JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

Study on Suitability of Reclaimed Asphalt Pavement Aggregate (RAPA) in Hot Mix Asphalt Production.

A Final Thesis Submitted To the School Of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Master's Degree of Civil Engineering (Highway Engineering).

By:

Tiruwork Mulatu

April, 2021

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Main Advisor: (Ass. Professor) Anteneh Geremew (Ph.D. Candidate.)

Co-Advisor: Engr. Biruk Yigezu (MSc)

April, 2021

Jimma, Ethiopia

Declaration

I, the undersigned declare that this thesis entitled "Study on Suitability of Reclaimed Asphalt in Asphalt Pavement Aggregate (RAPA) in Hot Mix Asphalt Production" is my original work and has not been presented by any other person on an award of degree in this or other university and all sources of materials used for this thesis have been duly acknowledged.

Candidate: Tiruwork Mulatu

Signature: ______________________ Date__________________

As masters research advisors, we hear by certifying that we have read and evaluated this MSc research prepare under our guidance, by Tiruwork Mulatu entitled by "Study on the Suitability of Reclaimed Asphalt Pavement aggregate(RAPA) in hot mix asphalt production"

We recommend that it can be submitted as fulfilling the MSc research requirement.

1. (Ass. Prof.) Anteneh Geremew (Ph.D. Candidate.) ____________ 21 / 04 / 2021 G.C

   Principal advisor Signature Date

2. Engr. Biruk Yigezu (MSc) ____________ ___/_______/____

   Co-advisor Signature Date

3. Engr. Oluma Gudina (MSc) ____________ ____/_______/____

   Chairperson Signature Date

Acknowledgements

First of all, I would like to give glory to the almighty God and the holy mother for making me finish one chapter of life and for giving me endurance and health to successfully deal with my educational career and to complete this research.

Then I would like to extend special thanks to the Ethiopian road authority (ERA) for giving sponsorship of further study in highway engineering. Jimma university institute of technology also deserves special thanks for accepting me as a postgraduate student. Also, the deepest gratitude and respect goes to my advisor Ass. Prof. Anteneh Geremew. (Ph.D. Candidate.) and Engr. Biruk Yigezu (MSc) for their comments, advice, guidance, and encouragement for the preparation of research. I would also like to express my sincere gratitude to Engr. Oluma Gudina (MSc) Highway Chair Person for all his guidance and constructive comments and Engr. Dejene Dereje to his guidance during laboratory works. I would like to extend my gratitude to Wolikite University for providing laboratory equipment for the research and my best friends Yisak Kibiru and Desta Moshe for their endless support during laboratory work.

Finally, yet importantly, I would like to thank my mother Tesemashe Mesfin, my father Mulatu Tilahun, my beloved brothers and all family members. Their support was instrumental for the successful completion of this research.

Abstract

Currently, a huge amount of reclaimed asphalt pavement is produced each year worldwide due to different reasons. These materials are generated when asphalt pavements are removed for reconstruction, resurfacing, or to obtain access to buried utilities. However, there are some concerns and uncertainties about the actual environmental, economic and mechanical performance resulting from the incorporation of recycled aggregates in asphalt mixtures. The main objective of this study was to evaluate the suitability of recycled asphalt aggregate with crushed aggregate in hot mix asphalt production. This research study was supported by experimental laboratory investigations. Also, Non-probable sampling techniques were adopted to collect samples from study areas such as crushed aggregate and fillers from Shandong Highway Engineering Construction Group Co. Ltd located at SNNP, Gurage zone in Gunchire site. RAPA and bitumen from Ethiopian road works construction corporation construction site found in Deneba. The engineering properties of extracted Reclaimed asphalt pavement aggregate and the crushed aggregate were identified based on standard specification before starting the Marshall Mix design. Then, the Marshall Stability test was conducted on crushed aggregate with three different aggregate gradation size (5.0%, 5.5% and 6.0%) by weight of aggregate and with five different bitumen content (4.0%, 4.5%, 5.0%,5.5% and 6.0%) by weight of total mix. Depending on the selected aggregate gradation Marshall Stability test was conducted for reclaimed asphalt pavement aggregate with a replacement rate of (5.0%, 15%, 25%, 35%, 45%, 55%, and 65%) by weight of crushed aggregate to determine its optimum bitumen content according to National Asphalt Pavement Association method (NAPA). A total of 64 mix designs and 190 specimens were prepared. Hence, Marshall Stability and Moisture Susceptibility test with 3-trials, and rutting test with 2-trials. From 190 specimens, 45 were for the control mix, 105 were for replacement proportion, 36 were for Moisture Susceptibility and 4 were for Rutting. Based on the Marshall test results and comparison with standard specification their performance tests such as Moisture Susceptibility and Rutting was performed to maximum allowable replacement percentage and also compared with standard specification. The optimum bitumen content result obtained in percent was (5.1, 5.04, 4.98, 4.87, 4.81, 4.74, 4.67 and 4.53) for 0 %(control), 5.0%, 15%, 25%, 35%, 45%, 55% and 65%, respectively. The obtained value of Tensile Strength Ratio, proportional rut depth and mean rut depth on 45% RAPA replacement was 85.42% and 4.48 %, 2.24 mm respectively. Finally, the test result obtained from the marshal stability and performance testes indicates that up to 45% replacement of aggregate by reclaimed asphalt pavement aggregate in hot mix asphalt production satisfies the standard specification.

Keywords: *Crushed Aggregate, Hot Mix Asphalt, Marshall Test, Optimum, Performance, proportional Rut Depth, Reclaimed Asphalt Pavement, Tensile Strength Ratio.*

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Acronyms

AASHTO	American Association of State Highways and Transport Officials
AC	Asphalt Concrete
ASTM	American Society for Testing of Materials
BC	Bitumen Content
BS	British Standard
CA	Crushed Aggregate
ERA	Ethiopian Roads Authority
HMA	Hot Mix Asphalt
HMAC	Hot Mix Asphalt Concrete
NAPA	National Asphalt Pavement Association
OBC	Optimum Bitumen Content
PRD	Proportional Rut Depth
RAP	Reclaimed Asphalt Pavement
RAPA	Reclaimed Asphalt Pavement Aggregate
RD	Rut depth
RT	Rutting Test
SNNP	South Nations Nationalities and People
TSR	Tensile Strength Ratio
Va	Air Voids
VFA	Voids Filled With Bitumen
VMA	Void in Mineral Aggregate
WTS	Wheel Tracking Slop

CHAPTER ONE

INTRODUCTION

1.1 Background

The government of Ethiopia has allocated a huge amount of resources to construct and upgrade the road network nationwide [1]. Roads are vital for the transport of goods and passengers hence; it dictates the economy of a country and the quality of our lives. In Ethiopia, the most common pavements are flexible, with several layers formed by asphalt mixtures. These layers include different blends of aggregates (roughly 95% of weight), obtained by crushing rock extracted in quarries, and bitumen (about 5.0% of weight) [2].

The vast majority of road pavements are made of Hot Mix Asphalt (HMA), due to its high mechanical and functional properties (driving comfort, skid resistance, durability and water resistance) [3]. Research studies showed that the strength of hot mix asphalt (HMA) depends on different factors such as aggregate type, and bitumen grade [4]. Natural aggregate have been carried out from a variety of rock sources and used as road materials bur the extraction of these virgin aggregate resources is increasingly being restrained by urbanization, increased coast and environmental concerns [5].

In designing an asphalt mixture, a large amount of aggregate is needed but those materials will not be available forever. Due to the increasing concerns over the recent environmental issues related to transportation activities, the interest to develop and evaluate eco-friendly alternative solutions for this sector has increased considerably [6]. Therefore, many local government bodies are struggling with the capacity of municipal solid waste. Recycling is one of the most suitable and economical ways of disposing of solid waste materials. With ever-diminishing material supply and increasing prices, there has been a renewed interest in reusing waste materials in many fields of construction [7]. One of the alternative materials that could be useful is Reclaimed Asphalt Pavement (RAP). The use of reclaimed asphalt pavement (RAP) materials in road construction could serve the purpose of reducing the amount of construction, land disposal, reducing environmental disturbance, and the rate of natural resource depletion [8].

Reclaimed Asphalt Pavement (RAP) is materials generated when asphalt pavements have been removed for reconstruction, resurfacing, or to obtain access to buried utilities. Reclaimed Asphalt pavement is generally removed by either milling or full-depth the removal. Milling entails removal of the pavement surface using a milling machine, which can remove up to 50 mm (2 in.) thickness in a single pass. Full-depth removal involves ripping and breaking the pavement using a rhino horn on a bulldozer and/or pneumatic pavement breakers. In most instances, the broken material is picked up, loaded into haul trucks by a front-end loader, and transported to a central facility for processing [9].

An attempt to conserve aggregate and asphalt usage in road construction becomes the major concern. The use of Reclaimed Asphalt Pavement (RAP) in asphalt pavement construction is expected to be a solution in the road paving industry [10]. In the early 1990s, FHWA and the U.S. Environmental Protection Agency calculated that more than 90 million tons of asphalt pavements were reclaimed every year, and over 80 percent of RAP was recycled, making asphalt the most frequently recycled material [11]. Using recycled materials in road pavements is nowadays considered not only as a positive option in terms of sustainability but also, as an attractive option in means of providing enhanced performance in service [12].

The purpose of the study was to investigate the suitability of Reclaimed Asphalt Pavement Aggregate (RAPA) in the production of hot mix asphalt by evaluating the engineering properties, Marshall Stability, volumetric properties, and performance test values.

1.2 Statement of the problem

The number and extension of roads are likely to continue to grow considerably [13]; their negative impacts are expected to follow the same trend if no effective actions are taken. Hence, the depletion and deterioration of land, the consumption of energy, the generation of solid waste, the emission of dust and gases, noise pollution, and the consumption of nonrenewable natural resources deserve particular attention [14]. The road industry is therefore looking forward to alternative materials and construction technology, which are environment-friendly, energy-efficient, and cost-effective for the construction and maintenance of roads. Most of the current road construction practices are primarily dependent on naturally occurring aggregates that are obtained from quarries [15].

According to FHWA and the U.S., Environmental Protection Agency calculated that more than 90 million tons of asphalt pavements were reclaimed every year, and over 80 percent of RAP was recycled [11]. In recent years, Ethiopia has dedicated three percent of GDP to road investments and investment program focuses mainly on rehabilitation, upgrading, and widening of the road [16]. Therefore, it is easily observed that large quantities of RAPA are expected to be waste and remain unused. With increased demand and limited aggregate and binder supply, Hot Mix Asphalt (HMA) producers have begun using reclaimed asphalt pavement (RAP) as a valuable component in HMA. As a result, there has been renewed interest in increasing the amount of RAP used in HMA [11].

The use of RAP in surface courses is an attractive option. This research was focus to investigate the suitability use of RAPA as replacement of crushed aggregate in HMA on the Marshall Properties and performance of asphalt production.

1.3 Research question

1. What are the engineering properties of crushed aggregate, bitumen, mineral filler, and reclaimed asphalt pavement aggregate in hot mix asphalt?
2. What are the effects of using reclaimed asphalt pavement blended with crushed aggregate in hot mix asphalt production?
3. What is the optimum percentage of reclaimed asphalt pavement aggregate to be added in hot mix asphalt?
4. What are the effects of reclaimed asphalt pavement on rutting and moisture susceptibility in hot mix asphalt?

1.4 Research objectives

1.4.1 General objective

The general objective of this research was to investigate the Suitability of Reclaimed Asphalt Pavement Aggregate (RAPA) in hot mix asphalt production.

1.4.2 Specific objective

- To identify the engineering properties of crushed aggregate, bitumen, mineral filler, and reclaimed asphalt pavement aggregate in hot mix asphalt production.

- To evaluate the effects of using reclaimed asphalt pavement blended with crushed aggregate in hot mix asphalt production.
- To identify the optimum percentage of reclaimed asphalt pavement aggregate to be added in hot mix asphalt production.
- To investigate the effects of reclaimed asphalt pavement on rutting and moisture susceptibility in hot mix asphalt.

1.5 Scope of the study

The scope of the study was to evaluate the suitability of Reclaimed Asphalt Pavement Aggregate (RAPA) blended with crushed aggregate in Hot Mix Asphalt production. This study was carried out by using RAP that was collected from the Jimma zone, Ethiopia, and crushed aggregate material sample from a selected quarry site nearby the laboratory. The study was confined to evaluate hot mix asphalt concrete properties using 60/70 penetration grade of bitumen, 19 mm maximum nominal size mineral aggregate gradation, crushed stone dust as mineral filler, and fine and coarse aggregate replaced with Reclaimed Asphalt Pavement Aggregate (RAPA). The studies were carried out on dense-graded HMA concrete mix to evaluate Marshall Properties using the Marshall Stability test. Also, investigate performance tests which are moisture susceptibility and rutting.

1.6 Significance of the Study

This study was helpful as guidance for further researches to be conducted in the area of investigation of Reclaimed asphalt pavement on road construction particularly in Ethiopia, and generally in the world. When the asphalt pavements badly deteriorate, maintenance and overlay may not be economical, and reconstruction can be a feasible solution by removing these pavement surfaces. By processing these removed surfaces into recycled asphalt pavement material, the amount of using freshly crushed aggregate will have reduced. It helps in the conservation of natural resources during the blasting of quarry in the production of crushed aggregate for road construction. The study was helpful to the concerned body to come up with appropriate measures to address the problem effect of using Reclaimed asphalt pavement and understanding the relationship of Marshall properties and performance of using RAPA in hot mix Asphalt. The researchers can be using the results of the study as reference or secondary data regarding recycled asphalt pavement in hot mix asphalt. In highway, authorities study has beneficial for owners, contractors, and consultant as a source of information for highway project implementation throughout the country by using recycled asphalt pavement.

1.7 Limitation of the Study

In this study, all experimental work was conducted only on the extracted aggregate but in the extraction process, the unknown volume of bitumen was also produced due to the solvent used for that reason only the aggregate is taken for experiment analysis. To study the economic feasibility of using RAPA in hot mix asphalt constant extraction costs like a machine to mill, solvent, loss, and labor are to be considered on aggregate and bitumen. In Ethiopia manuals, there is no constant cost. Due to these limitations, the economic analysis was not performed. As a result of time and budget, and availability of bitumen type the study is also limited.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 Introduction

A road pavement structure is made of multiple layers of processed and compacted materials, in different thicknesses and in both unbound and bound forms, which together form a structure that primarily supports vehicle loads as well as providing a smooth riding quality. There are three types of pavements flexible or asphalt pavements, rigid or concrete pavements, and composite pavements [17]. There are two types of pavements based on design considerations i.e. flexible pavement and rigid pavement. Difference between flexible and rigid pavements is based on the manner in which the loads are distributed to the subgrade [18].

Flexible pavement can be defined as the one consisting of a mixture of asphaltic or bituminous material and aggregates placed on a bed of compacted granular material of appropriate quality in layers over the subgrade. Water bound macadam roads and stabilized soil roads with or without asphaltic toppings are examples of flexible pavements. The design of flexible pavement is based on the principle that for a load of any magnitude, the intensity of a load diminishes as the load is transmitted downwards from the surface by virtue of spreading over an increasingly larger area, by carrying it deep enough into the ground through successive layers of granular material. Thus for flexible pavement, there can be grading in the quality of materials used, the materials with high degree of strength is used at or near the surface. Thus, the strength of subgrade primarily influences the thickness of the flexible pavement. A rigid pavement is constructed from cement concrete or reinforced concrete slabs. Grouted concrete roads are in the category of semi-rigid pavements. The design of rigid pavement is based on providing a structural cement concrete slab of sufficient strength to resist the loads from traffic. The rigid pavement has rigidity and high modulus of elasticity to distribute the load over a relatively wide area of soil [19].

2.2 Structure Layers of Flexible Pavement

1. Surface Course

Surface course or wearing course is the top most layer of flexible pavement, which has direct contact with the vehicular loads. Since it is directly in contact with traffic, good quality aggregates and high dense bitumen or asphalt is recommended for the construction of surface course. The main function of surface course is to provide skid-resistance surface, friction and drainage for the pavement. It should be water tight against surface water infiltration. The thickness of surface course generally provided is 25 to 50 mm [20].

2. Binder Course

Binder course is also constructed using aggregates and bitumen but with less quality than materials used for surface course. In general, its thickness is about 50 to 100 mm. If economy is not a problem, binder course and surface course can be constructed monotonically using good quality materials with 100 to 150 mm thickness. The function of binder course is to transfer the loads coming from surface course to the base course [21].

3. Base Course

The base course is important layer of pavement structure and it distributes the loads from top layers to the underneath Sub-base and sub-grade layers. It provides structural support for the pavement surface. It is constructed with hard and durable aggregates which may either stabilized or granular or both. The thickness of base course must be great enough to reduce the load capacity on sub-grade and Sub-base courses. The minimum base course thickness recommended is 100-mm. sub surface drainage system can be provided with in the base course [22].

4. Sub-base Course

The Sub-base course is provided beneath the base course and it functions as same as base course. If the sub-grade soil is strong and stiff, then there is no need to sub-base course. Granular aggregates are used to construct sub-base course. If sub-grade is weak, minimum 100 mm thick sub-base course should be provided [23]

5. Frost Protection Layer

Frost protection layer is provided for the pavements in colder regions where temperatures are very low. It is generally provided between Sub-base and sub-grade soil. The function of frost protection layer is to prevent damage of pavement from frost heaves, which are formed by freezing of groundwater. A good quality base course and Sub-base courses provided could also serve frost protection layer [23].

6. Subgrade

Subgrade is the bottom most layer, which is nothing but natural soil layer, compacted up to required depth generally about 150 to 300 mm to receive the loads coming from top layers. This layer is termed as foundation for the pavement system. The sub-grade should be strong enough to take the stresses and also it is important to keep the stresses coming from top layers should be within the limit of sub-grade capacity. To reduce the amount of stress on soil sub-grade, provide thick layers of base course, Sub-base course and surface course. Apart from the above layers, three types of coats or finishes are provided in flexible pavement systems, which are - seal coat, tack coat and prime coat [24]

a. Seal Coat

Seal coat is provided directly on the top of surface course to make it watertight and to provide skid resistance to the surface. Mixture of Emulsified asphalt, mineral fillers and water is used as seal coat material.

b. Tack Coat

Tack coat is provided on the top of binder course to develop strong bond between the binder course and surface course. Asphalt emulsion diluted with water is used as tack coat material.

c. Prime Coat

Prime coat is provided between base course and binder course to develop strong and water tight bong between them. Low viscous cutback bitumen is sprayed on the top of base course as prime coat material [25].

2.3 Asphalt concrete

Asphalt concrete(AC) , also known as asphaltic concrete is the basic type of hot mix asphalt that has been widely used around the world for many decades but has been developed into other mixture subtypes more recently. It consists of asphalt (used as a binder) and mineral aggregate mixed, then is laid down in layers and compacted. The mix is designed to have low air voids and low permeability to provide good durability and good fatigue behavior but this makes the material particularly sensitive to errors in proportioning, and mix tolerances are therefore very narrow [22].

2.4 Types of Asphalt

To be able to provide the best performance to different sectors, a large variety of asphalt mixes can be offered. Due to the different requirements e.g. a road needs to fulfill (high traffic, tough weather conditions, and other) the respective mix used needs to have sufficient stiffness and resistance to deformation to cope with the applied pressure from vehicle wheels on the one hand, yet on the other hand, the need to have an adequate flexural strength to resist cracking caused by the varying pressures exerted on them. Moreover, good workability during application is essential to ensure that they can be fully compacted to achieve optimum durability [26].

2.4.1 Cold Mix Asphalt

Cold mix asphalt is produced without heating the aggregate. This is only possible, due to the use of a specific bitumen emulsion which breaks either during compaction or during mixing. After breaking, the emulsion coats the aggregate and over time increases its strengths. Cold mixes are particularly recommended for lightly trafficked roads [26]. Cold mix is commonly used as a patching material and on lesser trafficked service roads.

2.4.2 Warm Mix Asphalt

A typical warm mix asphalt is produced at a temperature around 20 - 40 °C lower than an equivalent hot mix asphalt. Less energy is involved and, during the paving operations, the temperature of the mix is lower, resulting in improved working conditions for the crew and an earlier opening of the road [26].

2.4.3 Hot Mix Asphalt

HMA is the form of asphalt concrete most commonly used on high traffic pavements such as those on major highways, racetracks and airfields. It is also used as an environmental liner for landfills, reservoirs, and fish hatchery ponds [26]. Hot mix asphalt is produced at a temperature between 150 and 190 °C, it is the highest quality among the different types. Hot mix asphalt paving material consists of a combination of aggregates that are uniformly mixed and coated with asphalt cement (bituminous binder). HMA pavements serve in a multitude of traffic and environmental conditions, demanding that the materials and design meet specific engineering requirements. According to [20] HMA pavement mix types include:

- ❖ Dense-graded mixes: - A dense-graded mix is a well-graded HMA that has an even distribution of fine and coarse aggregate. Additionally, it consists of a dense HMA mixture of aggregates and asphalt binder. Properly designed and constructed mixtures are relatively impermeable. Dense-graded mixes are generally referred to by their nominal maximum aggregate size and can further be classified as either fine-graded or coarse graded. Fine-graded mixes have more fine sand size particles than coarse-graded mixes. It is suitable for all pavement layers and all traffic conditions.

- Stone Matrix Asphalt (SMA): - sometimes called stone mastic asphalt, is a gap-graded HMA originally developed in Europe to maximize rutting resistance and durability in heavy traffic road. SMA has a high coarse aggregate content that interlocks to form a stone skeleton that resists permanent deformation. The stone skeleton is filled with mastic of bitumen and filler to which fibers are added to provide adequate stability of bitumen and to prevent drainage of the binder during transport and placement. SMA is often considered a premium mix because of higher initial costs due to increased asphalt contents and the use of more durable aggregates. Typical SMA composition consists of 70−80% coarse aggregate, 8−12% filler, 6.0−7.0% binder, and 0.3 percent fiber. The deformation-resistant capacity of SMA stems from a coarse stone skeleton providing more stone-on-stone contact than with conventional dense graded asphalt (DGA) mixes.
- Open-graded mixes: - are designed to be permeable to water, which differentiates them from dense-graded and SMA mixtures that are relatively impermeable. These mixtures use only crushed stone or, in some cases, crushed gravel with a small percentage of manufactured sands.

2.5 Components of Hot Mix Asphalt

2.5.1 Crushed Aggregate

During production, construction, and the service life of the road, the aggregates may be subjected to the effects of weather, climate, and a range of mechanical processes which together contribute to the deterioration in its physical condition. Therefore, when the construction of a road is necessary, it is important to obtain a material sufficiently durable to last the design life of the road so that its performance is not affected by deterioration or degradation of the material. The qualities required of aggregates are described in terms of shape, hardness, durability, cleanliness, bitumen affinity, and porosity. In addition to these properties, the micro-texture of the aggregate particles will also strongly influence the performance of a compacted HMA layer. Smooth-surfaced river gravel, even partly crushed, may not generate as much internal friction as a crushed aggregate from particles having a coarse micro-texture. Therefore, aggregates should have the following characteristics for aggregates used in HMA [27]. Aggregates should be:

- Angular and not excessively flaky, to provide good mechanical interlock.
- Clean and free of clay and organic material.
- Resistant to abrasion and polishing when exposed to traffic.
- Strong enough to resist crushing during mixing and lying as well as in service.
- Non-absorptive since highly absorptive aggregate are wasteful of bitumen and also give rise to problems in mix the design.
- Have good affinity with bitumen, hydrophilic aggregates may be acceptable only where protection from water can be guaranteed or a suitable adhesion agent is used.

2.5.2 Bitumen

Asphalt binders, sometimes referred to as asphalt cement binders or asphalt cement, are an essential component of asphalt concrete. They are the cement that holds the aggregate to gather in HMA is thick, the heavy residue remaining after refining crude oil. Asphalt binder consisted mostly of carbon and hydrogen, with a small amount of oxygen, sulfur, and several metals. The physical properties of the asphalt binder vary considerably with temperature. At high temperature, asphalt binder is a fluid with a low consistency similar to that of oil. At room temperature, most asphalt binder will have the flexibility of a soft rubber. At sub-zero temperatures, asphalt binder can become brittle. Many asphalt binders will contain small percentages of polymer to improve their physical properties; these materials are called polymer modified binders. Most of the asphalt binder specification was designed to control change on consistency with temperature [28].

2.5.3 Mineral Filler

The mineral fillers or by-products of various stone crushing procedures and which is used in the design of hot mix asphalt (HMA). Also, Fillers increase the stiffness of the asphalt mortar matrix and can affect workability, moisture resistance, and aging characteristics of HMA mixtures [20]. Fillers are the main element asphalt concrete mix design that is used to fill the void space between coarse aggregate particles with physical size passing number 200 standard mesh sieve (75 microns), which plays an essential role in asphalt mixtures properties [28].

2.6 Reclaimed Asphalt Pavements

Asphalt pavements that have reached the end of their service life are frequently rehabilitated by milling the existing pavement surfaces and replacing the milled portion with new hot mix asphalt (HMA). Therefore, a large amount of reclaimed asphalt pavement (RAP) is generated every year because of this practice. RAP is most commonly used as an aggregate and virgin asphalt binder, but it is also used as a granular base or sub base, stabilized base aggregate, an embankment or fill material. RAP is a high-quality material that can replace more expensive virgin aggregates and binders [29].

2.6.1 Production of Reclaimed Asphalt Pavement (RAP) Material

Removal and reuse of asphalt layer of the existing pavement is termed as RAP. However, full depth reclamation is defined as removal and reuse of hot mix asphalt layer and entire base course. RAP can be reused immediately at sites; however, it may be stockpiled as the case may be. The required gradation of RAP is achieved by pulverizing the material in a crusher. Large quantities of Reclaimed asphalt pavement (RAP) materials are produced during highway maintenance, demolition, and construction. If these materials could be re-used in sub-base/base course of the roads, resulting in minimization of environmental impact, reduce the waste stream and also transportation costs connected with road maintenance and construction activities and before going to use such materials the mechanical properties must be tested and suitable blending is done if required [30].

2.6.2 Engineering Properties of Reclaimed Asphalt Pavement Aggregate

The properties of RAP are largely dependent on the properties of the constituent materials and the type of asphalt concrete mix (wearing surface, binder course, etc.). There can be substantial differences between asphalt concrete mixes in aggregate quality, size, and consistency. Since the aggregates in surface course (wearing course) asphalt concrete must have high resistance to wear/abrasion (polishing) to contribute to acceptable friction resistance properties, these aggregates may be of higher quality than the aggregates in binder course applications, where polishing resistance is not of concern [31].

Both milling and crushing can cause some aggregate degradation. The gradation of milled RAP is generally finer and denser than that of the virgin aggregates. Crushing does not cause as much degradation as milling; consequently, the gradation of crushed RAP is generally not as fine as milled RAP, but finer than virgin aggregates crushed with the same type of equipment [32].

The particle size distribution of milled or crushed RAP may vary to some extent, depending on the type of equipment used to produce the RAP, the type of aggregate in the pavement, and whether any underlying base or sub-base aggregate has been mixed in with the reclaimed asphalt pavement material during the pavement removal. During processing, virtually all RAP produced is milled or crushed down to 38 mm (1.5 in) or less, with a maximum allowable top size of either 51 mm (2 in) or 63 mm (2.5 in). The typical range of particle size distribution that normally results from the milling or crushing of RAP, Milled RAP is generally finer than crushed RAP. Studies on pavements in California, North Carolina, Utah and Virginia have shown that before and after milling, the pavement fraction passing a 2.36 mm (No. 8) sieve can be expected to increase from a pre-milled range of 41 to 69 percent to a post-milled range of 52 to 72 percent. The fraction passing a 0.075 mm (No. 200) sieve can be expected to increase from approximately 6 to 10 percent to a range of 8 to 12 percent [29]. Most sources of RAP will be a well-graded coarse aggregate, comparable to, or perhaps slightly finer and more variable than, crushed natural aggregates [33].

The unit weight of milled or processed RAP depends on the type of aggregate in the reclaimed pavement and the moisture content of the stockpiled material. Although available literature on RAP contains limited data pertaining to unit weight, the unit weight of milled or processed RAP has been found to range from 1940 to 2300 kg/m^3 (120 to 140 lb/ft^3), which is slightly lower than that of natural aggregates [30]. Information on the moisture content of RAP stockpiles is sparse, but indications are that the moisture content of the RAP will increase while in storage. Crushed or milled RAP can pick up a considerable amount of water if exposed to rain. Moisture contents up to 5 percent or higher have been measured for stored crushed RAP [31]. As noted earlier, during periods of extensive precipitation, the moisture content of some RAP stockpiles may be as high as 7 to 8 percent [32]. Lengthy stockpiling of crushed or milled RAP should, therefore, be kept to a minimum [34].

The asphalt cement content of RAP typically ranges between 3 and 7 percent by weight. The asphalt cement adhering to the aggregate is somewhat harder than new asphalt cement. This is due primarily to exposure of the pavement to atmospheric oxygen (oxidation) during use and weathering. The degree of hardening depends on several factors, including the intrinsic properties of the asphalt cement, the mixing temperature/time (increases with increasing high temperature exposure), the degree of asphalt concrete compaction (increases if not well compacted), asphalt cement/air voids content (increases with lower asphalt/higher air voids content), and age in service (increases with age) [34].

The RAP obtained from most wearing surface mixes will usually have asphalt content in the 4.5 to 6 percent range. The recovered asphalt from RAP usually exhibits low penetration and relatively high viscosity values, depending on the amount of time the original pavement has been in service. Penetration values at 25°C (77°F) are likely to range from 10 to 80 while the absolute viscosity values at 60°C (140°F) may range from as low as 2,000 poises (equivalent to AC-20) up to as high as 50,000 poises or greater, depending on the extent of aging. Viscosity ranges from 4,000 to 25,000 poises can normally be expected from the asphalt cement that is recovered from RAP material [34]

2.6.3 Determining Properties of Reclaimed Asphalt Pavement

In order to obtain aged bitumen from RAP, the oxidized sample was firstly placed in reservoir of extractor. The extraction process began by placing a specified amount the RAP in the extraction vessel with a specified amount of toluene. A motor was attached and rotate the vessel for a specified time with the amount of added toluene. This was allowed the toluene/bitumen mixture to flow into the first holding flask. Each of 1000 grams, ten batches of RAP were prepared and extraction test was performed on each of the batch to determine the bitumen content of RAP. For this test, a centrifuge extractor called Rota Test was utilized. In order to characterize the properties of the old bitumen obtained from the extraction test, conventional bitumen test methods such as: penetration test [35], softening point test [36], thin film oven test [37] etc. was performed. Following the characterization of the old bitumen, sieve analysis test were performed on the extracted aggregates.

2.6.4 Extraction Methods of Reclaimed Asphalt Pavement

The properties of RAP aggregate also depend upon the method used for extraction of aggregate. Ignition and centrifuge methods of extraction are two widely used methods to recover the aggregate from RAP [38]. In the ignition method, RAPs are burn off in an oven at 540ºC [39]. In the centrifuge method of extraction, a loose HMA is weigh and then solvent is added to disintegrate the sample, aggregate and asphalt binder are then separated using a centrifuge. Trichloroethylene (TCE) used as a solvent for the centrifuge method of extraction [40].

2.7 Marshall Mix Design

Marshall Mix Design method is used to determine the maximum mineral filler content and optimum asphalt content, and evaluate the volumetric properties of the mixtures in the laboratory. The Marshall Mix design procedure involves selecting a trial aggregate gradation and a compaction temperature, compaction level, number of blows [41].

2.8 Moisture Susceptibility of Hot Mix Asphalt

Moisture is a primary cause of failure of asphalt mix because its presence could lead to its loss of structural strength and durability [42]. Moisture can damage the HMA in the following two ways: 1) loss of bond between the asphalt cement or mastic and the fine and coarse aggregate and 2) weakening of the mastic due to the presence of moisture. Six contributing factors have been attributed to causing moisture damage in HMA: detachment, displacement, spontaneous emulsification, pore-pressure induced damage, hydraulic scour, and environmental effects [43]. Many test methods have been developed in the past to predict the moisture susceptibility of HMA mix. The test methods mentioned below are not the only ones and other tests are still being used throughout the world.

A. Static-Immersion Test (AASHTO T182) – HMA mix is immersed in distilled water at 25^0c for (16 to 18) hours. The percentage of the total visible area of the aggregate which remains coated will be estimated as above or below 95%.

B. Lottman Test (NCHRP 246) – This is a strength test developed by Lottman under National Cooperative Highway Research Program 246. Nine specimen 102 mm in diameter and 64 mm high are compacted at expected field air void content. The specimens are divided into three, three specimens per group. Group 1 is the control group. Group 2 is vacuum saturated with water for 30 minutes. Groups 3 are also vacuum saturates subjected to freeze at -18^0c for 15 hours and thaw for 24 hours at 60^0c. All nine specimens are tested for resilient modulus or indirect tensile strength. Retained tensile strength (TSR) is the quotient of ITS of the conditioned specimen to ITS of the control specimen. A minimum TSR of 70% is used as a guideline.

C. Modified Lottman Test (AASHTO T283) – is proposed by Kandhal. It uses the Lottman test with some modification. The sample size is reduced to six and grouped into two containing three specimens. The specimens are compacted to (6 – 8) % air void. Group 1 is a control specimen while group 2 is vacuum saturated (55 to 80) % saturation with water and then subjected to one cycle freeze and thaw. All specimens are tested for ITS at 25^0c at a loading rate of 51mm/min. TSR is determined based on the Lottman test and a minimum value of 70% is usually specified.

D. Marshall Immersion Test (ASTM D1075) – Six Marshall specimens are prepared for this test. The specimens are grouped into two groups, each with three specimens. Group 1 is the control specimen maintained in the air at 25^0c while group 2 is immersed in water for 24 hr. at 60^0c. Group 2 specimens are then transferred to 25^0c water bath for 2 hrs. and compressive strength of both groups is determined. A value of at least 70% is specified as a requirement in many agencies. Superpave design guideline requires a minimum of 80% retained strength.

2.9 Rutting Test

Permanent deformation results from the accumulation of small amounts of unrecoverable strain (small deformations) from repeated loads applied to the pavement. Wheel path rutting is the most common form of permanent deformation. Resistance to permanent deformation is provided by designing and constructing a stable HMA pavement that will resist shoving and rutting under traffic. It will maintain its shape and smoothness under repeated loading. An unstable pavement develops ruts and shows other signs of mixture shifting. Resistance to permanent deformation depends primarily on the internal friction provided by the aggregate particles and to a lesser extent the cohesion provided by the asphalt binder. Inter particle friction among the aggregate particles is related to the shape and surface texture of both the fine and the coarse aggregate and the characteristics of the aggregate gradation. Cohesion results from the bonding ability and the stiffness characteristics of the asphalt binder. A proper degree of both inter-particle friction and cohesion in a mix prevents the aggregate particles from being moved past one another by the forces exerted by traffic. The use of more angular aggregate particles with rougher surface texture will increase the stability of the mix. Cohesion increases as the stiffness of the asphalt binder increases or when the pavement temperature decreases. The degree to which internal friction versus cohesion influences a mix‘s resistance to permanent deformation varies from mix to mix. Two primary causes of rutting are subgrade failure and inadequate mix stability. First, deformation can occur in the subgrade or underlying layers such as base or sub-base rather than the asphalt layer. It is typically caused by poor in situ subgrade quality or condition required for the pavement structure and loading conditions. Stiffer paving materials may reduce this type of rutting, but it is better to correct the subgrade or underlying layer instability. In the case of an unstable mix, the deformation is limited to the asphalt layer and will result in an upheaval at the edge of the rut. While this might suggest that rutting is an asphalt binder problem, it is more correct to address rutting by considering the combined mineral aggregate and binder properties and through gradation and volumetric proportioning. Asphalt mixture shear strength is mainly increased by selecting an aggregate that has a high degree of internal friction—one that is angular, has a rough surface texture and is graded to develop particle-to-particle contact. When a load is applied to the mixture, the aggregate particles lock tightly together and function more as a large, single, elastic mass. If improving the aggregates does not give sufficient improvement in mixture shear strength, a stiffer binder and/or a modified binder may be selected [44].

Failures that occur during the useful life of the pavement, mainly includes permanent deformations in the path of vehicles wheel (rutting), fatigue cracking and thermal cracking. Since, enormous costs should be spent to repair and reconstruction of shortcomings and defects, so early prevention often is more economical. To avoid this failure, pavement materials should be selected so that they would have sufficient strength and stability. Aggregates must be broken, and applying excessive bitumen and fine aggregate should be avoided [45].

Wheel track groove (rutting) is the permanent deformation of pavement layers that can be increased over time. Pictures of wheel track groove are shown in Figure 2. Generally, three factors led to create rutting in the asphalt pavement include permanent deformation accumulation in the surface of asphalt layer, permanent deformation of the subgrade, and erosion or wear of asphalt at the wheels place due to the passing of vehicles. In the past it was believed that deformation of the subgrade is the main reason of occurring grooves in the pavement and many of the design methods were built based on limiting the vertical strain. However, research in recent years has indicated that the main reason of rutting is related to the upper part of asphalt surface layer or surface layer [46].

Figure 2.1: permanent deformation in Asphalt Pavement (Source: Google)

2.10 Related studies of RAP on Asphalt Concrete

Population influx towards big cities, in developing countries, has prompted rapid construction activities in order to cater for this population needs. These activities put enormous burden on natural resources in addition to generating construction, renovation and demolition. Natural aggregates have been carried out from a variety of rock sources and have been used as a road material. Recycling of asphalt pavements is a technology developed to rehabilitate and/or replace pavement structures suffering from permanent deformation and evident structural damage [47].

Significant amounts of laboratory testing on HMA mixes containing varying percentages of recycled asphalt pavement (RAP) aggregate have been finished and are documented in the literature. Some researchers reported on the effect of using recycled asphalt pavement in asphalt mix performance. Shortly in the past number of research work has been done to make use of Recycled Asphalt Pavement (RAP) aggregate materials into the bituminous mix to make it cost-effective and some researchers have been performing researches by using a different percentage of RAP aggregate with the fresh mixes to develop the physical property of bituminous mixes.

The use of reclaimed asphalt pavement with different mix proportions has more influence on the properties of asphalt mixture such as stability, flow, mix density, etc. Thus, the increasing percentage of Recycled asphalt aggregate is decreasing the stability of mixture and increasing the flow value [48].

As the researcher [49] is examined and concluded that the optimum bitumen content is decreased as increasing the percentage of Reclaimed Asphalt Pavement aggregate (RAPA) content and the recommended percentage of RAP mix is 20%.

Some researchers studied on the use of recycled asphalt pavement in HMA by Marshall Test, and they represented that the increasing percentages of RAP aggregate in the compacted mixtures; the optimum asphalt content (OAC) and air void is decreased and recommended using RAP in Hot mix asphalt is 30% [49].

Another research is also done on the RAP aggregate used in the compacted mixture and found Based on Marshall Test results; the optimum bitumen content is decreased as the RAP aggregate percent increase. With the increasing percentages of RAP aggregate, OBC is reduced due to the old bitumen filled the pores of the RAP aggregate and the recommended percentage of using RAP in HMA is 40% [50].

And also, some recent researchers have established that RAPA replacement at proportion above 50% is feasible to produce new HMA mixtures, obtaining satisfactory results in the mechanical properties [51]. An article presented that with adequate mixture design for 100% recycled asphalt mixtures can perform equally to conventional asphalt mixes. In this case, it is found that the reduction of harmful emission by 35% as well as reducing the cost of materials by half for using 100% RAP material. Actually, a suitable percentages of RAP aggregate is no limitation and it is depending upon the quality and composition of Reclaimed asphalt pavement materials and category of the layer in which it is to be used [52]

The majority of tests have been done on mixes different percent of RAP using the Marshall Test. As the study on the performance of Reclaimed asphalt pavement, the value of using RAP in pavement surfacing practice is common to find lower quantities of RAP, such as (10-15) %, being used regularly in asphalt surfacing mixes. The reason for this is practice is that in general, the mechanical performance of HMA is not negatively affected by the use of small quantities of Recycled asphalt pavement (RAP) aggregate while concurrently the benefits of using RAP, particularly material savings, can still be achieved [53].

According to, [54] depicts that mixtures paved with 45 % RAP demonstrated an excellent rutting performance even when a soft asphalt binder was used. Following the same conclusion, **[**55**]** also proved that plant-produced HMA mixtures containing 40 % RAP showed excellent rutting resistance.

CHAPTER THREE

RESEARCH MATERIALS AND METHODS

3.1. Study Area

This research was conducted in Jimma town. Jimma is found in the south-western part of Ethiopia that is 345 km far from Addis Ababa, the capital city of Ethiopia. It covers a total surface area of 19,305.5 km2. Jimma is geographically located between 7° 38’52” and 7° 43’ 14” N latitude, and between 36° 48’ 00” and 36° 53’ 24” E longitude. In general, the topographical features elevation varies from 1780 to 2000 m above sea level with average maximum & minimum temperatures in the range of 25-30°C. It was founded in 1837 E.C by the king of Abba Jifar and has a town administration, municipality, and 17 kebeles (N.B. Kebele is the smallest administrative unit in Ethiopia [56]. There is the reason to choose Jimma Zone as the study area; that this research was conceded to find and gives the alternatives construction material, for road construction and maintenance because construction and maintenance are obvious around Jimma town.

3.2 Study period

The study was conducted from October, 2020 to April, 2021 G.C for developing a proposal, collecting data’s and analysis which includes data collection Sampling, evaluation, writing up and finally, dissemination is executed.

3.3 Materials

The materials, which were used for conducting this final research work, are:

- ❖ Crushed Aggregate (Coarse, and Fine) and Mineral Filler (Crushed Stone Dust) from Shandong Highway Engineering Construction Group Co. Ltd located at SNNP, Gurage zone in Gunchire site.
- ❖ Bitumen (60/70 Penetration Grade) from ERA Jimma branch.
- ❖ Reclaimed Asphalt Pavement Aggregate (Extracted coarse and fine) from Ethiopian Road works construction corporation site in Jimma town Deneba site

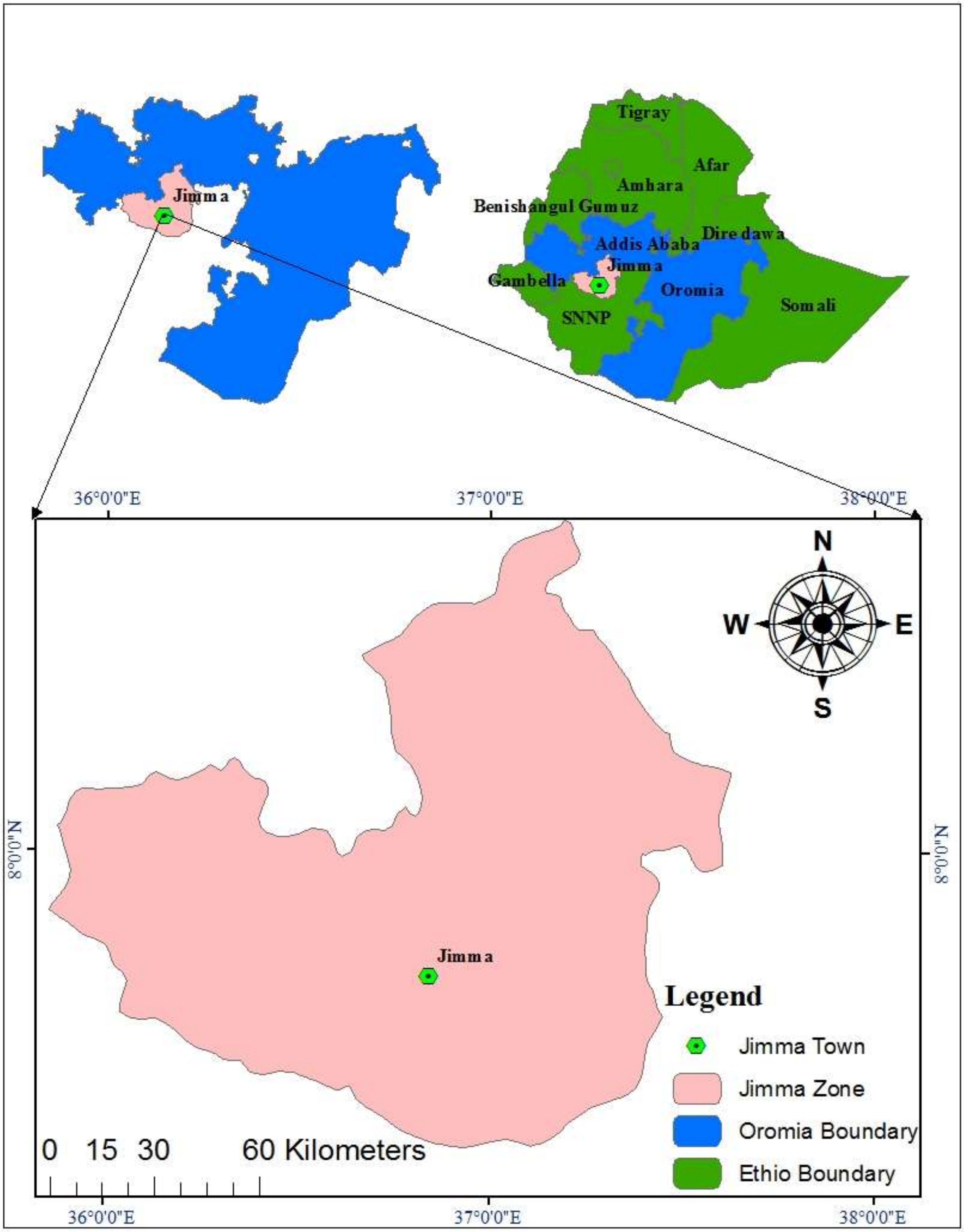


Figure 3.1: Study area (ArcGIS 10.3.1)

3.4 Study Variables

3.4.1 Dependent Variable

The dependent variable of this research work is the Suitability of Reclaimed Asphalt Pavement Aggregate (RAPA) in Hot Mix Asphalt production.

3.4.2 Independent Variable

Independent variables of this study were results of laboratory tests that are:

- ❖ Physical properties or quality test of materials (Crushed Aggregate, Crushed stone dust, Bitumen, and RAPA)
- ❖ Allowable percentage by mass of Reclaimed Asphalt Pavement Aggregate.
- ❖ Marshall Stability, flow and volumetric Properties of materials.
- ❖ Moisture susceptibility of asphalt mix.
- ❖ Rutting resistance of asphalt mix.

3.5 Study design

For this research work laboratory, an experimental type design was performed. To achieve the objective of the study, numerous laboratory tests were conducted to determine the suitability of RAPA as crushed aggregate in hot mix asphalt. Quantitative data types were employed. The major research data has rolled from a primary source and laboratory activities with experimental works to address the practical problems. All tests were carried out based on ASTM, AASHTO, BS, and UNE-EN12697-22 standards. Different stages were involved to determine the physical and Marshall Properties of these materials in a laboratory. The test designed to achieve the research objectives is a material quality test, Marshall Stability test, and performance tests i.e. moisture susceptibility and rutting tests were conducted. Materials were collected i.e. bitumen from ERA Jimma district ,RAPA from Ethiopia Road Construction Corporation site which found in Deneba and crushed aggregates from Shandong Highway Engineering Construction Group Co. Ltd located at SNNP, Gurage zone in Gunchire site. To extract aggregate from recycled asphalt pavement centrifuge method was performed by using ASTM D2172. In the centrifuge method of extraction, a loose HMA is weighed and then the solvent is added to disintegrate the sample, aggregate and asphalt binder is then separated using a centrifuge. Benzene was used as a solvent. The aggregates extracted from the RAP then, tested for the aggregate properties. The material quality test was conducted on all selected materials to identify their physical properties. The Marshall Mix design was conducted to determine the optimum bitumen content for the design of hot mix asphalt after the quality test of the material was getting acceptance according to standard specification. For the accomplishment of this task, several mix samples were prepared in groups. To determine the optimum bitumen and optimum filler content 15 mix design with three different aggregate gradation (5.0%, 5.5%, and 6.0%) with varying percentage of bitumen content (4.0%, 4.5%, 5.0%, 5.5% and 6.0%) total of 45 specimens for conventional (control mix) were prepared. Then, 105 HMA samples were prepared with recycled aggregates percent of 0% (Control), 5.0%, 15%, 25%, 35%, 45%, 55% and 65% blended with Crushed aggregates. A total of 50 mix designs were prepared for RAPA replacement. Marshall Test was conducted on all specimens for each mix design with 3 trails by applying 75 blows on each face according to the Marshall procedure specified in ASTM D1559. Then optimum bitumen content of each mix for fresh crushed aggregate and RAPA replacement was determined according to the National Asphalt Pavement Association (NAPA), which was at the middle range of air void (4.0%) is the optimum bitumen content. Having the optimum bitumen content the corresponding Marshall stability, flow, and volumetric properties were determined. To check the performance of the allowable replacement percentage additional 16 mixes were prepared, from those 12 mixes were for moisture susceptibility and 4 mixes were for rutting tests Final analyses were performed for the accomplishment of the research objectives. Figure 3.2 shows the consequence of the study design.

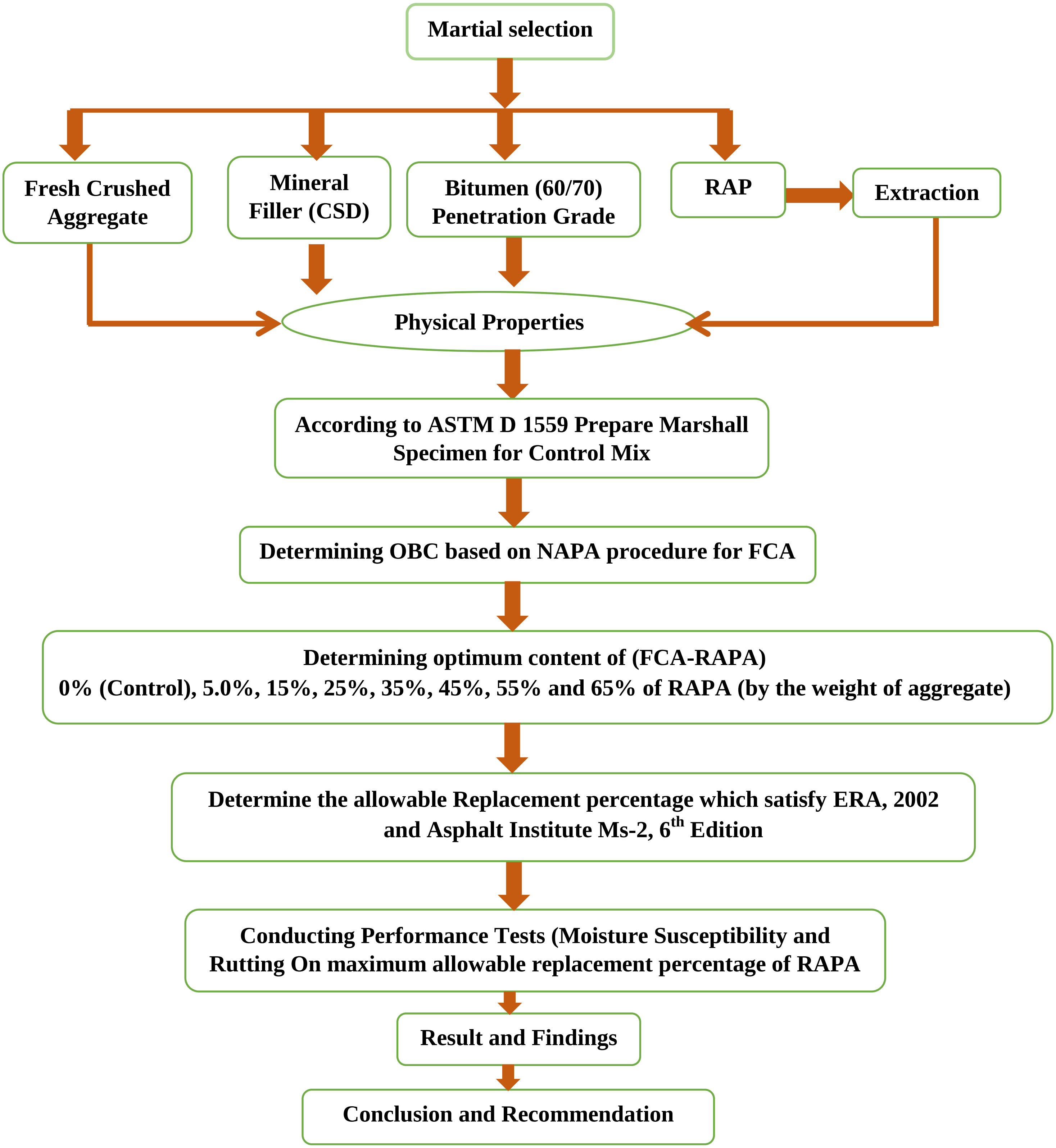


Figure 3.2: Research Design

3.6 Source of Data

3.6.1 Primary data

The primary data were laboratory test results on aggregate (course and fine), Filler, bitumen and Recycled asphalt pavement aggregate (RAPA).

3.6.2 Secondary data

Secondary data were obtained using desk study of related literature and standard pavement design manuals.

3.7 Sampling Technique and Sample Size

3.7.1 Sampling Technique

The sampling method used in this study was non probable sampling. In conducting this research different materials had been sampled from different sources, which could help as an input for the laboratory tests. A crushed aggregate was taken from Shandong Highway Engineering Construction Group Co. Ltd located at SNNP, Gurage zone in Gunchire site. 60/70 penetration grade bitumen was obtained from the ERA Jimma district. Reclaimed Asphalt Pavement was collected from Ethiopia Road work Construction Corporation site in Jimma town Deneba site, the samples were filled in 200-kilogram sack which is enough for to accomplish the total tests and packed, then transported to the laboratory. Samples were collected by using simple instruments and labor. All data with respect to material property was recorded for each of the tests specified.

3.7.2 Sample Size

In conducting this research the sample size shall be quantified enough to execute the necessary trials in fulfilling the Marshall property design requirements and performance test criteria. Based on that, three different percentages of crushed stone dust with five varying proportion of bitumen content were selected and Marshall Mix design with three trials were conducted. Total of 190 HMA specimens were prepared to complete the research. From those 45 HMA specimens were for the control mix to determine the optimum bitumen content, 105 were for replacement proportion, 36 were for Moisture Susceptibility and 4 were for Rutting.

3.8 Data Collection Method

The primary research data were collected through performing laboratory experiments, experimental results, etc. whereas the secondary data were collected from relevant documents or literature tried to review and analyze the issues related to the concerned objectives of the study.

3.9 Data processing and Analysis

Quantitative data obtained from test results were analyzed according to the specifications. Among the systematic analysis method, this particular research was employed percentages, tabulation, and graphs by using Microsoft office word and excel. The results of laboratory tests were analyzed using excel to draw different kinds of graphs. Comparison of test results with standard specification. The manuals were AASHTO, ERA, BS, ASTM, and EN standards.

3.10 Data quality assurances

Pre-test of the available instruments were done before the main data collection period begin and the data were collected after gaining awareness on how to collect relevant data by principal investigators. Samples were collected from appropriate sources. Standard formats were used for recording test results to prevent loss of data.

3.11 Materials Test and Procedures

3.11.1 Crushed Aggregate preparation

Aggregate governs about (92-96) percent of HMA by volume of total weight, and the quality and physical properties of this material have a major effect on mix performance. Form, hardness, durability, cleanliness, bitumen affinity, and porosity are all qualities that are expected from aggregates. In addition to these properties, the micro-texture of aggregate particles would also significantly influence the performance of the compacted HMA layer. Four separate stockpiles of crushed aggregate as shown in Figure 3.3 from Shandong Highway Engineering Construction Group Co. Ltd at SNNP, Gurage zone in Gunchire site were imported to the laboratory and prepared for quality test.

Figure 3.3: Materials preparation (Crushed Aggregate)

3.11.2 Reclaimed Asphalt Pavement (RAP) Aggregate Preparation

Reclaimed asphalt pavement is made up of recycled materials that have been milled or removed to their maximum depth during road pavement restoration and maintenance. The materials selected for the test were transported to the lab and prepared for the test. The preparation process involves crushing, extracting, and testing the quality as the same as a virgin aggregate material. For this study, RAP crushing was carried out manually using a rubber hammer to obtain an individual particle size of the recycled aggregate. The extraction of RAP is carried out using the centrifuge method to remove the old bitumen from the recycled aggregate and to obtain the recycled asphalt pavement aggregate (RAPA). Moreover, the quality test is carried out in the same way as the crushed aggregate procedure. The results of the laboratory experiments were summarized in Table 4.1, along with a summary of the tests.

3.12 Quality Test for CA and RAPA

Physical Properties of crushed aggregate and RAPA were conducted as per the respective ASTM, BS, and AASHTO. Table 3.1 summarizes the test conducted for crushed aggregate and RAPA quality test with specified test method by using the standard specification.

Table 3.1: RAPA and Crushed Aggregate Engineering Quality Tests and Methods

Materials	Test conducted	Test Method
RAP	Extraction by Centrifuge Method	ASTMD 2172
Aggregate test for Crushed aggregate and RAPA	Los Angles Abrasion value	AASHTO T-96
	Aggregate crushing value	BS 812, Part 110
	Aggregate Impact Value	BS 812, Part 112
	Elongation index	BS 812, part 105
	Flakiness index	BS 812, Part 105
	Specific Gravity of Coarse Aggregate	AASHTO T 85
	Specific Gravity of Fine Aggregate	AASHTO T 84
	Water absorption	BS 812, Part 2
	A sieve analysis (Gradation)	AASHTO T-27
	Blending	ASTMD 3515

A. Extraction by Centrifuge Method

The Centrifuge extraction method was used to determine the asphalt content of asphalt concrete using the ASTMD 2172 method. The process involves the use of solvents that are expensive, hazardous, and cause problems with disposal. The process started with the weight of the prepared loose mixture (RAP) of 500g and was placed in the centrifugal extractor bowl. An adequate amount of solvent (Benzene) was poured into the centrifuge bowl to fully submerge the loos mixture (RAP). For 30-40 minutes, the mixture, along with the solvent, was left undistributed, allowing the asphalt to dissolve into the solvent and the aggregates to separate. Also, the process of solvent addition and centrifugal extraction was repeated 2-3 times until the asphalt coating was removed and the solvent was removed. The aggregate was removed from the bowl and left to dry for 24 hours to remove the solvents. The extraction process was carried out as shown in Figure 3.4.

(a) (b) (c)

Source: For (a, b, c) Dejene Dereje

Figure 3.4: (a) RAP before extraction, (b) RAP during Centrifugal extraction, (c) RAPA

B. Los Angles Abrasion Test

The Los Angeles test is a measure of degradation of standard grade mineral aggregates resulting from a combination of actions including abrasion, impact, and grinding in a rotating steel drum containing a specified number of steel spheres. As the drum rotates, the shelf plate picks up the sample and the steel spheres, carrying them around until they fall to the opposite side of the drum, creating an impact/abrasive effect. The contents will be rolled inside the drum with abrading and grinding action until the shelf plate impacts and the cycle is repeated. The materials in the drum are removed after the specified number of resolutions, and the aggregate portion is sieved to determine the degradation as a percent loss. The Los Angles abrasion test was conducted on both and RAPA and crushed aggregate as shown in Figure 3.5

Figure 3.5: Loss Angels Abrasion Test

B. Aggregate Crushing value

The Aggregate Crushing value test defines a relative measure of an aggregate's resistance to breaking down under a constant wheel load as a compressive load. The regular aggregate crushing test must be carried out on aggregate that passes the 12.5 mm AASHTO test sieve and retained on the 9.5 mm AASHTO test sieve. Aggregate crushing value test for crushed aggregate and RAPA was conducted as shown in Figure 3.6.

Figure 3.6: Aggregate Crushing Value Test

C. Aggregate Impact Value

Hardiness refers to a substance's ability to withstand impact load. Due to the faction of the vehicle on the road, the aggregate is subject to a collision resulting in it being broken down into smaller particles. The aggregate must be tough enough to withstand impact and not break down. This aggregate efficiency is calculated by the impact value test. Since the aggregate has more influence on the hot mix performance, the aggregate impact value test was performed on both the RAPA and the virgin aggregate according to as shown in Figure 3.7 For this test, samples of Aggregate pass in 12mm and retained in a 10mm sieve was prepared and heated in a dry oven at 100^0C-110^0C for four hours and cooled. Then the aggregates were filled into the cylinder by three layers. After that, the compacted material is carried out by giving 25 blows to the rounded end of the tempering road, as shown in Figure 3.7 Finally, the loaded material was sieved using a sieve size of 2.36 mm, and the aggregate impact value was determined.

Figure 3.7: Aggregate Impact Value Test

D. Elongation Index

The elongation index of aggregate is used to determine the particle shape of aggregate and each particle shape being preferred under specific conditions. Elongation index is the percentage by weight of particles whose greatest dimension (length) is greater than 1.8 times their mean dimension. It is measured on particles passing through a mesh size of 63mm and retained on the mesh size of 6.3mm. for calculating the elongation index of a given sample of aggregates first the weight of each fraction of aggregate passing through and retaining on a specific set of sieves is noted down each of these pieces is then tried to pass through specified gauge length with its longest side and these elongated particles which do not pass through the specified gauge are separated. Then the elongation index was calculated as the total weight of material retained on various length gauges expressed as a percentage of the total weight of the sample gauged. The test has done as shown in Figure 3.8.

$$EI=\frac{W_2}{W_1}*100 \qquad \text{Eq. 3.1}$$

Where W_2= weight of aggregate passing through 1.8 *d mean size, W_1=Total weight of aggregate.

Figure 3.8: Elongation Index Test

E. Flakiness Index

This method is used to classify aggregates and stones. Aggregate particles are known as flaky if their thickness (smallest dimension) is less than 60% of their nominal size, with this size taken as the mean of the limiting sieve apertures used to determine the size fraction in which the particle occurs. Separating the flaky particles and expressing their mass as a percentage of the mass of the sample examined yields the flakiness Index of an aggregate sample. The test shall not apply to a material that passes a test sieve of 6.30 mm BS test sieve or is retained on a test sieve of 63.0 mm BS test sieve. The test has done as shown in Figure 3.9.

Figure 3.9: Flakiness Index Test

F. Specific Gravity and Water absorption of Aggregate

The specific gravity of coarse and fine aggregate has a significant effect on the properties of hot mix asphalt. Shortly aggregated specific gravity is needed to determine the weight of the volume ratios and to calculate various volume-related quantities, such as VMA and VFA.

(a)

(b)

Source: a and b (Yisak Kibru)

Figure 3.10: Specific Gravity and Water Absorption; (a) Course Aggregate (b) Fine Aggregate.

G. Sieve Analysis (Gradation)

It is a procedure that assesses the particle size distribution of granular material by allowing the materials to pass through a series of sieve progressively. Smaller mesh size and weighing the number of materials that are stopped by each sieve as a fraction of the whole mass. Particle size distribution is perhaps the single most important aggregate quality associated with control of HMA mixtures this may affect volumetric properties, mixture permeability, and workability. The purpose of controlling aggregate design gradation is to provide an adequate volume of voids in the asphalt-aggregate mixture to accommodate the proper asphalt film thickness on each particle and provide the design air void system to allow for thermal expansion of the asphalt within the mix. The test was performed on a sample of fresh crushed aggregate and RAPA in a laboratory and expressed as a percentage retained by weight on each sieve size. The results of the tests are providing in graphical or tabular form to identify the best type of gradation of aggregate. For this research, about ten different gradations were prepared one is the individual particle size distribution of RAPA and crushed aggregate which is shown in Appendix B, the three of them are for a conventional mix that shown in Table 4.2. The maximum nominal size selected for this study was 19 mm and the percentage passing maximum and minimum values are shown in Table 3.2 below.

Table 3.2: Gradation of Asphalt binder course (ASTM D-3515)

Sieve No (in.)	Sieve Size (mm)	Nominal maximum stone size (mm)									
		37.5 mm		25 mm		19 mm		12.5 mm		9.5 mm	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
2"	50	100	100	-	-	-	-	-	-	-	-
11/2"	37.5	90	100	100	100	-	-	-	-	-	-
1"	25	-	-	90	100	100	100	100	100	100	100
3/4"	19	56	80	-	-	90	100	100	100	100	100
1/2"	12.5	-	-	56	80	-	-	90	100	100	100
3/8"	9.5	-	-	-	-	56	80	-	-	90	100
NO.4	4.75	23	53	29	59	35	65	44	74	55	85
NO.8	2.36	15	41	19	45	23	49	28	58	32	67
NO.16	1.18	-	-	-	-	--	--	-	-	-	-
NO.30	0.60	-	-	-	-	-	-		-	-	-
NO.50	0.30	4	16	5	17	5	19	5	21	7	23
NO.100	0.150	-	-	-	-	-	-	-	-	-	-
NO.200	0.075	0	5	1	7	2	8	2	10	2	10
Bitumen Content (%)		3	8	3	9	4	10	4	11	5	12

H. Blending

The blending of two or more aggregates is used to obtain different aggregate properties. It is the ability to mix aggregates to meet a specified target. Asphalt concrete requires the combining of two or more aggregates, having different gradations, to produce an aggregate blend that meets gradation specifications for a particular asphalt mix. The aggregate blending was performed by using J.M.F for conventional aggregate gradation and RAP proportion Aggregate Gradation. crushed aggregate that I have taken from Shandong Highway Engineering Construction Group Co. Ltd located at SNNP, Gurage zone in Gunchire site has four stockpiles which it has 13.5-20,7-13.2,3-7 and 0-3 sizes. Additionally, mineral fillers also take from the site, and blending has been done to match the gradation requirement. The final blended gradation was controlled by ASTM D-3515 standard specification limit, which is shown in Table 4.2.

3.13 Bitumen Quality Test

In bituminous mixtures, bitumen serves as a binding agent for aggregates, fines, and stabilizers. The blend is made more durable with the use of a binder. The penetration grade of the asphalt binder used in this study was 60/70. The asphalt binder is often chosen following the traffic class and the environmental conditions. As a result, the asphalt binder chosen for this study was suitable for heavy traffic and the study area's environmental conditions. The physical properties of the asphalt binder were determined using the AASHTO and ASTM standard procedures. Several tests, including penetration, specific gravity, softening point, ductility Flash and fire point were conducted for the basic characteristics of penetration grade asphalt. The test requirement of ERA specifications and results are presented in Table 4.3, and the highlighted of the test method is explained as follows.

Table 3.3: Performed Bitumen Test and Test Methods

Materials	Test conducted	Test Method
Bitumen	Penetration test	AASHTO T- 49
	Specific gravity	ASTM D-70-97
	Ductility	AASHTO T- 51-94
	Softening point	AASHTO T- 53
	Flash and Fire point	ASTM D-92

A. Penetration test

The penetration test value of bitumen is a measure of the hardness of bituminous materials. The penetration value is the perpendicular distance transverse load applied by the peak of the standard needle to the bituminous materials under the specific load, time and temperature conditions the test was conducted as shown in Figure 3.11 (a).

B. Ductility test of bitumen

Bitumen's ductility refers to its ability to stretch under traffic load without cracking throughout road service life. So that the ductility tests on bitumen measure the distance in the centimeters to which it is extended before braking.

C. Softening point of bitumen

The softening point of bitumen is the temperature at which the material reaches the exact softening point. It's a temperature at 25 ^{0}C at which a normal ball passes through a sample of bitumen in the mold and falls through a height of 2.5 cm when water. The softening test of bitumen is conducted as shown in Figure 3.11 (b).

D. The specific gravity of bitumen

The mass of a given volume of a material divided by the mass of an equivalent volume of water at a normal temperature of 25^{O}C is the specific gravity of bitumen.

E. Flash Point and Fire Point

The Flashpoint of the bitumen is the critical temperature at and above which suitable precaution is required to be taken to eliminate the danger of fire during heating this temperature, however, is well below that at which the bitumen will burn. The latter as temperature is called the fire point. The fire and flash point of bitumen was conducted shown in figure 3.11 (c).

(a) (b) (c)

Figure 3.11: Bitumen Test (a) Penetration, (b) Softening Point, (c) Flash and Fire Point

3. 14 Physical Property of Filler

Mineral filler, fine-grained particles naturally present in or manufactured and add to aggregates play a significant role in the performance of asphalt mastic and asphalt mixtures. The fillers used for the study were crushed rock fine obtained from Shandong Highway Engineering Construction Group Co. Ltd located at SNNP, Gurage area at Gunchire site, as per ERA and AASHTO standards. This study was followed by an objective sample selection process. The sample selections depended on the type of tests required in accordance with the standards and the sampling technique was used for each test. The mineral filler used in the study was subjected to the tests listed in Table 3.4 below.

Table 3.4: Test and Test Methods of Mineral Filler Material

Materials	Test conducted	TEST METHOD
Filler	Specific gravity	ASTM D-854
	Plasticity Index (PI)	ASTM D-4318
	Gradation	ASTM D-242

3.15 Asphalt Mix Design

In HMA production, bitumen and aggregates are blended in precise proportions. The relative proportions of the materials determine the physical properties of the materials determine the final finished pavement. There are three commonly used design procedures for determining a suitable proportion of bitumen and aggregate in a mixture. Mix design involves laboratory procedures developed to establish the necessary proportions of materials for use in the asphalt mixture. These procedures include determining an appropriate blend of aggregate sources to produce a proper gradation of mineral aggregate and selecting the type and amount of bitumen to be used as the binder for that gradation. They are Marshall Method, the Hveem method, and the Super pave system method.

3.15.1 Marshall Mix design

The Marshall method of design was originally developed by Bruce Marshall, formerly of the Mississippi Highway Department, and improved by the U.S Army Corps of Engineers. The Marshall method applies only to hot mix asphalt using penetration, PG graded asphalt binder or cement, and containing aggregate with a maximum size of 25.0 mm. The purpose of the Marshall Method is to determine the optimum bitumen content for a particular blend of aggregate. Also provide information about the properties of the resulting pavement mix, including density and void content, which are used during pavement constriction. The Marshall method uses standard test specimen 64 mm (2.5 in) high and 102 mm (4 in.) internal diameter. For this study, a series of specimens were prepared which contained three different aggregate gradation with a bitumen content of (4-6) % by o.5% increment for the control mix than by using the control gradation for RAPA replacement (5-65) % by using ASTM D-1559 procedure. Those steps preliminary to specimen preparation are satisfied:

- ❖ All materials proposed for use meet the physical requirement of the project specification.
- ❖ Aggregate blend combination meets the gradation requirement of ASTM D-3515 standard specification
- ❖ Determine the bulk specific gravity of all aggregate used in blend and the specific gravity of the bitumen for performing volumetric properties analyses.

For this research Marshall Design is selected and several procedures followed.

3.15. 1.1 HMA Specimen Preparation

In determining OBC by using Marshall Method, materials and Apparatus such as blended aggregate and fillers, bitumen, oven-dry, Marshall Compacter, Marshall Mold, Balance, plate, mixer, mold for mixing were needed. And the series of test specimens are prepared for a range of different asphalt contents. The steps recommended for preparing the Marshall Test specimen are as follows:

A Marshall specimen weighing 1200 gm of blended aggregate and crushed stone dust filler is measured from all prepared aggregate with each sieve size by using balance for both control mix and RAP aggregate proportion (0%,5.0%,15%,25%,35% 45%, 55% & 65%) respectively as shown in Figure 3.12 (a), put the prepared materials together in the oven-dry in each separate container by a temperature (105 to 110) OC for minimum 16hrs as shown in Figure 3.12 (b) and the compaction mold was clean and heated in oven dry to a temperature between (95-150)OC Figure 3.12 (c).

(a) (b) (c)

Source: (a) Desta Moshe (b) and (c) Tiruwork Mulatu

Figure 3.12: (a) Weighting of Mix Samples (b) Weighted Samples in Oven (c) Molds in Oven

Bitumen is heated by (160-170) ^{O}C based on a standard heating temperature of bitumen 60/70 penetration grade as shown in Figure 3.13 (a). Then the heated blended aggregate is measured and calculated the required amount of binder. So starting from the first trial, bitumen was added in the required quantity of (4.0, 4.5, 5.0, 5.5, and 6.0) % by weight of total mix, and then heated aggregate and bitumen are mixed thoroughly by mechanical mixer until the aggregate is coated as shown in Figure 3.13 (b) piece of filter paper in the bottom of the mold before the mixture is placed in the mold and also the hammer is clean from dust and unimportant things which can affect the properties of the mixture. After the mold and mixture were prepared then, place the mixed specimen in the compaction mold and place the filter paper on the top of the mix, and placed the mold assembly on the compaction pedestal in the mold holder. Then the specimen is compacted by a Marshall Compacter hammer having a weight of 4.5 kg and a free fall of 45.7cm giving blows on each side of specimen-based traffic classification specified in the ERA standard and standard of Marshall Hammer as specified in ASTM D1559 as shown in Figure 3.13 (c).

(a) (b) (c)

Figure 3.13: Heating of Bitumen, (b) Mixing of HMA Specimen, (c) HMA Compaction

The compacted specimens were removed from the mold after the overnight cool or 24 hours by using the specimen extractor as shown in figure 3.14 (a). Consequently, the heights of specimens were measured using a caliper, as shown in Figure 3.14 (b). After height determination specimen mass was measured in Air, water, and saturated surface dry (SSD) for determination of bulk specific gravity of compacted mix as shown in Figure 3.14 (c).

(a) (b) (c)

Figure 3.14: (a) Extruding of Specimen (b) Height Measurement (c) Weighting of Specimen

After specimen height and Wight are measured, and calculation is made, the extracted specimen was put in a water bath to 60 ^{O}C for 30-40 minutes. After 30+5 minutes, samples are removed from the water bath and placed immediately in the Marshall Stability flow tester machine, and the test must be performed within 30 seconds as shown in Figure 3.15 (a) . U Test with proving ring Marshall Stability. All values of stability and flow were taken from the ring and multiplied by the ring factor as shown in Figure 3.15 (b). Pick load value are adjusted and the correction factor is based on specimen height, and volume is calculated manually.

(a) (b)

Source: a and b Yisak Kibru

Figure 3.15: (a) HMA Specimen in Water Bath, (b) Specimen in Marshall Stability Testing Machine

Generally, the flow and stability of a total of 150 specimens were prepared with the same procedure for both RAPA proportion with crushed Aggregate and Control mix to determine the Optimum bitumen content other Marshall properties. After all, data was recorded the other volumetric properties of the Asphalt mixture were determined from the relationship of various bitumen content to Volumetric parameters like VFA, VMA, Va, and Gmb.

3.15.1.2 Determination of Optimum Bitumen Content (OBC)

After Marshall, Flow stability was finished, and all data is recorded, and the next is determining the bitumen content. According to the Asphalt Institute, Ms-2, two methods are recommended to determine Optimum Bitumen Content (OBC) from the plotted graph.

Method A: NAPA (National Asphalt Pavement Association)

One commonly used procedure is recommended by NAPA, which suggests preparing the plot bitumen content Vs. Marshall properties. Then, the optimum bitumen content is determined by:

- ❖ The bitumen content corresponds to the specification's median air void content (4 percent typically) of the specification. This is the optimum bitumen content.
- ❖ The bitumen content is then used to determine the value for Marshall Stability, VMA, flow, bulk density, and percent voids filled from each of the plots.
- ❖ Compare each of these values against the specification values for that property, and if all are within the specification range, the bitumen content at 4 percent air voids is optimum. If any of these properties are outside the specification range, the mixture should be redesigned.

Method B: Asphalt Institute Method

According to the Asphalt Institute method, Optimum Bitumen content is determined according to the procedure as flows.

1. Plot the graph bitumen content versus stability, bulk specific gravity, and air void,
2. Determine
   a) Determine the bitumen content versus maximum stability
   b) Determine the bitumen content versus maximum bulk specific gravity from the graph
   c) Determine bitumen content at the midpoint of the air void (4%)
3. Take the average bitumen content selected above
4. For average bitumen content selected, go to plotted curve, and determine flow, stability, VFA, VMA, Air void, etc.

5. Compare the value of step 4 with criteria and acceptability.

For this Research National Asphalt Pavement Association method is selected to determine the optimum bitumen content. The marshal properties of asphalt mix, such as Air void, stability, void in mineral aggregate, void filled with asphalt, flow with recommended ERA and asphalt institute method on Marshall Criteria as shown in Table 3.5. The standards Table 3.5 indicated that the minimum stability of the Marshal Test at heavy traffic (75 blows) is 7.0 KN, and minimum flow is two, percent Air Voids between 3-5%, VMA for 4% air voids is 13% and VFA between 65-75%. The selected optimum binder content (OBC) and volumetric properties of each of all mixtures are included within the design criteria.

Table 3.5: Suggested Marshall Criteria for Asphalt concrete pavement (ERA, Pavement Design Manual, 2002).

Total Traffic (106 ESA)	< 1.5		1.5 - 10.0		> 10.0	
Traffic Class	T1, T2, T3		T4, T5, T6		T7, T8	
	Min	Max	Min	Max	Min	Max
No. of blows of Marshall Compaction hammer	2*35		2*50		2*75	
Stability (kN)	3.5	-	6	..	7	..
Flow, (mm)	2	4	2	4	2	4
Percent Air Voids	3	5	3	5	3	5
Percent Voids filled with Asphalt (VFA)	70	80	65	78	65	75
Percent VMA (for 4% air voids and Nom. Max, Particle size of 19mm)	13	..	13	..	13	..

3.16 Volumetric Properties of HMA

In asphalt mixture, binder and aggregate are blended in precise proportions. The relative proportion of these materials determines the physical properties of the asphalt mixture and, ultimately, how the asphalt mixtures perform as a finished pavement. When a sample of asphalt mixture is prepared in the laboratory, the asphalt mixture is analyzed to determine the probable performance in the pavement structures [20]. The volumetric properties of hot mix asphalt are as follows:

- ❖ Theoretical maximum specific gravity (Gmm),
- ❖ Bulk specific gravity**:** (Gmb),
- ❖ Air voids: AV (%),
- ❖ Void in mineral aggregate: VMA (%),
- ❖ Voids filled with asphalt (VFA %).

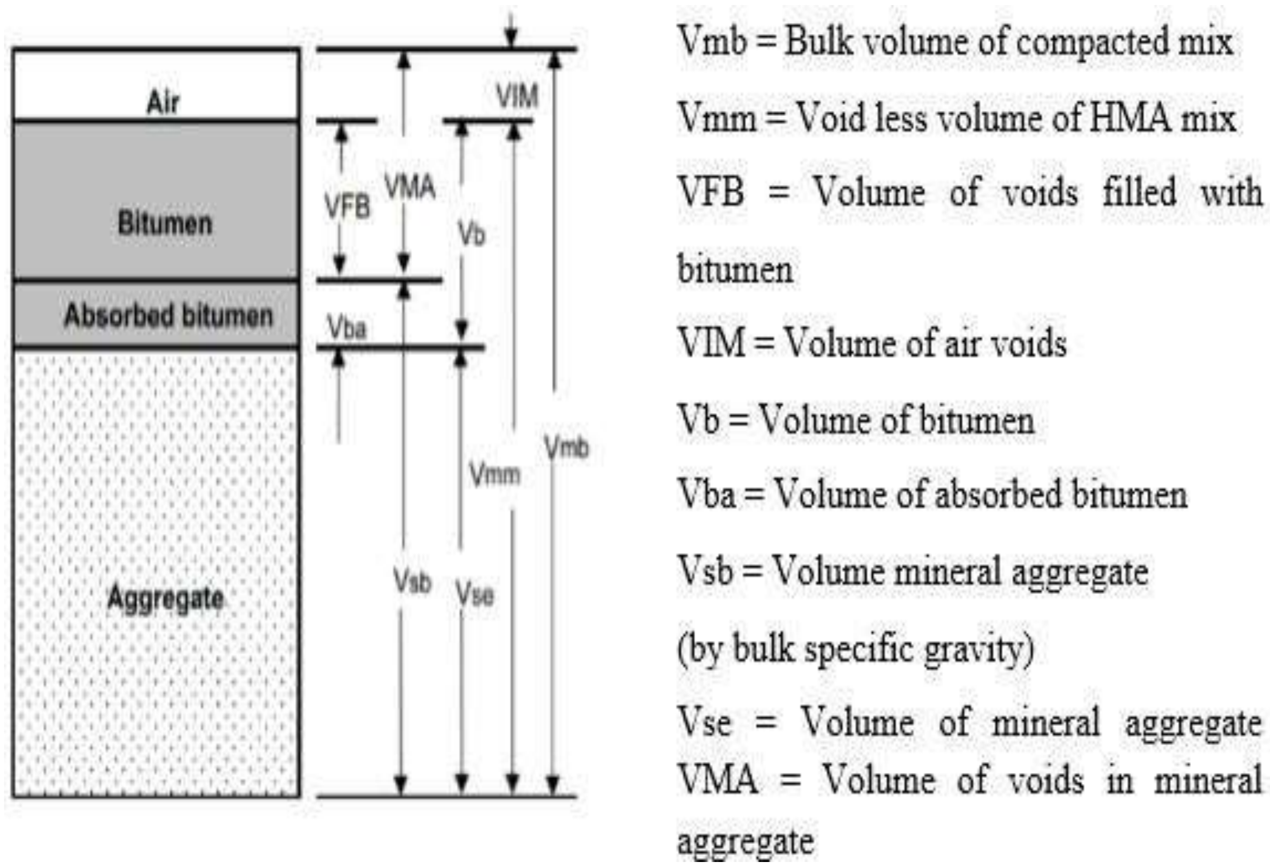


Figure 3.16: Phase diagram of the bituminous mix (Asphalt Institute Manual Series No.2 (Ms-2), Sixth Edition).

3.16.1 Theoretical Maximum Specific Gravity (Gmm)

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, in designing a pavement mixture with a given aggregate, the maximum specific gravity (Gmm) was measured at each asphalt content and it is essential to calculate air voids and VMA. Theoretical maximum specific gravity is the ratio of the weight in air of a unit volume of the un-compacted bituminous paving mixture at a stated temperature to the weight of an equal volume of gas-free distilled water at a stated temperature. It is calculated as:

$$Gmm = \frac{A}{(A+B)+C} \quad \text{...Eq. 3.2}$$

Where:

Gmm = Maximum Theoretical Specific Gravity is calculated as per ASTM D 2041

A = Mass of the dry sample in air, g

B = Mass of Jar Filled with Water, g, and

C = Mass of Jar Filled with Water + Sample, g

3.16.2 Bulk Specific Gravity

According to [20], the bulk specific gravity of mixture refers to the specific gravity of a sample of compacted mixture, including the volume of air voids within the mixture. It is equivalent to the mass of a given specimen in gram divided by its total volume in cubic centimeters. The standard procedure for determining the bulk specific gravity of compacted asphalt, concrete samples involves weighing the specimen in air and water.

$$Gmb = \frac{A}{B-C} \quad \text{...Eq. 3.3}$$

Where: Gmb= Bulk specific gravity of compacted specimen

A = Mass of the dry specimen in air, g

B = Mass of the saturated-surface-dry specimen in air, g,

C = Mass of the specimen in water, g

3.16.3 Air Voids

Air voids are small air space or pockets of air that occur between the aggregate particles in the final compacted asphalt mixture. A certain percentage of air voids is necessary for all dense-graded mixes to prevent the pavement from flushing, shoving, and rutting. Air void may be increased or decreased by lowering or raising the binder content. They may also be increased or reduced by controlling the amount of material passing the No. 200 sieve in the asphalt mixture. The finer added to the asphalt mixture generally the lower the air voids. Finally, the air void may be changed by varying the aggregate gradation in the asphalt mixture [20]. The following formula computes the air void:

$$Va = 100 * \frac{(Gmm - Gmb)}{Gmm} \quad \text{Eq. 3.4}$$

Where: VA= air void in compacted Mixtures

Gmm= Maximum specific gravity of paving mixtures.

Gmb=Bulk specific Gravity of compacted mixtures

3.16.4 Voids in the Mineral Aggregate (VMA)

According to [20] this is the volume of void space between the aggregate particles of a compacted paving mixture. It's the sum of VIM and Pbe expressed as a percent of the total volume of the sample. The more VMA in the dry aggregates, the more spaces are available for the binder. The following formula determined the void in mineral aggregate.

$$VMA = 100 - \frac{Gmb}{Gsb} * Ps \quad \text{Eq. 3.5}$$

Where: VMA= Voids in mineral Aggregate

Gsb= Bulk specific gravity of total Aggregate

Gmb= Bulk particular gravity of the compacted mixture

Ps=Aggregate content, percent by mass of the total mixture

3.16.5 Voids Filled With Asphalt (VFA)

According to [20], the percentage portion of the volume of inter-granular void space between the aggregate particles that is occupied by the effective asphalt. It's expressed as the ratio of (VMA-AV) to VMA. The void filled asphalt, VFA, is the percentage of integral void space between the aggregate particles (VMA) that are filled with asphalt. The mathematical relationship, as shown below:

$$VFA = 100 * \frac{VMA - Va}{VMA} \quad \text{.........Eq. 3.6}$$

Where: VFA= Voids filled with asphalt, percent of VMA

VMA=Void in mineral aggregates, percent of bulk volume

VA= Air void in a compacted mixture, percent of the total volume

3.17 Performance Tests

Performance tests are used to laboratory mix design to actual field performance for this study from number of performance tests resistance to permanent deformation (Rutting) and moisture susceptibility have done.

3.17.1 Moisture Susceptibility

Moisture damage is one of the primary kinds of distress in a mixture of asphalt concrete pavement and it is known that the presence of water reduces the performance of pavement resistance to moisture damage and may cause sudden failure of flexible pavement. To determine this damage the commonly used method is the Indirect Tensile Strength (ITS). In this test for each replacement percentage of RAPA, a set of cylindrical samples were prepared at the optimum bitumen content of the control mix and compacted. The compacted specimens are expected to have air void contents between six percent and eight percent. The higher percentage of air voids helps to accelerate moisture damage on the cores. Six specimens were manufactured and subdivided into two groups with the same number of specimens. The first group is the "control group" or "unconditioned", and the second is the "wet group" or "conditioned. The control group was kept dry at room temperature. The wet group was saturated between (70-80) percent and held in a water bath for 24 hours at 60^{o}c. After that time, the two groups have left a minimum of 2 hr.

at 25^{o}C with the "dry group" in air and the "wet group" in water. All specimens are tested to determine their indirect tensile strengths (ITS).

To evaluate the ITS the cylindrical specimen must be placed on its side between the bearing plates of the testing machine and loaded diametrically along the direction of the cylinder axis with a constant deformation rate of 2 in/min or (50.8mm/min) and the maximum load is recorded. The indirect tensile strength is the maximum tensile stress calculated from the peak load applied at break and the dimensions of the specimen according to equation 3.7 below.

$$ITS = \frac{2 \times P}{\pi \times t \times D} \qquad \text{Eq. 3.7}$$

Where: ITS = Indirect Tensile Strength (KPa),

P = Peak Load (KN),

t = Thickness of specimen (mm),

D = Diameter of specimen (mm).

The tensile strength ratio (TSR) is a common parameter to evaluate moisture susceptibility. It is determined as a ratio of the indirect tensile strengths of the conditioned group divided by the tensile strengths of the control group. A higher tensile strength ratio (TSR) indicates the mixture has good resistance to moisture damage. For construction purposes, the common specification requires a retained strength ratio to equal or exceed 80 percent. The test is conducted in agreement with AASHTOT-283, and it is calculated as follows.

$$TSR = \frac{ITS_W}{ITS_D} * 100 \qquad \text{Eq. 3.8}$$

Where: TSR = Tensile strength ratio (%),

ITS_W = Average tensile strength of for conditioned specimens (KPa),

ITS_D = Average tensile strength of for unconditioned specimens (KPa).

Source: Dejene Dereje

Figure 3.17: Moisture susceptibility

3.17.2 Rutting

Permanent deformation, or rutting, has been and continues to be a problem in the performance of hot mix asphalt (HMA) pavements. Rutting is defined as the accumulation of small amounts of Unrecoverable strain resulting from applied loads to the pavement. This deformation is caused by the consolidation, a lateral movement of the HMA under traffic, or both. Shear failure (lateral movement) of the HMA courses generally occurs in the top 100 mm of the pavement surface. A small Wheel-tracking test procedure B was used to evaluate the rutting resistance of mixtures after determining the best-performed percent of replacement (0% & 65%) of RAPA by all Marshall Criteria and according to UNE-EN 12697-22 selection of mold size, selection of compaction rate, mix design temperature, etc were selected for this research. Selection of mold type as shown in Figure 3.18 (a) mixing of materials as shown in Figure 3.18 (b) and the sample was compacted by using roller compacter as shown in Figure 3.18 (c). Specimens were subjected to 10 full cycles of compaction and have a minimum density of 98% of the Marshall density.

(a) (b) (c)

Source: Endale Mekuria

Figure 3.18: Rutting Compaction Mold, (b) Mixed Rutting Sample, (c) Compaction of Specimen

According to UNE-EN 12697-22 procedures B all the asphalt concrete samples were subjected to 10,000 passes of a loaded wheel. The load applied is 700 N at the rate of 26.5 revolutions per minute i.e. 53 passes per minute and tested at a temperature of 60 °C as shown in Figure 3.19 (a) and (b) before the test, the specimens were preheated at a temperature of 60^0C.The samples have visual rut depth as shown in Figure 3.19 (C). Two samples were tested for each control mix and allowable replacement percentage.

(a) (b) (c)

Source: Endale Mekuria

Figure 3.19: (a) and (b) Specimen in Wheel-Tracking Test, (c) Rutted Specimen

The mean rut depth and the proportional rut depth values of the control and maximum allowable replacement percentage values were compared with EN 13108 specification . After the wheel tracing slop ,rut depth and proportional rut depth calculations have done by using the following procedures.

Wheel-tracking slope in air Mean wheel-tracking slope in air

The result of the test is the average WTSAIR of the two specimens. The wheel-tracking slope shall be expressed in mm per 10^3 load cycles and calculated as:

$$WTS_{AIR} = \frac{(d_{10000} - d_{5000})}{5} \quad \text{…… Eq.3.9}$$

Where:

WTS_{AIR} = the wheel-tracking slope (mm/10^3 load cycles),

d_{5000}, d_{10000} = the rut depth after 5 000 load cycles or 10 000 load cycles respectively (mm).

Mean rut depth RD_{AIR} in air

The rut depth for the material under test at N cycles is the mean rut depth of the two specimens in mm.

$$RD_{AIR} = \sum_{i=1}^{2} \frac{d_{10000i}}{2} \quad \text{…… Eq.3.10}$$

Where:

RD_{AIR} = mean rut depth at 10^4 load cycles (mm),

$d_{10000,i}$ = the rut depth after 10,000 load cycles (mm).

Mean proportional rut depth PRD_{AIR} in air

The proportional rut depth for the material under test at N cycles is the mean proportional rut depth of the two (or more) specimens in %.

$$RD_{AIR} = \sum_{i=1}^{2} \frac{\frac{d_{10000}}{hi}}{2} * 100 \qquad \text{Eq.3.11}$$

Where:

RD_{AIR} = the mean proportional rut depth at 10^4 load cycles (%),

$d_{10000,i}$ = the rut depth after 10 000 load cycles in specimen i, (mm),

h_i = the thickness of test specimen i, (mm).

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Introduction

Generally, this chapter includes the analysis and discussion of the result obtained from laboratory tests. The results of the study are discussed and in three main sections. The first was the engineering properties of materials which are crushed aggregate, bitumen filler, and RAPA. The second section was a discussion on the Marshall result of control mixes (0% RAP) that prepared with three different aggregate proportions and fillers. This test was conducted by adding different percentages of bitumen (4%, 4.5%, 5%, 5.5%, and 6%) increasing by 0.5%, and the result is analyzed to find optimum bitumen content (OBC) and identify the design aggregate gradation for replacement of RAP. In the third section of the study, Reclaimed Asphalt Pavement aggregate (RAPA) was replaced in place of crushed aggregate with control mix design gradation proportion by 5.0%, 15%, 25%, 35% 45%, 55% and 65% (by weight of aggregate) then, laboratory tests were conducted. Moreover, the result was analyzed to determined optimum bitumen content (OBC) and corresponding volumetric properties of hot mix asphalt. Based on the result of OBC and volumetric properties of each mix, the maximum percentage of RAP used in Hot Mix asphalt was recommended. Finally, performance tests which were moisture susceptibility and rutting test results discussed.

4.2 Material Property Test Results

4.2.1 Aggregate Physical Property Test Result

To investigate the physical properties of aggregates and their suitability in road construction, various tests were conducted, and the test result is presented in Table 4.1. The specific gravity of aggregate was determined for each percentage replacement of RAPA in crushed aggregate with each size proportion of aggregate (9- 25 mm, 2.36-9.5 mm, and 0-2.36 mm), which is very important for the determination of VMA and VFA of HMA. The detailed work of the aggregate quality test was shown in Appendix A.

Table 4.1: Physical properties of RAPA and crushed Aggregate for the study

Test	Test method	Test Result (%)		Specification
		CA	RAPA	
Los Angeles Abrasion (LAA), %	AASHTO- T96	13.67	14.3	<35 %
Aggregate Crushing value (ACV), %	BS 812, Part 110	13.86	16.67	<25 %
Aggregate Impact Value(AIV), %	BS 812, Part 112	10.45	14.61	<25 %
Elongation Index, %	BS 812, Part 105	11.27	11.43	<15 %
Flakiness Index, %	BS 812, Part 105	23.89	23.07	<45 %
Specific Gravity (Coarse Aggregate)	AASHTO T- 85	2.381	2.68	N/A
Specific Gravity (Fine Aggregate)	AASHTO T- 85	2.703	2.824	N/A
Water Absorption (Coarse Aggregate)	BS 812, Part 2	1.23	1.48	<2
Water absorption(Fine Aggregate)	BS 812, Part 2	1.55	1.42	<2

i.e. N/A- Not Available

4.2.2 Aggregate Gradation

Hot mix asphalt (HMA) is graded by the percentage of different size aggregate particles it contains. Aggregate gradation should convince the control points specified by the specification guideline for Particle Size distributions. HMA production. With 19 mm, maximum aggregate nominal size and three different percentages of fillers (5.0%, 5.5%, and 6%) by weight of total weight added to the mix aggregate gradation. For this research, aggregate gradation was conduct for the control mix and checked the RAPA gradation with in the control gradation and with specification. Therefore, the proposed gradation meets the standard specification requirements. Figure 4.1, Figure 4.2 and Figure 4.3 shows aggregate gradation for control mix based on the standard specification of ASTM D3515.The gradation trials, Max density value, upper limit and lower limit indicated with different color. The gradation trials contains 5.0%, 5.5% and 6.0% indicated by broken black color, maximum density indicated by light blue color, upper limit indicated by red color and lower limit indicated by green color. The proposed gradation is between the upper and lower limits of ASTM specification as shown in the figure below. Table 4.2 shows the blending proportion of aggregate with three trials and four stockpiles aggregate size the detailed blending proportion table indicated in Appendix A.

Table 4.2: suggested percentage combination of stockpile aggregate

suggested percentage combination of stockpile aggregate						
Stock pile aggregate size	13.2-20 mm	6-13.2 mm	3-6 mm	0-3 mm	Filler (CSD)	sum
Trial 1	15.00%	31.00%	26.00%	26.00%	2.00%	100.0%
Trial 2	14.50%	31.00%	26.00%	26.00%	2.50%	100.0%
Trial 3	16.00%	27.00%	24.00%	30.50%	2.50%	100.0%

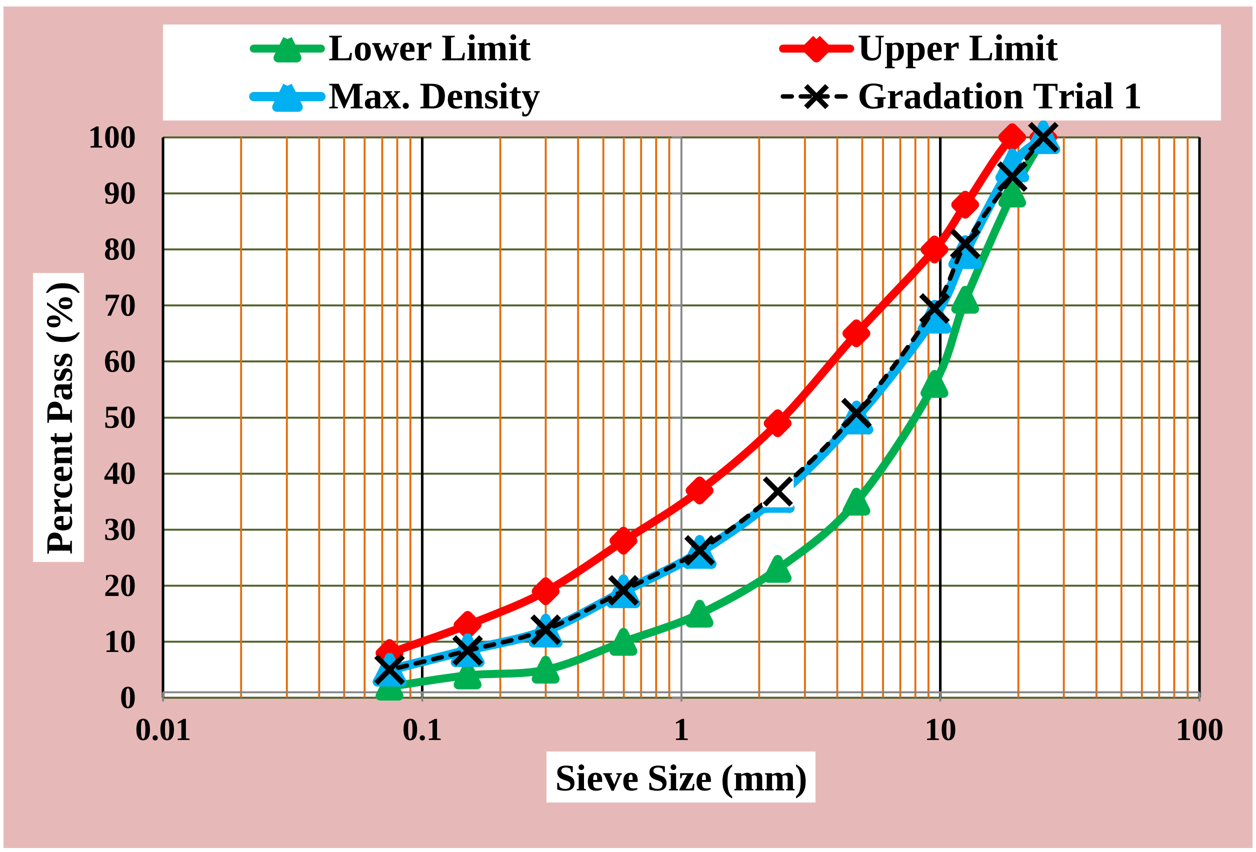


Figure 4.1: Aggregate gradation curve for 5.0% mineral filler gradation

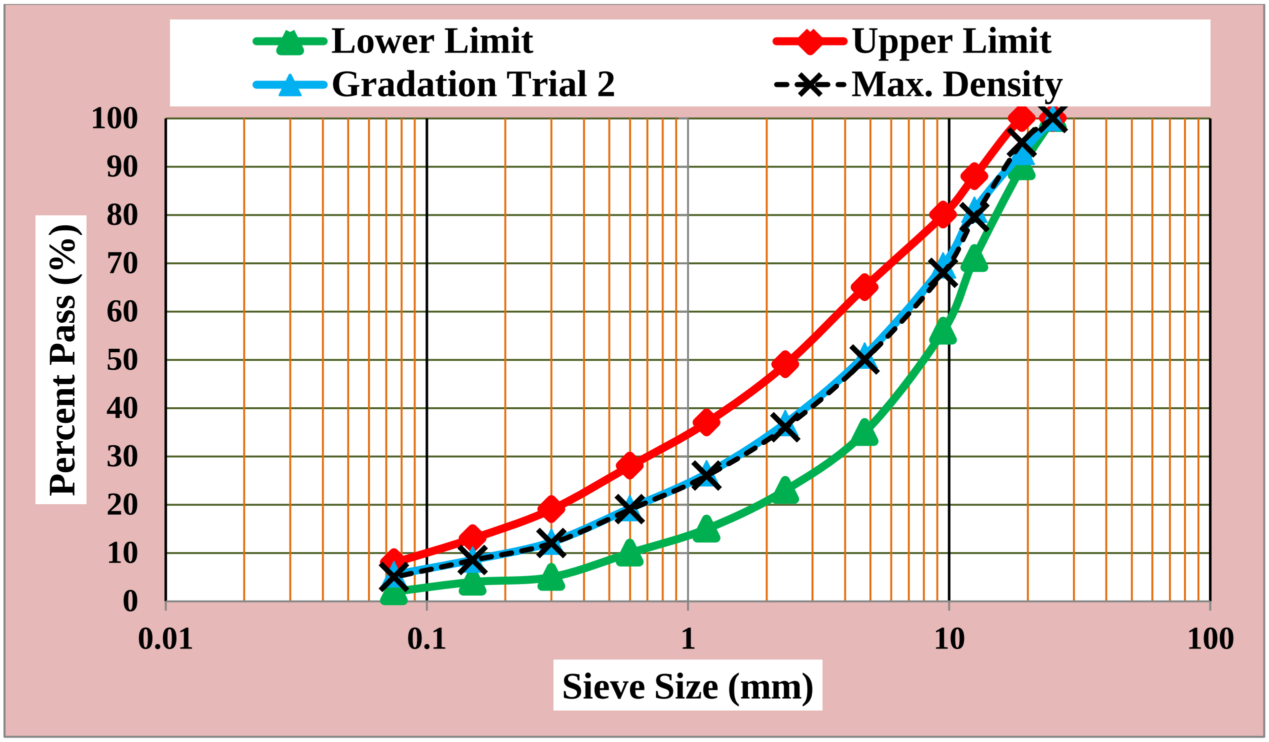


Figure 4.2: Aggregate gradation curve for 5.5% mineral filler gradation

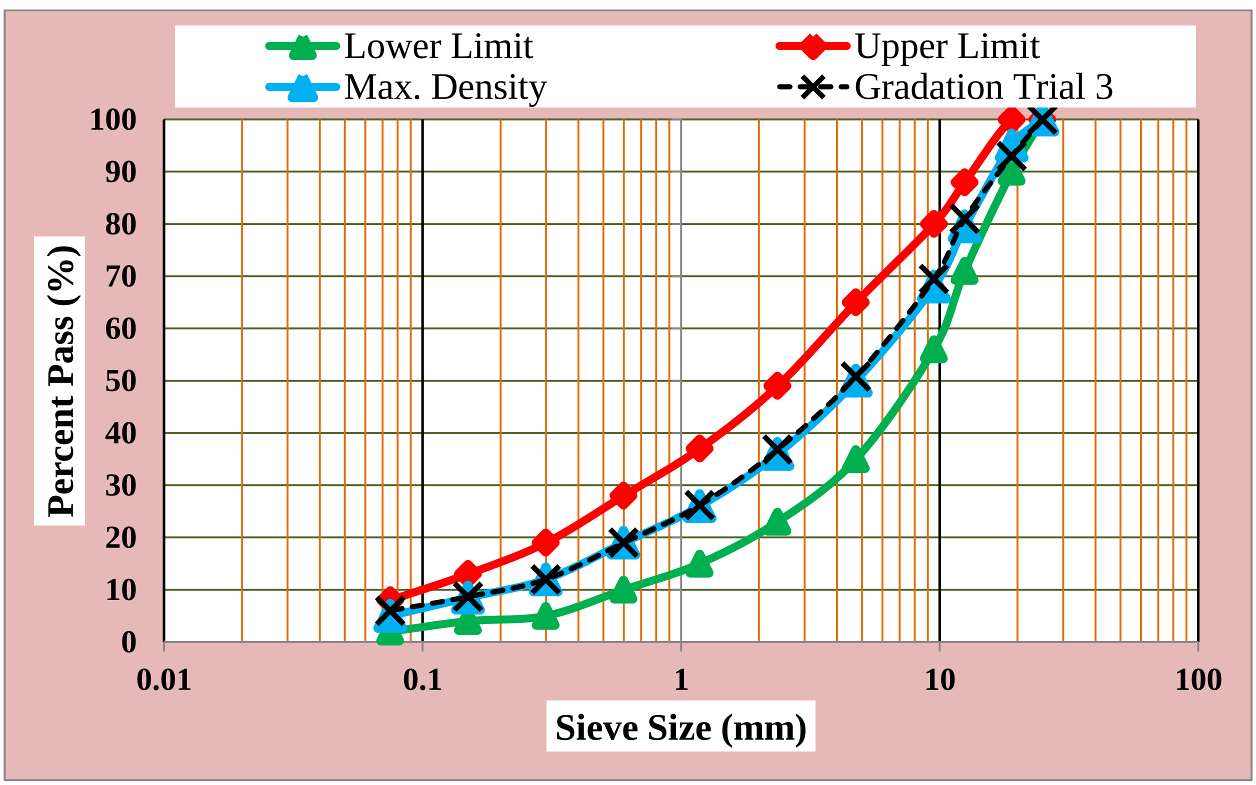


Figure 4.3: Aggregate gradation curve for 6.0% mineral filler gradation

4.2.3 Bitumen Quality Test Result

For the performance of this study, a series of bitumen quality tests were conducted before the mix design was started. These tests included penetration, ductility, softening point, Flashpoint, and specific gravity, and the test result was indicated in Table 4.3. The result of the bitumen quality test was meet the standard specification of selected bitumen of 60/70 penetration grade according to ERA,2013 pavement design manual standard specification the details of the tset showen in Appendix B.

Table 4.3: Physical Properties of Bitumen

Test	unit	Test method	Result	Recommended specification As ERA for bitumen 60/70
Penetration @ 25^{o}C	1/10mm	AASHTO T 49	65	60-70
Ductility @25 ^{o}C	cm	AASHTO T 51	108	Min 50
Softening point	^{o}C	AASHTO T 53	48	46-56
Specific Gravity 25 ^{o}C	Kg/cm^{3}	ASTM D-70-97	1022	---
Flashing point	^{o}C	ASTM D-92	546	Min 232

4.2.4 Mineral Filler Properties

Crushed Stone Dust is used as mineral filler in this research. Their physical properties affect the bituminous mixture property. The laboratory tests were conducted to evaluate the physical properties of Crushed Stone Dust, which consists of the apparent specific gravity and plasticity index according to ASTMD-854, using the water Pycnometer method. Table 4.4 illustrates the physical properties of crushed stone dust filler.

Table 4.4: Physical properties of filler material

S/No	Test description	Test Method	Result	ERA Design Standard Specification, (2002)
1	Apparent specific gravity (Kg/m^{3})	ASTM D-854	2.848	N/A
2	Plasticity Index (PI)	ASTMD-423	NP	≤ 4

i.e. NP-Non-Plastic, N/A -Not Available

4.3 Analysis of Asphalt Mixture Properties

4.3.1 Marshall Test Result

The laboratory work result of asphalt mix laboratory work was obtained and analyzed to achieve the research objectives. Marshall Test results of the mixtures with different bitumen content and with different mineral filler content are presented in Table 4.5, Table4.6, and Table 4.7. Further details are presented in Appendix D. Forty-five specimens were prepared to determine optimum bitumen content of control mix and by using control mix gradation one-hundred-five specimens were prepared to determine optimum bitumen content for RAPA to recommend the maximum allowable usage of RAPA in hot-mix asphalt. Table 4.9 through Table 4.15 indicate the properties of the mixture at their various bitumen contents for mix with different proportions of (5.0%, 15%, 25%, 35%, 45%, and 55%) RAPA based on control mix gradation. Further details are presented in Appendix D. According to Asphalt Institute recommended five mixed design criteria for the Marshall Mix design method. These are maximum Marshall Stability, range of acceptable Marshall Flow, range of acceptable air voids, percent voids filled with asphalt (VFA), and a minimum amount of VMA and ERA, pavement design Manual,(2002) Marshall design criteria for heavy traffic, Minimum stability must be 7KN at 60 ^{O}C, flow value must be ranged between 2-4 mm, Air void must be between 3 to 5%, Void filled with bitumen (VFA) must be between 65 to 75 % and minimum value of VMA for 19 mm nominal particle size is 13%. The conversion was made based on either measured thickness or measured volume. It is possible while making the specimen the thickness slightly varies from the standard specification of 63.5 mm. Therefore, measured stability values need to be corrected to those which would have been obtained if the specimens had been exactly 63.5 mm. This is done by multiplying each measured stability value by an appropriate correlation factor shown in Appendix E.

4.4 Marshall Test Result for Control Mix

control mix was prepared with three different aggregate gradation 5.0%,5.5% and 6.0% mineral filler content and with five different bitumen content 4.0%,4.5%,5.0%,5.5% and 6.0% to determine the optimum bitumen content and design gradation for the study. The control mix was used to govern the other RAPA replacement. For this study, all figures drawn to determine bitumen content were by 4th order degree because the data points those were bitumen content values are five as shown in Table 4.5, Table 4.6, and Table

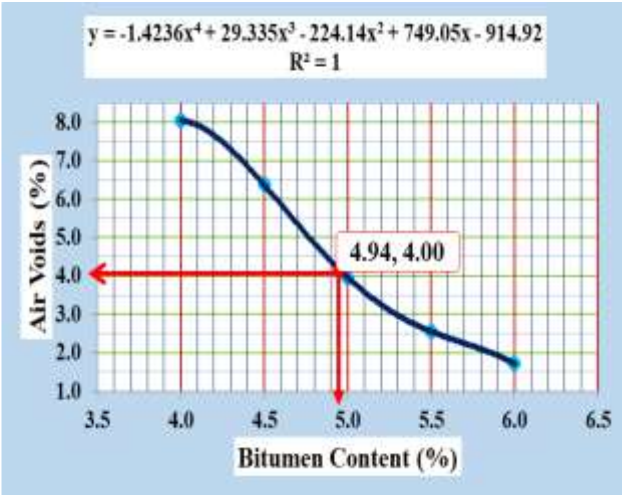
4.7 below. The Marshall Test result of the control mix was presented as follows.

Table 4.5 shows the obtained laboratory test result of the Marshall properties of the mix were performed on five different bitumen contents and with aggregate gradation contain 5.0% crushed stone dust content.

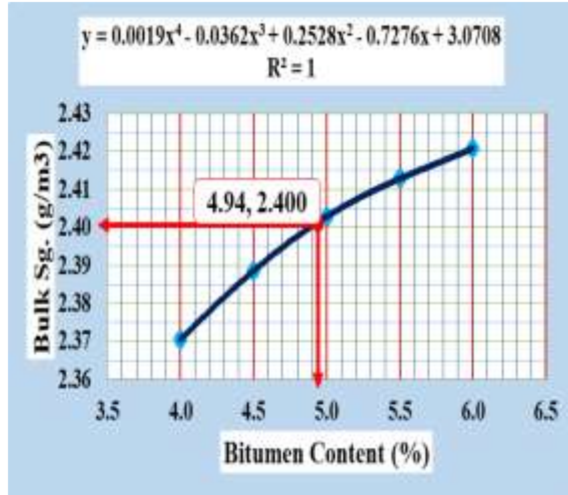
Table 4.5: Marshall Properties of asphalt mixes with 5.0% crushed stone dust

Marshall Properties Result 5.0% Crushed Stone Dust By Wt. Aggregate						
Bitumen Content By Wt. of Total Mix (%)	Air Voids (%)	Bulk Sg. (gm/cm^3)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
4.0	8.05	2.371	16.64	50.27	8.7	2.19
4.5	6.37	2.389	16.44	60.34	9.7	2.54
5.0	3.96	2.403	16.38	69.69	10.6	2.96
5.5	2.55	2.413	16.48	83.34	10.2	3.48
6.0	1.71	2.421	16.65	90.84	9.2	3.84

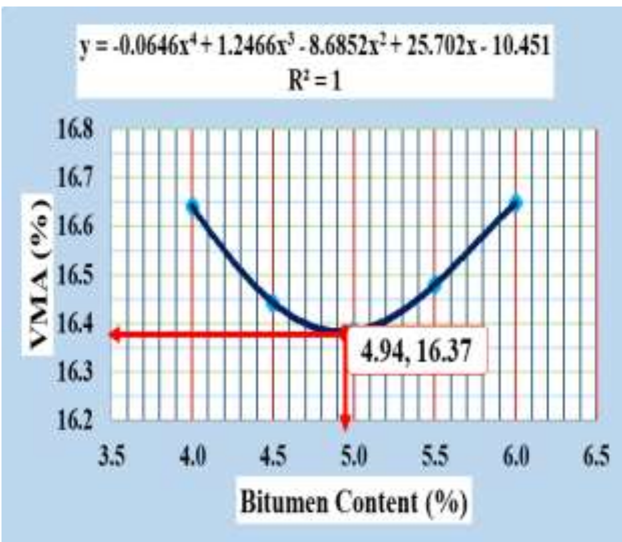
Figure 4.4 shows relationships between bitumen content and the mixture properties such as Air Voids, Bulk specific gravity, VMA, VFA, stability, and Flow by Marshall Method. From this figure, air void is decreasing with increased bitumen content, the value of stability and the unit weight the total mix (bulk density) increases with increasing bitumen content up to pick a point and then gradually decrease although the increase in bitumen content. The value of voids filled with asphalt (VFA) and flow increases with an increase of bitumen content. In contrast, the percent of voids in mineral aggregate (VMA) decreases up to minimum value then increase as bitumen content increase. According to the NAPA mix design method criteria, the mix to have 4.0% air voids at optimum bitumen content. Using this procedure, the Optimum Bitumen Content in Figure 4.4 was found to be 4.94% (by weight of the total mix). The summary of mixture properties at optimum bitumen content is presented in Table 4.6.



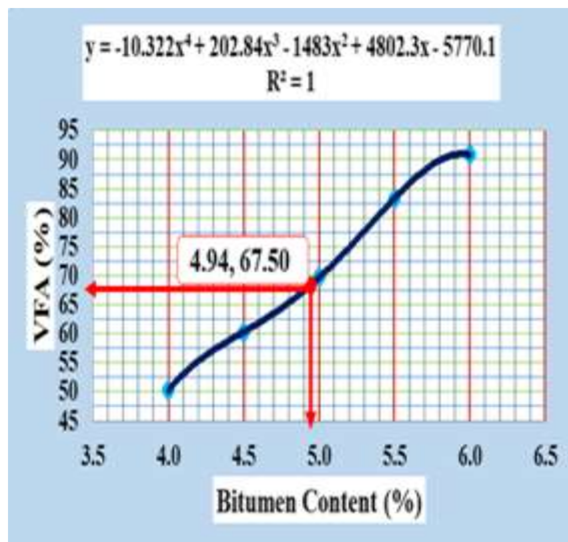
y = -1.4236x⁴ + 29.335x³ - 224.14x² + 749.05x - 914.92
R² = 1
Air Voids (%)
4.94, 4.00
Bitumen Content (%)



y = 0.0019x⁴ - 0.0362x³ + 0.2528x² - 0.7276x + 3.0708
R² = 1
Bulk Sg. (g/m3)
4.94, 2.400
Bitumen Content (%)



y = -0.0646x⁴ + 1.2466x³ - 8.6852x² + 25.702x - 10.451
R² = 1
VMA (%)
4.94, 16.37
Bitumen Content (%)



y = -10.322x⁴ + 202.84x³ - 1483x² + 4802.3x - 5770.1
R² = 1
VFA (%)
4.94, 67.50
Bitumen Content (%)

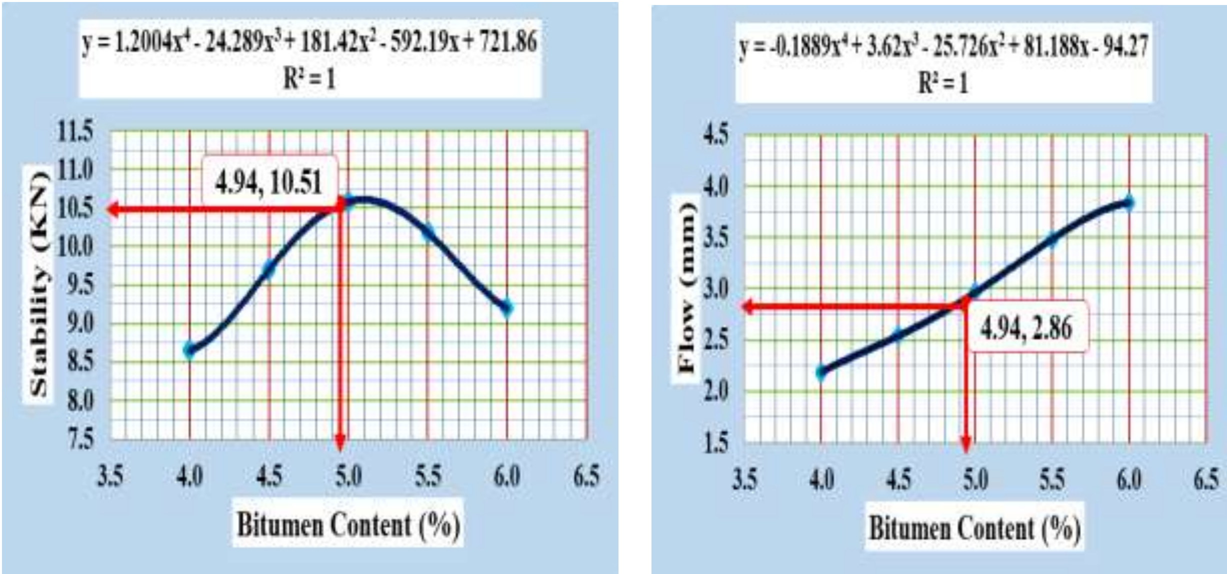


Figure 4.4: OBC and the properties of mixtures with 5.0% crushed stone dust

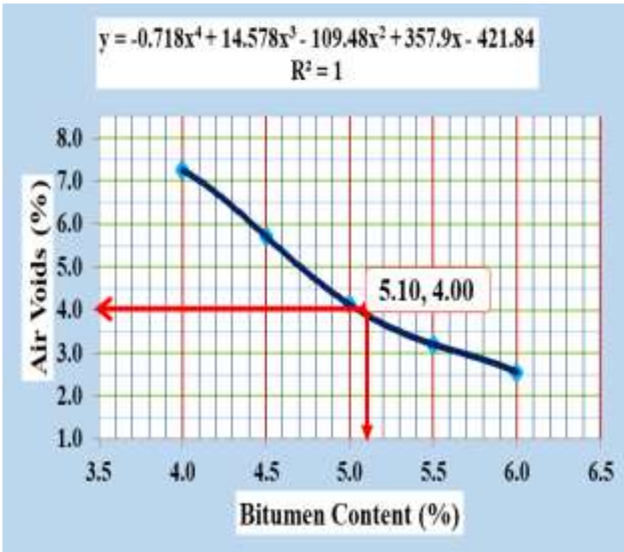
Table 4.6 presents the obtained laboratory test result of the mixture with an aggregate gradation of trial 2 which was 5.5% crushed stone dust and the corresponding values of Marshall Properties for the control mix. The relationships between bitumen content and the mixture properties such as Air Voids, Bulk specific gravity, VMA, VFA stability, and Flow curves are also plotted in Figure 4.5.

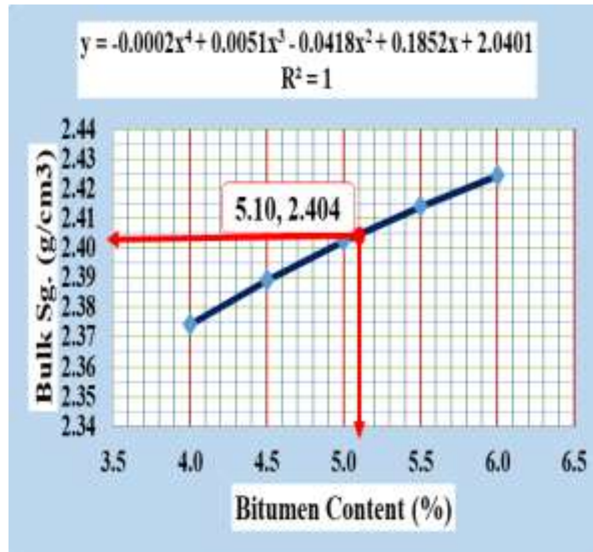
Table 4.6: Marshall Properties of asphalt mixes with 5.5% crushed stone dust

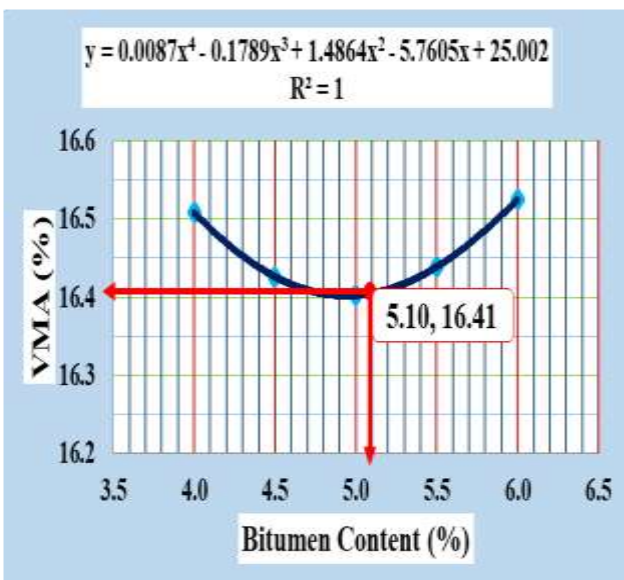
Marshall Properties Result 5.5% Crushed Stone Dust By Wt. Aggregate						
Bitumen Content By Wt. of Total Mix (%)	Air Voids (%)	Bulk Sg. (gm/cm^3)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
4.0	7.25	2.374	16.51	53.96	9.2	2.29
4.5	5.72	2.389	16.43	62.60	10.6	2.70
5.0	4.14	2.402	16.40	70.04	11.3	3.09
5.5	3.21	2.414	16.44	79.83	10.5	3.42
6.0	2.56	2.424	16.53	84.51	9.5	3.68

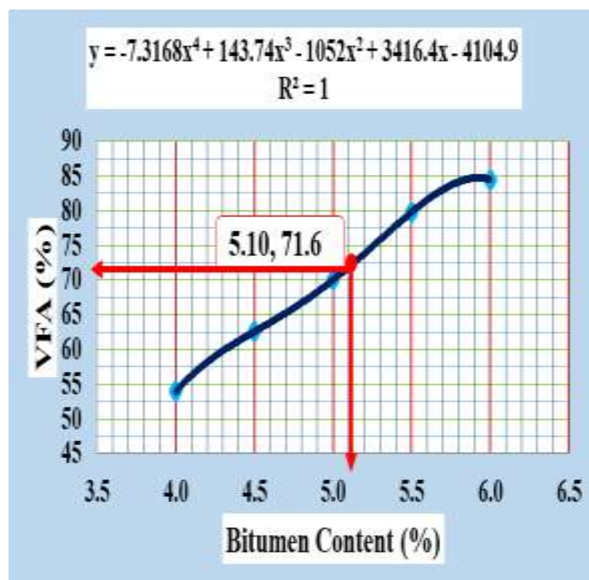
Figure 4.5 shows the relationship between bitumen content and mixture properties with an aggregate gradation of 5.5% crushed stone dust. From the figure shown below the optimum

bitumen content of the mix that resulted in 4.0% air voids of the specification is 5.10%. The overall curve correlation between bitumen content and the Marshall properties for 5.5% crushed stone dust is similar to 5.0% crushed stone dust.









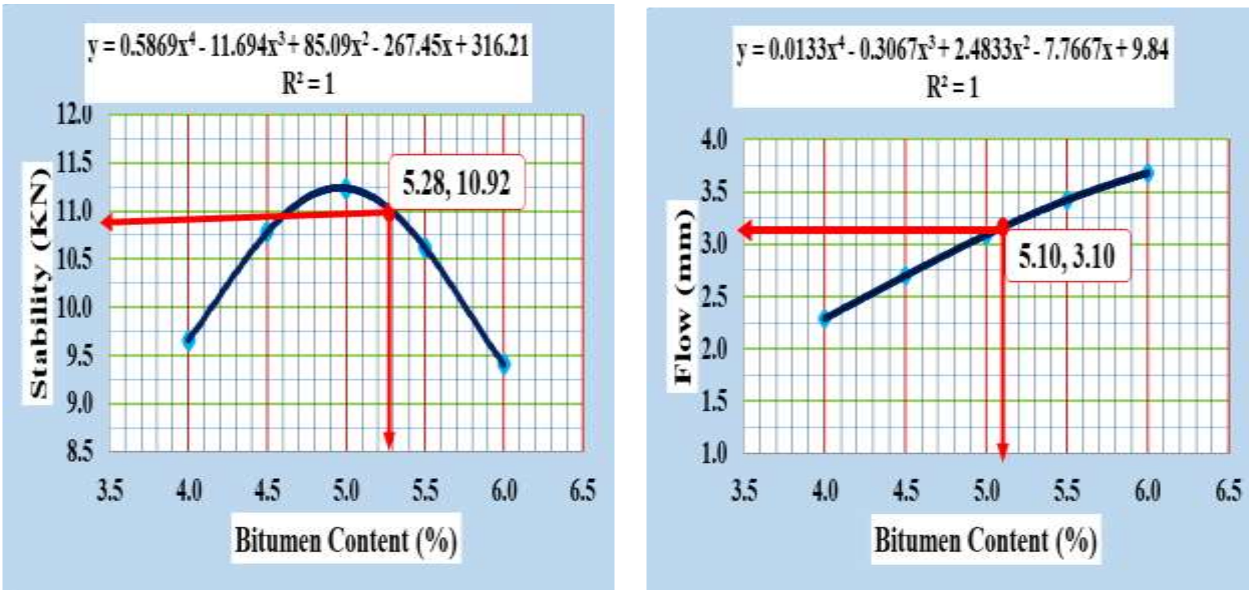


Figure 4.5: OBC and the properties of mixtures with 5.5% crushed stone dust

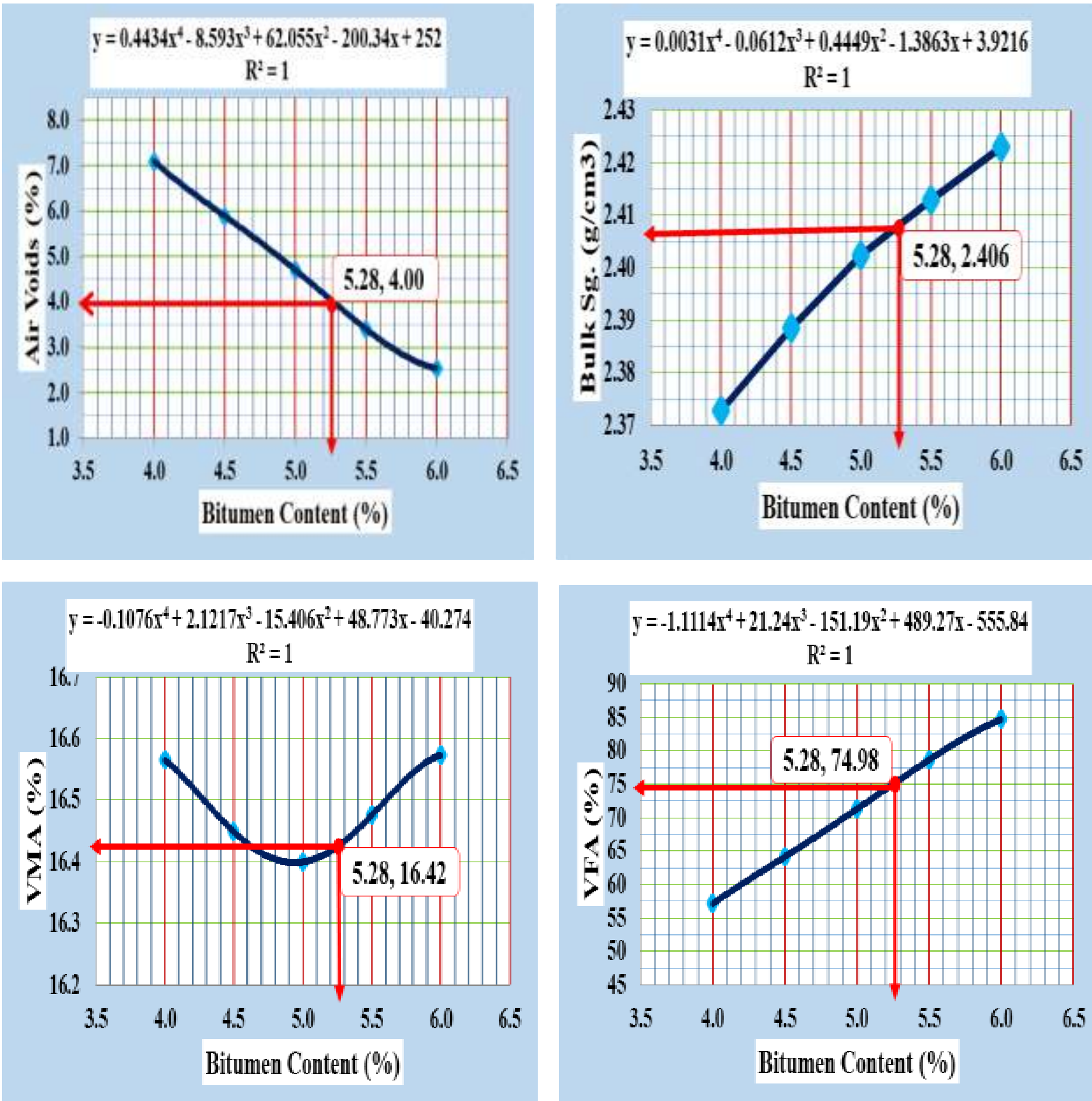
Table 4.5 shows the obtained laboratory test result of the Marshall properties of the mix at different bitumen content with aggregate gradation with 6.0% crushed stone dust content. The relationships between bitumen content and the mixture properties such as Air Voids, Bulk specific gravity, VMA, VFA stability, and Flow curves are also plotted in Figure 4.6.

Table 4.7: Marshall Properties of asphalt mixes with 6.0% crushed stone dust

Marshall Properties Result 6.0% Crushed Stone Dust By Wt. Aggregate						
Bitumen Content By Wt. of Total Mix (%)	Air Voids (%)	Bulk Sg. (gm/cm^3)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
4.0	7.10	2.373	16.57	57.15	9.7	2.39
4.5	5.89	2.388	16.45	64.17	10.8	2.90
5.0	4.70	2.402	16.40	71.32	11.2	3.32
5.5	3.41	2.413	16.48	78.68	10.6	3.69
6.0	2.54	2.423	16.57	84.69	9.4	3.85

Figure 4.6 shows the relationship between bitumen content and mixture properties with an aggregate gradation of 5.5% crushed stone dust. From the figure shown below the optimum bitumen content of the mix that resulted in 4.0% air voids of the specification is 5.28%. The over-

all curve correlation between bitumen content and the Marshall properties for 6.0% crushed stone dust is similar to 5.0 and 5.5% crushed stone dust.



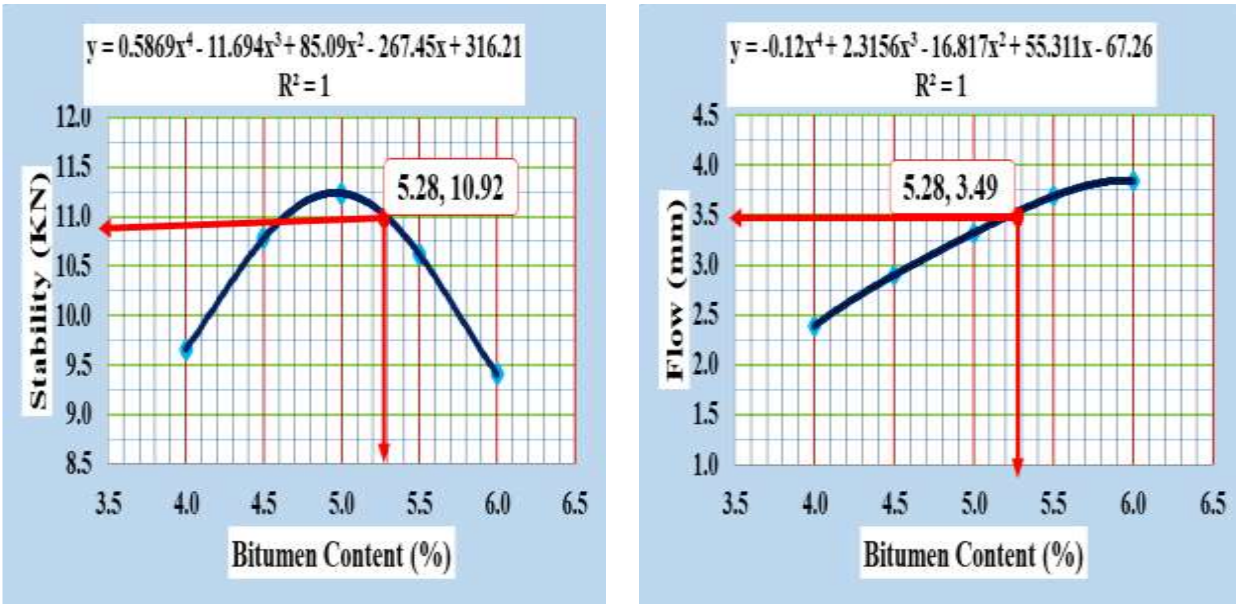


Figure 4.6 OBC and the properties of mixtures with 6.0% crushed stone dust

4.4.1 Determination of Optimum Bitumen Content for Control Mix

The optimum bitumen content for the control mix with three different aggregate gradations contains 5.0%, 5.5%, and 6.0% crushed stone dust was determined by using the Marshall Test (ASTM D1559) and one of the methods called the National Asphalt Pavement Association (NAPA). According to the procedure that was suggested that the optimum bitumen content was determined from the plotting curves as presented in Figure 4.4, Figure 4.5, and Figure 4.6. The OBC is determined by finding the bitumen content, which corresponds to the median air void 4.0% of the specification. Having this bitumen content Marshall Stability, Flow, VFA, VMA, and Bulk specific gravity was determined. Depending on the result, the optimum bitumen content at 4.0% air voids is 4.94%, 5.1%, and 5.28 % by weight of total mix for the respective 5.0%, 5.5 %, and 6.0% crushed stone dust.

Table 4.9 summarizes the bitumen content corresponding to the standard specification criteria. The Marshall Stability values of a mixture trial 1 (5.0% mineral filler content), trial 2 (5.5% mineral filler content), and trial 3 (6.0% mineral filler content) were 10.51 KN, 11.42 KN, and 10.92 KN respectively. It indicates that aggregate gradation which contains 5.5% crushed stone dust has maximum stability than the other two trials. So that, 5.5% and 5.1% were selected as the optimum mineral filler content and optimum bitumen content respectively. Therefore these results, OBC, and corresponding to other Marshall properties of this mix gradation were used as control mix and for RAPA replacement, moisture susceptibility, and rutting test evaluation.

Table 4.8: Comparison of Marshall Properties of control mix with specification

Marshall properties	Marshall result of control mix			ERA (2002) specification limit		Asphalt Institute Limits		Status
	Trail 1 (5.0%)	Trail 2 (5.5%)	Trail 3 (6.0%)	Lower	Upper	Lower	Upper	
Optimum bitumen (%)	4.94	5.10	5.28	4	10	4	10	Satisfied
Stability (KN)	10.51	11.42	10.92	Min 7	-	Min 8.006	-	Satisfied
Flow value (mm)	2.86	3.10	3.49	2	4	2	3.5	Satisfied
VMA (%)	16.37	16.41	16.42	Min 13	-	-	-	Satisfied
VFA (%0	67.54	71.6	74.98	65	75	65	75	Satisfied
Air Void (%)	4.00	4.00	4.00	3	5	3	5	Satisfied
Bulk specific Gravity (gm/cm^3)	2.400	2.404	2.406	_	_	_	_	_

4.5 Marshall Test Result of RAPA Replacement of Crushed Aggregate

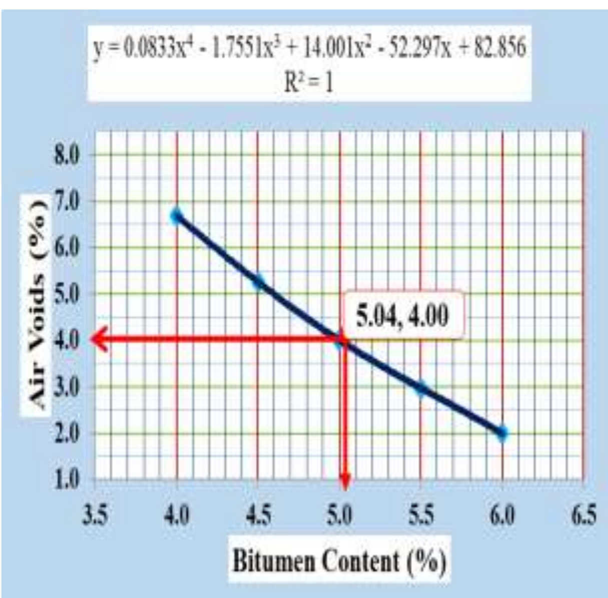
Marshall Test results of HMA mixed with different RAPA percentage was presented in Table 4.9 through Table 4.14 Where, VMA=Void in mineral aggregate, VFA=Void filled with asphalt, RAPA= Reclaimed asphalt pavement and CA= Crushed Aggregate.

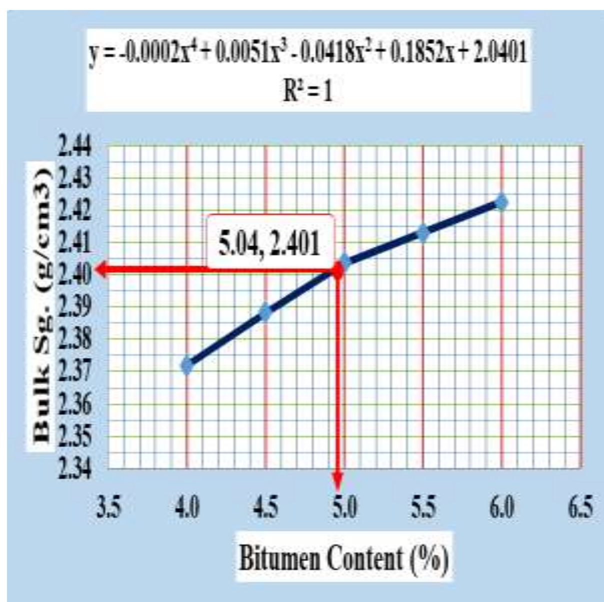
Table 4.9 presented the Marshall Test results of mixture properties mixed with 5.0% RAPA and 95% Crushed Aggregate. Marshall Properties of the mix at different bitumen content with aggregate gradation with 5.5% crushed stone dust content. The relationships between bitumen content and the mixture properties such as Air Voids, Bulk specific gravity, VMA, VFA, stability, and Flow curves are also plotted in Figure 4.7. The replacement RAPA in place of crushed aggregate was performed based on selected design gradation of control mix which is trial 2 that presented in Table 4.6.

Table 4.9: Marshall Properties of asphalt mixes with 5.0% RAPA replacement

Marshall Properties Result 5.5% CSD and 5% RAPA By Wt. Aggregate						
Bitumen Content By Wt. of Total Mix (%)	Air Voids (%)	Bulk Sg. (gm/cm^3)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
4.0	6.69	2.372	16.59	53.97	8.5	2.33
4.5	5.26	2.388	16.45	62.61	9.9	2.75
5.0	4.01	2.404	16.36	70.08	11.0	3.12
5.5	2.98	2.413	16.47	79.85	9.8	3.48
6.0	2.00	2.423	16.58	84.52	8.2	3.71

Figure 4.7 shows the relationships between optimum bitumen content and mix properties contain 5% RAPA and 95% FCA. The relationships between bitumen content and the mixture properties such as Air Voids, Bulk specific gravity, VMA, VFA stability, and Flow curves are plotted. The Optimum Bitumen Content was found equal to 5.04 by weight of the total mix. The details of mixture properties at optimum bitumen content are presented in Appendix D.





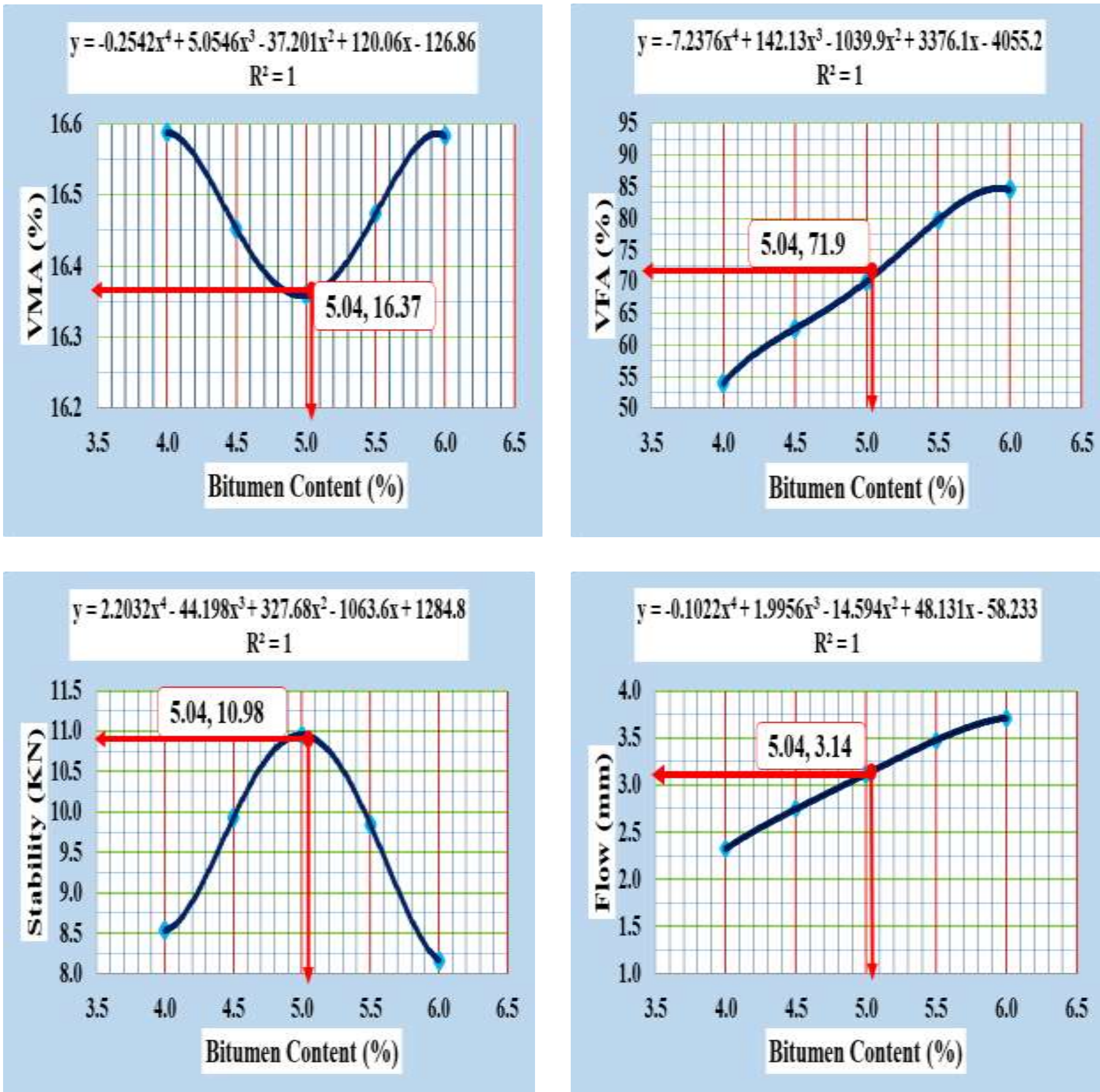


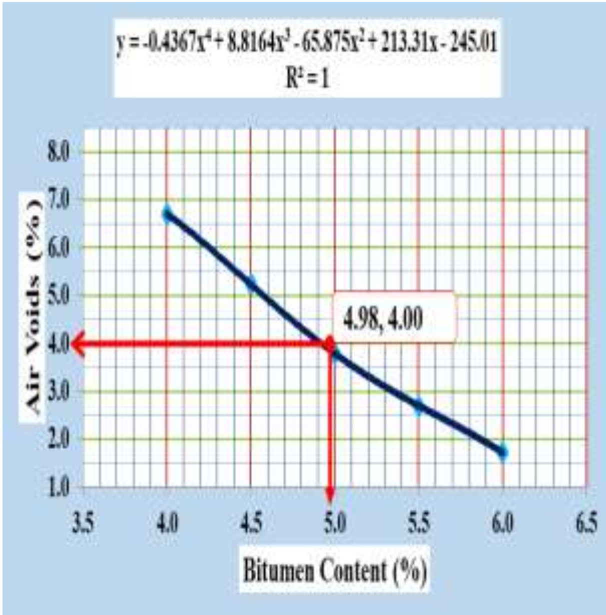
Figure 4.7: OBC and properties of mixtures with 5% RAPA and 95% CA

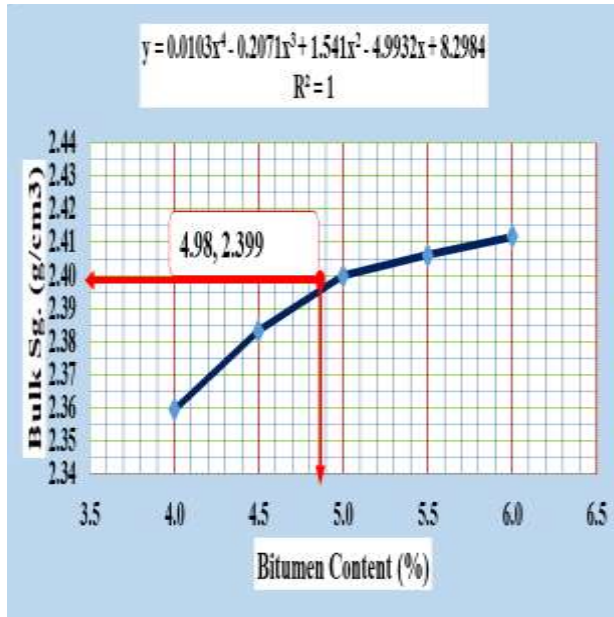
Table 4.10 presented the Marshall Test results of mixture properties mixed with 15% RAPA and 85% fresh Crushed Aggregate. Marshall Properties of the mix at different bitumen content with aggregate gradation with 5.5% crushed stone dust content. The relationships between bitumen content and the mixture properties such as Air Voids, Bulk specific gravity, VMA, VFA stability, and Flow curves are also plotted in Figure 4.8 as 15% RAPA replacement RAP aggregate in place of crushed aggregate was performed based on selected design gradation of control mix which is trial 2 that presented in Table 4.6.

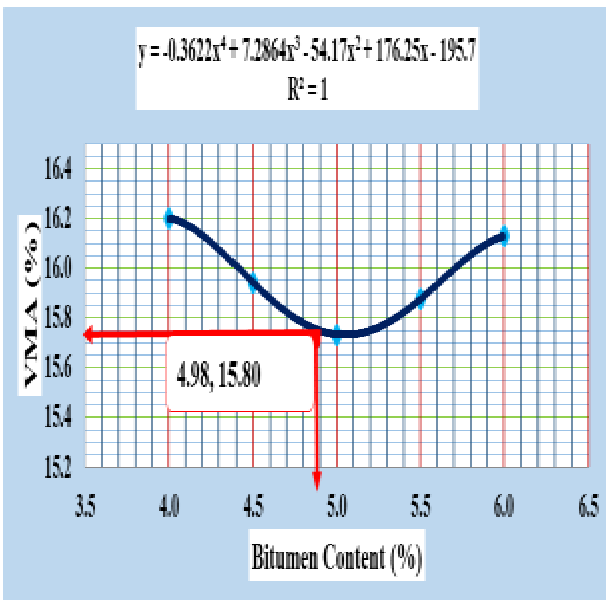
Table 4.10: Marshall Properties of asphalt mixes with 15% RAPA replacement

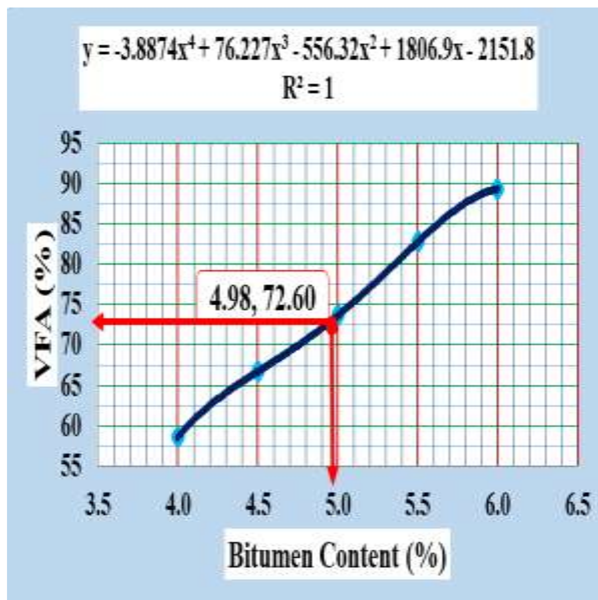
Marshall Properties Result 5.5% CSD and 15% RAPA By Wt. Aggregate						
Bitumen Content By Wt. of Total Mix (%)	Air Voids (%)	Bulk Sg. (gm/M^3)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
4.0	6.70	2.360	16.20	58.63	8.3	2.36
4.5	5.23	2.383	15.94	66.73	9.4	2.85
5.0	3.79	2.400	15.73	73.67	10.2	3.26
5.5	2.70	2.406	15.88	82.77	9.8	3.56
6.0	1.72	2.412	16.13	89.32	8.6	3.78

Figure 4.8 shows the relationships between optimum bitumen content and mix properties contain 15% RAPA and 85% CA. At 5.0% the relationships between bitumen content and the mixture properties such as Air Voids, Bulk specific gravity, VMA, VFA stability, and Flow curves are plotted. The Optimum Bitumen Content was found equal to 4.98 by weight of the total mix. The details of mixture properties at optimum bitumen content are presented in Appendix D.


y = -0.4367x⁴ + 8.8164x³ - 65.875x² + 213.31x - 245.01
R² = 1
Air Voids (%)
4.98, 4.00
Bitumen Content (%)


y = 0.0103x⁴ - 0.2071x³ + 1.541x² - 4.9932x + 8.2984
R² = 1
Bulk Sg. (g/cm3)
4.98, 2.399
Bitumen Content (%)


y = -0.3622x⁴ + 7.2864x³ - 54.17x² + 176.25x - 195.7
R² = 1
VMA (%)
4.98, 15.80
Bitumen Content (%)


y = -3.8874x⁴ + 76.227x³ - 556.32x² + 1806.9x - 2151.8
R² = 1
VFA (%)
4.98, 72.60
Bitumen Content (%)

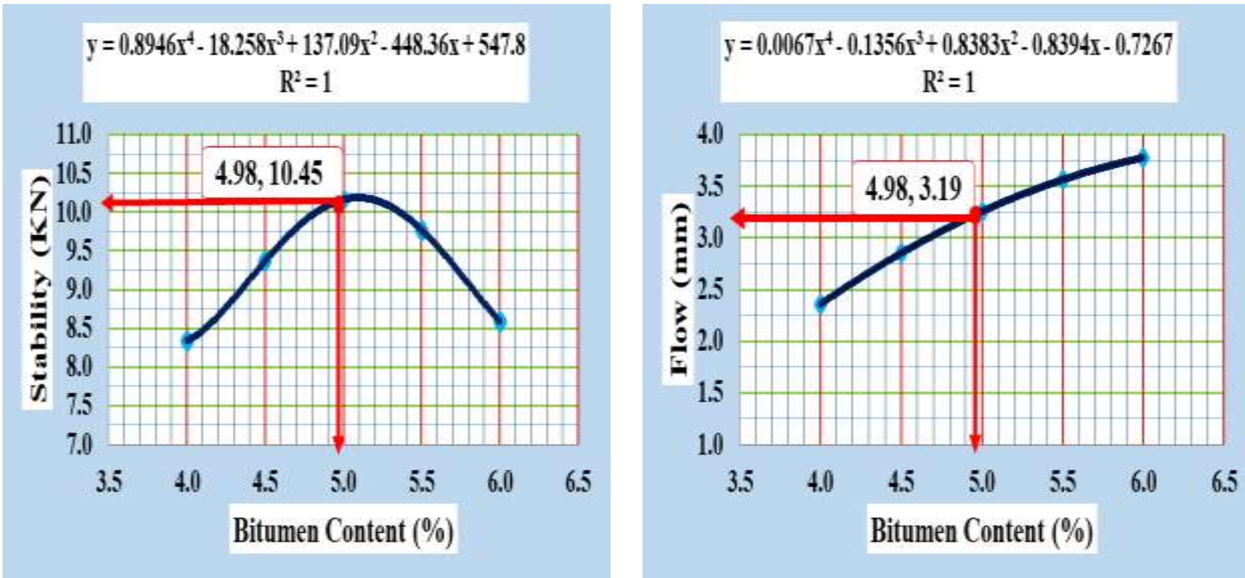


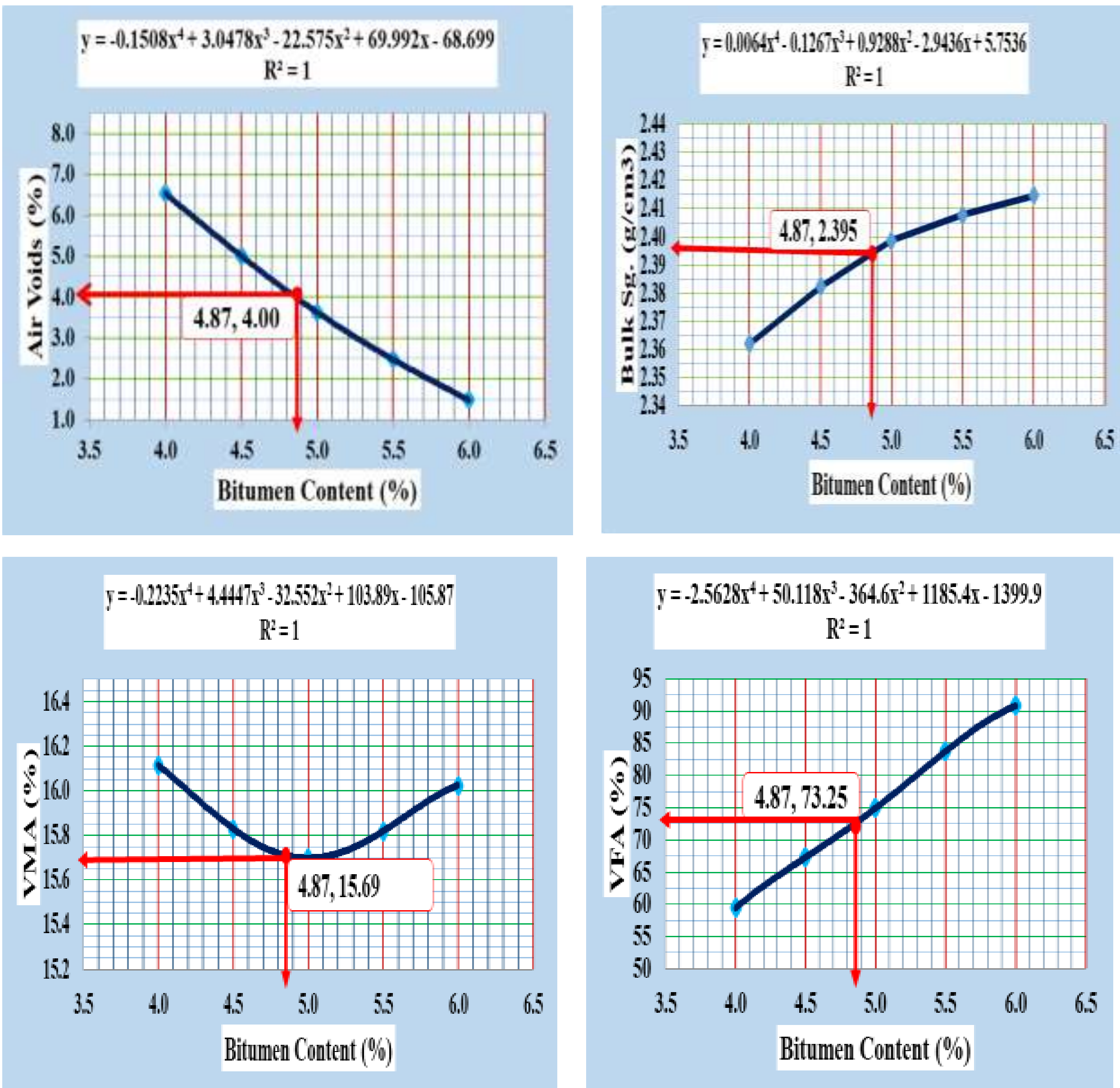
Figure 4.8: OBC and the properties of mixtures with 15% RAPA and 85% CA

Table 4.11 presented the Marshall Test results of mixture properties mixed with 25% RAPA and 75% Crushed Aggregate. Marshall Properties of the mix at different bitumen content with aggregate gradation with 5.5% mineral filler content. The relationships between bitumen content and the mixture properties such as Air Voids, Bulk specific gravity, VMA, VFA stability, and Flow curves are also plotted in Figure 4.9. As the RAPA replacement in 5.0% and 15% RAP aggregate in place of crushed aggregate was performed based on selected design gradation of control mix which is trial 2 that presented in Table 4.6

Table 4.11: Marshall Properties of asphalt mixes with 25% RAPA replacement

Marshall Properties Result 5.5% CSD and 25% RAPA By Wt. Aggregate						
Bitumen Content By Wt. of Total Mix (%)	Air Voids (%)	Bulk Sg. (gm/cm^3)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
4.0	6.53	2.362	16.11	59.46	8.1	2.40
4.5	5.01	2.382	15.83	67.29	9.2	2.83
5.0	3.63	2.399	15.70	74.93	9.8	3.28
5.5	2.48	2.408	15.82	83.71	9.7	3.56
6.0	1.48	2.415	16.03	90.77	8.4	3.79

Figure 4.9 shows the relationships between optimum bitumen content and mix properties contain 25% RAPA and 75% CA. The relationships between bitumen content and the mixture properties such as Air Voids, Bulk specific gravity, VMA, VFA stability and Flow curves are plotted. The Optimum Bitumen Content was found equal to 4.87% by weight of the total mix. The details of mixture properties at optimum bitumen content were presented in Appendix D.



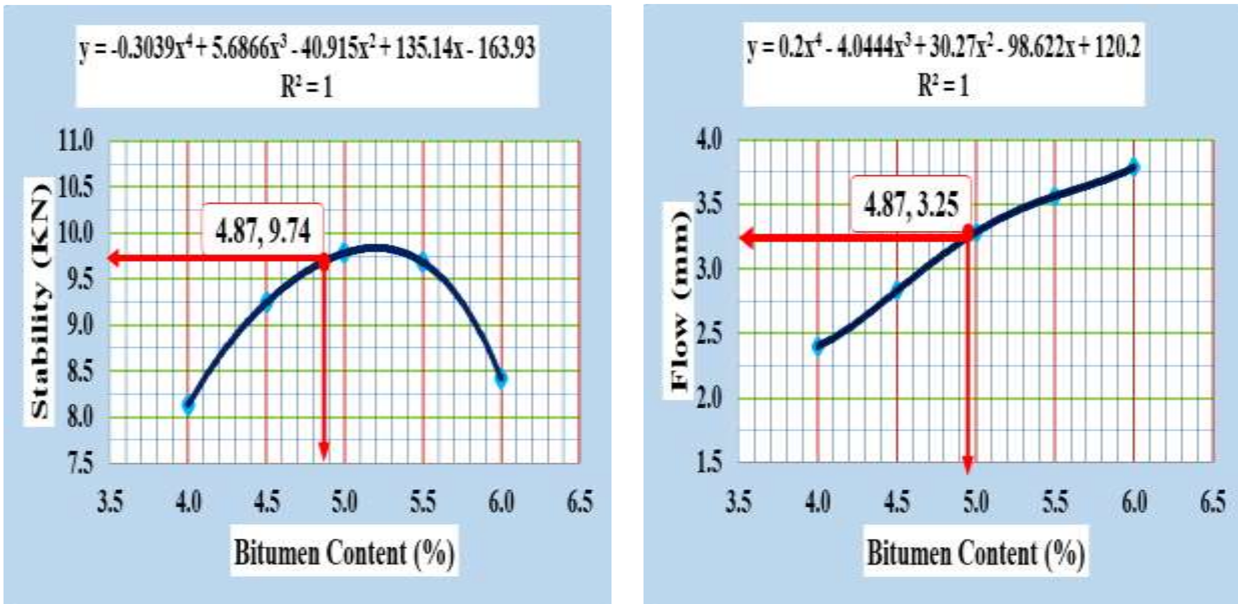


Figure 4.9: OBC and the properties of mixtures with 25% RAPA and 75% CA.

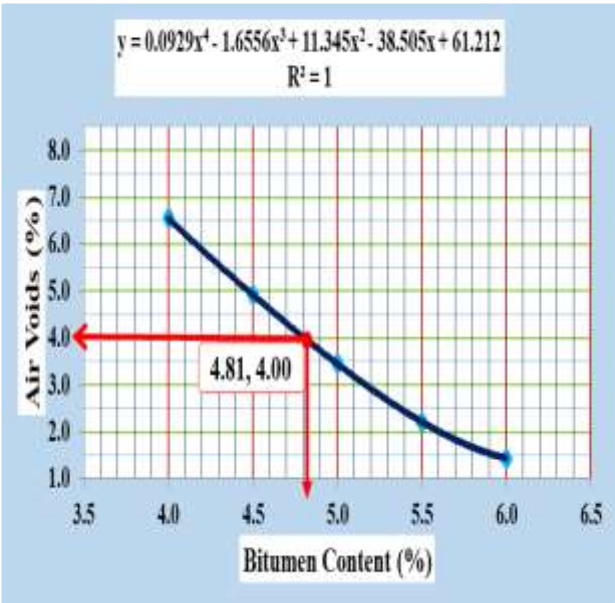
Table 4.12 presented the Marshall Test results of mixture properties mixed with 35% RAPA and 65% Crushed Aggregate. Marshall Properties of the mix at different bitumen content with aggregate gradation with 5.5% mineral filler content. All properties and gradation is performed as 5.0%, 15% and 25%.

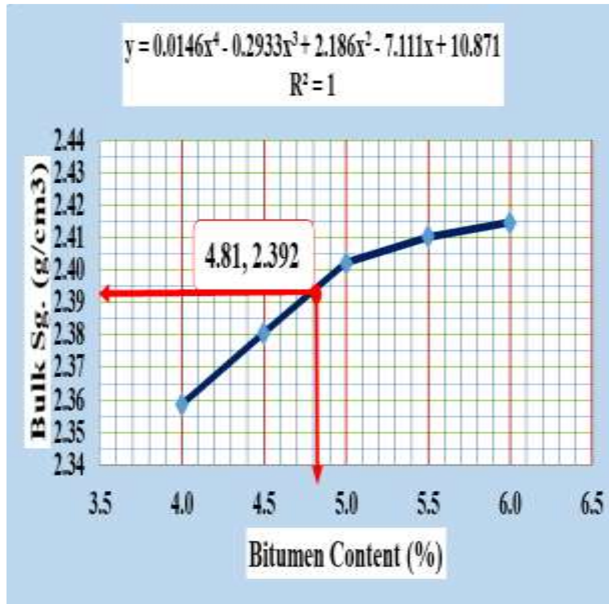
Table 4.12: Marshall Properties of asphalt mixes with 35% RAPA replacement

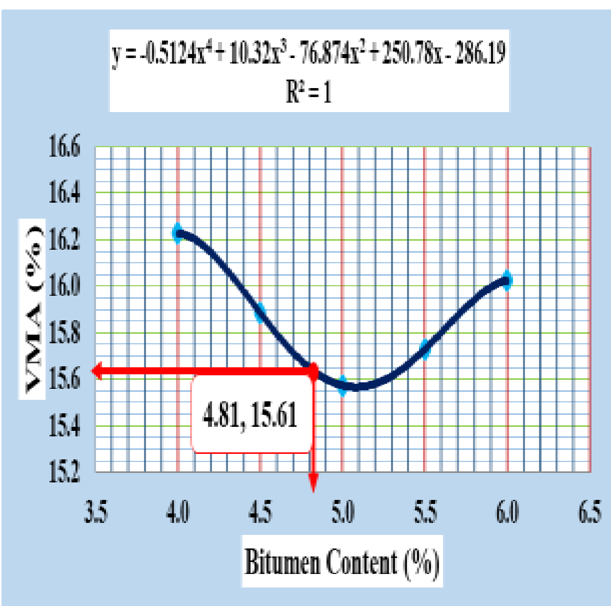
Marshall Properties Result 5.5% CSD and 35% RAPA By Wt. Aggregate						
Bitumen Content By Wt. of Total Mix (%)	Air Voids (%)	Bulk Sg. (gm/cm^3)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
4.0	6.55	2.359	16.23	59.65	7.7	2.44
4.5	4.92	2.381	15.89	68.60	8.4	2.95
5.0	3.45	2.402	15.57	76.91	9.0	3.40
5.5	2.22	2.410	15.73	85.92	8.8	3.67
6.0	1.44	2.415	16.02	91.02	7.8	3.85

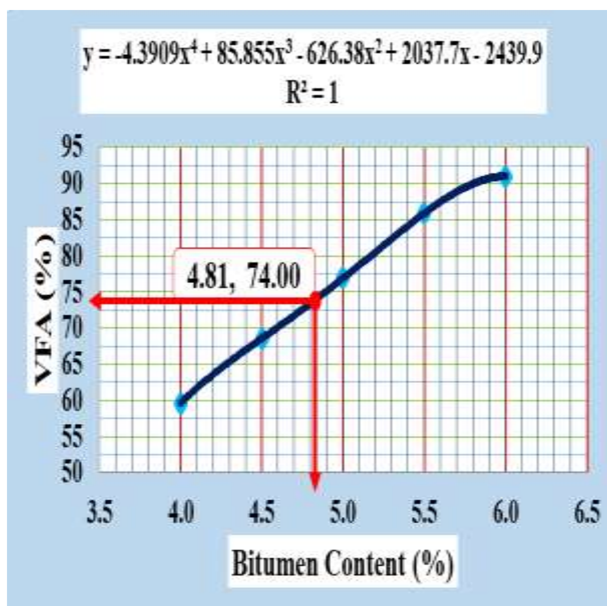
Figure 4.10 shows the relationships between optimum bitumen content and mix properties contain 35% RAPA and 75% CA. The relationships between bitumen content and the mixture

properties such as Air Voids, Bulk specific gravity, VMA, VFA stability and Flow curves are also plotted as done before. The Optimum Bitumen Content was found equal to 4.81% by weight of the total mix. The details of mixture properties at optimum bitumen content are presented in Appendix D.









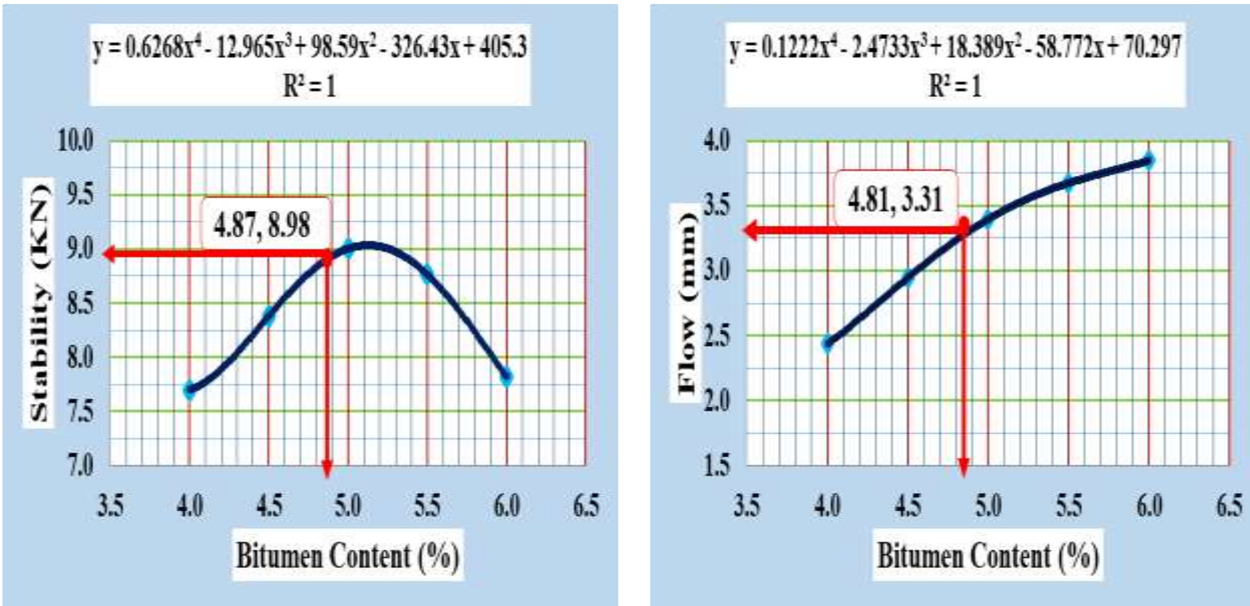


Figure 4.10: OBC and the properties of mixtures with 35% RAPA and 65% CA

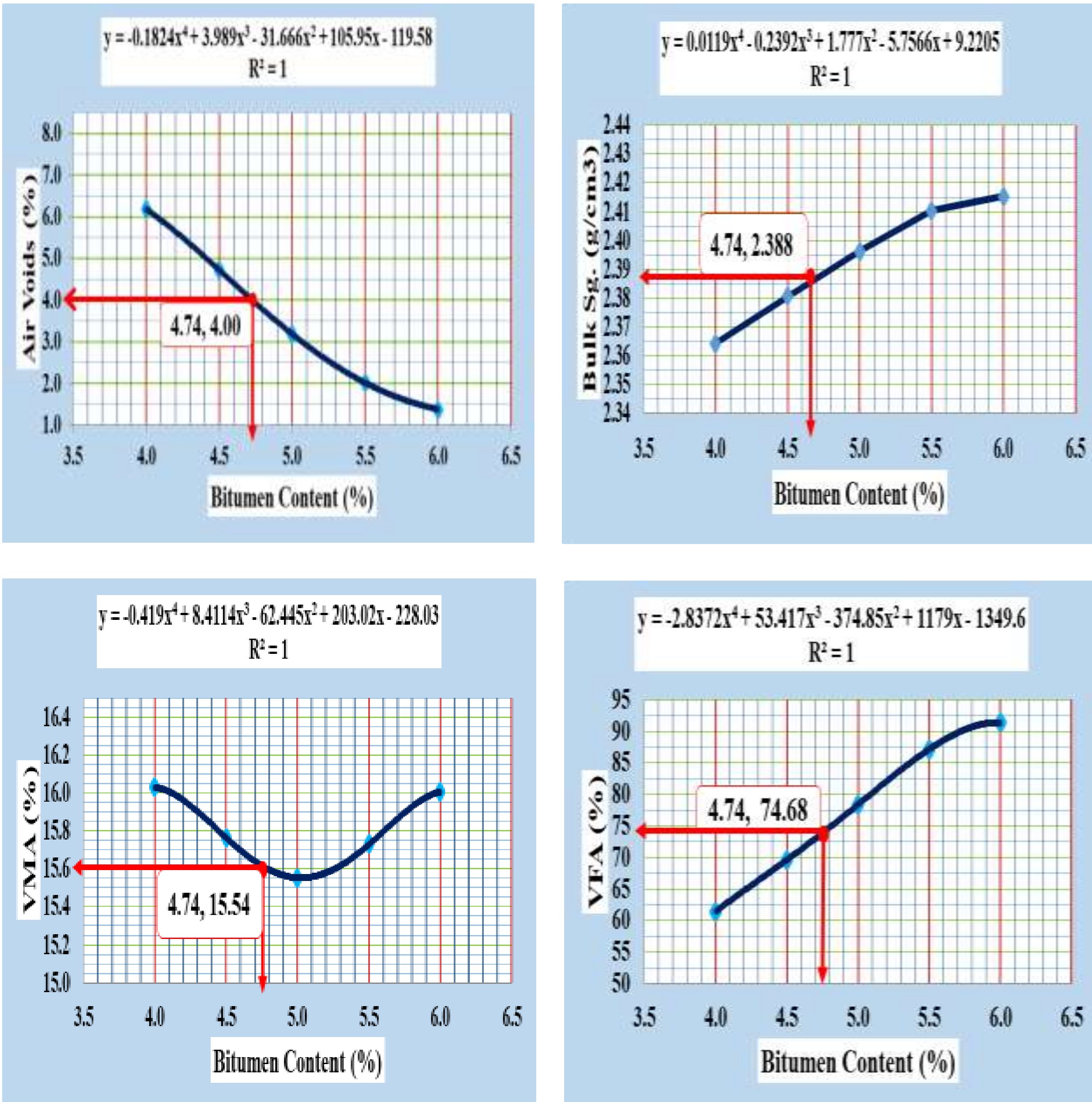
Table 4.13 presented the Marshall Test results of mixture properties mixed with 45% RAPA and 55% Crushed Aggregate. Marshall Properties of the mix at different bitumen content with aggregate gradation with 5.5% mineral filler content was performed.

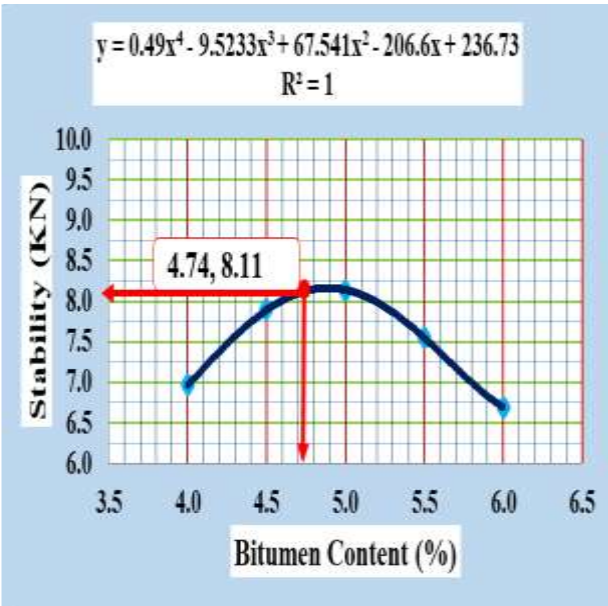
Table 4.13: Marshall Properties of asphalt mixes with 45% RAPA replacement

Marshall Properties Result 5.5% CSD and 45% RAPA By Wt. Aggregate						
Bitumen Content By Wt. of Total Mix (%)	Air Voids (%)	Bulk Sg. (gm/M^3)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
4.0	6.18	2.364	16.03	61.46	7.0	2.49
4.5	4.72	2.381	15.76	69.65	7.9	3.13
5.0	3.19	2.396	15.55	78.43	8.1	3.60
5.5	2.02	2.410	15.73	87.20	7.5	3.89
6.0	1.38	2.415	16.01	91.40	6.7	4.07

Figure 4.11 shows the relationships between optimum bitumen content and mix properties contain 45% RAPA and 55% CA. The relationships between bitumen content and the mixture properties such as Air Voids, Bulk specific gravity, VMA, VFA stability and Flow curves are

plotted. The Optimum Bitumen Content was found equal to 4.74% by weight of the total mix. The details of mixture properties at optimum bitumen content are presented in Appendix D.





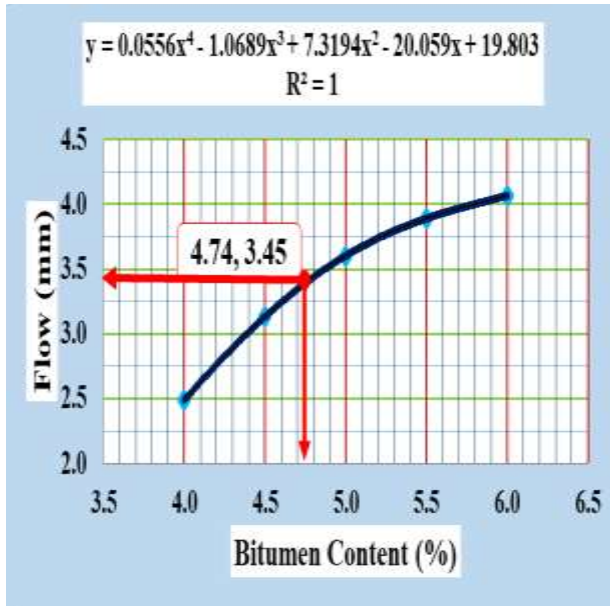


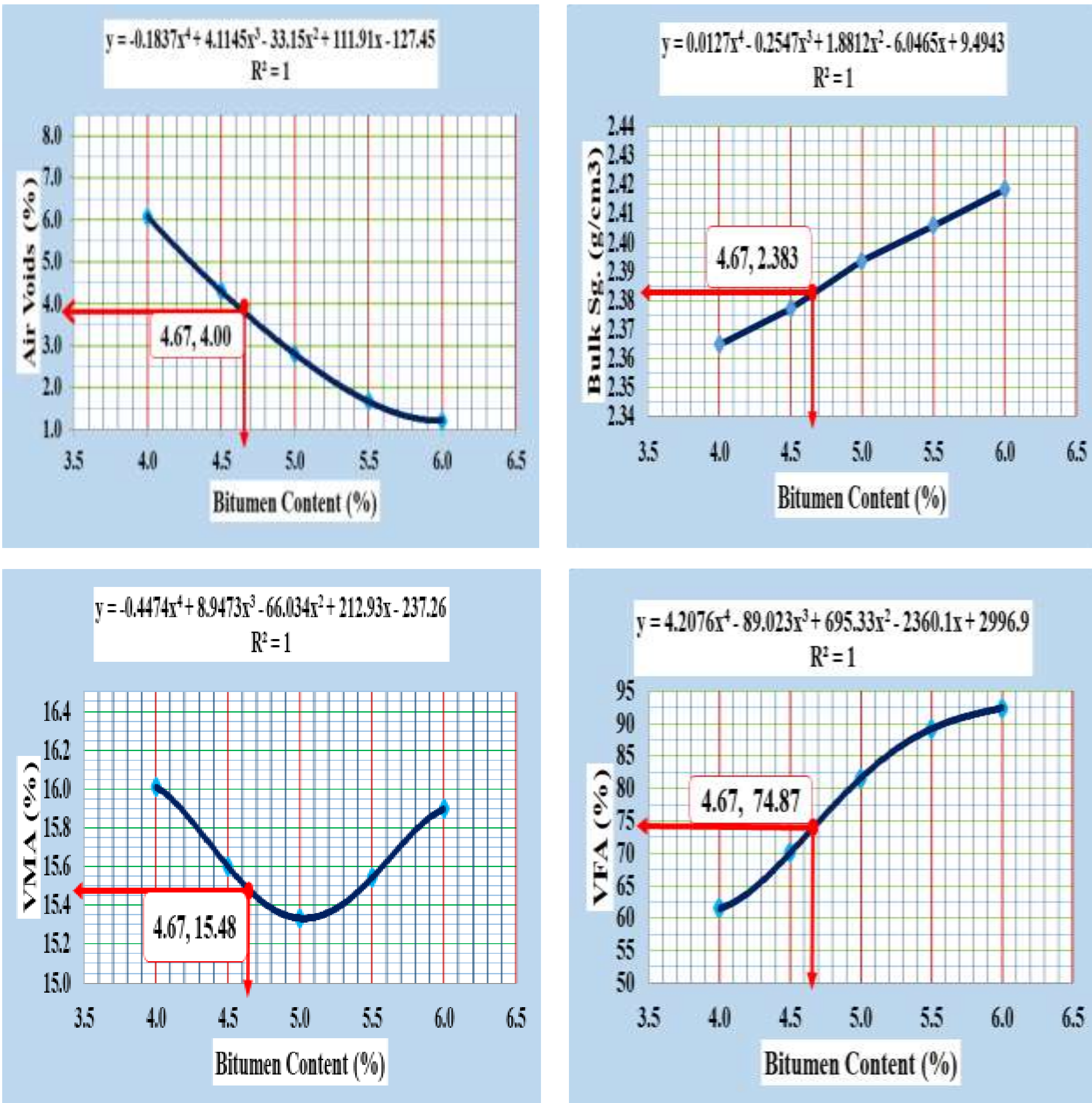
Figure 4.11: OBC and the properties of mixtures with 45% RAPA and 55% CA

Table 4.14 presented the Marshall Test results of mixture properties mixed with 45% RAPA and 55% Crushed Aggregate. Marshall Properties of the mix at different bitumen content with aggregate gradation with 5.5% mineral filler content. All Marshall Properties and gradation was used here were same as used for bitumen content 5.0%, 15%, 25%, 35% and 45%.

Table 4.14: Marshall Properties of asphalt mixes with 55% RAPA replacement

Marshall Properties Result 5.5% CSD and 55% RAPA By Wt. Aggregate						
Bitumen Content By Wt. of Total Mix (%)	Air Voids (%)	Bulk Sg. (gm/M^3)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
4.0	6.08	2.365	16.01	61.48	5.7	2.92
4.5	4.47	2.377	15.60	70.09	6.6	3.49
5.0	2.80	2.394	15.33	81.60	6.8	3.83
5.5	1.67	2.406	15.54	89.20	6.6	4.01
6.0	1.21	2.418	15.90	92.40	5.8	4.19

Figure 4.12 shows the relationships between optimum bitumen content and mix properties contain 55% RAPA and 45% CA. The relationships between bitumen content and the mixture properties such as Air Voids, Bulk specific gravity, VMA, VFA stability, and Flow curves plotted the same as for bitumen content 5%, 15%, 25%, 35%, and 45%. The Optimum Bitumen Content was found equal to 4.67 by weight of the total mix. The details of mixture properties at optimum bitumen content are presented in Appendix D.



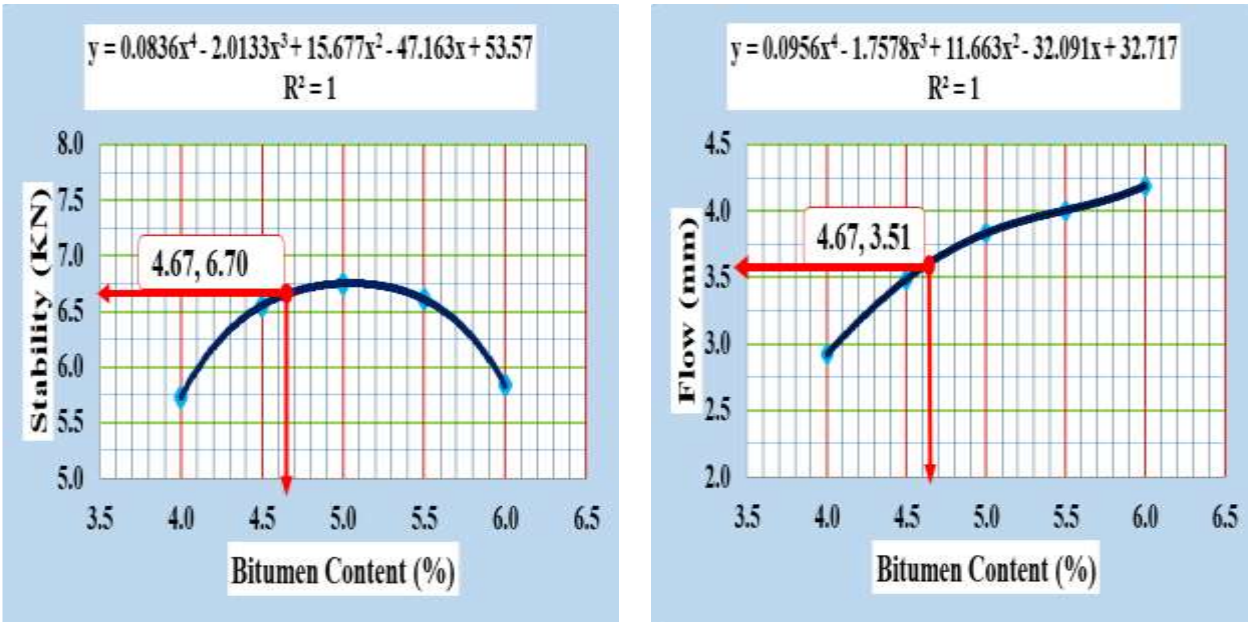


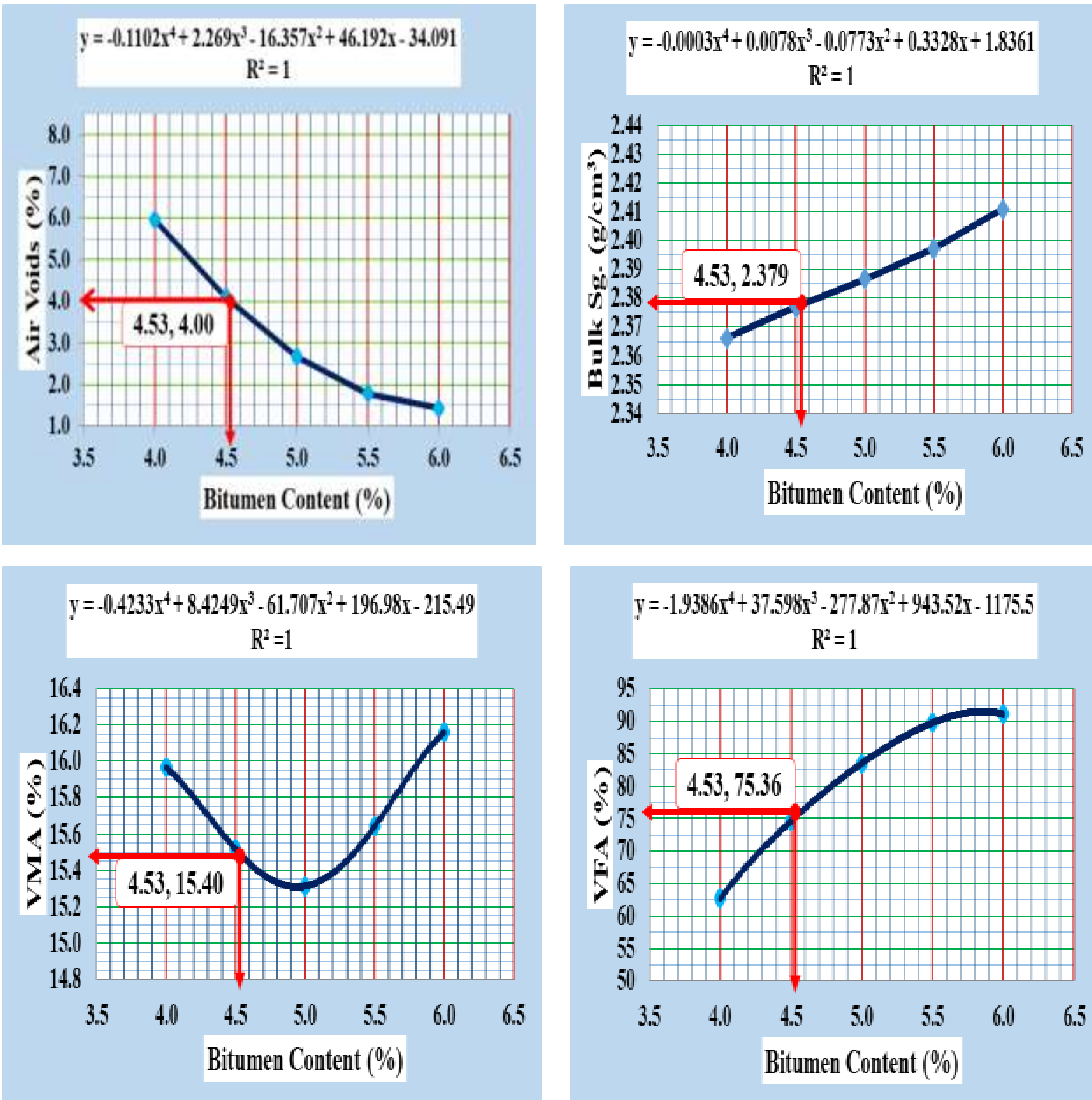
Figure 4.12: OBC and the properties of mixtures with 55% RAPA and 45% CA

Table 4.15 presented the Marshall Test results of mixture properties mixed with 65% RAPA and 35% Crushed Aggregate. Marshall Properties of the mix at different bitumen content with aggregate gradation with 5.5% mineral filler content. All things here were also done as 5%, 15%, 25%, 35%, 45% and 55%.

Table 4.15: Marshall Properties of asphalt mixes with 65% RAPA replacement

Marshall Properties Result 5.5% CSD and 55% RAPA By Wt. Aggregate						
Bitumen Content By Wt. of Total Mix (%)	Air Voids (%)	Bulk Sg. (gm/M^3)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
4.0	5.84	2.369	15.86	63.17	5.7	2.92
4.5	4.85	2.376	15.66	69.06	6.6	3.49
5.0	3.10	2.400	15.26	79.71	6.8	3.83
5.5	1.59	2.416	15.54	89.78	6.6	4.01
6.0	1.23	2.416	15.98	92.34	5.8	4.19

Figure 4.13 shows the relationships between optimum bitumen content and mix properties contain 65% RAPA and 35% CA. The relationships between bitumen content and the mixture properties such as Air Voids, Bulk specific gravity, VMA, VFA stability, and Flow curves are plotted. The Optimum Bitumen Content was found equal to 4.53 by weight of the total mix. This trial was done to be sure that the next replacement was not recommended. The details of mixture properties at optimum bitumen content were presented in Appendix D.



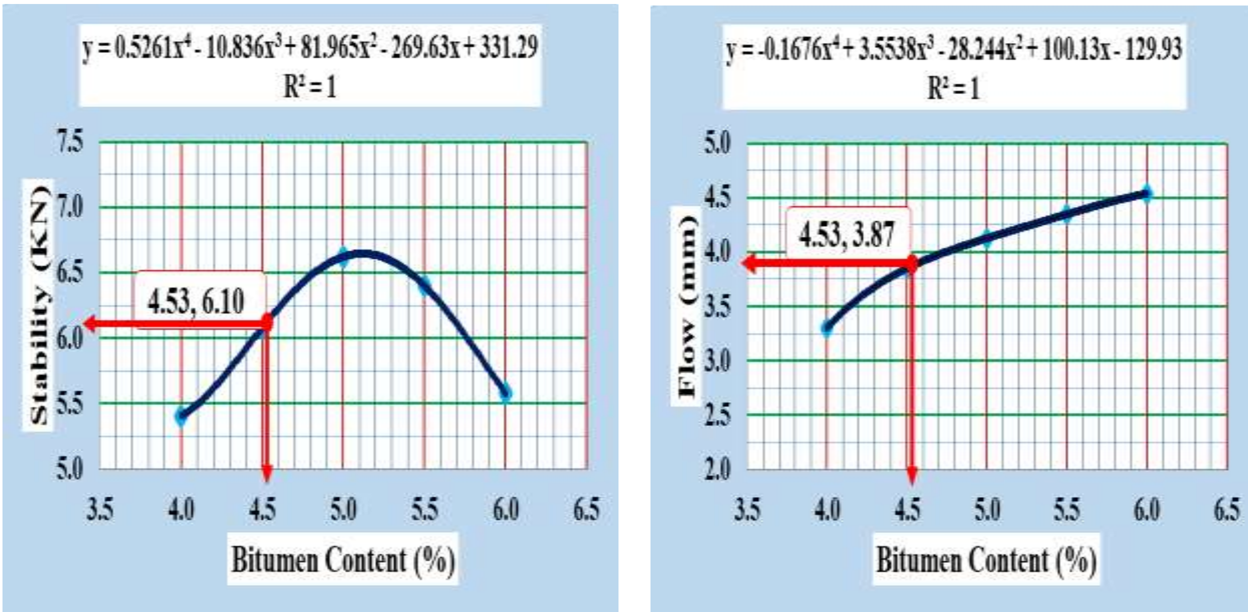


Figure 4.13: OBC and the properties of mixtures 65% RAPA and 35% CA

4.6 Optimum Bitumen Content Determination for RAPA

The optimum bitumen content for each RAPA Proportion is determined according to NAPA (National Asphalt Pavement Association, The bitumen content corresponds to the specification's median air void content 4.0% of the specification. This is the optimum bitumen content. The bitumen content is then used to determine the value for Marshall Stability, VMA, flow, bulk density, and percent voids filled asphalt from each of the plots. Compare each of these values against the specification values for that property, and if all are within the specification range, the bitumen content at 4 percent air voids is optimum bitumen content. If any of these properties are outside the specification range, the mixture should be redesigned. The result of Marshall Results and the mix performance of HMA are presented in Table 4.14.

Table 4.16 presented the Marshall Test results of mixture properties with 5.5% mineral filler and different contents of RAPA. Here the comparison with the standard specification also illustrated except 55% and 65% of all replacements satisfied for ERA (2002) and Asphalt institute manual ms-2 six edition.

Table 4.16: Summary of Marshall Properties for Control and Replacement

Marshall properties	Marshall result of control mix and replacement								ERA (2002) specification limit		Asphalt Institute Limits,Ms-2	
	0	5.0	15	25	35	45	55	65	LL	UL	LL	UL
OBC	5.10	5.04	4.98	4.87	4.81	4.74	4.67	4.53	4.0	10	4.0	10
Stability (KN)	11.42	10.98	10.45	9.74	8.98	8.11	6.7	6.1	7.0	-	8.006	-
Flow, (mm)	2.86	3.1	3.14	3.19	3.25	3.31	3.45	3.51	2.0	4.0	2.0	3.5
VMA, (%)	16.41	16.37	15.8	15.69	15.61	15.54	15.48	15.4	13	-	13	-
VFA, (%0	71.6	71.9	72.6	73.25	74	74.68	74.87	75.36	65	75	65	75
Air Void, (%)	4.0	4.0	4.0	4.0	4.0	4.0	4.0		3.0	5.0	3.0	5.0
Bulk sg (gm/cm^3)	2.404	2.401	2.399	2.395	2.392	2.388	2.383	2.379	-	-	-	-
status	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied	Not satisfied	Not satisfied				

4.7 Discussion and Analysis of Marshall Test Results

After the Marshall properties of asphalt mixture mixed with different percentages of RAPA at each optimum bitumen content was determined the next step was to evaluate the potential effect of RAP aggregate on Marshall Properties. Since the objective of the study was to determine the effect of RAP aggregate on Marshall Properties it's important to evaluate how the Marshall properties were changed by the addition of recycled percentage in the asphalt mix. The effect of RAP aggregate on Marshall Properties was evaluated based Control mix of the study and standard specification. By using the Marshall properties of conventional mix we can evaluate the other results of Marshall Properties mixed with different RAP aggregate percentages. And also the value of Marshall Properties obtained at each OBC mixed with different RAPA percentages was compared to ERA design standard specification to evaluate the effects and determine the maximum RAP aggregate used in hot mix asphalt (HMA). Based on Marshall Properties result at each of optimum bitumen content mixed with different percentage of RAP aggregate presented in Table 4.14 the following graph is drawn to evaluate the effect of RAP aggregate on different Marshall Properties such as stability, flow, air void, void in mineral aggregate, the specific gravity of compacted mix and void filled with asphalt by comparing to the study control (conventional) mix.

4.7.1 Effect of RAPA on Bitumen Content

From the result presented in Table 4.16 and Figure 4.14, the value of optimum bitumen content mixed with 0% RAPA aggregate (control mix) is greater than the other mixes 5%,15%,25%,35%,45%,55% and 65% RAP aggregate. From this it can be noticed that the optimum bitumen content is decreased as Reclaimed Asphalt Pavement (RAP) aggregate is increased. This is due to the old bitumen, filled the pore of the RAP aggregate. Moreover, increasing RAP from zero to 65% decrease the optimum bitumen content from 5.1 to 4.53%. This means that saving in optimum bitumen content by about 7.05% is achieved. But the bitumen might be old so is not considered as a high benefit.

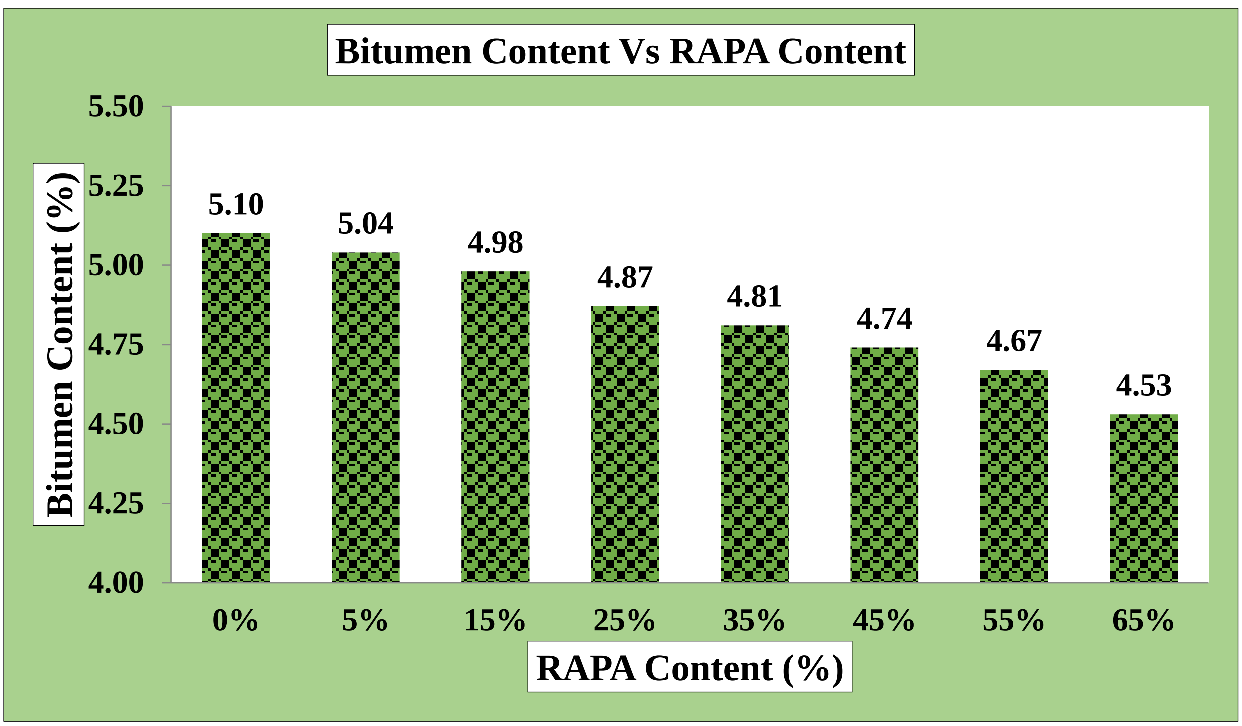


Figure 4.14: Compression of Bitumen Content result at each RAPA percentage

4.7.2 Effect of RAPA on Bulk Specific Gravity

Evaluating the result of using RAPA on the density of bitumen mixture, RAPA has an unpronounced effect on the bulk density. The result of the bulk density for all mix with different RAPA percentage is presented in Table 4.47, and Figure 4.15, from the result, it must be noticed that the value of Bulk density is decreased up to 65% RAPA replacement. This due to bulk specific gravity of is also decrease.

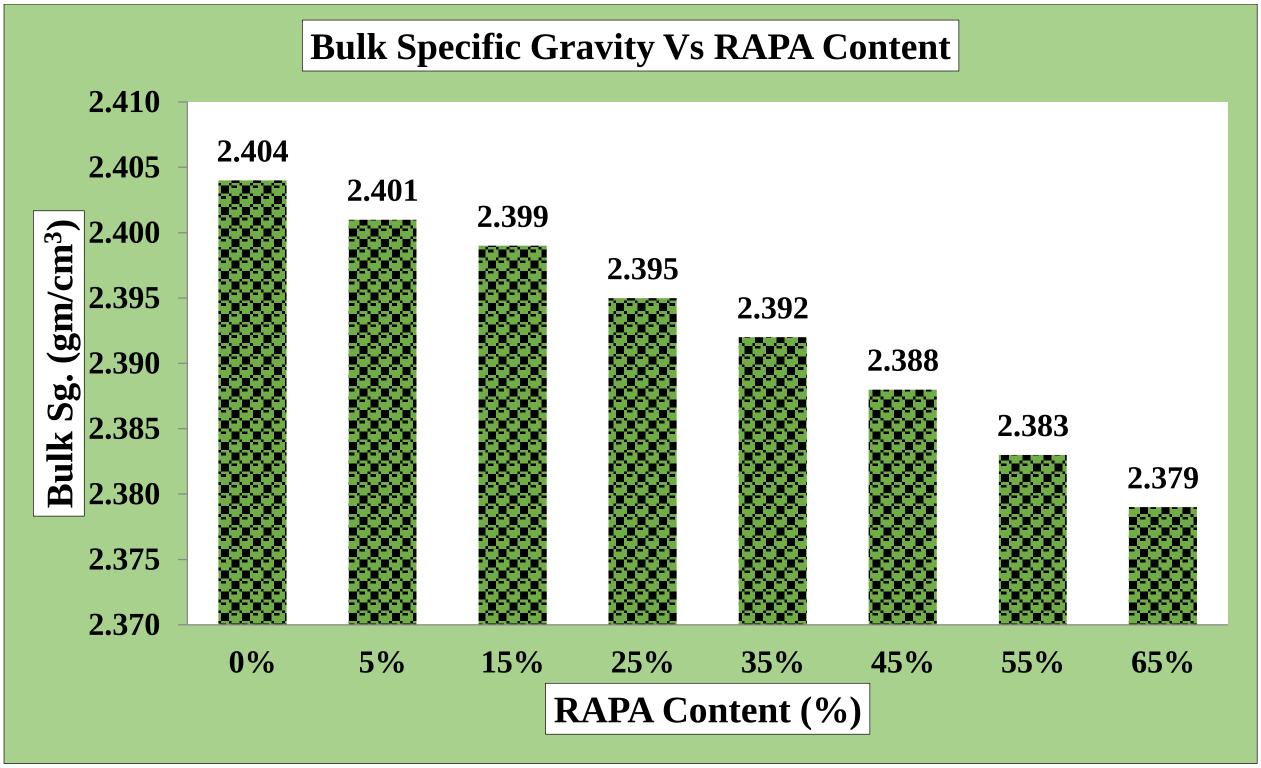


Figure 4.15: Compression of Bulk specific gravity result at each RAPA percentage

4.7.3 Effect of RAPA on Void In Mineral Aggregate

Void in mineral Aggregate is the volume of intergranular void space between the aggregate particles of a compacted paving mixture including air voids and bitumen volume not absorbed by aggregate. The durability of the mix increases with thin layer thickness on the aggregate particles and minimum requirements for VMA are recommending getting a more durable pavement structure. VMA value at OBC presented in Table 4.14 and Figure 4.14 was used to evaluate the effect of RAP aggregate on Void in Mineral Aggregate (VMA). As we see in Figure 4.16 the void in mineral aggregate (VMA) mix value is greater in 0% RAPA (control mix) and decreased up to RAPA replacement of 65%. This shows that the Void in mineral aggregate is decreased with the increase in RAPA percentage in the mixture. This is due to the Recycled aggregate and bitumen is perfectly blended with virgin materials and fills the space between compacted materials and no more space for more bitumen.

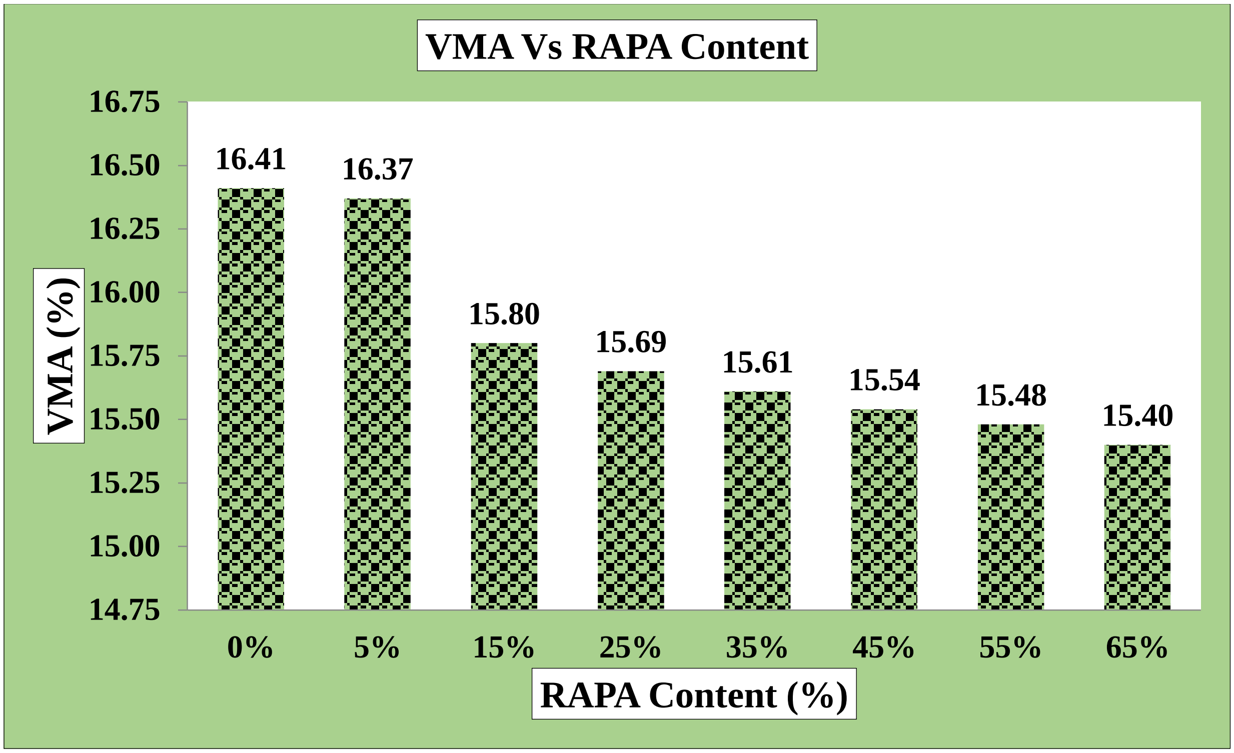


Figure 4.16: Compression of VMA result at each RAPA percentage

4.7.4 Effect of RAPA on Void Filled with Asphalt

VFA represents the volume of the effective bitumen content and is used to ensure that the effective asphalt part of the VMA in a mix is not too little or too great and helps to avoid those mixes that would be subject to rutting in heavy traffic situations. The value of VFA at optimum bitumen content was present in Table 4.16 and Figure 4.17. From the figure, we identify that the VFA the result of the conventional mix (0% RAP) was small rather than the VFA value mixed up to 65% RAPA replacement. Generally, this shows that VFA value is increasing as RAPA in the mix is increase due to old bitumen in the replaced aggregate.

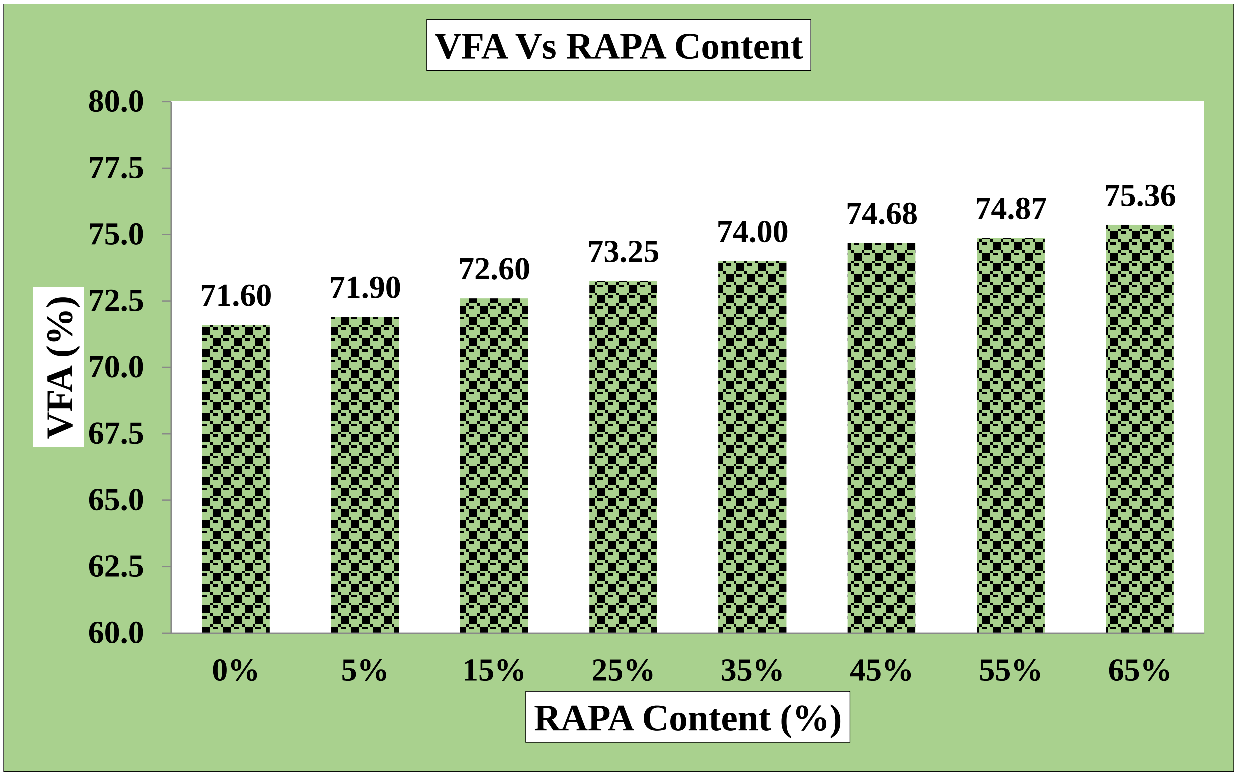


Figure 4.17: Compression of VFA result at each RAPA percentage

4.7.5 Effect of RAPA in Stability

Marshall Stability is the most important parameter to know the maximum load resistance that the specimen will achieve at 60°C under specified conditions in the asphalt mix design. Stability is always related to the aggregate gradation; the coarse aggregate gradation in the mix has higher stability rather than fine aggregate gradation. The result of stability at Optimum bitumen content is presented in Table 4.16 and Figure 4.18 to determine the potential effect of RAPA on Marshall Stability. From figure 4.18 we have seen that the value of stability at 0% RAPA (control mix) is greater than the value of stability mixed with the percentage of RAP aggregate. The value of stability decreases gradually up to 45% RAPA replacement and after that, it becomes out of the range. This may be due to the Recycled aggregate is used material and loaded before so it becomes finer than the virgin aggregate, which has less stability than the coarse aggregate. Generally, the RAPA has more effect on the value of stability of hot mix asphalt.

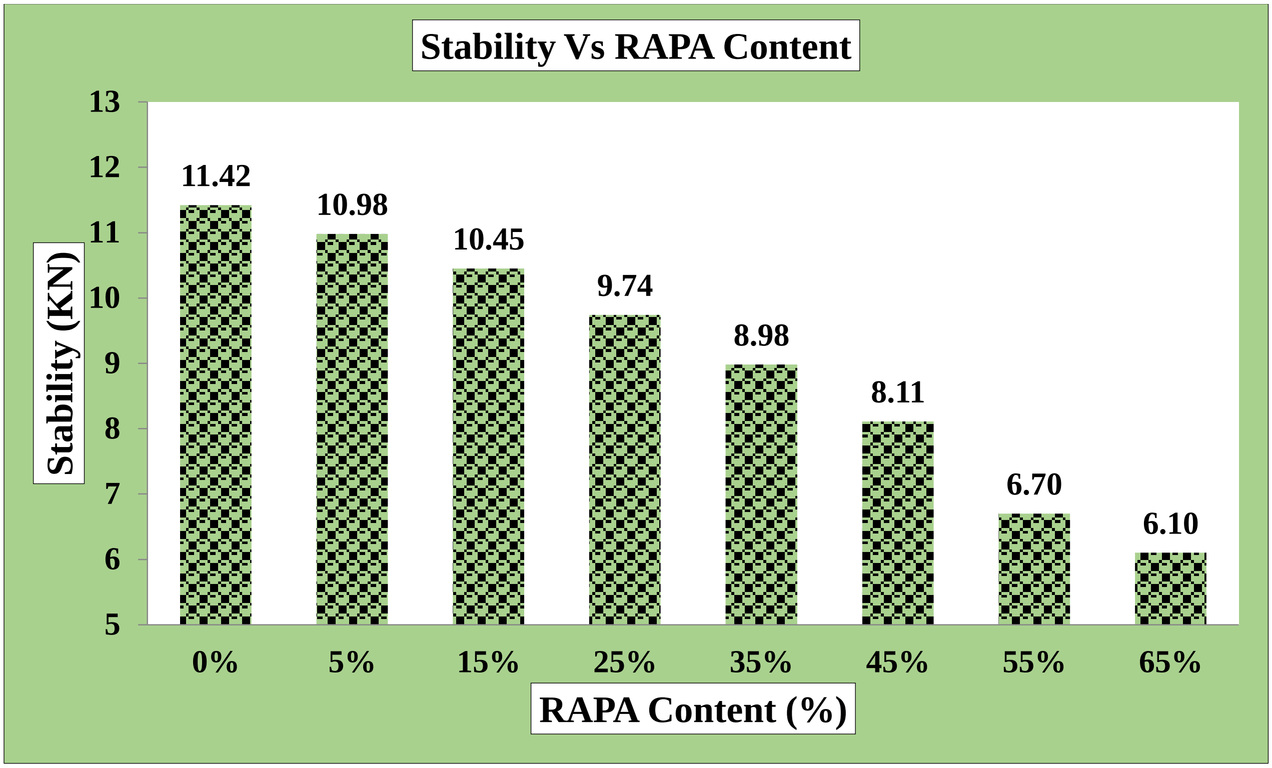


Figure 4.18: Compression of stability result at each RAPA percentage

4.7.6 Effect of RAPA on Flow

Flow in hot mix asphalt is an indicator of resistance to permanent vertical deformation. High flow values indicate that the mix contains a high amount of asphalt binder that fills all voids and affects the resistance to permanent deformation under traffic, In contrast, low flow values may indicate a mix has higher voids and insufficient asphalt binder so it cause crack mixture becomes brittle. From the Figure 4.19, we have seen that the value of Marshall Flow is increase as the percentage of RAP aggregate is increase. From the value presented we see that the flow result mixed with 0% RAP aggregate has a minimum value rather than RAPA replacement up to 65%. When the RAP aggregate is increased from zero to 65%, the mix flow value is increased but in range of specification. Here we see that the RAP aggregate content in hot mix asphalt can affect the value of Marshall Flow.

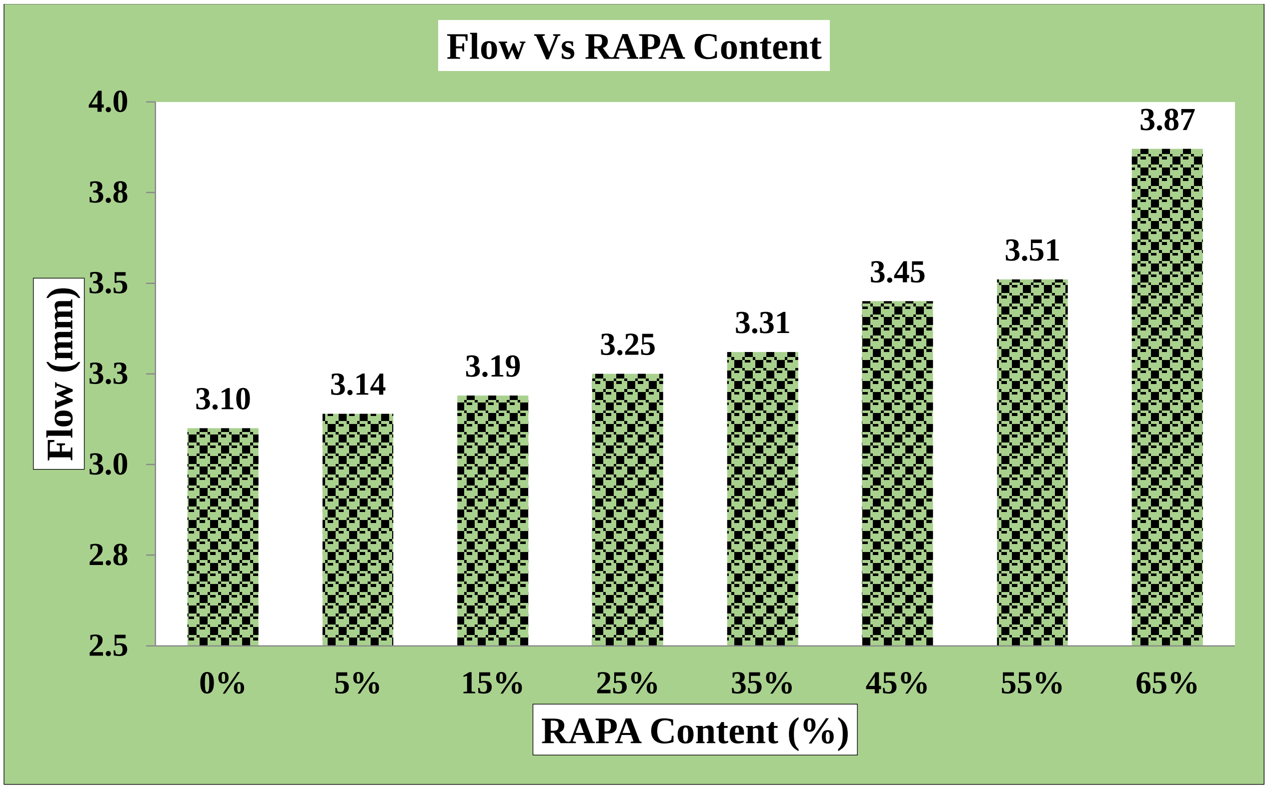


Figure 4.19: Compression of flow result at each RAPA percentage

4.8 Performance Tests

4.8.1 Effects of RAP on Moisture Susceptibility of HMA

Moisture damage can be defined as the loss of strength and durability in asphalt mixtures due to the effects of moisture. Moisture damage of HMA is evaluated based on comparing the several properties of the mix before moisture cases of conditioning and after it. Tensile strength ratio (TSR) is used to predict the moisture susceptibility of the mixtures. In this study, a total of 36 samples were prepared with a varying percentage of RAP 0% (Control mix) 5%, 15%, 25%, 35%, and 45% by weight of aggregate using optimum bitumen content of each replacement.

4.8.2 Indirect Tensile Strength

The dry and wet conditioned specimens were subjected to indirect tensile strength, and the result obtained for both cases were averaged. Table 4.17 indicates the results obtained from the indirect tensile strength (ITS) test. The detailed works are shown in Appendix F.

Table 4.17: Summary indirect tensile strength test results

RAPA Content (%)	OBC (%)	Indirect Tensile Strength (KPa)		TSR (%)
		Unconditioned	Conditioned	
0%	5.10	760.0	699.6	92.05
5%	5.04	750.9	684.5	91.16
15%	4.98	717.8	646.2	90.03
25%	4.87	708.2	625.1	88.27
35%	4.81	695.7	604.1	86.83
45%	4.74	673.7	575.5	85.42

Figure 4.10 shows the test result of the indirect tensile strength (ITS) for control mix and mixes containing RAP. The laboratory results of indirect tensile strength of conditioned samples have different values as compared to unconditioned specimens. As observed in the figure below the values of indirect tensile strength of the two cases decreases with increase RAP content until the optimum replacement proportion (45%) and it has a higher value of the control mix. The obtained results of the control sample (0% RAP) and mix prepared with replacement proportion RAP (i.e. 5%, 15%, 25%, 35%, and 45 %,) both for the un-conditioned, and conditioned or wet sample were (760 KPa, 750.9KPa, 717.8KPa, 708.2 KPa, 695.7KPa, and 673.7 KPa,) and (699.6 KPa, 684.5KPa, 646.2 KPa 625.1 KPa, 604.1 KPa, and 575.5KPa) respectively. The maximum ITS values were recorded at mixes containing 5.0% RAPA with a value of 760 KPa for un-conditioned samples and 699.6 KPa for conditioned samples.

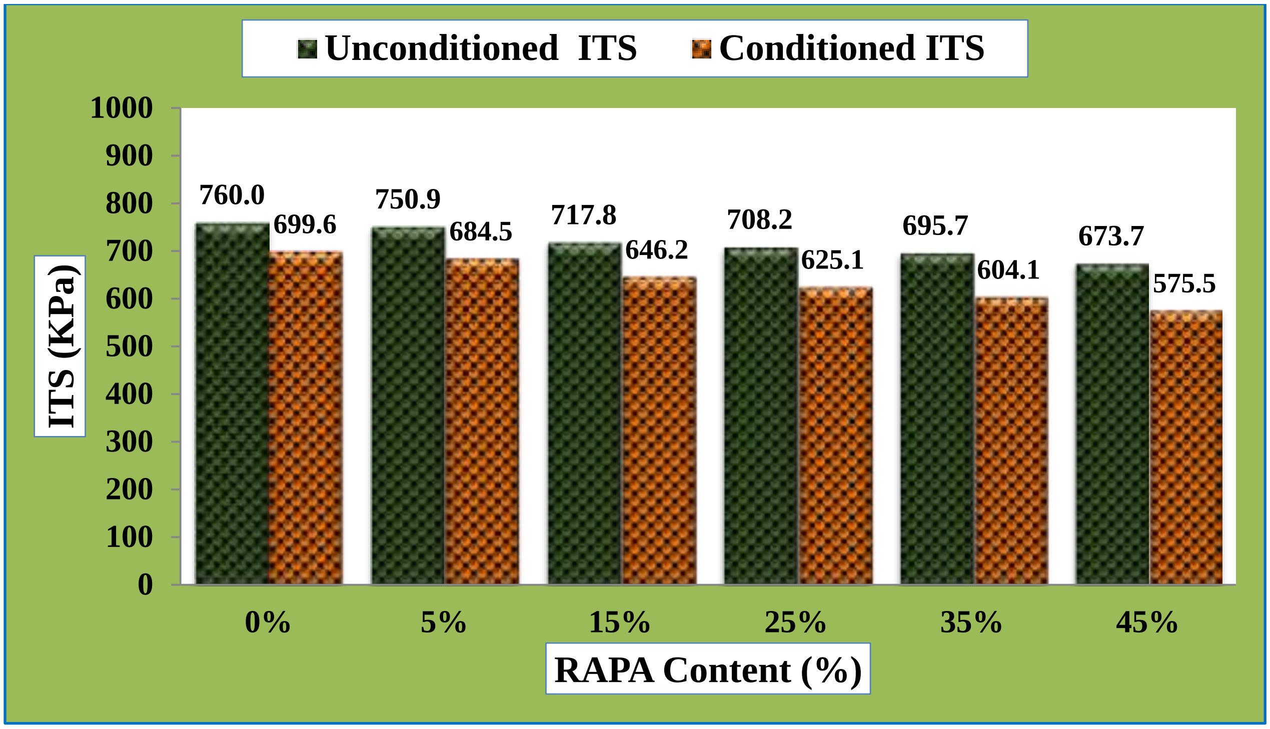


Figure 4.20: Unconditioned and Conditioned ITS of HMA with Varying Percentage of RAPA

4.8.3 Tensile Strength Ratios (TSR)

Figure 4.20 shows the tensile strength ratio for both control and RAP mixtures of HMA. As displayed in the graph below the TSR values decreases with increasing RAPA content. The highest TSR value is 92.06 KPa at 0% RAP and the minimum TSR value is 85.42 KPa at the control mix. The moisture susceptibility of HMA is improved for all RAPA mixtures compared with the control mixture. Therefore, it can be said that RAPA mix is highly susceptible to moisture damage compared to mixes containing control mix and the moisture damage rises with the increasing of RAPA content. But, all the mixes have the potential to resist moisture damage since the TSR values obtained are greater than the recommended specification (80%).

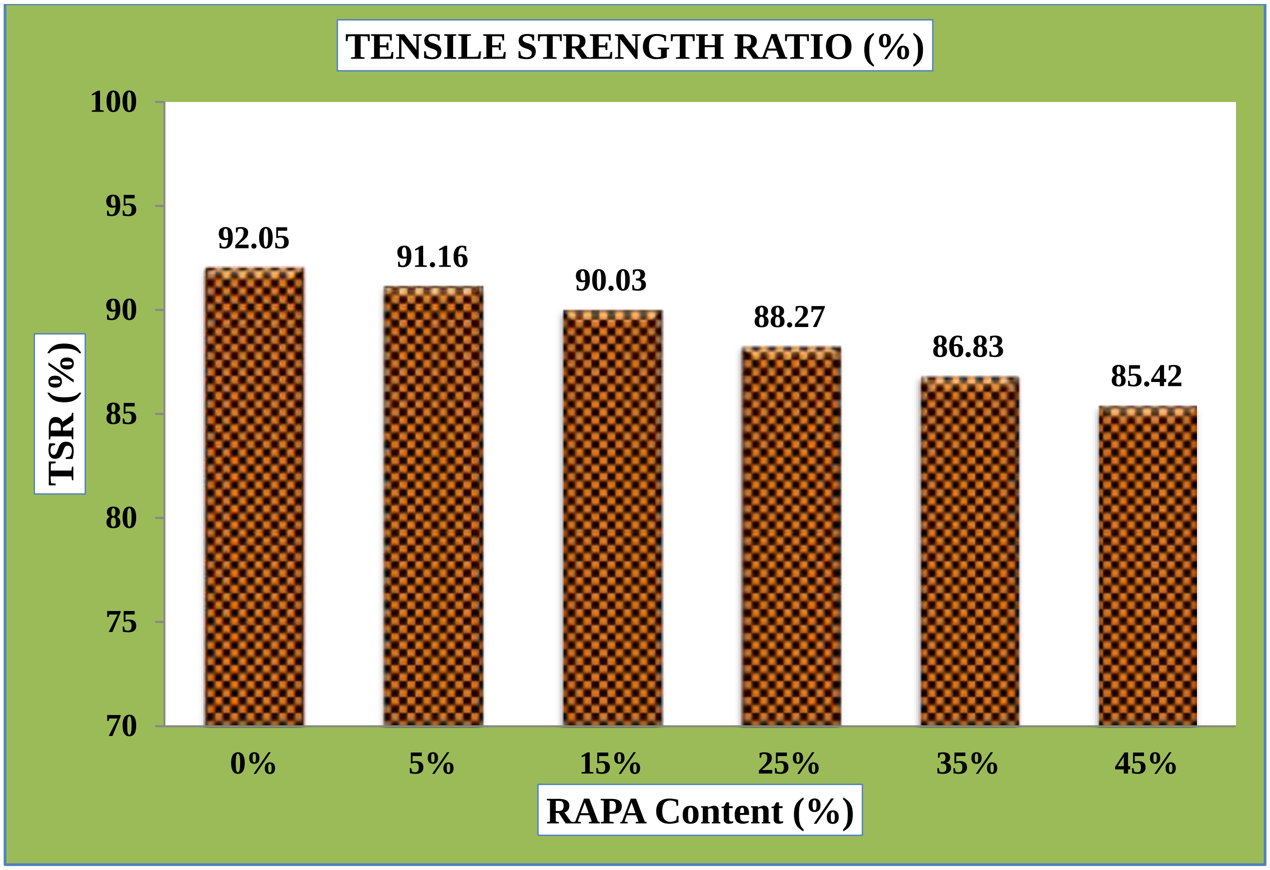


Figure 4.21: Tensile Strength Ratio (TSR) of HMA Mixture Containing RAPA

4.9 Rutting test

The most basic element in the performance of asphalt is its resistance to Rutting. It causes the loss of road surface regularity, which evidently has a negative impact on the quality of service to users. Resistance to rutting by using small Wheel Tracking test was performed for both control and highest allowable RAPA replacement mixes with respective technical specification for rutting. Table 4.18 shows the laboratory test result for both CA and control mix and 45% RAPA replacement. Proportional rut depth and mean rut depth values of RAPA were 4.48% and 2.24 mm respectively and for CA were 6.54% and 3.27mm respectively. From the result mix contains 45% RAPA replacement had minimum values of proportional rut depth and mean rut depth compared to CA consequently RAPA had better rutting resistance performance than mix contains 100% CA. This is due to the reason that RAPA becomes denser in volume than the newly used crushed aggregate.

Table 4.18: Analysis and Laboratory Test Result of Rutting

Mix Name	45% RAPA replacement			100% Crushed Aggregate		
Trial No	wheel-tracking slop (WTSAIR) =(d10000 − d5000)/5(mm/10^3 load cycles)	proportional rut depth (%)= ∑((rut depth) i/hi)/2)*100)	Mean RD (mm)	wheel-tracking slop (WTSAIR) =(d10000 − d5000)/5(mm/10^3 load cycles)	Proportional rut depth (%) = ∑((rut depth i)*/h i)/2)*100)	Mean RD (mm)
One	0.190	4.48	2.24	0.220	6.54	3.27
Two	0.194			0.218		
Average	0.192			0.219		

Figure 4.22 illustrate rut depth with respect to the number of passes and detailed format of rut depth in each 500 cycle shown in Appendix G. The comparison showed that the rutting occurred in the samples blended mix with recycled asphalt pavement aggregate at temperatures 60°C is less than that of control mix or fresh crushed aggregate. But the result was almost the same average rutting depth. The figure also showed rate of deformation decrease as depth of rutting increase.

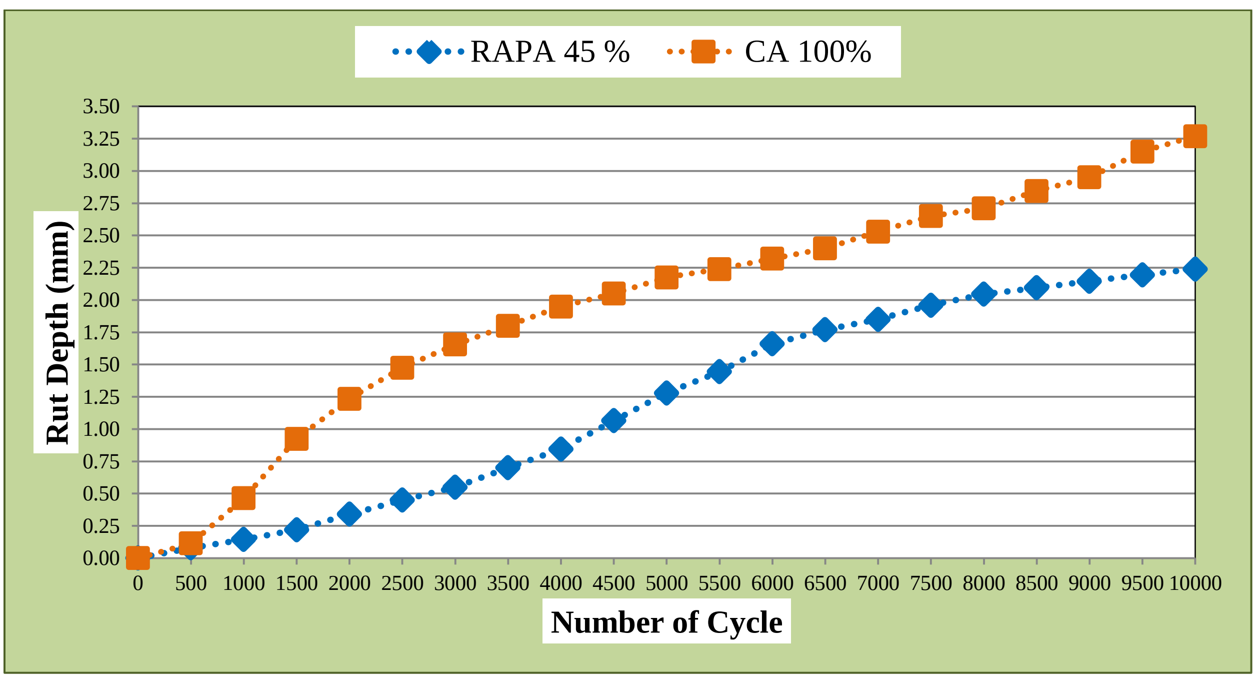


Figure 4.22: Wheel Tracking Test results for conventional and RAPA replacement

4.9.1 Comparison of Rutting Result with Specification

Table 4.19 showed the result of control mix and RAPA replacement satisfy the requirement. Here EN 13108 procedure B for small size wheel truck specification shows that proportional rut depth and mean rut depth were in permitted range of specification so reclaimed asphalt pavement aggregate replaces up to 45% of freshly crushed aggregate by the weight of aggregate.

Table 4.19: Comparison rutting performance of asphalt mix control and RAPA with standard specification

Results of the UNE-EN 12697- 22 Wheel-Tracking Test					
Mix Name	WTS_{AIR} =(d10000−d5000)/5 (mm/10^3 load cycles)	PRD (%) =((RD)*100/h)/2))	Mean RD (mm)	specification as per EN 13108	
				PRD (%)	RD (mm)
100% CA	0.219	6.54	3.27	<9	<6.5
55%CA& 45% RAPA	0.192	4.48	2.24	<9	<6.5

4.10 Maximum Allowable percentage of RAPA in HMA

Depending on the physical property of materials Marshall Stability results and some performance testes moisture susceptibility and Rutting compression of Marshall Properties with design standard specification the determination of the maximum percentage of RAPA have done. The maximum percentage of using RAP aggregate in hot mix asphalt is up to 45% only. That means 45% RAPA mixed with crushed aggregate all the results are within the required specification range, which illustrated in ERA, Pavement Design Manual, 2013 and Asphalt institute Ms-2, Sixth Edition.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This research was focused on evaluating RAPA performances for a partial replacement to crushed aggregate by different proportions. To satisfy the objective of the study, all the necessary quality tests of aggregates (RAPA and CA), bitumen, and mineral filler, were conducted using standard testing procedures and a detailed laboratory investigation was conducted to determine volumetric properties, Stability flow, moisture susceptibility and resistance to permanent deformation of mixes. Based on test results and analysis obtained, the following conclusions are drawn.

1. All quality test results for CA, RAPA, bitumen and crushed stone dust conform to ERA (2002) and Asphalt institute (Ms-2 6^{th} edition) standard specification.
2. Among the three aggregate gradations for CA; a gradation which contains 5.5% mineral filler has maximum stability and selected as optimum filler content with the respective optimum bitumen content of 5.1%.
3. Marshall Stability, flow and volumetric properties for RAPA replacement have done. Consequently, except 55% and 65% all replacements were under specification.
4. At 45% RAPA with 4.74% optimum bitumen content replacement of crushed aggregate, the mixture properties such as Marshall Stability, flow values and volumetric properties are satisfied with the ERA Pavement Design Manual and asphalt institute specification limits.
5. Tensile Strength Ratio value was decreased as the RAPA content increased, but highly satisfy the standard specification and the mix provide resistance to moisture-induced damage. Rutting depth also in permitted limits in EN 13108 specification so the mix provides resistance to deformation. The obtained value of Tensile Strength Ratio, proportional rut depth and mean rut depth on 45% RAPA replacement was 85.42% and 4.48%, 2.24 mm respectively.

As a whole, based on laboratory studies it was concluded that a maximum of 45% RAPA can be as crushed aggregate in the hot mix asphalt.

5.2 Recommendations

Pavement construction, maintenance, and rehabilitation are increasing in Ethiopia; hence 95% of hot mix asphalt is aggregate. An endeavor to work on replacing construction materials to be done by road authorities and any other concerned bodies.

Based on the study analysis, and conclusion, the following recommendations are forwarded:

- The Reclaimed Asphalt Pavement aggregate (RAPA) is recommended to use in hot mix asphalt mixes instead of pure crushed aggregate with minimum bitumen content to save the natural resource.
- RAP aggregate content is changing the value of volumetric parameters, so it is important to know the relationship between those two variables (RAPA and CA) during Asphalt mix design.
- A percent of RAPA up to 45 is suitable to be used in flexible pavement construction during hot mix production for the study.
- Using RAPA was not known. Contractors and other concerned bodies need awareness about using of RAPA in HMA is best alternative for pavement construction.
- Further studies are recommended by using 80/100 penetration grade bitumen.
- A large-scale study is recommended in several parameters such as the age of RAP materials, remaining binder content after extraction, and others to use RAP in HMA.

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APPENDIXIES

Appendix A: Photos during Laboratory Work


Date: 22/10/2020 G.C

(a)


Date: 26/12/2020 G.C

(b)


Date: 02/01/2021 G.C

(c)


Date: 01/01/2021 G.C

(d)


Date: 24/10/2020 G.C

(e)


Date: 25/10/2020 G.C

(f)

Source: (a, d, e) Tiruwork Mulatu; (b, c, f) Yisak Kibru