Comparing Superpave and Marshall Mix Design methods for Trunk Road: A Study of Volumetric Properties, Mechanical Performance, and Life Cycle Cost analysis

Mahilet Merkineh Mohammed

A thesis submitted to The Department of construction Engineering and management school of civil engineering and Architecture

Presented in partial fulfillment of the Requirements of Masters of Science in Civil Engineering (Specialization in Construction Engineering and Management)

Office of Graduate Studies

Adama Science and Technology University

July, 2023

Adama, Ethiopia

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DECLARATION

I declare that this Master Thesis entitled "**Comparing Superpave and Marshall Mix Design methods for Trunk road: A Study of Volumetric Properties, Mechanical Performance, and Life Cycle Cost analysis**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Mahilet Merkineh	______________________	____________________
Name of Student	Signature	Date

RECOMMENDATION OF ADVISOR

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "**Comparing Superpave and Marshall Mix Design methods for Trunk road: A Study of Volumetric Properties, Mechanical Performance, and Life Cycle Cost analysis**" prepared under my guidance by **Mahilet Merkineh Mohammed**. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr. Meseret Getnet (PhD) ____________________ ____________________

Major advisor/supervisor Signature Date

____________________ ____________________ ____________________

Co-advisor/co-supervisor Signature Date

APPROVAL PAGE

I, the principal advisor of the thesis entitled, hereby certify that the recommendation and suggestions made by the thesis review committee are appropriately incorporated into the final thesis entitled "**Comparing Superpave and Marshall Mix Design methods for Trunk road: A Study of Volumetric Properties, Mechanical Performance, and Life Cycle Cost analysis**" by **Mahilet Merkineh Mohammed**

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APPROVAL OF BOARD OF EXAMINERS

We, the undersigned members of the board of examiners of the thesis by **Mahilet Merkineh Mohammed**, have read and evaluated the thesis entitled "**Comparing Superpave and Marshall Mix Design methods for Trunk road: A Study of Volumetric Properties, mechanical Performance, and Life Cycle Cost analysis**", and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in construction engineering and management.

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Final approval and acceptance of the thesis is contingent upon the submission of its final copy to the office of postgraduate studies (OPGS) through the department graduate council (DGC) and school graduates (SGC).

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ABSTRACT

The Marshall mix design method has been used for asphalt pavements in Ethiopia for decades, but its use in trunk roads has resulted in unsatisfactory highway performance, with a shorter pavement lifespan than anticipated. The Superpave mix design approach has been developed to address these drawbacks and provides better performance, particularly for roads exposed to high climatic changes and traffic loadings. To conduct this study, crushed basalt aggregate, asphalt binder with a penetration grade of 60/70, and hydrated lime were used as materials for both mix designs. A quality test was conducted on the selected material to ensure that they met acceptable specification criteria for Ethiopian roads. Using each mix design method, the samples are mixed and compacted individually to determine their volumetric properties. Optimum binder content was determined using a national pavement association method, and samples are prepared for performance tests. The Superpave and Marshall mix designs are compared on the basis of their volumetric properties, mechanical performance, and Life Cycle Cost. Volumetric properties are determined by measuring the air voids, voids in mineral aggregate, and voids filled with asphalt. Their mechanical performance was also evaluated by conducting wheel tracking tests, indirect tensile strength tests, and retained stability tests. The Life Cycle Cost is determined by analyzing the pavement's initial cost, maintenance and rehabilitation cost, salvage value, and road user cost. The results of all tests indicated that the Superpave mix design outperformed the Marshall mix design in terms of volumetric properties, mechanical performance, and on life cycle cost. Therefore, adopting the Superpave mix design procedure in Ethiopia can help enhance the performance of trunk road, resulting in longer-lasting, more durable pavements that can potentially save costs in the long term.

Keywords: *Marshall, Superpave, mix design, trunk road, volumetric property, mechanical performance, Life-cycle cost*

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYM

AADT – Average Annual Daily Traffic

AASHTO – American Associates of State Highway and Transport Officials

AC – Asphalt Concrete

ACV – Aggregate Crushed Value test

AIV – Aggregate Impact value test

ARC – Asphalt Roller Compactor

ASTM – American Society for Testing Materials

BS – British Standards

DP – Dust Proportion

ERA – Ethiopian Roads Authority

ESAL – Equivalent Single Axle Load

ETB – Ethiopian Birr

Gmb – compacted mix Bulk Specific Gravity

Gmm – Theoretical maximum Specific Gravity

Gsb – Bulk Specific Gravity

Gse – Effective Specific Gravity

HMA – Hot Mix Asphalt

HWTT – Hamburg Wheel Tracking Test

JMF – Job Mix Formula

LAA – Loss Angeles Abrasion test

LCCA – Life cycle cost analysis

LCC – Life cycle cost

MS – Manual Series

NAPA—National Asphalt Pavement Association

Ndes – Design level of compaction

Nini – Initial level of compaction

Nmax – Maximum level of compaction

NPV – Net present value

OAC – Optimum Asphalt Content

OBC – Optimum Binder Content

Pba – Asphalt Absorption

Pbe – Effective Asphalt Binder Content

PG – Performance grade

PSV – Polish Stone Value Test

PW – Present Worth

RTFO – Rolling Thin-Film Oven

SGC – Superpave Gyratory Compactor

SHRP – Strategic Highway Research Program

SSS – Soundness by Sodium Sulphate

Superpave – Superior Performing Pavements

TSR – Indirect Tensile Strength Ratio

US – united states

Va – Air void

VFA – Voids Filled with Asphalt

VMA – Voids in Mineral Aggregate

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the study

Road infrastructure is a critical component of a nation's economic growth and development. The performance of pavement material plays a vital role in the longevity and sustainability of road networks, particularly in high-traffic areas (Rath, 2022). Over time, various mix design methods have been developed to enhance the performance of asphalt pavement, which are an essential process in constructing HMA as it aims to closely simulate the actual performance of HMA manufacture and construction, allowing for the prediction of the most suitable mix design for a specific application and its expected performance (Asi & Khalayleh, 2011; Jitsangiam et al., 2013).

Numerous mix design methods are used worldwide, including the Hubbard–Field mix design method, Asphalt Institute Triaxial mix design method, Marshall Mix design method, Superpave mix design method, and the Hveem mix design method (Jitsangiam et al., 2013). The Marshall mix design has been extensively employed globally since its development in the 1930s (Aziz Memon & Naeem, 2006). However, due to its limitations in addressing modern traffic loads and temperature extremes, the SHRP in the United States introduced the Superpave mix design in the 1990s (Brown et al., 2009). The Superpave system has demonstrated improved performance in terms of rutting, fatigue, and low-temperature cracking compared to the Marshall design (Asi, 2007), and now it’s being implemented by developed countries, including the European Union, Japan, and South Korea (Taylor et al., 2007).

In Africa, the demand for road infrastructure is rapidly growing to accommodate increasing economic and population growth (Gebeyehu, 2017). However, the World Bank reports that Africa has the lowest road density globally, with only 34% of its roads paved, compared to 90% in Europe and North America (World Bank, 2019). This has resulted in significant challenges for transportation and economic development across the continent. With the increasing traffic loads and the need for more durable roads, it is crucial to evaluate the performance of alternative mix designs, such as Superpave, to determine its suitability for the African context (Africa et al., 2019).

Ethiopia, one of the fastest-growing countries in Africa, has experienced rapid expansion of its road network in recent years (Banda, 2018). The country's road network increased from 26,550 km in 1997 to 145,763 km in 2020 (an average growth of 8% per year), and the total budget for the planned works during these 23 years of the Road Sector Development Program amounted to ETB 356.6 billion (Habte, 2021), making Ethiopia's road network the longest in Sub-Saharan Africa (Banda, 2018). The Ethiopian Roads Authority (ERA) has been using the Marshall mix design for its asphalt pavements for decades (Berhanu, 2020). The Marshall Mix design method is suitable for lower traffic or no rut potential situations (Tesema, Siyum Belew tesema, 2017). However, when used for trunk roads, it performs poorly, with pavement life much shorter than expected. Cracking, rutting, and potholes in asphalt pavements often develop before reaching their expected life (Ahmed et al., 2022; Kate & Gebeyehu, 2017).

Several factors contribute to the early development of distresses in asphalt pavements, including serious overloading of trucks, high-traffic intensity of commercial vehicles, and significant variations in daily and seasonal temperatures of the pavement (Ahmed et al., 2022). It is also believed that the continued use of the Marshall Mix design procedure for asphalt mixtures has contributed to premature pavement deterioration (Tessema & Ponnurangam, 2019). This necessitates evaluating the Superpave mix design method for its potential to provide better performance on the country's trunk roads, and its cost-effectiveness, by evaluating the LCCA which is a model that helps road agencies in decision-making to optimize the total benefit-cost relationships of a road over its lifetime in relation to the available financial capacity and different road maintenance alternatives (Gorfu, 2017).

This study aims to compare the mechanical performance, volumetric property, and cost-effectiveness of the Marshall and Superpave mix designs for trunk roads. The findings of this research are of great significance to the ERA and other stakeholders in the road construction industry to make informed decisions on the most suitable mix design method.

1.2 Statement of the problem

The rapid growth of urbanization and industrialization in Ethiopia has led to a significant increase in the volume of traffic on its roads. Trunk roads, in particular, are subjected to heavy loads and require a durable and resilient pavement structure to ensure their long-term functionality. The Marshall mix design has been the primary method used for designing asphalt pavements in Ethiopia (Teklu, 2015). However, recent studies and field observations have exposed the limitations of this approach, particularly in terms of performance and durability (Shewatatek, 2022; Banda, 2018). A comprehensive review of the literature revealed that trunk roads in Ethiopia, constructed using the Marshall mix design, have shown poor performance at the early stage (Kifle & Yitayew, 2015). These roads have exhibited signs of early distress, such as rutting, cracking, and surface deformation, leading to increased maintenance costs and reduced service life (Arega et al., 2021).

On the other hand, Ethiopia is not an oil-producing country and thus bitumen is imported from foreign countries with hard currency, and the price is increasing from time to time. Consequently, for the past 15 years (from 2006–2020) Ethiopia was spent USD 51,443,436.41 on bitumen for flexible pavement construction (Habte, 2021). Due to this fact, the search for alternative pavement construction materials is a key and fundamental factor for the sustainable growth of the road networks in the future of Ethiopia. Several research papers have compared Superpave and Marshall mix designs for asphalt pavement construction, but there is a lack of research on the long-term cost-effectiveness of these mix designs. On the other hand, the unique climatic and traffic conditions of the study area must be taken into account for successful pavement design. The study recognizes the importance of considering several factors such as the availability of materials, construction practices, weather condition, and specification criteria, in the selection of optimal mix design method and the cost implications associated with each design method.

The findings of this research serve as a valuable reference for transportation authorities, engineers, and policymakers in the implementation of more effective and sustainable pavement design practices. The study will be crucial in recommending the most cost-effective and sustainable mix design method for trunk road construction, considering the unique climatic and traffic conditions of the area.

1.3 Objective

1.3.1 General objective

The general objective of this study is to compare the Superpave and Marshall mix designs for trunk road by evaluating their volumetric properties, mechanical performance, and Life Cycle Cost analysis.

1.3.2 Specific objective

1. To determine the volumetric properties of Superpave and Marshall mix designs
2. To compare the mechanical performance of Superpave and Marshall mix designs for trunk road, using wheel tracking test, indirect tensile strength test, and retained stability test.
3. To analyze the Life Cycle Cost of Superpave and Marshall mix designs for trunk road.

1.4 Significance of the Study

The dramatic increase in traffic volume in built-up areas, such as the capital area, road corridor, and other Federal Trunk Roads of Ethiopia results in increasing new road construction (Habte, 2021). The road infrastructure that's not properly constructed in Ethiopia poses significant challenges, including road safety concerns and decreased transportation efficiency (Ketema et al., 2016a). The construction of numerous flexible pavements in the country has resulted in increased maintenance and rehabilitation costs, making the road network more expensive to construct and maintain (T Suryanarayana, C Laxmikanth, Dessalegn Gezahegn, 2021). This study aims to address these challenges by optimizing resource utilization and determining the most suitable pavement mix design.

The findings of this research will help road construction agencies in Ethiopia improve pavement design and quality, leading to better road safety and reduced maintenance costs. Additionally, this study seeks to enhance the understanding and performance of the Superpave mix design, which is currently not widely adopted in Ethiopia. By gaining knowledge about this advanced mix design, Ethiopia can potentially adopt more suitable mix design method, and improving the overall quality of the trunk road network, while minimizing costs and risks for road users.

Moreover, the study also includes a life cycle cost analysis (LCCA) to compare the economic feasibility of the two pavement mix design alternatives over their entire life cycle. This analysis considers all relevant costs associated with the trunk road construction, maintenance, and rehabilitation, as well as the expected performance and service life. By conducting a LCCA, decision-makers can select the most cost-effective pavement mix design alternative that meets the desired level of service. This research also holds the potential to inspire further studies in this field, contributing to the growth and development of Ethiopia's transportation industry.

1.5 Scope of the study

The road construction sector is a complex industry that involves several branches working together to plan, design, and build highways. One of the most critical components of road construction is asphalt mix design. The scope of this research paper is to compare the performance of Marshall and Superpave mix designs with a focus on factors critical for trunk road applications such as rutting resistance, indirect tensile strength, retained stability, and durability. Additionally, the study analyzes the cost-effectiveness of each mix design by considering the life cycle cost analysis. The research methodology is an experimental study involves laboratory testing of asphalt mix samples and for life cycle cost analysis, recent data from literatures and the market trend carefully investigated and taken into consideration during the analysis. The findings of this study will be useful in the road construction industry for selecting an optimal mix design with consideration of volumetric property, mechanical performance and cost-effectiveness.

1.6 Limitation of research

Limitations of this study include the following shortcomings that affect the validity or generalizability of the findings. First, the study was limited by the use of a small sample size, which was caused by limited access to testing machines and high material costs. Second, the location of the highway laboratory for each mix design method was found in different places, with the Marshall mix design highway laboratory located around Kality and the Superpave mix design highway laboratory located around Picok. Transporting materials from one place to another may have influenced the results. Third, due to the early stage of Superpave mix design implementation, the constructed pavements using this method are new and haven't yet exhibited any distress. Therefore, it was not possible to evaluate the performance of each mix design in field conditions under high-traffic loads to assess their real-world performance. Overall, this study provides valuable insights into the topic, but the limitations for the study should be considered. Future research should address these limitations to further advance the field.

1.7 Overview of the research

The research is divided into five chapters. Chapter one provides an introduction to the study, which includes the background, research objectives, significance of the research, problem statement, and scope and limitations of the study.

Chapter two presents an in-depth review of the literature on mix designs, with a particular focus on Marshall and Superpave mix designs.

Chapter three describes the methodology used to evaluate the volumetric property, mechanical performance and life cycle cost analysis of the Marshall and Superpave mix designs.

Chapter four presents and discuss the results obtained from the Marshall and Superpave mix designs.

Finally, Chapter five concludes the research by summarizing the conclusions and recommendations based on the research objectives and the results of the study presented in the previous chapters.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

Rock asphalt was first used as a sidewalk surfacing material in France in 1802 and later in Philadelphia in 1838. The first asphalt pavement was constructed in Newark, New Jersey in 1870. In 1876, the first sheet asphalt pavement, made from a fine sand mix and imported lake asphalt, was built in Washington, D.C. It was in 1902 that asphalt refining from petroleum began, which led to the use of the asphalt paving industry in the US (Zaniewski & Ph, 2003).

Over time, the pavement engineering field has evolved, and several mixture design methods have been developed to improve the performance, durability, and safety of asphalt pavements (Asi & Khalayleh, 2011). The Marshall mix design method, developed in the 1930s, was the first widely used method for designing asphalt mixtures. However, with the increasing use of asphalt and the demand placed on mixtures due to the increase in traffic volume and loading, refinements to the concepts of asphalt mix design procedures became essential (Ahmad et al., 2014; Omar et al., 2021).

In response, the Strategic Highway Research Program (SHRP) was established in 1987 to improve the performance, durability, and safety of roads (Omar et al., 2021). The SHRP led to the development of the Superpave mix design method, which is performance-related and performance-based, and aims to establish the appropriate amount of binder content in a mix that meets both the design specifications for specific traffic and environmental conditions (Ahmed et al., 2022; ALAZAWY, 2015). The Superpave mix design has shown proven success in terms of pavement performance and is designed to address the limitations of the Marshall mix design (Ahmed et al., 2022; Omar et al., 2021).

Currently, the Marshall and Superpave mix design methods are the two commonly used mix design methods for asphalt pavements (Omar et al., 2021). However, there is a need for a comprehensive analysis of the literature related to the comparative study on the performance of Marshall and Superpave mix designs under high-traffic conditions. Therefore, this literature review aims to provide a detailed analysis of the research related to the comparative study of the performance of Marshall and Superpave mix designs, with a focus on the differences in aggregate selection, gradation, and asphalt binder selection. The review will provide insights about each mix design method, and help to inform the selection of the appropriate mix design method for specific pavement applications.

2.2 Overview of Marshall and Superpave mix design methods

2.2.1 Marshall mix design method

The traditional Marshall method of mix design was developed by Bruce Marshall for the Mississippi Highway Department in the 1930s and was based on the concept of volumetric analysis of asphalt mixtures (Virginia, 2005). Despite the availability of newer technologies, the Marshall method remains a popular choice in many countries due to its affordability and portability (Zumrawi & Sheikh Edrees, 2016). By using the Marshall method criteria, engineers can determine the ideal amount of asphalt to add to a particular blend of aggregate for a mix that meets the desired properties of density, stability, and flow. This makes the method a valuable tool for designing asphalt mixes that meet specific project requirements (Shah et al., 2020).

The Marshall method has been widely used for many years, and its simplicity and ease of use have made it a popular choice for mix design. However, the method has some limitations, including a lack of consideration of the environmental and traffic loading conditions that the pavement will be subjected to (Africa et al., 2019). In addition, the procedures used in the Marshall mix design are empirical in nature and based on data produced by experiment, pavement trials, experience, and observation, rather than reliable actual field data (Omar et al., 2021). As a result, the Marshall Mix design procedure has substantial drawbacks with respect to replicating the real or actual behavior of asphalt during construction and in actual service conditions. Additionally, the Marshall Mix design is not appropriate for mixes with a high degree of shear susceptibility, as the compaction method used in the Marshall Mix protocol doesn’t effectively simulate the densification that occurs in real pavement under traffic loading (Jitsangiam et al., 2013).

2.2.2 Superpave mix design method

The Superpave mix design method was developed in the 1990s as a more advanced, performance-based approach of mix design, and to fulfill the limitations found in both asphalt binder and mix specifications of the Marshall mix design (Africa et al., 2019). The need for an improved mix design for different traffic volumes, loads, and environmental conditions arose due to factors such as increased traffic, higher tire pressures, and heavier axle loads (Virginia, 2005). The Superpave system is a performance-based asphalt binder specification that aims to incorporate traffic and climatic conditions more effectively, improve the evaluation and selection of asphalt binder and aggregate, also it enhance volumetric approaches to mix design (Jitsangiam et al., 2013).

One of the key features that sets the Superpave system apart from the Marshall mix design is its focus on performance-based criteria. The method uses a series of laboratory tests to predict the performance of asphalt mixtures under different loading and environmental conditions (Omar et al., 2021). The Superpave mix design method considers traffic and environmental conditions more effectively, and its performance-based approach enables the selection of appropriate binder content for the specific traffic volume, axle loads, temperature, and moisture, and uses performance tests to predict the performance of the mix under those conditions (Taylor et al., 2015; Zumrawi & Sheikh Edrees, 2016). The Superpave technology has been implemented by several countries worldwide, including Japan, South Korea, and the European Union, and has proven success in improving the performance and durability of asphalt pavements (Africa et al., 2019; Jitsangiam et al., 2013). Developing countries need to consider transitioning to Superpave for better pavement performance under high-traffic conditions and durability.

2.3 General concept about Asphalt pavement

Asphalt pavement is a type of flexible pavement that is commonly used for constructing roads, parking lots, and other transportation infrastructure. It is made up of asphalt binder and aggregates that are mixed together to form a durable and flexible material (Gemechu & Kebede, 2015). The asphalt binder is a petroleum-based material that acts as a glue that binds the aggregates together. The aggregates used in asphalt pavement typically include sand, gravel, and crushed stone (Essays, 2018) . The performance and durability of asphalt pavement depend on a variety of factors, including the quality and properties of the asphalt binder and aggregates, the design of the pavement structure, the quality of the construction process, and the environmental and traffic conditions to which the pavement is exposed (Asi & Khalayleh, 2011).

2.3.1 Aggregate

The properties of the aggregates used in asphalt mixtures, such as particle size distribution, shape, and texture, have a significant impact on the performance of the mixture. Studies have shown that the use of angular, rough, and elongated aggregates can lead to a higher level of aggregate interlock, resulting in improved resistance to permanent deformation (Tesema, 2017). However, the use of aggregates with high absorption can reduce the adhesion between the asphalt binder and the aggregate particles, leading to reduced durability and increased susceptibility to moisture damage (Kate & Gebeyehu, 2017).

Type of Aggregate: Studies have shown that the use of angular and crushed aggregates can improve the resistance of asphalt mixtures to rutting and permanent deformation, while the use of rounded and smooth aggregates can reduce their resistance to these forms of distress (Cooley et al., 2002). Furthermore, the use of lightweight aggregates can reduce the weight and cost of asphalt mixtures, but may also reduce their resistance to thermal cracking and moisture damage (Al-mistarehi, 2014).

Gradation of Aggregate: The gradation of the aggregate used in an asphalt mixture can have a significant impact on its mechanical performance under high-traffic conditions. Studies have shown that the use of a dense-graded aggregate gradation can improve the resistance of asphalt mixtures to rutting and fatigue cracking, while the use of an open-graded aggregate gradation can improve their resistance to noise and splash (Ahmed et al., 2022).

2.3.2 Asphalt binder

The properties of the asphalt binder, such as its viscosity, stiffness, and temperature susceptibility, can significantly affect the performance of asphalt mixtures under high-traffic loads. Studies have shown that the use of higher viscosity binders can improve the resistance of asphalt mixtures to permanent deformation (Addissie et al., 2018). However, the use of stiff binders can lead to increased susceptibility to fatigue cracking, while the use of soft binders can lead to rutting and bleeding (Alemu et al., 2023).

Type of asphalt binder: The type of asphalt binder used in an asphalt mixture can significantly affect its mechanical properties. Studies have shown that the use of polymer-modified asphalt binders can improve the resistance of asphalt mixtures to rutting, fatigue cracking, and low-temperature cracking (Zumrawi & Sheikh Edrees, 2016). Furthermore, the use of warm-mix asphalt binders can lead to reduced mixing and compaction temperatures, resulting in improved workability, reduced energy consumption, and reduced emissions (Alemu et al., 2023).

Grade of Asphalt binder: The grade of the asphalt binder used in an asphalt mixture can also affect its mechanical properties. Studies have shown that the use of stiffer asphalt binders can improve the resistance of asphalt mixtures to rutting and permanent deformation (Tesfaye, 2014). However, the use of softer asphalt binders can improve the resistance of asphalt mixtures to thermal cracking and fatigue cracking (Selvam et al., 2016).

Performance tests of Asphalt Binder: The Marshall test measures the resistance of an asphalt mixture to plastic deformation under a static load, while the Superpave test measures its resistance to rutting, fatigue cracking, and low-temperature cracking under cyclic loading conditions. Studies have shown that the Superpave test is more accurate and reliable in predicting the mechanical performance of asphalt mixtures under high-traffic conditions (Zumrawi & Sheikh Edrees, 2016).

2.3.3 Mineral filler

The mineral filler is a fine mineral powder that is added to the asphalt mix to fill the voids between the larger aggregate particles and improve the overall performance of the mix (Berhanu, 2020). The mineral filler is typically a finely ground limestone or dolomite powder that meets specific gradation requirements (Mulatu et al., 2020). The mineral filler helps to improve the stability, durability, and resistance to deformation of the asphalt mix (Dejen & Zelelew, 2020). In both mix design methods, the mineral filler plays a critical role in improving the overall performance of the asphalt mix. The proper selection and proportioning of the mineral filler are essential to achieving the desired performance characteristics of the asphalt mix (Selvam et al., 2016).

2.3.4 Environmental Factors

The environmental factors, such as temperature, humidity, and traffic volume, can also affect the performance of asphalt mixtures under high-traffic loads. Studies have shown that the temperature susceptibility of asphalt mixtures can significantly affect their resistance to rutting and fatigue cracking (R. West et al., 2018). Furthermore, the presence of moisture in the pavement structure can reduce the adhesion between the asphalt binder and the aggregate particles, leading to reduced durability and increased susceptibility to stripping and raveling (Shah et al., 2020).

2.4 Comparison between Marshall and Superpave mix design

The fundamental principles of the Superpave mix design methods from the conventional Marshall method can be compare in several ways (Asmael & Ahmed Alkawaaz, 2009).

2.4.1 In terms of compaction

The Marshall mix design method uses a relatively simple compaction procedure that involves compacting a cylindrical specimen of the asphalt mixture to a specified density using a hammer that drops a specified distance. The compaction process is repeated until the desired density and void content are achieved. The Marshall method doesn’t include performance testing as part of the design process (Jitsangiam et al., 2013). The Superpave mix design method, on the other hand, uses a more complex compaction procedure, a gyratory compactor to simulate the compaction of the asphalt mixture under the weight of traffic. The Superpave method also includes performance testing as part of the design process to ensure that the mixture meets the desired performance specifications. The tests are designed to evaluate the mixture's performance under specific loading and environmental conditions (Zumrawi & Sheikh Edrees, 2016).

Figure 2.1 Superpave gyratory compactor and Marshall hammer compactor

2.4.2 In terms of specimen size

The Marshall method uses a smaller specimen size of 101.6 mm diameter and 63.5 mm height for testing the properties of the asphalt mixture, while the Superpave method uses two different specimen sizes of 150 mm diameter and 300 mm height for the gyratory compaction test and 115 mm diameter and 150 mm height for the performance tests, which provides a more realistic simulation of the compaction of the asphalt mixture under the weight of traffic (Omar et al., 2021). The Marshall method provides a simpler and more straightforward approach for testing the properties of the asphalt mixture using a single size of the specimen. The use of two different specimen sizes in the Superpave method allows for a more comprehensive characterization of the asphalt mixture's properties (Al-khateeb et al., 2010). The use of a larger specimen size in the Superpave method can help to reduce the variability in the test results and improve the accuracy of the testing (McGennis et al., 2010).

2.4.3 In terms of aggregate selection

Several studies have compared the aggregate selection and gradation differences between Marshall and Superpave mix designs. One study by (Tamiru et al., 2022) found that the Superpave mix design method resulted in a more continuous and open aggregate gradation compared to the Marshall mix design method. The study also found that the Superpave mix design method provided better rutting resistance and fatigue life compared to the Marshall mix design method. Another study by (Zumrawi & Sheikh Edrees, 2016) compared the aggregate gradation and volumetric properties of Marshall and Superpave mix designs. The study found that the Superpave mix design method resulted in a more open aggregate gradation compared to the Marshall mix design method. The study also found that the Superpave mix design method resulted in a higher air void content compared to the Marshall mix design method.

Similarly, (Ahmad et al., 2014) compared the aggregate gradation and volumetric properties of Marshall and Superpave mix designs. The study found that the Superpave mix design method resulted in a higher VMA and VFA compared to the Marshall mix design method, which can improve the durability and resistance to moisture damage of the asphalt mixture. The Superpave mix design uses a 0.45 chart for aggregate gradation that includes control points through which aggregates should pass through, restricted zone where the aggregates aren't allowed to pass (Administration, 2001)

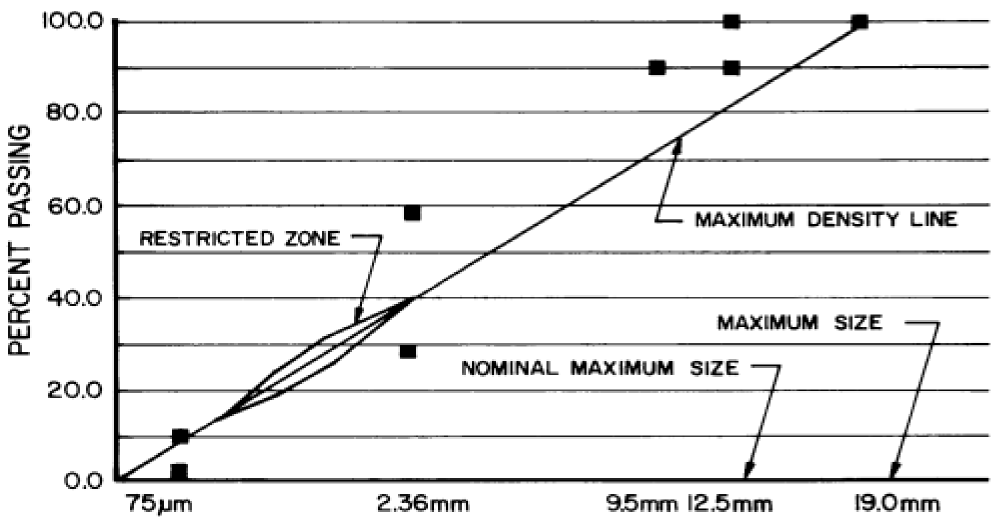


Figure 2.2 0.45 power chart: source (Administration, 2001)

2.4.3.1 Consensus and source property of aggregate

Consensus aggregate properties include, fine Aggregate angularity which is a measure of the degree of angularity or roundness of the fine aggregate particles, Coarse aggregate angularity which is a measure of the degree of angularity or roundness of the coarse aggregate particles (Asi & Khalayleh, 2011). Flat and elongated particles are particles of aggregate that are flat and elongated in shape, clay content is the percentage of clay particles in the aggregate, they can affect the workability and performance of the asphalt mixture (Ahmad et al., 2014). The Marshall mix design method does not consider the consensus properties explicitly, but it does specify the maximum percentage of fine aggregate passing the 0.075 mm sieve, the maximum particle size of the coarse aggregate, and the maximum percentage of aggregate passing each sieve size. The Superpave mix design method considers consensus properties and specifies a minimum aggregate angularity value to ensure good interlocking between the fine and coarse aggregate particles in the asphalt mixture (Asi, 2007).

The source properties of aggregate include toughness, soundness, and deleterious materials. Toughness refers to the ability of an aggregate particle to resist fragmentation or degradation during handling, stockpiling, and mixing (Al-mistarehi, 2014). Soundness refers to the ability of an aggregate particle to resist weathering and changes in volume due to freeze-thaw cycles. Deleterious materials refer to materials in the aggregate that can affect the performance and durability of asphalt concrete mixtures (Zumrawi & Sheikh Edrees, 2016). The Superpave mix design specifies minimum or maximum allowable values for each property, whereas the

Marshall mix design method specifies the maximum percentage of aggregate passing each sieve size and maximum allowable loss in weight due to soundness tests without explicitly considering these properties (Jitsangiam et al., 2013).

2.4.4 In terms of asphalt binder selection

The Marshall mix design typically uses a penetration-graded asphalt binder. The selection of a specific penetration grade of asphalt binder is based on the expected high pavement temperature and the traffic loading conditions. The binder is selected to ensure that the pavement will not become too soft at high temperatures, which can lead to rutting (Tessema & Ponnurangam, 2019). In contrast, the Superpave mix design method uses a performance-graded (PG) asphalt binder. The PG grade of asphalt binder is based on a range of high and low pavement temperatures and traffic loading conditions. The binder is selected to ensure that the pavement will not become too soft at high temperatures or too brittle at low temperatures, which can lead to cracking (Hube et al., 2010).

Several studies have compared the asphalt binder selection differences between Marshall and Superpave mix designs. One study by (Al-mistarehi, 2014) found that the use of a PG asphalt binder in Superpave mix designs resulted in better performance under high and low pavement temperature conditions compared to the use of a penetration-graded asphalt binder in Marshall mix designs. The study also found that the use of a PG asphalt binder in Superpave mix designs resulted in better resistance to rutting and cracking compared to the use of a penetration-graded asphalt binder in Marshall mix designs. Similarly, a study by (Jitsangiam et al., 2013) compared the performance of Marshall and Superpave mix designs using different asphalt binder grades. The study found that the use of a PG asphalt binder in Superpave mix designs resulted in better performance under high and low pavement temperature conditions compared to the use of a penetration-graded asphalt binder in Marshall mix designs. The study also found that the use of a PG asphalt binder in Superpave mix designs resulted in better resistance to rutting and fatigue cracking compared to the use of a penetration-graded asphalt binder in Marshall mix designs

2.5 Volumetric property of Marshall and Superpave mix design

Volumetric properties of asphalt mixtures are crucial factors affecting the performance and durability of asphalt pavements. The volumetric properties of Marshall and Superpave mix designs have been extensively studied to evaluate their performance and develop mix design specifications (Ahmad et al., 2014; Jitsangiam et al., 2013; Zumrawi & Sheikh Edrees, 2016).

Air Voids (VA): The air voids in an asphalt mixture are the percentage of the volume of void space in the mix that is filled with air. High air void content can lead to premature pavement distresses such as rutting, cracking, and stripping. Low air void content can result in a mix that is too dense and prone to rutting (Ozturk et al., 2017).

Voids in Mineral Aggregate (VMA): The VMA of an asphalt mixture is the percentage of the volume of void space in the aggregate particles that is not filled with asphalt. VMA is an indication of the aggregate gradation and the amount of asphalt needed to fill the voids in the aggregate. Low VMA can lead to flushing, bleeding, and stripping of the asphalt pavement (Tesfaye, 2014).

Voids Filled with Asphalt (VFA): The VFA of an asphalt mixture is the percentage of the volume of void space in the mixture that is filled with asphalt. VFA is an indication of the amount of asphalt in the mix and its ability to fully coat the aggregate particles. Low VFA can result in an asphalt mix that is too dry and prone to cracking (Al-khateeb et al., 2010).

Bulk Specific Gravity (Gsb): Gsb of an asphalt concrete sample is the ratio of the weight of the sample in air to the weight of an equal volume of water at a specified temperature. It is a measure of the density of the compacted asphalt mixture and is an indicator of its ability to resist deformation and cracking under traffic loads (Tessema & Ponnurangam, 2019).

Theoretical Maximum Specific Gravity (Gmm): Gmm of an asphalt concrete sample is the ratio of the weight of the sample in air to the weight of an equal volume of water at a specified temperature, but with the air voids filled with a gas of known density (Arshad et al., 2017).

On a study that’s done to compare the volumetric properties of asphalt mixtures prepared using the Marshall and Superpave methods by (Academics, 2007), found that the Superpave mix design produced asphalt mixtures with lower air voids and flow, higher VMA, VFA, and stability, compared to the Marshall mix design. On evaluating the volumetric Properties of Asphalt Mixtures Using Superpave gyratory compactor by (Aziz Memon & Naeem, 2006), this study evaluated the volumetric properties of asphalt mixtures using the SGC and found that the

Superpave mix design produced asphalt mixtures with higher stability and lower air voids compared to the Marshall mix design.

2.6 Life cycle cost analysis

A product's life cycle involves the various stages from raw-material extraction to disposal/recycling. For pavements, this includes material extraction, production, construction, operation, maintenance, rehabilitation, and end-of-life disposal or recycling (Habte, 2021). The life cycle model used to assess pavement sustainability consists of two integrated elements. First, a life cycle inventory analysis/impact assessment model evaluates energy use during the initial stages of the pavement life cycle, such as raw material extraction, manufacturing, and placement (Nur Izzi et al., 2016). Second, a life cycle cost model evaluates agency and social costs, including construction, maintenance, rehabilitation, vehicle operating costs, user delay costs, and greenhouse gas emissions over the pavement's service life (Habte, 2021).

Studies have shown that flexible pavement is initially cheaper than rigid pavement, but incurs higher maintenance costs over its design life, resulting in a higher cost per kilometer (Ketema et al., 2016b). Cement concrete pavement has been found to be more sustainable than asphalt concrete due to its longer lifespan, use of industrial byproducts, and recyclability, which reduces demand for non-renewable resources (Gebeyehu, 2017).

Stone matrix asphalt costs more than superpave dense-graded mixtures with polymer-modified binders but has better or equivalent field performance on similar trafficked highways (R. C. West, 2018). Using geosynthetic material in flexible pavement has been found to reduce agency cost by 50.34% of initial construction cost and avoid about 70.9% of user cost compared to conventional Marshall flexible pavement (Hailu et al., 2019).

Jointed concrete pavement has a 90% cost advantage over HMA pavement due to its durability, lower maintenance and social cost, and longer design life A study has also shown that the use of 45-Balanced Mix Design instead of the control mix 30-Superpave could achieve significant savings without extending the service life (Meroni et al., 2020)

2.7 Analysis of various performance tests

Performance tests used to evaluate the properties of asphalt mixtures under high-traffic, include the repeated load axial test, the indirect tensile test, and the dynamic modulus test. Each test has its own limitations and challenges, and the results may vary depending on the specific test conditions and the mix design parameters (Asi, 2007). The mechanical performance of asphalt mixtures under high-traffic loads is usually evaluated using a range of performance tests.

2.7.1 Indirect Tensile Strength (TSR) Test

The TSR test is a widely used performance test that measures the tensile strength of asphalt mixtures. The test involves applying a compressive load to a cylindrical specimen of asphalt mixture and measuring the resulting tensile strength. The TSR test is used to evaluate the resistance of asphalt mixtures to fatigue cracking and thermal cracking (Nouman et al., 2022).

2.7.2 Dynamic Modulus Test

The dynamic modulus test is a performance test that measures the stiffness of asphalt mixtures under cyclic loading conditions. The test involves applying a sinusoidal load to a cylindrical specimen of asphalt mixture and measuring the resulting strain response. The dynamic modulus test is used to evaluate the resistance of asphalt mixtures to rutting and fatigue cracking (Arshad et al., 2017).

2.7.3 Wheel tracking test

It’s a performance test that measures the resistance of asphalt mixtures to permanent deformation under repeated loading conditions. The test involves applying a repeated load to a cylindrical specimen of asphalt mixture and measuring the resulting deformation. It’s used to evaluate the resistance of asphalt mixtures to rutting and permanent deformation (Al-Humeidawi, 2016).

2.7.4 Hamburg Wheel-Tracking Test

The Hamburg wheel-tracking test is a performance test that measures the resistance of asphalt mixtures to rutting and moisture damage under simulated traffic loading and environmental conditions (Tamiru et al., 2022). The test involves placing a cylindrical specimen of asphalt mixture in a wheel-tracking device and applying a load while spraying water on the surface of the specimen. The Hamburg wheel-tracking test is used to evaluate the resistance of asphalt mixtures to rutting and moisture damage (Han et al., 2016).

2.7.5 Four-Point Bending Beam Test

The four-point bending beam test is a performance test that measures the flexural strength and stiffness of asphalt mixtures. The test involves applying a four-point bending load to a beam specimen of asphalt mixture and measuring the resulting deflection. The four-point bending beam test is used to evaluate the resistance of asphalt mixtures to fatigue cracking and thermal cracking (Pires et al., 2017).

2.7.6 Dynamic creep test

Dynamic creep testing is a common method used in pavement mix design to evaluate the deformation characteristics of asphalt mixtures under repeated loading. The test involves applying a cyclic load to a cylindrical specimen of the asphalt mixture while maintaining a constant temperature and measuring the resulting deformation (Asi & Khalayleh, 2011). The results of dynamic creep testing can be used to determine the resilient modulus and permanent deformation (rutting) characteristics of the asphalt mixture, which are important parameters in pavement design and performance prediction models (Ahmad et al., 2014).

2.7.7 Resilient modulus

The resilient modulus value is calculated as the ratio of the stress to the strain, providing a measure of the mixture's resistance to deformation under loading. In pavement mix design, the resilient modulus value is an important parameter that can be used to optimize the stiffness and durability of asphalt pavements (Jitsangiam et al., 2013). The resilient modulus value is influenced by a number of factors, including the aggregate gradation, binder type and content, and air void content. By adjusting these factors, the resilient modulus value can be optimized to meet the specific requirements of the pavement application, such as traffic loading and climate conditions (Nouman et al., 2022).

Literature review summery on works related to comparative study on Marshall and Superpave mix design.

Authors	Title	comparison	test conducted	Finding
(Taylor et al., 2007)	International Journal of Pavement Engineering A Comparison of the Marshall and Superpave Design Procedure for Materials Sourced in India	Mechanical performance	Marshall stability and loss of Marshall stability,	Superpave has 36% and 66% higher Marshall Stability and 14% lesser loss in Marshall stability,
			Indirect tensile strength and loss of indirect tensile strength	ITS Marshall mix was 9.067 kg/cm2 and that of Superpave mix was 13.49 kg/cm2,
			retained stability and moisture sensitivity	retained stability and moisture sensitivity comes out 80 for superpave and 91% for marshall mix design

(Asmael & Ahmed Alkawaaz, 2009)	Comparative Evaluation For Mix Design of Marshall and Superpave Methods Improve Asphalt Pavement Performance View project Bus demand estimation View project	volumetric property	OBC	the Superpave mixes have lower optimum asphalt content than those of Marshall mixes.
		Mechanical performance	Indirect Tensile Stiffness Modulus Test	Marshall mixes with OBC determined by Marshall method have higher tensile strength than Marshall mixes with OBC determined by Superpave system.
			Asphalt film thickness	The Marshall mixes yield a higher asphalt film thickness than the Superpave mixes.
		volumetric property	Stability and flow value	the stability values of the Superpave mixes are higher than that of Marshall mixes , while the flow values of Superpave mixes are slightly less than that of Marshall mixes .
(G. Al-khateeb & Khedaywi, 2010)	Volumetric Analysis-Based Comparison between Superpave and Marshall Mix Design Procedures	volumetric property	OBC	Superpave and Marshall mix design got same OBC was found 5.4%
		Mechanical performance	retained stability and moisture sensitivity	retained stability for Marshall was 83% and moisture sensitivity of Superpave was 92%.
(Asi & Khalayleh, 2011)	Adaptation of superpave asphalt concrete mix design procedure to Jordan climatic and traffic conditions	Mechanical performance	Dynamic creep test	Superpave samples showed better creep performance than Marshall samples
			resilient modulus tests	Superpave mixes have higher diametral resilient modulus than Marshall mixes
(Jitsangiam et al., 2013)	Evaluation on performance characteristics of superpave asphalt mix design under tropical climatic conditions	volumetric property	OBC	For Marshall and Superpave mix design 5.20% and 5 %.
		Mechanical performance	Marshall stability and loss of Marshall stability	Superpave bath samples show higher initial stability and wet stability values.
			Indirect tensile strength and loss of indirect tensile strength	the Superpave samples show higher ITS values than both Marshall samples.
			Resilient modulus tests	the Superpave samples show higher ITS values than both Marshall samples. higher

				diametric resilient modulus on superpave than Marshall Mixes.
			Dynamic creep test	Superpave mix samples were far superior to those of the Marshall Mix samples.
(Ahmad et al., 2014)	Evaluation on performance characteristics of superpave asphalt mix design under tropical climatic conditions	volumetric property	OBC	Superpave mixtures utilize less OBC compared to Marshall mixtures
		Mechanical performance	resilient modulus tests	Superpave mixtures showed a higher resilient modulus value compared to Marshall mixtures,
			Dynamic creep test	Superpave has lower initial permanent deformation at the densification stage compared to the Marshall mix
(ALAZAWY, 2015)	Comparative evaluation for the performance of paving materials by using marshall and superpave compaction method	volumetric property	OBC	Superpave and Marshall mixes were found to be 4.7% and 4.42%,
		Mechanical performance	ITS and loss of indirect tensile strength	Superpave mixtures have higher strength than the Marshall mixtures
		volumetric property	Density	2.362 g/cm3 for Superpave and 2.353 g/cm3 for Marshall
(Zumrawi & Sheikh Edrees, 2016)	Comparison of Marshall and Superpave Asphalt Design Methods for Sudan Pavement Mixes	volumetric property	OBC	Superpave and Marshall mixes were found to be 5.3 and 5.5%
			Density	Superpave and Marshall were 2.403 and 2.304 g/cm3
(Han et al., 2016)	Experimental Characterization of Rutting Performance of HMA Designed with Aggregate Gradations According to Superpave and Marshall Methods	volumetric property	OBC	Superpave mix design has lower binder content than the Marshall,
		Mechanical performance	Dynamic creep test	Marshall mixes have higher values of strain than those of Superpave as a result of high flow and low stiffness,
		volumetric property	Density	higher in the Superpave mix than the Marshall mix design.
(Selvam et al., 2016)	Feasibility Study On Transition From Marshall Mix Design To	Mechanical performance	Marshall stability and loss of Marshall stability	Superpave mix design has greater stability of 15.788 KN than that of Marshall Mix design of 14.41 KN,

	Superpave Mix Design		Indirect Tensile Stiffness Modulus Test	The Indirect Stiffness Tensile Modulus test indicates that the Superpave mix design has more stiffness modulus than Marshall Mix design.
(Al-Humeidawi, 2016)	Experimental Characterization of Rutting Performance of HMA Designed with Aggregate Gradations According to Superpave and Marshall Methods	mechanical performance	wheel truck Rutting Test	Superpave aggregate gradation procedure gives more resistance to permanent deformation and less rutting depth (about 50%) compared with mixes designed according to Marshall aggregate gradation procedure.
			Marshall Stability	lower Marshall stability resulted than the Superpave base aggregate gradation mixes
(Qasim, 2017)	Effect of Filler Content on Properties of Asphaltic Mixtures for Marshall and Superpave Gyratory Compactor	volumetric property	OBC	The Superpave mixtures had less optimum asphalt binder contents OAC than the Marshall mixtures.
			VA	Superpave achieves less air voids content of the Marshall Mixes; this prevents additional compaction that result due to traffic loads.
(Nouman et al., 2022)	Performance Evaluation of Wearing Course Asphalt Mixes Based on Resilient Modulus , Indirect Tensile Strength and Marshall Stability	Mechanical performance	Indirect tensile strength and loss of indirect tensile strength	Superpave mix are 26% and non-conditioned are 38% higher as compared to Marshall mix samples
			Resilient modulus tests	Superpave mixes have higher diametral resilient modulus than Marshall mixes, Marshall method showed a lower value of Resilient than Superpave method.
(Jweihan, 2023)	Performance of Aged Asphalt Mixes Containing Waste Oil Shale Filler	volumetric property	Stability and flow value	Superpave mix samples had generally higher stability and lower fow values at all combinations of oil shell mineral filler compared to Marshall samples.
		mechanical performance	Marshall Stability	The Superpave mixes showed generally better performance in the stability loss compared with the Marshall mixes at all

				asphalt mixtures at both aging conditions.
			Indirect tensile strength	superpave mixes showed better performance in the loss of ITS than that with the Marshall mixes at both aging conditions
(Qadr & Talabany , 2023)	Compaction Effort Evaluation of Crumb Rubber Modified Hot Mix Asphalt	volumetric property	OBC	OBC determined using the Superpave mix design was lower than that determined using the Marshall mix design
			Stability	In comparison to the Marshall mix design, the Superpave mix design provided the highest level of stability for all sources
		mechanical performance	compressive strength	The Superpave mix design provided higher tensile and compressive strengths than the Marshall mix design for the unmodified and modified mixtures
			Index of Retained Strength	The Marshall samples failed to satisfy the 80% criteria at four compaction levels from unmodified sources, while the Superpave samples satisfied these criteria
			Indirect tensile strength	Superpave samples conformed to the standard specifications than the marshall mix design

Table 2.1 Literature review summery

2.8 Research Gap

The performance and durability of asphalt pavements are influenced by various factors such as traffic load, weather conditions, and material properties (Jitsangiam et al., 2013; Omar et al., 2021). To enhance the performance and longevity of these roads, it is crucial to optimize the mix design for asphalt pavements, several studies shown that selecting Superpave mix design has shown the advantages over Marshall in terms of mix performance (Al-Humeidawi, 2016; Al-mistarehi, 2014; Zumrawi & Sheikh Edrees, 2016). While numerous studies have compared the performance of the two methods in terms of volumetric property and mechanical performance using an experimental methodology, there is a lack of study on the long-term life cycle costs analysis of the two methods. Therefore, there is a need for further research to compare their cost-effectiveness

Furthermore, while Superpave has been implemented in many developed and developing countries, its uptake in Ethiopia has been very limited (Mihretu, 2018). While Superpave implementation could benefit Ethiopia in improving pavement performance and service lives, there is a lack of performance data for Superpave mixes designed for trunk roads besides its cost-effectiveness with respect to Marshall mix design in Ethiopian context (Kassahun et al., 2021). Therefore, closing these gap through research tailored to local challenges may accelerate the adoption of advanced asphalt mix design methods to achieve durable and high-performing road infrastructure.

Therefore, based on the above literature review, it is evident that while both Marshall and Superpave mix design methods have been studied in various contexts, there is a clear gap in the existing research concerning their overall performance that includes comparing mechanical performance, volumetric property, and cost-effectiveness for trunk road. This research aims to fill this gap by providing a comprehensive comparison of the two methods, taking into consideration the unique factors affecting road performance. The outcomes of such research would contribute to the development of more durable and cost-effective pavements in Ethiopia, ultimately benefiting the country's transportation.

CHAPTER THREE

3. MATERIALS & METHODS

3.1 Introduction

In order to build high-quality roads and ensure their longevity, it is important to have a thorough understanding of the materials used in the HMA and how they interact. This is where the Superpave system comes in as it utilizes the properties of individual materials in innovative ways to create a durable asphalt mixture. However, in order to gain a better understanding of the Superpave system, a comparison with the Marshall system is advantageous as it's widely employed. An experimental investigation was conducted, comparing the Marshall Mix design with the Superpave mix design, also the life cycle cost analysis was performed, which takes into account all costs associated with the road over its entire lifespan, including construction, maintenance, and rehabilitation. The laboratory investigations for quality testing of the aggregate, bitumen, and mineral filler, sample preparation for Marshall mix design, and Marshall tests were all carried out at the Kality IFH highway laboratory. Tests for the Superpave mix design, starting from specimen preparation using the same samples brought from the Kality branch, and all performance tests for both Marshall and Superpave samples were conducted at the Picok IFH highway laboratory. All tests were conducted according to established standards, including AASHTO, ERA, BS, and MS-2.

3.2 Research design

The experimental design and LCCA was used for the study, the experimental design involved several steps. Firstly, asphalt and aggregate samples was collected based on defined criteria, and quality control tests were conducted on the samples. Next, the samples were prepared and compacted using gyratory compactor and the Marshall compactor, their volumetric properties, including air voids, VMA, VFA, Gmb, and Gmm, was then measured. The OBC for the asphalt samples determined by testing samples at different binder contents to identify the one that yielded the desired volumetric properties. Finally, asphalt samples prepared at OBC for performance testing using appropriate equipment, such as the wheel tracking test, the indirect tensile strength test, and the retained stability test. Finally, the LCCA was performed to evaluate the cost-effectiveness of the two methods. The results are then analyzed and interpreted to draw conclusions and provide recommendations for future research or practical applications.

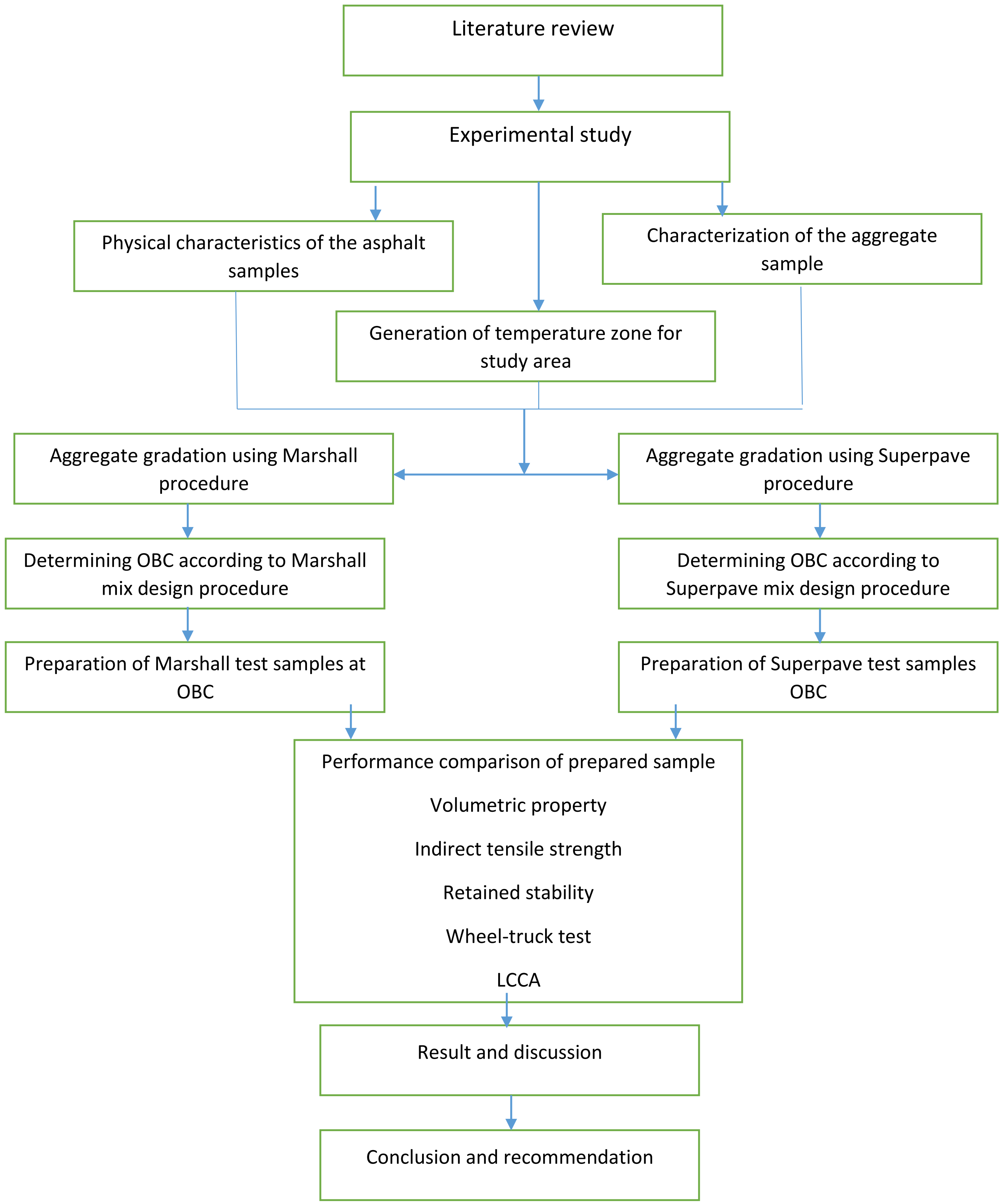


Figure 3.1 Flow chart or research design

3.3 Materials

- Aggregates: - Crushed Basalt (Coarse & Fine Aggregates)
- Binders: - Bitumen (60/70) penetration grade
- Mineral Filler: - Hydrated Lime

3.3.1 Aggregate Material

Mineral Aggregates – Granular material produced from deposits of rock or sand is typically classified into three sizes: coarse aggregate, medium aggregate, and fine aggregate. Coarse aggregate is generally larger than 5mm, while fine aggregate is smaller than 5mm. For this research, coarse aggregates are defined as having specified gradations between 20mm to 14mm. Medium aggregate size ranges from 14mm to 6mm, while fine aggregate size is typically crushed sand that passes through a 6mm to 3mm and 3mm to 0mm sieve.

Figure 3.2 Aggregate production and Stockpile**.**

3.3.2 Bitumen Material

Bitumen is a complex material with a complex response to stress. All bitumen's show a more or less pronounced viscous elastic behavior. Their resistance to deformation being dependent on both the temperature and time during which a force is applied. Only under extreme conditions a bitumen behave either as a typical elastic solid (low temperature very short loading time) or as a viscous liquid (high temperature, long loading time). Under normal temperature conditions, both viscous and elastic behavior play their part. Since both temperature and loading time are variable under the conditions of practice. The temperature and time susceptibilities of bitumen are important performance factors. To characterize the numerous bitumen grades a number of test methods have been developed.

Figure 3.3 Bitumen / Asphalt 60/70

3.3.3 Properties of Binder

For this study, bitumen 60/70 penetration grade was used. This type of bitumen is widely used and accepted for high-temperature zones. Before use, it was subjected to quality tests in the laboratory to determine its physical properties.

3.3.4 Mineral Filler Material

Pulverized limestone, a finely divided mineral product of which at least 65% pass a 75µm (No. 200) sieve, is the most manufactured filler. However, other materials, such as stone dust, silica, hydrated lime, Portland cement, fly ash, and certain natural deposits of finely divided mineral are also used. For this research, hydrated lime is used as a filler.

3.4 Sampling of Materials

The materials were selected by considering a construction works of package 37 Lot-1 Ring Road junction improvement Project, Contruct-1 Emperial and Kadisco Intersections. The selected area is appropriate for the research objective as it has determined to have a high-traffic flow of more than 30 million ESAL. The study area is representative of real-world conditions and ensures that the results obtained are applicable to high-traffic volume environments. This is important because heavy traffic loads can cause significant damage to road pavements over time, and it is critical to evaluate the performance of different mix designs under such conditions. The selected material must meet the specification requirements as set by the local highway agency.

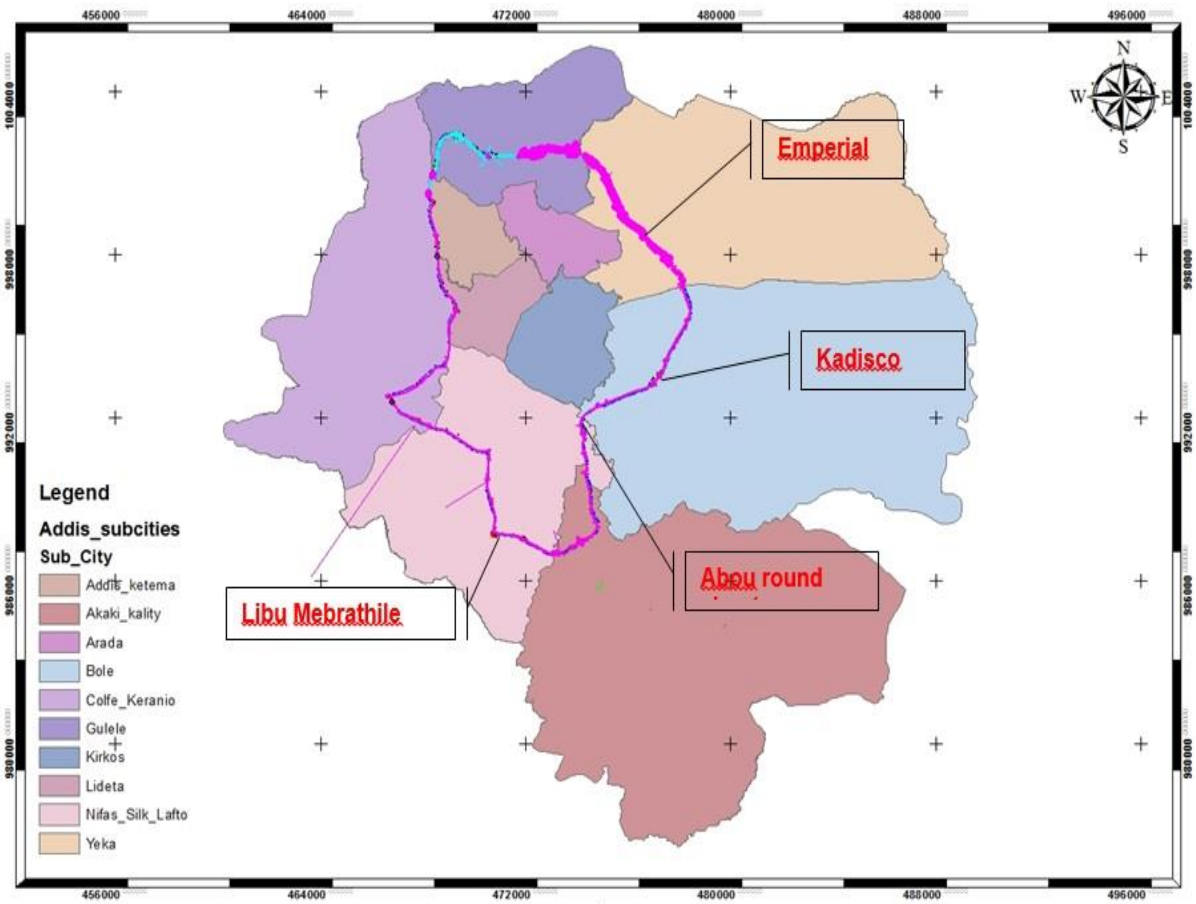


Figure 3.4 study area

For this study, a total of 88 samples were used. To get the lived experience of the mix designs, the obtained results from each test used in this research were calculated through an Excel sheet prepared by the IFH company according to Ethiopian specifications. The results were presented in a table form and analyzed and discussed through line charts and bar graphs

mix design	Superpave mix design	Marshall mix design
for determining OBC, stability, flow, volumetric property.	OBC (3.5-6), 6*3= 18 Stability and flow= 3	OBC (4-6), 5*3=15
(Gmm) 2 specimen for each trial binder content	6*2= 12	5*2 = 10
Wheel tuck test for rutting @ OBC	3	3
TSR (3 for dry and 3 for wet)	6	6
Retained stability (3 for dry and 3 for wet)	6	6
total sample	88	

Table 3.1 Total sample size

3.4.1 Sampling of Aggregate Materials.

Sampling of Aggregate materials were done from **Akaki-08 Quarry**, for making this research 6 bags of representative materials free from segregation, and contamination sampled. Aggregates can be classified by their mineral, chemical and physical properties. The pavement industry typically relies on physical properties for performance characterization. An aggregate's physical properties are a direct result of its mineral and chemical properties.

Figure 3.5 Aggregate Sampling by Size

3.4.2 Sampling of Bituminous Material

A representative sample of bitumen material from the **Hana Mariam** asphalt batching plant storage unit, precautions to ensure that the sample was not contaminated by dust, water, or other organic matter. A total of 12kg of bitumen material was collected for this research.

3.5 Characterization of the aggregate sample

To determine whether the aggregates meet the specification limits, several laboratory tests were conducted to evaluate their physical properties. These tests were carried out to assess the suitability of the aggregates for their intended use.

- ❖ Aggregate Crushed value test (ACV) [BS:812 part 110 (1990)]
- ❖ Loss Angeles Abrasion test (LAA) [AASHTO T 96-94]
- ❖ Ten Percent Fines Value & Wet/dry Ratio [BS:812 part 110 (1990)]
- ❖ Aggregate Impact value test (AIV) [BS 812, Part 112]
- ❖ Soundness by Sodium Sulphate (SSS) [AASHTO T 104-97]

- Flakiness & Elongation Index [BS 812: Section 105.1:1989]
- Bulk Specific Gravity & Water Absorption Test [AASHTO T 85-91]
- Sand Equivalent Test [AASHTO T176-86]
- Plastic Index [AASHTO T 89-90]
- Coating & Stripping test of Bituminous material [AASHTO T 182-84]
- Polish Stone Value Test (PSV) [BS 812 Part 114]
- Sieve Analysis of Aggregates (Gradation) [AASHTO T 27]

3.5.1 Aggregates Crushing Value Test (ACV)

The strength of coarse aggregates can be evaluated through the aggregates crushing test, which provides a relative measure of their resistance to crushing under a gradually applied compressive load of up to 400KN over a period of 10 minutes (Berhanu, 2020). For the test, the aggregate is prepared by passing it through a 14mm sieve and retaining it on a 10mm sieve. To ensure high-quality pavement according to the ERA standard manual, aggregates with a low aggregate crushing value less than 25% of the total weight of aggregate is preferred.

ACV = (Weight of crushed particles / Total weight of sample) x 100

Figure 3.6 Aggregate for ACV Test.

3.5.2 Los Angeles Abrasion Value Test. (LAA)

It is a method used to determine the toughness and abrasion resistance of aggregates, including their resistance to crushing, degradation, and disintegration. It measures the percentage wear of sample aggregates when rubbed with steel balls (Essays, 2018). For this research, method B used and of the sample prepared using the aggregates passing through a 19mm sieve and retained by the 12.5mm sieve were used. Additionally, the aggregates that passed through the 12.5mm sieve but retained by the 9.5mm sieve were also used. This method follows the guidelines set forth in the ERA Standard manual, which recommends that the weight of the total aggregate with an abrasion value of less than 35% of the total weight is used.

3.5.3 Aggregates Impact Value Test. (AIV)

The aggregate impact value provides a relative measure of an aggregate's resistance to sudden shock or impact, which may differ from its resistance to slow compressive loads (Anand, 2017). To conduct the test, the sample is prepared by passing it through a 14mm sieve and are retained by the 10mm sieve. The sample is then compacted by 25 stocks of the tamping rod, and the height of the hammer is adjusted so that it is 380±5mm above the upper surface of the aggregate in the cup. The hammer is allowed to fall freely on the aggregate to achieve a total of 15 blows at intervals of not less than 1 second. The loss of materials is then measured by sieving those that pass through a 2.36mm sieve. According to the ERA Standard manual, the weight of the total aggregate with an impact value of less than 25% of the total weight of the aggregate is used. AIV = (Weight of crushed particles / Total weight of sample) x 100

3.5.4 Soundness by Sodium Sulphate Test (SSS)

The soundness test is used to determine the resistance of an aggregate to disintegration due to weathering, especially freeze-thaw cycles. Durable aggregates that are resistant to weathering are less likely to degrade in the field and cause premature distress and potential failure of HMA pavement (Haynes, 2005). According to the ERA Standard manual, the amount of loss due to the soundness test should be less than 10% for coarse aggregates and 15% for fine aggregates.

3.5.5 Shape (Surface texture) Test on Aggregates.

The properties of hot mix asphalt are influenced by the shape and surface texture of the particles used in its composition. Rough-textured, angular, and elongated particles tend to require more asphalt to produce a workable mix than smooth, rounded compact aggregates. As a result, the asphalt content must also be increased. Flat and elongated particles are generally avoided or limited to less than 25% of the total weight of the aggregate, as specified by the ERA Standard manual. It's important to note that this test is not applicable for particle sizes smaller than 6.3mm.

Figure 3.7 Elongation Index test and Flakiness Index test

3.5.6 PSV - Polished Stone Value Test

The Polished Stone Value test is used to determine the rate of wear and polishing of an aggregate due to repeated tire traffic. The road surface's rough texture helps to provide skid resistance for traffic, and a higher polished stone value indicates that the aggregate will retain its texture for a longer period (Berhanu, 2020). The test involves using an accelerated polishing machine and apparatus to test friction, with samples of aggregate fixed into small molds using resin. After polishing, the friction test is conducted on each sample to determine its PSV. The machine used in the test consists of a road wheel, rotating at 320 rpm, with 14 specimen holders clamped to its periphery. A solid rubber-tired wheel is positioned vertically above the road wheel and loaded to apply a force of 725 N.

3.5.7 Cleanliness Test on Aggregates

When used in HMA, aggregates must be relatively clean to ensure optimal performance. Vegetation, soft particles, clay lumps, excess dust, and vegetable matter can quickly degrade and negatively affect structural support and binder-aggregate bonding.

- ❖ Measure by plasticity index: - According to ERA standard manual less than 4% or non-plasticity index.
- ❖ Clay lump: - According to AASHTO T-112 standard manual less than 1%.

3.5.8 Sand Equivalent test

The sand equivalent test is a quick field test that determines the relative proportions of fine dust or clay-like materials in fine aggregate as per ASTM, 2003. These materials can cover aggregate particles and impede proper asphalt binder-aggregate bonding. Sand equivalent According to ERA standard manual allowed to be min 40%.

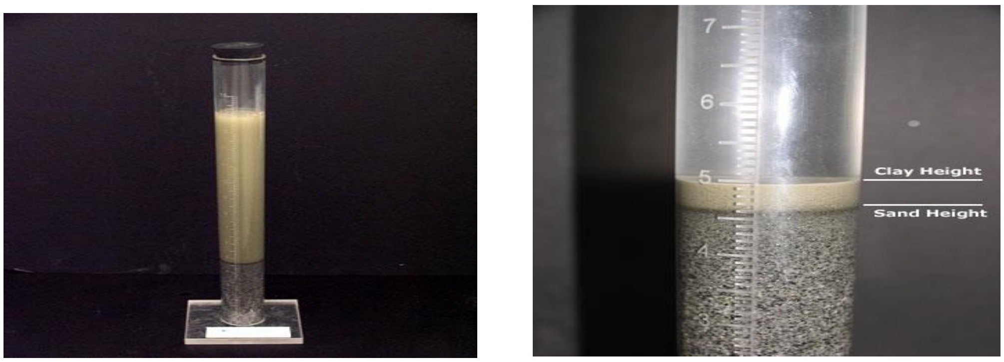


Figure 3.8 Cylinder after shaking and figure showing clay and sand height.

3.5.9 Coating & Striping Test

To conduct the film-stripping test, a specifically selected and prepared aggregate passing through 13.2mm and retained 9.5mm size is coated with bitumen at a temperature that is appropriate for the specific asphalt product. The coated aggregate is cured for a specific period at 135°C. After curing, the coated and cured aggregate is immersed in distilled water for 16 to 18 hours. The sample is then visually inspected to estimate the amount of film retained on the aggregate while it is still submerged in water. The amount of film retention is reported as either above or below 95 percent.

Figure 3.9 Coating & Striping Test

3.5.10 Specific Gravity and Water Absorption Test on Aggregates.

The specific gravity test is a useful tool in identifying different types of stone. Water absorption provides an indication of the strength of the aggregate. Aggregates with higher water absorption tend to be more porous and are generally considered unsuitable unless they pass strength, impact, and hardness tests and have a water absorption value of less than 2%, as specified in the ERA Standard manual.

- Determination of Bulk specific gravity of an aggregates
    - Bulk Specific Gravity of oven dry (Gsb)
    - Bulk Specific Gravity of Saturated Surface dry (SSD)
    - Apparent Specific Gravity of (Gsa)
    - Effective Specific Gravity of (Gse)
    - Then Evaluate the Gsb < Gse < Gsa

3.5.11 Gradation (Sieve analysis)

- Grading: - To distribution of aggregate particles from coarse to fine & select the mixture type like dense graded, surface course, binder course, base course & stone- matrices asphalt (ASM)
- Maximum size: - one sieve size larger than the nominal maximum size. For this study, the selected maximum aggregate size is 25mm from ms-2 manual series -2 page 7, table 2.1
- Nominal Maximum Size: - one sieve size larger than the first sieve to retained more than 10% by weight & to select the minimum VMA, our mix minimum VMA is 13% at 4% air voids. from MS-2 page 70, table 5.3

Gradation is usually measured by a sieve analysis. In a sieve analysis, a sample of dry aggregate of known weight is separated through a series of sieves with progressively smaller openings. Once separated, the weight of particles retained on each sieve is measured and compared to the total sample weight. Particle size distribution is then expressed as a percent passing by weight on each sieve size.

3.6 Physical characteristics of the asphalt samples

3.6.1 Binder Quality Test

Conventional performance measures are performed on bitumen to evaluate the physical properties of the asphalt.

- Penetration Test [IS 1203-1978]
- Softening Point Test [IS :1205-1978]
- Ductility @25℃ (AASHTO T 051-94)
- Flash Point ℃ (AASHTO T 048-96)
- Rolling thin film oven Test (AASHTO T 240)
- Specific Gravity @25℃ AASHTO T 228-94)
- Solubility in Trichloroethylene, % [AASHTO T 44]
- Dynamic Viscosity [AASHTO T 201]
- Residue Penetration [ASTM D5-IP49]
- Residue Ductility [AASHTO T 51]

3.6.2 Penetration Test

Penetration measures the consistency, whether the asphalt binder is hard or soft (Alemu et al., 2023). The standard test method for penetration of bituminous materials is described under ASTM D5 or AASHTO T 49. Penetration is determined by measuring the distance in tenths of a millimeter that a standard needle vertically penetrates a sample of the material under a specified load, temperature, and within a specific period. Under normal conditions, a loading of 100g at a temperature of 25°C and a testing time of 5 seconds is common. Higher values of penetration indicate a softer consistency, while lower values indicate a harder bitumen. Penetration can also be used as an indirect measure of viscosity by correlating it with an empirical formulation.

Figure 3.10 Bitumen Penetration Test.

3.6.3 Softening Point Test

The standard method of test for softening point, using the Ring and Ball Apparatus, is described in ASTM D 36 or AASHTO T 53. To carry out the test, two disks of specimens are prepared using shouldered brass rings. The rings, loaded with a 3.5g steel ball at the center of each ring, are placed in an assembly and immersed in a beaker of water. The water, initially at 5°C, is then heated at a controlled rate, usually 5°C per minute. The softening point is the mean of the temperatures recorded when the two balls enveloped with soft bitumen touch the lower plate 25mm below the rings. The softening point helps to classify bitumen, check uniformity, and indicate its tendency to flow at elevated temperatures. A higher softening point indicates lower temperature susceptibility and is preferred in warm climates.

Figure 3.11 Sample preparation by ring ball and Softening point test

3.6.4 Ductility test

According to the standard test method described in ASTM D113 or AASHTO T 51, the ductility of bituminous materials is measured by the distance in centimeters to which a standard briquette of bituminous sample can be stretched before the thread breaks when pulled apart at a specified speed and temperature. If there is no special reason, the standard test temperature, which will be maintained using a water bath, is 25°C (77°F), and the rate of pull to elongate the sample is 5cm per minute.

Figure 3.12 Ductility test

3.6.5 Flash Point Test

The flash point test determines the temperature to which asphalt can be safely heated in the presence of an open flame. The test involves heating an asphalt sample in an open cup at a specified rate and determining the temperature at which a small flame passing over the surface of the cup will cause the vapors from the asphalt sample to temporarily ignite or flash (Ymer, 2020). The Cleveland Open-Cup method is used for this research as per ASTM D92.

Figure 3.13 Flash Point Test.

3.6.6 Dynamic Viscosity Tests

The ERA specifications require that the dynamic viscosity of asphalt be measured using the AASHTO T201 test methods. These methods involve heating the asphalt to a specified temperature and measuring its resistance to flow under a specified shear rate using a rotational viscometer.

3.6.7 RTFO Short Term Ageing (Conditioning) Test

It's conducted according to AASHTO T 240, which is the standard method of testing for the impact of temperature and air on moving layer of asphalt. The oven is preheated for a minimum of 2 hours prior to testing, so that it will equilibrate at 163+/-0.5°C when fully loaded and the air is on. After preparing the oven, 35±0.5g of asphalt binder is poured into each bottle and placed in the carriage. The airflow is set at a rate of 4000 ml/min, and the carriage is rotated at a rate of 15 rev/min. The samples are subjected to these conditions for 85 minutes.

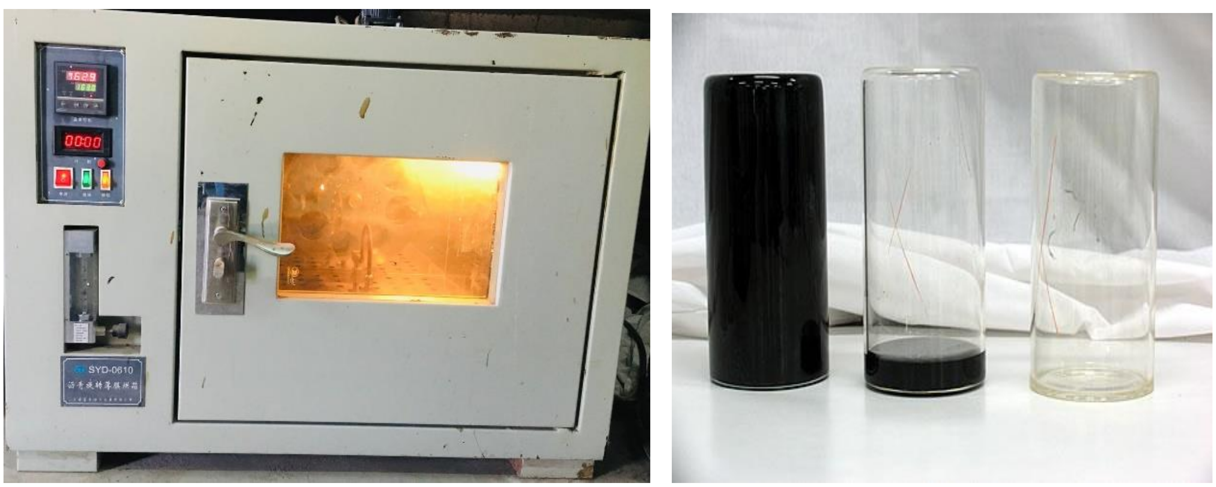


Figure 3.14 Rolling Thin-Film Oven Test (RTFO).

3.7 Methods

The Marshall mix design procedure consists of several main elements, including determining the maximum theoretical specific gravity, selecting the optimum asphalt content, and compacting the mixture to achieve the maximum density and strength (McGennis et al., 2010). The mix design procedure also involves testing the mixture's stability and flow, which are crucial to ensuring its performance under traffic loads (Shah et al., 2020).

In contrast, the Superpave method of mix design was introduced in 1993 as a more advanced and performance-based approach to mix design (Ahmad et al., 2014). The Superpave method focuses on achieving a mix design that is resistant to rutting, fatigue cracking, and thermal cracking. This is accomplished through a series of tests and analyses that evaluate the properties of individual materials used in the mix, such as aggregate gradation, asphalt binder properties, and air voids (Cooley et al., 2002). Overall, while the Marshall method is simpler and more widely used, the Superpave method is considered more advanced and better suited for designing mixtures that can withstand the harsh conditions of modern traffic loads (ALAZAWY, 2015).

3.8 The Marshall Mix design volumetric property characterization

Marshall mix design requires the preparation of laboratory specimens using a specified aggregate blend and bitumen content. The sample preparation involves the following procedure.

3.8.1 Selection of aggregates that meet the suitability criteria

After testing each aggregate sample using the method outlined in the previous section, it is important to evaluate the suitability of each sample based on the test results. This evaluation involves comparing the properties of each sample to the required specifications for the mix design, as well as assessing the durability of the aggregate. Only aggregate samples that meet the required specifications and have sufficient durability selected for use in the mix design. This ensures that the final mix will have the desired properties and will perform well over time.

3.8.2 Selection an asphalt cement suitable for the climate

Once the bitumen has been tested using the method outlined earlier, it is crucial to evaluate its suitability based on the results obtained. This evaluation involves comparing the properties of the bitumen sample to the required specifications for the mix design, as well as assessing its durability. The suitability of the bitumen sample is determined by selecting only those that meet the required specifications and exhibit sufficient durability for use in the mix design. This rigorous selection process ensures that the final mix is optimized to perform well and have the desired properties over time.

3.8.3 The determination of bulk specific gravity (Gsb)

The determination of Gsb is a test used to determine the density of aggregate. This test involves determining the weight of a known volume of dry aggregate, then immersing it in water to determine its SSD weight. The bulk specific gravity is then calculated by dividing the weight of the aggregate by its volume

3.8.4 Proportioning or blending of Aggregate

For proportioning and blending of aggregate, trial and error method used. Any number of trial blends can be attempted, but for this research two trial blending consists of varying stockpile percentages of each aggregate to obtain blend gradations proportioned and the average value of them is used to perform the gradation.

3.8.5 Compaction of the asphalt mixtures

The asphalt mixture is compacted in a 101.6-mm (4-in.) diameter cylindrical mold using a 4.54 kg (10 lb.) load hammer. Marshall compaction hammer dropped from a height of 457 mm (18 in.) for a specified number of blows per side of the specimen. For high-traffic design, 75 blows per side are applied. The study area was found to have more than 30 million ESAL. For this research, each side of the specimen was compacted with 75 blows.

Marshall mix design compaction effort	
ESAL (Million)	Blow
<0.1	35
0.1 – 1	50
>1	75

Table 3.2 Marshall mix design compaction effort

Figure 3.15 Asphalt Compactor apparatus

3.8.6 Mix volumetric properties (Gmb, Gmm, Va, VMA, and VFA)

An asphalt mixture, once compacted, consists primarily of aggregate, asphalt, and air, with the composition characterized by the proportioning of the volumes of these three components.

3.8.6.1 Bulk specific gravity determination (Gmb)

The bulk specific gravity test can be conducted once the freshly compacted specimens have cooled to room temperature, a compacted HMA sample, is weighed in dry, saturated surface dry (SSD), and submerged condition. These weights are then used to calculate the specific gravity and percentage of water absorbed by the sample. For this research, the test was performed according to AASHTO T 166.

3.8.6.2 Theoretical specific gravity determination (Gmm)

The theoretical maximum specific gravity (Gmm) of an asphalt mixture is the specific gravity of the binder-coated aggregate without any air voids. To determine Gmm, an oven-dry sample of loose paving mixture is weighed and placed into a tarred vacuum vessel. Water at a temperature of 25 ± 4°C is added to submerge the sample completely. The vacuum is applied gradually for 15 ± 2 minutes to reduce the residual pressure to 3.7 ± 0.3 kPa. At the end of the vacuum period, the vacuum is slowly released. The volume of the paving mixture sample is obtained by filling the vacuum container with water and weighing it in air. The temperature and mass are also measured. From the mass and volume measurements, the specific gravity or density at 25°C is calculated. This test is performed according to AASHTO Designation T 209.

Figure 3.16 Gmm Test apparatus

3.8.6.3 Air Voids (Va)

The total volume of air, expressed as a percentage of the bulk volume of the compacted mixture, which is distributed throughout a compacted paving mixture and is located between the coated aggregate particles. It’s found after calculating bulk specific gravity, and theoretical maximum specific gravity of the sample.

3.8.6.4 Voids in the Mineral Aggregate (VMA)

This is the volume of void space between the aggregate particles of a compacted paving mixture. It is the sum of Va and Pbe expressed as a percent of the total volume of the sample.

3.8.6.5 Voids Filled with Bitumen (VFB)

This is the portion of the volume of void space between the aggregate particles (VMA) that is occupied by the effective bitumen.

3.8.7 Determination of Stability and flow test on compacted specimen

Once the bulk specific gravity of the test specimens has been determined, the stability and flow tests are performed, which include (a) determining the specimen height, (b) immersing the specimen in a water bath at 60°C ± 1°C (140°F ± 1.8°F) for 30 to 40 minutes prior to testing, or in an oven at the same temperature for 120 to 130 minutes, and (c) The conditioned specimens are placed in a Marshall Stability testing machine, which consists of a loading frame and a load cell. The load is applied to the specimen at a constant rate of deformation. The maximum load that the specimen can sustain before failure is recorded as the Marshall Stability. The deformation of the specimen at the point of maximum load is recorded as the Marshall Flow.

Figure 3.17 Stability & Flow Test.

3.8.8 Determination of OAC according to Marshall Mix design procedure.

Optimum Asphalt Content Determination by using asphalt institute manual procedure. The following 6 graphs are plotted for determine the optimum asphalt content (OAC).

1. Unit weight vs. bitumen content
2. Marshall stability vs. bitumen content
3. Percent voids in mix vs. bitumen content

4. Percent voids in the mineral aggregate vs. bitumen content
5. Percent aggregate voids filled with bitumen vs. bitumen content
6. Flow Values vs. bitumen content

3.9 Super Pave mix design volumetric property characterization

The Superpave system was developed to give highway engineers and contractors the tools they need to design asphalt pavements that will perform better under extremes of temperature and high-traffic loads. Superpave is a performance-based specification for asphalt binder and aggregate, it employs restricted volumetric criteria and compaction methods to ensure that the asphalt mix will perform well in its intended application. The following criteria was considered for the study area.

Volumetric Mix Design Criteria					
Design air voids				4.0%	
Dust to bitumen ratio %				0.6 - 1.2	
Tensile Strength ratio, (AASHTO T283)				80% Minimum	
Nominal Maximum Size					
Minimum Void in Mineral Aggregate, (VMA) %	37.5 mm	25 mm	19 mm	12.5 mm	9.5 mm
	11	12	13	14	15
Design ESALs (millions)	Percent of Theoretical Maximum Specific Gravity			Percent Void Filled with Asphalt, (VFA)	
	$N_{initial}$	**N_{design}**	**$N_{maximum}$**		
< 0.3	≤ 91.5	96.0	≤ 98.0	70 – 80	
0.3 < 3	≤ 90.5	96.0	≤ 98.0	65 – 78	
3 < 10	≤ 89.0	96.0	≤ 98.0	65 – 75	
10 < 30	≤ 89.0	96.0	≤ 98.0	66 – 75	
≥ 30	≤ 89.0	96.0	≤ 98.0	67 – 75	

Table 3.3 Volumetric mix design criteria

Superpave applies three level of compaction which are:

1. Nini. The number of gyrations used as a measure of mixture compactability during construction.
2. Ndsign. This is the design number of gyrations required to produce a sample with the same density as that expected in the field after the indicated amount of traffic. A mix with 4.0 percent air voids at Ndesign is desired in mix design.
3. Nmax. The number of gyrations required to produce a laboratory density that should never be exceeded in the field. If the air voids at Nmax are too low, then the field mixture may compact too much under traffic resulting in excessively low air voids and potential rutting. The air void content at Nmax should never be below 2.0 percent air voids.

As this research considers high-traffic flow, the compaction parameter selected as shown below

Gyratory Compaction Criteria			
Design ESALs (millions)	**Compaction Parameters**		
	$N_{initial}$	**N_{design}**	**$N_{maximum}$**
< 0.3 (Light Traffic)	6	50	75
0.3 < 3 (Medium Traffic)	7	75	115
3 < 30 (Heavy Traffic)	8	100	160
≥ 30 (Extra Heavy Traffic)	**9**	**125**	**205**

Table 3.4 Super pave compaction criteria

Therefore, the process of designing Hot Mix Asphalt mix using Superpave method for Wearing Course has presented below by chart.

Volumetric Properties	Superpave Limit
Va at Ndesign	4.00%
VMA at Ndesign	Nominal Maximum Size
Cintial	<89.0% of Gmm
Cdesign	96% at 4% of Va
Cmax	<98.0% of Gmm

Table 3.5 Summery of Superpave Volumetric Design Criteria

3.9.1 Aggregate selection

The Superpave system is a performance-based method for designing asphalt pavements that considers the properties of the asphalt binder, the aggregate, and the mixture as a whole. The Superpave system includes several aggregate quality tests that are based on both consensus and source property criteria. The consensus-based tests included coarse aggregate angularity, fine aggregate angularity, flat and elongated particles, clay content, and gradation. Aggregate source properties, such as soundness, toughness, and deleterious materials. The aggregate used for the Superpave mix design were the same materials used in the Marshall mix design, but additional tests were conducted on the aggregate as shown below.

Superpave Fine Aggregate Angularity Requirements - AASHTO T 304		
Traffic Million ESALs	Percent, Minimum	
	Depth from Surface	
	<100mm	>100mm
< 0.3	--	--
0.3 to <3	40	40
3 to <10	45	40
10 to <30	45	40
≥ 30	45	45
Note: Criteria are presented as percent air voids in loosely compacted fine aggregate.		

Table 3.6 Superpave fine Aggregate Angularity Requirements

Superpave Coarse Aggregate Angularity Requirements ASTM D 5821			
Traffic, Million ESALs	Percent, Minimum		
	Depth from Surface		
	< 100 mm	>100 mm	
< 0.3	55/-	-/-	
0.3 to < 3	65/-	-/-	
3 to < 10	75/-	50/-	
10 to < 30	85/80	60/-	
≥30	95/90	85/80	
Aggregates	**One face fractured**	**Two or more face fractured**	**Criteria**
Coarse Aggregate		96%	95/90
Note: “95/90” means that 95 % of the coarse aggregate has one fractured face and 90 % has two fractured faces.			

Table 3.7 Superpave Coarse Aggregate Angularity Requirements

3.9.2 Asphalt binder selection

The asphalt binder grading system used in Superpave is called the Performance Grading (PG) system. PG binders are characterized based on fundamental engineering parameters, considering the impact of climatic factors on binder characteristics at both hot and cold temperature regimes. In addition to climatic conditions, traffic and aging also affect the performance of the pavement. The bitumen that has been tested using the method outlined earlier and used for marshall mix design, was also used for Superpave with some additional tests.

3.9.3 Sample preparation including Compaction

The job mix formula (JMF) gradation target values was established within the design criteria specified for the asphalt mixture to be produced. To determine the volumetric property, sufficient mix is used to create a specimen that is 115 mm ± 5 mm in height, requiring approximately 4500 grams of the mixture which can be tested without trimming. Alternatively, to obtain Gmm using AASHTO T 209, loose samples should remain uncompact. An aggregate weight of 2000 grams is usually sufficient for the specimens used to determine maximum theoretical specific gravity (Gmm). For performing moisture sensitivity tests (TSR) as per (AASHTO T283), test specimens are fabricated to a height of 95 mm, requiring approximately 3500 grams of the mixture.

The number of gyrations used for this mix compaction is determined based on the design high air temperature of the paving location and the traffic (≥ 30 million (Extra Heavy Traffic Load) ESALS). For these two conditions, the number of gyrations are identified as:

Nintial = 9 gyrations; Ndesign = 125 gyrations; and Nmaximum = 205 gyrations.

Each specimen is compacted to the maximum number of gyrations, during compaction, the height of the specimen is continually monitored. Knowing the initial weight of the mix, the fixed volume of the mould, and the measured height, the density can be continually monitored by the Supervision consultant. After compaction, the final density of the specimens determined by AASHTO T 166. The Gmm of each blend is also determined. From this data, the air voids of the specimen at each gyration can be determined

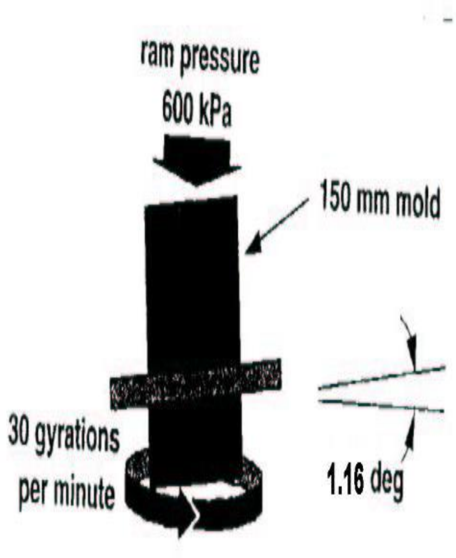


Figure 3.18 Superpave Gyratory Compaction

3.9.4 Superpave Density and voids Analysis (Volumetric properties)

This method covers the compaction of cylindrical specimens of hot mix asphalt (HMA) using the Superpave Gyratory Compactor. The Superpave mix design test volumetric requirements consist of Va, VMA, and VFA. Air void content is an important property, it is used as the basis for asphalt binder content selection and always be 4%. VMA requirements are a function of the maximum nominal aggregate size of the mixture, while VFA requirements are a function of traffic level (design ESALS).

3.9.5 Determining Optimum Asphalt Content (OAC) for Superpave mix

Using NAPA method, the binder content corresponding to average of allowable air void range is determined. As recommended by the Asphalt Institute, cylindrical specimens with a diameter of mm with a total aggregate mass of 4500 g, were used for this mix design. The aggregate and asphalt binder were oven-heated at the mixing temperature before mixing, then mixed in a mechanical mixer. The loose mixtures were aged for 2 hours at the compaction temperature and then placed in the gyratory mold and compacted using a gyratory compactor at the compaction temperature using the gyration number-controlled mode. Specimen preparation was performed in accordance with AASHTO T-312. Three specimens for each binder content were compacted at different asphalt contents to calculate the optimal asphalt content (OAC).

3.10 Mechanical Performance Tests of Superpave and Marshall mix design

After the volumetric test performed, trial mixes are then prepared to evaluate the TSR, retained stability, and rutting behavior of bituminous mixes. For the rutting test, three HMA samples for each mix design with a diameter of 300*300*50mm were compacted, for the retained stability and TSR test six specimens for each mix design were compacted. All compacted samples had air voids within the range of 7±1%. Volumetric tests were performed to prepare the samples with these specifications.

3.10.1 Preparation of Asphalt Roller Compactor

An Asphalt Roller Compactor is a laboratory testing device used to compact asphalt mixtures into cylindrical specimens for performance testing. The ARC simulates the compaction process used in the field to produce asphalt pavements and allows for the evaluation of the compactability, workability, and performance properties of the asphalt mixture. It's also a suitable test for evaluating the moisture resistance and overall stability of the asphalt mix. The test is conducted on a confined mold in which a slab specimen of dimensions (300 x 300 x 50) mm according to (EN 12697-Part 22:2003), is rigidly restrained on its four sides. The slab specimens are prepared with the desired job mix formula and compacted at the required compaction temperature to the target air void content (7±1%) and density according to BS EN 12697-35:2016 using an **Asphalt Roller Compactor.**

The weight of the asphalt mixture required for the asphalt slabs was calculated using the following equation.

$M = 10^{-6}*L*I*e*Gmm*100\text{-}V/100$ …………………………………………………. equ. 3.1

Where: M = mass of asphalt concrete slab, kg

L= length of mould, mm

I = width of mould, mm

V= air Voids level in slab, %

e = thickness of asphalt concrete slab, mm

Gmm = is the maximum theoretical specific gravity of a bituminous mixture, kg/m^3

$M = 10^{6}(300mm*300mm*50mm)*2.404*(100\text{-}7/100)$ = **10.061kg**

@7% the slab total mass is found = **10.061kg**

Figure 3.19 Sample preparation for rutting

3.10.2 Wheel Trucking or Rutting Test

The wheel tracking apparatus consists of a loaded wheel which bears on a sample held on moving table. The table moves in backward and forward motion with respect to the center of the top surface of the specimen. The tests were conducted at 60 ℃ at a load frequency of 53 passes per minute. The steel wheel with solid rubber tire is applied with a load of 705 N and indents a straight path in specimen. Each specimen was tested for 20,000 passes. A total of 6 samples used for Wheel Trucking test and the result from each trial have been placed in appendix L and N, for marshall and Superpave.

Figure 3.20 Sample for Wheel Trucking Test

3.10.3 Indirect Tensile Strength Ratio test (TSR)

Tensile strength ratio testing of asphalt mix is conducted to measure the mix's resistance to moisture damage. According to AASHTO T283, this test is performed on proposed mix the specimens are placed in a water bath maintained at 60°C for 24 hours, and then immediately placed in an environmental chamber maintained at 25°C for 2 hours, with a uniaxial compressive load acting along the vertical diametric-loading plane, and the tensile strength calculated from the load at which the specimen fails is taken as the dry tensile strength of the asphalt mix. A total of 12 samples used for TSR and the result from each trial have been placed in appendix K and M, for marshall and Superpave.

$$\text{Indirect tensile strength ratio} = \frac{\text{TSR of conditioned specimens}}{\text{TSR of unconditioned specimens}} \quad \text{.................................equ 3.2}$$

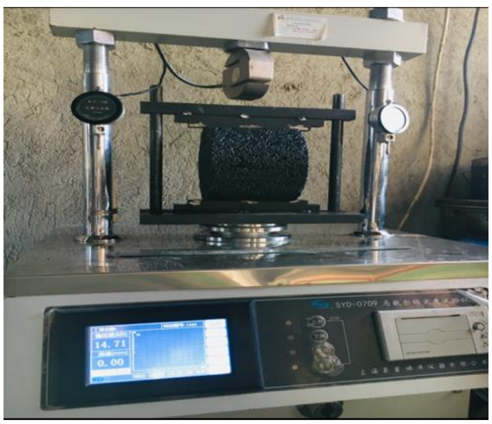


Figure 3.21 Indirect Tensile Strength Ratio (TSR) Test.

3.10.4 Retained stability

The retained stability used to evaluate the resistance of asphalt mixtures to rutting and deformation under traffic loading. for conducting the test: cylindrical specimens of the asphalt mixture prepared using a gyratory compactor and marshall compactor for each mix design. The specimens cured in an oven at a temperature of 60°C ± 1°C for 4 hours. The specimens then placed in a water bath at a temperature of 25°C ± 1°C for 20 hours to allow them to saturate. After saturation, remove the specimens from the water bath, wipe off any excess water, and placed on a level surface to cool to room temperature, detail calculation is on appendix J and total of 12 samples used.

$$\text{Retained stability} = \frac{\text{Retained stability of conditioned specimens}}{\text{Retained stability of unconditioned specimens}} \quad \text{.................................equ 3.3}$$

3.11 Life cycle cost analysis

The LCCA is comprehensive approach, particularly relevant in the case of pavements, where the life cycle begins with material extraction and production, followed by construction and facility operation, maintenance and rehabilitation, and ultimately ending with either disposal or recycling (Crespo Márquez et al., 2012).

3.11.1 Material composition

To perform an unbiased analysis, an equivalent cross-section design of Marshall and Superpave Mix Asphalt pavement was considered in this study. The design of each pavement type was carefully carried out to reflect the typical cross-sections of the two selected alternatives, with a focus on a hypothetical highway that is 1 km long and 7 m wide. The highway was assumed to have two lanes in free flow without a median, with each lane measuring 3.5 m wide to accommodate high volumes of traffic asphalt. The designs for each alternative were based on established standards, including the ERA and AASHTO Guide for Design of Pavement Structures, and it was assumed that a major trunk road was planned to be built. The design lane was assumed to experience 100% of the loading. The cumulative traffic loading, measured in ESAL, was expected to be between 30 million and 80 million over a design life of 20 years for a flexible pavement structure, according to ERA manual (ERA, 2013).

3.11.2 Method of LCCA

The NPV method is a popular technique used in LCCA because it takes into account the time value of money. It recognizes that money spent or received in the future is worth less than money spent or received today due to inflation and other factors. By discounting future costs and benefits to their present value, the NPV method provides a more accurate representation of the total cost of a project or product over its entire life cycle (Gorfu, 2017). The method used for LCCA is a NPV method as it helps to compare different options and choose the one that has the lowest net present value, which indicates the most cost-effective option.

3.11.3 Equation used for LCCA

The following equation was used in this particular case to determine the net present value of each alternative.

$$NPV = IC + \sum_{K}^{N} MC \frac{1}{(1+i)^n} + \sum_{K}^{N} RC \frac{1}{(1+i)^n} + \sum_{K}^{N} UC \frac{1}{(1+i)^n} - SV \frac{1}{(1+i)^n} \quad \text{equ. 3.4}$$

Where; IC = initial construction cost; MC= maintenance cost; RC= rehabilitation cost;

UC= user cost; SV = salvage value; n= analysis period in years;

k = number of years from the initial construction to the kth expenditure;

N= number of future costs incurred over the analysis period; i = discount rate.

3.11.4 Method of Data Gathering

Data for the study was gathered from multiple sources such as pavement design documents, manuals, internet sites, journals, and governmental institutions through document review, informal interviews, and internet searches.

3.11.4.1 Analysis period

When conducting a LCCA, it is important to choose an analysis period that is long enough to capture the cost differences associated with various design strategies over the lifespan of the pavement. In general, the analysis period should exceed the pavement design period, unless the pavement is expected to have an exceptionally long lifespan (Gorfu, 2017). Additionally, the analysis period should be long enough to include at least one rehabilitation activity. However, in some cases, a shorter analysis period may be appropriate if pavement design alternatives are used to temporarily extend the life of the pavement before total reconstruction is necessary (Guven et al., 2008). For this study analysis period of 35 years is used.

3.11.4.2 Interest Rate (r)

The National Bank of Ethiopia's Monetary Committee is responsible for making interest rate decisions. Analysts' expectations and Trading Economics global macro model suggest that the benchmark interest rate was 7% in the first quarter of 2023.

3.11.4.3 Inflation Rate (f)

Due to various reasons, it is very difficult to forecast the exact inflation rate. Hence, for this study the average inflation rate of 32.8% estimate was taken for the analysis period, according to expectations of trading economics global macro models and analysts, and it’s assumed that goods have higher opportunity to continue as it is now.

3.11.2.4 The discount rate (i)

The exact mathematical relationship between the discount rate, the interest rate, and the inflation rate was employed in selecting a discount rate for this particular case.

$$i = \left[\frac{1+r}{1+f}\right] - 1 \text{ ………………………………………………………………….. equ. 3.5}$$

$$\left[\frac{1+0.07}{1+0.328}\right] - 1 = 0.194$$

Where f= inflation rate 0.328

r = interest rate 0.07

3.11.5 Computation of pavement initial construction costs

Initial costs are determined at year zero of the analysis period. Although numerous activities are performed during the construction, only those activities that are specific to a pavement alternative should be included in the initial costs. Comparing the initial cost of construction involves the calculation of material quantities to be provided in each pavement structure and multiplication by their unit prices. Material quantities are generally direct functions of their thicknesses in the structure.

For the Superpave and Marshall mix design method the common assumed design period is 35 years and the assumed layer thickness was based on the federal democratic republic of Ethiopia ERA pavement design manual for flexible Pavements for trunk road construction.

Superpave pavement layer		**Marshall pavement layer**	
The layer type	**Thickness**	**The layer type**	**Thickness**
Road bed preparation	194mm	Clearing and grubbing	340mm
Borrow to fill layer	759mm	Preparation of road bed	1000mm
Rock fill	46mm	Cut to fill	357mm
Common excavation	313mm	subgrade layer	46mm
Capping layer	69mm	Sub-base layer	672mm
Sub-bases	672mm	Crushed aggregate base layer	200mm
Road bases	200mm	Asphalt concrete surfacing	50mm
Dense bitumen macadam	90mm		
wearing course	60mm		

Table 3.8 The layer type and thickness of road. source: (ERA, 2013)

3.11.5.1 The Construction method

The construction method and equipment used for both the Marshall and Superpave mix design methods are similar, involving the same basic steps of aggregate blending, asphalt binder heating and mixing, and laying and compacting the asphalt mixture. Similarly, the maintenance and rehabilitation process for both methods generally involves same activities such as crack sealing, pothole patching, and surface treatment application.

However, the main difference between these methods lies in the laboratory testing and evaluation of the asphalt mix properties. The Superpave method uses a more comprehensive set of tests, leading to longer-lasting pavements. The Superpave method's emphasis on mix design can also provide greater flexibility in selecting the appropriate aggregate gradations and asphalt binder types based on specific environmental and traffic conditions of the project site (Al-mistarehi, 2014). Moreover, the layered approach in the Superpave design can provide additional protection against deformation and cracking, resulting in improved pavement performance.

3.11.6 Pavement maintenance and rehabilitation costs

Unit cost rates have been obtained for those operations anticipated for the study roads. Unit cost rates for road improvements, including paving to AC standard, have been on a section-specific basis, the recommended treatment for each section varying slightly depending upon the depth of existing asphalt and the required depth of sub-base. In a typical LCCA, two or more alternate choices are available for an initial pavement design or cross-section. Based on the initial pavement designs, the expected maintenance and rehabilitation over the design life are then determined and incorporated into a single, inflation adjusted cost in order to evaluate and compare the different options in a fair and consistent manner.

$$PW = \frac{Ma}{(1+i)^n} \quad \text{......... equ. 3.6}$$

Where PW = Present value of maintenance activity (Mi) at year n

Ma = Maintenance activity applied at activity “a”

i = Discount rate

3.11.7 Salvage value of pavements

Salvage value is the remaining life in a pavement alternative at the end of the analysis period. It is primarily used to account for differences in remaining pavement life between alternative pavement design strategies at the end of the analysis period. For example, over a 35-year analysis, Marshall mix design pavement reaches terminal serviceability at year 35, while Superpave mix design pavement requires a 10-year design rehabilitation at year 30. In this case, the serviceable life of Marshall mix design pavement at year 35 would be 0, as it has reached its terminal serviceability (Hailu et al., 2019). Conversely, Superpave mix design pavement receives a 10-year design rehabilitation at year 30 and will have 5 years of serviceable life at year 35, the year the analysis terminates (Crespo Márquez et al., 2012). Marshall mix design pavement has 5 years and Superpave mix design pavement has 10 years.

Salvage Value=LR * $\frac{ERL}{TEL}$ ……………………………………………………..….. equ. 3.7

Where LR = Last construction or rehabilitation project costs

ERL = Expected remaining life of the last construction or rehabilitation project

TEL = Total expected life of the last construction or rehabilitation project

3.11.8 Determination of user cost

The Cost- Benefit analysis of the road project measures the capital cost in monetary terms, and the benefits that accrue in the form of travel time and the vehicle operating cost savings on the other. The major considerations in the measurement of costs and benefits for the economic appraisal of this road project are: the travel that incurs costs to road users such as the time spent on travelling; costs arising from the direct costs of fuel.

3.11.8.1 Vehicle Time Savings

This is the benefit of the pavements gained after the construction when the condition of the pavement is improved. For minimum, one (1) minute saved per kilometer and valued to one (1) Birr per one (1) minute saving. It means 40km/hr. to 80km/hr. speed of travel which resulted 0.29 time saving per day per km (Ketema et al., 2016b).

3.11.8.2 Cost of fuel for vehicle

Most of the types of fuel that are being used for all types of vehicles are petrol and diesel. Ethiopia's consumption of fuel is largely attributed to transport industries rather than some other economic sectors in the country (Habte, 2021). In Ethiopia, vehicles consume an average of 0.33 liters/km (Ketema et al., 2016b), and the current price of Fuel is **69.52** ETB.

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1 Introduction

A detailed laboratory investigation was carried out on specimens that are designed using the Marshall and Superpave mix design and this chapter discusses the result obtained from the tests done on the volumetric property, mechanical performance, and on the economic analysis in terms of bitumen cost for the marshall and Superpave mix design

4.2 Determining the volumetric properties of Marshall mix designs

4.2.1 Selection of aggregates that meet the suitability criteria.

The physical properties test result of aggregate used in this research is given in table 4.1, and the detail calculation put on appendices A.

Property	Test Items	Test Results	Specifications	Test Methods
Cleanliness	Clay Lump	0.64%	<1%	AASHTO T-112
	Sand Equivalent value	80.7%	min 40%	AASHTO T-176
Particle Shape & Texture	Flakiness Index	15.40%	max.25%	BS 812, Part 105.1
	Elongation Index	8.7%	max.25%	BS 812, Part 105.1
Strength	Aggregate Crushing Value	13.1%	max.25%	BS 812, Part 110
	Aggregate Impact Value	8.3%	max.25%	BS 812, part 112
	Wet /Dry Ratio %	84.3%	>75%	BS 812, part 110:1990
	Los Angeles Abrasion	15.0%	max.30%	AASHTO T-96-94
	Ten percent Fineness Value	403KN	Min 160KN	BS 812 part 110:1990
Durability	Soundness by Sodium Sulphate coarse aggregate	4.76%	max.12%	AASHTO T-104-97
	Water Absorption	1.84%	max.2%	ASTM C 127
	PSV-polished stone value	51.1ra	>50ra	BS 812 Part 114
Bitumen Affinity	Coating & Stripping	> 95%	min. Retained Coating value 95%	AASHTO T-182

Table 4.1 Aggregates Quality Test Result

4.2.2 Selection an asphalt cement suitable for the climate.

The property of the asphalt sample test result used in this study were determined as shown in table 4.2, the details on the calculation put in appendix B.

Tests	Results	Applicable Standard	Specification AASHTO M82
1. Penetration,100g 5sec.at 25℃	66.6	AASHTO T 49	60-70
2.Ductility,5cm/Min, cm	147	AASHTO T 51	min,100
3.Specific Gravity of Asphalt, (g/ml)	1.023	AASHTO T 228-06	1010 – 1060
4.Solubility in Trichloroethylene, %	99.8%	AASHTO T 44	min,99.5
5.(RTFO) Rolling Thin Film Oven Test	0.26%	AASHTO T 240	max,1%
6.Softening Point	51℃	AASHTO T 53	46 - 56℃
7.Dynamic Viscosity	0.375	AASHTO T 201	0.3pa.s
8.Flash Point	295℃	AASHTO T 48	min,232℃
9.Residue Penetration	88.4	ASTM D5-IP49	min,54
10.Residue Ductility	119	AASHTO T 51	min,50

Table 4.2 Asphalt Quality Test Result

4.2.3 Determination of Bulk specific gravity (Gsb)

The selected aggregate and asphalt materials have been tested and found to meet all the specification criteria for marshall mix design, so the next step is to determine bulk specific gravity. Using two trials for each aggregate size the bulk specific gravity is determined as it's clearly shown in Appendix – E.

$$\text{Gsb} = \frac{\text{P1+P2+P3+P4+P5}---\text{+Pn}}{\frac{P1}{G1}+\frac{P1}{G1}+\frac{P1}{G1}+\frac{P1}{G1}+\frac{P1}{G1}+---+\frac{P1}{G1}}$$

$$= \frac{11\%+42\%+15\%+30\%}{\frac{11\%}{2.609\%}+\frac{42\%}{2.605\%}+\frac{15\%}{2.600\%}+\frac{30\%}{2.597\%}+\frac{2\%}{2.740\%}} = 2.602$$

4.2.4 Proportioning or blending & Aggregate gradation using Marshall Procedure

The aggregate blending proportion done after several trial and error, the obtained blending is 11% for 20-14mm size, 42% for 14-6mm size, 15% for 6-3mm size, 30% for 3-0mm size, and 2% for filler, the table 4.3 below shows the particle size distribution taking average cumulative passing (%) details of proportion and blending are found in appendix C.

AGGREGATE BLENDING FOR ASPHALT MIX DESIGN WEARING COARSE (WC)

TYPE	SIEVE SIZE	25	19	12.5	9.5	4.75	2.36	1.18	0.60	0.300	0.150	0.075
14--20mm		100.0	100.0	24.9	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0
6--14mm		100.0	100.0	99.3	75.7	13.9	0.1	0.0	0.0	0.0	0.0	0.0
3--6mm		100.0	100.0	100.0	99.6	84.7	17.4	9.3	7.0	5.5	4.4	4.0
0--3mm		100.0	100.0	100.0	100.0	99.1	90.9	57.2	39.7	25.9	17.3	6.4
Filler		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	92.2	85.3

TYPE	SIEVE SIZE		25.0	19.0	12.5	9.5	4.75	2.36	1.18	0.60	0.30	0.15	0.075
14--20mm	Blending I (%)	11.0%	11.0	11.0	2.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6--14mm		42%	42.0	42.0	41.7	31.8	5.8	0.0	0.0	0.0	0.0	0.0	0.0
3--6mm		15%	15.0	15.0	15.0	14.9	12.7	2.6	1.4	1.0	0.8	0.7	0.6
0--3mm		30%	30.0	30.0	30.0	30.0	29.7	27.3	17.2	11.9	7.8	5.2	1.9
Filler		2.0%	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.8	1.7
Total		100%	100	100	91.4	78.8	50.3	31.9	20.6	15.0	10.6	7.7	4.2
SIEVE SIZE			25.0	19.0	12.5	9.5	4.75	2.36	1.18	0.60	0.30	0.15	0.075
Up (specaficition)			100	100	100	90	74	58	40	29	21	15	10
Down (specaficition)			100	100	90	74	44	28	15	10	5	4	2
Middle range			100.0	100.0	95.0	82.0	59.0	43.0	27.5	19.5	13.0	9.5	6.0

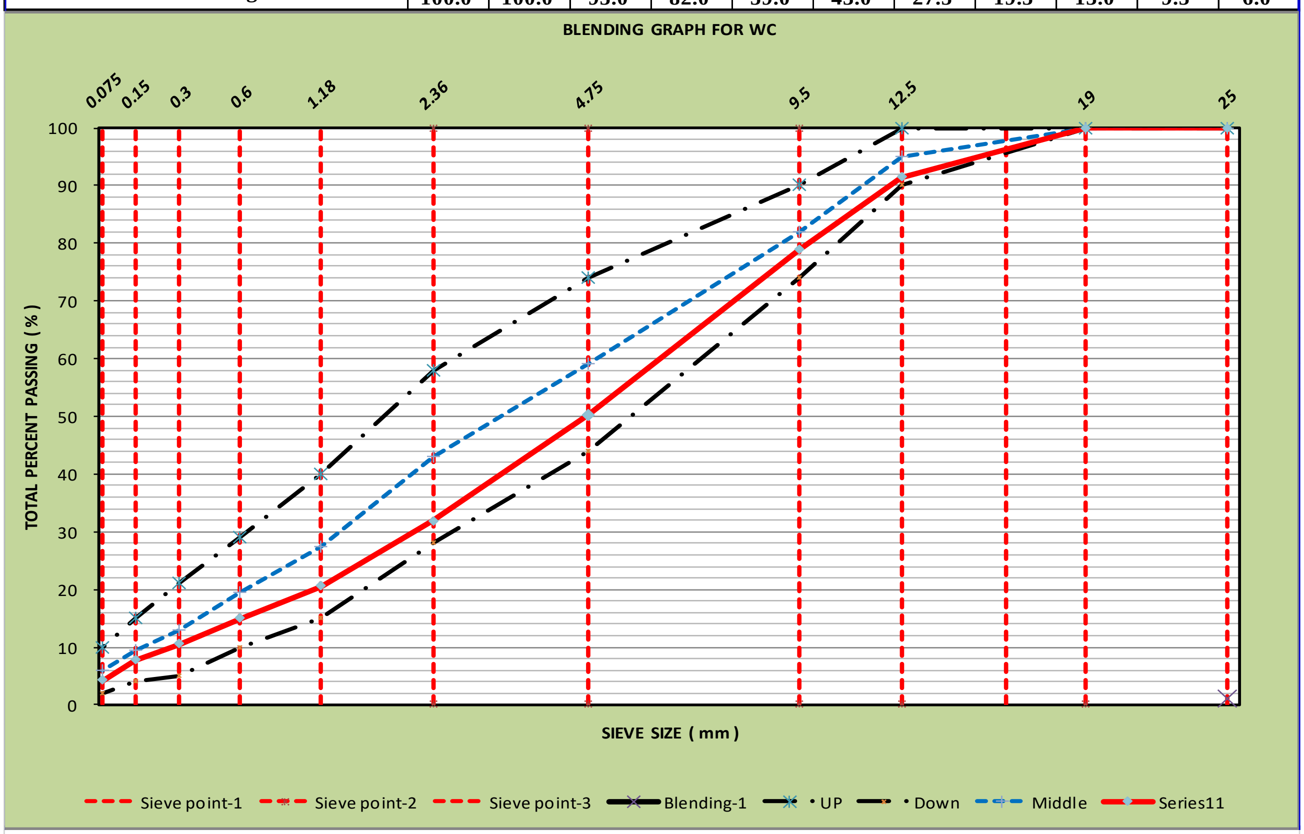


Table 4.3 Aggregate Blending Graph

Next a minimum of 3 specimens for each bitumen contents (4.0%–6.0%) is prepared at 0.5% increments, then they compacted using the Marshall compaction hammer. Then two specimens for each bitumen content are also prepared for determination of the mixture's maximum theoretical specific gravity (Gmm). The table below shows the sample proportion for one specimen.

WEIGHT FOR ONE MARSHELL SAMPLE FOR WEARING COARSE MIX DESIGN (WC)								
Design of asphalt content （％）				4.0	4.5	5.0	5.5	6.0
	Sieve Size	(%) Passing	(%) Retained	**WEIGHT FOR ONE MARSHALL & GMM SAMPLE (gram)**				
Sieve size No	25.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
	19.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
	12.5	91.4	8.6	102.9	102.9	102.9	102.9	102.9
	9.5	78.8	12.6	151.3	151.3	151.3	151.3	151.3
	4.75	50.3	28.5	342.5	342.5	342.5	342.5	342.5
	2.36	31.9	18.4	220.2	220.2	220.2	220.2	220.2
	1.18	20.6	11.3	136.2	136.2	136.2	136.2	136.2
	0.6	15.0	5.6	67.2	67.2	67.2	67.2	67.2
	0.3	10.6	4.4	52.8	52.8	52.8	52.8	52.8
	0.15	7.7	2.9	34.7	34.7	34.7	34.7	34.7
	0.075	4.2	3.5	41.6	41.6	41.6	41.6	41.6
Dust			2.2	26.6	26.6	26.6	26.6	26.6
Filler			2.0	24.0	24.0	24.0	24.0	24.0
Weight of Asphalt for Marshall (gram)				50.0	56.5	63.2	69.8	76.6
Total Weight of Aggregate for Marshall (gram)				1200.0	1200.0	1200.0	1200.0	1200.0
Total Weight of Marshall Sample (gram)				1250.0	1256.5	1263.2	1269.8	1276.6
Total Weight of Asphalt for Gmm (gram)				83.3	94.2	105.3	116.4	127.7
Weight of Gmm Sample (gram)				2000.0	2000.0	2000.0	2000.0	2000.0
Total Weight of Gmm Sample (gram)				2083.3	2094.2	2105.3	2116.4	2127.7

Table 4.4 Weight for One Marshall Specimen.

4.2.5 Mixing and Compaction of Marshall Specimen

According to Table 4.4, a total of 15 samples were prepared to determine volumetric properties, and an additional 10 samples were prepared for Gmm test. These samples are then mixed and compacted using a Marshall hammer for 75 blows due to the presence of heavy traffic, for Gmm test the mixed sample not compacted.

4.2.6 Determine the mix volumetric property, Stability and flow test

The volumetric properties of the Marshall Mix, including air voids, VMA, and VFA, are determined by measuring the dimensions and weight of compacted specimens. The stability of the mix is determined by measuring the maximum load that the compacted specimen can sustain before failure. The flow of the mix is determined by measuring the deformation of the compacted specimen under a load using a Marshall Test. This involves applying a load on the specimen and measuring the horizontal deformation using a dial gauge. Detailed calculations on the volumetric properties of the Marshall Mix design are provided in Appendix F.

% Asphalt	Gmb g/cm3	Air void %	Stability	Flow	VMA %	VFA %	Gmm (%)
4.0	2.276	7.53	10.07	2.47	16.0	53.1	2.461
4.5	2.309	5.31	10.88	2.72	15.2	65.1	2.439
5.0	2.322	4.44	11.88	2.91	15.2	70.8	2.430
5.5	2.326	3.43	11.26	3.21	15.5	77.9	2.408
6.0	2.320	2.66	10.48	3.80	16.2	83.6	2.383

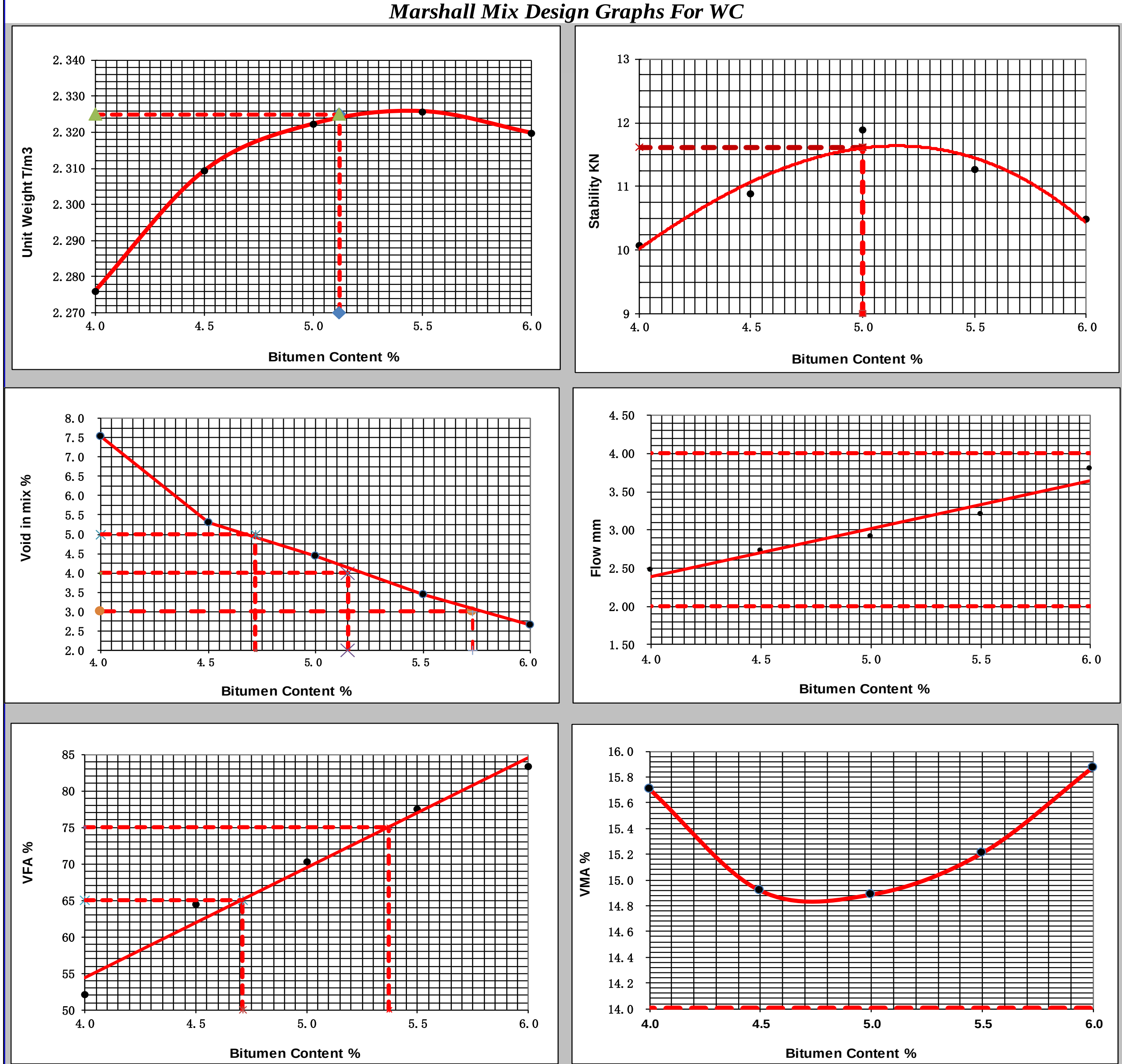
Table 4.5 volumetric property, stability and flow result.

4.2.7 Selection of Optimum bitumen content (OBC)

NAPA recommends that the optimum bitumen content (OBC) is the amount that results in precisely 4% air voids. To determine the OBC, six graphs are plotted. At 4% air voids, the OBC is found to be 5.12%, and the other volumetric properties of the mix are evaluated at this OBC.

As shown in the table 4.7, the test results also fall within the acceptable range; as a result, the selected OBC is considered to be suitable for use in the project. The acceptable range for bitumen content and the target volumetric properties are typically documented in the MS-2.

Marshall Mix Design Graphs For WC



Optimum Asphalt Content (OAC)	Results	Spcfication Limit
Stability at Target Asphalt Content - @ 5.12%	11.61	Min. 9 KN
Flow at Target Aspalt Content - @ 5.12%	3.10	2-3.5 mm
Air void at Target Aspalt Content - @ 5.12%	4.01	3-5 %
VFA at Target Aspalt Content - @ 5.12%	71.27	65--75 %
VMA at Target Aspalt Content - @ 5.12 %	14.88	Min. 14 %

Table 4.6 volumetric properties plotted graphs.

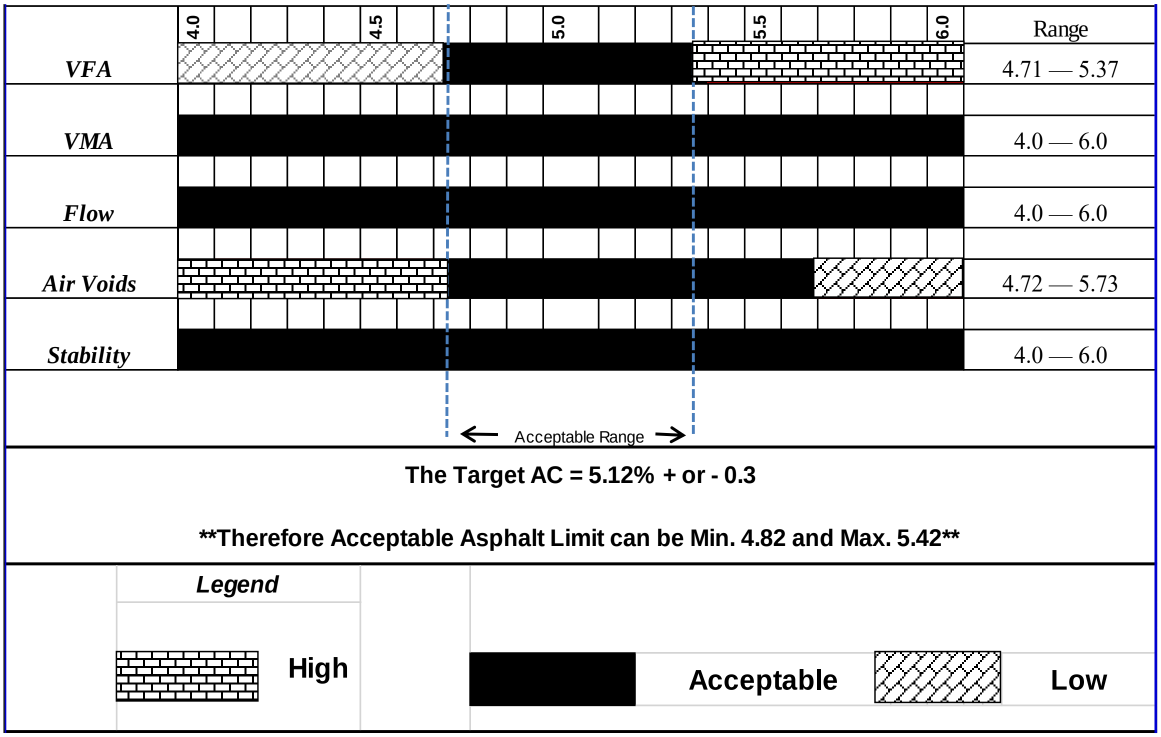


Table 4.7 Acceptable Range Graph.

Marshall Test Requirements	Marshall mix design results @ 5.12%	Specification Criteria (ERA - 6400/13)
Air Voids (Vv) %	4.0	**3-5 %**
Voids in the Mineral Aggregates (VMA) %	14.88	**>14%**
Voids Filled with Asphalt (VFA) %	71.27	**65-75 %**
Stability Value (KN)	11.61	**>9KN**
Flow Value (mm)	3.1	**2-3.5mm**
Compacted mix Bulk Specific gravity (Gmb)	2.325	—
Maximum Theoretical Density (Gmm)	2.423	—
Dust to Bitumen Proportion %	0.85	**0.6-1.2**

Table 4.8 Summary of Marshall Mix Design Results.

In conclusion, Marshall Mix design for this research was done using 60/70 grade bitumen and aggregate sourced from Akaki 08 quarry and all mix criteria were met successfully for marshall mix design and preparing Superpave mix design specimen shall be continued.

4.3 Determining the volumetric properties of Superpave mix designs

4.3.1 Superpave Aggregate Selection

The aggregate used for the Superpave mix design were the same materials used in the Marshall mix design, but additional tests were conducted on the aggregate as shown in Table 4.9 and the detail of calculation put in appendix A.

Aggregate Quality test results					
Property	**Test items**	**Test result**	**Specification**	**Test methods as per AASHTO & BS**	**Remark**
Deleterious material	Plastic Index	Non plastic	4max.	AASHTO T-89 & 90	Ok!
Aggregates angularity	Coarse aggr, angularity	96.0%	min 95/90%	ASTM-D5821	Ok!
	Fine aggr. Angularity	54.8%	min 45%	AASHTO-T304	Ok!
Soundness	soundness by sodium sulfate for fine aggr.	5.43%	max. 18%	AASHTO T-104-97	Ok!

Table 4.9 Summery of Aggregate Quality for Superpave mix.

4.3.1.1 Job Mix Formula

Gradation control for Superpave is based on four control sieves: the maximum sieve size, the nominal maximum sieve 12.5mm sieve, the 2.36 mm sieve, and the 0.075 mm sieve. There is also a restricted zone that is an area where the aggregate shouldn’t pass on either side of the maximum density line generally starting at the 2.36 mm sieve and extending to the 0.3 mm sieve. The minimum and maximum values required for the control sieves change (as does the restricted zone) as the nominal maximum size of the mixture changes.

As can be seen from the job mix formula (JMF) grading graph in the figure below, the grading falls within the envelops. The superpave mix design grading criteria have been placed in appendix D, same gradation used for the superpave as used in the marshall method.

SIEVE SIZE	Hot Bin													SPECIFICATION CONTROL POINTS	
	14/20mm	Pro, %	6/14mm	Pro, %	3/6mm	Pro, %	0/3mm	Pro, %	Filler	Pro, %	Combined JMF	SIEVE SIZE ^ 0.45	Maximum Density line		
(mm)		11		42		15		30		2%					
19.0	100.0	11.00	100.0	42.0	100.0	15.0	100.0	30.0	100	2	100.0	3.76	100	100	100
12.5	24.9	2.73	99.3	41.7	100.0	15.0	100.0	30.0	100	2	91.4	3.12	82.8	90	100
9.5	0.7	0.08	75.7	31.8	99.6	14.9	100.0	30.0	100	2	78.8	2.75	73.2		90
4.75	0.1	0.01	13.9	5.8	84.7	12.7	99.1	29.7	100	2	50.3	2.02	53.6		
2.36	0.0	0.00	0.1	0.0	17.4	2.6	90.9	27.3	100	2	31.9	1.47	39.1	28	58
1.18	0.0	0.00	0.0	0.0	9.3	1.4	57.2	17.2	100	2	20.6	1.08	28.6		
0.600	0.0	0.00	0.0	0.0	7.0	1.0	39.7	11.9	100	2	15.0	0.79	21.1		
0.300	0.0	0.00	0.0	0.0	5.5	0.8	25.9	7.8	100	2	10.6	0.58	15.5		
0.150	0.0	0.00	0.0	0.0	4.4	0.7	17.3	5.2	92.2	2	7.8	0.43	11.3		
0.075	0.0	0.00	0.0	0.0	4.0	0.6	6.4	1.9	85.3	2	4.5	0.31	8.3	2	10

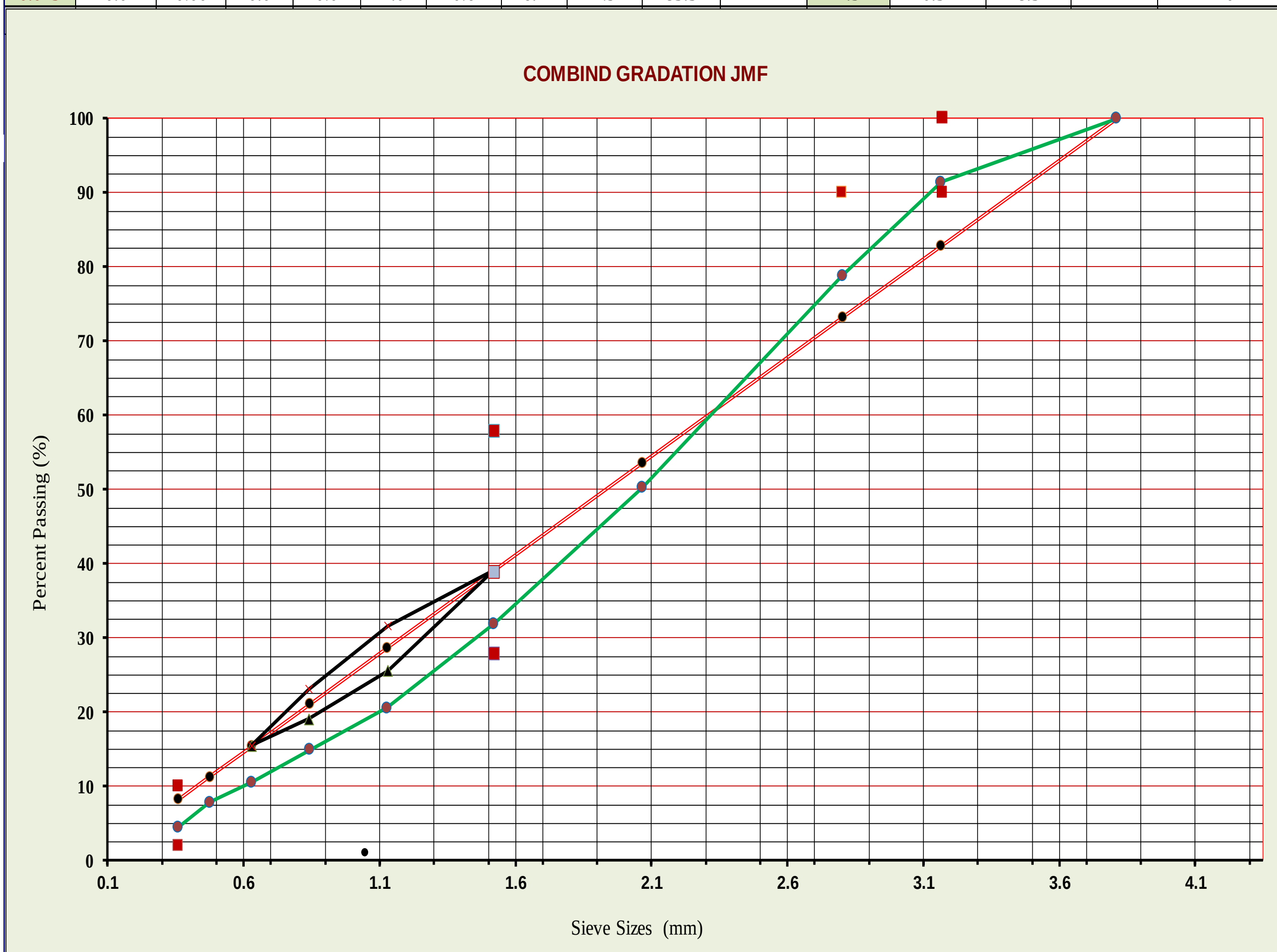


Table 4.10 Job Mix Formula (JMF) For Wearing Course Mix.

4.3.2 Asphalt binder selection

The asphalt binder grading system used in Superpave is called the Performance Grading (PG) system. PG binders are characterized based on fundamental engineering parameters, considering the impact of climatic factors on binder characteristics at both hot and cold temperature regimes. In addition to climatic conditions, traffic and aging also affect the performance of the pavement. Bitumen that is used for marshall mix design is also used for superpave mix design and some additional tests also performed as shown in the table 4.11 and the detail of calculation put in appendix B.

Test Result for Bitumen 60/70 Grade				
Tests	Results	Applicable Standard	Specification AASHTO M82	Remark
Flash Point	295°C	AASHTO T 48	232°C min	Ok
Dynamic Viscosity @ 135°C	0.488	AASHTO T 201	3pa.s, max	Ok
Dynamic Viscosity @ 165°C	0.15	AASHTO T 201	3pa.s, max	Ok
Elastic Recovery Test	86%	ASTM D 6084-06	>80%	Ok

Table 4.11 Summery of Asphalt Quality for Superpave.

4.3.2.1 Predication of Pavement Temperature

For this study the common depth 20 mm below the pavement surface are chosen and low temperature are calculated at the pavement surface (Mihretu, 2018). For predicting the project high pavement design temperature from seven-day mean high air temperature and geographical latitude of the project location were used. The project area's seven-day mean high air temperature (Tair = 28°c), geographical latitude (Lat = 42.4), and depth of below surface (d = 485) used for the Generation of temperature zone for study area.

$T20mm = (T_{air} - 0.00618\ Lat^2 + 0.2289 L_{at} + 42.4)\ (0.9545) - 17.78$ ……………….. Equ. 4.1

T20mm = (28°c - 0.00618 (8.98)2+0.2289 * 8.98+42.4) (0.9545)-17.78

T20mm = **50.72°C**

Where: T20mm = High pavement design temperature at a depth of 20mm, °C.

Tair = Seven-days mean high air temperature, °C.

Lat = Geographical latitude of project location, degree

The Strategic Highway Research Program (SHRP) low pavement design temperature model is presented in the following formula.

$T_d = T_{air} - 0.051d - 0.000063d^2$ ………………………………………. Equ. 4.2

Where:

Td = Low Pavement Temperature at pavement depth d,

d = Depth below surface, mm

$Td = (28°c - 0.051*485-0.00063(485)^2$

Td = -11.55°C

From the asphalt binder classification tests and the results of the tests performed, the results of the tests indicate that the tested asphalt binder can be graded as asphalt cement (60-70) penetration asphalt according to AASHTO M82. To find the performance grade of the used asphalt binder according to SHRP binder performance specification, testing of fresh and treated samples was conducted at Addis Abeba University and It was found that the performance grade of the asphalt was PG 64-10, which is the asphalt cement of 60-70 of a penetration grade for a commonly used asphalt binder in Ethiopia. PG 64-10 is used to indicate the lower and maximum temperature range according to the binder performance grade specification. This asphalt met both the high temperature property requirements, at least up to a temperature of 64 °C, and low temperature physical property requirements to at least –10 °C.

4.3.3 Sample preparation (including compaction)

six different bitumen contents (3.5%–6.0%) is prepared at 0.5% increments by weight of total mixes and for each bitumen content 3 samples used. Weight preparation for Superpave specimen volumetric property determination and Gmm, the following proportion is used.

Aggregate Size,	**14 - 20mm**	**6 - 14mm**	**3 - 6mm**	**0 - 3mm**	**Filler**	**Total**
Blend Proportion, (%)	**11%**	**42%**	**15%**	**30%**	**2%**	**100%**
Weight preparation for Superpave specimens	**4500.0**		Weight preparation for Gmm			**2000.0**

Sieve Size (mm)	Combined % Pass	Combined % Retained	Weight Each Sieve by (gm.)		Sieve Size (mm)	Combined % Pass	Combined % Retained	Weight Each Sieve by (gm.)
25.0	100.0	0.00	0.00		25.0	100.0	0.00	0.00
19.00	100.0	0.00	0.0		19.00	100.0	0.00	0.0
12.50	93.7	6.27	282.3		12.50	93.7	6.27	125.5
9.50	83.3	10.47	471.1		9.50	83.3	10.47	209.4
4.75	58.4	24.89	1120.1		4.75	58.4	24.89	497.8
2.36	40.1	18.26	821.9		2.36	40.1	18.26	365.3
1.18	25.7	14.38	647.0		1.18	25.7	14.38	287.6
0.600	18.6	7.17	322.6		0.600	18.6	7.17	143.4
0.300	12.9	5.64	254.0		0.300	12.9	5.64	112.9
0.150	9.2	3.67	165.1		0.150	9.2	3.67	73.4
0.075	4.8	4.45	200.2		0.075	4.8	4.45	89.0
	Filler =	4.80	215.8			Filler =	4.80	95.9

Table 4.12 Weight for Superpave sample preparation

The specimens are mixed at the appropriate mixing temperature, which ranges between 135°C and 163°C for the selected PG 64-10 binder.

4.3.3.1 Superpave Gyratory Compaction

After mixing, the specimens are short-term aged by placing the loose mix in a flat pan in a forced-draft oven at 135°C for 4 hours. Then to compact the specimens, the samples brought within the compaction temperature ranges between 150°C and 157°C, by placing them in another oven for a short time usually less than 30 minutes. Finally, the loose mix is removed and compacted through a kneading action at the vertical pressure to 600 kPa (±18 kPa), but if the sample is used to determine the maximum theoretical specific gravity then it allowed to loose cool.

4.3.4 Superpave Density and voids Analysis (Volumetric properties)

Here are average superpave volumetric properties test result at each binder content, all the volumetric property test results have been placed in Appendix I and the maximum theoretical specific gravity test result has been placed in appendix H.

Specimens	Asphalt Content	Wt. Of Specimen in air (gm.)	Wt. Of Specimen in Water (gm.)	SSD Wt. Of Specimen in air (gm.)	Vol. Of Specimen (g/cc)	Bulk Density (Gmb) (g/cc)	Theoretical Density, Gmm (g/cm3)	Air Void, (%)	VMA, (%)	VFA, (%)
1	3.5%	4561.5	2578.7	4601.5	2022.9	2.255	2.460	8.33	16.4	49.1
2	4.0%	4609.7	2600.5	4633.4	2032.9	2.268	2.433	6.80	16.3	58.4
3	4.5%	4593.2	2609	4608.9	1999.9	2.297	2.418	5.0	15.7	68.1
4	5.0%	4637.1	2655.5	4656.0	2000.6	2.318	2.398	3.34	15.4	78.3
5	5.5%	4626.1	2630.6	4634.1	2003.5	2.309	2.368	2.49	16.1	84.6
6	6.0%	4661.9	2635.7	4672.8	2037.1	2.289	2.335	1.99	17.3	88.5

Table 4.13 Superpave mix design volumetric data.

Gmb is then divided by Gmm to determine the % Gmm @ Ndes. The % Gmm at any number of gyrations (Nx) is then calculated by multiplying % Gmm @ Ndes by the ratio of the heights at Ndes and Nx.

Specimen	Asphalt Content	N_{intial} @ 9 Gyration Comp.	N_{design} @ 125 Gyration Comp.	Bulk Density, (G_{mb})	Theory Density, (Gmm) (g/cm3)	% of G_{mm} @ N_{design}, (%)	% of G_{mm} @ $N_{initial}$, (%)
		Gyratory Thickness, mm					
1	3.50%	125.0	115.8	2.255	2.460	91.7	84.9
2	4.00%	128.1	117.1	2.3	2.433	93.2	85.3
3	4.50%	127.3	116.9	2.294	2.418	95	87.1
4	5.00%	128.1	117.2	2.318	2.398	96.7	88.5
5	5.50%	127.8	117.0	2.309	2.368	97.5	89.3
6	6.00%	126.7	116.6	2.289	2.335	98.0	90.2

Table 4.14 Gyratory Thickness (mm)

4.3.5 Determining Optimum Asphalt Content (OAC) for Superpave mix

The optimum asphalt content was selected at 96.0% air voids at % Gmm @ Ndes, which was found to be 4.82%. The result shown in table 4.15, obtained after plotting a graph as shown in table 4.16.

Superpave Test Requirements	Superpave Mix design results @ 4.82%	Specification Criteria (ERA - 6400/13)
Air Voids (Vv) %	4.0	**3-5 %**
Voids in the Mineral Aggregates (VMA) %	15.6	**>14%**
Voids Filled with Asphalt (VFA) %	74.1	**65-75 %**
Compacted mix Bulk Specific gravity (Gmb)	2.308	—
Dust to Bitumen Proportion %	0.87	**0.6-1.2**
%Gmm @ Ninitial	87.8	**<89Nini**
%Gmm @ Ndesign	96	**96Ndes**
%Gmm @ Nmaximum	97.2	**<98Nmax**

Table 4.15 Superpave test requirement at OBC

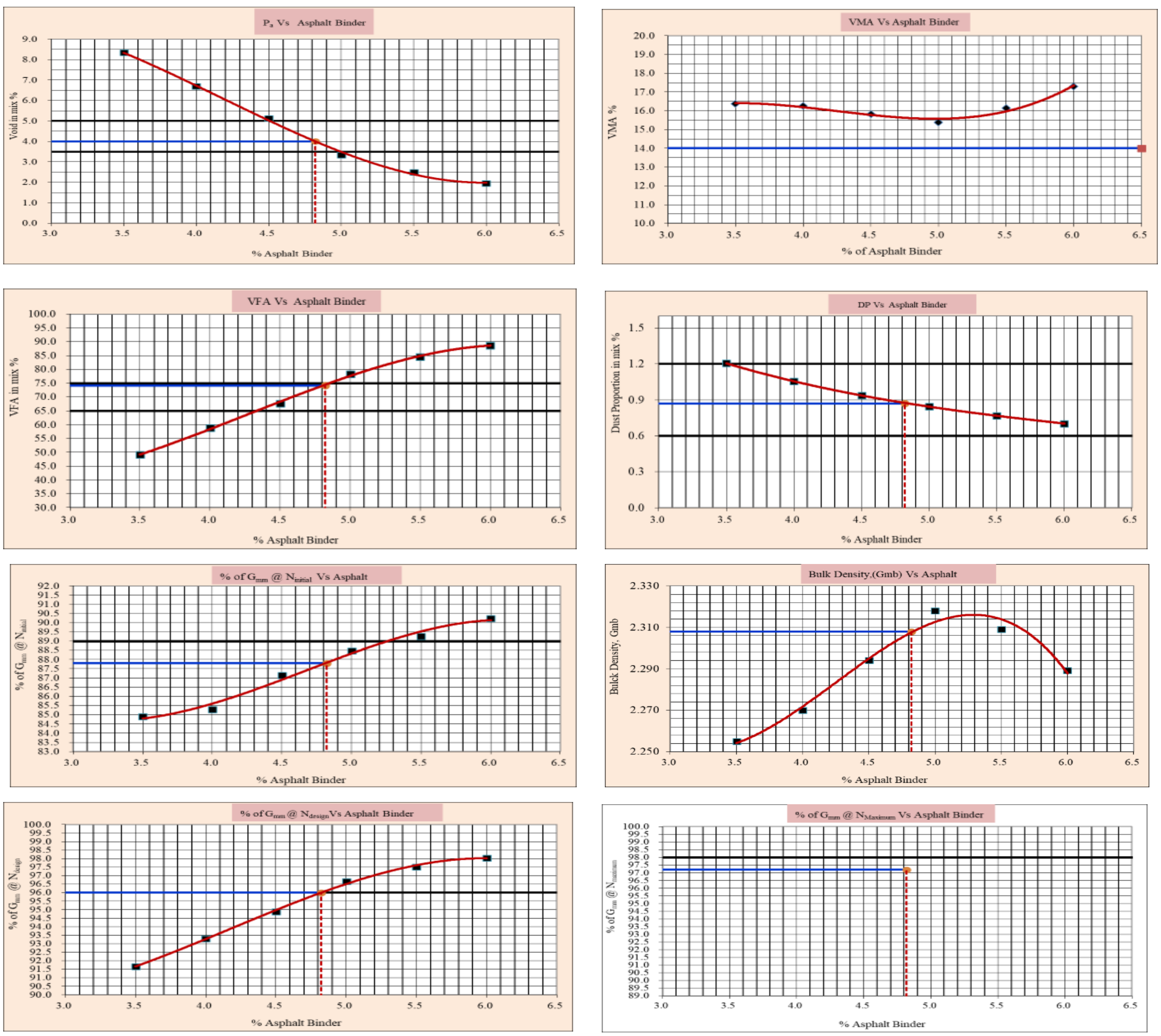


Table 4.16 Superpave mix design for wearing course

The first figure 4.1 below illustrates the compaction plots for data generated in the table 4.14, which shows %Gmm versus the logarithm of the number of gyration and the second figure 4.2 illustrates the number of gyration at OBC.

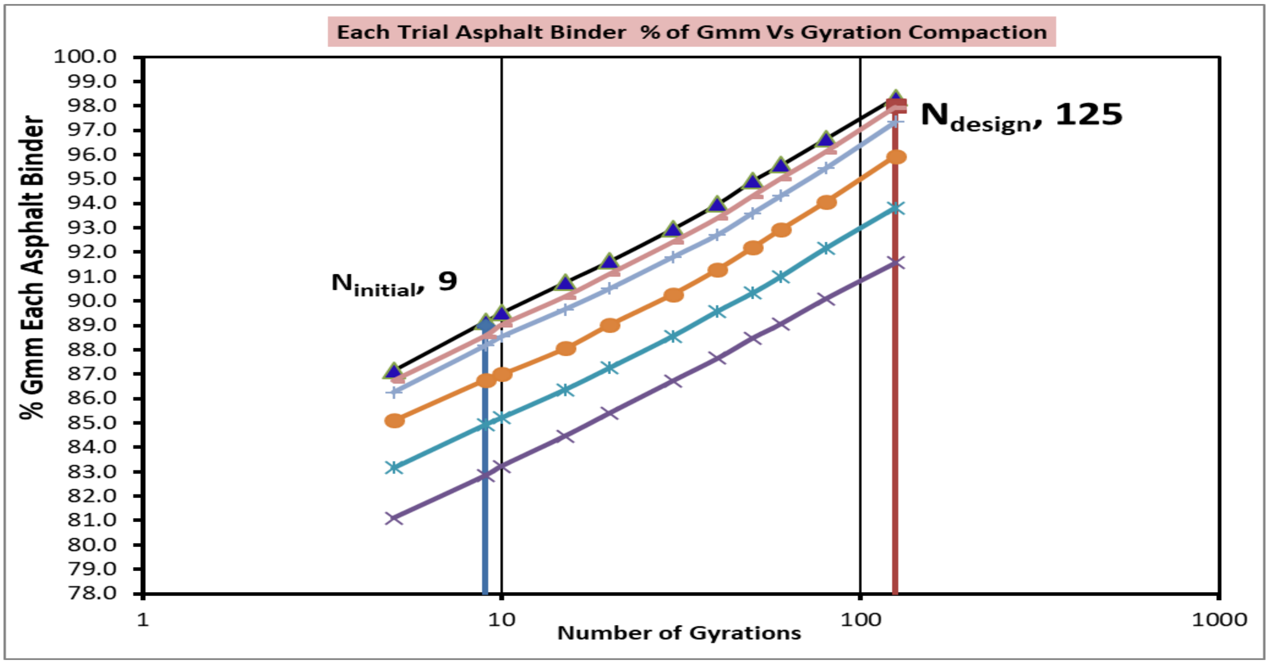


Figure 4.1 @ each trial asphalt binder Gyration Compaction Vs %Gmm

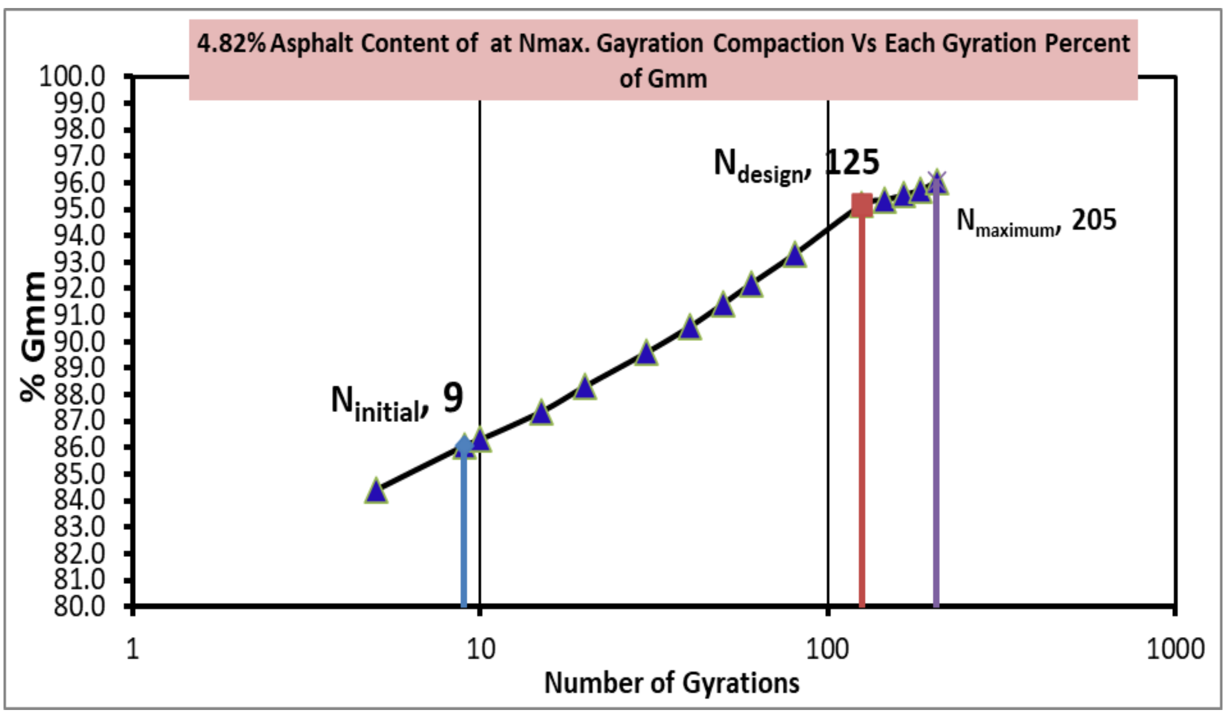


Figure 4.2 @ 4.82% OBC Gyration Compaction Vs Each Gyration % Gmm

4.4 Comparison on the volumetric property of Marshall and Superpave mix

4.4.1 comparison of the optimum binder content (OBC)

The optimum asphalt content is a critical parameter that must always be considered during the design evaluation of HMA, and it is highly dependent on aggregate characteristics such as gradation and absorption. In Marshall mix design, the OBC at 4% air voids was found to be 5.12%, while the Superpave mix design resulted in an OBC of 4.82%. Studies conducted by (ALAZAWY, 2015; Asmael & Ahmed Alkawaaz, 2009; Jitsangiam et al., 2013; Zumrawi & Sheikh Edrees, 2016) also reported lower OBC values for the Superpave mix design compared to Marshall mix design.

The primary reason for this difference is the variation in mix design criteria and testing methods. The Superpave mix design method is based on a more comprehensive set of criteria, which includes the use of the SGC to simulate the effects of traffic loading on the pavement. The SGC applies a more realistic load and deformation pattern to the mix during compaction, resulting in a higher degree of compaction and a lower air void content in the mix. In contrast, the Marshall mix design method uses a different compaction method, which results in a higher air void content in the mix. This higher air void content requires a higher asphalt content to fill the voids, resulting in a higher value of OBC obtained. Therefore, it can be concluded that the lower OBC obtained for Superpave mix design is due to the differences in mix design criteria and testing methods, as well as the more realistic load and deformation pattern applied during compaction.

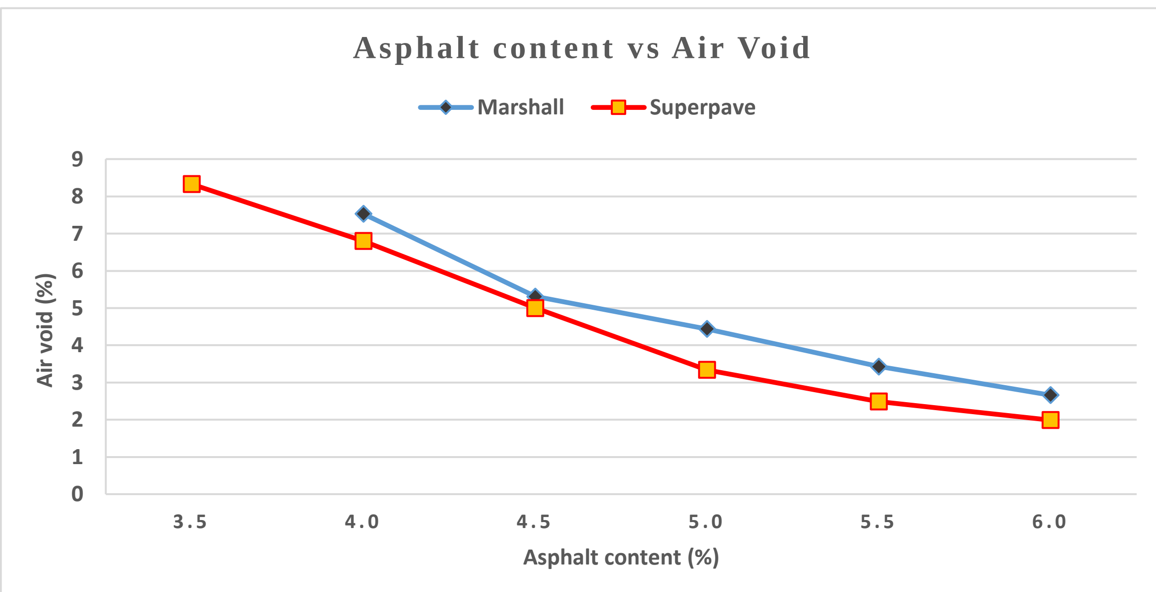


Figure 4.3 Relationship of asphalt content and air void

4.4.2 comparison of VMA and VFA content

The higher values of VMA and VFA observed in Superpave mix design compared to Marshall mix design can be attributed to several factors. Similar findings were reported in a study conducted by (Zumrawi & Sheikh Edrees, 2016). The Superpave method aims to achieve a higher degree of aggregate orientation and interlock by prohibiting the gradation from passing through the restricted zone and recommending the gradation to be below the restricted zone for high-traffic loads.

Superpave mixes are designed to be more resistant to rutting and fatigue cracking, which requires a higher VMA to ensure adequate asphalt binder coverage of the aggregate. This is necessary for achieving the desired level of stability and durability of the pavement, as shown in figure 4.2. In contrast, Marshall mixes are typically designed to be more workable and easier to compact, which may result in a lower VMA. However, a higher VMA can also lead to a more porous mix, which may be more susceptible to moisture damage and raveling. This can be especially problematic in colder climates where freeze-thaw cycles can cause the mix to break down more quickly. Therefore, the higher values of VMA and VFA observed in Superpave mix design can be attributed to the design criteria aimed at achieving greater stability and durability of the pavement

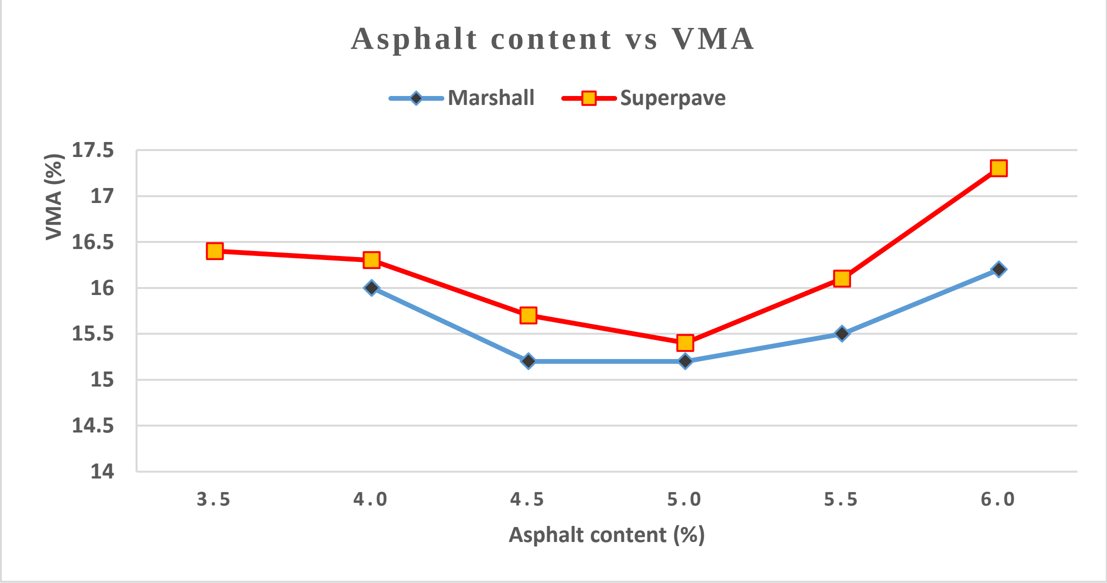


Figure 4.4 Relationship of asphalt content and VMA

Superpave mixes are designed to be compacted using SGC, which produces a lower density and higher air voids which leads to higher VFA which is 74.1% at OBC. A higher VFA generally indicates more space for asphalt cement and air voids, which can lead to a more flexible and rut-resistant mix. VFA depends on the aggregate gradation and shape. Higher VFA does not necessarily mean better performance. An optimal VFA needs to be determined based on other mix characteristics and desired performance. Superpave helps establish these optimal values.

One reason why Marshall mix designs may have lower VFA (71.27% at OBC) compared to Superpave mixes is that Marshall mixes typically use a higher asphalt binder content to achieve the desired density and stability. This higher binder content can result in a lower VFA, as there is a limit to the amount of binder that can be effectively used to fill the voids in the mix. Additionally, the compaction method used in Marshall mix design may also contribute to lower VFA values, as it may be more difficult to achieve high levels of compaction with this method compared to Superpave mix design.

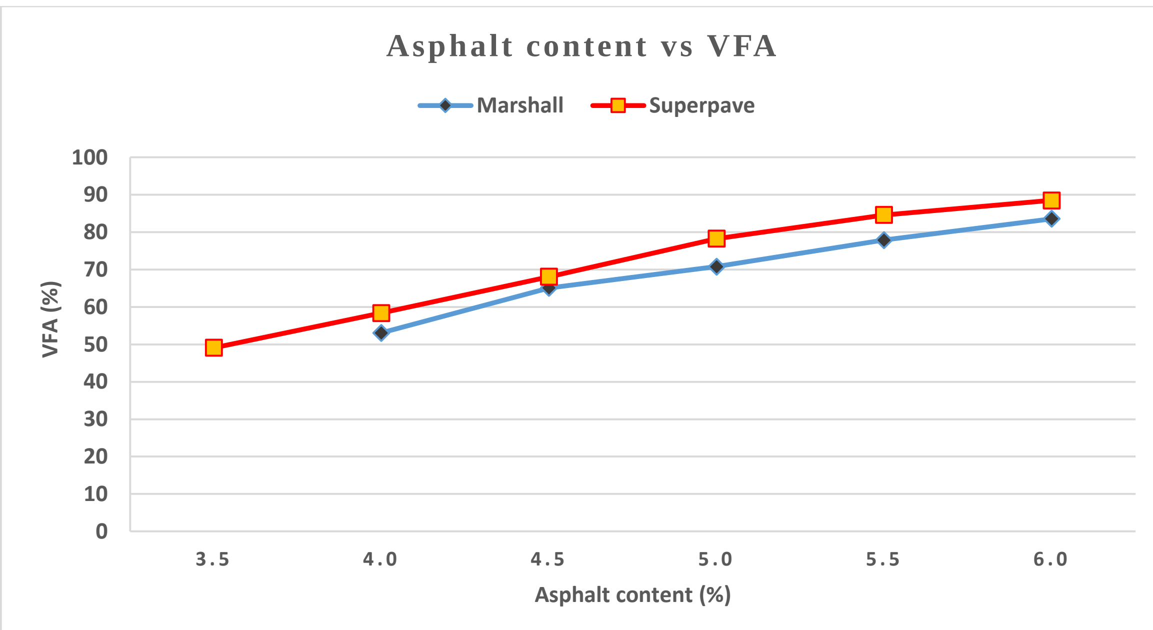


Figure 4.5 Relationship of asphalt content and VFA

4.4.3 comparison on the stability and flow

The comparison of the Marshall mix design method and the Superpave mix design method is based on two different approaches to designing asphalt mixtures. The Marshall method is an empirical method that relies on a set of empirical correlations between mixture properties and performance. In contrast, the Superpave method is a performance-based method that uses laboratory testing and field performance data to design asphalt mixtures.

The Marshall method requires stability and flow tests to ensure that the asphalt mixture has adequate resistance to deformation and can be properly compacted during construction. The Superpave method, on the other hand, focuses on selecting the proper binder and aggregate properties to achieve the desired performance characteristics of the mixture. The Superpave method uses a set of performance tests to evaluate the properties of the asphalt mixture, including resistance to rutting and fatigue cracking. These tests evaluate the stiffness and strength of the mixture, which are key factors in its performance.

Although the Superpave system does not require stability and flow tests as design requirements but to make a comparison 3 samples are prepared using OBC, the stability value obtained from the Superpave mix design method, which is 12.02% at OBC, is higher than that obtained from the Marshall mix design method, which is 11.61% at OBC. The higher stability value obtained from the Superpave mix design method indicates that the resulting asphalt mix is expected to have better resistance to deformation and cracking under traffic loads. This is because the Superpave mix design method is designed to produce a mix that is better tailored to the specific conditions of the project site, resulting in a mixture with better performance characteristics. Therefore, the Superpave mix design method produces a better-performing asphalt mixture compared to the Marshall mix design method

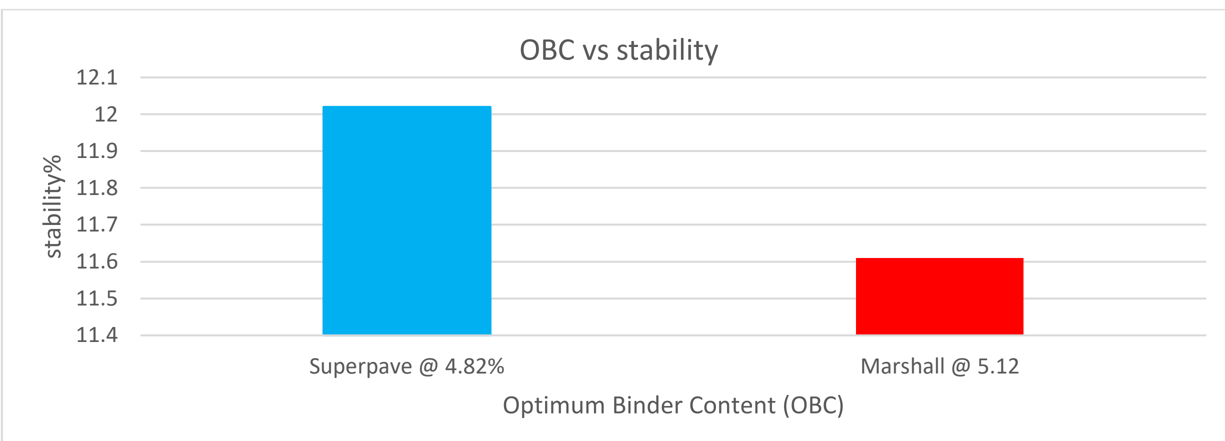


Figure 4.6 Relationship of asphalt content and stability

The flow value is an important measure of the deformation resistance of an asphalt mixture, which indicates its ability to resist plastic deformation under loading. When comparing the flow value obtained from the Superpave mix design method (2.58% at OBC) to that obtained from the Marshall mix design method (3.10% at OBC), the Superpave-designed asphalt mixture has a higher resistance to deformation compared to the Marshall-designed asphalt mixture. Therefore, the lower flow value generally indicates that the Superpave-designed mixture performs better under traffic loads and environmental conditions. This finding is consistent with the results of previous studies conducted by (Asmael & Ahmed Alkawaaz, 2009; Jitsangiam et al., 2013; Taylor et al., 2007) which also reported higher stability and lower flow values for Superpave-designed asphalt mixtures compared to Marshall-designed mixtures.

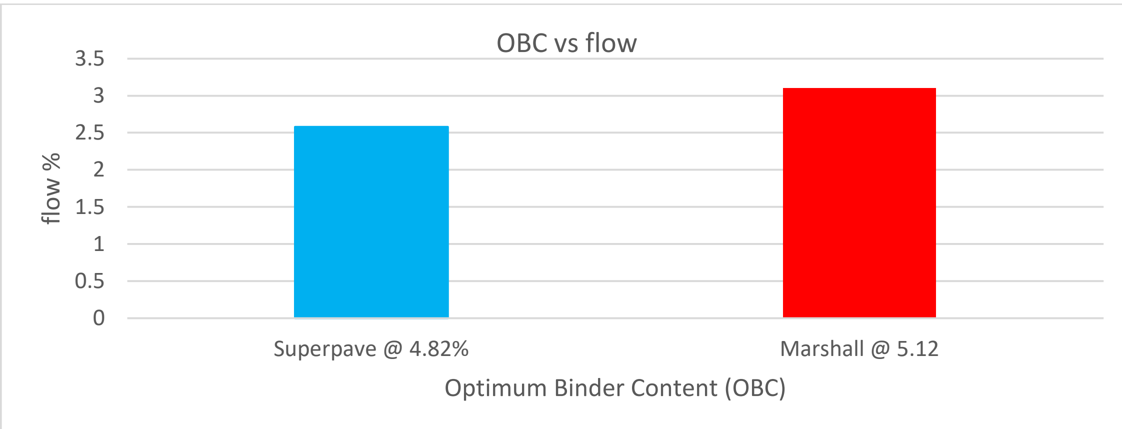


Figure 4.7 Relationship of asphalt content and flow

4.4.4 comparison on Gmm and Gmb content

The Maximum Theoretical Density (Gmm) and compacted mix bulk specific gravity (Gmb) values of Superpave mix design are slightly lower compared to those of Marshall mix design. This can be attributed to several factors related to the Superpave mix design method. The Superpave mix design method uses a higher compaction effort, higher aggregate gradations, and lower asphalt contents, which lead to a slightly denser mix, resulting in a lower Gmm (2.405 @ OBC) and Gmb (2.308 @ OBC) value. Additionally, the Superpave mix design method requires the use of a specified amount of mineral aggregate in the mix, which can also affect their value. In contrast, the Marshall mix design method has higher Gmm (2.423 @ OBC) and Gmb (2.325 @ OBC) values due to its smoother gradation with more fine aggregate. Denser packing is easier to achieve in this method, and the Gmm and Gmb value are determined using hammer compaction, which may not orient the aggregate as efficiently as gyratory compaction, resulting in higher values. These findings are consistent with the results of previous studies conducted by (Al-khateeb et al., 2010; Al-mistarehi, 2014).

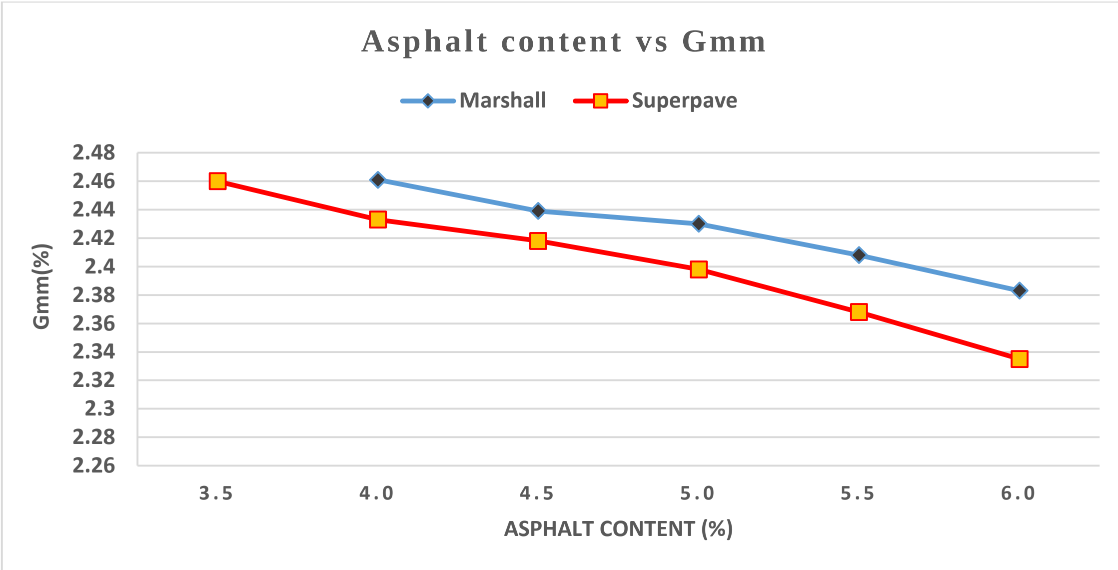


Figure 4.8 Relationship of asphalt content and Gmm

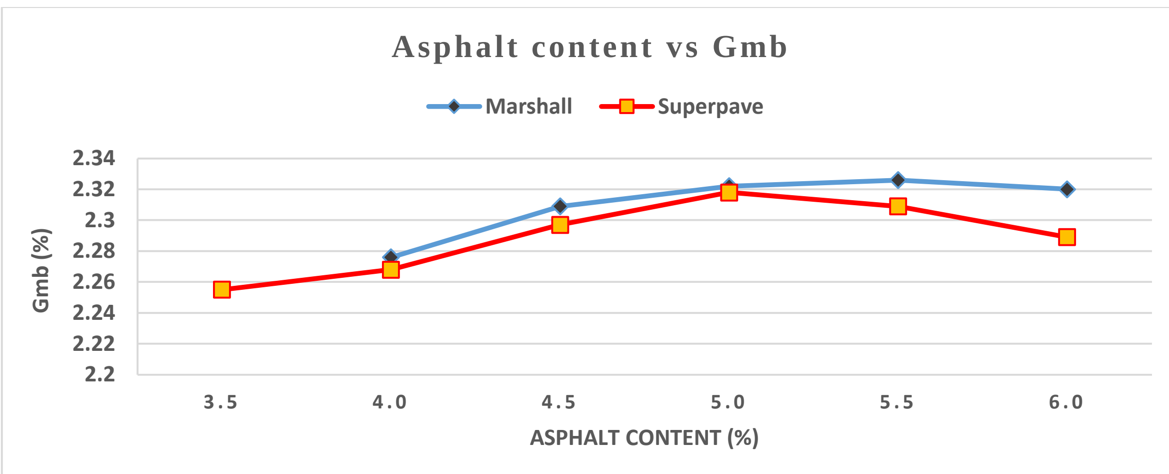


Figure 4.9 Relationship of asphalt content and Gmb

4.5 Comparison of the mechanical performance of Marshall and Superpave mix

When it comes to evaluating the performance of these asphalt mixes, several tests are typically conducted, including the TSR (Indirect Tensile Strength) test, wheel tracking test, and retained stability test. The TSR test measures the tensile strength of the asphalt mix and is used to evaluate the resistance of the mix to cracking under tensile stresses. The wheel tracking test evaluates the resistance of the asphalt mix to deformation and rutting under repeated wheel loads. The retained stability test measures the resistance of the asphalt mix to moisture damage.

4.5.1 Rut wheel tracking test

The wheel tracking test is used to measure the rut depth (mm) with respect to the number of passes. The rutting resistance of Superpave mix design is higher compared to that of Marshall mix design, indicating that the rut wheel tracking test result of Superpave mix design (2.08) is expected to be lower than that of Marshall mix design (4.54), as shown in figure 4.6. This finding is consistent with the results of previous studies (Africa et al., 2019; Al-mistarehi, 2014; Asmael & Ahmed Alkawaaz, 2009; Omar et al., 2021), which also reported lower rut depths for Superpave-designed asphalt mixtures compared to Marshall-designed mixtures. The Superpave method also uses a more rigorous compaction procedure, more comprehensive criteria, and a gyratory compactor, which can result in a more uniform and dense mix. Overall, the higher rutting resistance of the Superpave mix design method indicates that the resulting asphalt mixture is better suited to resist deformation and cracking under traffic loads.

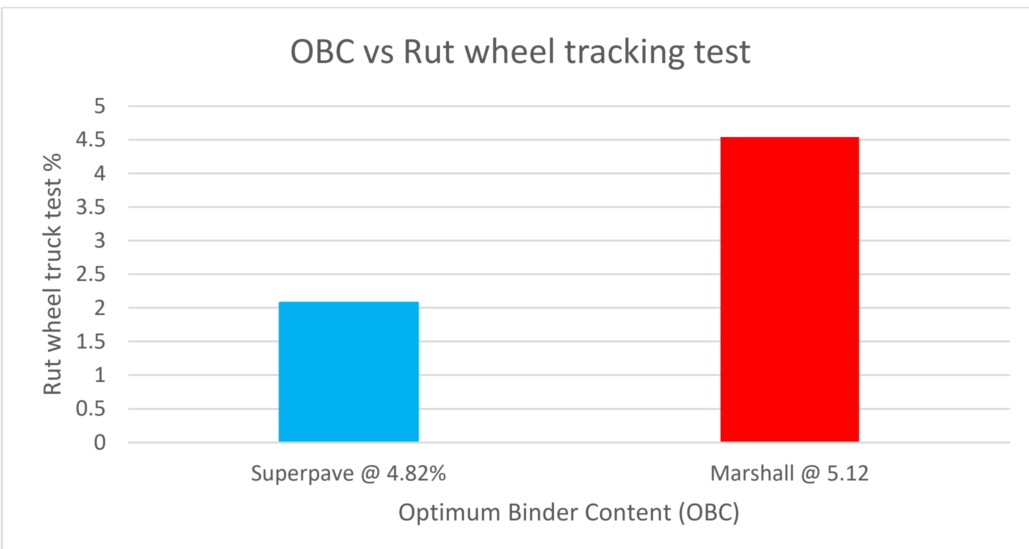


Figure 4.10 Relationship of Rut wheel truck test @ OBC

4.5.2 Indirect Tensile Strength Test

The TSR value of the Marshall mix at OBC was 82.6, while that of the Superpave mix at OBC was 87.9. It has been determined that the Superpave mix design method typically gives higher TSR values than the Marshall mix design method. This can be attributed to several factors, including the different aggregate orientation of the specimen in the SGC, the difficulty of specimen saturation, and lower asphalt contents used in the Superpave method compared to the Marshall method. These findings are consistent with the results of previous studies conducted by (Administration, 2001; Al-khateeb et al., 2010; Jitsangiam et al., 2013; Nouman et al., 2022; Taylor et al., 2007), which also reported higher TSR values for Superpave-designed asphalt mixtures compared to Marshall-designed mixtures.

The higher TSR values of Superpave-designed asphalt mixtures can be attributed to the higher aggregate gradations used in the Superpave mix design method, which results in a mix with a higher percentage of interlocking particles.

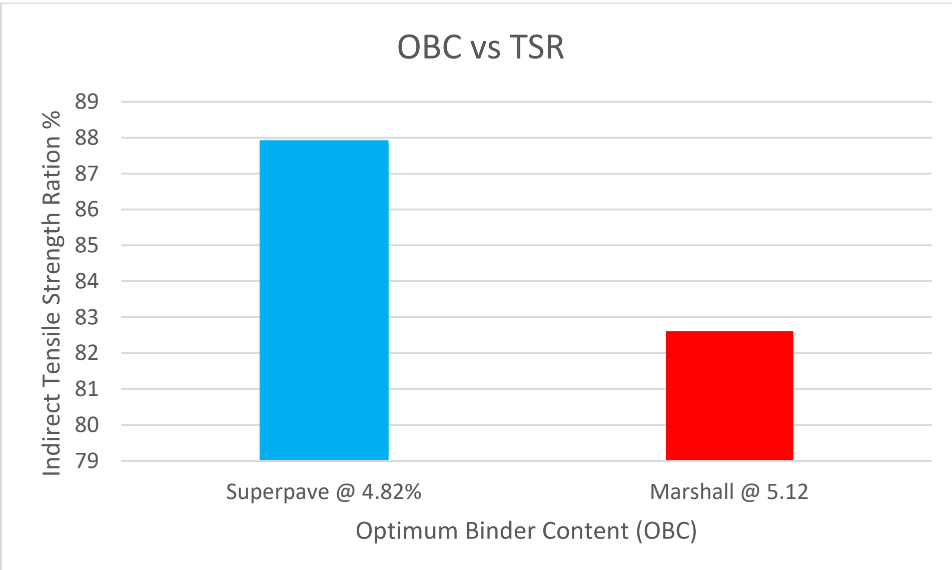


Figure 4.11 Relationship of TSR ratio % @ OBC

4.5.3 Retained stability

The retained stability test result of the Superpave mix design method is slightly higher than that of the Marshall mix design method, with values of 85.9% and 81.3%, respectively. This finding is consistent with the results of previous studies conducted by (Administration, 2001; Al-khateeb et al., 2010; Taylor et al., 2007), which also reported higher retained stability test results for Superpave-designed asphalt mixtures compared to Marshall-designed mixtures.

The higher retained stability test result of the Superpave mix design method can be attributed to its more rigorous testing procedure for evaluating the susceptibility of the mix to moisture damage. The Superpave method requires that the mix be subjected to a series of freeze-thaw cycles and then tested for retained stability, which is a measure of the strength of the mix after exposure to moisture and freeze-thaw cycles. This testing procedure ensures that the Superpave-designed asphalt mixture is more resistant to moisture damage compared to the Marshall-designed asphalt mixture.

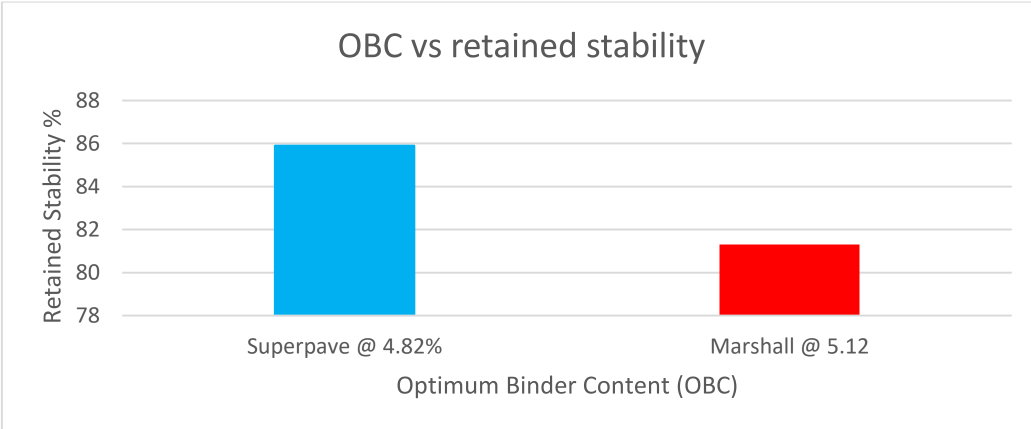


Figure 4.12 Relationship of Retained stability @ OBC

4.6 Life cycle cost analysis

4.6.1 Computation of pavement initial construction costs

The Superpave method typically requires the use of several road layers, including a subbase, base, and surface layer, which provide an additional level of protection against deformation and cracking. This layered approach is designed to distribute loads more effectively, reduce stress on the pavement, and improve overall pavement performance, resulting in longer-lasting and more durable roads. However, it is important to note that the additional road layers required in the Superpave method can make the construction cost more expensive than the traditional Marshall mix design as shown on the table below. The items and the unit price for the construction cost estimation was taken from projects that are recently constructed and the roads under construction.

Item No.	Item Description	Unit	Qtty	Unit price	Total amount (ETB)
1	Preparation of Road bed				
1.1	Road bed preparation and compaction to 95% of modified AASHTO density d=194mm	m3	1358	178	241724
1.2	Road way and borrow excavation cut and borrow to fill				
1.2a	Borrow to fill compacted to minimum 95% modified AASHTO T180 density d=759mm	m3	5313	418	2220834
1.2b	Rock fill d=46mm	m3	322	500	161000
1.2c	Capping layer material compacted to minimum 95% of AASHTO T180 density d=69mm	m3	483	215	103845
1.3	cut to spoil				
1.3a	common excavation to spoil d=313mm	m3	2191	84	184044
	Sub base, Road base and gravel wearing coarse				

2	Sub-bases				
2.1	Sub-base layer constructed from natural gravel and crushed gravel, crushed stone or a combination of them compacted to minimum 97% of AASHTO T180 density d=672mm	m3	4704	600	2822400
3	Road bases				
3.1	Crushed aggregate base course compacted to minimum 100% AASHTO T180 density, d = 200mm	m3	1400	1590	2226000
	Bituminous surfacing and road base				
4	Bituminous prime coat				
4.1	prime coat				
4.2a	MC-30, cutback bitumen (app. Rate = 1 lit/m2)	lt.	7000	180	1260000
4.3	Tack coat	m2	7000	150	1050000
4.4	Bituminous binder courses and surfacing				
4.4a	Dense bitumen macadam (90mm thick)	m2	7000	713	4991000
4.4b	continuously graded HMA wearing course (60mm thick)	m2	7000	1500	10500000
Total					**25,760,847**

Table 4.17 Superpave construction. Source: ERA (Melodoni junction–Manda–Bure)

Item No.	Item Description	Unit	Quantity	Unit price	Total amount (ETB)
1	Earthwork and Excavation				
1.1	Clearing and Grubbing d=340	m2	2380	18	42840
1.2	Preparation of road bed d=100mm	m3	7000	178	1246000
1.3	Cut to Fill d=357mm	m3	2499	280	699720
1.4	Borrow to fill compaction to minimum 93%	m3	5313	418	2220834
2	Subgrade, sub base and base coarse				
2.1	Improved sub grade layer materials compacted to minimum 95% d=46mm	m3	322	500	161000
2.2	Sub-base layer(s) constructed from natural gravel or crushed gravel, crushed stone or a combination of them compacted to a minimum of 97% of AASHTO T180 density d=672mm	m3	4704	600	2822400
2.3	crushed aggregate base layer d=200mm	m3	1400	1590	2226000
3	Bituminous surfacing and Road				
3.1	prime coat MC-30, cutback bitumen (app. Rate = 1 lit/m2)	lt	7000	180	1260000
3.2	AC-50mm Asphalt concrete surfacing	m2	7000	1800	12600000
Total					**23,278,794**

Table 4.18 Marshall construction. Source: Batu – Arsinegelle project (Kunhwa E & C Ltd)

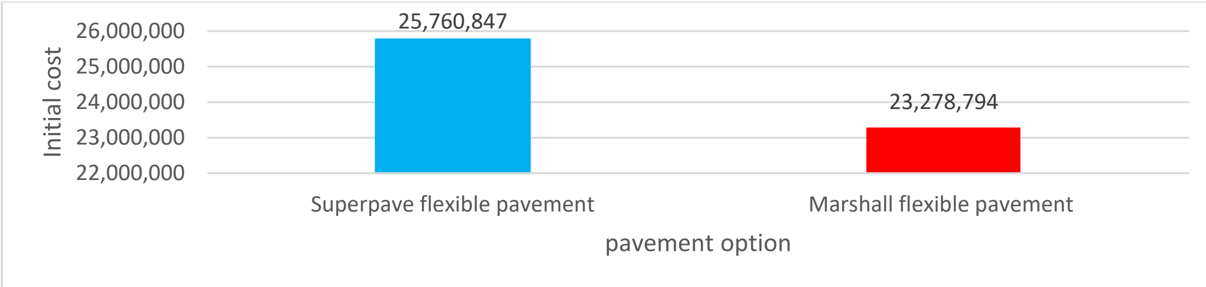


Figure 4.13 Relationship of Initial cost and pavement option

4.6.2 Pavement maintenance and rehabilitation costs

Studies have shown that the Superpave method's ability to provide a more accurate prediction of the pavement performance over time, it allows for more precise design and construction. Additionally, the Superpave method's use of a more comprehensive set of tests to evaluate mix properties can result in more durable and long-lasting pavements (Africa et al., 2019). In addition, the layered approach in the Superpave for the additional protection against deformation and cracking, resulting in improved pavement performance, as a result the marshall mix design requires early maintenance and rehabilitation cycle that is expected every 5 year over the entire life cycle (5^{th}, 10^{th}, 15^{th}, 20^{th}, 25^{th} and 30^{th} years) (Assefa, 2015) when it's compared with superpave that is expected every 7 year (7^{th}, 14^{th}, 21^{th} and 28^{th} year) (Nur Izzi et al., 2016). The unit price was taken from recently maintenance cost.

Name of Activity	Unit	Estimated Qtty.	Unit Price	Total
Culvert Cleaning	m^3	100.00	342.23	34,223.00
Ditch Cleaning (Manual)	m3	1,000.00	39.81	39,810.00
Brush Clearing	m^2	2,000.00	1.44	2,880.00
Asphaltic Concrete Overlay	m^3	500.00	7,287.07	3,643,535.00
Bitumen Prime Coat	Lt	3,000.00	180.00	540,000.00
Bitumen Tack Coat	Lt	3,000.00	150.00	450,000.00
Crushed Aggregate (Road Base)	m^3	100.00	575.93	57,593.05
Paved Waterway	m^2	2,000.00	419.74	839,488.05
Removing of sliding material	m3	1,000.00	74.80	74,795.65
white Painting	Km	0.50	111,155.22	55,577.61
Yellow Painting	Km	0.50	111,155.22	55,577.61
Zebras	No.	2.00	1,330.47	2,660.95
Total sum				**5,796,140.92**

Table 4.19 periodic maintenance. Source: ERA (Hageremariam – Yabelo maintenance)

The present worth for the periodic maintenance of Marshall and Superpave asphalt concrete pavement resulted as shown in figure below.

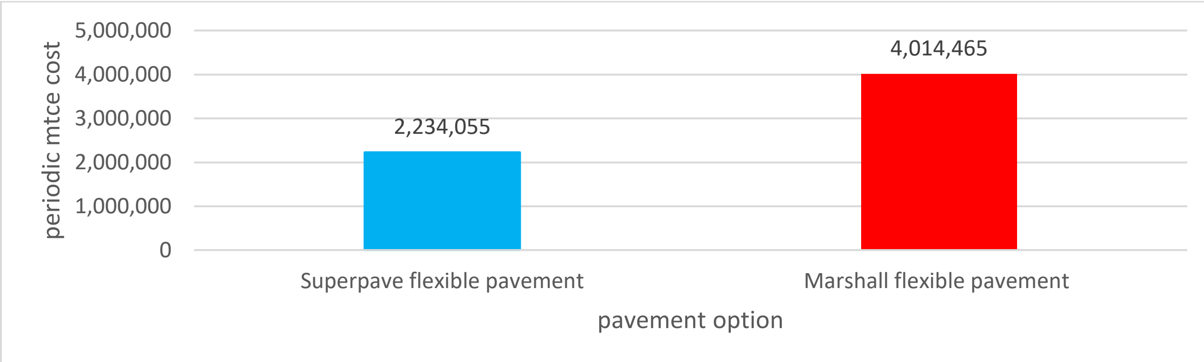


Figure 4.14 Relationship of periodic maintenance cost and pavement option

The routine maintenance and rehabilitation cost (this includes replacement of wearing course and reconstruction: only the subgrade of the existing pavement will remain) is expected early for the marshall mix design which is at the end of the 7th, 14th, 21th and 30th year (Habte, 2021), and for the superpave it was expected at the end of 10th, 20th and 30th year (Crespo Márquez et al., 2012). The unit rate was taken from the recent routine maintenance and rehabilitation activity.

Activity Name	**Unit**	**Unit Rate (Birr/unit)**	**Qtty**	**Amount**
Repair erosion damage (Selected fill)	m3	459.72	500.00	229,860.06
Repair erosion damage (Rock fill)	m3	735.35	500.00	367,677.02
Mortared Masonry Repair	m3	3,407.99	725.75	2,473,348.94
Gabion Structure	m3	5,475.04	1324.30	7,250,593.48
Asphalt Patching (Single Surface Treatment)	m2	428.52	500.00	214,262.40
Asphalt Patching (Double Surface Treatment)	m2	719.53	400.00	287,813.07
Asphalt Patching (Cold Mix)	m3	24,558.61	200.00	4,911,721.68
Pothole Reinstatement (Double Surface Treatment)	m2	595.93	100.00	59,592.90
Pothole Reinstatement (Cold Mix)	m3	25,309.85	100.00	2,530,985.01
Pothole (Base Failure Repair)	m3	1,453.17	400.00	581,269.68
Shoulder Blading	km	3,211.22	1.00	3,211.22
Shoulder Rehabilitation	m3	578.35	2000.00	1,156,696.68
Overhaul	m3km	16.03	456.00	7,311.54
				20,074,343.69

Table 4.20 Rehabilitation & routine maintenance. Source: ERA (Sodo–Waka, Hadero-Durgi)

The present worth for the Rehabilitation and routine maintenance cost of Marshall and Superpave asphalt concrete pavement resulted as shown in figure below.

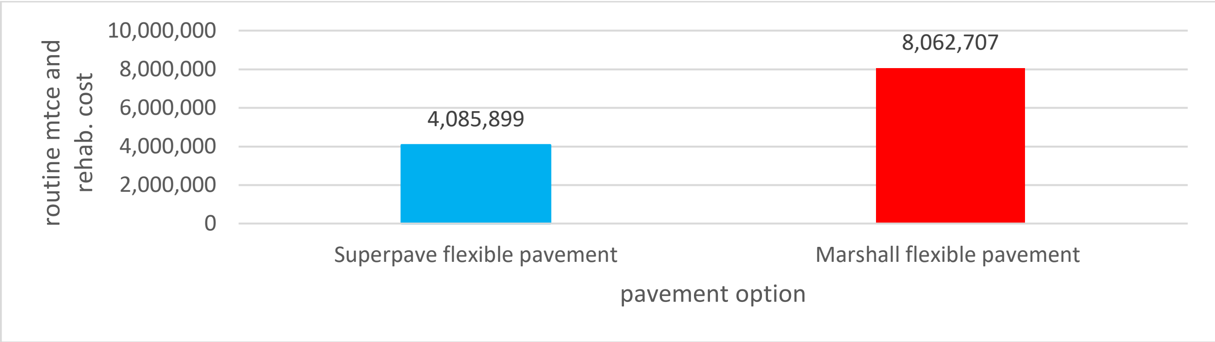


Figure 4.15 Relationship of routine maintenance and rehabilitation with pavement option

4.6.3 Salvage value of pavements

The salvage value, as a prorated share of the last rehabilitation, is 50 % (5 years remaining on a 10-year design) of its last rehabilitation cost for Marshall mix design pavement which is 0.5 * 20,074,343.69 = 10,037,171.85. The present worth of salvage value of Marshall becomes;

$$PW = \frac{10{,}037{,}171.85}{(1+0.194)^{35}} = 20{,}251.56 \text{ Birr/km}$$

The salvage value of Superpave mix design pavement, on the other hand, is 66.6 % (10 years remaining on a 15-year design) of its last rehabilitation cost 0.66 * 20,074,343.69 = 13,249,066.84. The present worth of salvage value of Superpave becomes;

$$PW = \frac{13{,}249{,}066.84}{(1+0.194)^{35}} = 26{,}732.148 \text{ Birr/km}$$

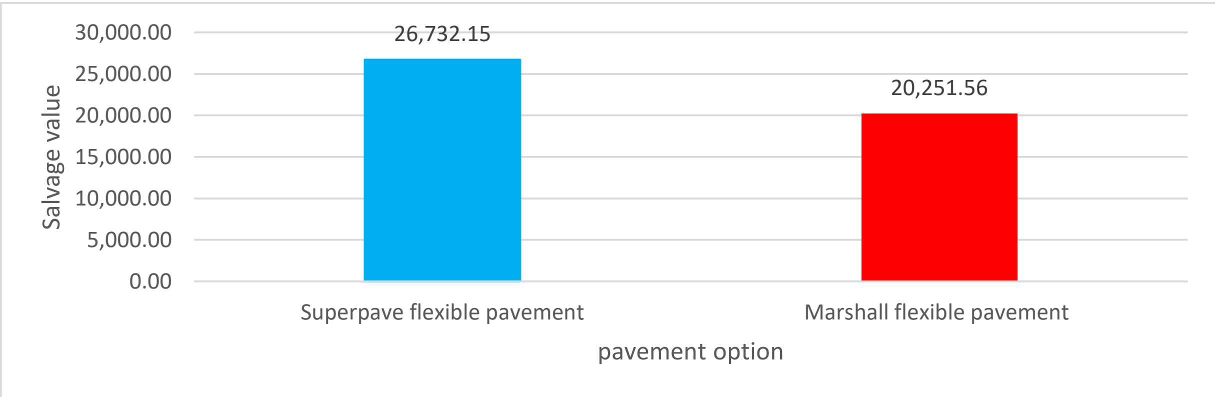


Figure 4.16 Relationship of salvage value and pavement option

4.6.4 Determination of user cost

4.6.4.1 Vehicle Time Savings

Vehicle Type	AADT (2014-2028)	Composition	No. of vehicle	Time saving/day/km	Time saving/day
Small bus	429	37%	159	0.29	46.03
Medium bus	429	2%	9	0.29	2.49
Large bus	429	1%	4	0.29	1.24
Medium truck	429	25%	107	0.29	31.10
Heavy truck	429	24%	103	0.29	29.86
Truck trailer	429	11%	47	0.29	13.69
Total time saved in a minute /per day					124.41

Table 4.21 Vehicle time source: (Ketema et al., 2016)

The total annual saved time = [124.41 minutes/day] *365days = 45,409.65 minutes. Therefore, the total annual benefit of time savings in Birr becomes = [45,409.65 minutes] *1 Birr/minutes = 45,409.65 Birr.

For Superpave mix design pavement the annual saved time is beneficial for a period of 32 years (35 years, -3 years) after deducting the years of maintenance and rehabilitation, where the saving time becomes non-benefit, delay due to maintenance and rehabilitation activities and lane closures for the remaining 3 years.

Total value in Birr for time delay (non–benefit) during the analysis period of 35 years becomes,

45,409.65 Birr/year *32 years= 1,453,108.8 Birr.

Total value in Birr of time savings during the analysis period of 35 years becomes, the total benefit = 1,453,108.8 - (45,409.65*3) = 1,316,879.85 Birr/km

$$PW = \frac{1,316,879.85}{(1+0.194)^{35}} = 2,657.02 \text{ Birr/km}$$

Likewise, for Marshall mix design pavement, the annual saved time is beneficial for a period of 29 years (35 years, -6 years) after deducting the years of maintenance and rehabilitation, where the saving time becomes non- benefit, delay due to maintenance and rehabilitation activities and lane closures for the remaining 6 years. The total value of Birr of time savings during the analysis period of 35 years becomes, Total value in Birr for time delay (non–benefit) during the analysis period of 35 years. Also, this becomes, 45,409.65 Birr/year*29years= 1,316,879.85 Birr

Total benefit= 1,316,879.85 - (45,409.65*6) = 1,044,421.95 Birr/km

PW = $\frac{1,044,421.95}{(1+0.194)^{35}}$ = 2,107.29 Birr/km

4.6.4.2 Cost of fuel for vehicle

The annual fuel consumption becomes: Cost of fuel per day =[0.33lit/km] * [1km*429] * [69.52Birr/lit] = **9,841.95** Birr/day.

The annual cost of fuel on the assumption of daily operation basis = 9,841.95 Birr/day*365 days = **3,592,310.44** Birr/km/year.

Superpave pavement reduces 4% fuel consumption (West, 2018), for a period of 32 years (35 years, -3 years) after deducting the years of maintenance and rehabilitation, where such reduction is not considered due to maintenance and rehabilitation activities and lane closures for the remaining 3 years.

Total fuel cost during the analysis period of 35 years once applying 4% reduction in consumption (West, 2018) for 32 years: 3,592,310.44 Birr/year*32 years*(1-0.04) = 110,355,776.7 Birr/km

Total fuel cost during maintenance and rehabilitation activities and lane closures during the analysis period of 35 years becomes without applying the percentage reduction becomes,

3,592,310.44 Birr/year*3 Years= 10,776,931.32 Birr/km

Therefore, the total fuel Cost = 10,776,931.32 + 110,355,776.7 = 121,132,708 Birr/km

PW = $\frac{121,132,708}{(1+0.194)^{35}}$ = 244,404.95 Birr/km

Marshall pavement reduces 1.8% fuel consumption (Ketema et al., 2016), for a period of 29 years (35 years, - 6years) after deducting the years of maintenance and rehabilitation, where such reduction is not considered due to maintenance and rehabilitation activities and lane closures for the remaining 6 years.

Total fuel cost during the analysis period of 35 years when applying 1.8% reduction in consumption for 29 years, 3,592,310.44 Birr/year*29 years*(1-.018) = 102,301,816.7 Birr/km

Then, the total fuel cost during maintenance and rehabilitation activities and lane closures in the analysis period of 35 years without applying the percentage reduction for 3 years becomes,

3,592,310.44 Birr/year *6 years = 21,553,862.64 Birr/km

Total fuel Cost= 21,553,862.64 + 102,301,816.7 = 123,855,679.3 Birr/km.

PW = $\frac{123,855,679.3}{(1+0.194)^{35}}$ = 249,898.99 Birr/km.

4.6.5 Total cost on the LCCA

The total life cycle cost of the pavement calculated as follows:

$$NPV = IC + \sum_{K}^{N} MC \frac{1}{(1+i)^n} + \sum_{K}^{N} RC \frac{1}{(1+i)^n} - SV \frac{1}{(1+i)^n} - VTS \frac{1}{(1+i)^n} + FC \frac{1}{(1+i)^n}$$

For the Superpave mix design:

No.	Description	Superpave flexible pavement
1	Initial construction cost	25,760,847
2	periodic maintenance cost	2,234,055
3	Routine maintenance and rehabilitation	4,085,899
4	Salvage value	-26,732
5	Vehicle Time Savings	-2,657
6	Cost of fuel for vehicle	244,404
Total cost in 35 years (ETB)		**32,295,816**

Table 4.22 Superpave total LCC

No.	Description	Marshall flexible pavement
1	Initial construction cost	23,278,794
2	periodic maintenance cost	4,014,465
3	Routine maintenance and rehabilitation	8,062,707
4	Salvage value	-20,252
5	Vehicle Time Savings	-2,107
6	Cost of fuel for vehicle	249,899
Total cost in 35 years (ETB)		**35,583,506**

Table 4.23 Marshall total LCC

4.7 Summary of tables on comparison

Table 4.22, Table 4.23 and Table 4.24 represents the summarized results obtained result from the volumetric properties, mechanical performance, and on Life Cycle Cost analysis.

Marshall Test Requirements	Marshall mix design results @ 5.12%	Superpave Mix design results @ 4.82%	Specification Criteria (ERA - 6400/13)
Air Voids (Vv) %	4.0	4.0	**3-5 %**
Voids in the Mineral Aggregates (VMA) %	14.88	15.6	**>14%**
Voids Filled with Asphalt (VFA) %	71.27	74.1	**65-75 %**
Stability Value (KN)	11.61	12.02	**>9KN**
Flow Value (mm)	3.1	2.58	**2-3.5mm**
Compacted mix Bulk Specific gravity (Gmb)	2.325	2.308	—
Maximum Theoretical Density (Gmm)	2.423	2.405	—
Dust to Bitumen Proportion %	0.85	0.87	**0.6-1.2**
%Gmm @ Ninitial	—	87.8	**≤ 89Nini**
%Gmm @ Ndesign	—	96	**96Ndes**
%Gmm @ Nmaximum	—	97.2	**≤ 98Nmax**

Table 4.24 summery of volumetric property results

Test requirements	Marshall mix design results @ 5.12%	Superpave mix design result @ 4.82%	Specification (AACRA & ERA)
Rut Wheel Tracking Test	4.54	2.08	**>7mm**
Indirect Tensile Strength Ratio %	82.6	87.9	**>80%**
Retained Stability %	81.3	85.9	**>75%**

Table 4.25 Summery of the mechanical performance test result

No.	Description	Superpave flexible pavement	Marshall flexible pavement	Difference
1	Initial construction cost	25,760,847	23,278,794	**-2,482,053**
2	periodic maintenance cost	2,234,055	4,014,465	**1,780,410**
3	Routine maintenance and rehabilitation	4,085,899	8,062,707	**3,976,808**
4	Salvage value	-26,732	-20,252	**6,481**
5	Vehicle Time Savings	-2,657	-2,107	**550**
6	Cost of fuel for vehicle	244,404	249,899	**5,495**
Total cost in 35 years (ETB)		**32,295,816**	**35,583,506**	**3,287,691**

Table 4.26 summery on life cycle cost analysis

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The aim of this study is to compare the Marshall and the Superpave mix design method on the design procedures, volumetric and mechanical performance using local materials and to perform economic analysis on their bitumen cost, under high-traffic loading and prevailing temperature regime, from the obtained result the following conclusions can be drawn:

- The Superpave mix design method follows more restricted mix design procedure than the Marshall mix design.
- Superpave mixes yield lower asphalt content than Marshall Mixes, this suggests that the Marshall mix design requires more bitumen to achieve maximum density and strength compared to the Superpave mix design.
- At OBC, the Gmm and Gmb values were lower for Superpave mix than for Marshall mix design. The difference in compaction methods and compaction energy levels may account for the lower values of Superpave.
- The stability and flow test results showed that the Superpave mix design had higher stability value and lower flow value at OBC than the Marshall mix design. This indicates that the Superpave mix design is better resistant to deformation and cracking under traffic loads.
- The values of VMA and VFA for Superpave mix design were higher than those for Marshall mix design. This is because the Superpave method aims to achieve a higher degree of aggregate orientation and interlock and recommends the gradation to be below the restricted zone for high-traffic loads, which can provide better resistance to rutting and stripping.
- The wheel tracking test showed that the rutting depth of Superpave mix design was lower than that of Marshall mix design. This indicates that Superpave mix design is more resistant to rutting and deformation.
- The TSR of Superpave mix design was higher than that of Marshall mix design at OBC. This is because the Superpave method, there's difficulty of specimen saturation compared to the Marshall method.

- The retained stability test result of Superpave mix design was higher than that of Marshall mix design. This is because the Superpave method uses a more rigorous testing procedure to evaluate the susceptibility of the mix to moisture damage.
- From the life cycle cost analysis, despite high initial construction cost of the superpave mix design method, it resulted a total saving of **3,287,691** birr per kilometer compared with the Marshall mix design method.
- Based on all the performance tests, it can be concluded that Superpave mix design showed overall superior performance than the Marshall mix design in all tests conducted in this study.

5.2 Recommendation

- Superpave mix design methods can be an alternative mix design approach for truck road in Ethiopia, as it has demonstrated superior performance in all tests conducted in this study.
- Adopting Superpave mix design is highly recommended due to its potential to significantly reduce the cost of bitumen, a major import product for our country that costs millions of dollars.
- To lower maintenance and rehabilitation costs for truck road, it's recommended to adopt Superpave mix design that exhibits superior resistance to rutting, cracking, deformation, and stripping.
- Revising the current mix design specifications and standards to incorporate the Superpave mix design method is recommended for ERA, transportation authorities, engineers, and policymakers to improve road performance.
- To validate the laboratory results accuracy, further study supplementing laboratory tests with field performance evaluations is recommended.
- To establish more robust confidence in Superpave mix design criteria, it's recommended to conduct a similar study using a larger variety of aggregate gradation and binder types and analyze the results using statistical analysis

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APPENDICES

APPENDIX - A Aggregate Quality Test Result

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Project :-	**For Research**		

AGGREGATE CRUSHING VALUE

TEST METHOD : BS:812 Part 110 (1990)

Source:	**Akaki - 08 Quarry**		
Material type:	**Course Aggregates**	**Date sample:**	**4/13/2023**
Sample from:	**Hot Bin**	**Date test:**	**4/14/2023**

MATERIAL DESCRIPTION :	**CRUSHED STONE**		
TRIAL No.	1	2	3
Mass of sample (14mm pass and 10mm Retain)	2922	2915	
Mass of sample retained on B.S Sieve,2.36mm	2530	2540	
Mass of sample passing B.S Sieve,2.36mm	392	375	
Aggregate Crushing Value (ACV)	13.4	12.9	
Average ACV	**13.1**		

AGGREGATE IMPACT VALUE

TEST METHOD : BS:812 Part 110 (1990)

TRIAL No.	1	2	3
Mass of sample (14mm pass and 10mm Retain)	387	393	
Mass of sample retained on B.S Sieve,2.36mm	354	361	
Mass of sample passing B.S Sieve,2.36mm	33	32	
Aggregate impact Value (Aiv)	8.5	8.1	
Average Aiv	**8.3**		

Remarks:

Tested By:-	**Approved By:**
(Sr. Lab. Technician)	**Supervision Consulant: (Sr. Material Eng.)**

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Project :-	**For Research**		
MATERIAL DESCRIPTION :	Crushed Basalt	**DATE SAMPLED :**	4/13/2023
MATERIAL SOURCE:	Akaki 08- Quarry	**DATE TESTED :**	4/15/2023
Sample From	Hot bin		

10 PERCENT FINE VALUE AND WET / DRY RATIO

BS 812 part 110:1990

		DRY SAMPLE		WET SAMPLE	
Test no.		1	2	3	4
Mass of the test specimen					
(Passing 14mm & Retained on 10mm Sieve	M1 (gm)	2939		2930	
Mass of Aggregate Retained on the 2.36mm	M2 (gm)	2660		2600	
Mass of Aggr passing the 2.36mm sieve	M1(gm)- M2(gm)	279		330	
%Pass m	((M1- M2)-M1)*100	9.5		11.3	
Maximum force	(KN)	388		370	
T.F.V.	14f/m+4	402.6		339.4	
AVERAGE T.F.V.	(KN)	403		339	
WET / DRY RATIO	(%)	84.3			

Remark

Tested By:- **Approved By:**

(Sr. Lab. Technician)

Supervision Consulant:
(Sr. Material Eng.)

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Project :- **For Research**

RESISTANCE TO ABRASION OF SMALL SIZE COARSE AGGREGATE BY USE OF THE LOS ANGELES MACHINE

TEST METHOD : AASHTO T 96-94

Source:	Akaki 08- Quarry	**Date sample:**	4/13/2023
Material type:	Course Agg	**Date test:**	4/16/2023
Sample from:	Hot Bin	**Material description**	Crushed basalt

SIEVE SIZES	1 1/2 - 1"	1 - 3/4 "	3/4 - 1/2 "	1/2 - 3/8 "	3/8 - 1/4 "	1/4" - No.4	No.4-No.8
GRADE	A				C		D
NUMBER OF BALLS	12 BALLS				8 BALLS		6 BALLS
WT. OF INDICATED SIZE	1250 ± 25	1250 ± 25	1250 ± 10	1250 ± 10	2500 ± 10	2500 ± 10	5000 ± 10
WT.OF TESTED SAMPLE							
GRADE			B				
NUMBER OF BALLS			11 BALLS				
WT. OF INDICATED SIZE			2500 ± 10	2500 ± 10			
WT.OF TESTED SAMPLE							

TEST RESULTS

TRIAL	1	2	3	Average
NUMBER OF REVOLUTION	500	500		
TOTAL WT. OF SAMPLE TESTED, (g)	5000	5000		
WT. OF TESTED SAMPLE RETAINED ON No. 12 SIEVE (g)	4255	4250		
PERCENT LOSS (%)	**14.9**	**15.0**		**15.0**
Remark				

Tested By:-

(Sr. Lab. Technician)

Approved By:

Supervision Consulant:
(Sr. Material Eng.)

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Project :- For Research

SAND EQUIVALENT VALUE

TEST METHOD : AASHTO T 176-86

Source:	Akaki - 08 Quarry	**Sample by**	Mahlet
Material type:	Curshed Sand (0-3mm)	**DATE SAMPLED:**	4/13/2023
Sample from:	Hot bin	**DATE TESTED:**	4/16/2023

TEST No.	1	2	3
A. SAND READING, mm	80.3	81.1	
B. CLAY READING, mm	100	100	
SAND EQUIVALENT = A / B x 100 %	80.3	81.1	
AVERAGE SAND EQUIVALENT, %	80.7		

COATING AND STRIPPING VALUE - (AASHTO T-182)

Material type:	Crushed Agg.(13.2 - 9.5mm)	**Date sample:**	4/13/2023
Sample from:	From Hot bin	**Date test:**	4/16/2023
Source:	Akaki 08- Quarry	**Material Description**	Crushed basalt

	TRIAL NO.	Trial- 1	Trial- 2
A	Stripping Value %	>95	>95
B	Average Stripping Value %	>95	

Tested By:-	**Approved By:**
(Sr. Lab. Technician)	**Supervision (Sr. Material Eng.)**

Use of Aggregate:- For Marshall Mix Design | **Types of works:-** Wearing Course

Sampled By:- Mahlet

Asphalt Aggregate Flakiness Index and Elongation Index

Sieve Size, (mm)	Mass Weight (g/mm)	% Retained	Flakiness gauge Sieve, mm					
			Sieve Size mm	Retained on BS Sieve, (mm)	Width of Slot in thickness gauge or special Sieve, (mm)	Weight Retained on Each Sieve, (gm)	Weight Passing Each Flakiness Gauge (gm)	Individual Percentage Passing Flakiness Index (%)
50.0	0	0.0	63.0	50.0	33.9 ± 0.3	0.0	0.0	0.00
37.5	0	0.0	50.0	37.5	26.3 ± 0.3	0.0	0.0	0.00
28.0	0	0.0	37.5	28.0	19.7 ± 0.3	0.0	0.0	0.00
20.0	357	8.3	28.0	20.0	14.4 ± 0.15	290.0	87.0	2.02
14.0	1670	38.7	20.0	14.0	10.2 ± 0.15	1508.0	192.0	4.45
10.0	961	22.3	14.0	10.0	7.2 ± 0.1	865.0	156.0	3.61
6.3	1328	30.8	10.0	6.3	4.9 ± 0.1	1139.0	231.0	5.35
Total =	4316		Total			3802.0	666.0	

Flakiness Index = (Total weight Passing Flakiness Gauge,(gm) / Total weight of Ballast Sample) **15.4%**

Sieve Size, (mm)	Mass Weight (g/mm)	% Retained	Elongation Index gauge Sieve, mm					
			Sieve Size mm	Retained on BS Sieve, (mm)	Width of Slot in thickness gauge or special Sieve, (mm)	Weight Retained on Each Sieve, (gm)	Weight Retained Elongation Each Gauge (gm)	Individual Percentage Passing Elongation Index (%)
50.0	0	0.0	63.0	50.0	33.9 ± 0.3	0	0	0.00
37.5	0	0.0	50.0	37.5	26.3 ± 0.3	0	0	0.00
28.0	0	0.0	37.5	28.0	19.7 ± 0.3	0	0	0.00
20.0	392	9.1	28.0	20.0	14.4 ± 0.15	326	75	1.70
14.0	1596	37.0	20.0	14.0	10.2 ± 0.15	1574	93	2.11
10.0	1027	23.8	14.0	10.0	7.2 ± 0.1	910	117	2.66
6.3	1385	32.1	10.0	6.3	4.9 ± 0.1	1240	98	2.23
Total =	4400		Total			4050.0	383.0	

Elongation Index = (Total weight Passing Elongation Gauge,(gm) / Total weight of Ballast Sample) = **8.7%**

Material Engineer's comments if any:

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Project :- **For Research**

SOUNDNESS OF AGGREGATE BY USE OF SODIUM SULFATE OR MAGNESIUM SULFATE

TEST METHOD : AASHTO T104-97

Source:	Akaki - 08 Quarry	**Date sample:**	4/13/2023
Material type:	Fine &Course Agg.	**Date test:**	4/21/2023
Sample from:	Hot Bin	**Purpose**	For quality Check

Cycles	IMMERSION				No. of Hours	Specific gravity of solution
	Beginning		End			
	Date	Time	Date	Time		
1. Immersion	15/04/2023	5.00 Pm	16/04/2023	10:00 Am	17 hours	1.163
2. Immersion	16/04/2023	5.00 Pm	17/04/2023	10:00 Am	17 hours	1.163
3. Immersion	17/04/2023	5.00 Pm	18/04/2023	10:00 Am	17 hours	1.163
4. Immersion	18/04/2023	5.00 Pm	19/04/2023	10:00 Am	17 hours	1.163
5. Immersion	19/04/2023	5.00 Pm	20/04/2023	10:00 Am	17 hours	1.163

SOUNDNESS TEST OF FINE AGGREGATE (Crushed Sand)

SIEVE SIZE (mm)	% Retained of Original Sample	Mass of Sample Before Test (g)	Wt. of Sample After Test	% Loss After Test		Weighted % Loss
Minus 0.15	7.8					
0.3 - 0.15	8.6					
0.6 - 0.3	17.4	100	92.1	7.9		1.37
1.18 - 0.6	19.8	100	93.3	6.7		1.33
2.36 - 1.18	25.7	100	94.6	5.4		1.39
4.75 - 2.36	20.6	100	93.5	6.5		1.34
10 - 5						
TOTALS						**5.43**

SOUNDNESS TEST OF COARSE AGGREGATE

SIEVE SIZE (mm)	% Retained of Original Sample	Mass of Sample Before Test (g)	Wt. of Sample After Test	% Loss After Test		Weighted % Loss
63 - 50						
50 - 37.5						
37.5 - 25						
25-19	16.7	508	498.8	9		1.54
19-12.5	46.8	1037	1033	4		1.87
12.5 - 9.5						
9.5 - 4.75	36.5	302	298.3	4		1.35
TOTAL	100.0					**4.76**

Remarks :

Tested By:-	Approved :
(Sr. Lab. Technician)	Supervision Consulant: (Sr. Material Eng.)

Aggregate Polish Stone Value Test
Test Method BS 812 Part 114

Project:-	For research		
Types of Material:-	Crushed Stone Aggregate	**Date of Sampling:-**	4/13/2023
Sampling Location:-	Akaki - 08 Quarry	**Date of Report:-**	4/18/2023
Sampling from:-	Hot bin	**Aggregate Size:-**	14-26mm
Sampled By:-	Mahlet	**Nominal maximum particle size:-**	20mm

Sample In Oven temper	40	(℃)	Sample In Oven time	3	(h)
Cool temper	20	20±5(℃)	Cool time	9	(h)
Coarse Sand rate of flow	27±7	(g/min)	Fine Sand rate of flow	3±1	(g/min)
Water rate of flow	60	(ml/min)	Rotate speed	57600	(r)
Water temperature	20	(℃)	In Water time	2	(h)
Slipping distance	76	(mm)	Standard PSV	49±3	(PSV)

Aggregate Size	Crushed Aggregate	Test															Criteria	Remarks
Sample Type	Asphalt Aggregate		1		2		3		4		5		6		7			
Sample No.	'A"	(n)	1	2	3	4	5	6	7	8	9	10	11	12	13	14		
Test Load 725N ± 10N / Frequency			6	13	3	10	5	12	4	11	2	9	7	14	1	8		
1	**PSV times**	1	51.0	50.9											52.4	50.8		
		2	50.6	50.3											49.7	51.1		
		3	51.0	50.5											51.9	50.5		
		4	50.8	50.0											50.8	49.6		
		5	50.0	51.0											50.7	51.3		
	Average PSV_r		**50.68**	**50.5**											**51.1**	**50.7**	**< 50**	**Pass**
2	**PSV times**	1	52.6	51.0											51.2	51.8		
		2	50.3	51.0											51.8	52.6		
		3	49.7	52.0											52.3	50.9		
		4	53.6	51.0											50.6	50.4		
		5	51.5	51.0											51.8	51.2		
	Average PSV_r		**51.54**	**51.2**											**51.54**	**51.38**		
Average PSV_{ra}			**51.0**												**51.2**			
Final Average PSV Test Results			**51.1**															

Fine Aggregate Angularity Test AASHTO T304					
Trials	Mass of dry Aggregate	Volume of cylinder	% Air Voids (Loose)	Gsb	Criteria
1	1181	1000	54.5	2.597	45%min
2	1167	1000	55.1		
Average			**54.8**		

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Source:	Akaki - 08 Quarry	**Date Sample :**	4/13/2023
Material Type :	Coarse & Medium agg	**Date tested :**	04/18/2023
Material Description:	Crushed basalt	**Sampled By:**	Mahlet
Sample From:	Hot Bin	**Tested BY :**	Jointly

Clay Lumps and Friable Particles in Aggregate
AASHTO T-112

Sive Size		G (%)	Weight of Fraction M(gm)	Weight Retained		D= (M-R)(gm)	P= D GX100 M
Passing (mm)	Retaind (mm)			Sieve	R(gm)		
4.75	1.18	17.8	500	850mm	499.8	0.2	0.71
9.5	4.75	36.7	500	2.36mm	499.9	0.1	0.73
19	9.5	26.5	500	4.75mm	499.9	0.1	0.53
3.75	19	15.1	500	4.75mm	499.8	0.2	0.60

<u>Note</u>

G = the gradation portion of each sive retained

R=Retained weight of orginal sieve after washed

Remarks

APPENDIX - B Bitumen (60/70) Quality test result

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Project :-	Reaserch
Client :-	

Test Record of Penetration、Ductility、Softening point of Bituminous Materials

Sample No	1	Sample by	Mahlet	Trade Mark /Grade	60/70
Sample Source	From Batching Plant	Proposed Use	For Quality Test	Sample Date	4/13/2023
Method Used	AASHTO M20-70			Test Date	4/20/2023

	Frequence	Test Temperature (^{0}C)	Time of Test (S)	Test Load (g)	Reading Date (0.1mm) First Time	Second Time	Third Time	Average(0.1mm)
Penetration	1	25	5	100	66.8	66.2	66.2	66.4
	2	√	√	√	66.7	66.8	66.9	66.8
	3	√	√	√	67.4	65.7	66.4	66.5
					Average			66.6

	Frequence	Test Temperature (^{0}C)	Speed (cm/min)	Ductility (cm) 1	2	3	Average(cm)
Ductility	1	25	5	145	148	147	147

	Frequence	Temperature when starting heating(^{0}C)	1min	2min	3min	4min	5min	6min	7min	8min	9min	10min	11min	12min	Softening point (^{0}C)	Average (^{0}C)
Softening point	1	5c°				√									51.6	51.0
	2	5 c°				√									50.4	

Remark :

Tested By	Approved by
Sr.Lab.Technican	Materials testing dapartment head (Sr.P/me)

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Project :-	Reaserch	Sampled Date	4/13/2023
Grade of Sample :	Bitumen (60/70)	Tested Date	4/20/2023

Specific Gravity of Semi-Solid Bituminous Materials (AASHTO - T228)

Sourse :	From Asphalt Batching Plant	
Determination	1	2
1. Weight of Pycnometer , g	36.80	33.72
2. Weight of Pycnometer Filled With Sample , g.	53.81	50.67
3. Weight of Pycnometer Filled with Water , g @ 25 ± 0.1^{0}C	61.93	58.23
4. Weight of Pycnometer + Sample + Water , g @ 25± 0.1^{0}C	62.44	58.59
5. Weight of Water replaced by Sample , g {(3-1)+2} - 4	16.5	16.59
6. Specific Gravity ,(2-1)/5	1.031	1.022
7. Average Specific Gravity (g/ Cm3)	1.026	
8. Density , 7*w_T (25 ^{o}C,w_T =0.9971 g/cm3)	1.023	
9. Density , 7*w_T (15.6 ^{o}C, w_T =0.9990 g/cm3)	1.025	

Remark

Tested By	Approved by
Sr.Lab.Technican	Materials testing dapartment head (Sr.P/me)

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Project :-	**Reaserch**
Client :-	

Test Record of Bitumen Loss On Heating

Sample No	1	Sample by	Mahlet	Trade Mark /Grade	60/70
Sample Source	From Batching Plant	Proposed Use	For Quality Test	Sample Date	4/13/2023
Method Used	AASHTO - T47	Test condition	163^{0}C, 5 Hours	Test Date	4/20/2023

Frequence	Wt of container m_1 (g)	Wt of container+sample before test m_2 (g)	Wt of sample m_3(g)	Mass of container+sample after test m_4 (g)		Loss of sample(%) $L_b=(m_4-m_1)/m_3$	Average Loss (%)
1	72.6	122.4	49.8	122.27	49.67	0.26	0.26
2	75.30	125.41	50.1	125.28	49.98	0.26	

Test Record of Flash & Fire Point Bituminous materials

Method Used	AASHTO - T48			Sample Date	4/13/2023
Grade of Asphalt	60/70			Test Date	4/20/2023

1	Flash point °C	295	1	Fire Point °C	335°C	Good
2	Flash ppoint°C	295	2	Fire Point °C	345°C	
Average		295°C		Average	340°C	

Tested By	Approved by
Sr.Lab.Technican	Materials testing dapartment head (Sr.P/me)

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Project :- Reasearch

Test Record of Solubility of Bituminous Material

Sample by	Mahlet		**Grade of Sample**	60/70
Sample Source	From Batching Plant		**Sample Date**	4/13/2023
Method Used	AASHTO - T44		**Test Date**	4/20/2023

Frequency	Wt of measuring bottle+filter paper (g) m_1	Wt of conical bottle+glass bar (g) m_2	Wt of conical bottle+glass bar+Sample (g) m_3	Wt of measuring bottle+filter paper+undistolved matter (g) m_4	Wt of conical bottle+glass bar+ cohesive undissolved matter (g) m_5	Solubility of sample(%)	Average (%)
1	24.96	157.550	159.820	24.97	157.570	99.88	**99.80**
2	24.96	157.550	163.000	24.97	157.589	99.72	

Remark :

Tested By	Approved by
Sr.Lab.Technican	Materials testing dapartment head (Sr.P/me)

ELASTIC RECOVERY AS PER ASTM D 6084-06

Elastic Recovery Test of Bitumen (60/70)

Sample no	1A	1B	1C
Test Temperature ℃	25℃	25℃	25℃
pour temperature℃	135℃	135℃	135℃
Speed (cm/min)	5cm/min	5cm/min	5cm/min
Hold time (min)	60min	60min	60min
Orginal Elongation (E)	10	10	10
Elongation After (X)	8.5	8.7	8.6
% Elastic Recovery	85.0	87.0	86.0
Averege % Elastic Recovery	**86%**		
Specification	**>80%**		

APPENDIX - C Grading Result for Marshall and Supeapave mix Design

Particle Size Distribution By Sieve Analysis AASHTO T 27

Aggregate Size 20mm to 14mm

Sample Number		Trial- 1			Trial-2			
Dry sample weight (g)		**3331.0**			**3268.0**			
After wash dry sample (g)		**3330.0**			**3268.0**			
Inch	**Sieve Size(mm)**	**Mass of Retained Sample (g)**	**Cumulative Passing (g)**	**Cumulative Passing (%)**	**Mass of Retained Sample (g)**	**Cumulative Passing (g)**	**Cumulative Passing (%)**	**Average Cumulative Passing (%)**
	25	0	3331.0	100.0	0.0	3268.0	100.0	100.0
	19	0	3331.0	100.0	0.0	3268.0	100.0	100.0
	12.5	2530	801.0	24.0	2429.0	839.0	25.7	24.9
	9.5	774	27.0	0.8	817.0	22.0	0.7	0.7
	4.75	25	2.0	0.1	19.0	3.0	0.1	0.1
	2.36	1.0	1.0	0.0	2.0	1.0	0.0	0.0
	1.18	0.0	1.0	0.0	1.0	0.0	0.0	0.0
	0.6	0.0	1.0	0.0	0.0	0.0	0.0	0.0
	0.3	0.0	1.0	0.0	0.0	0.0	0.0	0.0
	0.15	0.0	1.0	0.0	0.0	0.0	0.0	0.0
	0.075	0.0	1.0	0.0	0.0	0.0	0.0	0.0
Wash lose		1.0			0.0			
Total		3331.0			3268.0			

Aggregate Size 14mm to 6mm

Sample Number		Trial- 1			Trial-2			
Dry sample weight (g)		**3824**			**3972**			
After wash dry sample (g)		**3824**			**3972**			
Sieve Size (Inch)	Sieve Size (mm)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Average Cumulative Passing (%)
	25	0.0	3824	100.0	0.0	3972.0	100.0	100.0
	19	0.0	3824	100.0	0.0	3972.0	100.0	100.0
	12.5	25.0	3799	99.3	32.0	3940.0	99.2	99.3
	9.5	859.0	2940	76.9	980.0	2960.0	74.5	75.7
	4.75	2399.0	541	14.1	2420.0	540.0	13.6	13.9
	2.36	538.0	3	0.1	537.0	3.0	0.1	0.1
	1.18	2.0	1	0.0	1.0	2.0	0.1	0.0
	0.6	1.0	0	0.0	1.0	1.0	0.0	0.0
	0.3	0.0	0	0.0	1.0	0.0	0.0	0.0
	0.15	0.0	0	0.0	0.0	0.0	0.0	0.0
	0.075	0.0	0	0.0	0.0	0.0	0.0	0.0
Wash lose		0.0			0.0			
Total		3824.0			3972.0			

Particle Size Distribution by Sieve Analysis AASHTO T 27

Aggregate Size 6mm to 3mm

Sample Number		Trial- 1			Trial-2			
Dry sample weight (gram)		**2218.0**			**2202.0**			
After wash dry sample (gram)		**2129.0**			**2116.0**			
Inch	**Sieve Size(mm)**	**Mass of Retained Sample (g)**	**Cumulative Passing (g)**	**Cumulative Passing (%)**	**Mass of Retained Sample (g)**	**Cumulative Passing (g)**	**Cumulative Passing (%)**	**Average Cumulative Passing (%)**
	25	0.0	2218.0	100.0	0.0	2202.0	100.0	100.0
	19	0.0	2218.0	100.0	0.0	2202.0	100.0	100.0
	12.5	0.0	2218.0	100.0	0.0	2202.0	100.0	100.0
	9.5	9.0	2209.0	99.6	7.0	2195.0	99.7	99.6
	4.75	305.0	1904.0	85.8	355.0	1840.0	83.6	84.7
	2.36	1516.0	388.0	17.5	1458.0	382.0	17.3	17.4
	1.18	180.0	208.0	9.4	181.0	201.0	9.1	9.3
	0.6	50.0	158.0	7.1	50.0	151.0	6.9	7.0
	0.3	34.0	124.0	5.6	34.0	117.0	5.3	5.5
	0.15	25.0	99.0	4.5	20.0	97.0	4.4	4.4
	0.075	10.0	89.0	4.0	11.0	86.0	3.9	4.0
pan		0.0			0.0			
Wash lose		89.0			86.0			
Total		2218.0			2202.0			

Aggregate Size 3mm to 0mm

Sample Number		Trial- 1			Trial-2			
Dry sample weight (gram)		**2148**			**1918**			
After wash dry sample (gram)		**1992.0**			**1812.0**			
Sieve Size (Inch)	Sieve Size (mm)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Average Cumulative Passing (%)
	25	0.0	2148	100.0	0.0	1918.0	100.0	100.0
	19	0.0	2148	100.0	0.0	1918.0	100.0	100.0
	12.5	0.0	2148	100.0	0.0	1918.0	100.0	100.0
	9.5	0.0	2148	100.0	0.0	1918.0	100.0	100.0
	4.75	17.0	2131	99.2	18.0	1900.0	99.1	99.1
	2.36	178.0	1953	90.9	156.0	1744.0	90.9	90.9
	1.18	726.0	1227	57.1	644.0	1100.0	57.4	57.2
	0.6	384.0	843	39.2	328.0	772.0	40.3	39.7
	0.3	290.0	553	25.7	273.0	499.0	26.0	25.9
	0.15	182.0	371	17.3	168.0	331.0	17.3	17.3
	0.075	215.0	156	7.3	225.0	106.0	5.5	6.4
pan		0.0			0.0			
Wash lose		156.0			106.0			
Total		2148.0			1918.0			

Particle Size Distribution By Sieve Analysis AASHTO T 27								
Hydrated Lime (Filler)								
Sample Number		Trial- 1			Trial-2			
Dry sample weight (gram)		**116.0**			**116.0**			
After wash dry sample (gram)		**17.0**			**17.0**			
Inch	Sieve Size(mm)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Average Cumulative Passing (%)
	25	0.0	116.0	100.0	0.0	116.0	100.0	100.0
	19	0.0	116.0	100.0	0.0	116.0	100.0	100.0
	12.5	0.0	116.0	100.0	0.0	116.0	100.0	100.0
	9.5	0.0	116.0	100.0	0.0	116.0	100.0	100.0
	4.75	0.0	116.0	100.0	0.0	116.0	100.0	100.0
	2.36	0.0	116.0	100.0	0.0	116.0	100.0	100.0
	1.18	0.0	116.0	100.0	0.0	116.0	100.0	100.0
	0.600	0.0	116.0	100.0	0.0	116.0	100.0	100.0
	0.300	0.0	116.0	100.0	0.0	116.0	100.0	100.0
	0.150	9.0	107.0	92.2	9.0	107.0	92.2	92.2
	0.075	8.0	99.0	85.3	8.0	99.0	85.3	85.3
pan								
Wash lose		99.0			99.0			
Total		116.0			116.0			

APPENDIX - D Gradation Criteria for 12.5 mm Nominal Maximum Size Aggregate

Sieve	Maximum, (% Pass)	Minimum, (% Pass)
25.4 mm	100	100
19.0 mm	100	100
12.5 mm	100	90
9.5 mm	90	74
4.75 mm	74	44
2.36 mm	58	28
1.18 mm	40	15
0.600 mm	29	10
0.300 mm	21	5
0.150 mm	15	4
0.075 mm	10	2
Restricted Zone		
2.36 mm	39.1	39.1
1.18 mm	25.6	31.6
0.600 mm	19.1	23.1
0.300 mm	15.5	15.5

APPENDIX - E Specific gravity of aggregate for Marshall and Superpave mix Design

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATES

TEST METHOD : AASHTO T 85-91

Aggregate Size					**Coarse Aggregate (20mm To 14mm)**							
Trial					Trial - 1		Trial - 2		3		Average	
B. Mass of SSD sample in air				g	2581.9		2546.6					
Bs. Mass of basket in water				g								
Bs+C Basket + Sample in water				g								
C.Mass of saturated sample in water				g	1610.8		1588					
A. Mass of oven dry sample in air				g	2538.5		2501					
Water Temperature												
^{o}C	18	19	20	21	22	23	24	25	26	27	28	29
k	1.0004	1.0002	1.0000	0.9998	0.9996	0.9993	**0.9991**	0.9989	0.9986	0.9983	0.998	0.9977
Bulk sp. gravity (oven dry) Sd = A*k/(B-C)					2.612		2.607				**2.609**	
Bulk sp. gravity (SSD) Ss = B*k/(B-C)					2.656		2.654				**2.655**	
Apparent specific gravity Sr = A*k/(A-C)					2.734		2.737				**2.735**	
Water absorption Aw = (B-A)*100/A					1.71		1.82				**1.77**	

Aggregate Size					**Medium Aggregate (14mm To 6mm)**							
Trial					Trial - 1		Trial - 2				Average	
B. Mass of SSD sample in air				g	1566.9		1521.7					
Bs. Mass of basket in water				g								
Bs+C Basket + Sample in water				g								
C.Mass of saturated sample in water				g	976.9		948.8					
A. Mass of oven dry sample in air				g	1538.7		1493.7					
Water Temperature												
^{o}C	18	19	20	21	22	23	24	25	26	27	28	29
k	1.0004	1.0002	1.0000	0.9998	0.9996	0.9993	0.9991	0.9989	0.9986	0.9983	0.998	0.9977
Bulk sp. gravity (oven dry) Sd = A*k/(B-C)					2.606		2.605				**2.605**	
Bulk sp. gravity (SSD) Ss = B*k/(B-C)					2.653		2.654				**2.654**	
Apparent specific gravity Sr = A*k/(A-C)					2.736		2.739				**2.738**	
Water absorption Aw = (B-A)*100/A					1.83		1.87				**1.85**	

SPECIFIC GRAVITY AND ABSORPTION OF FINE AGGREGATES

TEST METHOD : AASHTO T 84-95

Aggregate Size					Crushed Agg (3-6mm)			Crushed Agg (0-3mm)				
Pycnometer No.					1	2	Average	1	2	Average	1	2
B. Mass of Pycnometer+Water (gram)					682.5	682.5	682.5	686.4	686.4	686.4		
S. Mass of SSD sample (gram)					250.0	250.0	250.0	250.0	250.0	250.0		
C.Mass of pycnometer+water+sample (gram)					838.1	838.2	838.15	841.9	841.8	841.9		
A.Mass of oveen dry sample in air (gram)					245.6	245.7	245.65	245.5	245.6	245.6		
Water Temperature ℃												
℃	18	19	20	21	22	23	24	25	26	27	28	29
k	1.0004	1.0002	1.0000	0.9998	0.9996	0.9993	0.9991	0.9989	0.9986	0.9983	0.998	0.9977
Bulk sp. gravity (oven dry) Gsb = A*k/(B+S-C)					2.599	2.602	2.600	2.598	2.596	2.597		
Bulk sp. gravity (SSD) Gsb(ssd) = S*k/(B+S-C)					2.645	2.647	2.646	2.646	2.643	2.644		
Apparent specific gravity Gsa = A*k/(A+B-C)					2.726	2.726	2.726	2.728	2.723	2.725		
Water absorption (%) Aw = (S-A)*100/A					1.79	1.75	1.77	1.83	1.79	1.81		

SPECIFIC GRAVITY OF HYDRATED LIME FOR FILLER

TEST METHOD : AASHTO T 84-95

Material Type					**Hydrated Lime for (Filler)**							
Pycnometer No.					Trial -1		Trial - 2				Average	
B. Mass of Pycnometer+Water gram					76.0		76.0					
C.Mass of pycnometer+water+sample gram					82.35		82.36					
A.Mass of oveen dry sample in air gram					10.0		10.0					
Water Temperature												
°C	18	19	20	21	22	23	24	25	26	27	28	29
k	1.0004	1.0002	1.0000	0.9998	0.9996	0.9993	0.9991	0.9989	0.9986	0.9983	0.998	0.9977
Bulk sp. gravity (oven dry) Sd = A*k/(B+S-C)												
Bulk sp. gravity (SSD) Ss = S*k/(B+S-C)												
Apparent specific gravity Sr = A*k/(A+B-C)					2.737		2.744				2.740	
Water absorption (%) Aw = (S-A)*100/A												

$$Gsb = \frac{P1+P2+P3+P4+P5---+Pn}{\frac{P1}{G1}+\frac{P1}{G1}+\frac{P1}{G1}+\frac{P1}{G1}+\frac{P1}{G1}+---+\frac{P1}{G1}}$$

$$= \frac{11\%+42\%+15\%+30\%}{\frac{11\%}{2.609\%}+\frac{42\%}{2.605\%}+\frac{15\%}{2.600\%}+\frac{30\%}{2.597\%}+\frac{2\%}{2.740\%}}$$

$$= 2.602$$

APPENDIX - F Marshall volumetric properties

Marshall Compaction:	2*75 Blows	Bulk Specific Gravity of Aggregate (Gsb).	2.602	Sampled Date:	4/13/2023
Grade of Asphalt	60/70	Specific Gravity of Asphalt (Pb)	1.023	Tested Date:	4/28/2023
Absorbation of Asphalt (pba) (%)	0.18	Effective Specific Gravity of Aggregate (Gse).	2.614	Description:	wearing Course

Asphalt content, %	Specimen Hight , [mm]	Effective Bitumen Content of Mix, %	Max SG of the mix [G_{mm}]	Mass Spacimen [g] in			Volume of specimen [cc]	Bulk S.G of compacted mix	Air voids %	VMA %	VFA %	Stability		Flow in (mm)	Filler/ Bitumen ratio
				Air dry	in Water	Air SSD						Load [KN]	Adjusted Load [KN]		
		C					H	J	K	L	M				
A	B	$A - P_{ba} * P_s/100$	D	E	F	G	G - F	E / H	(D-J)*100/ D	$100-[(100-A)*J/G_{sb}]$	(L-K)*100 / L				
4.0	66.9			1232.0	701.0	1239.0	538.0	2.290	7.0	15.5	55.1	10.67	10.2	2.49	
	65.5			1228.5	694.5	1234.0	539.5	2.277	7.5	16.0	53.2	9.86	9.5	2.38	
	66.8			1229.0	694.4	1238.0	543.6	2.261	8.1	16.6	50.9	10.93	10.5	2.54	
Average	**66.4**	**3.8**	**2.461**	**1229.8**	**696.6**	**1237.0**	**540.4**	**2.276**	**7.53**	**16.0**	**53.1**	**10.49**	**10.07**	**2.47**	**1.36**
4.5	65.8			1238.5	705.7	1242.0	536.3	2.309	5.3	15.2	65.1	11.68	11.2	2.72	
	65.9			1239.0	707.3	1243.5	536.2	2.311	5.3	15.2	65.4	10.53	10.1	2.65	
	65.9			1237.0	705.0	1241.0	536.0	2.308	5.4	15.3	64.9	11.80	11.3	2.79	
Average	**65.9**	**4.3**	**2.439**	**1238.2**	**706.0**	**1242.2**	**536.2**	**2.309**	**5.31**	**15.2**	**65.1**	**11.34**	**10.88**	**2.72**	**1.20**
5.0	64.7			1249.0	714.5	1252.5	538.0	2.322	4.5	15.2	70.7	11.97	12.0	2.93	
	64.8			1247.5	713.6	1250.5	536.9	2.324	4.4	15.2	71.1	11.81	11.8	2.82	
	65.2			1254.0	715.9	1256.0	540.1	2.322	4.5	15.2	70.7	11.86	11.9	2.99	
Average	**64.9**	**4.8**	**2.430**	**1250.2**	**714.7**	**1253.0**	**538.3**	**2.322**	**4.44**	**15.2**	**70.8**	**11.88**	**11.88**	**2.91**	**1.07**
5.5	64.2			1247.0	713.0	1249.0	536.0	2.326	3.4	15.5	78.1	11.60	11.6	3.31	
	64.1			1248.5	713.9	1249.9	536.0	2.329	3.3	15.4	78.7	11.76	11.8	3.23	
	64.6			1245.0	710.3	1246.6	536.3	2.321	3.6	15.7	77.0	10.43	10.4	3.08	
Average	**64.3**	**5.3**	**2.408**	**1246.8**	**712.4**	**1248.5**	**536.1**	**2.326**	**3.43**	**15.5**	**77.9**	**11.26**	**11.26**	**3.21**	**0.97**
6.0	62.0			1256.5	716.0	1257.0	541.0	2.323	2.5	16.1	84.2	10.62	10.6	3.66	
	63.7			1244.5	708.0	1245.0	537.0	2.318	2.8	16.3	83.1	11.46	11.5	3.92	
	64.0			1253.5	714.0	1254.5	540.5	2.319	2.7	16.2	83.4	9.35	9.4	3.81	
Average	**63.2**	**5.8**	**2.383**	**1251.5**	**712.7**	**1252.2**	**539.5**	**2.320**	**2.66**	**16.2**	**83.6**	**10.48**	**10.48**	**3.80**	**0.89**

APPENDIX - G Theoretical maximum specific gravity of marshall mix-AASHTO T 209

Sample Date:	4/14/2023	**Tested by:**	Mahlet
Tested Date:	4/29/2023	**Method**	Marshall Mix Design
Description:	Wearing Course	**Purpose:**	For Reaserch

Temperature-Density Correction Factors (°C)

°C	22.0	22.5	23.0	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5
k	1.0007	1.0006	1.0005	1.0004	1.0003	1.0001	1.0000	0.9999	0.9997	0.9996	0.9995	0.9993	0.9992	0.9990

Bitumen Content	**4.0**		**4.5**		**5.0**		**5.5**		**6.0**			
Test No	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2		
Temp. of test water, °C	22.0	22.0	24.0	25.0	22.5	22.5	23.0	23.5	25.0	25.0		
A. Weight of sample, g	2451	2478	2492	2474	2501	2502	2500	2500	2500	2500		
B. Wt. of Pycnometer filled with water, g	6018	5995	6018	5995	6018	5995	6018	5995	6018	5995		
C. Wt. of Pycnometer filled w/ sample + water, g	7473	7465	7488.5	7454	7490	7466	7480	7456	7470	7445		
D. Theo. Max. Specific Gravity, G_{mm}=A/(A+B-C)	2.461	2.458	2.440	2.437	2.431	2.427	2.408	2.406	2.385	2.381		
Correction Factor, k	1.0007	1.0007	0.9997	1.0006	1.0006	1.0006	1.0005	1.0004	1.0000	1.0000		
E. Corrected Theo. Max. Spe. Gravity, G_{mm} = D*k	2.463	2.460	2.439	2.439	2.432	2.428	2.410	2.407	2.385	2.381		
F. Avg.Theo.Max. Spe.Gravity, G_{mm}=(Test1+Test2)/2	**2.461**		**2.439**		**2.430**		**2.408**		**2.383**			
G. Effective Specific Gravity of Aggregate , G_{se}							2.614		2.604			
H. Avg. Effective Specific Gravity of Aggregate, G_{se}	2.609											

APPENDIX - H Theoretical maximum specific gravity of superpave mix-AASHTO T 209

THEORETICAL MAXIMUM SPECIFIC GRAVITY OF SUPERPAVE MiX AS PER - AASHTO T 209

Sample Date:	4/14/2023	**Tested by:**	Mahlet
Tested Date:	4/29/2023	**Method**	Superpave Mix Design
Description:	Wearing Course Superpave mix	**Purpose:**	For Reaserch

Temperature-Density Correction Factors (°C)

°C	22.0	22.5	23.0	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5
k	1.0007	1.0006	1.0005	1.0004	1.0003	1.0001	1.0000	0.9999	0.9997	0.9996	0.9995	0.9993	0.9992	0.9990

Bitumen Content %	**3.5**		**4.0**		**4.5**		**5.0**		**5.5**		**6.0**	
Test No	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Temp. of test water, °C	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
A. Weight of sample, g	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
B. Wt. of Pycnometer filled with water, g	6333	6330	6333	6330	6333	6330	6333	6330	6333	6330	6333	6330
C. Wt. of Pycnometer filled w/ sample + water, g	7519	7518	7512	7507	7507	7502	7499	7496	7489	7485	7476	7474
D. Theo. Max. Specific Gravity, G_{mm}=A/(A+B-C)	2.457	2.463	2.436	2.430	2.421	2.415	2.398	2.398	2.370	2.367	2.334	2.336
Correction Factor, k	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
E. Corrected Theo. Max. Spe. Gravity, G_{mm} = D*k	2.457	2.463	2.436	2.430	2.421	2.415	2.398	2.398	2.370	2.367	2.334	2.336
F. Avg.Theo.Max. Spe.Gravity, G_{mm}=(Test1+Test2)/2	**2.460**		**2.433**		**2.418**		**2.398**		**2.368**		**2.335**	

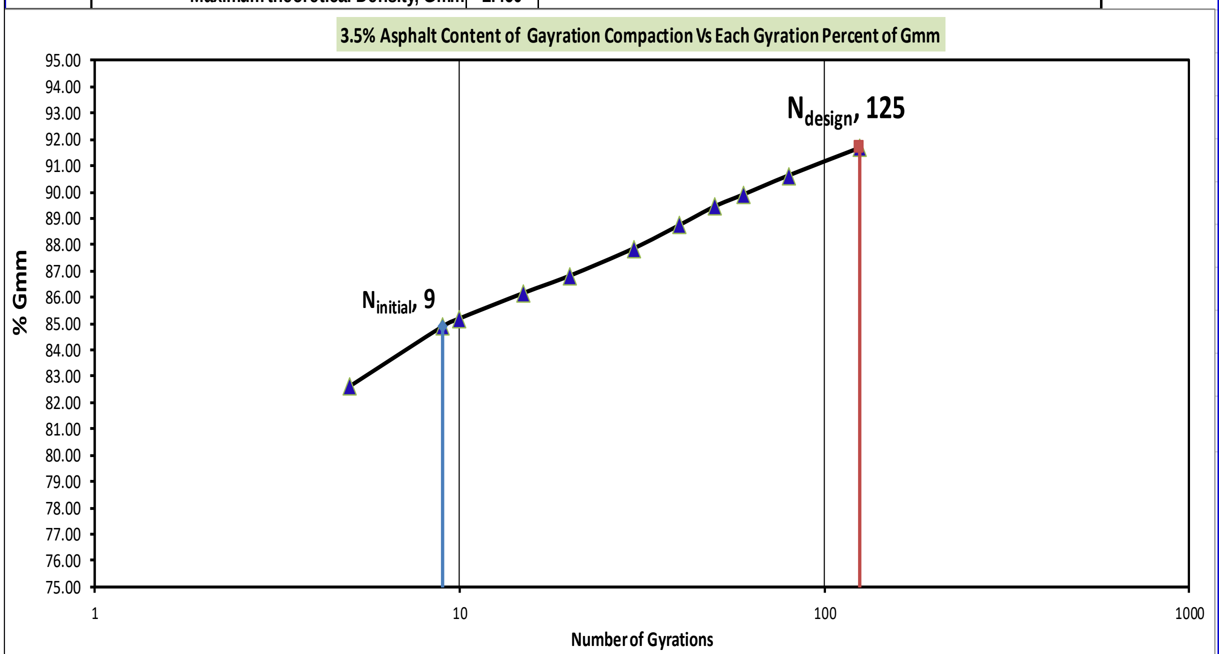
APPENDIX - I Superpave volumetric property

Superpave Mix Design Volumetric property, AASHTO R-35, 3.5% of Asphalt Content

Project:-	For Research	Lab. Reference No.:-	
Sampled By:-	Mahlet	Date of Sampling:-	5/26/2023
Type of Mix:-	Wearing Course	Date of Report:-	5/28/2023
Types of Method:-	Super pave Mix Design	Types of works:-	Gyration Compaction @ N_{des}

Asphalt Content (%)	Design ESALs (Million)	Gyratory Compaction		Trial - 1 Ht, mm	Trial - 2 Ht, mm	Trial - 3 Ht, mm	Trial Avarage Avarage of Ht, mm	Avarage, % of Gmm at any number of gyration, (Nx)	%Gmm	Each Gyration % of Gmm
3.50	≥ 30		5	128.3	128.6	128.5	**128.5**	0.90	91.7	82.62
		$N_{Initial}$	**9**	124.9	125.3	124.8	**125.0**	0.93		84.90
			10	124.6	124.9	124.2	**124.6**	0.93		85.19
			15	123.2	122.8	123.5	**123.2**	0.94		86.16
			20	121.1	123.4	122.3	**122.3**	0.95		86.81
			30	120.1	121.5	120.8	**120.8**	0.96		87.85
			40	119.0	120.2	119.6	**119.6**	0.97		88.73
			50	118.0	119.3	118.7	**118.7**	0.98		89.44
			60	117.6	118.5	118.1	**118.1**	0.98		89.90
			80	116.0	117.8	117.5	**117.1**	0.99		90.62
		N_{design}	**125**	116.1	116.1	115.1	**115.8**	1.00		91.67

Bulk Specific Gravity of the mix, Gmb	2.255
Maximum theoretical Density, Gmm	2.460

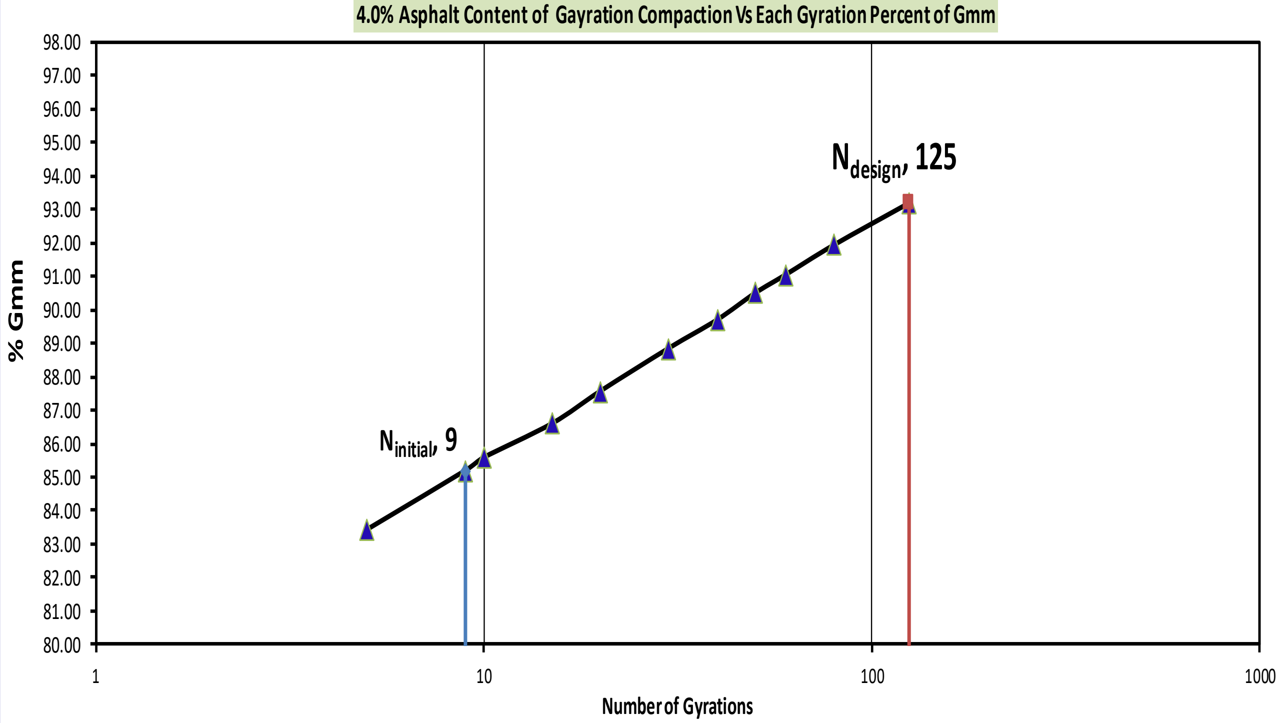


Superpave Mix Design Volumetric property, AASHTO R-35, 4.0% of Asphalt Content

Project:-	For Research	**Lab. Reference No.:-**	
Sampled By:-	Mahlet	**Date of Sampling:-**	5/26/2023
Type of Mix:-	Wearing Course	**Date of Report:-**	5/28/2023
Types of Method:-	Super pave Mix Design	**Types of works:-**	Gyration Compaction @ N_{des}

Asphalt Content (%)	Design ESALs (Million)	Gyratory Compaction		Trial - 1 Ht, mm	Trial - 2 Ht, mm	Trial - 3 Ht, mm	Trial Avarage Avarage of Ht, mm	Avarage, % of Gmm at any number of gyration, (Nx)	%Gmm	Each Gyration % of Gmm
4.00	≥ 30		5	132.1	131.2	129.2	**130.8**	0.90	93.2	83.42
		$N_{Initial}$	**9**	129.3	128.8	126.2	**128.1**	0.91		85.20
			10	128.1	128.4	126.1	**127.5**	0.92		85.57
			15	127.1	126.6	124.4	**126.0**	0.93		86.59
			20	125.2	125.4	123.3	**124.6**	0.94		87.57
			30	123.5	123.6	121.4	**122.8**	0.95		88.85
			40	122.2	122.4	120.4	**121.7**	0.96		89.70
			50	121.2	121.4	119.2	**120.6**	0.97		90.49
			60	120.4	120.7	118.5	**119.9**	0.98		91.05
			80	119.2	119.5	117.4	**118.7**	0.99		91.94
		N_{design}	**125**	117.5	117.9	115.9	**117.1**	1.00		93.20
	Bulk Specific Gravity of the mix, Gmb			**2.268**						
	Maximum theoretical Density, Gmm			**2.433**						

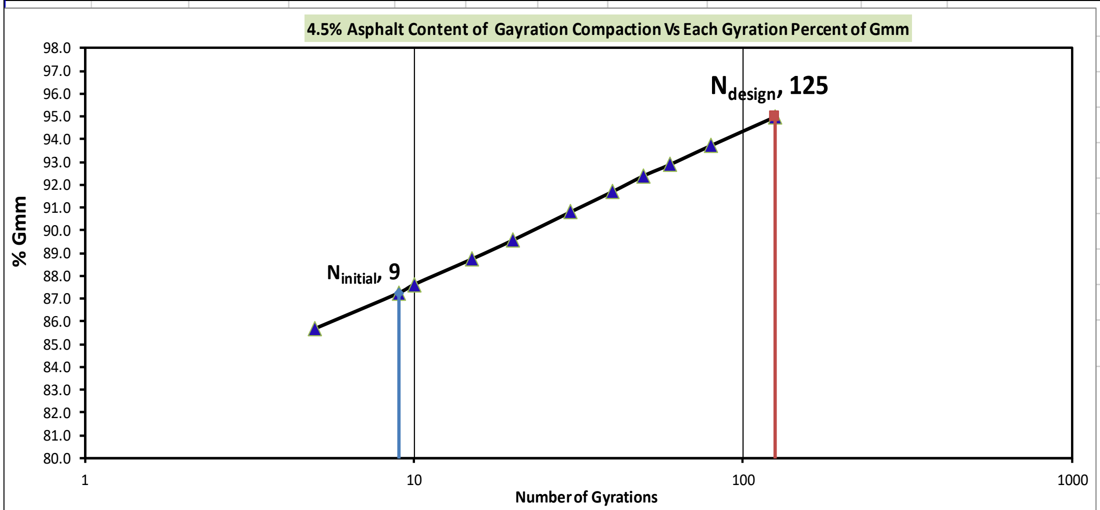
4.0% Asphalt Content of Gayration Compaction Vs Each Gyration Percent of Gmm



Superpave Mix Design Volumetric property, AASHTO R-35, 4.5% of Asphalt Content

Project:-	For Research	**Lab. Reference No.:-**	
Sampled By:-	Mahlet	**Date of Sampling:-**	5/26/2023
Type of Mix:-	Wearing Course	**Date of Report:-**	5/28/2023
Types of Method:-	Super pave Mix Design	**Types of works:-**	Gyration Compaction @ N_{des}

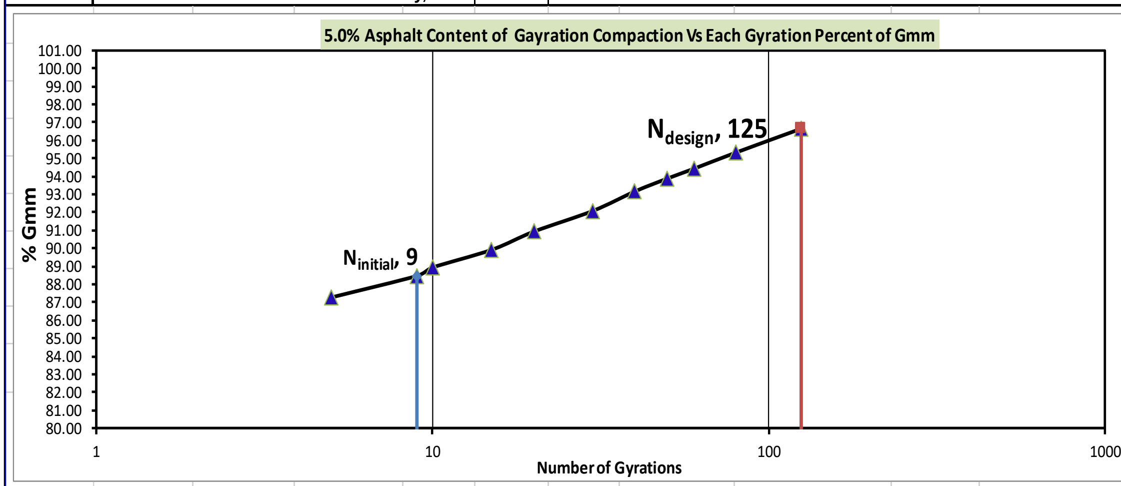
Asphalt Content (%)	Design ESALs (Million)	Gyratory Compaction		Trial - 1 Ht, mm	Trial - 2 Ht, mm	Trial - 3 Ht, mm	Trial Avarage Avarage of Ht, mm	Avarage, % of Gmm at any number of gyration, (Nx)	%Gmm	Each Gyration % of Gmm
4.50	≥ 30		5	129.5	131.5	127.8	**129.6**	0.90	95.0	85.7
		$N_{Initial}$	**9**	127.1	129.1	125.6	**127.3**	0.92		87.2
			10	126.2	128.8	125.2	**126.7**	0.92		87.6
			15	124.9	127.0	123.5	**125.1**	0.93		88.7
			20	123.7	125.8	122.4	**124.0**	0.94		89.6
			30	121.9	124.1	120.8	**122.3**	0.96		90.8
			40	120.8	122.9	119.6	**121.1**	0.97		91.7
			50	119.8	122.1	118.6	**120.2**	0.97		92.4
			60	119.1	121.4	118.1	**119.5**	0.98		92.9
			80	118.1	120.3	117.0	**118.5**	0.99		93.7
		N_{design}	**125**	116.5	118.7	115.5	**116.9**	1.00		95.0
Bulk Specific Gravity of the mix, Gmb				**2.297**						
Maximum theoretical Density, Gmm				**2.418**						



Superpave Mix Design Volumetric property, AASHTO R-35, 5.0% of Asphalt Content

Project:-	For Research	**Lab. Reference No.:-**	
Sampled By:-	Mahlet	**Date of Sampling:-**	5/26/2023
Type of Mix:-	Wearing Course	**Date of Report:-**	5/28/2023
Types of Method:-	Super pave Mix Design	**Types of works:-**	Gyration Compaction @ N_{des}

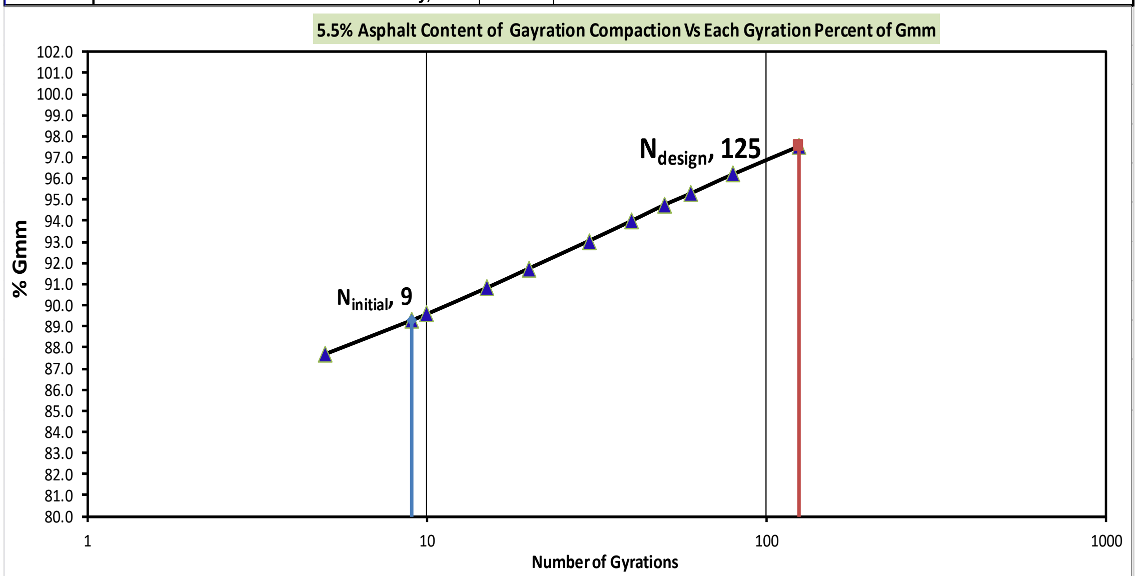
Asphalt Content (%)	Design ESALs (Million)	Gyratory Compaction		Trial - 1 Ht, mm	Trial - 2 Ht, mm	Trial - 3 Ht, mm	Trial Avarage: Avarage of Ht, mm	Avarage, % of Gmm at any number of gyration, (Nx)	%Gmm	Each Gyration % of Gmm
5.00	≥ 30		5	131.1	130.6	127.9	**129.9**	0.90	96.7	87.26
		$N_{Initial}$	**9**	128.6	128.3	127.4	**128.1**	0.92		88.46
			10	127.7	127.8	126.8	**127.4**	0.92		88.92
			15	126.3	126.1	125.7	**126.0**	0.93		89.91
			20	125.0	124.9	124.0	**124.6**	0.94		90.92
			30	123.7	123.2	122.3	**123.1**	0.95		92.08
			40	121.9	121.9	121.1	**121.6**	0.96		93.16
			50	120.9	121.0	120.2	**120.7**	0.97		93.88
			60	120.2	120.3	119.5	**120.0**	0.98		94.43
			80	119.0	119.2	118.4	**118.9**	0.99		95.33
		N_{design}	**125**	117.4	117.5	116.8	117.2	1.00		96.66
	Bulk Specific Gravity of the mix, Gmb			**2.318**						
	Maximum theoretical Density, Gmm			**2.398**						



Superpave Mix Design Volumetric property, AASHTO R-35, 5.5% of Asphalt Content

Project:-	For Research	Lab. Reference No.:-	
Sampled By:-	Mahlet	Date of Sampling:-	5/26/2023
Type of Mix:-	Wearing Course	Date of Report:-	5/28/2023
Types of Method:-	Super pave Mix Design	Types of works:-	Gyration Compaction @ N_{des}

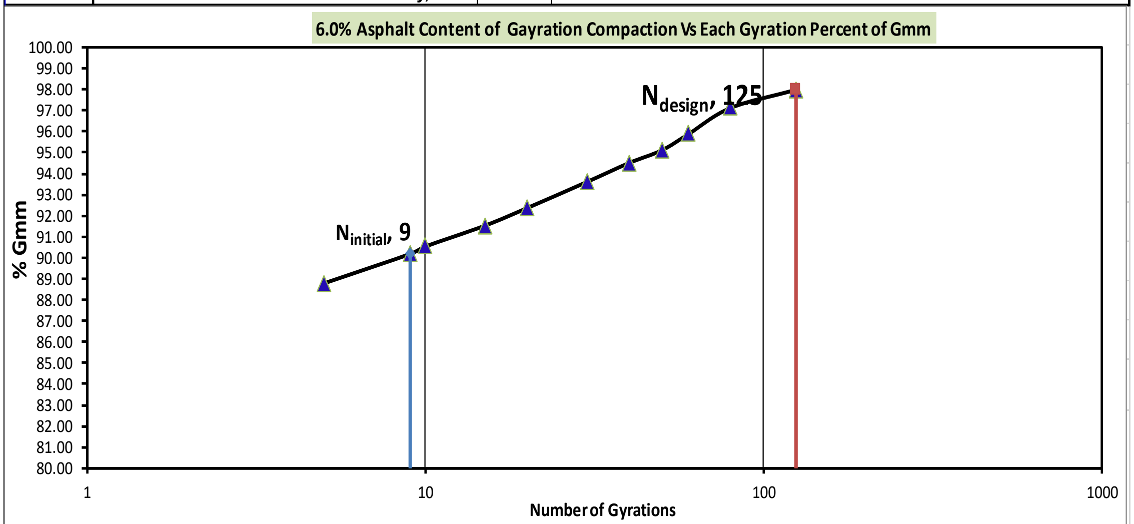
Asphalt Content (%)	Design ESALs (Million)	Gyratory Compaction		Trial - 1 Ht, mm	Trial - 2 Ht, mm	Trial - 3 Ht, mm	Trial Avarage Avarage of Ht, mm	Avarage, % of Gmm at any number of gyration, (Nx)	%Gmm	Each Gyration % of Gmm
5.50	≥ 30		5	131.4	129.7	129.3	**130.1**	0.90	97.5	87.7
		$N_{Initial}$	9	128.9	127.4	127.1	**127.8**	0.92		89.3
			10	128.4	127.0	126.7	**127.4**	0.92		89.6
			15	126.6	125.3	125.0	**125.6**	0.93		90.8
			20	125.2	124.0	123.9	**124.4**	0.94		91.7
			30	123.4	122.3	122.2	**122.6**	0.95		93.0
			40	122.1	121.1	121.0	**121.4**	0.96		94.0
			50	121.1	120.2	120.0	**120.4**	0.97		94.7
			60	120.4	119.5	119.3	**119.7**	0.98		95.3
			80	119.2	118.4	118.2	**118.6**	0.99		96.2
		N_{design}	125	117.5	116.8	116.7	**117.0**	1.00		97.5
	Bulk Specific Gravity of the mix, Gmb			2.309						
	Maximum theoretical Density, Gmm			2.368						



Superpave Mix Design Volumetric property, AASHTO R-35, 6.0% of Asphalt Content

Project:-	For Research	Lab. Reference No.:-	
Sampled By:-	Mahlet	Date of Sampling:-	5/26/2023
Type of Mix:-	Wearing Course	Date of Report:-	5/28/2023
Types of Method:-	Super pave Mix Design	Types of works:-	Gyration Compaction @ N_{des}

Asphalt Content (%)	Design ESALs (Million)	Gyratory Compaction		Trial - 1 Ht, mm	Trial - 2 Ht, mm	Trial - 3 Ht, mm	Trial Avarage Avarage of Ht, mm	Avarage, % of Gmm at any number of gyration, (Nx)	%Gmm	Each Gyration % of Gmm
6.00	≥ 30		5	128.7	128.9	128.5	128.7	0.91	98.0	88.79
		$N_{Initial}$	9	126.5	126.7	126.9	126.7	0.92		90.20
			10	126.1	125.9	126.6	126.2	0.92		90.55
			15	124.5	124.5	125.5	124.8	0.93		91.54
			20	123.3	123.5	124.3	123.7	0.94		92.38
			30	121.7	121.9	122.6	122.1	0.96		93.62
			40	120.5	120.8	121.4	120.9	0.96		94.52
			50	119.6	120.3	120.5	120.1	0.97		95.13
			60	118.9	119.9	118.7	119.2	0.98		95.90
			80	117.9	118.2	116.8	117.6	0.99		97.15
		N_{design}	125	116.3	116.7	116.8	116.6	1.00		98.01
	Bulk Specific Gravity of the mix, Gmb			2.289						
	Maximum theoretical Density, Gmm			2.335						



Superpave Mix Design Volumetric property, Test method AASHTO: M 323-07, R 35-09

Project:-	For Research	**Lab. Reference No.:-**	
Sampled By:-	Mahlet	**Date of Sampling:-**	5/26/2023
Type of Mix:-	Wearing Course	**Date of Report:-**	5/28/2023
Types of Method:-	Super pave Mix Design	**Types of works:-**	Gyration Compaction @ N_{des}

Material Name	14 - 26mm	6 - 14mm	3 - 6mm	0 - 3mm	Filler	Bitumen Denity (g/cm^3), P	1.023
Material Proportion (%)	11%	42%	15%	30%	2%	Avg. Bulk Sp. Gr. Total Agg. (Gsb)	2.602
Specific gravity, Gsb	2.609	2.605	2.600	2.597	2.740		

Specimen	Asphalt Content	Wt. Of Specimen in air "B" (gm)	Wt. Of Specimen in Water "C" (gm)	SSD Wt. Of Specimen in air "D" (gm)	Vol. Of Specimen E = (D-C) (g/cc)	Bulk Density (Gmb) F = (B/E) (g/cc)	Theory Density Gmm (g/cm3)	Air Void, (%) (G-F)/G x100	VMA, (%) (100-100F*1-A)/Gsb)	VFA, (%) (J-H)/J*100*100
	A	B	C	D	E	F	G	H	J	K
1	3.5%	4564.70	2580.20	4599.9	2019.70	2.260	2.460	8.13	16.18	49.78
2		4559.10	2590.20	4602.5	2012.30	2.266		7.90	15.98	50.54
3		4560.80	2565.60	4602.2	2036.60	2.239		8.97	16.95	47.09
AVG	**3.5%**	**4561.5**	**2578.7**	**4601.5**	**2022.9**	**2.255**	**2.460**	**8.33**	**16.4**	**49.1**

Specimen	Asphalt Content	Wt. Of Specimen in air "B" (gm)	Wt. Of Specimen in Water "C" (gm)	SSD Wt. Of Specimen in air "D" (gm)	Vol. Of Specimen E = (D-C) (g/cc)	Bulk Density (Gmb) F = (B/E) (g/cc)	Theory Density Gmm (g/cm3)	Air Void, (%) (G-F)/G x100	VMA, (%) (100-100F*1-A)/Gsb)	VFA, (%) (J-H)/J*100*100
	A	B	C	D	E	F	G	H	J	K
1	4.0%	4629.2	2612.4	4652.0	2039.6	2.270	2.433	6.71	16.26	58.72
2		4692.4	2646.6	4715.5	2068.9	2.268		6.78	16.32	58.46
3		4507.5	2542.5	4532.7	1990.2	2.265		6.91	16.44	57.96
AVG	**4.0%**	**4609.7**	**2600.5**	**4633.4**	**2032.9**	**2.268**	**2.433**	**6.80**	**16.3**	**58.4**

Superpave Mix Design Volumetric property, Test method AASHTO: M 323-07, R 35-09

Project:-	For Research	**Lab. Reference No.:-**	
Sampled By:-	Mahlet	**Date of Sampling:-**	5/26/2023
Type of Mix:-	Wearing Course	**Date of Report:-**	5/28/2023
Types of Method:-	Super pave Mix Design	**Types of works:-**	Gyration Compaction @ N_{des}

Material Name	**14 - 26mm**	**6 - 14mm**	**3 - 6mm**	**0 - 3mm**	**Filler**	Bitumen Denity（g/cm^3）, P	1.023
Material Proportion (%)	11%	42%	15%	30%	2%	Avg. Bulk Sp. Gr. Total Agg. (Gsb)	2.602
Specific gravity, Gsb	2.609	2.605	2.600	2.597	2.740		

Specimen	**Asphalt Content**	**Wt. Of Specimen in air "B" (gm)**	**Wt. Of Specimen in Water "C" (gm)**	**SSD Wt. Of Specimen in air "D" (gm)**	**Vol. Of Specimen E = (D-C) (g/cc)**	**Bulk Density (Gmb) F = (B/E) (g/cc)**	**Theory Density Gmm（g/cm3）**	**Air Void, (%)** (G–F)/G x100	**VMA, (%)** (100-100F*1-A)/Gsb)	**VFA, (%)** (J-H)/J*100*100
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**J**	**K**
1	4.5%	4532.50	2582.40	4553.5	1971.10	2.299	**2.418**	4.90	15.60	68.59
2		4641.80	2624.40	4648.0	2023.60	2.294		5.14	15.81	67.52
3		4605.33	2620.33	4625.3	2004.97	2.297		5.01	15.70	68.11
AVG	**4.5%**	**4593.2**	**2609.0**	**4608.9**	**1999.9**	**2.297**	**2.418**	**5.0**	**15.7**	**68.1**

Specimen	**Asphalt Content**	**Wt. Of Specimen in air "B" (gm)**	**Wt. Of Specimen in Water "C" (gm)**	**SSD Wt. Of Specimen in air "D" (gm)**	**Vol. Of Specimen E = (D-C) (g/cc)**	**Bulk Density (Gmb) F = (B/E) (g/cc)**	**Theory Density Gmm（g/cm3）**	**Air Void, (%)** (G–F)/G x100	**VMA, (%)** (100-100F*1-A)/Gsb)	**VFA, (%)** (J-H)/J*100*100
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**J**	**K**
1	5.0%	4636.60	2647.40	4653.0	2005.60	2.312	**2.398**	3.59	15.59	76.96
2		4638.40	2654.00	4653.6	1999.60	2.320		3.27	15.31	78.66
3		4636.20	2665.00	4661.5	1996.50	2.322		3.16	15.22	79.22
AVG	**5.0%**	**4637.1**	**2655.5**	**4656.0**	**2000.6**	**2.318**	**2.398**	**3.34**	**15.4**	**78.3**

Superpave Mix Design Volumetric property , Test method AASHTO: M 323-07, R 35-09

Project:-	For Research	Lab. Reference No.:-	
Sampled By:-	Mahlet	Date of Sampling:-	5/26/2023
Type of Mix:-	Wearing Course	Date of Report:-	5/28/2023
Types of Method:-	Super pave Mix Design	Types of works:-	Gyration Compaction @ N_{des}

Material Name	14 - 26mm	6 - 14mm	3 - 6mm	0 - 3mm	Filler	Bitumen Denity（g/cm^3）, P	1.023
Material Proportion (%)	11%	42%	15%	30%	2%	Avg. Bulk Sp. Gr. Total Agg. (Gsb)	2.602
Specific gravity, Gsb	2.609	2.605	2.600	2.597	2.740		

Specimen	Asphalt Content	Wt. Of Specimen in air "B" (gm)	Wt. Of Specimen in Water "C" (gm)	SSD Wt. Of Specimen in air "D" (gm)	Vol. Of Specimen E = (D-C) (g/cc)	Bulk Density (Gmb) F = (B/E) (g/cc)	Theory Density Gmm（g/cm3）	Air Void, (%) (G-F)/G x100	VMA, (%) (100-100F*1-A)/Gsb)	VFA, (%) (J-H)/J*100*100
	A	B	C	D	E	F	G	H	J	K
1	5.5%	4635.00	2632.30	4642.0	2009.70	2.306	2.368	2.60	16.24	83.96
2		4654.30	2648.80	4664.8	2016.00	2.309		2.51	16.15	84.49
3		4589.00	2610.70	4595.4	1984.70	2.312		2.36	16.03	85.29
AVG	**5.5%**	**4626.1**	**2630.6**	**4634.1**	**2003.5**	**2.309**	**2.368**	**2.49**	**16.1**	**84.6**

Specimen	Asphalt Content	Wt. Of Specimen in air "B" (gm)	Wt. Of Specimen in Water "C" (gm)	SSD Wt. Of Specimen in air "D" (gm)	Vol. Of Specimen E = (D-C) (g/cc)	Bulk Density (Gmb) F = (B/E) (g/cc)	Theory Density Gmm（g/cm3）	Air Void, (%) (G-F)/G x100	VMA, (%) (100-100F*1-A)/Gsb)	VFA, (%) (J-H)/J*100*100
	A	B	C	D	E	F	G	H	J	K
1	6.0%	4631.50	2615.00	4640.1	2025.10	2.287	2.335	2.05	17.38	88.18
2		4698.40	2660.50	4716.1	2055.60	2.286		2.11	17.43	87.88
3		4655.80	2631.50	4662.1	2030.60	2.293		1.81	17.17	89.48
AVG	**6.0%**	**4661.9**	**2635.7**	**4672.8**	**2037.1**	**2.289**	**2.335**	**1.99**	**17.3**	**88.5**

Stability & Flow test For Superpave mix Design - AASHTO T 245		
Trials	**Stability (Kn)**	**Flow (mm)**
1	11.43	2.58
2	12.16	2.65
3	12.46	2.51
Average	**12.02**	**2.58**

APPENDIX – J Retained stability of Marshall and Superpave mix design

Retained Stability As per AASHTO T 283			
Retained Stability % For Marshall Mix Design			
Test Condition		Wet Condition, KN	Dry, Condition KN
No-	1	12.38	14.24
	2	12.81	15.45
	3	11.98	15.73
Average, KN		12.39	15.14
Retained Stability %		**81.8**	

Retained Stability %, For Superpave Mix Design			
Test Condition		Wet Condition, KN	Dry Condition, KN
No-	1	13.13	14.99
	2	13.61	15.45
	3	12.78	15.79
Average, KN		13.17	15.41
Retained Stability %		**85.4**	

APPENDIX – K Indirect tensile strength ratio for Marshall

Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage

Test Method : AASHTO T-283

Source of aggregate	Akkaki-08 Quarry	Date of Sampling	5/29/2023
Bitumen From.	Grade 60/70	Date tested	5/30/2023
Material Description.	Hot Mix Asphalt	Purpose	For Research
Compaction Method	Marshall Mix Design	Nominal max. size	12.5mm
Bitumen Content	5.12%		

at OBC 5.12%

Sample condition			Partial Saturation & Moisture conditioned			Dry condition		
	Test No		5	6	7	1	2	3
D	Diameter	**mm**	150	150	150	150	150	150
t	Thickness	**mm**	95.3	94.9	95.8	95.2	95.1	95.4
A	Dry mass	**gm**	3817	3803.8	3802.7	3837.2	3836.9	3797.4
B	SSD mass	**gm**	3899	3888.9	3886.8	3880.5	3893.1	3857
C	Mass in water	**gm**	2204.5	2198.8	2197.2	2179.9	2188.6	2168.5
E	Volume (B-C) cm3	**cm^3**	1694.5	1690.1	1689.6	1700.6	1704.5	1688.5
G_{mb}	Bulck specific gravity (A/E)	**gm/cm^3**	2.253	2.251	2.251	2.256	2.251	2.249
G_{mm}	Maximum specific Gravity	**gm/cm^3**			2.423			
P_a	% air voids [100(G_{mm}-G_{mb})/G_{mm}]	**%**	**7.0**	**7.1**	**7.1**	**6.9**	**7.1**	**7.2**
V_a	Volume of air voids (P_a*E/100)	**cm^3**	119.2	120.2	120.2	116.9	121.0	121.3
P	Load	**KN**	12.90	12.87	13.29	15.90	15.60	15.71
	For conditioned Sample - Saturated @ 10 min. with 40 kpa							
t'	Thickness	**mm**	95.3	95.1	95.6			
B'	SSD mass	**gm**	3899	3888.9	3886.8			
J'	Volume of Absorbed water(B'-A)	**cm^3**	82.0	85.1	84.1			
S'	% saturation (100J'/Va)	**%**	69	71	70			
Tensile Strength (2000*P/∏tD)		Kpa	574.8	574.7	590.3	709.2	696.6	699.3
Average Tensile Strength		**kpa**	**579.9**			**701.7**		
Retained Tensile strength ratio(conditioned/Dry)		**%**	**82.6**					
Specification								**≥ 80 %**

APPENDIX – L Wheel Tracking rate depth for Marshall

WHEEL TRACKING RATE AND DEPTH

TEST METHOD: BRITISH STANDARD : BS 598-110

Sample for research	Laboratory Marshall Mix	Date of Sampling	20/05/2023
TYPE OF MIX	Wearing Coarse	Date of Testing	22/05/2023
Temperature	60^{o} C	Load (L)	700N
Wheel width(w)	50mm	Testing Time (min)	45
Bitumen Content ,%	5.12%	Material Description	HMA

at OBC 5.12%

T-1		T-2		T-3	
TIME @ (min)	DEFORMATION (mm/hr.)	TIME (min)	DEFORMATION (mm/hr.)	TIME (min)	DEFORMATION (mm/hr.)
0	**0.00**	0	**0.00**	0	**0.00**
5	**0.60**	5	**0.71**	5	**0.83**
10	**0.81**	10	**0.97**	10	**0.98**
15	**0.93**	15	**1.03**	15	**1.17**
20	**1.34**	20	**1.42**	20	**1.48**
25	**1.86**	25	**1.89**	25	**1.92**
30	**2.55**	30	**2.09**	30	**2.42**
35	**3.13**	35	**2.85**	35	**2.98**
40	**3.81**	40	**3.75**	40	**3.79**
45	**4.69**	45	**4.34**	45	**4.59**
Tracking Rate For Each Trial(mm/hr.)					
$T_R=3.6[r_n-r_{(n-3)}] + 1.2[r(_{n-1})-(r_{n-2})]$					
8.52		**9.18**		**8.78**	
Average Tracking Rate (mm/hr)					
8.83					
Wheel Tracking Rate (mm/hr)					
$W_{TR}= 10.4 \times T_R \times w/L$					
6.56					

	Wheel Tracking Rate(mm/hr) @ 60^{o}C	Wheel tracking depth(mm)
	6.56	4.54
Specification →	< 5mm/hr	< 7mm

APPENDIX – M Indirect tensile strength ratio for superpve

Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage

Test Method : AASHTO T-283

Source of aggregate	Akkaki-08 Quarry	Date of Sampling	5/29/2023
Bitumen From.	Grade 60/70	Date tested	5/30/2023
Material Description.	Hot Mix Asphalt	Purpose	For Research
Compaction Method	Superpave Mix Design	Nominal max. size	12.5mm
Bitumen Content	4.82%		

at OBC 4.82%

Sample Condition			Partial Saturation & Moisture Conditioned			Dry Condition		
Test No			5	6	7	1	2	3
D	Diameter	mm	150	150	150	150	150	150
t	Thickness	mm	95.1	95.5	95.3	95.7	95.6	95.2
A	Dry mass	gm	3823	3808.2	3813.5	3835.9	3820.1	3792.5
B	SSD mass	gm	3901.7	3894.1	3898.8	3886.4	3893.1	3877.4
C	Mass in water	gm	2208.5	2198.8	2203.2	2183.8	2194.6	2196.5
E	Volume (B-C) cm3	cm^3	1693.2	1695.3	1695.6	1702.6	1698.5	1680.9
G_{mb}	Bulck specific gravity (A/E)	gm/cm^3	2.258	2.246	2.249	2.253	2.249	2.256
G_{mm}	Maximum specific Gravity	gm/cm^3			2.423			
P_a	% air voids [100(G_{mm}-G_{mb})/G_{mm}]	%	**6.8**	**7.3**	**7.2**	**7.0**	**7.2**	**6.9**
V_a	Volume of air voids (P_a*E/100)	cm^3	115.4	123.6	121.7	119.5	121.9	115.7
P	Load	KN	13.43	13.89	13.76	15.57	15.90	15.37
For conditioned Sample - Saturated @ 10 min. with 40 kpa								
t'	Thickness	mm	95.1	95.5	95.3			
B'	SSD mass	gm	3901.7	3894.1	3898.8			
J'	Volume of Absorbed water(B'-A)	cm^3	78.7	85.9	85.3			
S'	% saturation (100J'/Va)	%	68	69	70			
Tensile Strength (2000*P/∏tD)		Kpa	598.4	620.2	611.2	690.9	706.2	685.6
Average Tensile Strength		**kpa**		**609.9**			**694.2**	
Retained Tensile strength ratio(conditioned/Dry)		**%**				**87.9**		
Specification								**≥ 80 %**

APPENDIX – N Wheel trucking test for superpave

WHEEL TRACKING RATE AND DEPTH

TEST METHOD: BRITISH STANDARD : BS 598-110

Sample for research	Laboratory Superpave Mix	Date of Sampling	20/05/2023
TYPE OF MIX	Wearing Coarse	Date of Testing	21/05/2023
Temperature	60^{o} C	Load (L)	700N
Wheel width(w)	50mm	Testing Time (min)	45
Bitumen Content ,%	4.82%	Material Description	HMA

at OBC 4.82%

T-1		T-2		T-3	
TIME @ (min)	DEFORMATION (mm/hr.)	TIME (min)	DEFORMATION (mm/hr.)	TIME (min)	DEFORMATION (mm/hr.)
0	**0.00**	0	**0.00**	0	**0.00**
5	**0.41**	5	**0.36**	5	**0.45**
10	**0.56**	10	**0.44**	10	**0.51**
15	**0.63**	15	**0.67**	15	**0.65**
20	**0.74**	20	**0.75**	20	**0.82**
25	**0.86**	25	**0.88**	25	**0.89**
30	**1.05**	30	**1.10**	30	**1.18**
35	**1.28**	35	**1.49**	35	**1.36**
40	**1.45**	40	**1.55**	40	**1.45**
45	**1.96**	45	**2.15**	45	**2.13**
Tracking Rate For Each Trial(mm/hr.)					
$T_R=3.6[r_n-r_{(n-3)}] + 1.2[r(_{n-1})-(r_{n-2})]$					
3.48		3.85		3.53	
Average Tracking Rate (mm/hr)					
3.62					
Wheel Tracking Rate (mm/hr)					
$W_{TR}= 10.4 \times T_R \times w/L$					
2.69					

	Wheel Tracking Rate(mm/hr) @ 60^{o}C	Wheel tracking depth(mm)
	2.69	2.08
Specification →	< 5mm/hr	< 7mm