JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIROMENTAL ENGINEERING

CIVIL ENGINEERING DEPARTMENT

HIGHWAY ENGINEE0RING STREAM

INVESTIGATING THE SUITABLITY OF CRUMBLE RUBBER AND SISAL FIBERS AS ASPHALT MIXTURES

By:
DUBIWAK NEMERA HANBISA

THIS THESIS IS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF A JIMMA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING (HIGHWAY ENGINEERING STREAM)

Jimma, Ethiopia

February, 2021

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MAIN ADVICER: DR. ENG. FIKADU FUFA

CO- ADVICER: Mr. ABUBEKIR JEMAL

Jimma, Ethiopia

February, 2021

DECLARATION

I hereby declare that this thesis entitled "INVESTIGATING THE SUITABLITY OF CRUMBLE RUBBER AND SISAL FIBERS AS ASPHALT MIXTURES.. " was composed by myself, with the guidance of my advisor, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted, in whole or in part, for any other degree or processional qualification.

Name	**Signature**	**Date**
Dubiwak Nemera Hanbisa	________________	______________

CERTIFICATE

This is to certify that the thesis prepared by Mr. Dubiwak Nemera Hanbisa entitled "INVESTIGATING THE SUITABLITY OF CRUMBLE RUBBER AND SISAL FIBERS AS ASPHALT MIXTURES." and submitted in fulfillment of the requirements for the Degree of Master of Science complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Thesis advisor:	Signature:	date
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ABSTRACT

Hot Mix Asphalt (HMA) is particulate composite material consisting of mineral aggregates, asphalt binder and air voids. Asphalt binder is considered as the most expensive and economically variable material. The increase in energy cost, the need for improvement of pavement quality and Environmental concerns enforcing the researcher to find alternative materials to modify the properties of ASPHALT binder.

The aim of this research is to investigating the stability of asphalt mixtures using crumble rubber and sisal fibers mixes. Common laboratory tests was performed on the modified bitumen asphalt mix using various proportions of CR-SF and thus analyzed. Marshal Mix design procedure was used, first to determine the Optimum Bitumen Content (OBC) and then further to test the modified mixture properties.

From 48 total numbers of samples required for this investigation, 16 samples were used to determine the OBC and the remaining were used to investigate the effects adding different CR-SF percentages to asphalt mix. The OBC was 5.5 % by weight of asphalt mix. Seven proportions of CR: SF by weight of OBC were tested (0%:1%, 3%:0.9%, 5%:0.7%, 7%:0.5%, 10%:0.3%, 12%:0.1%, and 15%:0%) besides testing of ordinary asphalt mix. Tests include the determination of stability, bulk density, flow and air voids. Results indicated that CR:SF can be conveniently used as a modifier for asphalt mixes as a part of sustainable management of crumble rubber waste as well as for improved performance of asphalt mix.
CR: SF content of 5 %:0.7% by weight of OBC is recommended as the optimum CR: SF content for the improvement of performance of asphalt mix. Asphalt mix modified with 5.5%:0.7% CR: SF by OBC weight has approximately above 40% higher stability value compared to the conventional asphalt mix. Asphalt mix modified with higher percentages of CR: SF exhibit lower bulk density, higher flow and higher air voids.

Key words: *Hot Mix Asphalt, Optimum Binder Content, Indirect Tensile Strength Test, rutting resistance*

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ACRONYMS

AACRA	Addis Ababa City Road Authority
AASHTO	American Association of State High way and Transportation Officials
AC	Asphalt Concrete
ASTM	American Society for Testing and Materials
CR	Crumble Rubber
CR: SF	Crumble rubbers: sisal fibers
ERA	Ethiopian Road Authority
HMA	Hot Mix Asphalt
ITS	Indirect Tensile Strength
MAS	The maximum aggregate size
NAPA	National Asphalt Pavement Association
NMAS	Nominal maximum aggregate size
OBC	Optimum Binder Content
SF	Sisal fibers
VMA	Void in Total Mix
VTM	Void in Mineral Aggregate
ρ_r	Density of Asphalt mix

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Road networks are mainly classified into two categories: namely, flexible pavements and rigid pavements. Flexible pavements are more vastly used compared to rigid pavement due to advantages such as low initial cost, good resistance to temperature variation, easy repair work, and easy to locate underground works [1].

Throughout the last decades, there has been a rapid increase in traffic loading intensity in terms of numbers of axles and large tire pressures caused by weighty vehicles. This rapid growth leads to some undesirable distresses in pavements such as rutting (permanent deformation) under the influences of repeated vehicle loading at high temperature, low temperature thermal cracking, and freeze–thaw cycles [2,3,4,5], which decrease the ride quality and service life of road pavements [6]. Therefore, technologists are always trying to enhance the properties of asphalt pavement mixes, where any extension in the service life of road pavements will be of course a great benefit to the economy [7].

Asphalt, or asphalt mixes modified with additives, is the most commonly applied approach to save natural resource and improve pavement performance when the asphalt produced does not meet the weather, traffic loads, and pavement structure requirement [8, 9].

There are several types of additives which can be used as a single additive or composite reinforcement in asphalt mix. For more knowledge, most of the literature revealed that a single additive cannot improve all the performances of pavement asphalt mixes at the same time. As an example, asphalt binder with additives like crumb rubber, polymers, and natural rubber have been used to resist the rutting at high temperatures and raveling in asphalt mixes. However, the problem of low temperature cracking still persists. On the other hand, the fibers can improve fatigue life by increasing the resistance to low temperature cracking [10, 11]. Thus, the use of double additives may improve the overall performance of asphalt mix, but most of the researchers are focused on the single modification and the composite reinforcement is still in its premature stage [12].

The main purpose of this study is to experimentally investigate a new compound of waste disposal materials (combination of CR and SF) to modify stability of asphalt. From an environmental and economic viewpoint, the use of CR and SF as bitumen modifying agents contributes to solving a waste disposal problem.

1.2 Statement of the Problem

The most dominant mode of the transport in Ethiopia is the Road Transport, including the passenger traffic and the freight transport. In Ethiopia, flexible pavement type of construction is preferred over the rigid pavement type of construction due to its various advantages such as low initial cost, maintenance cost, etc. In spite of the prominence of the surface transport, most of the roads are poorly managed and badly maintained. Bitumen is used as binder and water proofing material for construction of roads, pavements and air field surfacing for several years. The demand of bitumen has increased tremendously because of rapid urbanization in recent years. The objective can be achieved by enhancing the durability of existing road surfacing which will result in reducing maintenance and resurfacing operations.

Over the past 15 years, Ethiopian government had invested a huge amount of money in the field of road construction to reach excellent pavement performance. However, these roads show early signs of distress such as rutting and fatigue cracking. The pavement distress is due to change in weather and high traffic loads. Environmental condition and heavy loads affect directly the durability and pavement performance. Modified bitumen is one of among different solutions for pavement distress. A better understanding of the rheological properties of binders strengthens the ability to produce durable asphalt concrete pavements and to increase pavement life.

Conventional way of road construction have been experiencing problem of premature failure of pavements like potholes, roughness, and cracks which leads to poor performance of roads and its life. Modified bitumen will have an advantage of higher resistance to deformation at elevated pavement temperature, better aging resistance properties, and higher fatigue resistance, better adhesion between aggregates and binder, prevention of cracking and overall improved performance in extreme climatic conditions and under heavy traffic conditions.

Performance of roads with regards to readability and roughness is known to have a significant cost implication to the road users in terms of operational cost, in addition to affecting their safety and comfort. Permanent deformation in paved roads can be attributed to various factors such as the pavement structure, quality of individual constituent pavement materials, magnitude and regime of loading, environmental factors, such as moisture temperature, and others.

This study was conducted to investigate the possible use of CR: SF as additives of hot-mix asphalt and to review the feasibility of incorporating CR: SF to improve the performance of asphalt mix.

1.3 Research Questions

This study will be aimed to answer the following questions:

- Is it possible to increase the performance of asphalt mixtures by using crumble rubber and sisal fibers as mixtures?
- How to determine the optimum percentage of sisal fibers and rubber to be blended with commonly used bitumen to produce maximum compressive strength?
- How to compare the performance of unmodified and CR: SF modified of asphalt mix.

1.4 Objectives of the study

1.4.1 General objective

The purpose of the study is investigating the stability of asphalt mixtures using crumble rubber and sisal fibers mixes.

1.4.2 Specific objectives

The specific objectives of the study are.

- To Study the behavior and properties of asphalt mix (stability, plastic flow, stiffness, voids).
- To compare the performance of unmodified and CR: SF modified of asphalt mix.

- To select the optimum percentage of sisal fibers and rubber to be blended with commonly used bitumen to produce maximum compressive strength.

1.5 Scope of the Study

The scope of study is to evaluate the performance (flow, stability, void filled by bitumen, Void in total mix, density, optimum binder content) of the sisal fibers and crumble rubber is going be used as a mixture material in asphalt mix design. The study covers modifying the asphalt mixtures by using sisal fibers and crumble rubber mixes. It is supported by different types of literatures and a series of laboratory experiments.

1.6 Significance of the study

The construction of hot mix asphalt pavement by using natural fibers and crumble rubber mixes is not a common practice in Ethiopia. Therefore, the result of this research will be used for different highway agencies in our country. The benefit of in this research paper to increase the stability and reduced permanent deformation as compering to the control hot mix asphalt mixtures. This research will valid after completion of the study and it will be used for the input of different highway agencies like Ethiopia Road Authority (ERA), Oromia Roadwork Enterprise and Addis Ababa City Road Authority (AACRA) and for other Ethiopia highway agencies. Ethiopian highway agencies will be practiced this research results in order to improve the performance of hot mix asphalt properties and at the same time to reduce maintenance cost of the road.

Also the others significance of this study are increasing The possibility of having investment on the production of local Sisal fibers material by using locally available materials and Creating further research opportunities.

1.7 Limitation of the study

The following were the limitation of the study

1. This study will be limited to the bitumen used on the wearing course alone. The investigator has assumed that the other pavement layers like sub-grade, sub-base and base courses have been done to road designer’s satisfaction and they can adequately support the wearing course.

2. lack of excess laboratory equipment

1.8 Organization

Chapter one defines the overall importance of the problem areas and provides an introduction into what the research is all about, chapter two deals with literatures on basic pavement concepts and pavement materials and past studies and works on pavements of crumble rubber and sisal fibers ingredients as a construction material. Chapter three describes how the experimental work is done with detailed procedures and the results are analyzed and discussed in chapter four. Conclusions derived from experimental results and recommendations for this study and other further studies are presented in chapter five.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Asphalt is known as brittle and hard in cold and soft environments respectively. As a pavement material, it is characterized with a number of failures represented by the low temperature cracking, fatigue cracking, and the rutting (permanent deformation) at high temperature, causing its quality and performance in pavement of roads to decrease [13].

Asphalt is basically a mixture of natural raw materials: coarse and fine aggregates, filler and bitumen. In addition to these standard materials from natural sources, some additives may be incorporated to influence the performance of the product [14]. The design of asphalt paving mixes is largely a matter of selecting and proportioning the ingredient materials to optimize all desired properties in the finished paved road [15].

Different studies revealed that certain modifications in the mixture such as, changing the type, size and gradation of aggregate, varying the filler to asphalt ratio, type and amount of filler alter the physical properties of HMA concrete [16]. The purpose of this chapter is to review the literature on various studies have been conducted on the properties of HMA using natural fibers and crumble rubber.

2.2 Road Pavement.

Road pavements are designed to limit the stress created at the subgrade level by the traffic travelling on the pavement surface so that the subgrade is not subject to significant deformations. The pavement spreads the concentrated loads of the vehicle wheels over a sufficiently large area at subgrade level. At the same time, the pavement materials themselves should not deteriorate to any serious extent within a specified period of time.

Road pavement can be categorized to two groups flexible and rigid. Flexible pavements are those which are surfaced with bituminous (or asphalt) materials. These can be either in the form of pavement surface treatments such as a Bituminous Surface Treatment (BST), generally found on lower volume roads or, Hot Mix Asphalt (HMA) surface courses, generally used on higher volume roads. These types of pavements are called flexible since the total pavement structure bends due to traffic loads.

Roads are built up in several layers, consisting of sub-grade, sub-base, base and surface layer; these layers together constitute the pavement. Because asphalt concrete is much more flexible than Portland cement concrete, asphalt concrete pavements are called flexible pavements. Asphalt concrete is composed primarily of aggregate and asphalt binder. Aggregate typically makes up about around 95% of a Hot Mix Asphalt (HMA) mixture by weight, whereas asphalt binder makes up the remaining approximately 5%. By volume, a typical HMA mixture is about 85% aggregate, 10% asphalt binder, and 5% air voids. Asphalt binder glues the aggregate together and that means without asphalt binder HMA would simply be crushed stone or gravel.

Small amounts of additives and admixtures are added to many HMA mixtures to enhance their performance or workability. Asphalt cement binds the aggregate particles together, enhancing the stability of the mixture and providing resistance to deformation under induced tensile, compressive and shear stresses. The performance of asphalt mixture is a function of asphalt cement, aggregate and its volumetric properties. Bitumen is the main component, which controls the viscoelastic properties during production in the plant and service on road. Viscoelastic material defined as material, which store and dissipate mechanical energy in response by a mechanical stress [17].

Bitumen's materials are viscoelastic material and their mechanical behavior is dependent on both the temperature and rate of loading. At low temperatures and short loading times asphalt cements behave as elastic solids, while at high temperatures and long loading times they behave as simple viscous liquids. At intermediate temperatures and loading times, the behavior is more complex. The relationship between modified asphalt binders and field pavement performance is still being researched because many modified binders are rheological complex. However, it is clear that asphalt binder and concrete modification is an effective method for preventing pavement distress [18].

Asphalt pavements typically provide excellent performance and value. They are smooth and durable. They do not require long construction times and they are easy to maintain resulting in minimal traffic delays. Asphalt surfaced roads subjected to heavy traffic in hot climates may experience early failures in the form of rutting. The rutting failures are the result of heavy truckloads with high tire pressures and high pavement temperatures.

Careful selection of asphalt binder and aggregate combination will help in providing optimum performing Hot Mix Asphalt, HMA, pavements. The use of Performance Graded binder system has the advantage of the binder being selected based on the climate in which it will serve. The aggregate structure used must be capable of carrying the load and developing a high degree of stone-to-stone interlock that will resist shear. In addition to materials selection, the mix design procedure is crucial in achieving desired performance.

Asphalt concrete pavements are not a thin covering of asphalt concrete over soil, they are engineered structures composed of several different layers. Figure below illustrates a vertical section of flexible pavement structure [19].

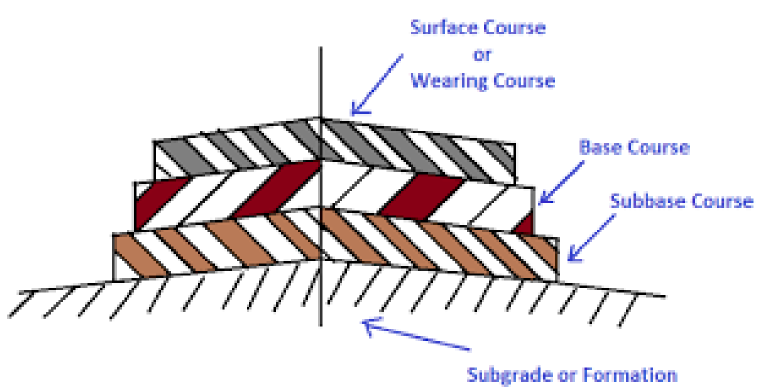


Figure 2.1 conventional Layers of Flexible Pavement

2.3 Asphalt Pavement distresses

Rutting and Cracking Pavement deterioration is the process by which distresses develop in pavement under the combined effects of traffic loading and environmental conditions. Deterioration of pavement greatly affects serviceability, safety and riding quality of the road. After construction, roads deteriorate with age as a result of use and therefore, they need to be maintained to ensure that the requirements for safety, efficiency and durability are satisfied.

Normally, new paved roads deteriorate very slowly in the first ten to fifteen years of their life, and then go on to deteriorate much more rapidly unless timely maintenance is undertaken [20].

Rutting is a longitudinal surface depression in the wheel path accompanied, in most cases, by pavement upheaval along the sides of the rut. Pavement rutting which results in distorted pavement surface is the accumulation of permanent deformation in all or a portion of the layers in a pavement structure. Longitudinal variability in the magnitude of rutting causes roughness. Water may become trapped in ruts resulting in reduced skid resistance.

Increased potential for hydro planning and spray that reduces visibility. Progression of rutting can lead to cracking and eventually complete disintegration. Repetitive application of heavy trucks with increasingly high pressure tires drives rut formation in high quality layers. The stresses induced near surface layers by the high pressure tires may exceed the ability of the materials to resist densification below Critical void levels and subsequent densification [21].

Rutting can occur in all layers of the pavement structure and generally results from lateral distortion and densification. Moreover, rutting represents a continuous accumulation of incrementally small permanent deformations from each load application [22].

Another researcher defined Permanent deformation in the form of rutting, as an unrecoverable deformation visible as a depressed channel in the wheel path of the roadway. According to this researcher, it is a progressive movement of materials under static or cyclic loads either in the top (asphalt) layer or the underlying layers [23].

On the other hand, cracking is one of the main modes of asphalt pavement deterioration caused by traffic and environmental factors. Cracking of flexible pavements is based on the horizontal tensile strain at the bottom of asphalt concrete layer [24].

In the stage of crack initiation water trapped in the cracks and this led to reduction of the materials strength under repeated loading. Due to the strength reduction crack start to propagate and lead to pavement collapse. The development of cracks on pavement surface can be due to expansion arising from variation in weather, stress from excessive wheel load, settlement of the base material, etc. The most common types of cracks on the pavement are: Transverse, Longitudinal and Alligator or Miscellaneous cracks.

2.4 Basic Procedure in HMA Mix Design

Hot-Mix-Asphalt mixture consists of two basic ingredients: mineral aggregate and asphalt binder. The process in HMA mix design involves determining what type of aggregate to use, what asphalt binder to use and what proportion of these two ingredients to use so as to achieve the desired bituminous mixture performance. HMA is a complex material where different, and sometimes conflicting, performance demands are placed. It must resist deformation and cracking, be durable over time, resist water damage, and yet be inexpensive, readily made and easily placed [25].

The most common methods used to go about this process are the Marshall, Hveem and Super pave methods. In general, all mix design methods involve manipulation of three basic variables: namely aggregate selection, asphalt binder choice and optimum asphalt binder content determination where they are briefly discussed under this section.

2.4.1 Aggregate Type and Quality Selection

Aggregates (or mineral aggregates) are hard, inert materials such as sand, gravel, crushed rock, slag, or rock dust. Properly selected and graded aggregates are mixed with the asphalt binder to form HMA pavements. Aggregates are the principal load supporting components of HMA pavement. Aggregates can be classified to three types according to their size distribution: Course aggregates, fine aggregates, and mineral filler. Coarse aggregates are generally defined as those retained on the 2.36-mm sieve i.e. it comprise the portion of the aggregates that has large particle sizes. Fine aggregates are those that pass through the 2.36-mm sieve and are retained on the 0.075-mm sieve. That is, the aggregate particles that can fill the voids created by the coarse aggregates in the mixture [26].

Mineral filler is defined as that portion of the aggregate passing the 0.075-mm sieve. It consists of very fine, inert mineral with the consistency of flour, which is added to the hot mix asphalt to improve the density and strength of the mixture [27].

Pavement engineers have worked for many years to relate specific aggregate properties to HMA performance. Rutting, raveling, fatigue cracking, skid resistance, and moisture resistance have all been related to aggregate properties. It is essential that engineers and technicians responsible for HMA mix design thoroughly understand aggregate properties, how they relate to HMA pavement performance, and how aggregate properties are specified and controlled as part of the mix design process.

Generally aggregates for HMA are required to be resistant to abrasion, sound, clean, and hydrophobic. In addition to this the aggregate should be durable and Abrasion Resistance. Aggregates through internal friction and must transmit the wheel loads to the underlying layers and also be resistant to abrasion and polishing due to traffic. Aggregates are subject to crushing and abrasive wear during manufacturing, placing, and compaction of HMA. They must be hard and tough to resist crushing, degradation; disintegration when stockpiled fed through a HMA facility, placed with paver, compacted with rollers, and travelled over with trucks. The properties of aggregates are very important to the performance of hot mix asphalt (HMA) pavements. Often pavement distress such as rutting, stripping, surface disintegration, and lack of adequate surface frictional resistance can be attributed directly to improper aggregate selection and use. Thus, care has to be made while selecting the mineral aggregate and all quality test assurance has to be conducted to confirm whether they satisfy a definite project specification. Aggregates are deemed to give the mixture stability after various traffic loads, resistance to wear due to abrasive action of traffic, and still resistant to frost action. Thus, to obtain a mixture having a good performance, evaluation of various mineral aggregate physical properties is essential [25].

2.4.2 Aggregate Gradation and Size

An aggregate's particle size distribution, or gradation, is one of its most influential characteristics. It determines almost every HMA properties including stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage [28].

In conjunction with this, care has to be taken while determining maximum aggregate size in a mixture. In HMA mixtures, instability may result from excessively small maximum sizes; and poor workability and/or segregation may result from excessively large maximum sizes [28].

2.4.3 Asphalt Binder Selection

Asphalt binder is supplied in various forms and grades having a wide range of consistency from fluid to hard and brittle for bituminous pavement construction. Asphalt binders are most commonly characterized by their physical properties. This is because an asphalt binder's physical properties directly describe how it will perform as a constituent in HMA pavement. Different quality tests shall be carried out on asphalt cement to assess its physical properties through various laboratory steps [29].

Asphalt is the most commonly used material in pavement construction today because of its high engineering performance capabilities such as elasticity, adhesion and water resistance. Asphalt is known to be a complicated colloidal system of hydrocarbon materials which are composed of asphalteness, resins and oils. Today's asphalt is produced mainly by the refining of crude oil and the physical and chemical properties can be altered or improved by blending, air blowing, additives etc. The interface between the asphalt and aggregate has been much focused in order to determine the chemical factors that influence bonding between the two materials [30].

The binder source will also affect the ability to prevent or minimize moisture induced damage of asphalt pavements. Asphalt cement generally is obtained from distillation of crude petroleum using different refining techniques. At ambient temperatures asphalt cement is a semi-solid material that must be heated to mix with an aggregate. Asphalt is strong and durable cement with excellent adhesive and waterproofing characteristics.

2.4.4 Optimum asphalt binder content determination

Mix design methods are generally distinguished by the way in which they determine the optimum asphalt binder content. This process can be categorized into: Make several trial mixes with different asphalt binder contents, Compact these trial mixes in the laboratory (This compaction is means to be a rough simulation of actual field conditions) , Run laboratory tests to determine key sample characteristics and Pick the asphalt binder content that best satisfies the mix design objectives. The various important mixture properties which show weight-volume relationship and strength are discussed here in after [31].

2.4.4.1 Bulk Specific Gravity Determination

The bulk specific gravity test on the freshly compacted specimens may be performed as soon as when they have cooled to room temperature. This test is conducted according to ASTM D 2726, “Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-dry Specimens” [31].

In the Marshal Mix design procedure, the density varies with asphalt content in such a way that it increases with increasing asphalt content in the mixture as the hot asphalt lubricates the particles allowing the compaction effort to force them closer together. The density reaches a peak and then begins to decrease because additional asphalt cement produces thicker films around the individual aggregates, and tend to push the aggregate particles further apart subsequently resulting lower density.

The bulk density of the compacted mixture can also be altered with the proportion of mineral filler. It is expected that the bulk density increases as the amount proportion of mineral filler increases in the mixture up to some point and then decreases. This is because an increased amount of mineral fillers will increase the amount of fines in the mix and the large amount of fine particles tend to push the larger particles apart and act as lubricating ball-bearings between these larger particles which subsequently lower the bulk density.

2.4.4.2 Total Voids in Mineral Aggregate

The voids in the mineral aggregate, VMA, is the total available volume of voids between the aggregate particles in the compacted paving mixture that includes the air voids and the effective asphalt content expressed as a percent of the total volume. It is calculated based on the bulk specific gravities of the combined aggregates and compacted paving mixture.

The VMA has two components: the volume of voids that is filled with asphalt, and air volume remaining after compaction for thermal expansion of the asphalt cement during hot weather. It is significantly important for the performance characteristics of a mixture. For any given mixture, the VMA must be sufficiently high enough to ensure there is space for the required asphalt cement, for its durability purpose, and air space. If the VMA is too small, there will be no space for the asphalt cement required to coat around the aggregates and this subsequently results in durability problems. On the other hand, if VMA is too large, the mixture may suffer stability problems. The available VMA will decrease as the amount of mineral fillers in the mixture increases. This can be due to both fillers can be used for filling voids or extend the asphalt binder [29].

2.4.4.3 Percent Air Voids in Compacted Mixture

The air voids, Va, in a compacted paving mixture that consists of small air spaces between the coated aggregate particles expressed as percent of the bulk volume of the compacted paving mixture. To address this, HMA mix design seeks to adjust items such as asphalt content and aggregate gradation to produce design air voids. As the air void in the compacted mix is high, the HMA will experience stability and moisture damage problems, and rutting will develop for low air void values.

2.4.4.4 Percent Voids Filled with Asphalt in Compacted Mixture

The voids filled with asphalt, VFA, is a percentage of inter granular voids space between the aggregate particles (VMA) that are filled with asphalt cement. The amount of asphalt cement that fills the voids in the mixture is termed as “effective asphalt content”. It is the effective asphalt cement that provides the required asphalt film thickness around the aggregate particles, which subsequently determines the durability of the mixture.

2.4.4.5 Marshal Stability and Flow

Marshal stability values can be determined by conducting a test on a prepared bituminous specimen. It is the maximum load carried by a compacted specimen tested at 60^0C.

The stability value obtained is an indication of the mass viscosity of the aggregate-asphalt cement mixture. In most cases, it is affected significantly by the angle of internal friction of the aggregate and the viscosity of the asphalt cement at 60^oC. Hence, one of the easiest ways to increase the stability of an aggregate-asphalt mixture is to use a higher viscosity grade of asphalt cement. It is also possible to increase the stability of the mix by selecting a more crushed angular aggregate than rounded shape aggregates [32].

The flow is measured as the vertical deformation of the specimen in millimeter from start of loading up to the point where the stability begins to decrease. It is obtained at the same time as the Marshal Stability test is conducted. Generally, high flow values indicate a plastic mix that is more prone to permanent deformation problem due to traffic loads, whereas low flow values may indicate a mix with higher than normal voids and insufficient asphalt for durability and could result premature cracking due to mixture brittleness during the life of the pavement.

2.5 Moisture Susceptibility of Hot Mix Asphalt

One of the desirable properties of bituminous mixtures is that the resistance to moisture induced damages. Water affects asphalt concrete in various ways. It may act directly and literally strip binder from the aggregate. However, generally, the effects are more subtle. Water weakens the structure to a point where the mix can no longer sustain the traffic it was designed to support, and finally fails under the repeated loading. The resistance to moisture damage under the presence of moisture in the mixture is a complex matter and the degree mainly depends on the properties of each ingredient materials in the mixture, type and use of mix, environment, traffic, construction practice, and the use of anti-strip additives. Among these factors, aggregate response to asphalt cement under water is primarily responsible for this phenomenon, although some asphalt cement are more subjected to stripping than others. The damage of asphalt pavements due to moisture also can significantly increase the maintenance costs of a pavement and ultimately, reduce the life of the pavement [33].

2.6 Modification of Asphalt

Asphalt modification is a process done to enhance the strength and life of pavement. Modifications can combined or put an additive to asphalt. Thermoplastic, polymers, thermo set, polymers, reinforce agents; adhesion, promoter, catalyst, chemical reaction, and aging inhibitors use in modified of asphalt, only to strength the road pavement and avoid the maintenance every year. Certain additives or blend of additives called as bitumen modifiers can improve properties of Bitumen and bituminous mixes. Bitumen treated with these modifiers is known as modified bitumen.

A conventional bituminous material does not have the performance requirements for the road construction, which are increasingly subjected to heavy loads, heavy traffic and several environmental conditions. When the produced asphalt does not meet climate, traffic, and pavement structure requirements, modification has been used as one of the attractive alternatives to improve its properties.

Modification offers one solution to overcome the pavement distress deficiencies of bitumen and thereby improve the performance of asphalt concrete pavement. Isacsson, U. (1995) reported that using of polymer modified bitumen's to achieve better asphalt pavement performance has been observed for a long time [34].

The main objective of the bitumen improvement is to produce ideal modified bitumen's materials with high resistance to permanent deformation, and fatigue cracking. The technical reasons for using modifiers in asphalt concrete mixtures are to produce stiffer mixes at high service temperature to resist rutting as well as to obtain softer mixtures at low temperature to minimize thermal cracking and improve fatigue resistance of asphalt pavement. Improvement in the performance of asphalt concrete mixtures that contain polymer is largely due to the improvement in the rheological properties of the asphalt binder. The rheological properties of a binder that allow flexibility under load controls resistance to fatigue. The modified mixtures are less brittle at lower temperatures and it has higher stiffness at higher temperatures compared to normal mixtures. This makes polymer modification extremely attractive for pavement designers and highway agencies.

Asphalt modifiers have been used over 60 years. They are more commonly used in Europe compared to the United States in the 20th century. A greatly increased effort has been dedicated to the research and application of asphalt modifiers over the past 20 years in the United States. The Super pave asphalt binder specifications based on Strategic Highway Research Program (SHRP) require the asphalt binders to meet stiffness criteria at both high and low pavement service temperatures. However, most regular asphalt binders are not qualified for the requirements in areas with extreme climate conditions. In the meantime, traffic volume and loads have increased significantly in recent years. This has caused lots of premature rutting and cracking of HMA pavement constructed with neat asphalt binders. Modifications of asphalt binders become of considerable interest in the improvement of pavement performance and service life. Although high initial cost discourages the use of modifiers, some state highway agencies started to specify modified asphalt binders and to be willing to pay a higher initial cost for pavements with a longer service life and reduced risk of premature distress, and therefore, lower life cycle costs. Additionally, the disposal of waste materials and industrial byproducts, such as tires, glass, sulfur, etc., used as additives in HMA is economical and benefits the environment.

Some specific technical reasons for using additives and modifiers in HMA are obtaining stiffer mixtures at high service temperatures to minimize rutting, Obtain softer mixtures at low service temperatures to minimize thermal cracking, Improve fatigue resistance of HMA mixtures at intermediate temperature and/or heavy traffic loads, Improve asphalt-aggregate bonding to reduce stripping or moisture susceptibility, Improve fatigue resistance of HMA mixtures at intermediate temperature and/or heavy traffic loads, Improve abrasion resistance of mixture to reduce raveling and Reduce flushing or bleeding; reduce structural thickness of pavement layers [35]:

2.7 Background and significance of work

2.7.1 Historical Background of modifying the asphalt mixtures by using crumble rubber

Rubbers crumbs can be introduced into asphalt mixtures through either wet or dry processes **[5]**. The wet process involves the addition of rubber crumbs into hot asphalt and allowing the asphalt to react with the rubber. During this process, the major event is the swelling of the rubber. However, in the dry process, the rubber crumbs are first mixed with a hot aggregate before being added to the bitumen. The resistance of an asphalt mixture to high temperate deformation and low temperature cracking can be improved through the addition of rubber crumbs via a dry process **[6]**. Only the specified volumetric properties of an asphalt mixture can be obtained through the wet process **[3]**. This work mainly aims at investigating the influence of rubber crumbs addition into asphalt mixtures via the wet process.

Issa Y. (2016) said that bitumen binder properties affect the properties of pavement performance. Continuous increased consumption, result a large amount of waste rubber materials generated every year. The main objective of this paper is to study the changes in properties of asphalt mixture after adding tires rubber. In this paper, some important things of asphalt mix properties, including stability and flow are investigated. We can prepare the original sample without adding rubber for (4%, 4.5%, 5%, 5.5% and 6% bitumen). Other samples have to be prepared by adding rubber to bitumen in wet process with 5%, 10%, and 20% by bitumen weight. The results show that the rubber–asphalt mixture properties are improved in comparison with normal asphalt pavement. It is concluded that the use of tires rubber in asphalt pavement is desirable. The suitable amount of added rubber by bitumen weight was found to be 10%.

2.7.2 Historical Background of modifying the asphalt mixtures by using sisal fibers

In the present study, an attempt has been made to study the effects of use of a naturally and locally available fiber called sisal fiber is used as stabilizer in SMA and as an additive in BC. For preparation of the mixes aggregate gradation has been taken as per MORTH specification, binder content has been varied regularly from 4% to 7% and fiber content varied from 0% to maximum 0.5% of total mix. As a part of preliminary study, fly ash has been found to result satisfactory Marshall Properties and hence has been used for mixes in subsequent works. Using Marshall Procedure Optimum Fiber Content (OFC) for both BC and SMA mixes was found to be 0.3%. Similarly Optimum Binder Content (OBC) for BC and SMA were found to be 5% and 5.2% respectively. Then the BC and SMA mixes prepared at OBC and OFC are subjected to different performance tests like Drain down test, Static Indirect Tensile Strength Test and Static Creep Test to evaluate the effects of fiber addition on mix performance. It is concluded that addition of sisal fiber improve the mix properties like Marshall Stability, Drain down characteristics and indirect tensile strength in case of both BC and SMA mixes. Ii is observed that SMA is better than BC in respect of indirect tensile strength and creep characteristics.

CHAPTER THREE

RESEARCH METHODOLOGY

.1 Introduction

Results of laboratory work had been obtained and analyzed in order to achieve study objectives which include studying the effect of adding different percentages of CR: SF on the mechanical properties of asphalt mix and identify the optimum percent of CR:SF to be added to hot mix asphalt. Laboratory work results are presented in this chapter in three stages. First, handle the results of blending aggregates to obtain asphalt binder course gradation curve. Second stage, Marshal Test is carried out with different percentages of bitumen which are (4.0, 4.5, 5.0, 5.5 and 6.0%) and the results are analyzed in order to obtain the optimum bitumen content (OBC).

After obtaining OBC, the following step is to study the effect of adding different percentages of CR: SF on asphalt mix properties which are (0%:1%, 3%:0.9%, 5%:0.7%, 7%:0.5%, 10%:0.3%, 12%:0.1% and 15%:0%) by the weight of OBC. Marshal test results for modified asphalt mixes are analyzed and finally the optimum CR: SF modifier content is obtained.

The guidelines and manuals used for this study are taken from ERA 2013 manuals specifically Flexible Pavement Design Manual and Standard Technical Specification, Asphalt Institute MS-2 and AASHTO Standard Technical Specifications M20-70

3.1 Study Design

This research was designed to answer the research questions and meet its objectives based on experimental findings.

The first step in the research work was sample collection. At this stage, the samples of the component materials viz. crushed aggregate; bitumen, crumble rubber and sisal fiber were collected. The second step was laboratory testing. This step is comprised of three major phases: First phase Quality testing, second phase mix design and third phase moisture sensitivity

Quality tests were undertaken on each of the component materials so that their physical and/or chemical properties are identified. During the mix design phase, 18 types of mixtures were designed for determining OBC without any modifiers. The remaining twenty eight mixes were composed of CR-SF at different percentages. The bituminous mixtures were tested and evaluated according to Marshall Method of mix design.

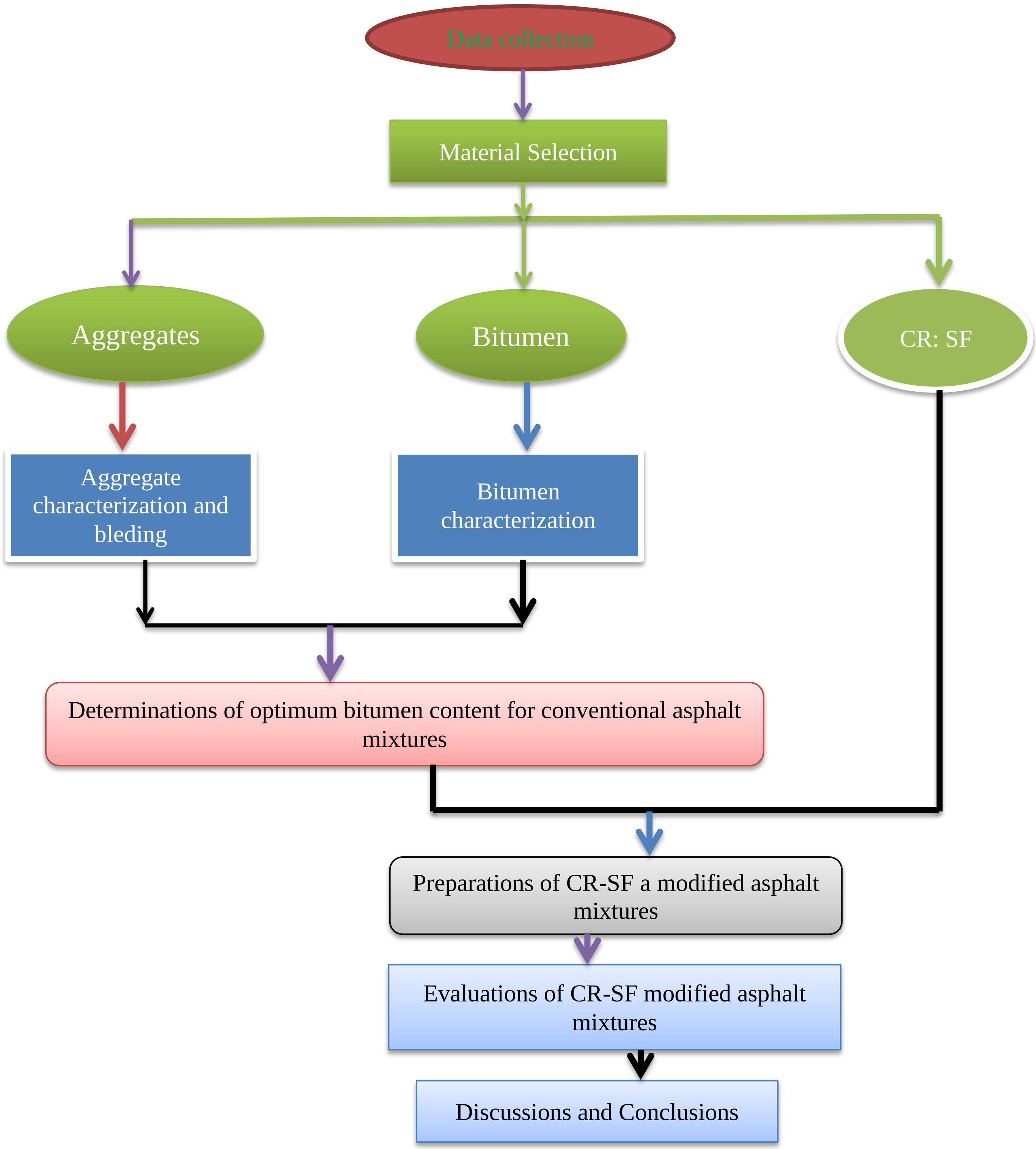


Figure 3.2 Flow chart of entire research process

The third step of the research was analyses and interpretation of the laboratory test data. In this step, the laboratory test data were analyzed and interpreted. This includes discussing the effects of CR-SF on the volumetric and Marshall Properties of the mix. This include the effect CR-SF has on Stability, Flow, unit weight, VTM, VMA, VFA and effective asphalt content and optimum asphalt content . Effect of the CR-SF on optimum asphalt content and the selection of an optimum CR-SF content are also discussed. Further, in this step, the bituminous mixtures were compared, based on the performance and volumetric properties with normal mix and the three mixes so as to identify the cheaper option.

The fourth and final step was declaration of the research findings and recommendations based on those findings. The entire research process is shown by the flow chart in Figure 3.2.

3.2 Material Properties

3.2.1 Aggregate

The aggregates used in the research were subjected to various tests in order to assess their physical characteristics and suitability in the road construction. To produce identical controlled gradation, aggregates were sieved and recombined in the laboratory to meet the selected gradation which satisfying ASTM specifications for asphalt binder average gradation. The coarse and fine aggregate particles were separated into different sieve size and proportioned to obtain the desired gradation for bituminous mixtures of ASTM 3515 for 19 mm nominal maximum aggregate size (NMAS).

Table 3.1 presents the physical properties of fine and coarse aggregates. The soundness tests were conducted by using Sodium Sulphate (Na_2SO_4) solution. The absorption characteristic of the aggregates is relatively high. This resulted to relatively greater consumption of bitumen in HMA.

An aggregate's particle size distribution, or gradation, is one of its most influential characteristics. In hot-mix asphalt, gradation helps to determine almost every important property including stiffness, stability, durability, permeability, workability, fatigue resistance, and resistance to moisture damage. Gradation is usually measured by a sieve analysis.

The results of detailed aggregate properties are presented in Materials quality test result of Appendix A of the Research paper.

Table 3.3.1 Aggregate physical properties

Types of Tests	Results	Specification (ERA, 2002)	Test Method
Los Angeles Abrasion (%)	13.00	< 30	AASHTO T96
Soundness (%)	4.57	< 12	AASHTO T104
Particle Shape,Flakiness (%)	21.06	< 45	BS 812, Part 105
Aggregate Crushing Value (%)	12.85	< 25	BS 812, Part 110
Sand Equivalent (%)	76.45	> 40	AASHTO T 176
Water Absorption (%)			
i. Coarse Aggregate	1.561	< 2	AASHTO T85-91
ii. Fine Aggregate	1.937	< 2	AASHTO T85-91
Bulk Specific Gravity			
i. Coarse Aggregate	2.68	N/A	AASHTO T85
ii. Fine Aggregate	1.94	N/A	AASHTO T84

3.2.2.1 Aggregate Gradation

Crushed aggregates were obtained from the crusher plant of deneba Crusher plant site in Oromia region Jimma Zone . The aggregates of each were sieved by dry sieve method and then mixed with different mix ratio to satisfy the ERA 2002 (Table 6400/8 Grading limits for combined aggregate and mix proportions for asphaltic surfacing) specification. The nominal maximum aggregate size (NMAS) and the maximum aggregate size (MAS) is found to be 19.0mm and 25.0mm respectively. Figure 3.2.2.1 shows the blended graduation of aggregate used in this study.

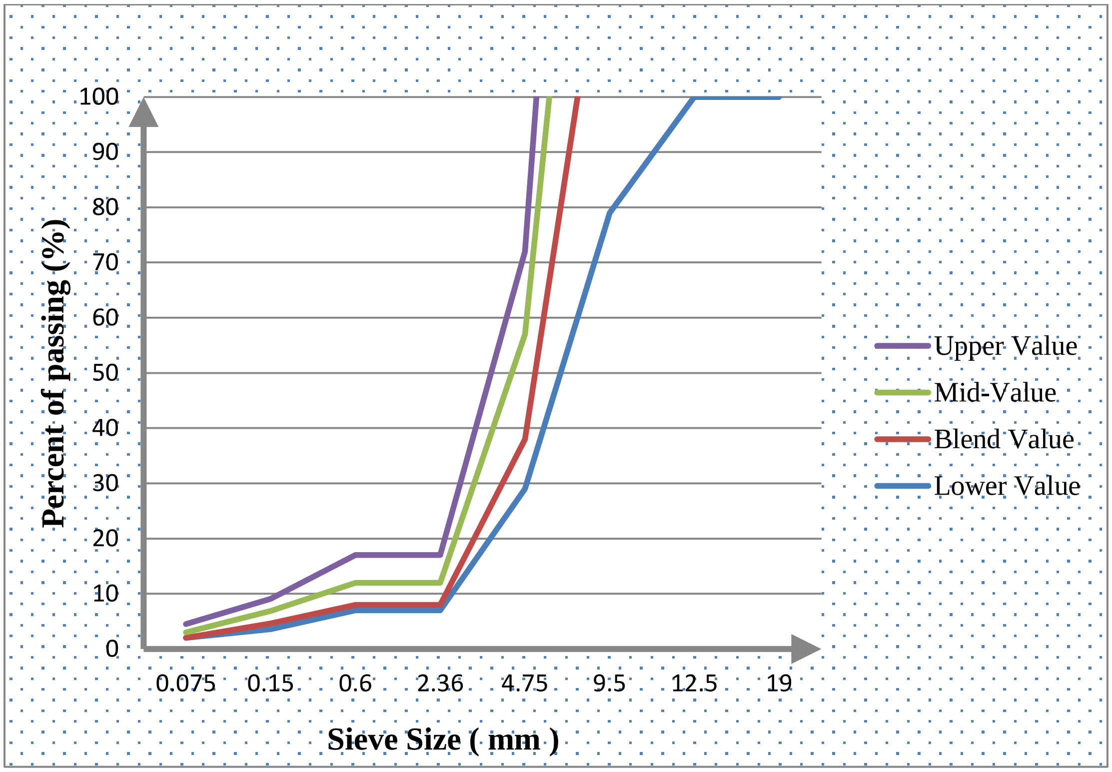


Figure 3.2.2.1 The blended graduation of aggregate used in this study

3.2.2 Bitumen

In this investigation, 60–70 penetration bitumen, obtained from Jimma Mineral Oil Refinery in Deneba, was used. The bitumen quality tests were conducted before the start of the mix design and compared to the specifications set in ERA 2013 PDM, AASHTO Standard Technical Specifications M20-70 and SABS-307. The result of the quality tests are presented in Table 3.3.2 below.

Table 3.3.2 Conventional rheological properties of the bitumen used in this study

Test	Standard ASTM	value
Penetration (100g, 5 s, 25◦C), 0.1 mm	ASTM D5-73	70
Softening point (◦C)	ASTM D36-76	43
Ductility (25◦C, 5 cm/min) (cm)	ASTM D113-79	>100
Flashing point (◦C)	ASTM D92-78	>302

3.2.3 Crumble rubbers

The rubber powder used for the purpose of this study is the one prepared through ambient procedure from cutting, scraping and powdering waste. The rubber powder sifts through a No. 30 sieve (fiber and metals have been removed from the rubber) and its density is 1320 kg/m3. Granulated crumb rubber used is shown in Table 3.3.4

Table 3.3.4 Crumb rubber gradation used in this study

Sieve No.	Sieve size(mm)	%Passing
# 30	0.6	100
# 50	0.3	65
# 100	0.15	24
# 200	0.075	3

3.2.4 Sisal Fibers

Sisal Fiber used in this study was obtained from market; SF was produced in pieces with an approximate dimension of 10cm*10cm. Then, the SF was taken into the laboratory and changed into the small pieces by a hammer. The amounts of SF passing through #200 sieves are shown in Figures 3.3.4A and 3.3.4B. The chemical properties of SF are indicated in Table 3.3.4.

Figure 3.3.4A Sisal fiber used

Figure 3.3.4B Sisal fiber plants

Sl.No	Chemical compositions		Physical property	
	Compositions	Test Results	Property	Test Results
1	Cellulose %	65	Density (gm/cc)	1.5
2	hemicellulose	12	Tensile strength (MPa)	511-635
3	lignin	9.9	Young's modulus (MPa)	9.4-2.4
4	waxes	2	Elongations at break (%)	2.0-2.5

Table 3.3.4 Chemical compositions and physical properties of used sisal fibers

3.3 Experimental Mix Design

Approximately 1200gm of aggregates is heated to a temperature of 175°C to 190°. Bitumen is heated to a temperature of 135-170°C with the first trial percentage of bitumen (4 to 6% by weight of the mineral aggregates for determination of optimum bitumen content). The heated aggregates and bitumen are thoroughly mixed at a temperature of 160°C. The mix is placed in a mould and compacted by a gyratory.

The experimental methodology of the study involved laboratory tests (Marshall, stability and flow test) on three (3) specimens per set per experiment. The bitumen at (4%, 4.5%, 5%, 5.5% and 6%) was combined with the graded aggregates and the optimum bitumen content was determined using Marshall Test procedure. This optimum binder content was systematically and partially replaced with properly prepared SF: CR at 0%:1%, 3%:0.9%, 5%:0.7%, 7%:0.5%, 10%:0.3%, 12%:0.1% and 15%:0% by weight of the optimum bitumen content.

In summary, the experimental mix design entails all the ratio and proportioning of materials required for the optimum result of the study. This study encompasses, the aggregate blending and proportioning and optimum binder content determination.

3.3.1 Theoretical Maximum Specific Gravity and Density (AASHTO T 209)

The theoretical maximum specific gravity of an asphalt concrete mixture is the specific gravity of the mixture at zero air void content. It is one of the most difficult tests performed in paving materials laboratories and also one of the most important. Like bulk specific gravity, theoretical maximum specific gravity in and of itself does not affect the performance of a paving mixture. However, it is essential in determining volumetric factors that are good indicators of performance, such as air void content, VMA and the amount of binder absorbed by the aggregate particles.

Maximum specific gravity is determined by measuring the specific gravity of the loose paving mixture, after removing all of the air entrapped in the mixture by subjecting the mixture to a partial vacuum (vacuum saturation). The loose mix is prepared by gently heating the sample in an oven until it can be easily broken apart. The mixture is then removed from the oven and occasionally stirred while cooling, to make sure that it remains broken up as much as possible into separate particles of asphalt-coated aggregate.

For this test, asphalt mix specimens for each mix variation were prepared and cured for two hours. Mixes were then cooled in a loose, un-compacted state and placed in a vacuum container filled with distilled water. A high vacuum pump attached to the container and activated for at least 15 minutes, removing entrapped air.

Shaking of the container was required to remove air bubbles. After vacuum saturation, the container was removed from the pump and filled to the calibrated level with water. Then the mass of the container, specimen, and water was determined. This value, along with the dry mass of the specimen and mass of the container filler with just water, was used to determine the theoretical maximum specific gravity.

The theoretical maximum specific gravity of each mix design is shown in the Appendix-C that used for air voids calculation.

Figure 3.3.1 Theoretical Maximum Specific Gravity and Density determination

3.3.1 Marshall flow, stability and Volumetric Analysis

First the aggregates were heated to a temperature of 175°C to 190°C the compaction mould assembly and rammer were cleaned and kept pre-heated to a temperature of 100°C to 145°C. The bitumen was also heated to a temperature of 135-170°C and the required amount of first trial of bitumen was added to the heated aggregate and thoroughly mixed. The mix was placed in a mould and compacted with 75 numbers of blows. The sample is taken out of the mould after cooling for overnight using sample extractor. Once the sample is extracted, it is subjected for volumetric measurements such as bulk specific gravity of compacted mix, air voids, voids in mineral aggregates, and voids filled with asphalt. Further the sample is kept in 25°C water bath for 30 to 40 minutes for flow and stability recording. Then graphs will be plotted for the following combination of parameters for further analysis.

- Stability vs. Bitumen Content
- Flow vs. Bitumen Content

- Bulk Specific Gravity vs. bitumen Content
- Air voids (Va) vs. Bitumen Content
- Voids Filled with Bitumen (VFB) vs. Bitumen Content

3.3.2 Determination of OBC by marshal test

It is common practice to design the mix using the Marshall Test (ASTM D1559) and to select the design binder content by calculating the mean value of the binder contents for (a) maximum stability, (b) maximum density and (c) the mean value for the specified range of void contents. The following method (which is used for this thesis) is commonly used to determine the optimum asphalt content from the plots of volumetric analysis and stability.

NAPA (National Asphalt Pavement Association) Procedure

1. Determine the asphalt content which corresponds to the specification's median air void content (4 percent typically). This is the optimum asphalt content.
2. Determine the following properties at this optimum asphalt content by referring to the plots:
   - Marshall Stability
   - Flow
   - VMA and VFA.
3. Compare each of these values against the specification values and if all are within the specification, then the preceding optimum asphalt content is satisfactory. If any of these properties is outside the specification range, the mixture should be redesigned.

Figure 3.4.1 Compacted asphalt mixture samples without additives

Thus, all the calculated and measured mix properties for the average asphalt content is compared with criteria for acceptability given in Table 3.4. The Marshal properties of individual mixes, prepared using different amount of CR: SF, obtained at their optimum binder content was evaluated and will be discussed in chapter 4.

Table 3.4.1 Marshall Mix Design Criteria [ERA Manual]

Marshall Method Criteria	Light Traffic Wearing & binder coarse HMA		Medium Traffic Wearing & binder coarse HMA		Heavy Traffic Wearing & binder coarse HMA	
	Min	Max	Min	Max	Min	Max
Compaction, number of blows each end of specimen	35		50		75	
Stability (N)	3336		5338		8006	
Flow (0.25 mm)	8	18	8	16	8	16
Percent Air Voids (%)	3	5	3	5	3	5
Voids Filled With Asphalt (VFA) (%)	70	80	65	78	65	75

.

The optimum bitumen content (OBC) for proposed mix is the average of three values of bitumen content, which include:

1. Bitumen content at the highest stability (*% mb*)*Stability*
2. Bitumen content at the highest value of bulk density (*% mb*) *bulk density*
3. Bitumen content at the median of allowed percentages of air voids (*% mb*) *Va*

Marshal graphs are utilized to obtain these three values.

$$\mathbf{OBC} = \frac{\mathbf{A+B+C}}{\mathbf{3}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{1}$$

Where: A is the Bitumen content at maximum stability,

B is the Bitumen content at maximum density and

C is the Bitumen content at medium air voids.

3.5 Experimental Sample Preparation

Bitumen without debris and adulterants was collected and heated to a temperature of above 150^{o}C to transform it to liquid. The SF: CR was weighed with respect to 0%:1%, 3%:0.9%, 5%:0.7%, 7%:0.5%, 10%:0.3%, 12%:0.1% and 15%:0% weight of the bitumen optimum bitumen content.

Table 3.5 shows the mix ratio for modified asphalt mixtures

Sample No	CR(% by bitumen weight)	SF(% by bitumen weight)	Weight of CR (g)	Weight of SF (g)	Weight of SF-CR (g)	OBC (g)	Weight of Bitumen (g)	Aggregate Blend (g)
1	0%	1%	0.000	0.660	0.660	66	65.340	1134
2	3%	0.90%	1.980	0.594	2.574	66	63.426	1134
3	5%	0.70%	3.300	0.462	3.762	66	62.238	1134
4	7%	0.50%	4.620	0.330	4.950	66	61.050	1134
5	10%	0.30%	6.600	0.198	6.798	66	59.202	1134
6	12%	0.10%	7.920	0.066	7.986	66	58.014	1134
7	15%	0%	9.900	0.000	9.900	66	56.100	1134

The weight of the pure liquid bitumen was measured into a steel cylinder and heated till it fully liquefied and was in a state to dissolve the SF: CR. The SF: CR were separately weighed and blended into measured bitumen and after continuous stirring by steel spoon, it was thoroughly mixed with hot bitumen. The aggregate blend was also weighed and heated in order to remove moisture as well as making the sample a Hot Mix Asphalt mixture. Table **3.5** shows the mix ratio for modified asphalt mixtures.

3.6 Testing Program

3.6.1 Marshall Test

Mix work prepared according to Marshall procedure specified in ASTM D1559 for bituminous, course aggregate fine aggregate and filler were mixed according to the adopt gradation. The test was conducted on all the samples in order to determine optimum bitumen content and optimum CR: SF content. The mixing of ingredients was done as per the following procedure:-

step 1. Required quantity of course aggregate, fine aggregate and filler were taken in a pan and kept at a temperature of 160°C in an oven for pre heating so that the aggregate and bitumen are to be mixed in heated state.

step 2. Required amount CR: SF was weighed and kept separate in the pan.

step 3. Side by side the bitumen was also heated up to its melting point before mixing.

step 4. After that compaction mold assembly is cleaned and kept for pre heating at a temperature of 100°C.

step 5. The aggregates are kept over hot plate and mixed thoroughly for two minutes after that required quantity of CR: SF is added to heated bitumen.

step 6. Now required percentage of bitumen is added to the whole mix and the whole mix was stirred for twenty minutes until whole mix forms the uniform color.

step 7. Whole mix is transferred to casting mould which was placed in Marshall Compaction pedestal.

step 8. The mix is compacted with 75 no. of blows of the hammer on both side.

step 9. After compacting the sample with mould is kept to cool down for few hours.

step 10. The sample is extracted out from the mould and kept at room temperature for 24 hours.

step 11. Before testing weight in air and sub merge weight of sample is measured, after that the sample is kept in a water bath for 45minutes having temperature of 60℃.

step 12. After that the sample is placed in Marshall testing machine to measure stability and flow.

3.6.2 Permeability

Permeability of all the samples was measured using constant-head procedure. According to Equation (4), permeability of the compacted porous asphalt mixtures was calculated:

$$K = \frac{QL}{Aht} \qquad (4)$$

where Q is the volume of accumulated water, A the cross-section of the compacted asphalt mixture, t the time collecting water, L the length of asphalt sample, and h the height of the water inlet to the water outlet.

3.6.3 Volumetric Properties

Mix design is meant to determine the volume of bitumen binder and aggregate necessary to a mixture with the desired properties. Since weight, measurements are typically much easier; weights are taken and then converted to volume by using specific gravities. The volumetric properties of a compacted paving mixture provide some indication of the mixture’s probable pavement service performance.

The properties that are to be considered include the theoretical maximum specific gravity G_{mm}, the bulk specific gravity G_{mb}, percentage of voids in total mix VTM, percentage volume of bitumen V_b, percentage void in mineral aggregate VMA, percentage voids filled with asphalt VFA, Effective asphalt content P_{be} and film thickness. Figure 3.4.1 below will show a phase diagram of the bituminous mix.

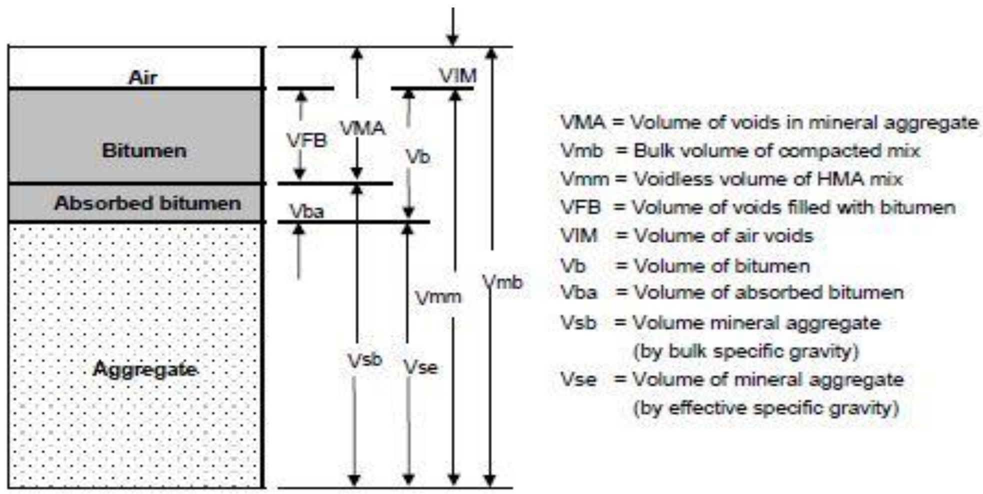


Figure 3.4.1 A phase diagram of the bituminous mix

Percent Air Void in Total Mix – It is the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture. It is computed as:

$$\text{VTM} = 100 * \frac{G_{mm}-G_{mb}}{G_{mm}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Percent Voids in Mineral Aggregate – is the volume of inter granular void space between the aggregate particles of a compacted paving mixture. It includes the air voids and the volume of bitumen not absorbed in to the aggregate. It is expressed as a percentage of the total mix. It is calculated as:

$$\text{VMA} = 100 - \frac{G_{mb}}{G_{sb}} * P_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Percentage Voids Filled with Asphalt – is the voids in the mineral aggregate framework filled with bitumen binder. This represents the volume of the effective bitumen content. It is inversely related to air voids. It is calculated as:

$$\text{VFA} = 100 * \frac{VMA - G_a}{VMA} \quad (7)$$

Effective Asphalt Content of a Mix – is total asphalt content of the HMA less the portion of asphalt binder that is lost by absorption into the aggregate (Pavement Interactive, 2010). The effective asphalt content is the measure of the asphalt film around the aggregate. The asphalt film thickness around the aggregate particle can be correlated to the durability, fatigue and moisture damage. The effective asphalt content is calculated as:

$$\text{P}_{be}\,,\% = P_b - \frac{P_{ba}}{100} * P_s \quad (8)$$

Where; P_{be} = effective asphalt content, percent by total weight of the mix

P_b = asphalt content, percent by total weight of mix

P_s = aggregate content, percent by total weight of mixture

P_{ba} = absorbed asphalt, percent by weight of aggregate given by the

$$\text{P}_{ba}\,,\% = 100 * \frac{G_{se} - G_{sb}}{G_{se} * G_{sb}} * G_b \quad (9)$$

Where G_{sb}= bulk specific gravity of total aggregate

G_b = specific gravity of bitumen

G_{se} = is the effective specific gravity of aggregate given by the equation

$$G_{se} = \frac{100 - P_{mb}}{\frac{100}{G_{mm}} * \frac{P_b}{G_b}} \quad (10)$$

Where P_b = bitumen content at which G_{mm} was performed

G_{mm} = maximum specific gravity of mixed materials (no air voids)

G_b = specific gravity of bitumen

Film Thickness – It refers to the average of binder coating aggregate particles in the mixture. It is a computed value that defines the thickness of the effective asphalt binder coating on each particle in the mixture and is use to ensure that the HMA has adequate asphalt binder to achieve a desired level of mix durability (Krishnamurthy, et al., 2012). Film thickness is calculated by:

$$F = \frac{P_{be}}{100-P_b} * \frac{1}{A} * \frac{1}{S} * 10^6 \quad \ldots\ldots\ldots\ldots\ldots (11)$$

Where; F = Film thickness (μm)

P_{be} = effective asphalt content, percent by total weight of the mix

P_b= asphalt content, percent by total weight of mix

A = surface area of aggregate blend (m2/kg)

S = density of bitumen at 250^0C (kg/m3)

In addition, the surface area of the aggregate blend is computed by:

A = (2+0.02a+0.04b+0.08b+0.14d+0.3e+0.6f+1.6g)*0.20482

Where; a = percentage passing 4.75mm sieve

b = percentage passing 2.36mm sieve

c = percentage passing 1.18mm sieve

d = percentage passing 0.600mm sieve

e = percentage passing 0.300mm sieve

f = percentage passing 0.150mm sieve

g = percentage passing 0.075mm sieve

CHAPTER FOUR

RESULTS AND DISCUSISION

4.1 Introduction

Results of laboratory work had been obtained and analyzed in order to achieve study objectives which include studying the effect of adding different percentages of CR: SF on the mechanical properties of asphalt mix and identify the optimum percent of CR: SF to be added to hot mix asphalt. Laboratory work results are presented in this chapter in three stages. First, handle the results of blending aggregates to obtain asphalt wearing course gradation curve. Second stage, Marshal Test is carried out with different percentages of bitumen which are (4, 4.5, 5.0, 5.5 and 6.0%) and the results are analyzed in order to obtain the optimum bitumen content (OBC). After obtaining OBC, the third step is to study the effect of adding different percentages of CR: SF on asphalt mix properties which are (0%: 1%, 3%: 0.9%, 5%: 0.7%, 7%: 0.5%, 10%: 0.3%, 12%: 0.1% and 15%: 0%) by weight of bitumen. Marshal test results for modified asphalt mixes are analyzed and finally the optimum CR: SF modifier content is obtained.

As it was discussed in the previous chapters, various experiments need to be performed to reveal the physical and performance properties of the asphalt mixtures. Therefore, volumetric, stability and flow properties of mixtures were measured to evaluate the effect of HMA incorporation with dry process CR: SF modification. In this chapter, the results of these tests were presented and discussed in order to determine the advantages and disadvantages of the proposed method.

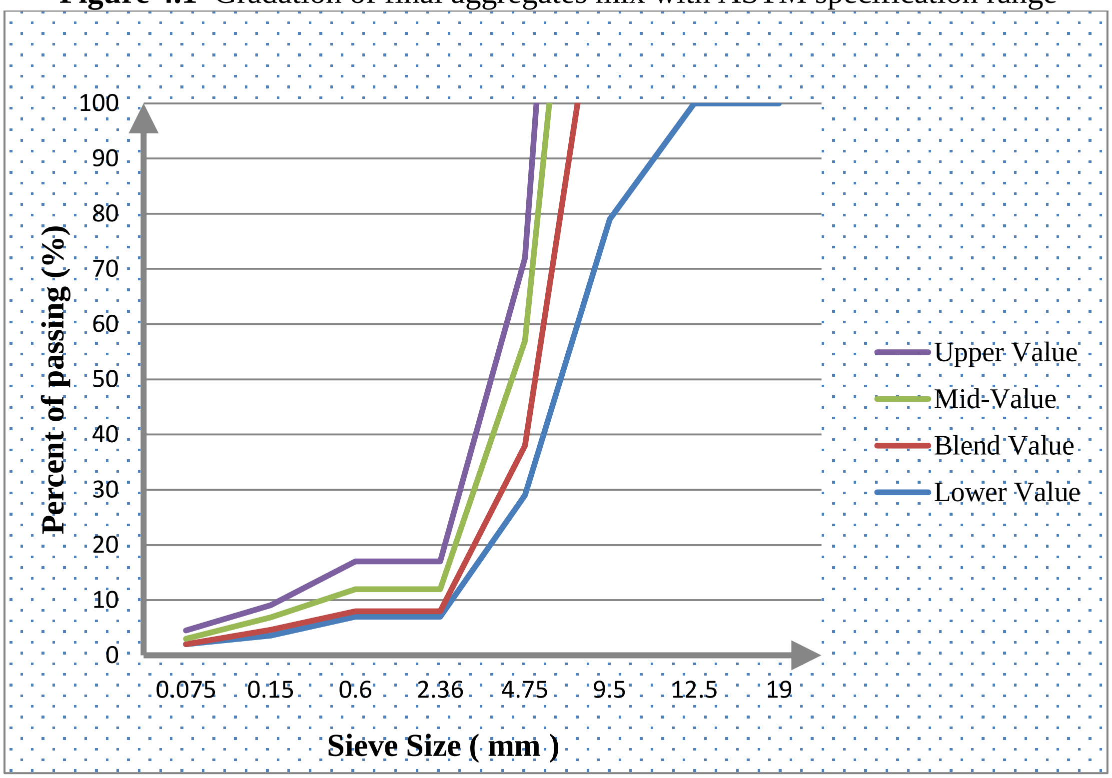
This chapter discusses about the laboratory test results and the interpretations of the results. These interpretations are then used to draw up a conclusion on the mix design and provide a recommendation.

4.2 Blending of aggregates

HMA is graded by percentage of different-size aggregate particles it contains. Appendix's A illustrates HMA gradations which is the normal gradation used as a control for the study. Certain terms are used in referring to aggregate fractions: Course aggregate -G-1 ¾ inch, Coarse Aggregate -G-2, 3/8 inch, Fine Aggregate - G-3, Brick Mineral Filler & dust– G-4.

The final ratio of each aggregate material in asphalt wearing course is shown in Appendix's A. The proposed aggregates gradation curve is found to be satisfying ASTM specification for asphalt wearing course gradation. The gradation of final aggregate mix with ASTM gradation limits is presented in Figure 4.1.

Figure 4.1 Gradation of final aggregates mix with ASTM specification range



4.3 Optimum Bitumen Content

It is considered that the effective asphalt content in the mixture determines the performance of mixtures. This can be explained as that it is the effective asphalt binder content that makes the asphalt film around the aggregate particles. If the asphalt film thickness around the aggregate particles is thick enough, various desirable characteristics such as better durability, more fatigue resistance, and higher resistance to moisture induced damage can be achieved from bituminous mixtures. But, there should be a maximum limit where up on an increase in temperature and loading, the asphalt content in the mix gets increased and results bleeding on the surface of paved road. Table 4.3 and Figures 4.2 – 4.7 show summary of Marshal Test results. Further details are offered in Appendix C.

Table 4.3 Optimum bitumen content determination of bituminous mixtures

Asphalt Content, (%)	Unit Weight, (mg/m^3)	Air Void,Va, (%)	VMA,(%)	VFB,%	Stabilty,(N)	Flow,(mm)
4.0	2.215	10.3	20.31	49.3	10.68	3.65
4.5	2.249	8.8	19.5	54.9	11.35	3.66
5.0	2.288	5.6	18.54	69.8	11.71	3.78
5.5	2.298	4.6	18.62	75.3	10.88	3.60
6.0	2.307	3.8	18.72	79.7	10.81	3.48

4.3.1 Stability – bitumen content relationship

The stability results for various bitumen contents are shown in Figure 4.2. Stability of asphalt mix increased as the bitumen content increased till it reached the peak at bitumen content 5.0 % then it started to drop gradually at higher bitumen content.

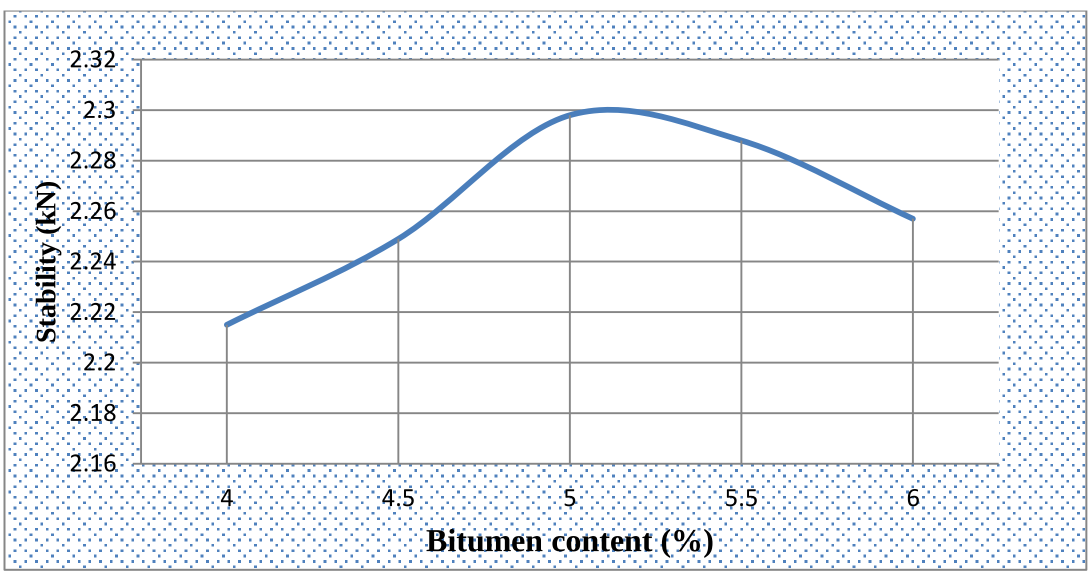


Figure 4.2 Stability vs. bitumen contents

4.3.2 Flow – bitumen content relationship

Figure 4.3 displays the Flow results for different bitumen contents. Maximum bitumen content of 6.0% is the peak of Flow of asphalt mix; with the Flow increasing gradually before this peak.

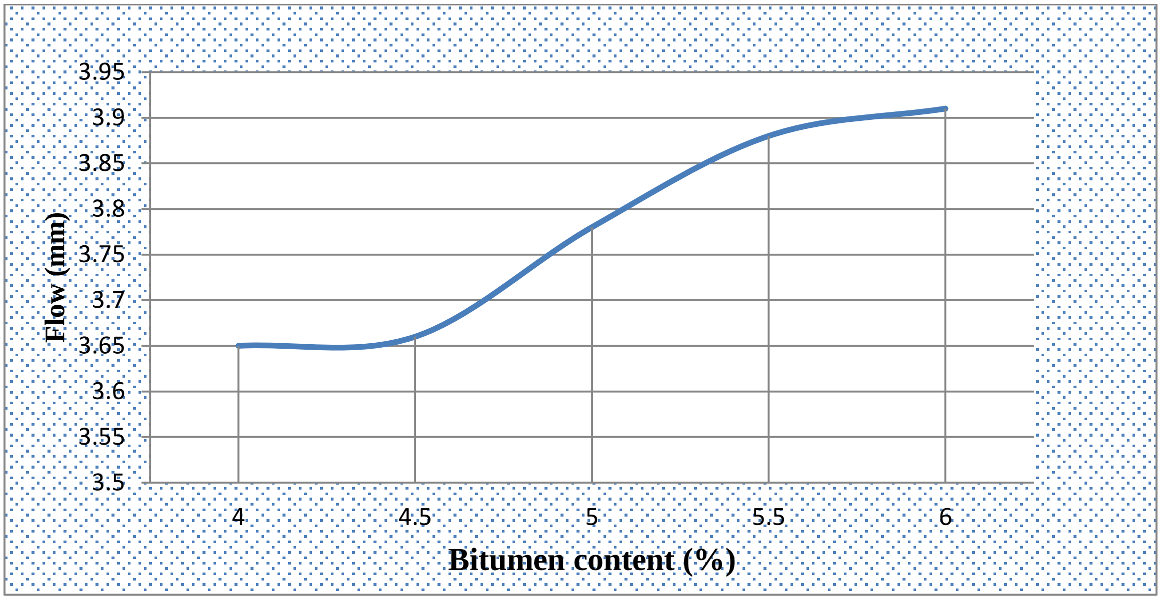


Figure 4.3 Flow vs. bitumen content

4.3.3 Bulk density – bitumen content relationship

Bulk density is the real density of the compacted mix. Figure 4.4 display the Bulk density results for different bitumen contents are represented. Bulk density of asphalt mix increases as the bitumen content increase till it reaches the peak (2.298 g/cm3) at bitumen content 5.5 % then it started to decline gradually at higher bitumen content.

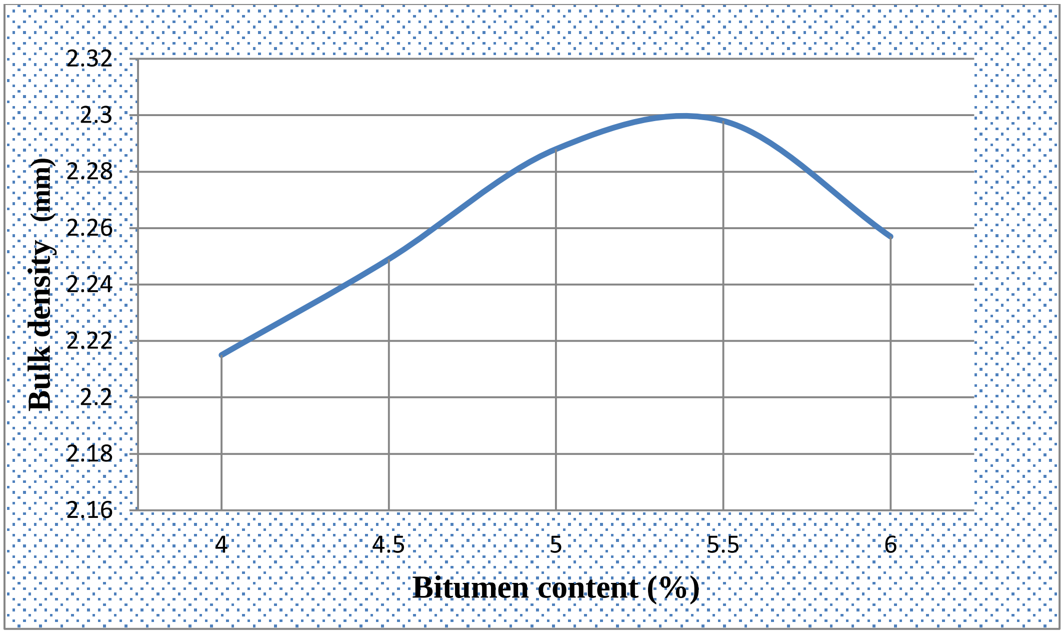


Figure 4.4 Bulk density vs. bitumen content

4.3.4 Air voids content – bitumen content relationship

Figure 4.5 display the V_a % results for different bitumen contents are represented. Maximum air voids content value is at the lowest bitumen percentage (4.5%), V_a % decrease steadily as bitumen content increase due to the increase of voids percentage filled with bitumen in the asphalt mix.

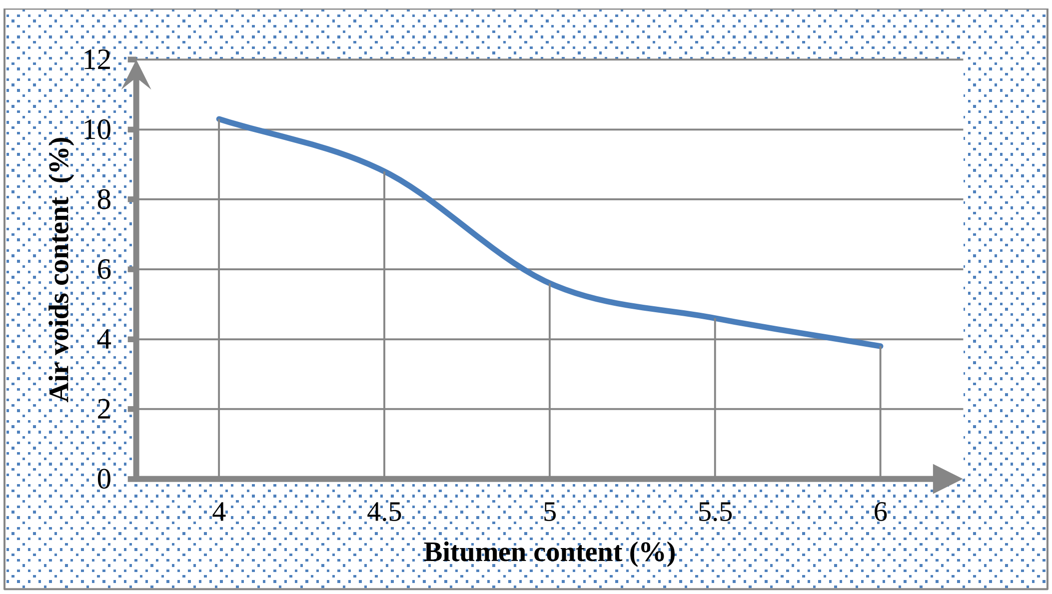


Figure 4.5 Mix air voids proportion vs. bitumen content

4.3.5 Voids Filled with Bitumen– bitumen content

Figure 4.6 display the VFB % results for different bitumen contents are represented. Minimum VFB content value is at the lowest bitumen percentage (4.5%), VFB% increase steadily as bitumen content increase due to the increase of voids percentage filled with bitumen in the asphalt mix.

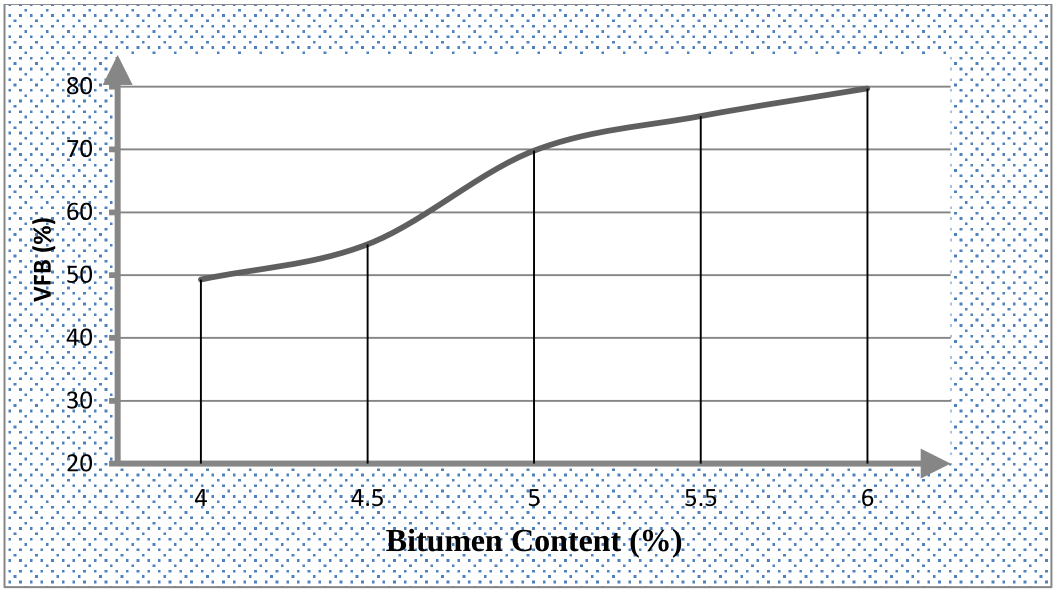


Figure 4.6 Voids filled bitumen proportion vs. bitumen content

4.3.6 Voids in Mineral Aggregates - bitumen content relationship

Figure 4.7 display the VMA results for different bitumen contents are represented. VMA decrease steadily as bitumen content increase and fill higher percentage of voids in the asphalt mix.

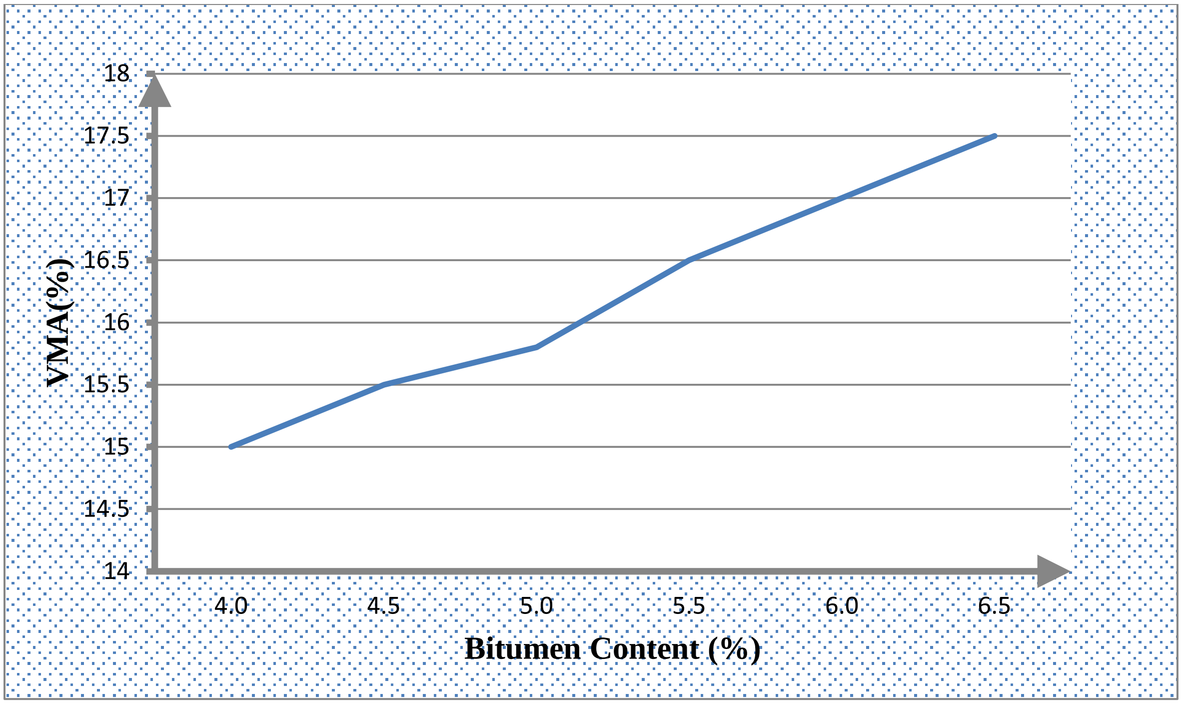


Figure 4.7 Voids of mineral aggregates proportion vs. bitumen content

4.3.7 Determination of optimum bitumen content (OBC)

After measurement of stability and Flow from the prepared specimen using Marshall test (ASTM D 1559) it is common practice to select the design binder content by calculating the mean value of the binder contents for (a) maximum stability, (b) maximum density and (c) the mean value for the specified range of void contents .

Compare values from with criteria for acceptability given in Table 4.4. The properties of the mix design at this design binder content with recommended Marshall Criteria is then shown in Table 4.8 and Table 4.9. The detail work procedure of the Marshall Test method for this study is attached in Appendix C. The optimum asphalt content values were required to fulfill the Marshall requirement is 5.5%.

Table 4.4 Properties of the asphalt mix using optimum bitumen content

Property	Value	Mix Criteria	Range of bitumen content that satisfy the specific requirements
Stability (kg)	10.88	Min. 9KN	4.0 - 6.0
Flow (mm)	3.60	2-4mm	4.0 - 5.7
VMA (%)	18.62	10%-16 %	4.0 - 6.0
Va (%)	4.60	3%-6%	5.0 - 6.0

4.4 Effect of adding CR-SF on the mechanical properties of asphalt mix

4.4.1 Phase I: Conventional asphalt mix

The mechanical properties of asphalt mix prepared with OBC (5.50 %) without addition Of CR: SF is shown in Table 4.5

Table 4.5 Mechanical properties of asphalt mix without addition of CR: SF

Bitumen %(by total weight)	Sample No.	Stability (Kg)	Flow (mm)	ρA (g/cm3)	Va (%)	VMA (%)	VFB (%)
5.5 %	1	10.70	3.55	2.290	4.9	18.89	74.1
	2	10.10	3.40	2.294	4.8	18.75	74.4
	3	11.84	3.85	2.309	4.2	18.22	76.9
	Average	**10.88**	**3.60**	**2.298**	**4.6**	**18.62**	**75.3**

4.4.2 Phase II: Asphalt mix with CR: SF

According to procedure previously illustrated in Chapter (3), twenty one samples were prepared at OBC to evaluate the effect of adding CR: SF to asphalt mixture samples by considering seven proportions of CR: SF (0%:1%, 3%:0.9%, 5%:0.7%, 7%:0.5%, 10%:0.3%, 12%:0.1% and 15%:0%) by weight of bitumen. Table 4.6 shows the mechanical properties of asphalt mix using different percentages of CR: SF at the OBC. Further details are presented in Appendix D.

Table 4.6 Summary of Mechanical properties of asphalt mix with CR: SF

CR:SF (%)	% SF of bitumen content	% CR of bitumen content	Stability (Kg)	Flow (mm)	ρA (g/cm3)	Va (%)	VMA (%)	VFB (%)
S-1	1%	0%	14.8	3.33	2.335	4.8	17.2	72.1
S-2	0.9%	3%	15.8	3.40	2.342	4.4	17.0	74.1
S-3	0.7%	5%	18.3	3.80	2.671	4.1	16.7	75.7
S-4	0.5%	7%	16.9	3.67	2.361	3.7	16.4	77.1
S-5	0.3%	10%	13.4	3.48	2.652	4.0	5.9	32.7
S-6	0.1%	12%	13.9	3.17	2.592	4.3	8.1	46.2
S-7	0%	15%	14.4	3.37	2.595	4.2	8.1	47.3

4.4.3 Stability – CR: SF content relationship

The stability test results are shown in Figure 4.8. The results show that the stability increases with increasing crumble rubber and decreasing sisal fibers content up to the optimum modifier content and thereafter decreases. The optimum modifier content was found to be S-3.

It can be seen that the stability values for both mixtures met the ERA specification of not less than 9 KN. The results indicate that the asphalt mixture with 0.7% of SF & 5% of CR has better stability than that of asphalt mixtures without any mixtures. The increase in stability can be attributed to improved adhesion between the aggregate and bitumen.

Generally, the stability of modified asphalt mixes is higher than the conventional asphalt mix (10.88 kg). The maximum stability value is found nearly (18.3 kg) at CR: SF content around **S-3 (0.7% of SF & 5% of CR**). Figure 4.8 shows that the stability of modified asphalt mix.

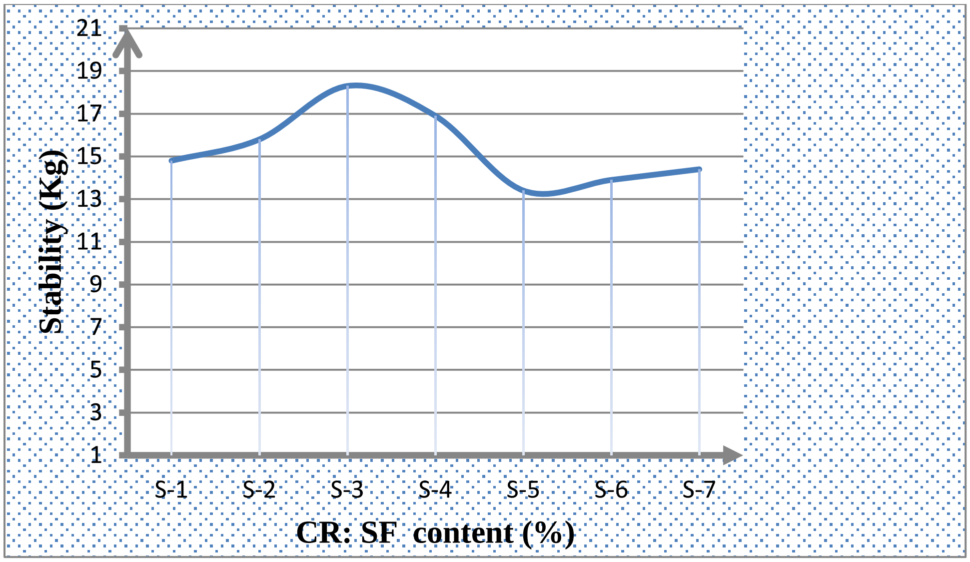


Figure 4.8 Asphalt mix Stability – CR: SF content relationships

4.4.4 Flow – CR-SF content relationship

Marshall Flow measured simultaneously with Marshall Stability, measured the vertical deformation of the samples while loaded. The flow value for the porous asphalt with CR: SF is presented in Fig. 4.9. The flow value for 0% of CR & 1% of SF content was 3.33 mm. An increase in crumble rubber and decreasing sisal fibers content resulted in an increase in flow up to an optimum value of 0.7% of SF & 5% of CR content (3.8 mm). Further addition of crumble rubber and reducing of sisal fibers content caused the flow to decrease.

Generally, the flow of modified asphalt mix is higher than the conventional asphalt mix (3.6 mm). Figure 4.9 shows that the flow increases continuously as the percentage of CR increase SF decrease increase then start to decrease after S-3. The flow value extends from 3.33mm till it reaches 3.8mm at S-3 content (0.7% of SF & 5% of CR).

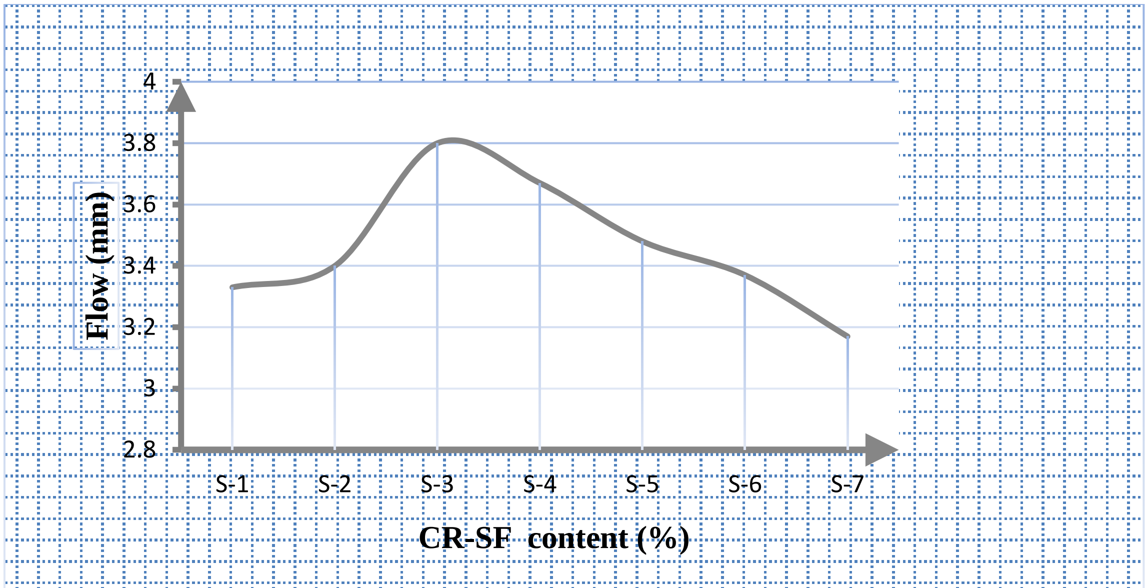


Figure 4.9 Asphalt mix flow – CR: SF mixes content relationship

4.4.5 Bulk density – CR: SF content relationship

The bulk density of CR: SF modified asphalt mix is higher than the conventional asphalt mix (2.307g/cm3). The general trend shows that the bulk density decreases as the CR: SF content increase. The maximum bulk density is (2.671 g/cm3) at S-3 and the minimum bulk density is (2.335 g/cm3) at S-1. Figure 4.10 show the curve which represents asphalt mix bulk density – CR: SF content relationship.

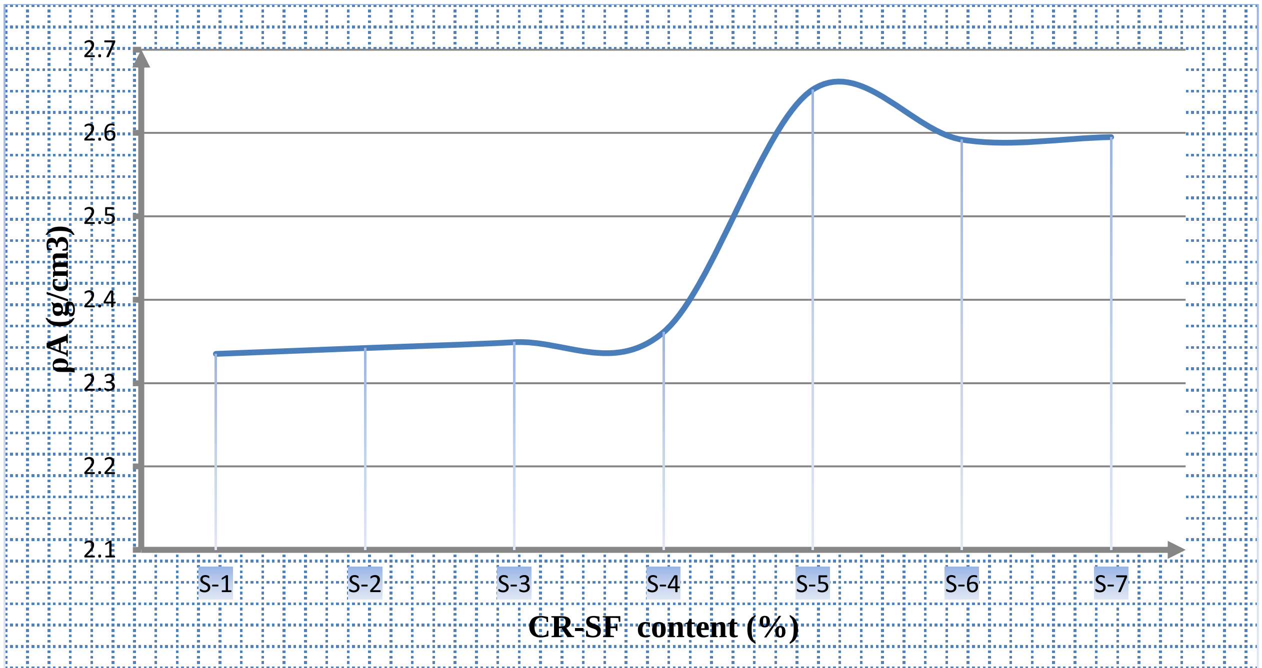


Figure 4.10 Asphalt mix bulk density – CR: SF relationship

4.4.6 Air voids – CR: SF content relationship

In general, the air voids proportion of modified asphalt mixes is lower than conventional asphalt mix (5.1 %). Va % of modified asphalt mixes have maximum value at S-1 . Generally modified asphalt mixes have Va% content within specifications range. Figure 4.11 shows the curve which represents asphalt mix air voids – CR: SF content relationship.

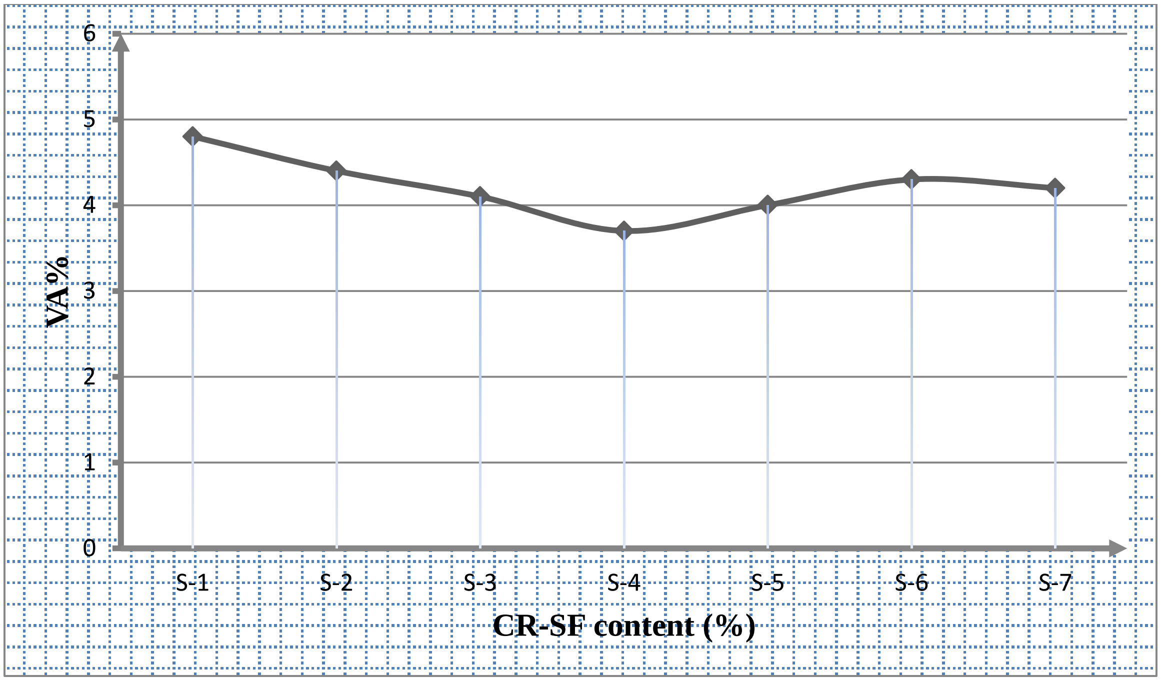


Figure 4.11 Asphalt mix air voids – CR:SF content relationship

4.4.7 Voids in mineral aggregates – CR: SF content relationship

The voids in mineral aggregates percentage for asphalt mix is affected by air voids in asphalt mix and voids filled with bitumen. VMA % of modified asphalt mixes decreases as the CR-SF content increase, it reaches (17.2%) at S-1. Figure 4.12 show the curve which represents asphalt mix VMA% – CR: SF content relationship.

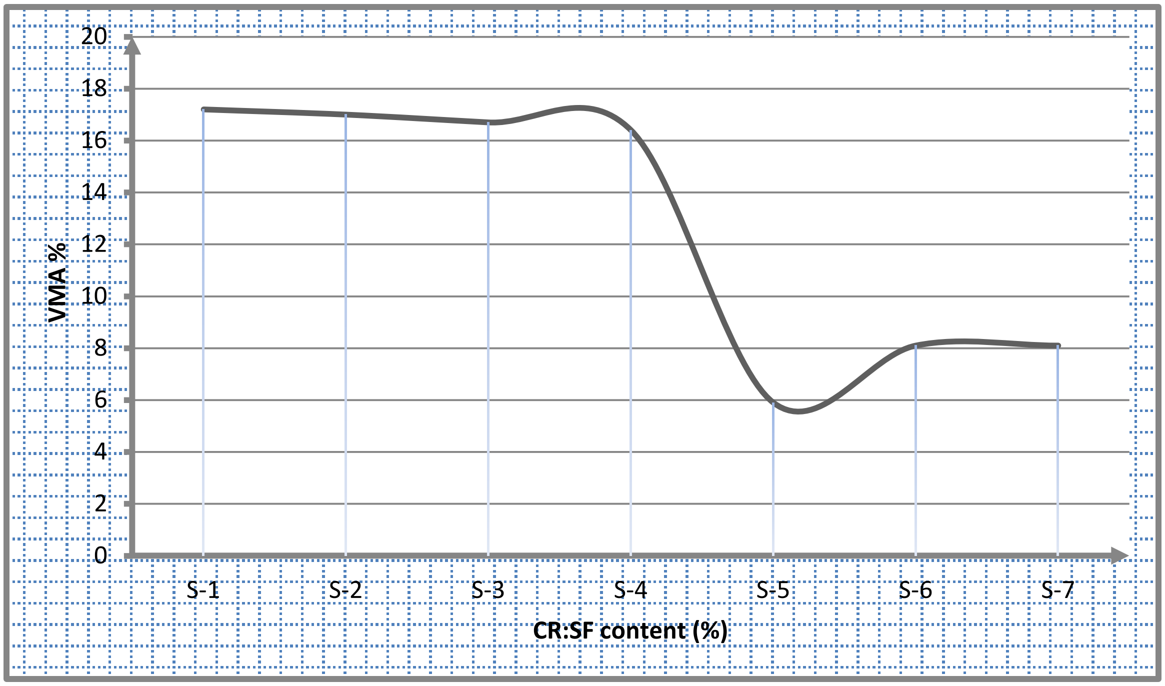


Figure 4.12 Asphalt mix voids of mineral aggregates – CR: SF content relationship

4.4.8 Optimum modifier content

A set of controls is recommended in order to obtain the optimum modifier content that produce an asphalt mix with the best mechanical properties (Jendia, 2000). Asphalt mix with optimum modifier content satisfies the Maximum stability, Maximum bulk density & Va % within the allowed range of specifications.

It's clearly shown that asphalt mix modified with (9 % WPB by OBC weight) have higher stability and stiffness compared to the conventional asphalt mix, other properties of modified mix are still within the allowed range of the specifications.

As shown in Figures (4.8, 4.10 and 4.11) it's obvious that modified asphalt mix with 0.7% of SF and 5% of CR by weight of OBC satisfy the requirements of specifications, and Asphalt Institute specifications for all tested properties.

4.4.9 Evaluation of CR: SF modified asphalt mix:

The mechanical properties of CR: SF modified asphalt mix at the optimum CR: SF content with 0.7% of SF and 5% of CR by weight of OBC of bitumen is shown in Table 4.8.

Table 4.8 Properties of CR-SF modified asphalt mix with MPWH specification range

Property	Unmodified asphalt mix	modified asphalt mix
Stability (Kg)	10.88	18.3
Flow (mm)	3.6	3.8
Bulk Specific Gravity (g/cm^3)	2.298	2.349
V_a(%)	4.6	4.1
VFB (%)	75.3	77.1
VMA (%)	16.62	16.7

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

1.1 Conclusions

Stability and flow were improved by adding rubber and sisal fibers to the asphalt pavement. The appropriate percentage was 0.7% of SF and 5% of CR by weight of OBC. Standards indicated that minimum stability of Marshal Test at heavy traffic (75blows) is 680 Kg. and maximum flow is 4mm. The 0.7% of SF and 5% of CR by weight of OBC added match with the above standards.

Based on experimental work results for CR: SF modified asphalt mixtures, the Following conclusions can be drawn:

1. CR: SF can be conveniently used as a modifier for asphalt mixes for sustainable Management of plastic waste as well as for improved performance of asphalt mix
2. The optimum amount of CR: SF to be added as a modifier of asphalt mix was found to be 0.7% of SF and 5% of CR by weight of OBC.
3. Asphalt mix modified with (0.7% of SF and 5% of CR by weight of OBC) has approximately above 40% higher stability value compared to the conventional asphalt mix
4. Asphalt mix modified with CR-SF exhibits higher flow value when the Crumb Rubber percentage increased and SF decreased. However, the stiffness of the modified mix decreased.
5. All test values are consistent with the specifications limits.
6. The results of this study apply only to the type of rubber and fibers that was used. Other sources of rubber and fibers may produce different results.

1.2 Recommendations

- Study recommends local authorities to confirm using CR-SF in asphalt mix with the proposed percentage (0.7% of SF and 5% of CR by weight of OBC) for improved performance of asphalt mix.
- Further studies are needed in various topics related to effective utilization and best incorporation techniques of waste materials in asphalt pavements.
- It is recommended to conduct similar studies on the wearing course layer of asphalt pavement.
- Government and researchers should integrate efforts toward preparing and implementing a sustainable solid waste management plan taking into consideration getting the maximum benefit from the high quantities of solid waste.

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APPENDIX A

Table A-1 Specific gravity and Water Absorption of Coarse aggregates

Specific Gravity And Water Absorption of coarse Aggregate			
Test Method : AASHTO T 85-91			
Trial	**Sample 1**	**Sample2**	**Average**
B. Mass of SSD sample in air (g)	2570	2561	
C. Mass of saturated sample in water (g)	1603.3	1612.1	
A. Mass of oven dry sample in air (g)	2527.12	2525	
Bulk sp. gravity (oven dry) Sd = A/(B-C)	2.614	2.661	**2.638**
Bulk sp. gravity (SSD) Ss = B/(B-C)	2.659	2.699	**2.679**
Water absorption (%) Aw = (B-A)*100/A	1.697	1.426	**1.561**
Water Absorption Specification			**<2**

Table A-2 Specific gravity and Water Absorption of Fine Aggregates

Test Method : AASHTO T 84-95			
Pycnometer number	**1**	**2**	**Average**
B. Mass of Pycnometer + water (g)	672.3	672.3	
S. Mass of SSD sample (g)	250	250	
C. Mass of pycnometer + water+ sample (g)	837.2	829.2	
A. Mass of oven dry sample in air (g)	245.1	245.4	
Bulk sp. gravity (oven dry) Sd = A*k/(B+S-C)	2.880	2.636	**2.758**
Bulk sp. gravity (SSD) Ss = S*k/(B+S-C)	3.117	2.825	**2.971**
Apparent specific gravity Sr = A*k/(A+B-C)	3.056	2.773	**2.914**
Water absorption (%) Aw = (S-A)*100/A	1.999	1.874	**1.937**
Water Absorption Specification (%)			**<2**

Table A-3 Aggregate Crushing Value

Aggregate Crushing Value			
Test Method : BS:812 Part 110 (1990)			
TRIAL No.	**1**	**2**	**Average**
Mass of sample (12mm pass and 10mm Retain) (g)	2385	2390	
Mass of sample retained on B.S Sieve,2.36mm (g)	2105	2091	
Mass of sample passing B.S Sieve,2.36mm (g)	290	299	
Aggregate Crushing Value (ACV) (%)	13.2	12.5	
Average ACV (%)			**12.85**
Specification (%)			**<25**

Table A-4 Aggregate LAA test result

Resistance to Abrasion of Aggregate by using LAA			
Test Method : AASHTO T 96-94			
Material Description :	Crushed Stone		
Sieve Sizes	3/4 - 1/2 "	1/2 - 3/8 "	
Grade	B		
Number Of Balls	11 BALLS		
Wt. Of Indicated Size	2500 + 10	2500 + 10	
Test Results			
Trial	1	2	
Average			
Number Of Revolution	500	500	
Total Wt. of Sample Tested (g)	5000	5000	
Wt. Of Tested Sample Retained On No. 12 Sieve (1.7mm) (g)=W1	4345	4355	
Wt. Of Tested Sample passed On No. 12 Sieve (1.7mm) (g)=W2	655	645	
Percent Loss, (%)=W2/W1*100	13.10	12.90	**13.00**

Table A-5 Aggregate Flakiness Test

Flakiness Index Record		
BS 812:Section 105.1:1989		
SieveNominal Size (mm)	**Retained Sample (g)**	**% Retained**
63	0	
50	0	
37.5	0	
28	0	
20	775	44
14	498	28
10	255	14
6.3	253	14
SUM	1781	100
Take Mass Retained in gm for FI Calculation only that of % Retained >5%.		

Flakiness Index Calculation			
Sieve Size (mm)		**Mass Retained (g)**	**Mass Passing (g)**
100% Passing	**100% Retained**		
63	50	0	0
50	37.5	0	0
37.5	28	0	0
28	20	775	98
20	14	498	86
14	10	255	111
10	6.3	253	80
TOTAL		**1781**	**375**
FI=Total Mass Passing / Total Mass Retained * 100			
		FI=	**21.06**
Specification (%)			**<45**

Table A-6 Sand Equivalent Value

SAND EQUIVALENT VALUE		
TEST METHOD : AASHTO T 176		
TEST No.	**1**	**2**
A. Sand Reading (mm)	92	93
B. Clay Reading (mm)	120	122
Sand Equivalent (%) =A/B x 100 %	76.67	76.23
Average Sand Equivalent (%)		**76.45**
Specification (%)		**>40%**

Table A-7 Soundness test by using Sodium Sulfate solution

SOUNDNESS OF AGGREGATE BY USE OF SODIUM SULFATE OR MAGNESIUM SULFATE						
TEST METHOD : AASHTO T104-97						
Cycle	**IMMERSION**				**Number of hours**	**Specific gravity of solution**
	Beginning		**Ending**			
	Date	**Time**	**Date**	**Time**		
1.Immersion	13/10/2020	5:00pm	14/10/2020	10:00AM	17	1.161
2.Immersion	14/10/2020	5:00pm	15/10/2020	10:00AM	17	1.161
3.Immersion	15/10/2020	5:00pm	16/10/2020	10:00AM	17	1.161
4.Immersion	16/10/2020	5:00pm	17/10/2020	10:00AM	17	1.161
5.Immersion	17/10/2020	5:00pm	18/10/2020	10:00AM	17	1.161

SOUNDNESS TEST OF FINE AGGREGATE					
SIEVE SIZE (mm)	**% Retained of Original Sample**	**Mass of Sample Before Test (g)**	**Wt. of Sample After Test (g)**	**% Loss After Test**	**Weighted % Loss**
Minus 0.15	3.9				
0.3 - 0.15	10.1				
0.6 - 0.3	13.8	100	93	7.0	0.97
1.18 - 0.6	21.4	100	95	5.0	1.07
2.36 - 1.18	26.7	100	94	6.0	1.6
4.75 - 2.36	8.4	100	93	7	0.59
10.0-5					
TOTALS					**4.23**

SOUNDNESS TEST OF COARSE AGGREGATE					
SIEVE SIZE (mm)	**% Retained of Original Sample**	**Mass of Sample Before Test (g)**	**Wt. of Sample After Test (g)**	**% Loss After Test**	**Weighted % Loss**
63 - 50					
50 - 37.5					
37.5 - 25					
25-19	20.2	500	470	6.0	1.25
19-12.5	26	1020	975	4.4	1.14
12.5 - 9.5 9.5 - 4.75	33.6	308	288	6.5	2.18
TOTAL	79.8				**4.57**
Specification					**<12**

APPENDIX B

Aggregate Gradation

Table B-1 Aggregate Gradation

AGGREGATE BLENDING FOR ASPHALT MIX DESIGN

LOCATION:	Asphalt mix plant				Aggregate Spec (UL & LL)				ERA 2002, Technical Specification Table			
JIMMA												
PURPOSE:	Agg. For Asphalt mix											
Material Descption:	Crushed Basalt											
Percent Passing												
SIEVE SIZE		**25**	**19**	**12.5**	**9.5**	**4.75**	**2.36**	**1.18**	**0.6**	**0.3**	**0.15**	**0.075**
14--25mm		100	71.2	7.6	0.9	0.1	0.1	0.1	0.1	0.1	0.1	0.1
6--14mm		100	100	98.919	76	6.5	0.5	0.2	0.1	0.1	0.1	0.1
3--6mm		100	100	100	99.491	90.7	15.7	5.8	3.3	1.6	0.3	0.2
0--3mm		100	100	100	99.6	99.2	95.018	64.318	44.718	29.418	23.518	14.718
Filler		100	100	100	100	100	100	100	100	100	100	100
SIEVE SIZE	**Blending %**	**25**	**19**	**12.5**	**9.5**	**4.75**	**2.36**	**1.18**	**0.6**	**0.3**	**0.15**	**0.075**
14--25mm	25	25	17.8	1.9	0.2	0	0	0	0	0	0	0
6--14mm	22	22	22	21.8	16.7	1.4	0.1	0	0	0	0	0
3--6mm	11	11	11	11	10.9	10	1.7	0.6	0.4	0.2	0	0
0--3mm	40	40	40	40	39.8	39.7	38	25.7	17.9	11.8	9.4	5.9
Filler	2	2	2	2	2	2	2	2	2	2	2	2
Total	**100**	**100**	**92.8**	**76.7**	**69.6**	**53.1**	**41.8**	**28.3**	**20.3**	**14**	**11.4**	**7.9**
UL (specification)		100	100	84	76	60	48	38	20	20	15	10
LL (specification)		100	85	71	62	42	30	22	16	12	8	4
Middle range		100	92.5	77.5	69	51	39	30	18	16	11.5	7
Blended Grading		100	92.8	76.7	69.7	53.1	41.9	28.4	20.3	14	11.5	7.9

APPENDIX C

Volumetric Analysis & Marshal Stability Results Without any modifiers

Determination of the theoretical maximum density for the asphalt mix

It is known that calculating the theoretical asphalt mix density can be done by using the Pycnometer or by calculations using specific gravities for all aggregates.

The Inputs of the Binder Course Job Mixes

Used Equations to calculate the mechanical properties of asphalt mix

- ✓ Va =Air voids contents in total mix.
- ✓ Vb = Percent bitumen volume.
- ✓ Mb =percent of bitumen
- ✓ %VMA $= Va + Vb$
- ✓ %VFA $= \frac{Vb}{VMA} * 100$
- ✓ VMA $= 100 - \frac{G_{mb}}{G_{sb}} * P_s$
- ✓ VFA $= 100 * \frac{VMA - G_a}{VMA}$
- ✓ P_A=Densityofcompactedmix $(\frac{g}{cm3})$

G_{se} = is the effective specific gravity of aggregate given by the equation

$$G_{se} = \frac{100 - P_{mb}}{\frac{100}{G_{mm}} * \frac{P_b}{G_b}}$$

Where P_b = bitumen content at which G_{mm} was performed

G_{mm} = maximum specific gravity of mixed materials (no air voids)

G_b = specific gravity of bitumen

OPTIMUM BITUMEN CONTENT DETERMINATION OF BITUMINOUS MIXTURES

Table C-1 Volumetric Analysis and OBC Determination of asphalt mixtures without any modifiers

OPTIMUM BITUMEN CONTENT DETERMINATION OF BITUMINOUS MIXTURES

Date 12/10/2020

Compaction = 75 Blows | Specific Gravity of AC = 1.033 | Date 5/12/2020

% AC by wt. of mix,Spec.No.		Spec. Height,mm	Specimen Mass, gm			Bulk Volume, cc	Bulk S.G of Specimen	Th. Max. S.G. (Loose Mix)	Unit Weight, Mg/m^3	% Air Void	% VMA	% VFB	Stability			Flow,mm
			In Air	In Water	SSD In Air								Measured,div	Factor	Adjusted, KN	
4.0	A	65.00	1225.5	676.0	1233.5	557.5	2.198	2.469	2.198	11.0	20.91	47.4	915.0	1.09	12.24	3.98
4.0	B	65.20	1222.5	682.0	1231.0	549.0	2.227	2.469	2.227	9.8	19.87	50.7	945.0	1.09	12.64	3.52
4.0	C	64.82	1229.5	684.0	1238.0	554.0	2.219	2.469	2.219	10.1	20.16	49.9	985.0	1.09	13.17	3.48
Average		65.01					2.215	2.469	2.215	10.3	20.31	49.3			12.68	3.66
4.5	A	64.56	1235.5	691.0	1242.0	551.0	2.242	2.467	2.242	9.1	19.75	53.9	865.0	1.09	11.57	3.45
4.5	B	65.12	1237.0	694.0	1242.5	548.5	2.255	2.467	2.255	8.6	19.28	55.4	830.0	1.09	11.10	3.80
4.5	C	65.2	1240.0	699.0	1250.0	551.0	2.250	2.467	2.250	8.8	19.46	54.8	850.0	1.09	11.37	3.70
Average		64.97					2.249	2.467	2.249	8.8	19.50	54.9			11.35	3.65
5.0	A	65.2	1244.0	699.0	1246.0	547.0	2.274	2.423	2.274	6.1	19.03	67.9	850.0	1.09	11.37	3.60
5.0	B	64.5	1250.0	697.5	1242.5	545.0	2.294	2.423	2.294	5.3	18.32	71.1	930.0	1.09	12.44	3.90
5.0	C	64.95	1238.0	702.0	1241.5	539.5	2.295	2.423	2.295	5.3	18.28	71.0	845.0	1.09	11.30	3.85
Average		64.88					2.288	2.423	2.288	5.6	18.54	69.8			11.70	3.78
5.5	A	64.56	1248.0	705.0	1250.0	545.0	2.290	2.409	2.290	4.9	18.89	74.1	800.0	1.09	10.70	3.55
5.5	B	65.02	1250.0	707.5	1252.5	545.0	2.294	2.409	2.294	4.8	18.75	74.4	755.0	1.09	10.10	3.40
5.5	C	65.12	1247.0	709.0	1249.0	540.0	2.309	2.409	2.309	4.2	18.22	76.9	885.0	1.09	11.84	3.85
Average		64.90					2.298	2.409	2.298	4.6	18.62	75.3			10.88	3.60
6.0	A	65.21	1243.0	703.5	1243.5	540.0	2.302	2.398	2.302	4.0	18.90	78.8	875.0	1.14	12.24	3.50
6.0	B	64.91	1247.5	708.0	1248.0	540.0	2.310	2.398	2.310	3.7	18.61	80.1	770.0	1.09	10.30	3.50
6.0	C	65.02	1252.5	711.0	1253.5	542.5	2.309	2.398	2.309	3.7	18.65	80.2	740.0	1.09	9.90	3.45
Average		65.05					2.307	2.398	2.307	3.8	18.72	79.7			10.81	3.48

THEORETICAL MAXIMUM SPECIFIC GRAVITY OF HOT-MIX ASPHALT PAVING MIXTURES (AASHTO T 209-05)

Date Sampled 02-2-2020
Date Testing 12-3-2020

Table C-2 Theoretical maximum specific gravity of HMA without modifiers

% AC by wt. of mix,Spec.No.		Temprature of Test Water	Mass of Oven Dry Sample in air, g	Mass of Pycnometer filled with water , g	Mass of Pycnometer filled with Sample and water , g	Theoretical Maximum Specific Gravity	Specific Gravity of Bitumen	Effective Specfic Gravity of Combined Aggregate,Gse:
4	A	20.9	3633	1244.4	4373.40	2.469	1.033	2.621
4	B	20.9	3633	1244.4	4373.40	2.469	1.033	2.621
4	C	20.9	3633	1244.4	4373.40	2.469	1.033	2.621
Average								
4.5	A	20.50	3633.00	1245.30	4373.60	2.467	1.033	2.640
4.5	B	22.30	3633.00	1245.30	4373.60	2.467	1.033	2.640
4.5	C	20.90	3633.00	1245.30	4373.60	2.467	1.033	2.640
Average								
5	A	22.30	3633.00	1251.60	4368.00	2.42	1.033	2.608
5	B	21.60	3633.00	1251.60	4368.00	2.42	1.033	2.608
5	C	22.00	3633.00	1251.60	4368.00	2.42	1.033	2.608
Average								
5.5	A	22.00	3633.00	1259.60	4369.70	2.41	1.033	2.611
5.5	B	22.10	3633.00	1259.60	4369.70	2.41	1.033	2.611
5.5	C	22.00	3633.00	1259.60	4369.70	2.41	1.033	2.611
Average								
6	A	22.40	3633.00	1264.90	4370.50	2.40	1.033	2.619
6	B	22.30	3633.00	1264.90	4370.50	2.40	2.033	2.426
6	C	22.00	3633.00	1264.90	4370.50	2.40	3.033	2.366
Average								

OPTIMUM BITUMEN CONTENT DETERMINATION OF BITUMINOUS MIXTURES

Figure C-2 Optimum bitumen content determination of bituminous mixtures

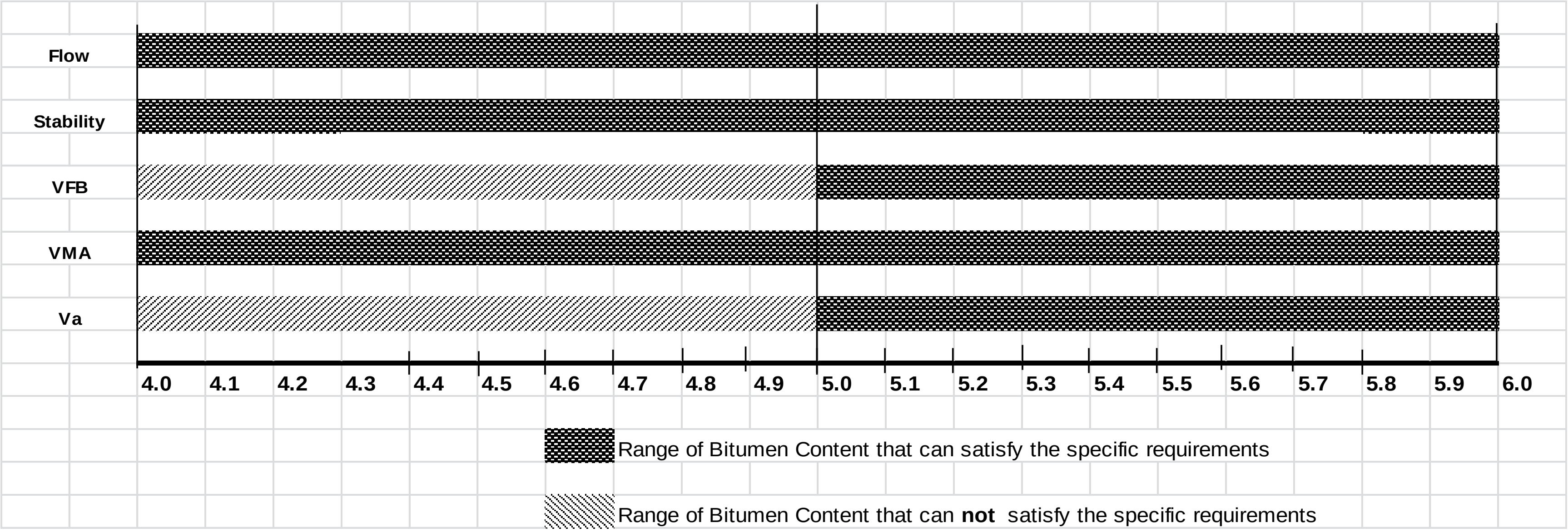

Table C-2 Optimum bitumen content determination of bituminous mixtures

Mix property	Mix Criteria	% Range of bitumen content Compliance with the mix criteria
Va	3-6%	5.0 - 6.0
VMA	10-16 %	4.0 - 6.0
VFB	65-80 %	5.0 - 6.0
Stability	Min. 9KN	4.0 - 6.0
Flow	2-4mm	4.0 - 5.7

APPENDIX D

MARSHALL PROPERTIES OF BITUMINOUS MIXTURES WITH MODIFIERS FOR SAMPLE S-1

CR: SF = 0%:1% (By OBC weight)

Compaction = 75 Blows

Bitumen = 65.34% (By total weight)

Mixing temp. : 150 C

Date Sampled 02-2-2020
Date Testing 12-3-2020

Table D-1 Summary of Volumetric and Marshall Data for Sample 1

% AC by wt. of mix,Spec.No.		Spec. Height, mm	Specimen Mass, gm			Bulk Volume, cc	Bulk S.G of Specimen	Th. Max. S.G. (Loose Mix)	Unit Weight, Mg/m³	% Air Void	% VMA	% VFB	Stability			Flow, mm
			In Air	In Water	SSD In Air								Reading N/div.	Factor	Adjusted, KN	
5.50	A		1244.1	713.0	1246.0	533.0	2.334	2.453	2.334	4.8	17.2	72.0	1200	0.96	14.2	3.30
5.50	B		1245.5	714.0	1247.0	533.0	2.337	2.453	2.337	4.7	17.1	72.5	1250	0.96	14.8	3.20
5.50	C		1247.0	714.0	1248.5	534.5	2.333	2.453	2.333	4.9	17.3	71.8	1290	0.96	15.3	3.50
Average							2.335	2.453	2.335	4.8	17.2	72.1			14.8	3.33
±0.3		Specifiction Limit								3-6%	<14%	65-80%			Min.9KN	2-4mm

THEORETICAL MAXIMUM SPECIFIC GRAVITY OF HOT-MIX ASPHALT PAVING MIXTURES (AASHTO T 209-05)

Table D-2 Theoretical maximum specific gravity of HMA Paving mixtures for Sample 1

% AC by wt. of mix,Spec. No.		Temprature of Test Water	Mass of Oven Dry Sample in air, g	Mass of Pycnometer filled with water , g	Mass of Pycnometer filled with Sample and water , g	Theoretical Maximum Specific Gravity	Specific Gravity of Bitumen	Effective Specfic Gravity of Combined Aggregate,Gse:
4.0	A	25.0	3630.0	1202.3	4341.5	2.5	1.0	2.6
4.0	B	25.2	3630.0	1202.3	4342.5	2.5	1.0	2.6
4.0	C	20.9	3630.0	1202.3	4342.5	2.5	1.0	2.6
Average		23.7	3630.0	1202.3	4342.2	2.5	1.0	2.6

FOR SAMPLE S-2

CR: SF = 3%: 0.9% (By OBC weight)

Compaction = 75 Blows

Bitumen = 63.426% (By total weight)

Mixing temp. : 150^0c

Date Sampled 02-2-2020
Date Testing 12-3-2020

Table D-2 Summary of Volumetric and Marshall Data for Sample 2

% AC by wt. of mix,Spec.No.		Spec. Height, mm	Specimen Mass, gm			Bulk Volume, cc	Bulk S.G of Specimen	Th. Max. S.G. (Loose Mix)	Unit Weight, Mg/m^3	% Air Void	% VMA	% VFB	Stability			Flow, mm
			In Air	In Water	SSD In Air								Reading N/div.	Factor	Adjusted, KN	
5.50	A		1241.5	712.0	1242.5	530.5	2.340	2.450	2.340	4.5	17.0	73.7	1295	0.96	15.3	3.10
5.50	B		1243.6	714.0	1245.0	531.0	2.342	2.450	2.342	4.4	17.0	74.1	1320	0.96	15.6	3.60
5.50	C		1242.5	714.0	1244.0	530.0	2.344	2.450	2.344	4.3	16.9	74.5	1400	0.96	16.6	3.50
Average							2.342	2.450	2.342	4.4	17.0	74.1			15.8	3.40
±0.3		Specifiction Limit								3-6%	<14%	65-80%			Min.9KN	2-4mm

THEORETICAL MAXIMUM SPECIFIC GRAVITY OF HOT-MIX ASPHALT PAVING MIXTURES (AASHTO T 209-05)

Table D-2 Theoretical maximum specific gravity of HMA Paving mixtures for sample 2

% AC by wt. of mix,Spec.No.		Temprature of Test Water	Mass of Oven Dry Sample in air, g	Mass of Pycnometer filled with water , g	Mass of Pycnometer filled with Sample and water , g	Theoretical Maximum Specific Gravity	Specific Gravity of Bitumen	Effective Specfic Gravity of Combined Aggregate,Gse:
4	A	20.9	3633	1244.4	4373.40	2.469	1.033	2.621
4	B	20.9	3633	1244.4	4373.40	2.469	1.033	2.621
4	C	20.9	3633	1244.4	4373.40	2.469	1.033	2.621
Average		20.9	3633	1244.4	4373.4	2.469	1.033	2.621

FOR SAMPLE S-3

CR: SF = 5%:0.7% (By OBC weight)

Compaction = 75 Blows

Bitumen = 62.238% (By total weight)

Mixing temp. : 150^0c

Table D-3 Summary of Volumetric and Marshall Data for sample 3

% AC by wt. of mix,Spec.No.		Spec. Height, mm	Specimen Mass, gm			Bulk Volume, cc	Bulk S.G of Specimen	Th. Max. S.G. (Loose Mix)	Unit Weight, Mg/m^3	% Air Void	% VMA	% VFB	Stability			Flow, mm
			In Air	In Water	SSD In Air								Reading N/div.	Factor	Adjusted, KN	
5.50	A		1236.0	711.0	1237.0	526.0	2.350	2.449	2.350	4.0	16.7	75.9	1500	0.96	17.8	3.90
5.50	B		1235.0	710.0	1236.0	526.0	2.348	2.449	2.348	4.1	16.7	75.5	1550	0.96	18.3	3.60
5.50	C		1224.0	704.0	1225.0	521.0	2.349	2.449	2.349	4.1	16.7	75.7	1580	0.96	18.7	3.90
Total Average							2.349	2.449	2.349	4.06	16.7	75.7			18.3	3.8
5.2																
±0.3		Specifiction Limit								3-6%	<14%	65-80%			Min.9KN	2-4mm

THEORETICAL MAXIMUM SPECIFIC GRAVITY OF HOT-MIX ASPHALT PAVING MIXTURES (AASHTO T 209-05)

Table D-3 Theoretical maximum specific gravity of HMA Paving mixtures for sample 3

% AC by wt. of mix,Spec.No.		Temprature of Test Water	Mass of Oven Dry Sample in air, g	Mass of Pycnometer filled with water , g	Mass of Pycnometer filled with Sample and water , g	Theoretical Maximum Specific Gravity	Specific Gravity of Bitumen	Effective Specfic Gravity of Combined Aggregate,Gse:
4	A	25	3633	*1206.0*	4342.50	2.429	1.033	2.574
4	B	25	3633	*1204.0*	4343.20	2.438	1.033	2.584
4	C	25	3633	1205.1	4343.20	2.435	1.033	2.581
Average		25	3633	1205.0	4342.97	2.434	1.033	2.580

FOR SAMPLE S-4

CR: SF = 7%:0.5% (By OBC weight)

Compaction = 75 Blows

Bitumen = 61.05% (By total weight)

Mixing temp. : 150^0c

Table D-4 Summary of Volumetric and Marshall Data for sample 4

% AC by wt. of mix,Spec.No.		Spec. Height, mm	Specimen Mass, gm			Bulk Volume, cc	Bulk S.G of Specimen	Th. Max. S.G. (Loose Mix)	Unit Weight, Mg/m^3	% Air Void	% VMA	% VFB	Stability			Flow, mm
			In Air	In Water	SSD In Air								Reading N/div.	Factor	Adjusted, KN	
5.50	A		1220.5	705.0	1221.0	516.0	2.365	2.453	2.365	3.6	16.2	78.0	1450	0.96	17.2	3.90
5.50	B		1225.0	706.0	1225.5	519.5	2.358	2.453	2.358	3.9	16.4	76.6	1420	0.96	16.8	3.50
5.50	C		1224.5	706.0	1225.0	519.0	2.359	2.453	2.359	3.8	16.4	76.8	1405	0.96	16.6	3.60
Average							2.361	2.453	2.361	3.7	16.4	77.1			16.9	3.67
±0.3		Specifiction Limit								3-6%	<14%	65-80%			Min.9KN	2-4mm

THEORETICAL MAXIMUM SPECIFIC GRAVITY OF HOT-MIX ASPHALT PAVING MIXTURES (AASHTO T 209-05) FOR SAMPLE S-4

Table D-3 Theoretical maximum specific gravity of HMA Paving mixtures for sample 4

% AC by wt. of mix,Spec.No.		Temprature of Test Water	Mass of Oven Dry Sample in air, g	Mass of Pycnometer filled with water , g	Mass of Pycnometer filled with Sample and water , g	Theoretical Maximum Specific Gravity	Specific Gravity of Bitumen	Effective Specfic Gravity of Combined Aggregate,Gse:
4	A	25.0	3633	1210.0	4346.5	2.437	1.033	2.583
4	B	25.0	3633	1209.5	4346.5	2.439	1.033	2.586
4	C	25.0	3633	1209.1	4346.5	2.440	1.033	2.587
Average		25.0	3633	1209.5	4346.50	2.439	1.033	2.585

FOR SAMPLE S-5

CR: SF = 10%:0.0.3% (By OBC weight)

Compaction = 75 Blows

Bitumen = 59.202% (By total weight)

Mixing temp. : 150^0c

Table D-5 Summary of Volumetric and Marshall Data for sample 5

% AC by wt. of mix,Spec.No.		Spec. Height, mm	Specimen Mass, gm			Bulk Volume, cc	Bulk S.G of Specimen	Th. Max. S.G. (Loose Mix)	Unit Weight, Mg/m³	% Air Void	% VMA	% VFB	Stability			Flow, mm
			In Air	In Water	SSD In Air								Reading N/div.	Factor	Adjusted, KN	
5.50	A		1245.3	776.5	1246.0	469.5	2.652	2.763	2.652	4.0	6.0	32.6	1100	0.96	13.0	3.50
5.50	B		1244.0	776.0	1245.0	469.0	2.652	2.763	2.652	4.0	6.0	32.6	1150	0.96	13.5	3.55
5.50	C		1246.0	777.9	1247.5	469.6	2.653	2.763	2.653	4.0	5.9	32.8	1165	0.96	13.7	3.40
Average							2.652	2.763	2.652	4.0	5.9	32.7			13.4	3.48
±0.3		Specifiction Limit								3-6%	10-16%	65-80%			Min.9KN	2-4mm

THEORETICAL MAXIMUM SPECIFIC GRAVITY OF HOT-MIX ASPHALT PAVING MIXTURES (AASHTO T 209-05) FOR SAMPLE S-5

Table D-5 Theoretical maximum specific gravity of HMA Paving mixtures for sample 5

% AC by wt. of mix,Spec.No.		Temprature of Test Water	Mass of Oven Dry Sample in air, g	Mass of Pycnometer filled with water , g	Mass of Pycnometer filled with Sample and water , g	Theoretical Maximum Specific Gravity	Specific Gravity of Bitumen	Effective Specfic Gravity of Combined Aggregate,Gse:
4	A	25.0	3633	1202.3	4344.5	2.450	1.033	2.599
4	B	25.2	3633	1202.3	4344.5	2.450	1.033	2.599
4	C	25.1	3633	1202.3	4344.5	2.450	1.033	2.599
Average		25.1	3633	1202.3	4344.50	2.450	1.033	2.599

FOR SAMPLE S-6

CR: SF = 12%:0.1% (By OBC weight)

Compaction = 75 Blows

Bitumen = 58.014% (By total weight)

Mixing temp. : 150^0c

Table D-6 Summary of Volumetric and Marshall Data for sample 6

% AC by wt. of mix,Spec.No.		Spec. Height, mm	Specimen Mass, gm In Air	In Water	SSD In Air	Bulk Volume, cc	Bulk S.G of Specimen	Th. Max. S.G. (Loose Mix)	Unit Weight, Mg/m^3	% Air Void	% VMA	% VFB	Stability Reading N/div.	Factor	Adjusted, KN	Flow, mm
5.50	A		1242.3	763.2	1242.6	479.4	2.591	2.710	2.591	4.4	8.1	45.9	1150	0.96	13.5	3.20
5.50	B		1257.3	772.2	1257.6	485.4	2.590	2.710	2.590	4.4	8.2	45.7	1180	0.96	13.9	3.20
5.50	C		1230.7	757.1	1231.1	474.0	2.596	2.710	2.596	4.2	7.9	47.1	1200	0.96	14.1	3.10
Total Average							2.592	2.710	2.592	4.34	8.1	46.2			13.9	3.2
5.2																
±0.3		Specifiction Limit								3-6%	10-16%	65-80%			Min.9KN	2-4mm

THEORETICAL MAXIMUM SPECIFIC GRAVITY OF HOT-MIX ASPHALT PAVING MIXTURES (AASHTO T 209-05) FOR SAMPLE S-6

Table D-6 Theoretical maximum specific gravity of HMA Paving mixtures for sample 6

% AC by wt. of mix,Spec.No.		Temprature of Test Water	Mass of Oven Dry Sample in air, g	Mass of Pycnometer filled with water , g	Mass of Pycnometer filled with Sample and water , g	Theoretical Maximum Specific Gravity	Specific Gravity of Bitumen	Effective Specfic Gravity of Combined Aggregate,Gse:
4	A	25.0	3633	1202.3	4344.5	2.450	1.033	2.599
4	B	25.2	3633	1202.3	4345.5	2.455	1.033	2.604
4	C	25.1	3633	1202.3	4346.5	2.460	1.033	2.610
Average		25.1	3633	1202.3	4345.50	2.455	1.033	2.604

FOR SAMPLE 7

CR: SF = 15%:0.0% (By OBC weight)

Compaction = 75 Blows

Bitumen = 56.1% (By total weight)

Mixing temp. : 150^{0}c

Table D-7 Summary of Volumetric and Marshall Data for sample 7

% AC by wt. of mix,Spec.No.		Spec. Height, mm	Specimen Mass, gm			Bulk Volume, cc	Bulk S.G of Specimen	Th. Max. S.G. (Loose Mix)	Unit Weight, Mg/m^3	% Air Void	% VMA	% VFB	Stability			Flow, mm
			In Air	In Water	SSD In Air								Reading N/div.	Factor	Adjusted, KN	
5.50	A		1245.0	766.0	1246.0	480.0	2.594	2.710	2.594	4.3	8.1	47.1	1210	0.96	14.3	3.50
5.50	B		1244.0	766.0	1245.0	479.0	2.597	2.710	2.597	4.2	8.0	47.7	1220	0.96	14.4	3.50
5.50	C		1245.0	766.0	1246.0	480.0	2.594	2.710	2.594	4.3	8.1	47.1	1230	0.96	14.5	3.10
Total Average							2.595	2.710	2.595	4.24	8.1	47.3			14.4	3.4
5.2																
±0.3		Specifiction Limit								3-6%	10-16%	65-80%			Min.9KN	2-4mm

THEORETICAL MAXIMUM SPECIFIC GRAVITY OF HOT-MIX ASPHALT PAVING MIXTURES (AASHTO T 209-05) FOR SAMPLE S-7

Table D-6 Theoretical maximum specific gravity of HMA Paving mixtures for sample 7

% AC by wt. of mix,Spec.No.		Temprature of Test Water	Mass of Oven Dry Sample in air, g	Mass of Pycnometer filled with water , g	Mass of Pycnometer filled with Sample and water , g	Theoretical Maximum Specific Gravity	Specific Gravity of Bitumen	Effective Specfic Gravity of Combined Aggregate,Gse:
4	A	25.0	3630	1202.3	4344.5	2.465	1.033	2.616
4	B	25.2	3630	1202.3	4345.5	2.470	1.033	2.622
4	C	25.1	3630	1202.3	4346.5	2.475	1.033	2.628
Average		25.1	3630	1202.3	4345.50	2.470	1.033	2.622

APPENDIX E

SAMPLE PHOTO

Figure E-1 Sample photo