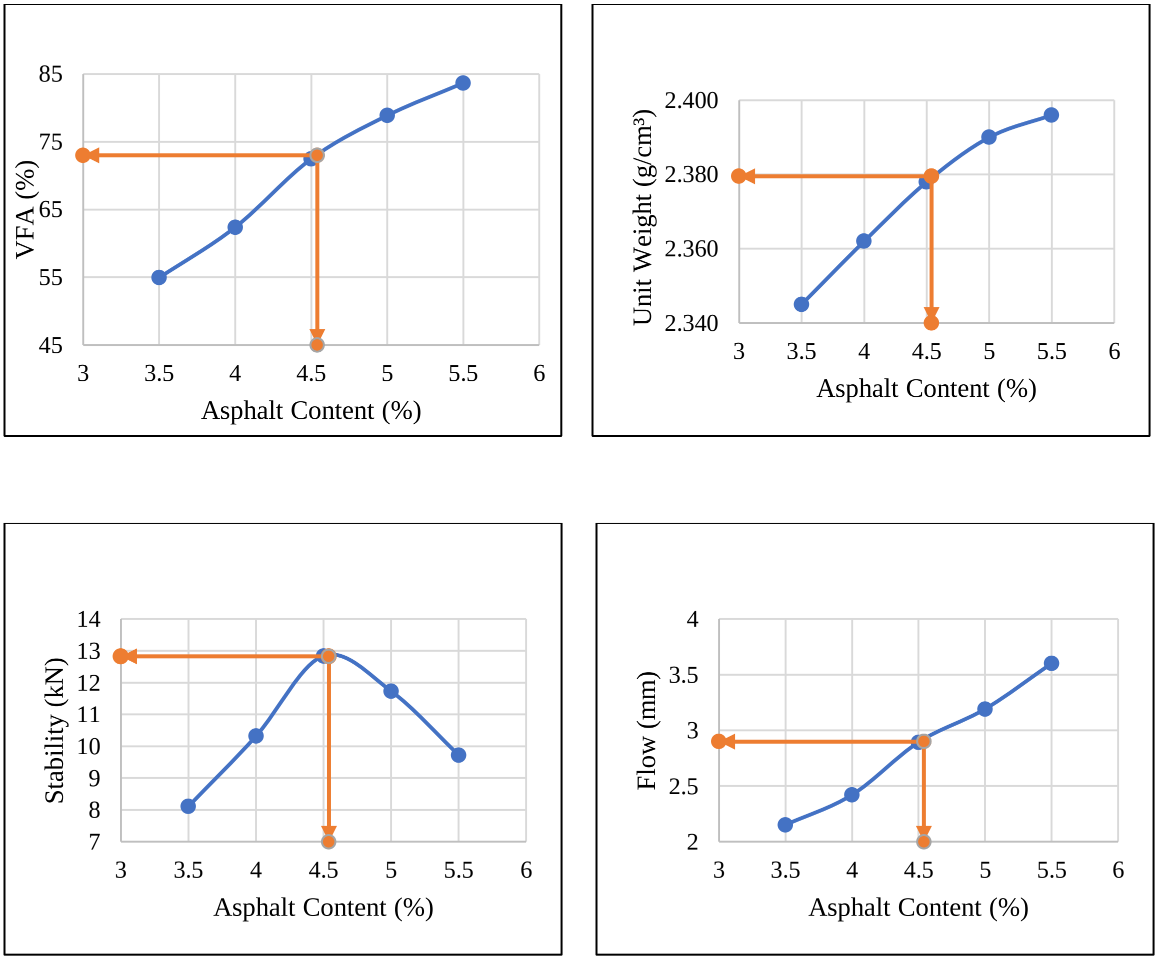
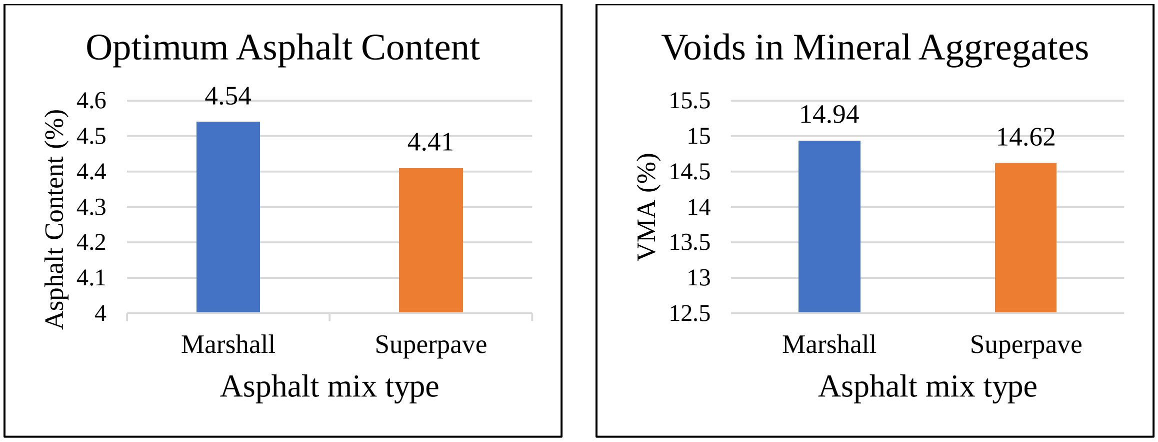


Figure 4.2. Volumetric properties, stability and flow of Marshall mix



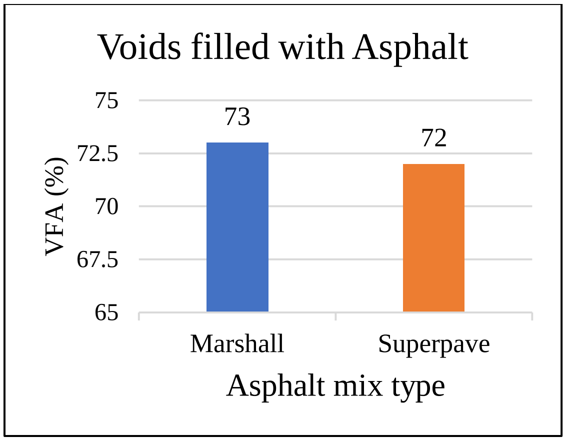


Figure 4.3. Comparison of volumetric properties

The results of volumetric properties including air voids (Va), voids in mineral aggregate (VMA) and voids filled with asphalt are summarized in table 4.1. It was observed that optimum asphalt content (OAC) calculated in conformity to Marshall mix design method was 4.54% whereas optimum content calculated according to Superpave mix design method was 4.41%. VMA of Marshall samples at OAC was estimated to be 14.94% whereas VMA for Superpave samples at OAC came to be 14.62%. VFA values of Marshall samples was 73% at OAC while those for Superpave samples was 72%. The volumetric properties of both mix design approaches have been reported in the table below to highlight the volumetrics-based comparative evaluation.

Table 4.3. Summary of volumetric properties

Property	Marshall method	Superpave method	Specified Criteria
Optimum asphalt content	4.54	4.41	-
VMA (%)	14.94	14.62	> 13 %
VFA (%)	73	72	65 - 75 %
Dust proportion	-	1.13	0.6 - 1.2
Stability (kN)	12.83	-	> 8.006
Flow (mm)	2.9	-	2 - 3.5

4.3 Indirect tensile strength test results

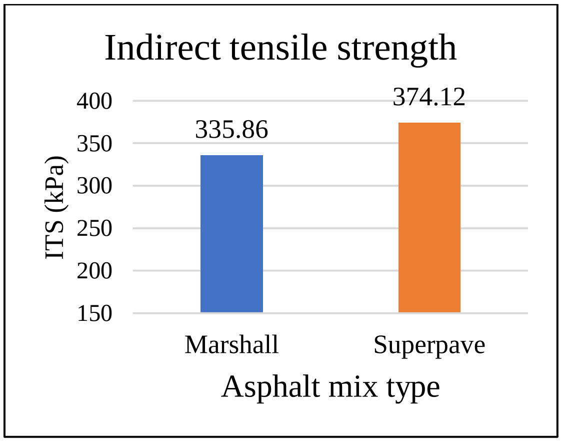
The results signify that Superpave mix design yields better indirect tensile strength as compared to Marshall mix design despite using same materials and mechanism. The average ITS value for Superpave specimens prepared at OAC was 374.12 kPa in comparison to Marshall mean value of 335.86 kPa. The tensile strength ratio (TSR) was assessed using conditioned and unconditioned samples. The acceptable criterion for TSR is minimum 80%. Both mix design specimens fulfilled the specified critetria. The results have been tabulated in table 5.

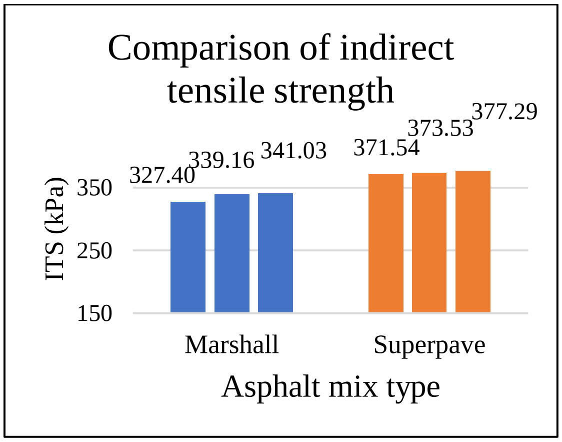
Table 4.4. ITS and TSR test results (Marshall)

Sr. No.	Type	Avg. ITS (kPa)
1	Unconditioned specimens	335.86
2	Conditioned specimens	279.82
Tensile strength ratio = TSR = 83.31 %		

Table 4.5. ITS and TSR test results (Superpave)

Sr. No.	Type	Avg. ITS (kPa)
1	Unconditioned specimens	374.12
2	Conditioned specimens	310.67
Tensile strength ratio = TSR = 83.04 %		





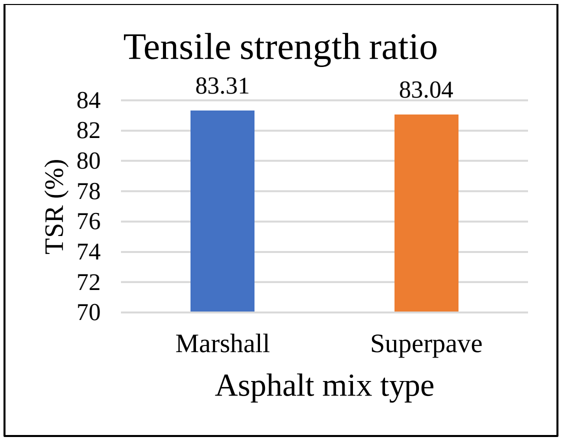


Figure 4.4. Comparison of ITS

4.4 Resilient modulus test results

The resilient modulus values of Marshall mix design samples are within the range of 2190 MPa to 2443. While on the contrary, the range of resilient modulus values for gyratory compacted specimens was 2723 MPa to 3623 MPa. The results of indirect tension resilient modulus tests are shown in table 4.6.

Table 4.6. M_R test results

Sr. No.	**Type of asphalt mix**	**Avg. MR**
1	Marshall	2310
2	Superpave	3231

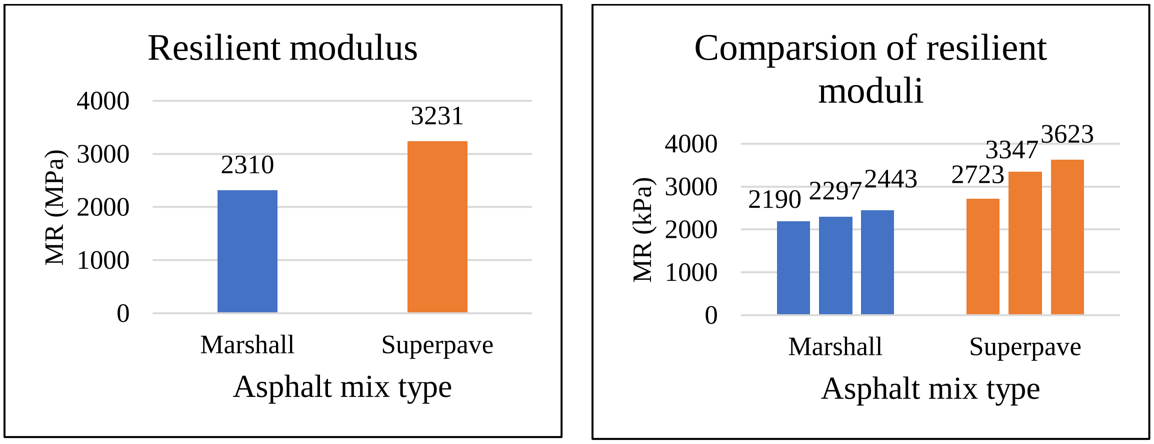


Figure 4.5. Comparison of M_R

4.5 Summary

The results of volumetric properties based analysis and performance tests have been tabulated in this chapter. Optimum bitumen content (OBC) suggested by Superpave design method was 0.13 % lesser in comparison with OBC suggested by Marshall method. exist in the optimum bitumen content of these mix designs. The values of VMA and VFA were slighltly lesser for Superpave as compared to Marshall. Superpave samples' ITS values are 10 percent higher than Marshall specimens' strength. The mean value of Superpave samples M_R (3231 MPa) was found to be 28 % higher as compared to Marshall samples average M_R (2310 MPa). The difference in terms of tensile strength ratio was almost negligible.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

Superpave mix design method yields lower optimum bitumen content as compared to Marshall method despite using same materials and identical gradation. It justifies the cost-effectiveness of Superpave mechanism of asphalt mix design. Superpave samples possess slightly lower VMA and VFA values at OAC which indicates that this method provides a more compacted asphalt mix. The compaction effort imparted by gyratory compactor results in a dense orientation of asphaltic concrete constituents.

5.2 Conclusions

Based on the volumetrics-based analysis and performance testing, following conclusions can be drawn:

i. There exists a minor difference in volumetric properties of both types of asphalt mixes when similar gradation of aggregates is used, but performance based testing results validate the superiority of Superpave method for asphaltic concrete design. Superpave method provides better results despite lower bitumen content.

ii. Higher ITS values imply that Superpave asphalt mix possesses more resistance against major pavement distresses like rutting and cracking which will eventually lead to strong and durable pavements.

iii. Furthermore, higher values of resilient modulus reveal that Superpave mix design method provides enhanced stiffness against designated traffic loads. Also it provides increased resistance against varying stress levels of traffic loading and moisture.

iv. It can be concluded on the basis of TSR results that there is insignificant difference between these design methods in terms of moisture susceptibility. This can be attributed to their nearly equal air voids percentage, VMA and VFA at OBC.

v. The aggregates’ gradation corresponding to midpoints for NHA B class gradation limits produced best results in terms of volumetrics.

vi. Huge differences in the results of performance based testing suggest that Superpave method of mix design provides durable and long-lasting pavements with extended service lives.

vii. In spite of the fact that there is slight difference of volumetric properties for both mix design techniques, the lower asphalt content of Superpave design strategy along with enhanced service life can provide economical solution for construction of low-budget pavements.

viii. Although cost analysis for small sections of roads provides a minor reduction in costs. But if we extend this analysis to large sections of multi-lane highways, Superpave proves to be an economically feasible option because of its cost effectiveness and fuel-saving.

5.3 Recommendations

i. With the drastic increase in heavy traffic vehicles and high demand of freight, there is an absolute need to adopt advanced strategies and design mechanisms for construction of pavements. Marshall method of mix design remained a remarkable design technique in previous century undoubtedly, however Superpave method has proven to be more beneficial in terms of better outcomes and performance. This study investigated both methods and emphasizes the use of Superpave design process for asphaltic pavements.

ii. Since extensive research is ongoing on Superpave design method, there is still a lot of room to refine the design practices by making use of diverse materials and their various combinations along with modified asphalt concrete mix as well as reclaimed asphalt pavement (RAP) material.

iii. Comparison should be made between these methods by using different types of gradations ranging from finer to coarser ones.

iv. Comparative study can be conducted to correlate the number of Marshall blows to Superpave compactor’s gyrations in terms of similar unit weight / densities. Equivalent compaction effort of 35, 50 and 75 Marshall hammer blows should be found that corresponds to those number of gyrations where both asphalt mixes attain equal densities. This will be helpful in finding levels of uniform compaction.

v. Cost analysis should be done for highways and pavements in long term scenario by bringing the increment in service life of Superpave pavements under consideration. The routine maintenance, periodic maintenance and rehabilitation must be kept in view.

REFERNCES

MN Department of Transportation, 2022. [Online]
Available at: http://www.dot.state.mn.us/materials/mr
[Accessed 27 November 2022].

Anon., 1998. *NHA General Specifications.* s.l.:Ministry of Communications, Pakistan.

Anon., 2014. *MS-2 Asphalt Mix Design Methods 7th Edition.* s.l.:Asphalt Institute.

Anon., 2017. Standard Tet Method for Indirect Tensile Strength of Bituminous Mixtures. In: *ASTM D 6931.* s.l.:ASTM International, p. 5.

Anon., 2019. Muhammad Kamran Khan, Arshad Hussain. *The Civil Engineering Journal,* Volume 3.

Anon., 2020. Standard Test Method for Determining the Resilient Modulus of Bituminous Mixtures by Indirect Tension Test. In: *ASTM D 7369.* s.l.:ASTM International, p. 12.

Anon., 2022. Standard Specification for Superpave Volumetric Mix Design. In: *AASHTO M 323-13.* Washington: American Association of State Highway and Transportation Officials.

Anon., n.d. *Air Voids in Asphalt-Technical Note.* [Online]
Available at: https://www.pavertrend.com.au/
[Accessed 08 November 2022].

Arshad Hussain, M. K. K., 2019. Rutting and Moisture Susceptibility Assessment of Asphalt Wearing Course Gradations. *The Civil Engineering Journal,* Issue 3, pp. 458-468.

Cominsky, R. J., Huber, G. A., Kennedy, T. W. & Anderson, M., 1994. *The Superpave Mix Design Manual for New Constructions and Overlays.* Washington DC: Strategic Highway Research Program, National Research Council.

Consuegra, A., Little, D. N., Quintus, H. V. & J. B., 1989. Comaparative Evaluation of Laboratory Compaction Devices based on their ability to produce mixtures with

Engineering Properties similar to those produced in the field. *Transporatation Research Record 1228.*

Copeland, A. & Willis, J. R., 2019. *Design andConstruction of Heavy-Duty Pavements.* s.l.:National Asphalt Pavement Association.

Gerald Huber, P. E., 2013. History of Asphalt Mix Design in North America, Part 1. *Asphalt : The Magazine of Asphalt Institute.*

Ghazi Al-Khateeb, T. K. T. I. A.-S., 2010. *Research Gate.* [Online]
[Accessed 25 November 2022].

Huber, G., 2013. History of Asphalt Mix Design in North America, Part 2. *Asphalt : The Magazine of the Asphalt Institute.*

Hussain, M., Fager, G. & Maag, R. G., 2017. *Superpave Volumetric Mixture Design And Analysis Handbook.* Kansas: KDOT and Dept. of Civil Engg. Kansas State University.

Jasim, I. F., 2012. Comparison between Marshall and Superpave Mixtures Design. *Al-Qadisiya Journal For Engineering Sciences,* 5(4).

Kassab, T. G. I., 2021. Comparative Study of Hot Asphalt Mixtures Properties Designed by Marshall and Superpave Methods. *Mansoura Engineering Journal,* 46(3).

Khan, K. M., 2012. Rutting Based Evaluation of Asphalt Mixes. *Pakistan Journal of Engineering and Applied Sciences,* Volume 11, pp. 60-65.

Khan, Z. A., Abdul Wahab, H. I. A., Asi, I. & Ramzan, R., 1998. Comparative Study of Asphalt Concrete Laboratory Compaction Methods to simulate Field Compaction. *Construction And Building Materials.*

Linden, R. N., Mahoney, J. P. & Jackson, N. C., 1989. Effect of Compaction on Asphalt Concrete Performance. *Transportation Research Record 1217.*

Lozano, J. L., 2013. *Asefma.* [Online]
[Accessed 25 November 2022].

Magdi M. E. Zumrawi, S. A. S. I., 2016. Comparison of Marshall and Superpave Asphalt Design Methods for Sudan Pavement Mixes. *International Journal of Scientific and Technical Advancements,* 2(1).

Ozdemir, D. K., 2019. *Comparative Study of Marshall and Superpave Asphalt Pavement Design Methods.* Izmir, Turkey, s.n.

Rosa Veropalumbo, N. V. a. F. R., 2019. Indirect Tensile Strength Method for Defining a Proper Practice of Asphalt Mixtures Design. In: *Materials and Contact Characterisation IX.* s.l.:WIT Press, pp. 255-265.

S Varma, H. S. J. M. A. A. G., 2019. *Experimental Investigation of Marshall and Superpave Mix Design Methods for Rutting Criteria*, s.l.: s.n.

Speight, J. G., 2016. Test Methods for Aggregate and Asphalt Concrete. In: *Asphalt Materials Science and Technology*. s.l.:s.n.

APPENDICES

APPENDIX - A

Compaction data of Superpave asphalt mix samples

Superpave mix samples compaction data @ A.C = 4.2 %			
Property	**Value**		**Superpave Criteria**
	Sample 1	Sample 2	
Asphalt Content (A.C)	4.2	4.2	-
Bulk Specific Gravity (Gmb)	2.379	2.377	-
Theoretical Maximum Specific Gravity (Gmm)	2.493	2.493	-
Air Voids (%)	4.57	4.65	4%
VMA (%)	14.64	14.71	> 13 %
VFA (%)	68.78	68.39	65 - 75 %
% Gmm @ Nini	85.36	84.84	< 89 %
% Gmm @ Ndes	95.43	95.35	< 96 %

Superpave mix samples compaction data @ A.C = 4.7 %			
Property	**Value**		**Superpave Criteria**
	Sample 1	Sample 2	
Asphalt Content (A.C)	4.7	4.7	-
Bulk Specific Gravity (Gmb)	2.394	2.392	-
Theoretical Maximum Specific Gravity (Gmm)	2.474	2.474	-
Air Voids (%)	3.23	3.31	4%
Voids in Mineral Aggregate (%)	14.55	14.62	> 13 %
Voids filled with Asphalt (%)	77.80	77.36	65 - 75 %
% Gmm @ Nini	86.14	86.01	< 89 %
% Gmm @ Ndes	96.77	96.69	< 96 %

Superpave mix samples compaction data @ A.C = 5.2 %			
Property	**Value**		**Superpave Criteria**
	Sample 1	Sample 2	
Asphalt Content (A.C)	5.2	5.2	-
Bulk Specific Gravity (Gmb)	2.400	2.404	-
Theoretical Maximum Specific Gravity (Gmm)	2.463	2.463	-
Air Voids (%)	2.56	2.39	4%
VMA (%)	14.79	14.64	> 13 %
VFA (%)	82.69	83.39	65 - 75 %
% Gmm @ Nini	87.25	86.72	< 89 %
% Gmm @ Ndes	97.44	97.31	< 96 %

Superpave mix samples compaction data @ A.C = 5.7 %			
Property	**Value**		**Superpave Criteria**
	Sample 1	Sample 2	
Asphalt Content (A.C)	5.7	5.7	-
Bulk Specific Gravity (Gmb)	2.406	2.408	-
Theoretical Maximum Specific Gravity (Gmm)	2.452	2.452	-
Air Voids (%)	1.88	1.79	4%
VMA (%)	15.02	14.95	> 13 %
VFA (%)	87.48	88.03	65 - 75 %
% Gmm @ Nini	86.74	86.74	< 89 %
% Gmm @ Ndes	98.12	98.21	< 96 %

APPENDIX - B

ITS and TSR test results (Marshall)

Type	Sample No.	ITS (kPa)	Avg. ITS (kPa)
Unconditioned specimens	1	327.40	335.86
	2	339.16	
	3	341.03	
Conditioned specimens	1	270.41	279.82
	2	283.01	
	3	286.04	
Tensile Strength Ratio = TSR = 83.31 %			

ITS and TSR test results (Superpave)

Type	Sample No.	ITS (kPa)	Avg. ITS (kPa)
Unconditioned Specimens	1	371.54	374.12
	2	373.53	
	3	377.29	
Conditioned Specimens	1	303.83	310.67
	2	311.99	
	3	316.19	
Tensile Strength Ratio = TSR = 83.04 %			

APPENDIX - C

Resilient modulus test results (Marshall)

Sample No.	MR (MPa)	Avg. MR (MPa)
1	2190	2310
2	2297	
3	2443	

Resilient modulus test results (Superpave)

Sample No.	MR (MPa)	Avg. MR (MPa)
1	2723	3231
2	3347	
3	3623	