Jimma University

School of Graduate Studies

Jimma Institute of Technology

Faculty of Civil and Environmental Engineering

Highway Engineering Stream

Laboratory-Based Correlation Analysis of Volumetric Properties in Asphalt mixtures Using Recycled Asphalt Pavement (RAP) Aggregate as Partial Replacement of Crushed Aggregate

A Final Thesis submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Highway Engineering Stream)

By:

Diriba Alemu

November 2019

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By: Diriba Alemu Maru

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Declaration

I, the undersigned, declare that this thesis entitled: "**Laboratory-Based Correlation Analysis of Volumetric Properties in Asphalt Mixtures Using Recycled Asphalt Pavement (RAP) Aggregate as Partial Replacement of Crushed Aggregate**" is my original work, and has not been presented by any other person for an award of a degree in this or any other University, and all sources of material used for this thesis have to be duly acknowledged.

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As Master's Research Advisors, I hereby certify that I have read and evaluated this MSc Thesis prepared under my guidance by **Mr. Diriba Alemu** entitled: "**Laboratory-Based Correlation Analysis and of Volumetric Properties in Asphalt Mixtures Using Recycled Asphalt Pavement (RAP) Aggregate as Partial Replacement of Crushed Aggregate**."

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Abstract

The road network is the backbone for the socio-economic development of the countries over the world. In Ethiopia, most of the leading road network is flexible pavement. The construction and maintenance of those pavements are needed construction materials such as aggregate, bitumen, and fillers. Because of the increasing price of those virgin materials, it's challenging to construct the road network as well. So that, the use of the available Recycled Asphalt Pavement (RAP) aggregate in hot mix asphalt (HMA) as partial replacement of crushed aggregates, is the best alternative. The purpose of this research was focused on using and evaluating the effect of Recycled Asphalt Pavement (RAP) aggregate on the volumetric parameters by determining the relationship between volumetric properties and RAP aggregate percentage using linear regression technique.

For the achievement purpose of this study, the previous research was reviewed, and the experimental program was designed and conducted. After study materials such as RAP, bitumen, crushed aggregate, and fillers, are collected, the quality test was conducted on all the selected materials. Next, the Marshall Stability test was conducted on six mix samples containing a different percentage (0%, 10%, 20%, 30%, 40%, and 50%) of RAP aggregate and mixed with five different bitumen content of (4%, 4.5%, 5%, 5.5%, and 6%).A total of 40 mix designs with 3- trials and a total of 120 mix specimens were prepared, From 120 specimens, 45 were for the control mix, and 75 were for RAPA proportion. OBC was determined from the Marshall Stability Test conducted on all mixes with six different RAPA proportion according to Asphalt Institute (2003) method, and the result obtained in percent was (5.08, 5, 4.71, 4.67, 4.35 and 4) respectively. The Marshall Properties of each mix was also determined at each of OBC, and analysis was conducted by using correlation with regression.

From final analysis, some volumetric properties of HMA such as OBC, Air void and VMA has a good negative correlation with recycled percentage, by correlation coefficient (R^2) of (0.948, 0.736 and 0.743) respectively. Whereas, Void filled with asphalt has a positive correlation with R^2 of 0.961. Based on the result obtained the values of volumetric parameters of HMA are changed by RAP aggregate content in mix and recommended maximum use of RAP aggregate in HMA for this study is up to 40% only.

Keywords: *Crushed Aggregates, Hot Mix Asphalt, Optimum Asphalt Content, and Recycled Asphalt Pavement, Regression Analysis, and Volumetric properties.*

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Acronym

AASHTO	American Association State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
BC	Bitumen Content
BS	British Standard
ERA	Ethiopian Road Authority
FHWA	Federal Highway Administration
ERCC	Ethiopian Road Construction Corporation
GMB	Bulk Specific Gravity of compacted mix
GMM	Theoretical Maximum Specific Gravity
HMA	Hot Mix Asphalt
JMF	Job Mix Formula
JiT	Jimma Institute of Technology
NAPA	National Asphalt Pavement Association
OBC	Optimum Bitumen Content
RAP	Reclaimed (Recycled) Asphalt Pavement
RAPA	Recycled Asphalt Pavement Aggregate
USACE	United State Army Corps of Engineers
VA	Air Void
VFA	Void Filled with Asphalt
VMA	Void in Mineral Aggregate

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Recycling of different materials is a matter of global concern; it is the most significant International interest. The critical need for recycling material has been raised in recent years as a result of the shortage of natural materials and increasing the cost of a landfill in most countries of the world [1]. It creates a cycle of reusing materials that optimizes the use of natural resources. Reclaimed asphalt pavement is useful alternatives to natural materials because it can reduce the need to utilize virgin aggregate and bitumen, which is a scarce commodity [3].

The most frequent application recycling materials in the pavement are the reuse of Recycled asphalt pavement aggregate (RAPA).The significant source of RAP is the rehabilitation of existing asphalt pavement by milling or full-depth removal. Recycled asphalt pavement can be combined with the crushed aggregate and new binder to producing a hot recycling mix after crushed and extracted, which is the most frequent use of asphalt mixtures [7]. Since the road infrastructure is the backbone of the development, and it has a bearing on the sustainability of the growth of any country, the construction and maintenance of this road is not an easy investment. Many countries used the RAP aggregate as a replacement of virgin aggregates in hot mix asphalt. In Ethiopia large amount of RAP is created every year during rehabilitation and reconstruction of asphalt pavement. The removed RAP can be used in asphalt mixture as partial replacement of crushed aggregate to make flexible pavement after extracted. The reclaimed asphalt pavement (RAP) aggregate used in HMA can change the properties of mixtures and mix performance such as stability, flow, air voids, bitumen absorption, etc, due to the aging, loaded and the quality of aggregates in the RAP [7]. The volumetric properties of hot mix asphalt (HMA) are requirements to ensure good performance for asphalt mixtures. The aggregate used for mixtures is classified into three based on the size of the aggregates. Those are coarses, fine aggregates, and fillers. Filler materials have traditionally used in asphalt mixtures to fill the void between the larger aggregate particles. Crushed stone dust is the conventional filler that plays a significant role in the characteristics and performance of hot mix asphalt [4]. The study was focused on the laboratory-based correlation analysis of volumetric properties of HMA, based on the effect using Recycled asphalt pavement aggregate and crushed aggregates as independent parameters by regression analysis.

1.2 Statement of the problem

Road network infrastructure plays a vital role in the development of the modern era as an integral part of the socio-economic and political structure of the countries over the world [2]. For this reason, the government of Ethiopia gives more attention to increasing the road network structure throughout the country.

The most common type of road network pavement structure used for highway construction is flexible pavement. Those pavements are strong need various types of maintenance to preserve the efficiency of the road network to accommodate the volume of traffic safely [7]. The construction and maintenance of pavements are needed construction materials such as aggregate, bitumen, and fillers.

The quality of pavement structures largely depends on aggregate materials, which are the main constituents of pavement structural layers [4]. In spite of the increment prices of bitumen and aggregates within time and also the shortage of virgin aggregates, it's challenging to construct and maintain the road network structures as well. To reduce such a problem, the reusing of existing materials with understanding the effects on mixture properties by modification and utilization are the best alternatives.

In Ethiopia, a large amount of recycled asphalt pavement (RAP) material is created every year during the rehabilitation and reconstruction of existing flexible pavement [8]. However, the use of recycled materials for asphalt pavement is not common, and the vast quantities of RAP aggregates remain unused. Another problem faced in using recycled asphalt pavement (RAP) aggregate in hot mix asphalt is the cause of the effects of using RAP aggregate proportion on asphalt mix performance, which leads to cracking, low durability, and low strength of the flexible pavement. Because of the physical properties of (RAP) aggregate not same with new aggregates in the mix, cause of aging, loading, and quality of aggregates. Those problems above are attracting the researcher's attention to search the way of construction and maintenance of flexible pavement by using the existing Recycled asphalt pavement (RAP) aggregates as partial replacement of crushed aggregate by understanding the effects of RAP aggregate on asphalt mix properties and also recommend the maximum RAP aggregate used in hot mix asphalt. Generally, this study was considered a laboratory-based correlation analysis of volumetric properties of asphalt mixes using RAP aggregate as partial replacement of crushed aggregates. The researchers was focused on evaluating the effect of RAP aggregate on Marshall Properties and determine the relationship between volumetric parameters of asphalt mixes as dependent variables and recycled asphalt pavement (RAP) aggregate percentage as independent variables by linear Regression Analysis.

1.3 Research questions

1. What are the physical properties of selected materials used in Hot Mix Asphalt?
2. What are the potential effects of using RAP aggregate on Marshall Properties in Hot Mix Asphalt?
3. What is the relationship (correlation) between volumetric properties and RAPA percentage in asphalt mix by linear regression?
4. How much is the maximum percentage of RAP aggregate Used in Asphalt Mix that meet ERA design standard specification?

1.4 Objectives

1.4.1 General Objective

The general objective of the study is to correlate the Optimum Bitumen Content and Corresponding Volumetric properties as dependent variables in compacted mixture using effect of Recycled Asphalt Pavement (RAP) aggregate as independent variables by Regression technique.

1.4.2 Specific Objectives

- To identify the physical properties of selected materials used in hot mix asphalt.
- To analyze the potential effects of using RAP aggregate on Marshall Properties of Hot Mix Asphalt.
- To correlate and determine a statistical equation using linear regression to establish the relationship between volumetric parameters and recycled asphalt pavement aggregate (RAPA) percentage in Hot Mix Asphalt.
- To determine the maximum percentage of using RAP aggregate in HMA that satisfies the Marshall Criteria of ERA design standard specification

1.5 Significance of the Study

Recycled Asphalt Pavement (RAP) aggregate is the most important material for road construction by partial replacing of crushed aggregates. Since the road structure has a significant role in the development of the country, the road authority can use reclaimed asphalt pavement to reduce the cost of paying to virgin aggregates. The purpose of highway authority was to provide safe and smooth pavements to carry the load as well. So the 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 where there are a shortage of virgin (crushed) aggregates. And, also 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 volumetric properties of using (RAP) aggregate in hot mix. The researchers or scholars can be using the results of the study as reference or secondary data regarding recycled asphalt pavement in hot mix asphalt.

1.6 Scope of the Study

The study was supported by a different type of literature and conducting a series of laboratory experiments and analyses with the software application. However, the finding of the research was limited to two main tests conducted, material quality and Marshall Flow stability test. The result is also specific to the percentage replacement of RAP aggregate in crushed aggregates and the test procedure that has been adopted in experimental work. The study was covered the correlation analysis and modeling the correlation equation of Marshall Properties of asphalt mixes used the Reclaimed asphalt pavement and crushed aggregates for asphalt road construction by conducting a diffident laboratory test. The relevant laboratory tests were conducted, and the results of Marshall Properties were correlated to the mix proportion of RAP aggregate in the compacted mix. The overall test results were compared to the ERA design specification and Marshall Criteria. The test was conducted in Jimma town and Jimma Institute of Technology (JiT).

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 Introduction

With the expanding world and the remarkable growth of freight volume, the demand for extensive road networks and adequately designed pavement is increasing [10]. Because of this, it's essential to improve and find a way to optimize the pavement construction materials for increasing road network supplies as well by understanding the effects of recycled materials on volumetric properties of asphalt mixtures. Various studies have been conducted on the recycled materials used in pavement construction as aggregates and fillers. In general, the main objectives of the research was to understand the effect of using Recycled Asphalt Pavement (RAP) aggregate on volumetric properties and mix performance in asphalt mixes and evaluate the relationship of these parameters of an asphalt mix by using Recycled asphalt pavement Aggregate (RAPA) in the compacted mixture as independent variables.

2.2 Theoretical Review of Using RAP aggregate in HMA

Several studies have been made on the use of recycled materials for pavement construction. As available natural resources become scarce, utilization of recycled materials for construction purposes, including flexible pavement construction, has become increasingly common. Since the past decade, there has been a significant increase in the application of waste materials in different layers of flexible pavements, including asphalt surface layer, base layer, and sub-base layer [10]. The primary purpose of highway pavement is to provide a suitable surface upon which highway vehicles can move on its [9]. Generally, there are two different types of pavement, which are flexible and rigid pavement. Flexible pavement consists of different layers that are carrying the load that applied to it from the live load. Among the different layers of flexible pavements, asphalt layer plays a fundamental role in a flexible pavement structure system as it should withstand varying traffic loads and continuously changing environmental conditions. Moreover, the asphalt surface layer is vital for safe and comfortable driving [5].

According to the nature of the asphalt surface layer, the application of recycled materials in asphalt layer reduces not only environmental issues associated with waste disposal but also the demand for virgin asphalt binder as well as the coarse and fine aggregates which will subsequently result in cost-saving and economic advantages. With increased demand and limited aggregate and binder supply, HMA producers have begun using reclaimed asphalt pavement aggregate (RAP) as a valuable component in hot mix asphalt [3] The use of Reclaimed Asphalt Pavement (RAP) aggregate in the construction of new hot mix asphalt (HMA) pavement has increased in recent years. Because the pavement industry has long emphasized the need to reuse RAP materials obtained from deteriorated road as these materials still possess pleasing properties to be used for the surfacing layers [23] Use of RAP in construction of flexible pavements may lead to economic saving and presentation of natural resource [24]. RAP is a useful alternative to natural materials because it reduces the use of virgin aggregate and the amount of virgin asphalt binder required in the production of HMA. Reclaimed asphalt pavement is the result of milling an existing flexible pavement layer that was removed for the preservation of rehabilitation on the road. The milled material is transported to stockpile for future use [11]

The use of recycled asphalt pavement also conserves energy, lowers transportation costs required to obtain quality virgin aggregates and preserves the resources. Additionally, using RAP decreases the volume of construction debris that placed into landfills and does not deplete nonrenewable natural resources such as virgin aggregates and asphalt binders. Ultimately, recycling asphalt will create a cycle that optimizes the use of natural resources and sustains the asphalt pavement industry [3].

2.2.1. Federal Highway Administration Recycled Materials Policy

The FHWA states that "when appropriately used recycled materials can effectively and safely reduce cost, save time, offer equal or, in some cases, significant improvements to performance qualities, and provide long-term environmental benefits" [FHWA 2007]. The Federal Highway Administration has developed a Recycled Materials Policy as an initial step to increasing RAP use. The Recycled Materials Policy is made up of the following five points

1. Recycling and reuse can offer engineering, economic and environmental benefits.

2. Recycled materials should get first consideration in materials selection.
3. Determination of the use of recycled materials should include an initial review of engineering and environmental suitability.

4. An assessment of economic benefits should follow in the selection process.

2.3. Laboratory Studies related to Using of RAP Aggregate in HMA.

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 [7]

In examining the effects of RAP aggregate on mix properties studied and found that as the percentage of RAP aggregate in a mix increased, there was increasing the variability (changeability) of mixture properties [6].

As the researcher [26] 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%

The flow value is increased with increasing RAP aggregate content in the HMA and that mixes containing low RAP aggregate had improved permanent resistance deformation and decreased the resistance of cracking. And also the mixture with RAP aggregate content has more Void in Mineral Aggregate (VMA) and void filled with asphalt (VFA) than the conventional combinations [12].

As another researcher [25] concluded on his finding the addition of RAP aggregate improves all properties of bituminous mixtures. This indicates that a mix with 20% RAP performs better than the fresh mix under similar condition.

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% [7].

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% [13].

The mix properties of asphalt can be affected by the physical and mechanical properties of aggregates. The RAP aggregate content could be related to a decrease in the crushed faces an increase in the intercept of the fine portion of the gradation, which is more effects on volumetric properties and mix performance of asphalt mixtures, as the result of study is suggested maximum percentage of using RAP in HMA is depend on quality and gradation of Aggregate in RAP [11].

As the RAP aggregate content was increased, the stability of the mix is decreased when testing is conducted, and the researcher concluded that the reduced performance could be attributed to change in the aggregate structure in the combination, which was playing a more significant role in asphalt mixtures. Therefore, considerable care needs to be taken in regard to the quality and structures of reclaimed asphalt pavement Aggregate (RAP). [14].

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 [15].

The Marshall design was used to find the Optimum Asphalt Content (OAC), and the corresponding properties (stability, flow value, air voids, voids in mineral aggregates and Bulk specific gravity) for the investigates mixes, with different percentage of RAP and satisfactory performance of asphalt pavement layers could be achieved by adding RAP partially replaced to virgin aggregates [7].

2.4 Review on the maximum percentage of using RAP aggregate in HMA

The related document regarding the recommended maximum percentage of recycled asphalt pavement (RAP) used in hot mix asphalt was reviewed. Some researchers and organizations were suggested on the RAP aggregate percentage in HMA. According to the National Asphalt Pavement Association (NAPA), the use of RAP aggregate in hot mix asphalt mixes has become an accepted and common practice. And it's explained and suggested that some state specifications allow HMA to contain up to 70% RAP under certain conditions. However: in practice, typically, a maximum of 25 to 50% RAP is actually used because of quality control [27].

According to researcher [28] study on experimental of reclaimed asphalt pavement in asphalt mix concrete and found that the utilization of 35% RAP aggregate ensures the same physical and strength parameters as virgin mixes. 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 [25]. 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 [29]. 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 [29]

2.5 Physical properties of used materials in hot mix asphalt

2.5.1 Reclaimed Asphalt Pavement and its properties

According to Copeland, A.(FHWA,2011), "Reclaimed Asphalt pavement in asphalt mixtures," the typical RAP contains 3-7% asphalt binder and 93-97% aggregate which is used as virgin aggregate and binder in asphalt concrete mix. As a result, there has been rejuvenated interest in increasing the amount of RAP used in HMA more in place of virgin aggregates [3].

2.5.2 Crushed Aggregate and its physical properties

Aggregate materials constitute the structure of the aggregate structure and subsequently, the most substantial proportion by weight of asphalt mixtures, as they contribute up to 90-95% of the mixture weight. Aggregates used in asphalt mixtures are classified into three main parts those are coarse and fine aggregates and fillers. Coarse aggregates are generally defined as those retained on the 2.36-mm sieve. Fine aggregates are those that pass through 2.36-mm sieve and are retained on the 0.075-mm sieve. Mineral filler is defined as that portion of aggregates passing the 0.075-mm sieve. Mineral filler is the very fine material with the consistency of flour and is also referred to as mineral dust or rock dust. The high proportion of aggregate materials in the volumetric design of asphalt mixes inherently links aggregate properties to the strength, stiffness, and generally the performance of asphalt surface layer [16].

According to the important role of aggregates in the properties of asphalt mixture, including the load-bearing and strength characteristics of the mix, a better understanding of the aggregate features will be essential in selecting appropriate materials to optimize asphalt mixture, and subsequently the pavement performance with enough resistance to permanent deformation and cracking. The most important physical and mechanical characteristics of aggregates include size and gradation, shape and angularity, surface texture, absorption, particle density, durability, hardness, resistance to polishing, soundness, and the harmful materials contained. The researcher [10] has been conducted to link the properties of the aggregates to the performance of asphalt concrete pavement. As the results of this study are proved that the physical and mechanical properties of the aggregates significantly affect the performance of the asphalt pavements.

According to the Ethiopia Road Authority specification has suggested, the following characteristics for aggregates used in HMA. So the aggregate should have the following features [4];

- ✓ Be angular and not excessively flaky, to provide suitable mechanical interlock;
- ✓ Be clean and free of clay and organic material;
- ✓ Be resistant to abrasion and polishing when exposed to traffic

2.4.2.1 Aggregate gradation for asphalt mixture

Aggregate grading is one of the most critical factors that affect the strength and bearing capacity of asphalt concrete, and an aggregates particle size distribution, or gradation, is one of its most essential characteristics. In hot-mix asphalt, gradation will help to determine almost every valuable property, including stiffness, stability, durability, workability, permeability, fatigue resistance, and resistance to moisture damage. Gradation is usually measured by a sieve analysis [17].

Table 2.1 Gradation of Asphalt binder course (ASTM 3515)

Sieve No	Sieve size (mm)	Nominal maximum stone size (mm)					
		Percentage passing sieve					
		19		12.5		9.5	
		Min	**Max**	Min	Max	Min	Max
1"	25	**100**	**100**	100	100	100	100
3/4	19	**90**	**100**	100	100	100	100
1/2	12.5	**-**	**-**	90	100	100	100
3/4	9.5	**56**	**80**	-	-	90	100
No. 4	4.75	**35**	**65**	44	74	55	85
No.8	2.36	**23**	**49**	28	58	32	67
No.16	1.18	**-**	**-**	-	-	-	-
No.30	0.600	**-**			-	-	-
No.50	0.300	**5**	**19**	5	21	7	23
No. 100	0.150	**-**	**-**	-	-	-	-
No.200	0.075	**2**	**8**	2	10	2	10
Bitumen content (%)		**4**	**10**	4	11	5	12

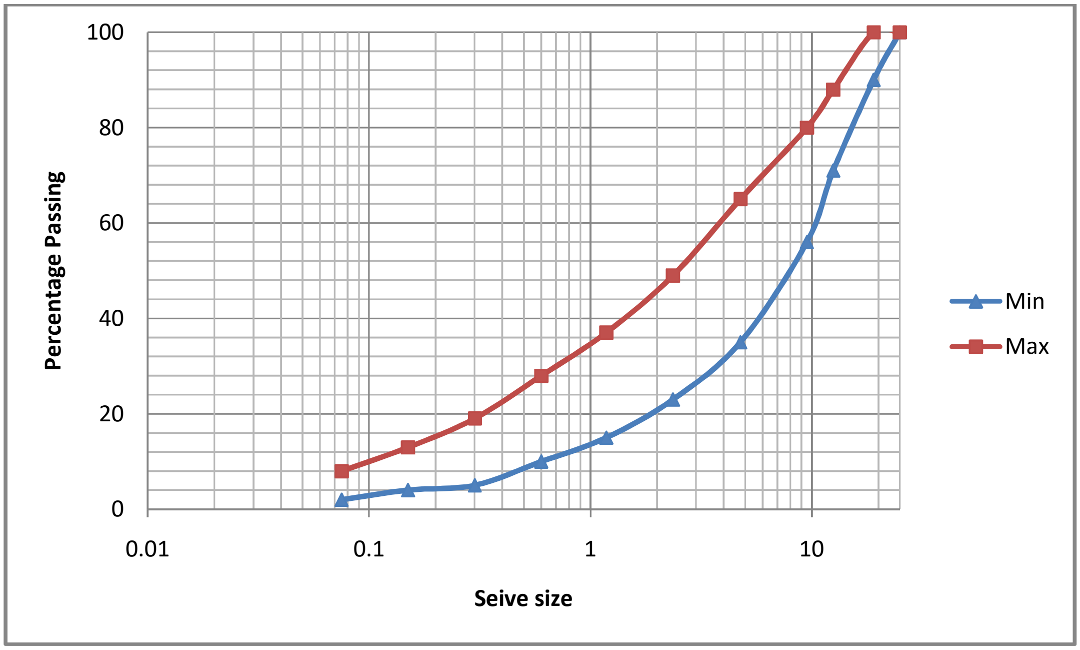

Figure 2.1 Gradation of asphalt binder course Graph Limit (ASTM 3515)

2.5 Mechanical properties specification for asphalt binder

Specification for the mechanical properties of the asphalt binder was reviewed. The binder asphalt specification is the one that controls the result of any asphalt laboratory. The specification reviewed is ERA design standard specification this specification was shown in the table 2.2

Table 2.2 Mechanical properties local specifications for asphalt binder course (ERA, Pavement Design Manual, 2002)

Total traffic (10^6 Million 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	35*2		50*2		75*2	
Stability (KN)	3.5	-	6	-	7	-
Flow (mm)	2		2		2	4

Percent Air Void	3	5	3	5	3	5
Percent VFA	70	80	65	78	65	75
%VMA (4%, VTM, & nom max, particle size 19mm)	13	-	13	-	13	-

2.3.4 Mineral Fillers and physical properties

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 [18]. 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 [19].

As Ethiopian Road Authority is, suggested that the filler (material passing the 0.075 mm sieve) can be crushed rock fine, Portland cement, or Hydrated lime. Generally, filler plays a vital role in the properties of bituminous mixtures, particularly in terms of filled the air voids and voids in mineral aggregates [4].

2.3.5 Asphalt binder (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 [16].

Table 2.3 Requirements for bitumen penetration Grade

S/No	Test	Test method	Penetration grade
			60/70
1	Penetration at 25 C^0	ASTM D-5	60-70
2	Softening point (C^0)	ASTM D-36	46-56
3	Flash Point (C^0)	ASTM D-92	Min 232
4	Ductility at 25 C^0	ASTM D-113	Min 50

2.4 Marshall Mix Design of HMA

The Marshall Method of HMA mix design was initially developed by Bruce Marshall in the 1940s, while he was working for the Mississippi State Highway Department. The procedure was later adopted and further refined by the U.S. Army Corps of Engineers (USACE). A wide range of engineers and organizations have proposed improvements and variations to the design procedures; publications of the Asphalt Institute are considered by many to the best reference for this and many other mixes design methods. The standard Marshal method is suitable for design and field control of HMA mixtures containing aggregates, fillers, and bitumen to determine the optimum asphalt content [16]. There are four primary features of the Marshall method:

- Asphalt binders and aggregate should be selected to meet all applicable project specifications.
- Evaluation of trial mixtures is done using laboratory compacted specimens 100mm diameter by approximately 70 thick compacted using standardized drop hammer.
- Laboratory –compacted specimens must meet requirements for air void content and VMA and, in some cases, VFA
- Laboratory-compacted specimens must also meet the needs for stability and flow-properties related to the strength and flexibility that determined in a quick, simple mechanical test

  An essential aspect of the Marshall Design method is a compaction of laboratory specimens over a range of asphalt binder contents and evaluation of the mixture volumetric over this entire range to determine optimum binder content.

2.4.1 Marshall properties of hot mix Asphalt

Marshall Mix design is the method to determine the appropriate Optimum bitumen content and corresponding volumetric properties. The reviewed Marshall properties of HMA have included stability, flow value, air void, bulk density, void in mineral aggregate, and the void filled with asphalt [27].

2.4.1.1 Marshall Stability

According to the asphalt institute [31], Marshall Stability is defined as the maximum load carried by a compacted specimen tested at 60^0 C at a loading rate of 50.08 mm per minute. The Marshall stability is significantly affected by selecting a more angular aggregate; i.e., the crushed angular aggregate of the same gradation yield higher stability mixes than do aggregate that is rounded or sub rounded. Other parameters that affect the Marshall stability are adding the maximum percentage of fine aggregate to HMA mixtures; one may add the more percentage of fine aggregate into mixture; it acts like a higher asphalt content and lower stability value. So one must carefully and completely analyze the effect of change in components on the properties of an HMA material

2.4.1.2 Flow value

According to National Asphalt Pavement Association (NAPA) [27], the flow value is measured at the same time as the Marshall stability, and it is defined as the vertical deformation of the sample (measured from the start of loading to the point at which stability begins to decrease) in hundredth of an inch. High flow values generally indicate a plastic mix that will experience permanent deformation under traffic, whereas low flow values may indicate a mix with higher than normal voids and insufficient asphalt for durability and one that may experience premature cracking due to mixture brittleness during the life of the pavement.

2.4.1.3 Air voids

According to the ERA pavement design manual [4] suggestion, the air voids are small air spaces or pockets of air that occur between the coated 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 voids may be increased or decreased by lowering or raising the binder content. The air void may also be increased or decreased by controlling the amount of material passing the No. 200 sieve in asphalt mixture. The more fines added to the asphalt mixture generally, the lower the air voids. Finally, the air voids may be changed by varying the aggregate gradation in asphalt mixture. And the recommended range of Air voids of asphalt mixture is between 3 and 5 percent.

2.4.1.4 Bulk Specific gravity (Mix Density)

According to asphalt institute [31], the density of the compacted mix is the unit weight of the mixture (the weight of a specific volume of asphalt mixture). Density is an important property because proper density in the finished product is essential for lasting pavement performance. Mix properties are required to measure in volumetric terms as well as weight. Density allows us to convert units of weight to volume. In mix design testing and analysis, the density of compacted specimens is usually expressed in kilograms per cubic meter (Kg/m^3).

2.4.1.5 Void in mineral Aggregate

Void in mineral aggregate is the total volume of voids (spaces) that exists within the mass of compacted aggregate. VMA represents the space that is available to accommodate the effective volume of binder (i.e., all of the binder except the portion lost by absorption into the aggregate) and the volume of air voids necessary in the asphalt mixture. The more VMA in the dry aggregate, the more space is available for the binder. Minimum VMA values are required so that a durable binder film thickness may be achieved. Increasing the density of asphalt mixture by changing the gradation of the aggregate may result in minimum VMA values with thin films of binder and a dry looking, low durability of asphalt mixture [27].

2.4.1.6 Void filled with asphalt

Voids filled with asphalt (VFA) are the void spaces that exist between the aggregate particles in compacted paving asphalt mixture that is filled with the binder. VFA is expressed as a percentage of VMA that contains a binder. The purpose of the VFA is to avoid less durable asphalt mixtures resulting from thin films of binder on the aggregate particles in light traffic situations [20].

2.4.1.7 Optimum bitumen content (OBC)

The optimum binder content of the asphalt mixture is highly dependent on aggregate characteristics such as gradation and absorptiveness. Aggregate gradation is directly related to optimum binder content. The finer the asphalt mixture gradation, the larger the total surface area of the aggregate, and the greater the amount of binder required to uniformly coated the particles. Conversely, because the coarser asphalt mixture has a less total aggregate surface area, the aggregates require less binder. This is why surface asphalt mixture requires more binder than base asphalt mixture. The absorptiveness (ability to absorb binder) of the aggregate used in the asphalt mixture is critical in determining optimum binder content. Enough binder is required to be added to the asphalt mixture to allow for absorption and also coat the particles with an adequate film. Total binder content and effective binder content are the terms normally used [27].

2.4.2 Properties considered in mix design

A. Durability

The durability of an asphalt mixture pavement is the ability of the asphalt mixture pavement to resist changes in the binder oxidation and disintegration of the aggregate. These factors may be the result of weather, traffic, or a combination of the two.

Generally, the durability of an asphalt mixture may be enhanced by three methods. They are: using maximum binder content, using a sound aggregate and designing and compact the asphalt mixture for maximum impermeability [4]. Maximum binder content increases durability because thick binder films do not age and harden as rapidly as thin films. Consequently, the binder retains the original characteristics longer. Also, maximum binder content effectively seals off a greater percentage of interconnected air voids in the pavement, making the penetration of water and air difficult. A certain percentage of air voids are required to be left in the pavement to allow for expansion of the binder in hot weather. A dense gradation of sound, tough aggregate contributes to pavement durability by providing closer contact between aggregate particles that enhances the impermeability of the asphalt mixture and resists disintegration under traffic [31].

B. Impermeability

Impermeability is the resistance of an asphalt mixture pavement to the passage of air and water into or through the mixture. This characteristic is related to the void content of the compacted asphalt mixture, and much of the discussion on voids in the mix design relates to the impermeability. Even though void content is an indication of the potential for passage of air and water through the pavement, the character of these voids is more important than the number of voids. The size of the voids, whether or not the voids are interconnected, and the access of the voids to the surface of the pavement all determine the degree of impermeability [31].

C. Workability

Workability describes the ease with which a paving asphalt mixture may be placed and compacted. Workability may be improved by changing mix design parameters, aggregate sources, and/or gradation. Harsh asphalt mixture (asphalt mixture containing a high percentage of coarse aggregate) has a tendency to segregate during handling and also may be difficult to compact. Through the use of trial mixes in the laboratory, additional fine aggregate and perhaps binder may be added to a harsh asphalt mixture to make the mixture more workable. Care is required to be taken to ensure that the altered asphalt mixture meets all the other design criteria [21].

Excess fines may also affect workability. Depending on the characteristics of the fines, the fines may cause the asphalt mixture to become tough or gummy, making the mixture difficult to compact. Workability is especially essential where excessive hand placement and raking around manhole covers, sharp curves, and other obstacles is required. Asphalt mixture used in such areas is required to be highly workable.

E. Flexibility

Flexibility is the ability of an asphalt mixture pavement to adjust to gradual settlements and movements in the sub grade without cracking. Since virtually all sub-grades settle (under loading) or rise (from soil expansion), flexibility is a desirable characteristic for all asphalt mixture pavements. An open-graded asphalt mixture with high binder content is generally more flexible than a dense graded, low binder content asphalt mixtures. Sometimes the need for flexibility conflicts with stability requirements so that tradeoffs are required to be made.

F. Fatigue Resistance

Fatigue resistance is the pavement's resistance to repeated bending under wheel loads (traffic). Air voids (related to binder content) and binder viscosity has a significant effect on fatigue resistance. As the percentage of air voids in the pavement increases, either by design or lack of compaction, pavement fatigue life (the length of time during which an in-service pavement is adequately fatigue-resistant) is drastically shortened. Likewise, a pavement containing binder that has aged and hardened significantly has reduced resistance to fatigue. The thickness and strength characteristics of the pavement and the supporting strength of the sub-grade also have an effect on the pavement life and prevention of load associated cracking [21]. Thick, well-supported pavements do not bend as much under loading as thin or poorly supported pavements.

2.5 Correlation with Regression analysis

Correlation is a statistical tool that can help to measure and analyze the degree of relationship between two or more variables. Correlation indicates the interdependency among the variables for correlating two variables, it is essential that the two variables should have a cause-effect relationship, & if such a relationship does not exist then the two variables cannot be correlated. The measure of correlation is the degree of the coefficient, which is the range of correlation **($-1 \leq R \leq +1$).** The correlation analysis enables us to have an idea about the degree & direction of the relationship between the two variables, and the sign indicates the direction of change. According to statistical system, there are two types of correlation that are a positive and negative correlation. The correlation is positive if the values of two variables changing in the same direction, while the correlation is said to be a negative correlation when the values of variables change in the opposite direction. In negative correlation, when the value of independent variables increase the value of dependent variable is decrease. Strong negative and positive correlation is the range of correlation coefficient is between 0.9 and 1. And weak correlation value is correlation coefficient less than 0.5. According to [22], Studied on modeling the stability of asphalt concrete by statistical method, the statistical analysis was performed for all of the asphalt mix properties: air voids, bulk specific gravity, etc. the relationship between stability and other characteristics of asphalt mixture were determined using the statistical software.

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 Introduction

The main objective of this study was to evaluate the effect of using Reclaimed Asphalt Pavement aggregate (RAPA) on volumetric properties of asphalt mixture and evaluate the relationship of asphalt parameters with using RAP aggregate percentage replacement of crushed aggregate by determine statistical equation using Regression Analysis. This chapter focuses on the material used and methodology or explained how the experimental work has been done to perform the research objectives

3.2 Study Area

The laboratory was conducted in the Jimma Institute of Technology Highway Engineering Laboratory and Jimma Institute of Technology is located Jimma Town, Jimma town is the capital town of Jimma zone, which is located in the Oromia Regional State and located in the southwest of Ethiopia 346 km away from the capital city of Addis Ababa. The study area is situated at an average altitude of 1700m above the mean sea level. The astronomical location of Jimma is 7º 4' North Latitude and 36º 5' East Longitude. The town has a total area of 46.23 km2 (4623 hectares), with an average temperature ranges between 7.3 C^0 to 31 C^0. 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).

3.3 Study design

A study design is a process that guides researchers on how to collect samples; the test is conducted and analysis the result. So this research was designed based on experimental research methods. That means the experimental research method is always based experimental work with description and analysis of what will occur under the carefully controlled conditions of qualitative and quantitative. For the accomplishment of this research objective, the secondary data of the related study were reviewed, and Primary data of different laboratory tests were conducted. The laboratory procedure was conducted based on the ASTM, AASHTO, and BS material testing standard laboratory procedure guidelines for all tests performed for the accomplishment of this research objective, as shown in Table 3.3. The test designed to achieve the research objectives is a material quality test and Marshall Stability Test. For the performance of this research, the materials were collected from different Jimma areas. The material quality test was conducted on all selected materials to identify its physical and mechanical properties for the performance of this research. The Marshall Mix design is used 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. Each group was prepared with some Specified percent of Reclaimed Asphalt pavement blended with crushed aggregate, fine aggregate, and fillers by Using Job Mix Formula (JMF) for all six samples. Then six mix samples from (M1-M6) were prepared with recycled aggregates percent of (0%, 10%, 20%, 30%, 40%, and 50 %) blended with Crushed aggregates. Total of 40 mix design was prepared, from this 15 mix design with three different aggregate gradation as shown in table 4.1 and total of 45 specimens for conventional (control mix) and 25 mix design with five different aggregate gradation were prepared for RAP aggregate replacement as shown in table 4.2. And total of 75 mix specimens were prepared. Totally 120 specimens were prepared. Then Marshall Test were conducted on all specimens by applying 75 blows on each face according to the Marshall procedure specified in ASTM D1559 to obtain the optimum asphalt content for each mix with different proportion of RAPA and bitumen content of (4%, 4.5%, 5%, 5.5% and 6%) for each mix design with 3 trail. There are about 120 mix specimens that were prepared to determine optimum bitumen content and corresponding volumetric properties of HMA. Then optimum bitumen content of each mix RAPA replacement was determined according to Asphalt institute (2003), which was the average bitumen content from bitumen versus maximum bulk specific gravity, maximum stability, and medium of 4% air void. Final analyses were performed by using Regression Analysis. Figure 3.1shows the overall research designs for the accomplishment of the research objectives.

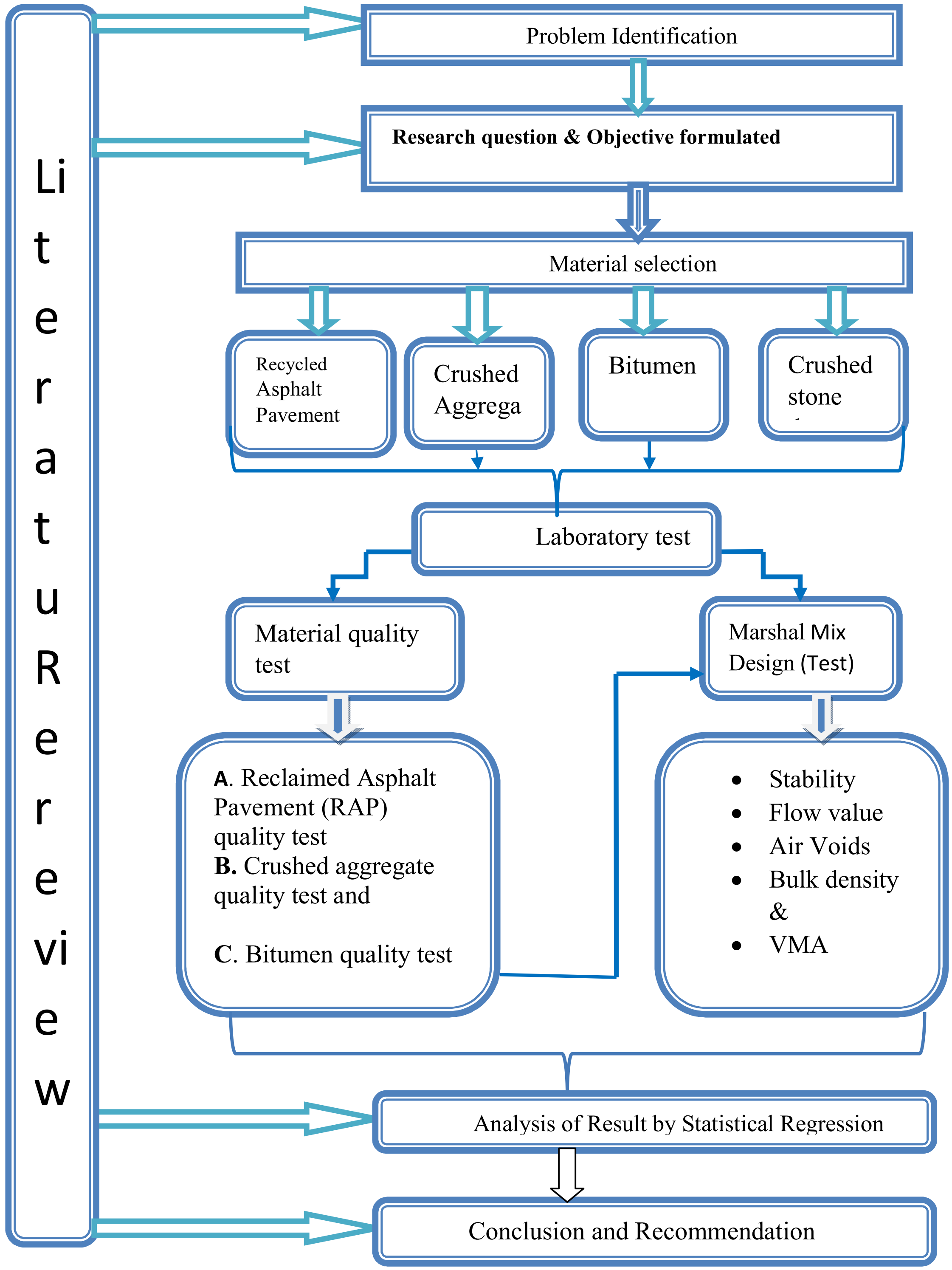

Figure 3.1 Study design

3.4 Study population

The study population for this study was including the materials used in the research works; those are Reclaimed asphalt pavement, crushed aggregate (courser, intermediate and finer), and asphalt binder (bitumen).

3.5 Data Collection

The data collection was carried out from two different data sources, primary and secondary data sources. This was conducted first by identifying the effects of Reclaimed Asphalt Pavement (RAP) aggregate on volumetric and Marshal properties from the different literature reviews, scientific researches, and laboratory tests to come up with the research output.

3.4.1 Sample collection

Several materials were required for producing asphalt specimens in the laboratory. Since the main objective of the study was to evaluate the effect of RAPA on volumetric properties of HMA, the selected materials was including the Reclaimed Asphalt Pavement (RAP) Which were collected from Jimma Agaro Road around Yebu town, which is ongoing of rehabilitation, crushed aggregate of course aggregate, intermediate and finer aggregate with size of (9-25mm,2.36-9.5mm and 0-2.36 mm) respectively were collected from ERCC Deneba crusher site and bitumen 60/70 Penetration grade was also collected from ERCC. The collected materials for the achievement of research objectives from the different source are shown in Table 3.1

Table 3.1 Location from the sample is collected

S/no	Sample name (materials)	Location from collected	Sample form
1	Reclaimed Asphalt Pavement (RAP)	Jimma- Agaro road maintenance around Yebu town	Solid
2	Crushed Aggregate and fine	Ethiopian road construction corporation (Deneba Crusher Quarry Site) approximately 80km away from Jimma town	solid
3	Bitumen 60/70 penetration grade	ERCC (Ethiopian Road Construction Corporation)	Liquid

3.5.3 Laboratory test performed and test methodology

The laboratory test performed and test methodology for the achievement of this research are shown in Table 3.2

Table 3.2 Test conducted and test methodology

s/n	Materials	Test conducted	TEST METHOD
1	Aggregate test for RAP & Crushed aggregate	A sieve analysis (Gradation)	AASHTO T-27
		Los Angles Abrasion value	AASHTO T-96
		Aggregate crushing value	B. S 812 Parts 110
		Aggregate Impact Value	B.S Parts 112
		Flukiness index	BS 812 Part 105
		Specific gravity (course & fine)	AASHTO T 85-91/ASTM C-127
2	Bitumen quality test	Penetration test	AASHTO T- 49
		Specific gravity	ASTM D-70-97
		Ductility	AASHTO T- 51
		Softening point	AASHTO T- 53
		flashing point	ASTM D-92
3	Filler test	Specific gravity	ASTM D-854
4	Un compacted mix	Theoretical maximum specific gravity (Gmm)	ASTM D -2041 /AASHTO T-209
5	Compacted mix	The bulk specific gravity of compacted mix (Gmb)	AASHTO T-166/ASTM D-2726
		Marshall mix design (Marshall Stability test)	ASTM D-1559/AASHTO T-245

3.6 Study Variables

There are two types of variables that considered in this research those are the dependent variable and the independent variable.

3.6.1 Independent Variables

The independent variables of the study are the mechanical and physical properties of Crushed and Reclaimed asphalt pavement (RAP) (such as aggregate crushing value, aggregate impact value, specific gravity, gradation, Los angles abrasion value and RAP percentage), bitumen properties (Penetration, ductility, softening point and specific gravity) and filler properties (Specific gravity and plastic index).

3.6.2 Dependent Variable

The dependent variable is more related to the general objectives of the study. Hot Mix Asphalt (HMA), properties.

3.7 Data Processing and Analysis

3.7.1 Data Processing

For the accomplishment of this research objective, the data was processed according to the following tasks. Those are:

- Data handling and recording format were prepared for laboratory tests.
- All data were properly observed and recorded using the standard format.
- By Arranging and wrote the results, then the relationship was noted.
- Using a table, graphs and another method of data presentation was carried out

3.7.2. Data Analysis

After the data was processed and presented, the final analysis was conducted by the following methods and applications.

- Statistical regression analysis was used to correlate based on the scattered plot of test results.
- Evaluation of the relationship between the dependant and independent variables formed from the test result obtained.
- Comparing the formulated relationship with specification and Marshall Criteria.
- Finally, the Conclusion and recommendations were formulated.

3.8 Correlation using Regression Analysis

Regression is the statistical process used for evaluating the relationships between variables. The regression analysis has many techniques for modeling the statistical equation and analysis of several variables, which is focused, on the relationship between a dependent variable and independent variables. It helps to understand how the value of the dependent variable was changed by changing the independent variables. Regression modeling is consisting of the following variables. Those are,Y (dependent variables), X (independent variables), and β is the slope of the line. In regression modeling, Y is the function of X and β.Thus, Y= *f(X,* β). The regression statistical modeling analysis for this study was linear regression, which was one dependent variable and one independent variable or parameters. Those parameters were the effects of RAP on mixture properties, and mix performance was done using regression analysis for modeling the relationship of volumetric properties (dependent variables) by using recycled asphalt pavement (independent variables) in compacted mixtures based on laboratory test result obtained. The correlation equation was modeled for the volumetric properties of asphalt mixtures (optimum bitumen content, air voids, etc.) using a different proportion of RAP and bitumen content by linear statistical regression. The regression equations used for analysis were as follows:

Linear (straight) Regression equation: $Y_i = \beta_0 + \beta_1 X_i + \epsilon_{i...}$ ……………equation (3.1)

Where: Y= dependent variables plotted on Y-axis (OBC%, etc.)

X= Independent variables plotted on X-axis (RAPA%)

β1= the slope of the line and

*β*0 = is the y-intercept, at X=0

i= Indicate particular observation unit (1,2,3…)

€= random error give to statistical model

The equation above was used to correlate the test result of dependent variables such as optimum bitumen content and air void with variation proportion of recycled asphalt pavement (independent variable) in hot mix asphalt.

Linear polynomial (curve) regression equation: $Y = \beta x^2 + \beta x + c$ …equation (3.2)

The equation above was used for determining the OBC by the relation of dependent variables of stability, air void and specific gravity with Bitumen content varies from (4%-

6%) by an increment of 0.5% based on the test result. The regression modeling has also consisted of a regression line which represents by an equation and coefficient of determination, which is represented by R^2. Thus, it provides a measure of how the model represents the observed outcomes. The better linear regression fits the data, the closer the value of R^2 is to 1.

3.9 Laboratory test procedure

Since the finding of this research is based on experimental work, the laboratory procedure is the backbone for the achievement of the research objectives. For the accomplishment of this lab work, the following procedure was conducted:

1. Materials such as Reclaimed Asphalt Pavement, Crushed Aggregate (courser and finer), and Asphalt binder were collected from the ERCC quarry site and different areas of Jimma town.
2. Crushing and Extraction of Reclaimed Asphalt Pavement were conducted using extractor machine to get each particle size of RAP Aggregate.
3. Aggregate quality tests such as Sieve Analysis (Gradation), aggregate crushing value, aggregate impact value, and the specific gravity of course and fine and Los angles abrasion value for RAPA and Crushed aggregate were conducted.
4. Bitumen quality test like penetration, ductility, softening point, specific gravity was conducted.
5. After the material quality test was completed and getting acceptance-based on ASTM and AASHTO standard specification, the Marshall Stability test was conducted according to ASTM D-1559 procedure. For the accomplishment of this step, Blending of Aggregate were carried out for conventional mix (0% RAPA), blending is the way of determining the design aggregate gradation by adding the different proportion of Aggregate size (Course, intermediate, fine and filer) for hot mix asphalt. For this study, Design Aggregate gradation was prepared with three trails (samples) by different proportions (percentage) of Aggregate size based on the ASTM D-3515 Specification limit. Then 15 mix designs with five different percentages of (4%-6%) bitumen content and a total of 45 specimens were prepared, then the Marshall stability test was conducted on each specimen for determining of Optimum bitumen content. After the conventional (Control mix) gradation were finished, and optimum bitumen content is obtained, next, five

samples were prepared with different RAP aggregate proportion of (10%, 20, 30% 40% and 50%) and crushed aggregate with different bitumen content of (4%, 4.5%, 5%, 5.5% and 6%) using the same control mix design aggregate gradation on which optimum bitumen content were obtained by using Job mix formula. So that 25 mix design with 3- trials and a total of 75 specimens were prepared. Then Marshall Stability test was conducted on each specimen to determine optimum bitumen content and corresponding volumetric properties HMA.

6. Plotting the graph of bitumen content versus stability, bulk density, air void, flow value, void in mineral aggregate, and void filled with asphalt.
7. Optimum Bitumen content was determined according to the asphalt institute (2003) method, that Optimum bitumen content is the average value of bitumen content at Maximum bulk specific gravity, maximum stability, and Bitumen content at 4% Air voids plotted on the graph. Based on optimum bitumen content obtained, other volumetric properties and mix performance was determined at OBC determined.
8. Finally, the laboratory results obtained were analyzed by Statistical Regression analysis.

3.10. Test and preparation of material used for the study

3.10.1 RAP Aggregate and crushed Aggregate Tests

Aggregate is the major component in HMA, and the quality and physical properties of this material have a great influence on mix performance. 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 totally crushed aggregate from particles having a coarse micro-texture. The coarse aggregates used for making HMA should be produced by crushing sound, unweathered rock, or natural gravel. Gravel should be crushed to produce at least two fractured faces on each particle. By volume of total weight, at about 92-96 percent of HMA is governed by aggregate. The Aggregate test including, Aggregate crushing value, Aggregate impact value, Aggregate specific gravity, flakiness index, and Los angles abrasion value, were conducted and the result of the laboratory test were explained in table 4.3 and highlighted of the test were explained as follows.

3.10.1.1 Reclaimed Asphalt pavement (RAP) aggregate preparation for a mix

Reclaimed Asphalt pavement is recycled materials that are milled or full depth removed during rehabilitation and maintenance of road pavement. The selected materials were transported to the laboratory and prepared for the test. The process of preparation includes crushing, extracting, and quality tests required as the same to virgin materials. For this study, the crushing of RAP was conducted in a manual way by using a hammer for the purpose of getting an individual particle size of recycled aggregate. The extracting of RAP is conducted by the oven ignition method for the purpose of removing the old bitumen from Recycled aggregate and get Recycled asphalt pavement aggregate (RAPA). And also, the quality test is conducted with the same as crushed aggregate procedure. The selected RAP materials and the process was explained in **Appendix G**

3.10.1.2 Preparation of Aggregate Gradation for the study

Sieve analysis or gradation of the aggregate is one of the factors that must be carefully conducted in the design of asphalt paving mixtures. The purpose 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. Since the objectives of the research were to evaluate the effect of RAP aggregate on volumetric properties of HMA, and Aggregate gradation has more influence on volumetric properties. So the gradation of aggregate was conducted for both individual aggregate gradation for RAPA and crushed aggregate and blending of aggregate gradation. The aggregate blending was performed by using J.M.F for conventional aggregate gradation and RAP proportion Aggregate Gradation. The final blended gradation was controlled by ASTM D-3515 standard specification limit, which is shown in Table 3.3. For this research about nine different gradations were prepared one is individual particle size distribution of RAPA and crushed aggregate which is shown in **Appendix B**, the three of them are for conventional mix that shown in table 4.1 and figures 4.1 and the other five are for RAP aggregate partial replacement of crushed aggregate which is shown in table 4.2 and figures 4.2 The detail particle size distribution of RAP aggregate, Course, fine aggregate and blending of aggregate procedure were explained in **Appendix A**

Table 3.3 Gradation of Asphalt binder course (ASTM D-3515)

Sieve No	Sieve size (mm)	Nominal maximum stone size (mm)									
		Percentage passing sieve									
		37.5 mm		25mm		**19mm**		12.5mm		9.5mm	
		min	max	min	max	**Min**	**Max**	Min	Max	Min	Max
2"	50	100	100	-	-	**--**	**--**	--	--	--	--
1 1/2"	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
3/4	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	0.600	-	-	-	-	**-**	**-**		-	-	-
No.50	0.300	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

3.10.1.3 RAP and crushed aggregate quality test

A. Aggregate Crushing value

The A.C.V test is the test that gives a relative measure of the resistance of an aggregate to break down under a steadily applied wheel load as a compressive load. The standard aggregate crushing test shall be conducted on aggregate passing 12.5 mm and Retained on a 9.5 mm AASHTO test sieve. The aggregate crushing value was performed for both RAP and crushed aggregate as shown in figure 3.2

B. Los Angles Abrasion Test

LAA test is a common method used to indicate the aggregate hardiness and abrasion characteristics. These characteristics are significant because the ingredient aggregate in HMA should resist crushing, degradation, and breakdown in order to produce high quality of HMA. The L.A abrasion test is determined the degradation, of course, aggregate sample prepared placed in a rotating drum with steel spheres. When the drum is rotated, the aggregate is broken down by abrasion, impact with aggregate particles each other and steel sphere. After the test is completed, the calculated mass of the aggregate that has broken into smaller sizes is articulated as a percentage of the total mass of aggregate. Therefore the lower abrasion value indicates aggregate that is tougher and more resistant to abrasion. The Los Angles abrasion test was conducted on both and RAPA and virgin aggregate for identification of their quality according to AASHTO T-96 Grading (B) using spheres numbers of eleven as shown figure 3.2

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Figure 3.2 Aggregate crushing value and Los Angles Abrasion test

C. Aggregate impact Value

The property of a substance to resist impact is known as hardiness. Due to the faction of the vehicle on the road, the aggregate is subjected to a collision resulting in their breaking down into smaller particles. The aggregate must have adequate hardiness to resist their breakdown due to impact. The impact value test determines this quality of aggregate. Since the aggregate has more influence on the hot mix performance, the Aggregate impact value test was conducted on both RAPA and virgin aggregate according to B.S Parts 112 laboratory test procedure for identifying the quality of those materials. For conducted this test, samples of Aggregate size of 12mm pass and 10mm retained were prepared and heated in oven dry at $100C^0$-$110C^0$ for a period of four hours and cooled. Then pour aggregates were dived into three and filled into cylinder. After that, compacted material by giving 25 blows with the rounded end of the temping road is conducted, as shown in figure 3.3. Finally, the loaded material was sieved by using 2.36mm sieve size, and aggregate impact value was determined.

D. Flukiness index test

Since the particle shape and surface texture is influence properties of Hot Mix Asphalt, the flakiness index test was conducted according to B.S 812 part 105 for determining the quality of materials used for the mix.

E. Specific Gravity and Water absorption of Aggregate

Hot mix asphalt properties are highly affected by the specific gravity of course and Fine Aggregate. Shortly aggregate specific gravity is needed to determine the weight to volume relationships and to calculate various volume-related quantities such as volume in mineral aggregate (VMA) and VFA.

For the determination of specific gravity and water absorption of aggregate: sample was prepared from different sizes of Aggregate (Course, Intermediate, and fine) according to AASHTO T-85 Laboratory procedure. Then prepared samples were put in water with a steel basket for 24 hours. After 24 hours, the mass of samples in water, mass saturated surface dry (SSD), and Oven dry mass were measured. Finally, using the three weight and their relationships, apparent specific gravity, bulk specific gravity, bulk SSD, and water absorption ware calculated. For this study specific gravity was determined for each partial replacement of (0%, 10%, 20%, 30%, 40% and 50%) RAP aggregate for each of Aggregate size proportion in mixture (Course (9-25mm), Intermediate (2.36-9.5mm) and fine (0-2.36mm), because bulk specific gravity of each proportion was used for calculation of volumetric properties of asphalt mixture. And also, the crush dust stone dust filer was conducted to identifying the quality of hot mix asphalt fillers.

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Figure 3.3 Specific Gravity test for RAP Aggregate and CA and Aggregate impact value test

3.10. 2 Bitumen selection and test

Bitumen acts as a binding agent to the aggregates, fines, and stabilizers in bituminous mixtures. Binder provides durability to the mix. The asphalt binder used in this study was a penetration grade of 60/70. The asphalt binder is always selected based on the traffic class and the environmental condition. So selected asphalt binder of this study was suitable for heavy traffic and environmental condition of the study area. The physical properties of the asphalt binder were determined according to the procedure specified by AASHTO and ASTM standard. A series of tests, including penetration, specific gravity, softening point, ductility, were conducted for the basic characterization properties of penetration grade asphalt. The test requirement of ERA specifications and results are presented in table 4.4, and the highlighted of the test method is explained as follows.

A. Penetration test

Penetration test value of bitumen is a measure of the hardiness of bituminous materials. Penetration value is the perpendicular distance transverse load applied by the peak of the standard needle into the bituminous materials under the specific condition of load, time, and temperature. For this study, penetration tests were conducted according to AASHTO T-49 Procedure on selected bitumen 60/70 penetration grade. Figure 3.4 shows the penetration test of bitumen for the study.

B. Ductility test of bitumen

The ductility of bitumen is the property of bitumen to extend under traffic load with no getting cracked in road construction works. So that ductility tests on bitumen measure the distance in centimeters to which it elongates before braking. The ductility test on bitumen 60/70 penetration grade was conducted based on the AASHTO T-51 laboratory guideline. Figure 3.4 shows the ductility test conducted for the study.

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Figure 3.4 Penetration test and Ductility Test for bitumen respectively

C. The softening point of bitumen test

The softening point of bitumen is the temperature at which the material attains the exacting point of softening. As per AASHTO T-53/ASTM D-36, it's a temperature in C^0 at which a standard ball passes through a sample of bitumen in the mold and falls through a height of 2.5cm, when heated water or specified condition. The softening test of bitumen is conducted based on AASHTO T-53 procedure in the laboratory as shown in figure 3.5

D. The specific gravity of bitumen

The specific gravity of bitumen is the ratio of the mass of a given volume of a substance to the equal volume of water at a standard temperature of $25C^0$. The specific gravity of bitumen is conducted according to ASTMD-70-97.


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Figure 3.5 Softening point of bitumen and specific gravity test of bitumen

3.11 Asphalt Mix Design

In the production of hot mix asphalt, asphalt and aggregate are blended together in precise proportions. The relative proportions of the materials determine the physical properties of the materials determine the finished pavement. There are three commonly used design procedures for determining a suitable proportion of asphalt and aggregate in a mixture. They are Marshall Method, the Hveem method, and the Super pave system method.

3.11.1 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 is applicable only to hot mix asphalt using penetration, viscosity, or PG graded asphalt binder or cement and containing aggregate with a maximum size of 25.0 mm (1 in.) or less (source: Asphalt Institute, Ms-2, 2014). The purpose of the Marshall Method is to determine the optimum bitumen content for a particular blend of aggregate. And 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 and each containing three varying in the aggregate blend and varying of bitumen content 4%-6% by an increment of 0.5% prepared and using ASTM D-1559 procedure to heat, mix and compact the aggregate mixture. Generally, the Marshall Test procedure has been standardized by the ASTM and published as ASTM D-1559 or AASHTO T-245. The test procedure of Marshall Mix design starts with the preparation of test specimen and step preliminary to specimen preparation are:

- 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 (course, intermediate and fine) used in blend and the specific gravity of the asphalt cement for performing volumetric properties analyses.

There was a significant amount of testing conducting throughout the progression of this study, and there were several procedures followed for mix design such as sample preparation, temperature controlling, and testing. The laboratory sampling plan consists of both crushed aggregate blending for control mix and Reclaimed Asphalt Pavement (RAP) aggregate partial replacement of crushed aggregate blending based on control mix or aggregate design gradation for determining effects on volumetric properties of HMA. The following flow chart shows the procedure of Marshall Mix Design.

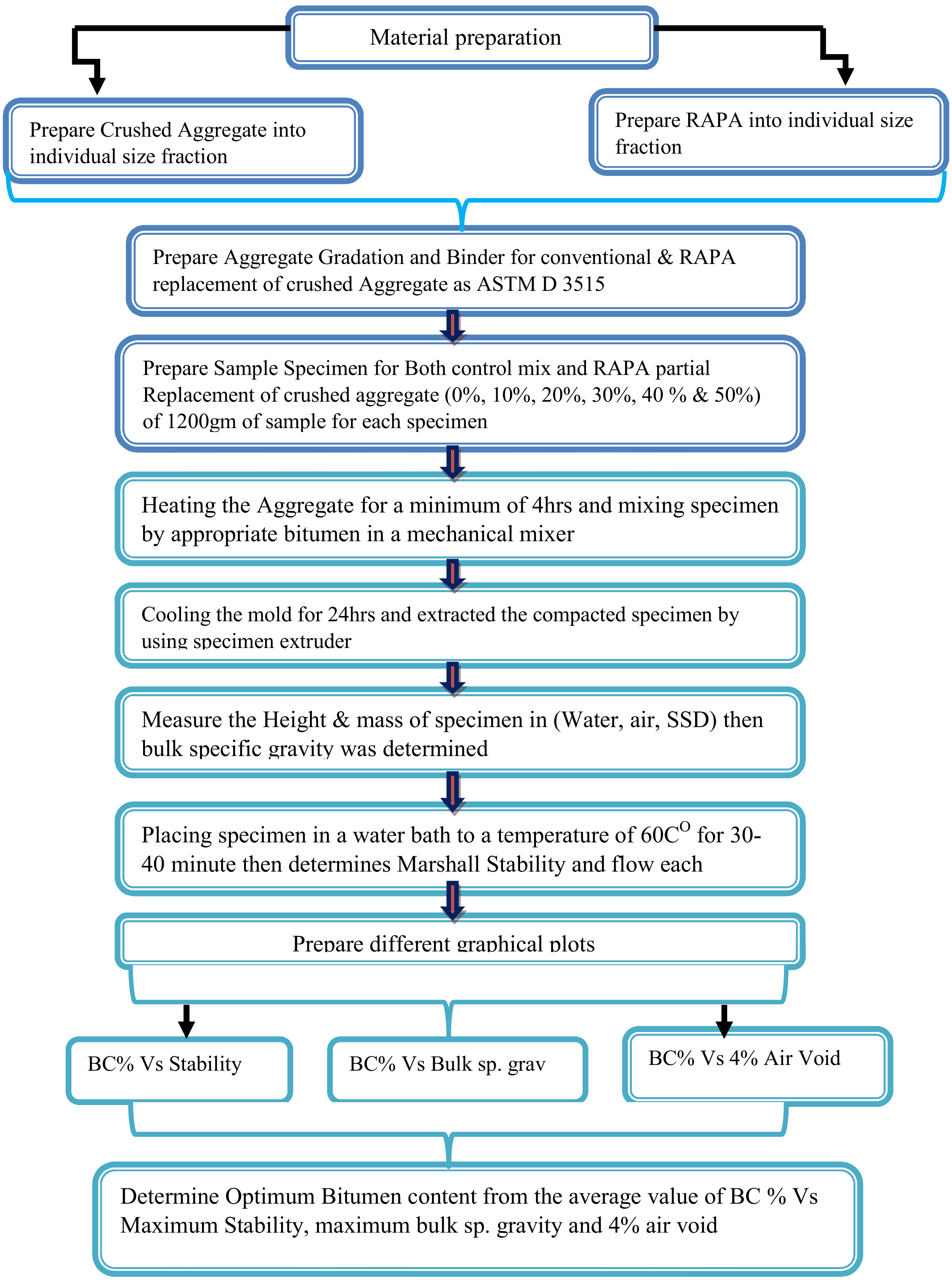

Figure 3.6 flow chart of Marshall Mix design procedure

3.11.1.1 Marshall Mix Design Mixture Specimen Preparation

In determining the design asphalt content 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 are needed to prepare an HMA mixture specimen. 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: Prepare a number of specimens

Preparing a number of the specimen using the Marshall Procedure for the individual specimen is very important. The number of specimen preparation has always based the objectives of the study; for this study, about 120 specimens were prepared for both conventional and RAPA proportion. From these 45 specimens are for control mix to determining Optimum bitumen content and design aggregate gradation, and another 75 specimens were for the proportion of crushed Aggregate and RAPA to determine the effects on Optimum Bitumen content and corresponding volumetric properties of HMA. Each specimen was prepared by a weight of 1200gm with blended aggregate.

B. Preparation of Aggregate and control mixing temperature

Since the objective of the study is related to the effect of RAPA on the volumetric properties of HMA, the preparation of Aggregate is very important. Because the RAPA is replaced in place of aggregate, which is more constituent of hot mix asphalt and has more influence on Marshall Characteristics. For this study, there are two types of aggregate gradation used; one is for the control mix, which is not blended with RAP, and another is Aggregate that is blended with RAPA proportion. To perform this following procedure were conducted, at the first step, 1200gm of blended aggregate and crushed stone dust filler is measured from all prepared aggregate with each sieve size as shown in Appendix F, using balance for both control mix and RAP aggregate proportion (0%, 10%, 20, 30%, 40, & 50) respectively as shown in figure 3.7

0% RAPA (Aug 4, 5:52 PM) 10% RAPA (Aug, 6:3:24 PM) (20% RAPA (Aug, 8, 8:20PM)

30% RAPA (Aug 9, 4:52 AM) 40% RAPA (Aug, 10:3:24 PM) (50% RAPA (Aug, 12, 9:30PM)

Figure 3.7 Aggregate preparation for mix contain RAP Aggregate from 0%-50%

After the preparation was finished put the prepared materials together in the oven-dry in each separate container by a temperature 105 to 110 C^0 for minimum 16hrs as shown in figure 3.8 and bitumen is also heated by 160-170 C^o based on a standard heating temperature of bitumen 60/70 penetration grade suggested by ERA standard specification. Also it’s essential to control temperature during mix if the temperature is above mixing temperature allows it too cool to compaction temperature and if the temperature is below the compaction temperature, discard the materials and new mix because the mixing temperature has more effect on Marshall Properties. The mixing Temperature was controlled by thermometer as shown in figure 3.8

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Figure 3.8 Drying of Aggregate and checking mixing temperature respectively

C. **Preparation of compaction mold, Hammer and Mixture**

The compaction mold was clean and heated in oven dry to a temperature between 95-150C^o as shown in figure 3.9 and place a 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. In preparation of the mixture, Place the pan (mixing) mold in oven-dry, and heat to a temperature not exceeding above mixing temperature specified. 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, 4.5, 5, 5.5 and 6) percent 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 3.9

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Figure 3.9 preparation of mold & heated and mixing by mechanical mixer

D. **Compaction of Specimen**

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, as shown in figure 3.10, and placed the mold assembly on the compaction pedestal in the mold holder. Then the specimen is compacted by 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 3.10.


(8:44PM, Aug, 19, 2019)


(8:46 PM, Aug, 18, 2019)

Figure 3.10 Placing of a specimen in mold and compaction of specimen respectively

E. Determination of specimen height and mass

The compacted specimens were removed from the mold after the overnight cool or 24 hours by using the specimen extractor, as shown in figure 3.11. After extracting of a specimen is conducted specimen mass were measured in Air, water and saturated surface dry (SSD) for determination of bulk specific gravity of compacted mix as shown in figure 3.12


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(9:48 PM, Aug, 21, 2019)

Figure 3.11 Extracting of specimen and measuring of specimen height respectively

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Figure 3.12 measuring of weight in Water and overnight cool of specimen respectively

F. Marshall Flow Stability Test

After specimen height and Wight are measured, and calculation is made, the extracted specimen was put in a water bath to $60C^0$ 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, as shown in figure 3.13, and the test must be performed with in30 seconds. U Test Digital Marshall Flow Stability machine is different from the manual one. In U Test Digital Marshall Stability All values of stability, flow, and pick load value are adjusted and displayed on a displayed screen, as shown in figure 3.13. And the correction factor is based on specimen height, and volume is given automatically from the testing machine.

Generally, the flow and stability of a total of 120 specimens were determined 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 Asphalt mixture were determined from the relationship of various bitumen content to Volumetric parameters like VFA, VMA, VA, and Gmb

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Figure 3.13 Prepare specimens for Test and Digital Marshall Flow stability test respectively

G. 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 [32], there are two methods that are recommended to determine Optimum Bitumen Content (OBC) from the plotted graph.

Two methods are:

Method A: NAPA (National Asphalt Pavement Association)

One commonly used procedure is recommended by NAPA, which they suggest preparing the plot bitumen content Vs Marshall properties.

Then the optimum bitumen content is determined by:

A. The bitumen content which corresponds to the specification's median air void content (4 percent typically) of the specification. This is the optimum bitumen content.
B. 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.
C. 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.

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 and etc.
5. Compare the value of step 4 with criteria and acceptability that showed in table 3.4

For this Research Asphalt Institute procedure 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, on Marshall Criteria. As shown in table 3.4

Table 3.4 Suggested Marshall Criteria for Asphalt concrete pavement (ERA, Pavement Design Manual, 2002)

Total traffic (10^6 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	35*2		50*2		75*2	
Stability (KN)	3.5	-	6	-	7	-
Flow (mm)	2		2		2	4
Percent Air Void	3	5	3	5	3	5
Percent VFA	70	80	65	78	65	75
%VMA (4%, VTM, & nom max, particle size 19mm)	13	-	13	-	13	-

The standards table 3.4 indicated that the minimum stability of the Marshal Test at heavy traffic (75 blows) is 7 KN, and minimum flow is 2, 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.

3.11.3 Volumetric Properties of HMA by the Marshall Method.

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 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 %)

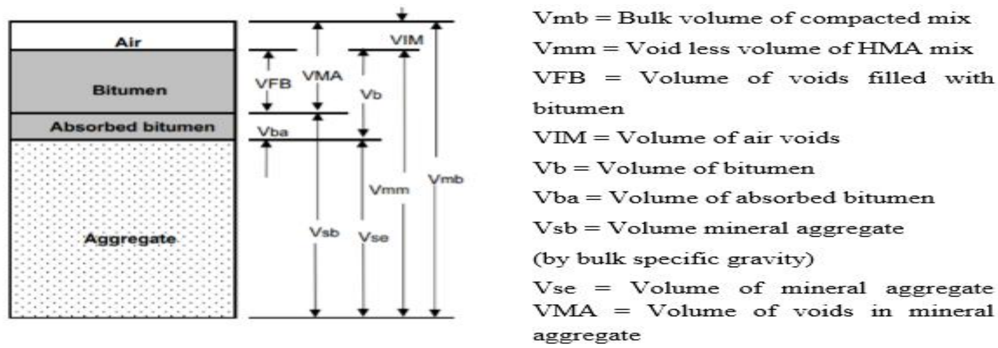

Figure 3.14 Phase Diagram of Bituminous Mix. **[Source 21]**

3.11.3.1 Theoretical maximum specific gravity (Gmm)

3.11.3.2 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. The bulk specific gravity (Gmb) of a computed mix is equal to:

$$G\,mm = \frac{A}{B-C} \quad \text{....................equation (3.3)}$$

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

3.11.3.3 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:

$$VA = 100 * \frac{(Gmm - Gmb)}{Gmm} \text{ ....equation (3.4)}$$

Where: VA= air void in compacted Mixtures

Gmm= Maximum specific gravity of paving mixtures.

Gmb=Bulk specific Gravity of compacted mixtures

3.11.3.4 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.

$$VA = 100 * \frac{(Gmm - Gmb)}{Gmm} \text{...............equation (3.5)}$$

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

3.11.3.5 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. Its 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:

$$VFA = 100 * \frac{(VMA - VA)}{VMA} \text{................equation (3.6)}$$

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

CHAPTER FOUR

RESULT AND DISCUSSION

4.1Introduction

Generally, this chapter includes the analysis and discussion of the result obtained from laboratory tests. The results of the study are discussed and in two main sections. The first section was 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 second section of the study, Reclaimed Asphalt Pavement (RAP) aggregate was replicated in place of crushed aggregate with control mix design gradation proportion by (10%, 20%, 30% 40%, and 50%) by weight of the total mix then laboratory tests were conducted. And 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. The final analysis of the test result of volumetric properties from each mix was analyzed by Regression statistical technique to determine the statistical equation that represents the relationship between volumetric properties and recycled percentage. Test result obtained for material quality, and the final result test is discussed under the subsequent section.

4.2: Material Property Test Results

4.2.1 Aggregate gradation for the study

Hot mix asphalt (HMA) is graded by the percentage of different size aggregate particles it contains. The aggregate gradation for the study was performed in two different parts. The first part of aggregate gradation is for the control mix with three different gradation proportions, as shown in table 4.1 and figure 4.1. And the second gradation is gradation blended with RAPA partial replacement, as shown in table 4.2 and figure 4.2. The detail aggregate gradation of the study was explained in **Appendix A.**

Table 4.1 Aggregate Gradation for control mix

Sieve size (mm	Aggregate Gradation Trail 1	Aggregate Gradation Trail 2	Aggregate Gradation Trail 3	Specification limit ASTM D-3515 (For nominal size of Aggregate is 19mm	
				Lower	Upper
25	100	100	100	100	100
19	94.4	93.2	93.7	90	100
12.5	82.4	77.8	80.2	-	-
9.5	71.9	66.7	68.9	56	80
4.75	53.7	47.8	50.5	35	65
2.36	38.6	32.7	35.6	23	49
1.18	28.9	24.5	26.7	-	-
0.6	21.0	17.7	19.4	-	-
0.3	14.0	11.7	12.8	5	19
0.15	9.3	7.9	8.6	-	-
0.075	6	5.0	5.5	2	8
Blending Proportion	0%, 25.6 % 36 % 38.4 %	0 %, 31 %, 37 %, 32 %	0 %, 28.8 %, 36 %, 35.18%		
Total	100 %	100 %	100%		

***Note**: the proportion is the percentage of Aggregate 1 (9-25mm), Aggregate 2 (2.36-9.5mm) and fine Aggregate contain crushed stone dust (filler) (0-2.36 mm) respectively*

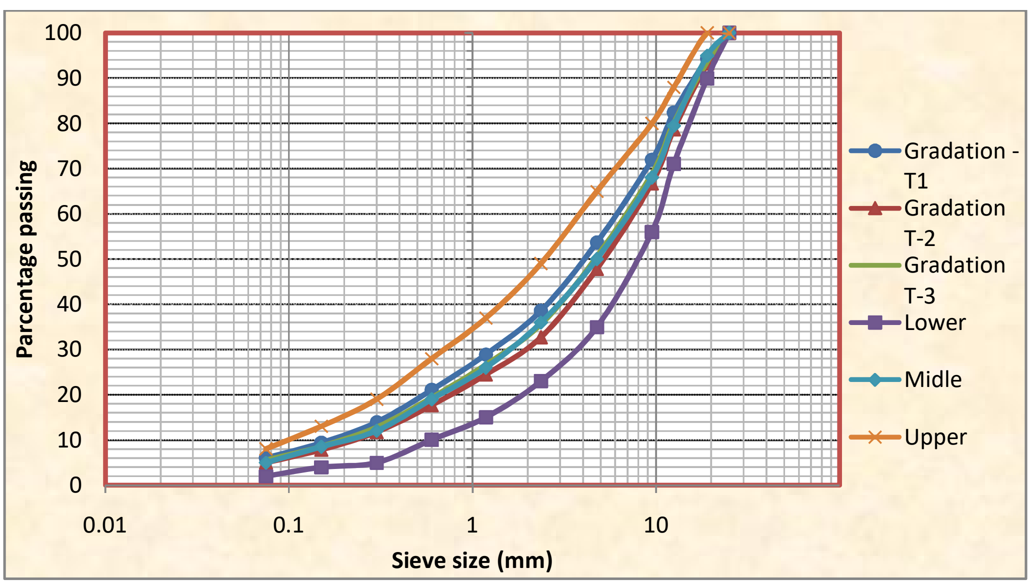

Figure 4.1 Aggregate Gradation for control mix

Table 4.2 Blending of Aggregate gradation with different percentage of RAPA

Sieve size (mm)	0% RAPA &Crushed Aggregate	10% RAPA	20% RAPA	30% RAPA	40% RAPA	50% RAPA	Specification limit ASTM D-3515 (For the nominal size of Aggregate is 19mm	
							Lower	Upper
25	100	100	100	100	100	100	100	100
19	93.2	93.1	93.0	92.9	92.9	92.8	90	100
12.5	78	77.8	77.6	77.4	77.2	77.0	-	-
9.5	65.3	66.0	66.7	67.4	68.2	68.9	56	80
4.75	46.2	47.3	48.4	49.6	50.7	51.8	35	65
2.36	33.3	33.8	34.4	34.9	35.4	36.0	23	49
1.18	25	24.9	24.8	24.7	24.6	24.4	-	-
0.6	18.1	17.7	17.2	16.8	16.4	15.9	-	-
0.3	12.2	12	11.9	11.8	11.7	11.5	5	19
0.15	8.0	8.0	8.1	8.2	8.3	8.3	-	-
0.075	5.0	5.0	5.0	5.0	5.0	5.0	2	8
Blending Proportions	0%, 31% 37% 32%	10%, 27.9%, 33.3%, 28.8%	20 %, 24.8 %, 29.6 %, 25.6 %	30 %, 21.7 %, 25.9 %, 22.4 %	40 %, 18.6%, 22.2 %, 19.2 %	50 %, 15.5%, 18.5 % 16.0 %		
Total	100 %	100 %	100%	100 %	100%	100%		

Note*: the blending proportions are the percentage of RAPA, Aggregate 1 (9-25mm), Aggregate 2 (2.36-9.5mm), and fine Aggregate contain crushed stone dust (filler) (0-2.36 mm) respectively.*

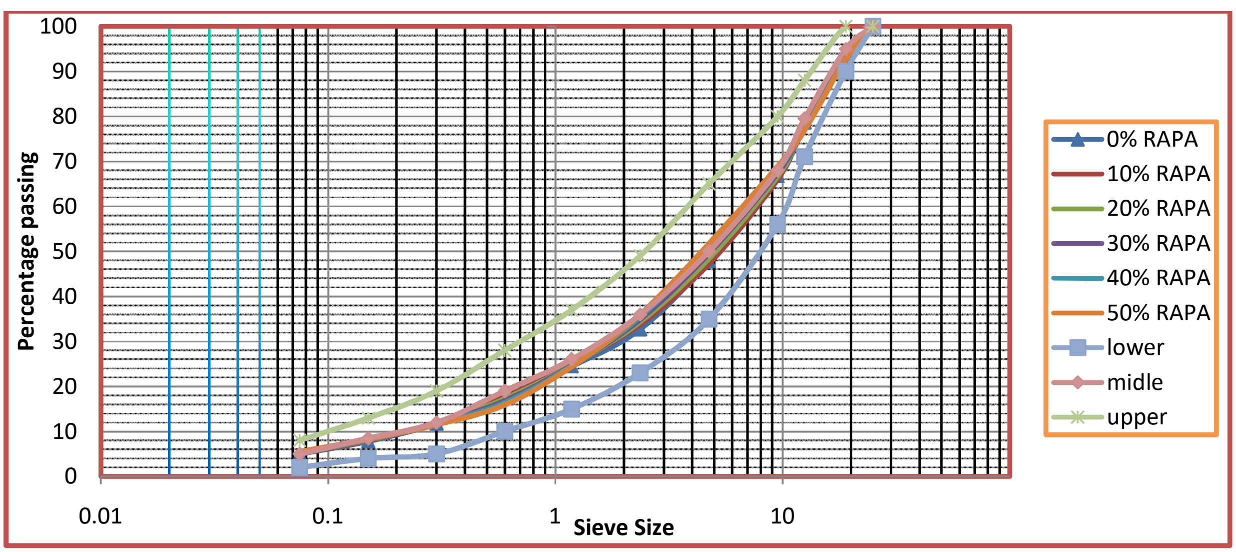

Figure 4.2 Blended aggregate gradation of RAPA & Crushed Aggregate

4.2.2 Aggregate quality test result

To investigate physical the physical properties of aggregates and their quality (suitability) in road construction, the various tests were conducted, and the test result is presented in Table 4.3. The specific gravity of aggregate was determined for each percentage replacement of RAPA in crushed aggregate with each size proportion of aggregate (9-25mm, 2.36-9.5mm, and 0-2.36mm), which is very important for the determination of VMA and VFA of HMA. The detail work of the aggregate quality test was shown in **Appendix B**

Table 4.3 Physical properties of RAPA and crushed Aggregate for the study

Test	Test method	Result						Specification
		0% RAP	10% RAP	20% RAP	30% RAP	40% RAP	50% RAP	
Bulk dry S.G (9-25mm)	AASHTO T 85-91	2.618	2.542	2.510	2.573	2.517	2.608	--
Bulk dry S.G (2.36-9.5mm)		2.612	2.538	2.508	2.532	2.510	2.501	--
Bulk dry S.G (0-2.36mm)		2.609	2.525	2.503	2.512	2.494	2.491	--
Bulk SSD S.G (9-25mm		2.652	2.576	2.554	2.621	2.565	2.659	--
Bulk SSD S.G (2.36-9.5mm)		2.648	2.573	2.553	2.579	2.559	2.551	--
Bulk SSD S.G (0-2.36mm)		2.653	2.568	2.551	2.559	2.543	2.540	--
Apparent S.G (9-25mm)		2.710	2.631	2.625	2.703	2.645	2.750	--
Apparent S.G (2.36-9.5mm)		2.708	2.629	2.625	2.658	2.639	2.632	--
Apparent S.G (0-2.36mm)		2.728	2.640	2.629	2.636	2.621	2.620	--
Water absorption (9-25mm)	BS 812, Part 2	1.3	1.3	1.7	1.9	1.92	1.98	< 2
Water absorption (2.36-9.5mm)		1.4	1.4	1.8	1.9	1.94	1.99	< 2
Water absorption (0-2.36mm)		1.6	1.73	1.9	1.9	1.95	1.99	< 2
Flakiness Index	BS 812 Part 105	**CA**	**RAPA**					<45
		20.22	23.7					
Aggregate Crushing Value (ACV),%	BS:812 Part 110	14.70	15.91					<25
Aggregate Impact Value (AIV)%	BS:812 Part 112	6.32	17.05					<25
Los Angeles Abrasion (LAA),%	AASHTO T- 96	11.58	14.82					<35

4.2.3 Bitumen quality test and result

For the performance of this study, the series of bitumen quality test was conducted before the mix design was started. These tests included penetration, ductility, softening point, and specific gravity, and the test result was indicated in Table 4.4.

Table 4.4 Bitumen quality test result

Test	Test method	Result	Recommended specification As ERA for bitumen 60/70
Penetration (25 C^0)	AASHTO T 49	65	60-70
Ductility (25 C^0)	AASHTO T 51	108	Min 50
Softening point (C^0)	AASHTO T 53	47.2	46-56
Specific Gravity25 C^0	ASTM D-70-97	1.024	---
Flashing point (C^0)	ASTM D-92	325	Min 232

The result of the bitumen quality test result presented in table 4.4 was met the standard specification of selected bitumen of 60/70 penetration grade according to ERA design standard specification. The detail work of the bitumen quality test was explained in **appendix C.**

4.2.4 Crushed stone dust filler properties

The filler used for the current study was crushed stone dust powder. The laboratory tests have been conducted in order to evaluate the physical properties of crushed stone dust filler, which consists of the apparent specific gravity and plasticity index. The apparent specific gravity was conducted according to ASTMD-854, using the water Pycnometer method. Table 4.5 illustrates the physical properties of crushed stone dust filler.

Table 4.5 Physical properties crushed stone dust filler

S/No	Test description	Test Method	Result	ERA Design standard specification (2002)
1	Apparent specific gravity (Kg/m^3)	ASTM D-854	2.548	N/A
2	Plasticity Index (PI)	ASTMD-423	NP	≤ 4

4.3 Marshall Test Result Discussion and Analysis

4.3.1 Marshal test result

The result of asphalt mix laboratory work had been obtained and analyzed in order to achieve the research objectives. The result of Marshall Properties of specimens prepared with three varying proportion of aggregate (trail 1, trial 2 and trial 3) for control mix (0% RAP) and with different proportion of (10%, 20%, 30%, 40%, and 50%) of RAP aggregate and crushed Aggregate. A total of 120 specimens with each weight of 1200 grams were prepared using five different bitumen contents (4%, 4. 5%, 5%, 5.5%, and 6%) of the total weight in order to determine optimum bitumen content for each mix design. From 120 specimens prepared, 45 specimens were for control mix, and 75 specimens were for RAP proportion in order to determine optimum bitumen content of each RAP proportion and Recommend the maximum using of RAP aggregate in Hot-mix Asphalt. Table 4.6, 4.7, and 4.8 indicated the properties of the mixture at varying bitumen content for a mix with different Proportion of aggregate gradation and fillers for trial 1, trial 2, and trial 3 respectively to determine design gradation and optimum bitumen content for next RAPA replacement. And table 4.11, 4.12, 4.13, 4.14 and 4.15 indicate the properties of the mixture at their various bitumen contents for mix with different proportions of (10%, 20%, 30%, 40%, and 50%) RAPA based on control mix gradation. Further details are presented in **Appendix (E).** According to (ERA, pavement design Manual,(2002) Marshall design criteria for heavy traffic, Minimum stability must be 7KN at 60 C^0, flow value must be ranged between 2-4mm, 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 19mm nominal particle size is 13%.

4.3.1.1 Marshal test result of Control mix

Conventional (control) mix was prepared with zero percent RAP aggregate and with three different aggregate gradation to determine the optimum bitumen content and design gradation for the study. The conventional mix was used to control the other RAPA replacement for this study. The Marshall Test result of control mix was presented as follows.

Table 4.6 Marshall Properties of Asphalt mixture trail 1 for control mix

% of Bitumen by weight of the total mix	Trail No	Gmb	VA (%)	VMA (%)	VFA (%)	Pick load (KN)	Stability (KN)	Flow (mm
4	1	2.318	5.6	14.8	62.2	9.59	8.3	2.58
	2	2.322	5.5	14.7	62.8	9.33	8.2	2.54
	3	2.316	5.7	14.9	61.7	9.73	8.6	2.57
Ave.		2.319	5.6	14.8	62.2	9.55	8.4	2.56
4.5	1	2.329	4.5	14.9	69.9	10.41	9.1	2.59
	2	2.327	4.6	15.0	69.5	11.15	9.7	2.61
	3	2.354	3.5	14.0	75.2	11.20	9.9	2.63
Ave.		2.336	4.2	14.6	71.5	10.92	9.6	2.61
5.0	1	2.341	3.8	14.9	74.8	11.23	10.1	2.98
	2	2.333	4.1	15.2	73.2	11.82	10.5	3.04
	3	2.339	3.8	14.9	74.5	12.47	11.1	3.11
Ave.		2.338	3.9	15.0	74.2	11.84	10.6	3.04
5.5	1	2.331	3.8	15.7	75.9	10.98	9.8	3.18
	2	2.331	3.8	15.7	75.8	10.78	9.6	3.22
	3	2.329	3.9	15.8	75.4	10.17	9.1	3.37
Ave.		2.330	3.8	15.7	75.7	10.64	9.5	3.26
6.0	1	2.334	2.7	16.0	83.0	9.68	8.8	3.43
	2	2.329	2.9	16.2	81.9	9.53	8.6	3.47
	3	2.336	2.6	16.0	83.6	8.60	7.9	3.46
Ave.		2.333	2.8	16.1	82.9	9.3	8.4	3.45

Where, Gmb=bulk specific gravity, VA=Air void, VMA=Void in mineral aggregate, VFA=Void filled with asphalt, BC=bitumen content. Table 4.6 show that Marshall Test result of mixture with aggregate gradation of (25.6%, 36% and 38.4%) of Coarse aggregate, intermediate aggregate and fine with filler respectively and the corresponding values of Marshall Properties such as stability, flow, void in mineral aggregate, air void, bulk specific gravity and void filled with bitumen at different bitumen contents.

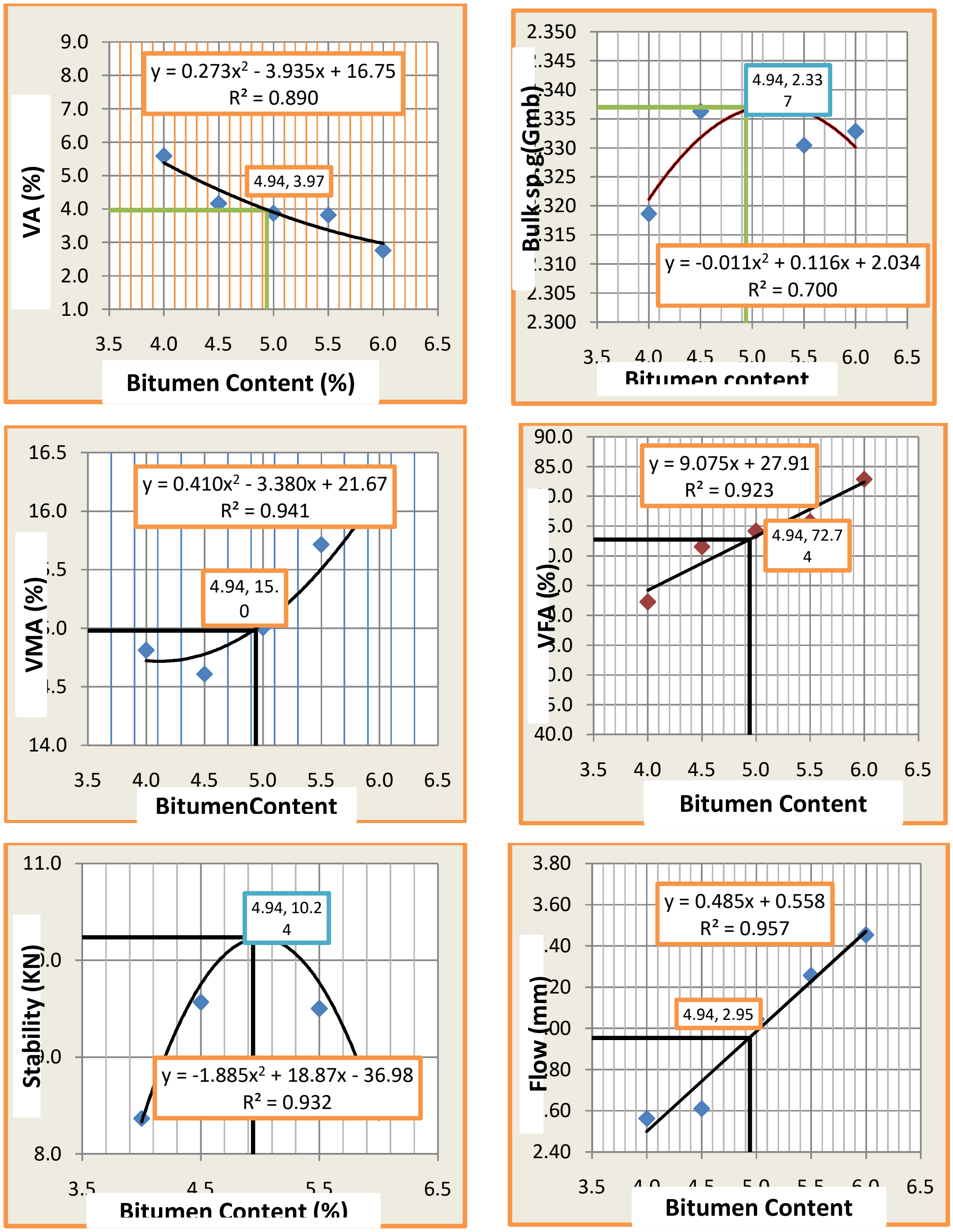

Figure 4.3 OBC and properties of HMA trail 1 for the control mix

Figure 4.3 shows the relationship between the bitumen content and hot mix properties by Marshall Method. From this figure, air void is decreasing with increase bitumen content, bulk density, and stability increased, and then decrease at pick point with increase the bitumen content whereas flow and void filled with bitumen were increased with increase the bitumen content. In addition, void in mineral aggregate (VMA) decrease up to minimum value then increase as bitumen content increase. The optimum bitumen content of mix design was determined according to Asphalt instate procedure; the OBC was the average value of bitumen content at maximum stability, maximum density, and at 4% air void, which is presented in table 4.9. Using this procedure, the Optimum Bitumen Content was found equal to 4.94 by weight of the total mix. The summary of mixture properties at optimum bitumen content is presented in Table 4.10

Table 4.7 Marshall Properties of Asphalt mixture trail 2 for control mix

% of BC by weight of the total mix .	Trial No	Gmb	VA (%)	VMA (%)	VFA (%)	Pick load (KN)	Stability (KN)	Flow (mm
4	1	2.300	6.2	15.5	59.8	10.47	8.9	2.58
	2	2.295	6.5	15.7	58.9	10.26	8.7	2.65
	3	2.305	6.0	15.3	60.6	11.12	9.5	2.61
Average		2.300	6.2	15.5	59.8	10.62	9.0	2.61
4.5	1	2.328	4.7	14.9	68.3	11.53	9.8	2.71
	2	2.322	5.0	15.1	67.2	12.38	10.5	2.67
	3	2.328	4.7	14.9	68.3	14.63	12.6	2.56
Average		2.326	4.8	15.0	67.9	12.85	11.0	2.65
5	1	2.349	3.7	14.6	74.4	14.82	12.6	3.06
	2	2.331	4.5	15.3	70.7	15.37	12.7	3.23
	3	2.342	4.0	14.8	73.0	16.29	14.1	3.03
Average		2.341	4.1	14.9	72.7	15.50	13.1	3.11
5.5	1	2.349	3.6	15.1	75.9	14.86	12.5	3.21
	2	2.333	4.3	15.6	72.7	14.51	12.3	3.32
	3	2.341	3.9	15.3	74.3	14.07	11.9	3.34
Average		2.338	3.9	15.3	74.3	14.48	12.2	3.29
6	1	2.343	2.4	15.7	84.7	12.00	10.6	3.35
	2	2.333	2.8	16.1	82.4	12.13	10.5	3.39
	3	2.339	2.6	15.9	83.7	12.08	10.4	3.31
Average		2.338	2.6	15.9	83.6	12.1	10.5	3.35

Where, Gmb=bulk bulk specific gravity, VA=Air void, VMA=Void in mineral aggregate, VFA=Void filled with asphalt, BC=bitumen content. Table 4.7 presented the Marshall Test result of the mixture with an aggregate gradation of trail 2 (31%, 37%, and 32%) of Course aggregate, intermediate aggregate and fine with filler respectively, and the corresponding values of Marshall Properties for control mix.

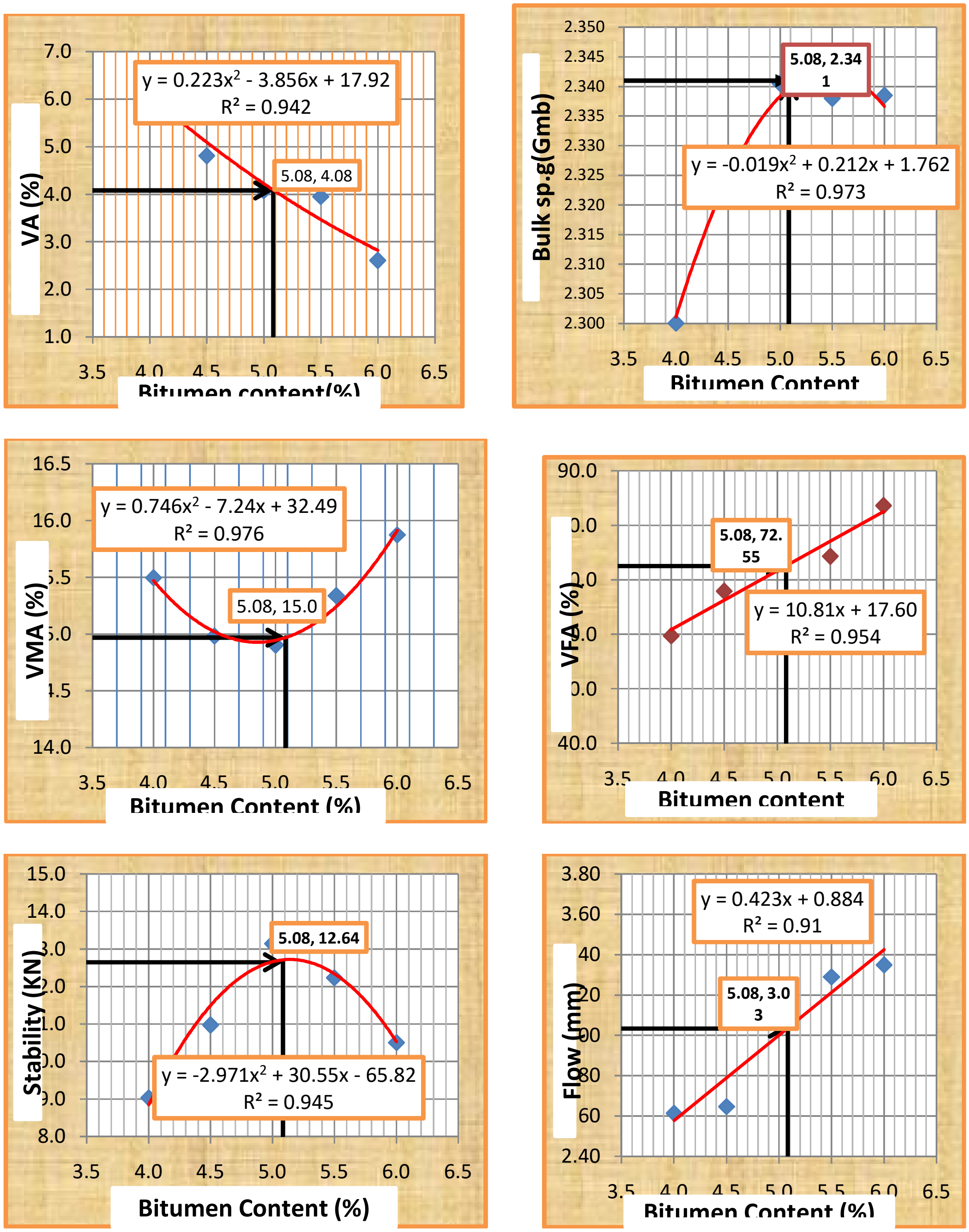

Figure 4.4 OBC and properties of HMA trial 2 for the control mix

Figure 4.4 shows the relationships between bitumen content and mix properties for trial 2 for the control mix. The Optimum Bitumen Content was found equal to 5.08 by the weight of the total mix. The summery of mixture properties at optimum bitumen content is presented in Table 4.10

Table 4.8 Marshall Properties of Asphalt mixture of trial 3 for control mix

% of BC By weight of the total mix	Trial No	Gmb	VA (%)	VMA (%)	VFA (%)	Pick load (KN)	Stability (KN)	Flow (mm)
4	1	2.284	7.2	16.1	55.1	10.46	8.6	2.53
	2	2.303	6.4	15.4	58.1	10.45	8.7	2.58
	3	2.306	6.3	15.3	58.6	10.58	8.9	2.61
Ave.		2.298	6.7	15.6	57.2	10.50	8.7	2.57
4.5	1	2.320	5.7	15.2	62.6	11.41	9.7	2.62
	2	2.306	6.2	15.7	60.2	11.71	9.9	2.64
	3	2.329	5.3	14.9	64.2	12.43	10.7	2.58
Ave.		2.318	5.8	15.3	62.3	11.85	10.1	2.61
5.0	1	2.342	4.2	14.8	71.4	12.76	10.9	2.89
	2	2.336	4.5	15.1	70.1	13.88	11.8	3.08
	3	2.334	4.6	15.1	69.8	13.41	11.7	3.01
Ave.		2.337	4.4	15.0	70.4	13.35	11.5	2.99
5.5	1	2.328	3.9	15.8	75.2	13.60	11.5	3.25
	2	2.337	3.5	15.5	77.1	14.29	12.3	3.29
	3	2.335	3.6	15.5	76.7	13.41	11.4	3.35
Ave.		2.333	3.7	15.6	76.3	13.77	11.7	3.30
6.0	1	2.330	3.4	16.2	79.0	11.85	10.2	3.39
	2	2.331	3.4	16.2	79.1	11.67	10.1	3.42
	3	2.328	3.5	16.3	78.5	11.06	9.6	3.48
Ave.		2.329	3.4	16.2	78.9	11.5	10.0	3.43

Where, Gmb=bulk bulk specific gravity, VA=Air void, VMA=Void in mineral aggregate, VFA=Void filled with asphalt, BC=bitumen content. Table 4.8 presented the Marshall Test result of the mixture with the aggregate gradation of trail 3 (28.8%, 36%, and 35.18%) of Course aggregate, intermediate aggregate and fine with filler respectively, and the corresponding values of Marshall Properties for control mix.

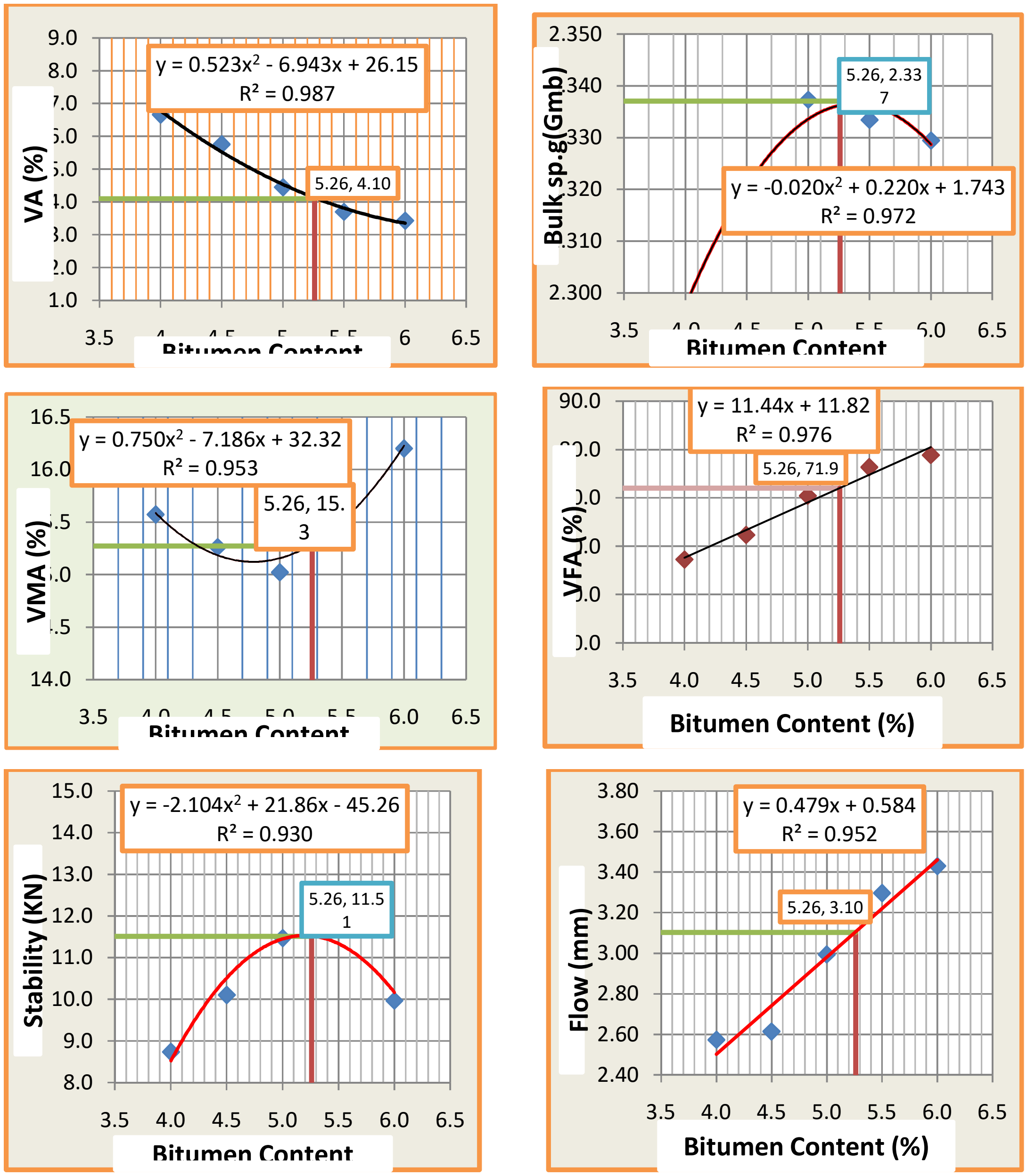

Figure 4.5 OBC and properties of HMA trial 2 for the control mix

Figure 4.5 shows the relationships between bitumen content and mix properties for trial 3 (28.8%, 36%, and 35.18%) of the course, intermediate and fine aggregate proportion respectively for the control mix. The Optimum Bitumen Content was found equal to 5.26 by the weight of the total mix. The general trend curve represents the relationship between different bitumen contents and Marshall Properties. The summery of mixture properties at optimum bitumen content is presented in Table 4.10

4.3.1.1.1 Determination of Optimum bitumen Content for Control mix (0% RAPA)

The optimum bitumen content was determined according to Asphalt institute [32] procedure that was suggested that the optimum bitumen content was determined from the average value of bitumen content at maximum stability, maximum bulk specific gravity, and bitumen content at 4% air void. From table 4.6 to 4.8 and Figure 4.3 to 4.5, the optimum bitumen content of each mix was determined. The optimum bitumen content of three trails obtained was presented in table 4.9. And the detail procedure of OBC determination is explained in **Appendix F**

Table 4.9 Optimum bitumen content for the control mix

Optimum Bitumen Content for control mix				
S/No	Properties	Selected bitumen content (BC)		
		Trail 1	Trail 2	Trail 3
1	Maximum stability (KN) (A)	5	5	5.5
2	Maximum bulk specific gravity (kg/m^3) (B)	5	5	5
3	4 percent Air void (C)	4.83	5.25	5.29
4	Average value =(A+B+C)/3	4.94	5.08	5.26

For determination of optimum bitumen content first, the bitumen content at 4 percent air void, at maximum stability, and maximum bulk density was determined, then adding those bitumen values and determine the average value of bitumen content. That bitumen content is then used to determine the values of Marshall Stability, flow value, Air Void (VA), Void in Mineral Aggregate (VMA), Void filled with asphalt (VFA) and Bulk specific gravity (Gmb) of mix which presented on Figure 4.3 to 4.5 for trial 1 to trial 3 respectively. Each value obtained was compared to standard specification and Marshall Criteria, and if all values are within the specification range, the bitumen content is the Optimum bitumen content. According to Asphalt institute (2003). Based on the result, the optimum bitumen content for the control mix from trial 1 to trial 3 is 4.94, 5.08, and 5.26, respectively. Table 4.10 shows the value of Marshall Properties of asphalt mixture for three different aggregate gradations of trial 1, trial 2, and trial 3. From three design mix gradation, the Optimum bitumen content was determined by comparing each property with standard specification.

Table 4.10 Marshall Properties at OBC for control and specification limit

Marshall properties	Marshall result of control mix			ERA (2002) specification limit		status
	Trail 1	Trail 2	Trail 3	Lower	Upper	
Optimum bitumen (%)	4.94	**5.08**	5.26	4	10	Ok
Stability (KN)	10.24	**12.64**	11.51	Min 7	--	Ok
Flow value (mm)	2.94	**3.03**	3.10	2	4	Ok
VMA (%)	15	**15**	15.3	Min 13	--	Ok
VFA (%0	72.74	**72.55**	71.9	65	75	Ok
Air Void (%)	3.97	**4.08**	4.10	3	5	Ok
Bulk specific Gravity	2.337	**2.341**	2.337	--	--	Ok

Table 4.10 Presented optimum bitumen content corresponding to Marshall Properties and comparison with standard specification. From table 4.10 presented the mix properties of first trial mix with proportion of (25.6%, 36 and 38.4%) of course (9-25mm), intermediate (2.36-9.5mm) and fine (0-2.36mm) aggregate size respectively at (4.94 %) Optimum bitumen content are stability, flow, VMA, VFA, Air void and bulk specific gravity results are (10.24, 2.94,15,72.74,3.97 and 2.337) respectively as shown in table 4.10. The value obtained was within speciation range and greater than minimum value based on specified by the standard as given table 3.4 for heavy traffic. For the second trail mix with (31%, 37% and 32%) of Coarse (9-25mm), intermediate (2.36-9.5mm) and fine (0-2.36mm) aggregate respectively. The Marshall properties at optimum bitumen content of 5.08 are stability, flow value, Void in mineral aggregate (VMA), Void filled with Asphalt (VFA), Air void (VA), and bulk specific gravity (Gmb) results are (12.64, 3.03, 15, 72.55, 4.08 and 2.341) respectively. When the result obtained was compared to the standard specification of Marshall Criteria, all values are meet the entire specification limit. And also, the third trial mix with a proportion of (28.8%, 36%, and 35.18%) of Course (9-25mm), intermediate (2.36-9.5mm), and fine (0-2.36mm) aggregate size respectively. The value of mix property was presented in table 4.10 from this table stability, flow value, void in mineral aggregate (VMA), void filled with asphalt (VFA), air void (VA) and bulk specific gravity at 5.26 optimum bitumen contents are (11.5, 3.10, 15.3, 71.9,4.10 and 2.337) respectively. As compared with standard specification presented in table 3.4, all values are meeting the specified standard specification.

4.3.1.1.1 Selecting optimum bitumen content from trails for control mix

Table 4.10 Illustrates Marshall Properties of HMA with corresponding to three different proportions of aggregate gradation. The OBC of three varying gradation mixes is 4.94, 5.08, and 5.26 for trial 1, trial 2, and trial 3, respectively. The Marshall Stability of a mixture of trial1, trial 2, and trial 3 aggregate gradations were 10.24, 12.64, and 11.51 KN respectively in which all results are within specification. And also, the flow value of all mixes corresponding to OBC was within specification range, which is 2-4mm. From the above the result all mix properties with three different gradation was a meet specification that suggested by ERA Pavement design manual (2002). From the result presented in Table 4.10 comparing of all three mixes of different gradation and it's was found that the mix of trail 2 (31%, 37%, and 32%) of course (9-25mm), intermediate (2.36-9.5mm) and fine (0-2.36mm) proportion sample indicate the higher stability and maximum bulk specific gravity than the other mixture. So the OBC and corresponding to other Marshall properties of this mix gradation were selected as control mix and for RAP replacement.

4.3.1.2 Marshal test result of RAP aggregate replacement of crushed aggregate

Marshall Test results of HMA mixed with different RAPA percentage was presented in the following tables

Table 4.11 Marshall Properties of Asphalt mixture contain 10% RAPA. And 90 % CA

% of Bitumen by weight of the total mix	Trail No	Gmb	VA (%)	VMA (%)	VFA (%)	Pick load (KN)	Stability (KN)	Flow (mm
4.0	1	2.249	6.1	14.8	59.0	10.28	8.9	2.54
	2	2.218	7.4	16.0	53.8	10.73	9.1	2.61
	3	2.253	5.9	14.7	59.7	10.35	8.8	2.78
Average		**2.240**	**6.5**	**15.2**	**57.5**	**10.46**	**8.9**	**2.64**
4.5	1	2.261	5.2	14.8	65.2	12.69	11.0	2.74
	2	2.246	5.8	15.4	62.3	12.09	10.2	2.72
	3	2.260	5.2	14.9	65.0	11.03	9.5	2.95
Average		**2.255**	**5.4**	**15.0**	**64.1**	**11.94**	**10.2**	**2.80**
5.0	1	2.291	3.3	14.2	76.4	12.30	10.4	3.21
	2	2.264	4.5	15.2	70.5	12.21	10.3	2.93
	3	2.268	4.3	15.0	71.2	11.72	10.2	3.28
Average		**2.274**	**4.0**	**14.8**	**72.7**	**12.08**	**10.3**	**3.14**
5.5	1	2.300	2.0	14.3	86.2	11.12	9.4	3.34
	2	2.268	3.3	15.5	78.5	11.21	9.7	3.28
	3	2.240	4.5	16.5	72.5	10.22	8.8	3.44
Average		2.269	3.3	15.4	79.1	10.85	9.3	3.35
6.0	1	2.256	2.3	16.3	85.8	9.25	7.8	3.81
	2	2.257	2.3	16.3	86.0	9.53	8.1	4.22
	3	2.279	1.3	15.5	91.4	8.30	7.2	4.23
Average		**2.264**	**2.0**	**16.0**	**87.7**	**9.0**	**7.7**	**4.09**

Where, Gmb=bulk bulk specific gravity, VA=Air void, VMA=Void in mineral aggregate, VFA=Void filled with asphalt, BC=bitumen content. Table 4.11 presented the Marshall Test result of the mixture with 10% RAP aggregate and 90% Crushed Aggregate.

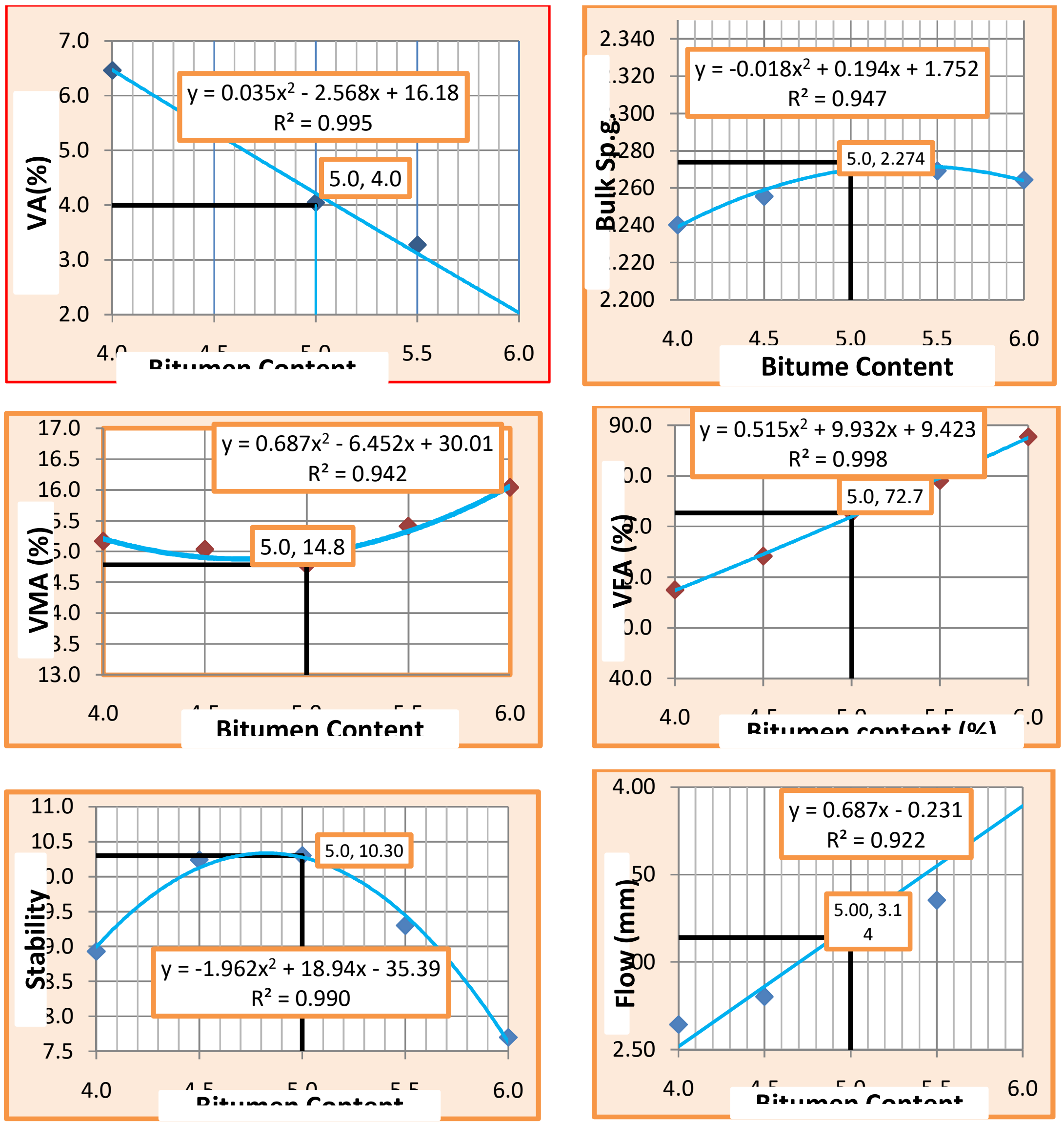

Figure 4.6 OBC and properties of the mixture with 10% RAPA and 90% CA

Figure 4.6 illustrates the relationships between bitumen content and mix properties contain 10% RAPA and 90% CA. The Optimum Bitumen Content was found equal to 5.0 by the weight of the total mix. The general trend curve represents the relationship between different bitumen contents and Marshall Properties. The summary of mixture properties at optimum bitumen content is presented in Table 4.17

Table 4.12 Marshall Properties of Asphalt Mixture contain 20% RAPA and 80% CA

% Bitumen content by weight of the total mix	Trail No	Gmb	VA (%)	VMA (%)	VFA (%)	Pick load (KN)	Stability (KN)	Flow (mm)
4.0	1	2.245	4.4	14.0	68.9	10.28	8.9	2.85
	2	2.202	6.2	15.7	60.4	9.73	8.6	3.29
	3	2.225	5.2	14.8	64.8	10.31	9.7	3.21
Average		**2.224**	**5.3**	**14.8**	**64.7**	**10.11**	**8.7**	**3.12**
4.5	1	2.265	3.1	13.7	77.3	10.78	9.6	3.42
	2	2.191	6.3	16.6	61.9	11.27	9.8	2.81
	3	2.274	2.8	13.4	79.5	10.09	9.9	3.39
Average		**2.243**	**4.1**	**14.6**	**72.9**	**11.05**	**9.8**	**3.21**
5.0	1	2.242	4.1	15.0	73.0	10.89	9.5	3.26
	2	2.273	2.7	13.9	80.3	11.27	9.8	3.37
	3	2.238	4.2	15.2	72.2	10.33	9.2	3.48
Average		**2.251**	**3.7**	**14.7**	**75.2**	**10.83**	**9.5**	**3.37**
5.5	1	2.291	1.9	13.6	86.3	10.33	9.1	3.45
	2	2.252	3.5	15.1	76.6	10.92	9.6	3.52
	3	2.207	5.5	16.8	67.4	10.05	8.9	3.81
Average		**2.250**	**3.6**	**15.2**	**76.8**	**10.43**	**9.2**	**3.59**
6.0	1	2.239	3.9	16.0	75.5	9.48	8.1	3.92
	2	2.240	3.9	16.0	75.6	9.08	7.9	4.01
	3	2.270	2.6	14.9	82.4	8.71	7.5	4.12
Average		**2.250**	**3.5**	**15.7**	**77.8**	**9.1**	**7.8**	**4.02**

Where, Gmb=bulk bulk specific gravity, VA=Air void, VMA=Void in mineral aggregate, VFA=Void filled with Asphalt, BC=bitumen content RAPA=Reclaimed Asphalt Pavement aggregate and CA=crushed aggregate. Table 4.12 presented the Marshall Test results of mixture properties mixed with 20% RAPA and 80% Crushed Aggregate. The proportion of aggregate gradation of this mixture was presented in table 4.2. The replacement RAP aggregate in place of crushed aggregate was performed based selected design gradation of control mix which is trial 2 that presented in table 4.10

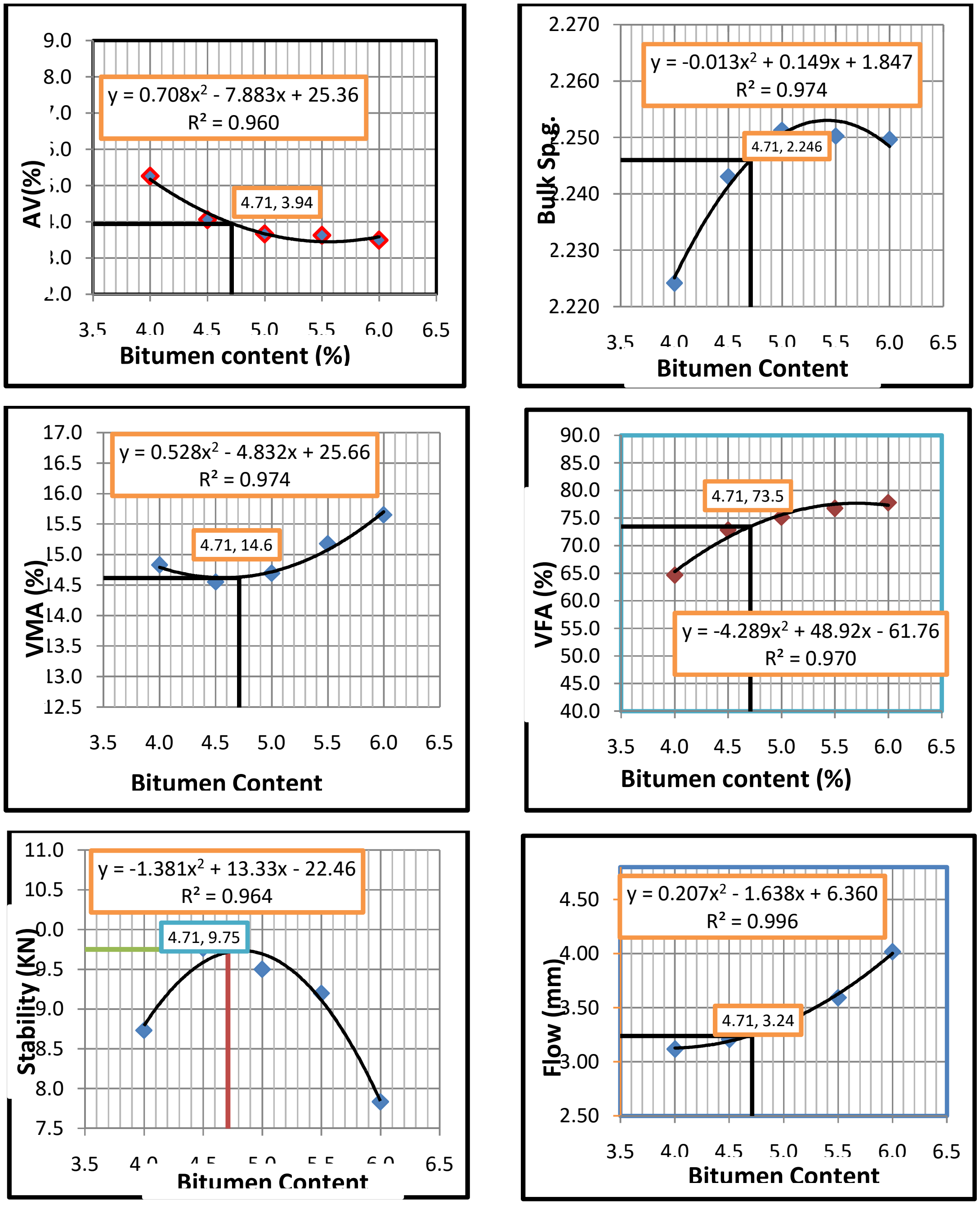

Figure 4.7 OBC and properties of the mixture with 20% RAPA and 80% CA

Figure 4.7 shows the relationships between optimum bitumen content and mix properties contain 20% RAPA and 80% CA. The Optimum Bitumen Content was found equal to 4.71 by weight of the total mix. The summery of mixture properties at optimum bitumen content is presented in Table 4.17

Table 4.13 Marshall Properties of Asphalt mixture contain 30% RAPA and 70% CA

% of Bitumen content by weight of the total mix	Trial No	Gmb	VA (%)	VMA (%)	VFA (%)	Pick load (KN)	Stability (KN)	Flow (mm)
4.0	1	2.187	8.4	17.3	51.1	7.84	7.2	3.21
	2	2.289	4.2	13.4	68.7	8.56	7.7	3.22
	3	2.288	4.2	13.5	68.6	8.36	7.5	3.25
Average		**2.255**	**5.6**	**14.7**	**62.8**	**8.25**	**7.5**	**3.23**
4.5	1	2.267	4.2	14.7	71.2	9.36	8.6	3.29
	2	2.271	4.1	14.5	72.1	9.82	8.9	3.39
	3	2.282	3.6	14.1	74.7	9.77	8.7	3.45
Average		**2.273**	**4.0**	**14.5**	**72.7**	**9.65**	**8.7**	**3.38**
5.0	1	2.270	3.4	15.1	77.3	9.97	8.9	3.57
	2	2.263	3.7	15.3	75.8	10.67	9.4	3.49
	3	2.274	3.2	14.9	78.2	10.14	9.1	3.59
Average		**2.269**	**3.5**	**15.1**	**77.1**	**10.26**	**9.1**	**3.55**
5.5	1	2.268	3.1	15.6	80.1	8.81	7.7	3.85
	2	2.266	3.1	15.6	79.9	9.75	8.5	3.82
	3	2.273	2.9	15.4	81.4	9.22	8.1	3.81
Average		**2.269**	**3.0**	**15.5**	**80.5**	**9.26**	**8.1**	**3.83**
6.0	1	2.280	1.7	15.6	88.9	9.32	8.3	3.41
	2	2.259	2.6	16.3	83.9	7.97	6.9	4.54
	3	2.238	3.5	17.1	79.3	7.61	6.5	4.12
Average		**2.259**	**2.6**	**16.3**	**84.1**	**8.3**	**7.2**	**4.02**

Where, Gmb=bulk bulk specific gravity, VA=Air void, VMA=Void in mineral aggregate, VFA=Void filled with asphalt, BC=bitumen content RAPA=Reclaimed Asphalt Pavement Aggregate and CA=crushed aggregate. Table 4.13 presented the Marshall Test results of mixture properties mixed with 30% RAPA and 70% Crushed Aggregate. The proportion of aggregate gradation of this mixture was presented in table 4.2 the replacement RAP aggregate in place of crushed aggregate was performed based selected design gradation of control mix which is trial 2 that presented in table 4.10

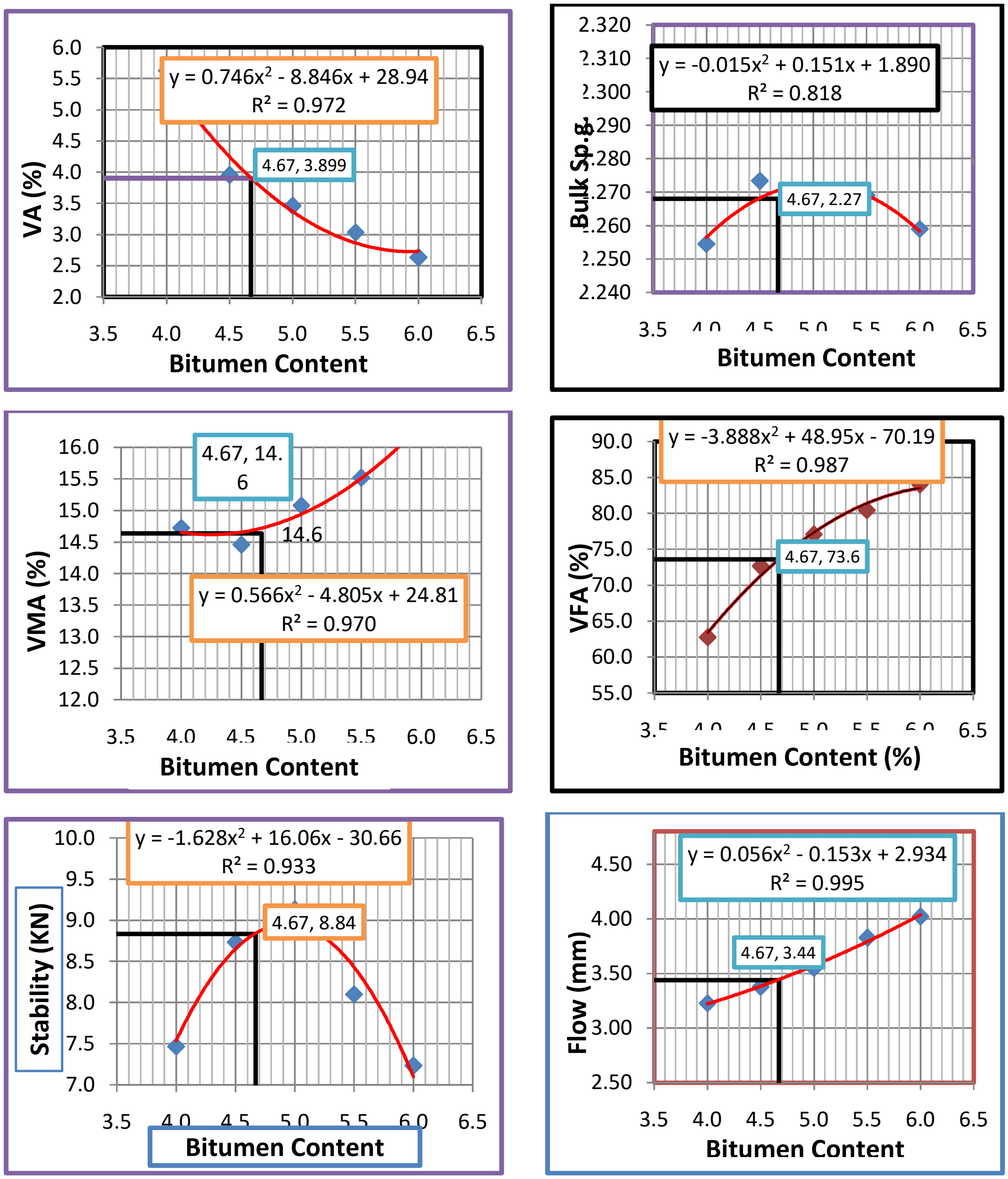

Figure 4.8 OBC and properties of the mixture with 30% RAPA and 70% CA

Figure 4.8 shows the relationships between optimum bitumen content and mix properties contain 30% RAPA and 70% CA. The Optimum Bitumen Content was found equal to 4.67 by the weight of the total mix. The general trend curve represents the relationship between different bitumen contents and Marshall Properties. The summary of mixture properties at optimum bitumen content is presented in table 4.17

Table 4.14 Marshall Properties of Asphalt mixture contain 40% RAPA and 60% CA

% of Bitumen content by weight of the total mix	Trial No	Gmb	VA (%)	VMA (%)	VFA (%)	Pick load (KN)	Stability (KN)	Flow (mm)
4.0	1	2.225	4.9	14.8	66.7	8.65	7.3	3.51
	2	2.271	2.9	13.0	77.4	8.96	7.6	3.61
	3	2.238	4.4	14.3	69.5	8.59	7.3	3.68
Average		2.245	4.1	14.0	71.2	8.74	7.4	3.60
4.5	1	2.303	2.9	12.3	76.5	8.51	7.4	3.90
	2	2.278	3.9	13.2	70.4	8.62	7.5	3.82
	3	2.306	2.7	12.2	77.5	8.83	7.6	3.91
Average		2.296	3.2	12.9	74.8	8.65	7.5	3.88
5.0	1	2.284	2.6	13.5	81.0	8.43	7.3	3.95
	2	2.296	2.1	13.0	84.2	8.71	7.4	3.98
	3	2.294	2.1	13.1	83.8	8.25	7.1	3.92
Average		2.291	2.2	13.2	83.0	8.46	7.3	3.95
5.5	1	2.296	1.6	13.4	88.0	7.68	6.8	4.01
	2	2.281	2.3	14.0	83.7	7.52	6.7	4.12
	3	2.292	1.8	13.6	86.9	7.81	6.9	4.21
Average		2.290	1.9	13.7	86.2	7.67	6.8	4.11
6.0	1	2.280	3.1	14.5	78.7	7.39	6.5	4.35
	2	2.291	0.0	11.7	100.3	7.59	6.6	4.41
	3	2.284	0.2	11.9	98.6	7.30	6.4	4.34
Average		2.285	1.1	12.8	92.5	7.4	6.5	4.37

Where, Gmb=bulk bulk specific gravity, VA=Air void, VMA=Void in mineral aggregate, VFA=Void filled with asphalt, BC=bitumen content RAPA=Reclaimed Asphalt Pavement Aggregate and CA=crushed aggregate. Table 4.14 presented, the Marshall Test results of mixture properties mixed with 40% RAPA and 60% Crushed Aggregate. The proportion of aggregate gradation of this mixture was presented in table 4.2. The replacement RAPA in place of crushed aggregate was performed based selected design gradation of control mix which is trial 2 that presented in table 4.10

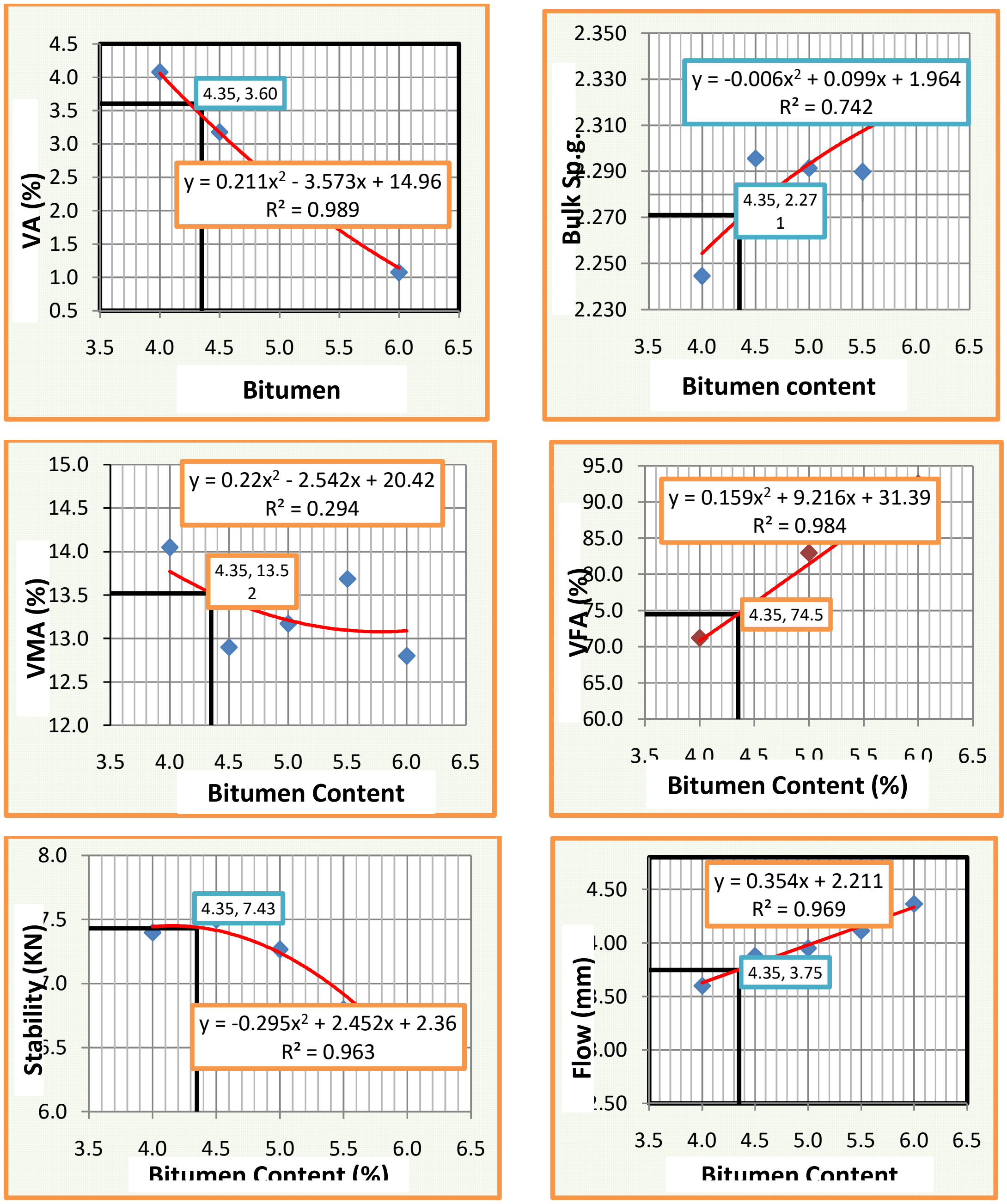

Figure 4.9 OBC and properties of the mixture with 40% RAPA and 60% CA

Figure 4.9 shows the relationships between optimum bitumen content and mix properties contain 40% RAPA and 60% CA. The Optimum Bitumen Content was found equal to 4.35 by the weight of the total mix. The general trend curve represents the relationship between different bitumen contents and Marshall Properties. The summary of mixture properties at optimum bitumen content is presented in table 4.17

Table 4.15 Marshall Properties of Asphalt mixture contain 50% RAPA and 50% CA

%of BC by weight of the total mix	Trail No	Gmb	VA (%)	VMA (%)	VFA (%)	Pick load (KN)	Stability (KN)	Flow (mm)
4.0	1	2.317	2.4	11.2	78.5	8.78	7.6	4.15
	2	2.298	3.2	11.9	73.4	7.82	6.6	4.10
	3	2.304	3.0	11.7	74.8	7.69	6.5	4.20
Average		2.306	2.9	11.6	75.6	8.10	6.9	4.15
4.5	1	2.293	3.3	12.6	73.9	8.25	7.1	4.91
	2	2.306	2.8	12.1	77.2	7.49	6.4	4.38
	3	2.324	2.0	11.4	82.8	7.33	6.1	4.61
Average		2.308	2.7	12.0	78.0	7.69	6.5	4.63
5.0	1	2.316	2.1	12.2	83.0	7.03	6.1	4.84
	2	2.282	3.5	13.5	73.9	7.16	6.2	4.92
	3	2.327	1.6	11.8	86.2	7.32	6.3	4.98
Average		2.308	2.4	12.5	81.1	7.17	6.2	4.91
5.5	1	2.340	0.9	11.8	92.7	6.76	5.9	5.24
	2	2.305	2.3	13.1	82.3	6.55	5.8	5.56
	3	2.302	2.5	13.2	81.3	5.89	5.2	5.72
Average		2.316	1.9	12.7	85.4	6.40	5.6	5.51
6.0	1	2.293	2.9	14.0	79.4	6.72	6.0	6.77
	2	2.339	0.9	12.3	92.3	5.39	4.9	7.02
	3	2.330	1.3	12.6	89.6	6.05	5.5	7.12
Average		2.321	1.7	12.9	87.1	6.1	5.5	6.97

Where, Gmb=bulk bulk specific gravity, VA=Air void, VMA=Void in mineral aggregate, VFA=Void filled with asphalt, BC=bitumen content RAPA=Reclaimed Asphalt Pavement Aggregate and CA=crushed aggregate. Table 4.15 presented the Marshall Test results of mixture properties mixed with 50% RAPA and 50% Crushed Aggregate. The proportion of aggregate gradation of this mixture was presented in table 4.2. The replacement RAPA in place of crushed aggregate was performed based on selected design gradation of the control mix, which is trial 2 that presented in table 4.10.

4.3.1.2.1 OBC determination for each RAP Aggregate Proportion with CA

The optimum bitumen content for each RAPA Proportion is determined according to asphalt institute procedure, which means the optimum bitumen is the average value of bitumen content at maximum stability, maximum density, and bitumen content at 4% air void. The optimum bitumen content of each RAPA proportion was determined from the result presented in Table 4.11 to 4.15 and figure 4.6 to 4.9. The OBC of each RAP aggregate proportion with crushed aggregate was presented in table 4.16.

Table 4.16 Optimum bitumen content result for each RAPA aggregate proportion with CA

Optimum Bitumen Content for Each RAP aggregate proportion						
S/No	Properties	Selected bitumen content (BC)				
		10% RAPA	20% RAPA	30% RAPA	40% RAPA	50% RAPA
1	Maximum stability (KN) (A)	5.0	4.5	5	4.5	4
2	Maximum bulk specific gravity (kg/m^3) (B)	5.0	5	4.5	4.5	4
3	4 percent Air void (C)	5.0	4.625	4.5	4.055	4
4	Average value =(A+B+C)/3	5.0	4.71	4.67	4.35	4

To determine the optimum bitumen content first, the bitumen content at 4% air void was determined through interpolation from the graph of air void versus bitumen content, bitumen content at pick curve of stability, and bulk specific gravity from table 4.11 to 4.15 and figure 4.6 to 4.9 and the detail procedure for determination of OBC is explained in **Appendix F**. The final result of optimum bitumen content (OBC) of asphalt mix using the different proportions of Reclaimed Asphalt Pavement (RAP) aggregate and crushed aggregate was presented in table 4.16.

4.3.1.2.2 Marshall Test result at each optimum bitumen content

The Marshall Flow stability and volumetric properties of hot mix Asphalt were obtained at each Optimum Bitumen Content of RAP aggregate proportion with crushed aggregate. After plotting the graph of bitumen content versus Marshall Properties, including (air void, VMA, VFA, Stability, flow, and bulk density), the optimum bitumen content was determined. Based on OBC, another volumetric property and mix performance at optimum bitumen content were determined. The result of volumetric properties and mix performance of HMA was presented in table 4.17

Table 4.17 Summary of Marshall Properties results at each of OBC

Marshall properties	Marshall test results of RAP Aggregate proportion					
	M1	**M2**	**M3**	**M4**	**M5**	**M6**
	0%RAPA & 100% CA	10%RAPA &90% CA	20%RAPA & 80% CA	30%RAPA &70% CA	40% RAPA & 60% CA	50% RAP 50% CA
Optimum bitumen	5.08	5	4.71	4.67	4.35	4
Stability (KN)	12.64	10.30	9.75	8.84	7.43	6.9
Flow value (mm)	3.03	3.14	3.24	3.44	3.75	4.15
VMA (%)	15	14.8	14.6	14.6	13.52	11.9
VFA (%0	72.55	72.7	73.5	73.6	74.5	75.6
Air Void (%)	4.08	4	3.94	3.89	3.60	2.9
Bulk specific Gravity	2.341	2.274	2.246	2.270	2.271	2.306

4.4 Discussion and Analysis of Marshall Test results at optimum bitumen content

4.4.1 Analysis of the potential effect of RAP Aggregate on Marshall Properties and compression with standard specification

After the Marshall properties of asphalt mixture mixed with different percentages of RAP aggregate at each optimum bitumen content was determined the next step was 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 addition of recycled percentage in asphalt mix. The effect RAP aggregate on Marshall Properties were 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 percentage. And also the value of Marshall Properties obtained at each OBC mixed with different RAPA percentage 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 4.17 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, specific gravity of compacted mix and void filled with asphalt by comparing to the study control (conventional) mix.

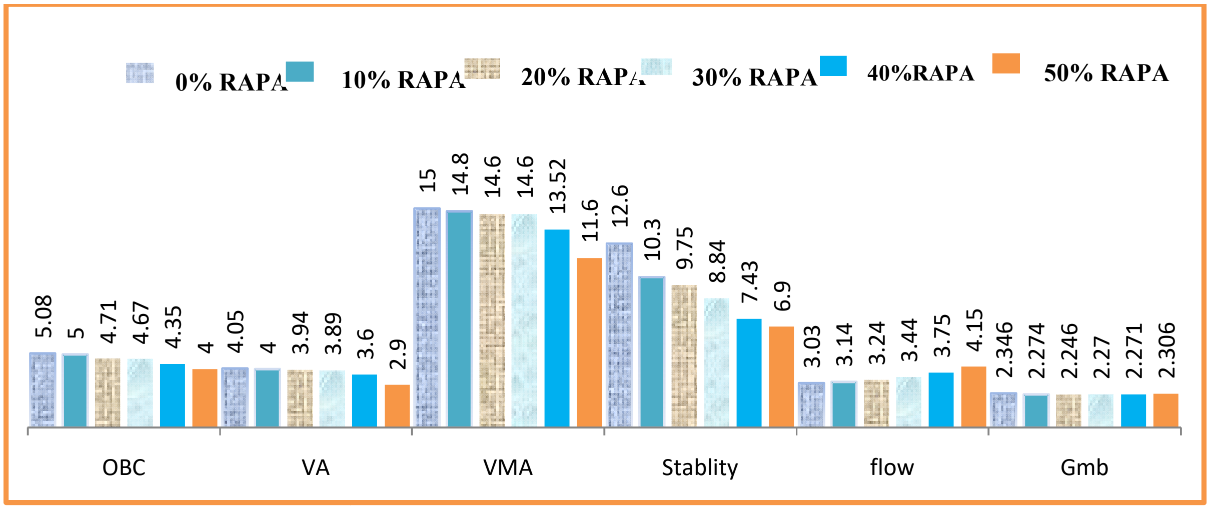

Figure 4.10 Compression of Marshall properties at five different % of RAPA & Control mix

4.4.1.1 Analysis of the Effect RAP aggregate on Optimum Bitumen Content

From the result presented in table 4.17 and figure 4.10, the value of optimum bitumen content mixed with 0% RAP aggregate (control mix) is greater than the other mix with 10% to 50% of 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 40% decrease the optimum bitumen content from 5.08 to 4.35%. This means that saving in optimum bitumen content by about 14.37% is achieved. And also, when RAP aggregate percentage reaches 50%, the optimum bitumen content is decreased to 4 %. This means that when using the identical weight of crushed aggregate and reclaimed asphalt pavement, bitumen saving reaches about 21%

4.4.1.2. Analysis of the effect of RAP aggregate on Air voids

Air void is the important parameters in asphalt mix design, the air void limits are range from 3 to 5 percentage of total mix volume. When air voids lower than 3% bleeding of asphalt will occur, especially with higher temperature degrees causing decreasing of asphalt in the pavement with time. This decline in asphalt content will already reason to pavement cracking. On the other hand, for air void percent greater than 5% of the mix, the pavement will be weak and unstable. For these considerations, the asphalt binder is a very susceptible element in pavement design. From the result of Air void obtained at optimum bitumen content mixed with different percentage of RAP aggregate in asphalt mixture presented in table 4.17 and figure 4.10, we notice that the air void of compacted mixture with 0% RAP (control mix) has higher value than the Air void results mixed with 10% to 50% RAP aggregate. Increasing the RAP aggregate percent from zero to 40% decrease the air voids percent from 4.05% to 3.6% i.e., by about 11.1%. Further increase in the recycled percent will lead to a more decreasing in air void percent. When the reclaimed asphalt pavement percent reaches 50%, the air void reaches 2.9%. This decreased by about 28.39%. Moreover, the mix design with 50% RAP aggregate gives air voids percent of 2.9%, which is out of specification range of (3%-5%) that recommended by ERA design manual presented in table 3.4 From the result, we concluded that the percentage of air void is decreased with the increase percentage of RAP aggregate. So that the addition of RAP aggregate in hot mix asphalt has more effect on Air voids parameters. This may be attributed to the old bitumen filled the aggregate pores, and the particle size of RAP aggregate is finer than virgin aggregate in mixture, which can reduce the voids percent, and also, the RAP binder is perfectly blended with a virgin binder .for compression of air void results with ERA design standard specification at each percentage of RAP aggregate mixed with crushed aggregate the following figure 4.11 is presented

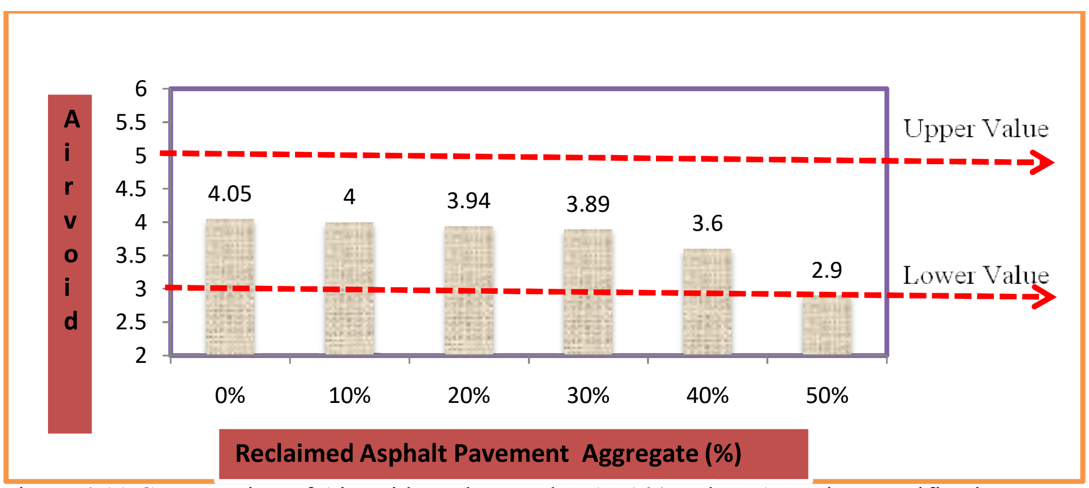

Figure 4.11 Compression of Air void result at each RAPA% and ERA Design specification

From figure 4.11 we see that the value of air voids are within the specification range except the value of air void mixed with 50% RAP aggregate.

4.4.1.3. Analysis of the effect of RAP aggregate on (VMA %)

Void in mineral Aggregate is the small space between the aggregate particles; the VMA value at OBC presented in table 4.17 and figure 4.10 was used to evaluate the effect of RAP aggregate on Void in Mineral Aggregate (VMA). Figure 4.10 we see that void in mineral aggregate (VMA) value mix with 0% RAP aggregate (control mix) was greater than the other value and the result of VMA mixed with 30% and 40% RAP aggregate was almost the same and the value VMA at 50% RAP aggregate is out of specification. This shows that the Void in mineral aggregate is decreased with the increase in both bitumen content and RAP percentage in the mixture. This may is due to the Recycled aggregate and bitumen is perfectly blended with virgin materials and fills the space between compacted materials. To compare the result of VMA to standard specification figure 4.12 is presented

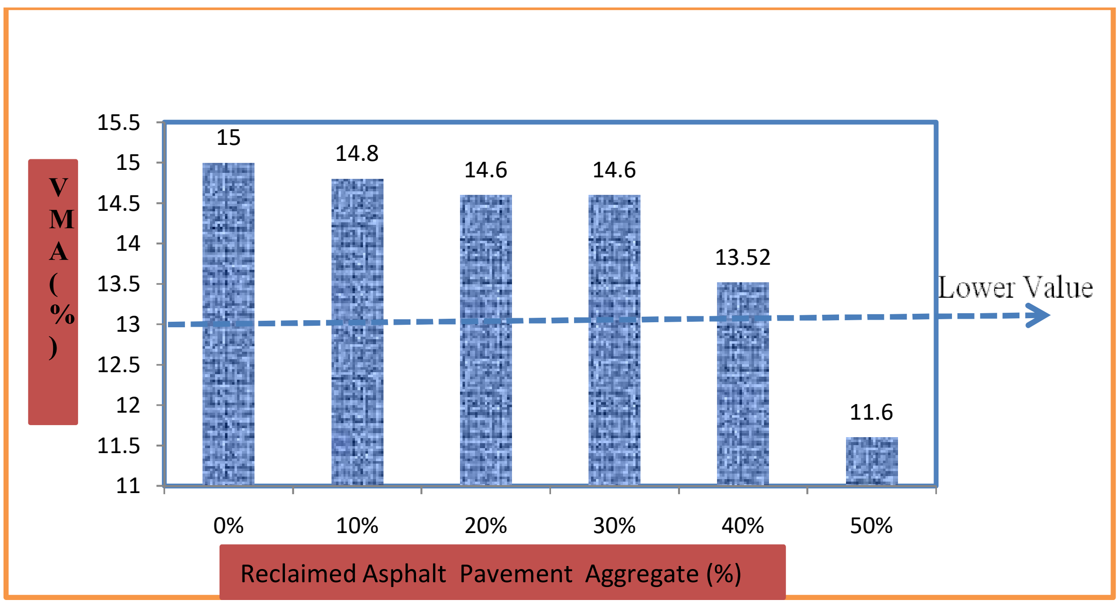

Figure 4.12 Compression of VMA result at each RAPA% and ERA Design specification

From figure 4.12 we concluded that the value of void in mineral aggregate mixed with 0% RAP aggregate to 40% RAP aggregate is meet the standard specification except the VMA result mixed with 50% of RAP aggregate. From this, we can conclude that the percentage of RAP used in HMA is not exceeded by 40%.

4.4.1.4. Analysis of the effect of RAP aggregate Void filled with Asphalt (%)

The void VFA criteria help to avoid those mixes that would be subject to rutting in heavy traffic situations. The main effect of the VMA criteria is to limit the highest levels of VMA, and consequently, maximum levels of bitumen content. The value of VFA at optimum bitumen content was present in table 4.17 and figure 4.13. From the figure 4.13 we identify that the VFA the result of conventional mix (0% RAP) was small rather than the VFA value mixed with 10% to 50% RAP aggregate. And the VFA Value mixed with 50% RAP aggregate is higher than the other with the value of 75.6 which is out of specification. Generally this shows that VFA value is increasing as RAP aggregate in mix is increase. For compression of VFA results mixed with different percentage of RAP aggregate to ERA design standard specification figure 4.13 was presented.

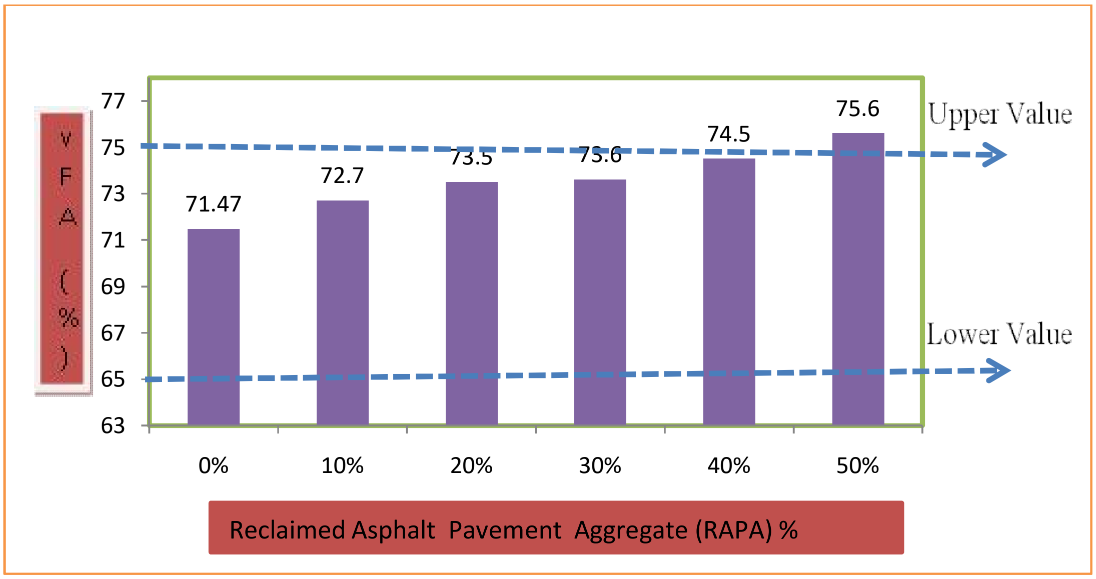

Figure 4.13 Compression of VFA result at each RAPA% and ERA Design specification

Figure 4.13 shows that the value of Void filled with asphalt mixed with different RAPA percentage is meet the standard specification limit except the VFA value mixed with 50% RAP aggregate. The specification limit recommended by ERA for VFA between the ranges of 65%-75%. From this result, we concluded that RAP aggregate percentage use in HMA is only up to 40%.

4.4.1.5 Analysis of the Effect RAP aggregate on Marshall Flow

Mix flow gives an indicator of resistance to permanent deformation .From the figure 4.10 we 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 the other mix with 10% to 50% RAP aggregate. When the RAP aggregate is increased from zero to 40%, the mix flow value is increased from 3.03 to 3.75 i.e., increased by 23.76%. When RAPA reaches 50%, the flow, value is 4.15. This is out of the specification limit suggested by ERA design manual (2002). As we see from figure 4.14. From this we see that the RAP aggregate content in hot mix asphalt can affect the value of Marshall Flow.

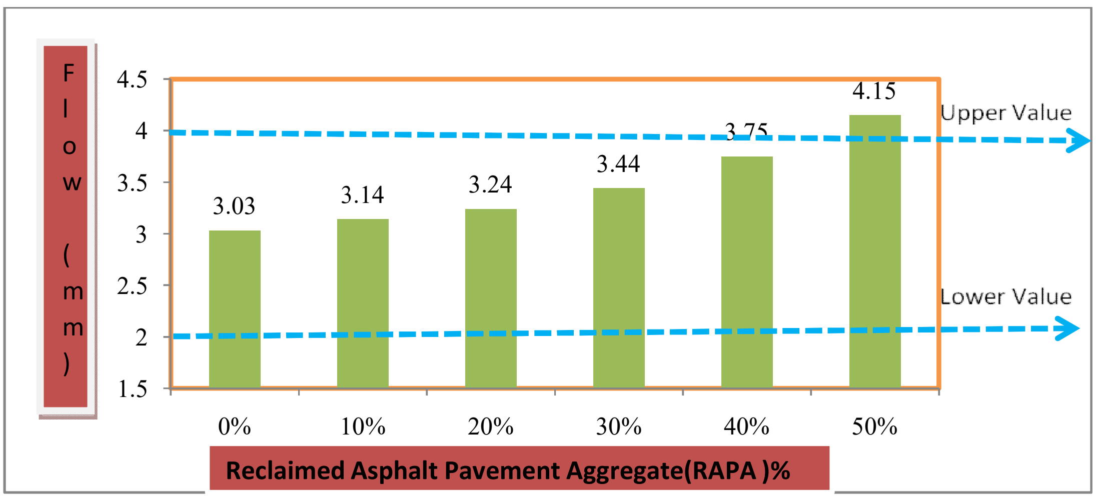

Figure 4.14 Compression of flow result at each RAPA% and ERA Design specification

From figure 4.14 above the value of Marshall Flow at OBC mix with 0%, 10%, 20%, 30%, 40%, and 50% RAP aggregate are 3.03, 3.14, 3.24, 3.75 and 4.15 respectively. Based the result presented the value of flow at different RAPA percentage is fulfill the ERA design standard specification except the value mixed with 50% of RAP aggregate. From this, we can conclude that the RAPA percentage used in HMA is not exceeded by 40%.

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4.4.1.6 Analysis of the Effect RAP aggregate on Marshall Stability

Marshall Stability is the most important parameter 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 4.17 and figure 4.10 to determine the potential effect of RAPA on Marshall Stability. From figure 4.10 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 and the value of stability at 50% RAPA smaller than the other. It can also be noted that increasing recycled aggregate from zero to 40% decrease the stability value from 12.6 KN to 7.43 KN, which is decreased by 41%. When the RAPA reaches 50%, the stability value is 6.9KN, i.e., decreased by 45.2%. This is out of specification. This shows that the value of stability decreases as the RAPA percentage increases in HMA. This may be due to the Recycled aggregate is loaded and become finer than the virgin aggregate, which has less stability than the coarse aggregate. Generally, the RAPA has more has more effect on the value of stability of hot mix asphalt. The relationship between ERA design standard and value of stability obtained at OBC mixed with different percentage of RAP aggregate is shown in figure 4.15

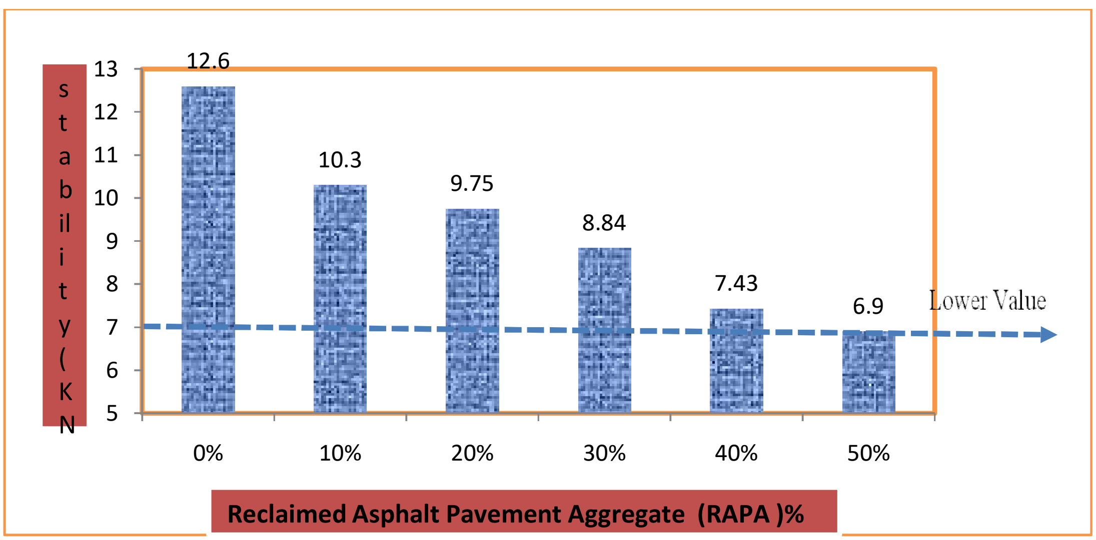

Figure 4.15 Compression of Stability result at each RAPA% and ERA Design specification

Based on the result presented in figure 4.15, we notice that the maximum using of RAP aggregate in hot mix asphalt only up to 40% only.

4.4.1.7 Analysis of the Effect RAP aggregate on Bulk density

Evaluating the result of using RAPA on the density of bitumen mixture, RAPA has an unpronounced effect on the bulk density. The result of bulk density for all mix with different RAPA percentage is presented in table 4.17, and figure 4.10, from the result, it must be noticed that the value of Bulk density is decreased by up to 20% RAPA and then increase. This may be due to bulk specific gravity of Aggregate that means the bulk specific gravity of aggregate is also decrease up to 20% RAPA and increase after 30% to 50% of RAP aggregate in mixture.

Table 4.18 Summary of Marshall Test results compression with ERA standard spec.

Marshall properties	Marshall test results of RAP proportion from **M1-M6**								
	M1 0% RAPA	**M2** 10% RAPA	**M3** 20% RAPA	**M4** 30% RAPA	**M5** 40% RAPA	**ERA (2002) spec. limit**	Status	**M6** 50% RAPA	Status of Mix with 50% RAP Based on specification
OBC (%)	5.08	5	4.71	4.67	4.35	4-10	Ok	4	Satisfied
Stability (KN)	12.64	10.30	9.75	8.84	7.43	Min-7	Ok	6.9	Unsatisfied
Flow value (mm)	3.03	3.14	3.24	3.44	3.75	2-4	Ok	4.15	Unsatisfied
VMA (%)	15	14.8	14.6	14.6	13.52	Min-13	Ok	11.9	Unsatisfied
VFA (%0	72.55	72.7	73.5	73.6	74.5	65-75	Ok	75.6	Unsatisfied
Air Void (%)	4.08	4	3.94	3.89	3.60	3-5	Ok	2.9	Unsatisfied
BulkDensity(Kg/m^3	2.341	2.274	2.246	2.270	2.271	---	Ok	2.306	------------

From Table 4.18 we concluded that the result of Marshall Properties of mixes M1-M5 or Marshall Properties mixed with 0% to 40% RAP aggregate was meet the requirement standard specification for Heavy traffic with Traffic class of (T7, T8) specified in table 3.4. Where the Marshall Properties of asphalt mixture mixed with 50% RAP aggregate (M6) was not fulfill the specified standard specification and Marshall Criteria. From this we can recommend that Maximum of percentage of RAP used in hot mix asphalt is only up to 40%.

4.5 Correlation analysis with linear Regression technique

Since the objective of this research is to correlate the volumetric properties and mix performance of hot mix asphalt to the effect of using RAP aggregate proportion in asphalt mixture, the correlation analysis carried out using the statistical regression to evaluate the relationship of Marshall Properties with percentage of using RAP aggregate in the mixture in numerical way. Based on the test results presented in table 4.17, the following correlation analyses were performed for the achievements of the research objectives. The regression analysis used for this study was linear regression. This has one dependent and one independent variable. The dependent variables of the study were the volumetric properties of HMA and Marshall Flow and stability, whereas the reclaimed asphalt pavement (RAP) aggregate percentage in the mix was independent variables. By the linear regression, we can identify the relationship between those two variables by determining the correlation equation and correlation coefficient of each Parameter with recycled aggregate percentage.

4.5.1 Correlation Analysis of Volumetric properties using linear regression

4.5.1.1 Analysis of Optimum Bitumen content result and Recycled percentage

Based on Marshall Test results presented in table (4.17), the statistical line (scatter) is plotted to show the relationship between optimum bitumen content and recycled percentage for an investigated mixture. From the regression line plotted, it can be noticed that the optimum bitumen content is decreased as Reclaimed Asphalt pavement (RAP) aggregate is increased. To deduce the relationship between optimum bitumen content and reclaimed Asphalt pavement (RAP) aggregate the figure 4.16 was plotted using the linear statistical regression. The correlation equation which can show the relationship between optimum bitumen content (OBC %) and RAP aggregate % is presented as follows.

Optimum Bitumen Content (OBC) = -2.111RAPA +5.162   R2=0.948

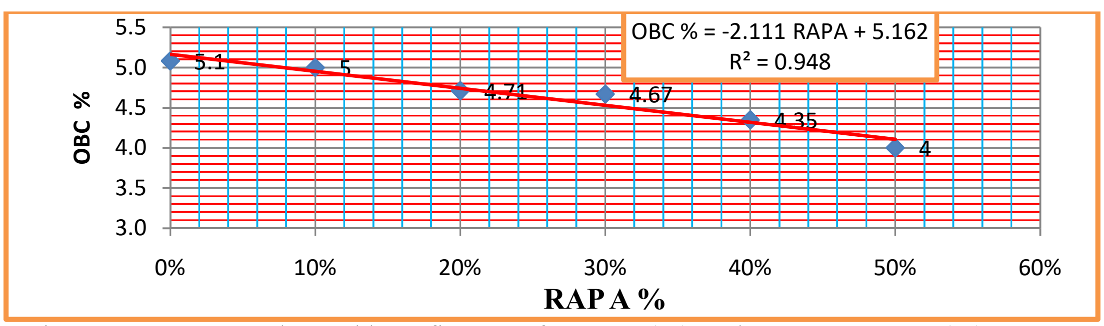

Figure 4.16 Scatter plot and best-fit curve for OBC (%) and RAP aggregate (%)

From figure 4.16 we concluded that the correlation (relationship) between OBC and RAP aggregate percentage is a strong negative correlation, with correlation coefficient (R^2) of 0.948 which means when RAPA increases; the value of OBC is decreased.

4.5.1.2 Correlation Analysis of Air void result with (%) Recycled aggregate

Based on the air void result presented in table 4.17, the analysis was occurred using linier statistical regression. From the scatter plot, we see that the increasing RAP aggregate percentage would decrease the corresponding air voids ratio. To derive the relationship between the air void (dependent variable) and recycled percentage (independent variable), the following correlation equation and correlation coefficient was presented.

Air void (VA %) = -2RAPA+4.23, R^2=0.736

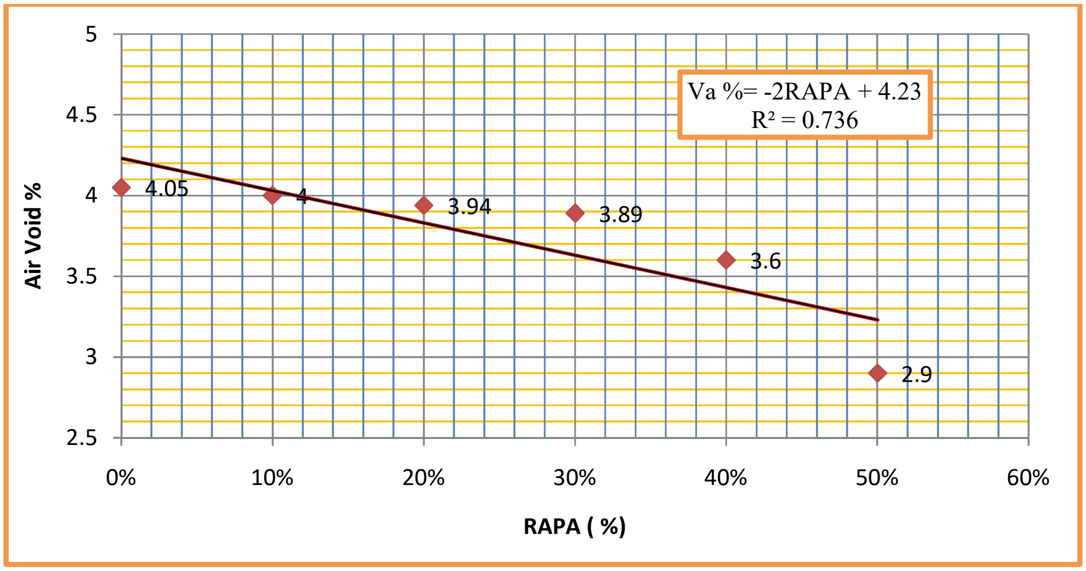

Figure 4.17 Scatter plot and best-fit curve for Air void (%) and RAP aggregate (%)

Figure 4.17, indicates that the relationship between the Air void and the percentage of RAP is a negative correlation with correlation coefficient (R^2) of 0.736. This means when the value of RAP aggregate (independent variable) increase the value of air void (dependent variable) is decrease. As RAP aggregate increase from zero% to 50% the value of air void is decreased from 4.05% to 2.9 %.Based on the discussion above, it can be concluded that RAP aggregate percentage must not exceed 40% of the total aggregate weight to ensure acceptable air void range. This suggestion is very significant to avoid asphalt bleeding after construction. Generally, the RAPA percentage in the mixture has more effect on the value of air voids.

4.5.1.3 Correlation Analysis of void in Aggregate mineral results (VMA)

Based on the result of void in mineral aggregate (VMA) presented in table 4.17,the scatter is plotted to show the relationship between VMA result as dependent variables and Recycled aggregate as independent variable. For evaluating the relationship between RAP aggregate % and VMA value, the following correlation equation is presented VMA= -5.954RAPA+15.50, R^2=0.743

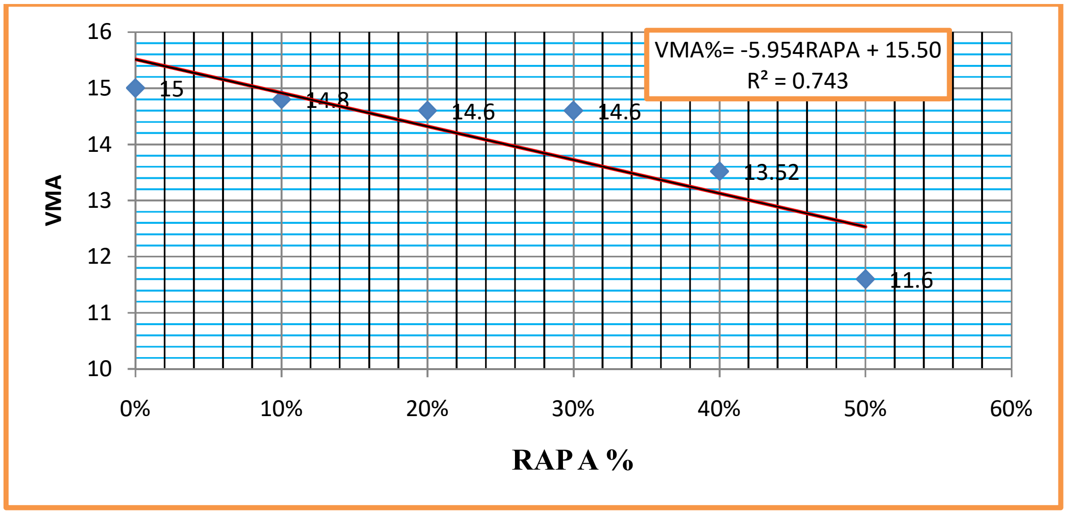

Figure 4.18 Scatter plot and best-fit curve for (VMA %) and RAP aggregate (%)

From figure 4.18, it can be noticed that the relationship between the Recycled percentage and VMA is a negative correlation with the correlation coefficient (R^2) of 0.743. From the scatter plotted we see that as the RAP aggregate percentage is increase from zero percent to fifty percent the value of VMA is decreased from 15% to 11.5%. This means the value of VMA is decreased slightly with an increase in the RAP percentage.

4.5.1.4 Correlation Analysis of void filled with asphalt (VFA)

The void VFA criteria help to avoid those mixes that would be subject to rutting in heavy traffic situations. The main effect of the VMA criteria is to limit the highest levels of VMA, and consequently, maximum levels of bitumen content. VFA is used to ensure appropriate asphalt film thickness in the mix if it is too low, the mix has poor durability, or if it is too high, the mix can be unstable. Table 4.17 presents the void filled with asphalt for all the investigated mixes with different RAPA proportions. Based the result the regression line was plotted to determine the relationship between dependent variable and independent variable. To derive the relationship between VFA and Recycled percentage in mixture the following correlation equation is presented.

VFA%= 7.471RAP+71.69, R^2=0.961

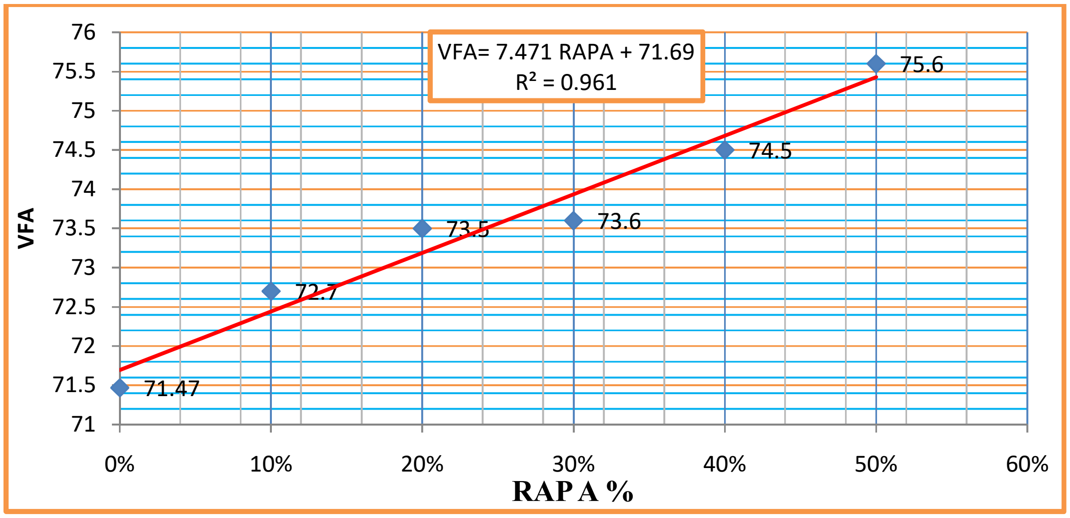

Figure 4.19 Scatter plot and best-fit curve for (VFA %) and RAP aggregate (%)

From the figure 4.19 we see that the relationship between VFA and RAP aggregate percentage is strong positive correlation with correlation coefficient (R^2) of 0.961. This means, as the RAP aggregate percentage increase in mix the value VFA is also increase.

4.5.2 Correlation Analysis of Marshall Flow-Stability

4.5.2.1 Correlation Analysis of Mix Stability results to recycled percentage

The stability of the investigated mixtures with different RAP aggregate proportion is presented in table 4.17. Based the result the regression line is plotted to determine the relationship between mix stability and Recycled asphalt aggregate. From the regression line we noticed that the value of stability is decrease as the RAP aggregate percentage is increase. As the RAP aggregate increase from zero to fifty percent the value of stability is decreased from 12.6KN to 6.9. At 50% RAP aggregate mixed with crushed aggregate the value of stability is become 6.9KN which out of specification. To deduce the relationship between two variables the following correlation equation is presented.

Stability =-11.00 RAPA+12.10, R^2=0.967

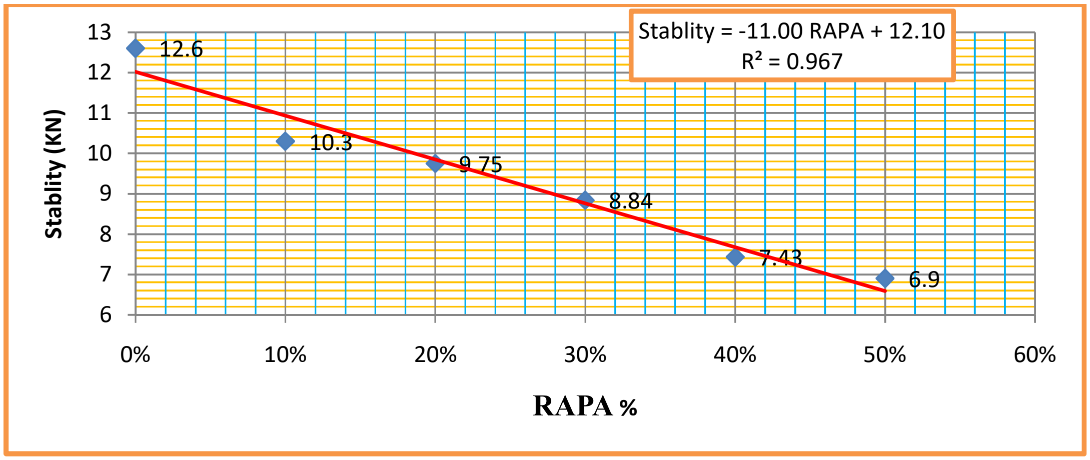

Figure 4.20 Scatter plot and best-fit curve for Mix Stability and RAP aggregate (%)

Figure 4, 20 shows that the relationship between stability and RAPA percentage is a strong negative correlation with a correlation coefficient of 0.967. Decreasing of stability is due to low quality and loaded of aggregate in RAP materials and also particles size of RAP aggregate is finer than virgin aggregate. Based on the discussion above, it is recommended that the use of reclaimed material up to 40% only.

4.5.2.2 Correlation of Mix Flow results to recycled percentage

The flow values obtained for all mixes with different RAPA proportion is presented in table 4.17. To determine the relationship between the mix flow value and RAPA percentage, the following scatter is plotted, and the statistical equation is presented.

Flow (%) = 2.18 RAPA +2.913

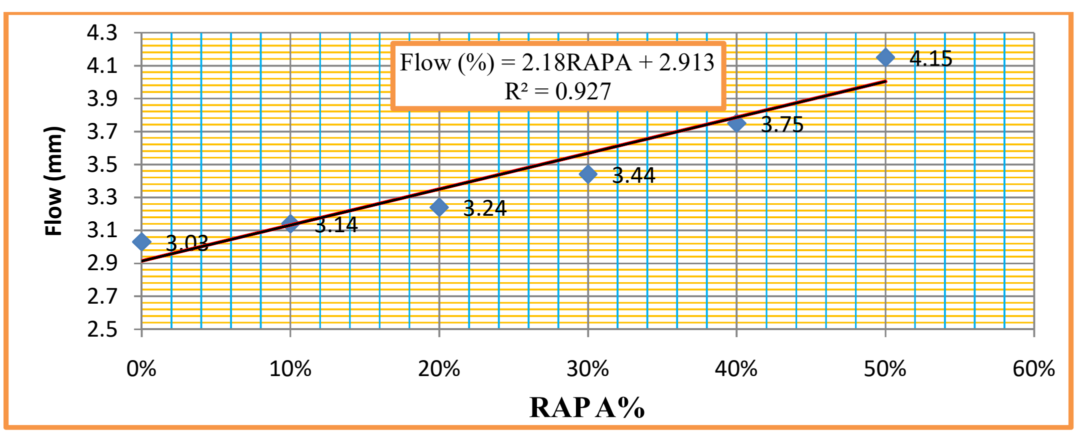

Figure 4.21 Scatter plot and best-fit curve for Mix flow and RAP aggregate (%)

From figure 4.21 we observe that the relationship between RAPA% and Mix flow is a positive correlation with the correlation coefficient ($R^{2)}$ of 0.927. That means the mixed flow is increase as RAPA percent increase. When RAPA reaches 50%, the flow, value is 4.15. This is out of the requirement limit suggested by ERA. From the result above we have recommended that the use of RAP is only up to 40%

Table 4.19 Summary of Correlation equation by Regression Analysis

S/No	Marshall properties (Dependent variables)	Independent variable	Correlation equation	Correlation coefficient	Confidence level	significance
1	OBC (%)	RAPA%	OBC=-2.111RAPA+5.162	R^2=0.948	95%	0.001013
2	VA (%)	RAPA%	Air voids = -2RAPA+4.23	R^2=0.736	95%	0.028801
3	VMA (%)	RAPA%	VMA= -5.954RAPA+15.50	R^2=0.743	95%	0.027214
4	VFA (%)	RAPA%	VFA= 7.471RAPA+71	R^2=0.961	95%	0.000558
5	Stability (KN)	RAPA%	Stab= -10.86RAPA+12.01	R^2=0.957	95%	0.000679
6	Flow (mm)	RAPA%	Flow= 2.18RAPA+2.913	R^2=0.927	95%	0.001998

4.5.3 Discussion on the liner correlation equation

After carefully evaluating and analyzing the data on the scatter plot and different linear correlation equations are determined, it was discovered that volumetric properties of asphalt mixture are highly influenced by Reclaimed asphalt pavement (RAP) aggregate. From the result presented in table 4.19 the volumetric properties of asphalt mixture such as OBC, Air voids, VMA, and VFA are influenced by RAP aggregate by achieving a coefficient of determination (R^2) of 0.948, 0.736, 0.743, and 0.961 respectively with a significance level of 0.001013, 0.028801, 0.027214 and 0.000558 respectively. From the summary of the linear regression equation presented in table 4.19, we conclude that there is a good correlation between volumetric properties and Reclaimed asphalt pavement aggregate. And also, there is a good correlation between Marshall Flow Stability and Reclaimed asphalt pavement aggregate.

4.6 Determination of Maximum percentage of using RAP aggregate in HMA

The determination of the maximum percentage of RAP aggregate used in hot mix asphalt is based on Marshall Stability test results. So based on Marshall Test result presented in table 4.17 and compression of Marshall Properties with ERA design standard specification presented in table 4.18 the maximum percentage of using RAP aggregate in hot mix asphalt is up to 40% only. At 40% RAP aggregate mixed with crushed aggregate and all the results are within the required specification range. Table 4.20 illustrates a comparison of the marshal properties of asphalt mix containing 40% of RAP aggregate with specifications of (ERA, Pavement Design Manual, 2002)

Table 4.20 Comparison of Marshall properties at Maximum RAPA Percentage used in HMA

Marshall properties	Marshall test results mixed with 40% RAP aggregate			
	Result of 40% RAPA mix	(ERA, Pavement Design Manual, 2002) Standard specification limit		Remark
		Traffic Heavy		
		Min	Max	
Number of blows	2*75	2*75		
Optimum bitumen (%)	4.35	4	10	Satisfied
Stability (KN)	7.43	7	--	Satisfied
Flow value (mm)	3.75	2	4	Satisfied
VMA (%)	13.52	13	--	Satisfied
VFA (%)	74.5	65	75	Satisfied
Air Void (%)	3.60	3	5	Satisfied

As indicated in table 4.20 the asphalt mix with 40% recycled asphalt pavement aggregate by Wight of aggregate in mix satisfied the requirements of (ERA, Pavement Design Manual, 2002) specifications for all tested properties. Based the result above maximum percentage of Recycled asphalt pavement aggregate (RAPA) used in hot mix asphalt is up to 40% only.

Chapter 5

Conclusion and Recommendation

This research was focused on evaluating the effect of RAPA on the volumetric properties of HMA that have been partially replaced to crushed aggregate by different proportions. On the basis of test results and analysis obtained, the following conclusions are drawn, and finally, recommendation and suggestions for further studies are presented.

5.1 Conclusion

This study tries to evaluate the effect and Relationship of RAPA percentage in the mix with volumetric properties of the HMA based Marshall Mix Design test. The result obtained showed that there was a significant effect in volumetric properties of mix, between control (0% RAP) aggregate and mixes with Variable % of RAP aggregate from 10% to 50%. Based on the results of the research, the following conclusions are drawn.

- For performance of research objectives the engineering properties of selected materials for the laboratory tests were conducted based on standard test procedures of ASTM, AASHTO and B.S, such as aggregate quality test, filler test, and bitumen quality test and all results passed ERA the standard specification.
- The Marshall properties of asphalt mixture such as Marshall Flow stability and volumetric properties are highly influenced by addition of RAP aggregate in mixture, this show that the changing percentage of RAP aggregate in mixture has the potential effect to change the value of Marshall Properties in general.
- The optimum bitumen content for control mix was 5.08%, OBC for 10% RAPA mix is 5%, OBC for 20% RAPA mix, is 4.71%, OBC for 30% RAPA is 4.67%, and OBC for 40% RAP is 4.35%. This shows that increasing percentage of RAP aggregate in mix decrease the value of optimum bitumen content. And the relationship between optimum bitumen content and the recycled percentage is a strong negative correlation with a correlation coefficient of 0.948. The specimen prepared with the control mix (0% RAPA) sample has slightly maximum air void than other specimens prepared with RAP aggregate mixes, it indicates that air voids value goes on slightly decreased while increasing the RAPA percentage. The Relationship between Air voids and Recycled percentage was a negative correlation with a correlation coefficient of 0.736.

- At optimum bitumen content, the VMA of the control mix be higher than the other mix specimen with RAPA percentage. As the percentage of RAPA is increasing, the value of VMA is decreased. And the relationship between VMA and Recycled percentage is a negative correlation with a correlation coefficient of 0.743
- At Optimum bitumen content (OBC), the value of VFA for the control mix (0% RAPA) was less than the value of the VFA mix with RAPA. It shows that the value of VFA is increase as RAPA percentage increases in the mix. So the relationship between VFA and RAPA percentage is strong positive correlation with a correlation coefficient of 0.961.
- At 40% RAP aggregate replacement of crushed aggregate, the mixture properties such as Marshall Stability, flow values and volumetric properties are satisfy with the ERA Pavement Design Manual specification limits.
- Generally, in this paper, based on laboratory studies, it was concluded that the volumetric properties of HMA are influenced by Reclaimed asphalt pavement (RAP), aggregate and the relationship between those parameters and percentage RAP aggregate is more correlated. Based on the discussion and analysis of laboratory test results, the Maximum of 40% RAP can be used in the bituminous concrete mix.

5.2 Recommendations

Based on the study, analysis, and conclusion, the researcher forwarded the following recommendation:

1. The Reclaimed Asphalt Pavement (RAP) aggregate is recommended to use in hot mix asphalt mixes to save the virgin aggregate and bitumen and also to improve the environment.

2. The relationship between volumetric properties and reclaimed asphalt pavement is a good correlation; the changed the value of RAP aggregate content is change the value of volumetric parameters, so it's important to know the relationship between those two variables during Asphalt mix design.

3. A percent of RAP up to 40% is suitable to be used in flexible pavement for the study.

4. In Ethiopia, a large amount of recycled asphalt pavement (RAP) material is created every year during the rehabilitation and reconstruction of existing flexible pavement. However, using these materials in hot mix asphalt is not known, so the researcher recommends that the using of RAP aggregate in HMA is best alternative for contractors and other concerned bodies.

Scope for further study

1. A large scale study can be carried out, taking into consideration several parameters such as the age of RAP materials, remaining binder content in RAP, the viscosity of binder in RAP and etc., need to study for suitability RAP in HMA.

2. Performance-based test methods can be carried out static or creep, Dynamic loading, and rutting tests to provide accurate and realistic relationships under the actual traffic loading and environmental condition.

3. Laboratory-based test methods carried out taking into consideration of aggregate mixing temperature of RAP and virgin aggregate for evaluation of perfectly RAP materials are mixed with virgin aggregate and bitumen.

4. The economic analysis of using RAP aggregate in hot mix asphalt is taken into consideration for evaluation of cost saving from material cost mixed with RAP aggregate.

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Appendix A: Particle size distribution and aggregate gradation for the study

Table A.1: Particle size distribution of Crushed Aggregate and filler

Test Method: AASHTO T-2

Material type:		Coarse Aggregate (9.5-25 mm) sieve For Binder course					
Dry sample weight (g)		3078.6		4075			
After wash dry sample(g)		3017.7		4057.0			
Sieve Size(mm)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Average Cumulative Passing (%)
25	0.0	3078.6	100.0	0.0	4075.0	100.0	100.00
19	672.9	2405.7	78.1	890.7	3184.3	78.1	78.14
12.5	1509.0	896.7	29.1	1997.4	1186.9	29.1	29.13
9.5	730.8	165.9	5.4	967.3	219.6	5.4	5.39
4.75	79.1	86.8	2.6	104.7	114.9	2.8	2.69
2.36	15.4	71.4	2.3	20.4	94.5	2.3	2.32
1.18	5.2	66.2	2.2	17.4	77.1	1.9	2.02
0.6	3.3	62.9	2.0	42.9	34.2	0.8	1.44
0.3	2.1	60.9	2.0	16.2	18.0	0.4	1.21
0.15	0.0	0.0	0.0	0.0	0.0	0.0	0.00
0.075	0.0	0.0	0.0	0.0	0.0	0.0	0.00
pan	0.0						
W.loose	60.9			18.0			
Total	3078.6			4075.0			

Table A.1.2 Particle size distribution of Course Aggregate (2.36-9.5mm)

Dry sample weight (g)		3200		3400			
After wash dry sample (g)		3160		3358			
Sieve Size(mm)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Average Cumulative Passing (%)
25	0.0	3200.0	100.0	0.0	3400.0	100.0	100.00
19	0.0	3200.0	100.0	0.0	3400.0	100.0	100.00
12.5	0.0	3200.0	100.0	0.0	3400.0	100.0	100.00
9.5	467.8	2732.2	85.4	497.0	2903.0	85.4	85.38
4.75	1552.1	1180.1	36.9	1649.1	1253.9	36.9	36.88
2.36	944.5	235.6	7.4	1003.5	250.3	7.4	7.36
1.18	88.4	147.2	4.6	93.9	156.4	4.6	4.60
0.6	79.0	68.2	2.1	83.9	72.5	2.1	2.13
0.3	22.8	45.4	1.4	24.4	48.2	1.4	1.42
0.15	5.4	40.0	1.3	5.7	42.5	1.3	1.25
0.075	0.0	0.0	0.0	0.0	0.0	0.0	0.00
pan				0.0			
Wash Loose	40.0			42.5			
Total	3200.0			3400.0			

Table A 1.3 Particle size distribution of Fine aggregate (0-2.36mm)

Dry sample weight (g)		4000		4000			
After wash dry sample(g)		3474.4		3524.4			
Sieve Size(mm)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Mass of Retained Sample (g)	Cumulative Passing (g)	Cumulative Passing (%)	Average Cumulative Passing (%)
25	0.0	4000.0	100.0	0.0	4000.0	100.0	100.0
19	0.0	4000.0	100.0	0.0	4000.0	100.0	100.0
12.5	0.0	4000.0	100.0	0.0	4000.0	100.0	100.0
9.5	0.0	4000.0	100.0	0.0	4000.0	100.0	100.0
4.75	38.1	3961.9	99.0	38.1	3961.9	99.0	99.0
2.36	236.2	3725.7	93.14	236.2	3725.7	93.1	93.1
1.18	896.4	2829.3	70.73	896.3	2829.3	70.7	70.7
0.6	719.9	2109.4	52.74	719.9	2109.5	52.7	52.7
0.3	699.8	1409.6	35.24	699.8	1409.7	35.2	35.2
0.15	477.3	932.3	23.31	477.3	932.4	23.3	23.3
0.075	306.7	625.6	15.64	306.7	625.6	15.6	15.6
pan	100.0			150.0			
Wash lose	525.6			475.6			
Total	4000.0			4000.0			

Table A 1.4 Particle size distribution of crushed stone dust (< 0.075mm)

Dry sample weight (g)			**350**		**370**		
After wash dry sample (g)			**0.0**		**0.0**		
Sieve Size(mm)	**Mass of Retained Sample (g)**	**Cumulative Passing (g)**	**Cumulative Passing (%)**	**Mass of Retained Sample (g)**	**Cumulative Passing (g)**	**Cumulative Passing (%)**	**Average Cumulative Passing (%)**
0.6	0.0	350.0	100.0	0.0	370.0	100.0	100.0
0.3	0.0	350.0	100.0	0.0	370.0	100.0	100.0
0.15	0.0	350.0	100.0	0.0	370.0	100.0	100.0
0.075	0.0	350.0	100.0	0.0	370.0	100.0	100.0
pan	0.0			0.0			
Wash loose	350.0			370.0			
Total	350.0			370.0			

Table A 1.5 Summary of Individual particle size distribution of CA and RAPA

Material type	RAPA	Aggr.1 (9.5-25mm)	Aggr.2 (2.36-9.5mm)	Aggr.3 (0-2.36mm)
sieve (mm)	Passing (%)	Passing (%)	Passing (%)	Passing (%)
25	100	100	100	100
19	92.3	78.13	100	100
12.5	75.9	31.2	100	100
9.5	72.5	5.7	89.10	100
4.75	57.4	1.1	42.60	99.10
2.36	38.7	0.6	7.30	93.20
1.18	23.9	0.4	4.60	70.80
0.6	13.8	0.2	2.10	52.70
0.3	10.9	0.1	1.20	35.20
0.15	8.7	0	1	23.40
0.075	6	0	0	15.64

Table A 2: Aggregate Gradation for the study

Table A2:1 aggregate blending for control mix trail 1

Aggregate type	Aggregate 1 (9.5-25mm) sieve		Aggregate 2(2.36-9.5mm) sieve		Aggregate 3 (0-2.36mm) sieve		Total Blend	Middle value	Design Specification
Blend %	25.6 %		36 %		38.4 %				
	%	%	%	%	%	%			
sieve (mm)	Pass	Blend (A)	Pass	Blend (B)	Pass	Blend (C)	A+B+C		
25	100	25.6	100	36.0	100	38.40	100	100	100
19	78.13	20.0	100	36.0	100	38.40	94.4	95	90-100
12.5	31.2	7.99	100	36.0	100	38.40	82.4	79.5	-----
9.5	5.7	1.46	89.1	32.08	100	38.40	71.9	68	56-80
4.75	1.1	0.28	42.6	15.34	99.1	38.05	53.7	50	35-65
2.36	0.6	0.15	7.30	2.63	93.2	35.79	38.6	36	23-49
1.18	0.4	0.10	4.6	1.66	70.8	27.19	28.9	26	---
0.6	0.2	0.05	2.10	0.76	52.7	20.24	21.0	19	----
0.3	0.1	0.3	1.20	0.43	35.2	13.52	14.0	12	5_19
0.15	0	0.00	1	0.36	23.4	8.99	9.3	8.5	----
0.075	0	0.00	0	0.00	15.64	6.01	6	5	2_8

Table A2:2 Control mix gradation trail 2 for a mix

Aggregate type	Aggregate 1 (9.5-25mm) sieve		Aggregate 2(2.36-9.5mm) sieve		Aggregate 3 (0-2.36mm) sieve		Total Blend	Middle value	Design Specification
Blend %	31 %		37 %		32 %				
	%	%	%	%	%	%			
sieve (mm)	Pass	Blend (A)	Pass	Blend (B)	Pass	Blend (C)	A+B+C		
25	100	31	100	37	100	32.0	100	100	100
19	78.13	24.22	100	37	100	32.0	93.2	95	90-100
12.5	31.2	9.67	100	37	100	32.0	77.8	79.5	-----
9.5	5.7	1.77	89.1	32.97	100	32.0	66.7	68	56-80
4.75	1.1	0.34	42.6	15.76	99.1	31.71	47.8	50	35-65
2.36	0.6	0.19	7.30	2.70	93.2	29.82	32.7	36	23-49
1.18	0.4	0.12	4.6	1.70	70.8	22.66	24.5	26	---
0.6	0.2	0.06	2.10	0.78	52.7	16.86	17.7	19	----
0.3	0.1	0.03	1.20	0.44	35.2	11.26	11.7	12	5_19
0.15	0	0.00	1	0.37	23.4	7.49	7.9	8.5	----
0.075	0	0.00	0	0.00	15.64	5.0	5.0	5	2_8

Table A2:3 Control mix gradation trail 3

Aggregate type	Aggregate 1 (9.5-25mm) sieve		Aggregate 2(2.36-9.5mm) sieve		Aggregate 3 (0-2.36mm) sieve		Total Blend	Middle value	Design Specification
Blend %	28.8%		36 %		35.18 %				
	%	%	%	%	%	%			
sieve (mm)	Pass	Blend (A)	Pass	Blend (B)	Pass	Blend (C)	A+B+C		
25	100	28.8	100	36.0	100	35.18	100	100	100
19	78.13	22.50	100	36.0	100	35.18	93.7	95	90-100
12.5	31.2	8.99	100	36.0	100	35.18	80.2	79.5	-----
9.5	5.7	1.64	89.1	32.08	100	35.18	68.9	68	56-80
4.75	1.1	0.32	42.6	15.34	99.1	34.86	50.5	50	35-65
2.36	0.6	0.17	7.30	2.63	93.2	32.79	35.6	36	23-49
1.18	0.4	0.12	4.6	1.66	70.8	24.91	26.7	26	---
0.6	0.2	0.06	2.10	0.76	52.7	18.54	19.4	19	----
0.3	0.1	0.03	1.20	0.43	35.2	12.38	12.8	12	5_19
0.15	0	0.00	1	0.36	23.4	8.23	8.6	8.5	----
0.075	0	0.00	0	0.00	15.64	5.50	5.5	5	2_8

Table A2:4:10% RAP aggregate Blending with crushed aggregate for binder course

Aggregate type	RAPA		Aggregate 1 (9.5-25mm) sieve		Aggregate 2(2.36-9.5mm) sieve		Aggregate 3 (0-2.36mm) sieve		Total Blend	Middle value	Design Specific
Blend %	10 %		27.9 %		33.3 %		28.8 %				
	%	%	%	%	%	%	%	%			
sieve (mm)	Pass	Blend (A)	Pass	Blend (B)	Pass	Blend (C)	Pass	Blend (D)	A+B+C+D		
25	100	10	100	27.9	100	33.30	100	28.80	100	100	100
19	92.3	9.23	78.13	21.8	100	33.30	100	28.80	93.1	95	90-100
12.5	75.9	7.59	31.2	8.13	100	33.30	100	28.80	77.8	79.5	-----
9.5	72.5	7.25	5.7	1.5	89.1	28.44	100	28.80	66.0	68	56-80
4.75	57.4	5.74	1.1	0.75	42.6	12.28	99.1	28.54	47.3	50	35-65
2.36	38.7	3.87	0.6	0.65	7.30	2.45	93.2	26.84	33.8	36	23-49
1.18	23.9	2.39	0.4	0.56	4.6	1.53	70.8	20.39	24.9	26	---
0.6	13.8	1.38	0.2	0.40	2.10	0.71	52.7	15.18	17.7	19	----
0.3	10.9	1.09	0.1	0.34	1.20	0.47	35.2	10.14	12.0	12	5_19
0.15	8.7	0.87	0	0.00	1	0.42	23.4	6.74	8.0	8.5	----
0.075	6	0.6	0	0.00	0	0.00	15.64	4.44	5.0	5	2_8

Table A2:5: 20% RAP aggregate blending of crushed aggregate for binder course

Aggregate type	RAPA		Aggregate 1 (9.5-25mm) sieve		Aggregate 2(2.36-9.5mm) sieve		Aggregate 3 (0-2.36mm) sieve		Total Blend	Middle value	Design Specific
Blend %	20 %		24.8 %		29.6 %		25.6 %				
	%	%	%	%	%	%	%	%			
sieve (mm)	Pass	Blend (A)	Pass	Blend (B)	Pass	Blend (C)	Pass	Blend (D)	A+B+C+D		
25	100	20	100	24.8	100	29.6	100	25.6	100	100	100
19	92.3	18.46	78.13	19.38	100	29.6	100	25.6	93	95	90-100
12.5	75.9	15.18	31.2	7.22	100	29.6	100	25.6	77.8	79.5	-----
9.5	72.5	14.5	5.7	1.34	89.1	25.28	100	25.6	66.7	68	56-80
4.75	57.4	11.48	1.1	0.67	42.6	10.92	99.1	25.37	48.4	50	35-65
2.36	38.7	7.74	0.6	0.58	7.30	2.18	93.2	23.86	34.4	36	23-49
1.18	23.9	4.78	0.4	0.50	4.6	1.36	70.8	18.12	24.8	26	---
0.6	13.8	2.76	0.2	0.36	2.10	0.63	52.7	13.49	17.2	19	----
0.3	10.9	2.18	0.1	0.30	1.20	0.42	35.2	9.01	11.9	12	5_19
0.15	8.7	1.74	0	0.00	1	0.37	23.4	5.99	8.1	8.5	----
0.075	6	1.2	0	0.00	0	0.00	15.64	4.00	5.2	5	2_8

Table A2:6: 30% RAP aggregate blending for binder course

Aggregate type	RAPA		Aggregate 1 (9.5-25mm) sieve		Aggregate 2(2.36-9.5mm) sieve		Aggregate 3 (0-2.36mm) sieve		Total Blend	Middle value	Design Specific
Blend %	30 %		21.7 %		25.9 %		22.4 %				
	%	%	%	%	%	%	%	%			
sieve (mm)	Pass	Blend (A)	Pass	Blend (B)	Pass	Blend (C)	Pass	Blend (D)	A+B+C+D		
25	100	30	100	21.7	100	25.90	100	22.40	100	100	100
19	92.3	27.69	78.13	16.96	100	25.90	100	22.40	92.9	95	90-100
12.5	75.9	22.77	31.2	6.32	100	25.90	100	22.40	77.4	79.5	-----
9.5	72.5	21.75	5.7	1.17	89.1	22.12	100	22.40	67.4	68	56-80
4.75	57.4	17.22	1.1	0.58	42.6	9.55	99.1	22.20	49.6	50	35-65
2.36	38.7	11.61	0.6	0.50	7.30	1.91	93.2	20.88	34.9	36	23-49
1.18	23.9	7.17	0.4	0.44	4.6	1.19	70.8	15.86	24.7	26	---
0.6	13.8	4.14	0.2	0.31	2.10	0.55	52.7	11.80	16.8	19	----
0.3	10.9	3.27	0.1	0.26	1.20	0.37	35.2	7.88	11.8	12	5_19
0.15	8.7	2.61	0	0.00	1	0.32	23.4	5.24	8.2	8.5	----
0.075	6	1.8	0	0.00	0	0.00	15.64	3.5	5.3	5	2_8

Table A2:7: 40% RAP aggregate gradation for binder course

Aggregate type	RAPA		Aggregate 1 (9.5-25mm) sieve		Aggregate 2(2.36-9.5mm) sieve		Aggregate 3 (0-2.36mm) sieve		Total Blend	Middle value	Design Specific
Blend %	40 %		18.6 %		22.2 %		19.2 %				
	%	%	%	%	%	%	%	%			
sieve (mm)	Pass	Blend (A)	Pass	Blend (B)	Pass	Blend (C)	Pass	Blend (D)	A+B+C+D		
25	100	40	100	18.6	100	22.20	100	19.20	100	100	100
19	92.3	36.92	78.13	14.53	100	22.20	100	19.20	92.9	95	90-100
12.5	75.9	30.36	31.2	5.42	100	22.20	100	19.20	77.2	79.5	-----
9.5	72.5	29.0	5.7	1.00	89.1	18.96	100	19.20	68.2	68	56-80
4.75	57.4	22.96	1.1	0.50	42.6	8.19	99.1	19.03	50.7	50	35-65
2.36	38.7	15.48	0.6	0.43	7.30	1.63	93.2	17.89	35.4	36	23-49
1.18	23.9	9.56	0.4	0.38	4.6	1.02	70.8	13.59	24.6	26	---
0.6	13.8	5.52	0.2	0.27	2.10	0.47	52.7	10.12	16.4	19	----
0.3	10.9	4.36	0.1	0.23	1.20	0.32	35.2	6.76	11.7	12	5_19
0.15	8.7	3.48	0	0.00	1	0.28	23.4	4.49	8.3	8.5	----
0.075	6	2.40	0	0.00	0	0.00	15.64	3.00	5.4	5	2_8

Table A2:8:50% RAPA Gradation for binder course

Aggregate type	RAP		Aggregate 1 (9.5-25mm) sieve		Aggregate 2(2.36-9.5mm) sieve		Aggregate 3 (0-2.36mm) sieve		Total Blend	Middle value	Design Specific
Blend %	50 %		15.5 %		18.5 %		16 %				
	%	%	%	%	%	%	%	%			
sieve (mm)	Pass	Blend (A)	Pass	Blend (B)	Pass	Blend (C)	Pass	Blend (D)	A+B+C+D		
25	100	50	100	15.5	100	18.50	100	16.00	100	100	100
19	92.3	46.15	78.13	12.11	100	18.50	100	16.00	92.8	95	90-100
12.5	75.9	37.95	31.2	4.52	100	18.50	100	16.00	77.0	79.5	-----
9.5	72.5	36.25	5.7	0.84	89.1	15.80	100	16.00	68.9	68	56-80
4.75	57.4	28.7	1.1	0.42	42.6	6.82	99.1	15.86	51.8	50	35-65
2.36	38.7	19.35	0.6	0.36	7.30	1.36	93.2	14.92	36.0	36	23-49
1.18	23.9	11.95	0.4	0.31	4.6	0.85	70.8	11.33	24.4	26	---
0.6	13.8	6.9	0.2	0.22	2.10	0.39	52.7	8.43	15.9	19	----
0.3	10.9	5.45	0.1	0.19	1.20	0.26	35.2	5.63	11.5	12	5_19
0.15	8.7	4.35	0	0.00	1	0.23	23.4	3.74	8.3	8.5	----
0.075	6	3	0	0.00	0	0.00	15.64	2.50	5.5	5	2_8

Appendix B: Aggregate quality test and Result for RAPA and crushed aggregate

A. Aggregate Crushing Value (A.C.V %)

TEST METHOD B. S 812 Parts 110 (1990)

Table B 1: aggregate crushing value test result for crushed and RAPA

1. Aggregate crushing value for crushed aggregate				
Test No	Mass of Sample (A) gm	Mass of proportion passing B.S 2.36 mm sieve (B) after crushing	Aggregate Crushing Value (A.C.V %)	
			Individual (B/A*100)	Average %
1	**2566.6**	**382.4**	**14.89**	**14.70**
2	**2566.6**	**372.3**	**14.51**	
2. Aggregate crushing value for RAPA				
Test No	Mass of Sample (A) gm	Mass of proportion passing B.S 2.36 mm sieve (B) after crushing	Aggregate Crushing Value (A.C.V %)	
			Individual (B/A*100)	Average %
1	**2750**	**409.3**	**14.88**	**15.91**
2	**2750**	**465.8**	**16.94**	

B. Aggregate impact value (A.I.V %) (For crushed aggregate)

Table B 2: Aggregate Impact value test result for crushed and RAPA

1. Aggregate impact value result for crushed aggregate TEST METHOD B.S Parts 112 (1990)			
s. no	Details	Trail number	
		1	2
1	Total Weight of aggregate sample filling the cylindrical measure=w1	566.7	566.7
2	Weight of aggregate passing 2.36 mm sieve after the test=w2	41.8	29.7
3	Weight of aggregate retained on 2.36 mm sieve after the test=w3	524.9	537
4	W2=W1-W3	41.8	29.7
5	Aggregate impact value=w2/w1*100	7.4%	5.24%
Average		6.32%	
2. Aggregate impact value result for RAPA TEST METHOD B.S Parts 112 (1990)			
1	Total Weight of aggregate sample filling the cylindrical measure=w1	598	598
2	Weight of aggregate passing 2.36 mm sieve after the test=w2	108.1	95.4
3	Weight of aggregate retained on 2.36 mm sieve after the test=w3	489.9	502.6
4	W2=W1-W3	108.1	95.4
5	Aggregate impact value=w2/w1*100	18.1	16.0
Average		**17.05**	

C.LOS ANGELS ABRASION VALUE
TEST METHOD AASHTO T-96
Table B 3: Los angles abrasion value test result

Grading of test sample	Trails	Fraction and Mass		No of spheres	Mass of sample retained on 1.70 mm sieve after washing and oven-dried (B)	Loss through 1.70 mm sieve (g) A-B=C	Loss Angles Abrasion (LAA) (%)
		Fraction	Mass (g) A				
B	1	19-12.5	2500	11	4430	5000-4430=570	570/5000*100=11.4%
		12.5-9.5	2500				
	2	19-12.5	2500	11	4412	5000-4412=588	588/5000*100= 11.76%
		12.5-9.5	2500				
	Average						11.58%

D.Specific gravity and absorption of Coarse (9.5-25 mm) aggregate for 0% to 40% RAP

TEST METHOD: AASHTO T 85-91

Table B 4: Specific gravity and absorption of Coarse (9.5-25 mm) aggregate for 0% to 40% RAPA

Trail No:	0% RAPA			10% RAPA			20% RAPA			30% RAPA			40% RAPA		
	1	**2**	**Av**	**1**	**2**	**Av**	**1**	**2**	**Av**	**1**	**2**	**Av**	**1**	**2**	**Av**
B. mass of SSD sample in the air (gm)	2500	2400		200	2100		2020	2105		2070	2125		2040	2033	
C. Mass of saturated sample in water (gm)	1543	1508.5		1229.2	1278.6		1232.2	1277.4		1270.2	1324.4		1243.1	1242.2	
A. Mass of Oven dry sample (gm)	2469.1	2368.2		1971.1	2075.2		1984.1	2070.2		2031.1	2087.2		2002.8	1993.6	
Bulk sp, gravity (Oven dry) sd=A*k/(B-C)	2.580	2.656	**2.618**	2.557	2.526	**2.542**	2.519	2.501	**2.510**	2.540	2.607	**2.573**	2.513	2.521	**2.517**
Bulk sp. gravity (SSD) SS=B*k/(B-C)	2.612	2.692	**2.652**	2.595	2.557	**2.576**	2.564	2.543	**2.554**	2.588	2.654	**2.621**	2.560	2.571	**2.565**
Apparent specific gravity sr=A*k/(A-C)	2.666	2.755	**2.710**	2.657	2.605	**2.631**	2.639	2.611	**2.625**	2.669	2.736	**2.703**	2.636	2.653	**2.645**
Water Absorption Aw= (B-C)*100/A	1.3	1.3	**1.3**	1.5	1.2	**1.3**	1.81	1.68	**1.7**	1.92	1.81	**1.86**	1.86	1.98	**1.92**

Table B 5: Specific gravity and absorption of intermediate (2.36-9.5mm) aggregate

Trail	0% RAPA			10% RAPA			20% RAPA			30% RAPA			40% RAPA		
	1	2	Av	1	2	Av	1	2	Av	1	2	Av	1	2	Av
B. mass of SSD sample in the air (gm)	2000	2000		2000	2000		2040	2033		2060	2053		2050	2125	
C. Mass of saturated sample in water (gm)	1244.2	1245.1		1223.8	1221.5		1239.8	1237.6		1257.3	1260.9		1232	1311.5	
A. Mass of Oven dry sample (gm)	1974.8	1971.6		1975.8	1970.6		2003.8	1998.6		2020.8	2016.6		2010.4	2085.2	
Bulk sp, gravity (Oven dry) sd=A*k/(B-C)	2.613	2.612	2.612	2.545	2.531	2.538	2.504	2.513	2.508	2.518	2.546	2.532	2.458	2.563	2.510
Bulk sp. gravity (SSD) SS=B*k/(B-C)	2.646	2.649	2.648	2.577	2.569	2.573	2.549	2.556	2.553	2.566	2.592	2.579	2.506	2.612	2.559
Apparent specific gravity sr=A*k/(A-C)	2.704	2.714	2.708	2.627	2.631	2.629	2.623	2.626	2.625	2.647	2.669	2.658	2.583	2.695	2.639
Water Absorption Aw= (B-C)*100/A	1.28	1.44	1.36	1.2	1.5	1.4	1.81	1.72	1.76	1.94	1.81	1.87	1.97	1.91	1.94

D. Specific gravity and absorption of Finer (0-2.36mm size) aggregate for 0% to 40 RAPA
TEST METHOD: AASHTO T 84-95

Table B 6: Specific gravity and absorption of intermediate (2.36-9.5mm) aggregate

Trail	0% RAPA			10% RAPA			20% RAPA			30% RAPA			40% RAPA		
	1	2	Av	1	2	Av	1	2	Av	1	2	Av	1	2	Av
B. mass of Pycnometer + Water (gm)	700	695		780	793		787	775		785	773		780	782	
S. Mass of SSD Sample gm)	253	248		233	248		253	278		243	268		263	288	
C. mass of Pycnometer + Water + sample (gm)	856.8	850.30		923.5	943.1		941.1	943.7		934.07	935.12		939.5	956.8	
Mass of Oven –dry sample in air	248.9	243.9		229.2	243.6		248	273.1		238.4	263.3		257.8	282.7	
Bulk specific gravity (oven dry) Sd=A*K/(B+S-C)	2.587	2.631	2.609	2.561	2.488	2.525	2.508	2.499	2.503	2.538	2.487	2.512	2.491	2.497	2.494
Bulk specific gravity (SSD) Ss=S*k/(B+S-C)	2.630	2.675	2.653	2.603	2.533	2.568	2.558	2.543	2.551	2.587	2.531	2.559	2.541	2.544	2.543
Apparent specific gravity Sr=A*k/(A+B-C)	2.702	2.753	2.728	2.674	2.605	2.640	2.641	2.616	2.629	2.669	2.602	2.636	2.623	2.620	2.621
Water absorption (%) Aw=(S-A)*100/A	1.6	1.7	1.66	1.66	1.81	1.73	2.0	1.89	1.905	1.93	1.79	1.86	2.02	1.87	1.95

Table B 7: Specific Gravity of crushed stone dust filler

Matreial type	**Crushed stone dust filler**	
Pycnometer No.	**1**	**2**
B. Mass of Pycnometer + Water, g	97.2	95.3
C. Mass of pycnometer + water + sample, g	104.58	102.58
A. Mass of oven dry sample in air, g	12.35	11.8
Apparent specific gravity Sr = A*k/(A+B-C)	2.485	2.61
Average	2.548	

Appendix C. Bitumen Quality Test and Result

Table C: Bitumen Quality Test and Result

1.Penetration test
Test Method AASHTO T 49

Test No	Test temp (C^0)	Time of test (S)	Test load	Reading (0.1mm)			Average (0.1mm)
				1^{st} time	2^{nd} time	3^{rd} time	
1	25	5	100	64.2	65.1	63.5	64.03
2	25	5	100	67.2	63.8	62.7	64.57
3	25	5	100	65.7	67.3	66.2	66.40
Average penetration							65.00

2.Ductility
Test method-AASHTO T51

Test No	Test temp (C^0)	Speed (cm/min)	Ductility (cm)	Average (cm)
1	25	5	109	108
2	25	4	107	
3	25	5	108	

3.Softening point
Test Method AASHTO T 53

Test No	The temperature when starting to heating (C^o)	Record of liquid temp. in beaker			Softening point (C^0)
		4min	5min	6min	
1	24	32	40	46	46.15
2	24	34	42	48	48.25
Average					47.2

4.Specific Gravity of bitumen
Test Method ASTM D 70-97

Group	Weight					
	Pycnometer (A) gm	Pycnometer +water (B) gm	Pycnometer + Asphalt (C) gm	Pycnometer + water + asphalt (D) gm	Relative Density= $\frac{C-D}{(B-A)-(D-C)}$	Specific Gravity= Relative density * Density of water (0.997gm/cm^3)
1	31.89	130.43	108.06	132.49	1.027	1.024

Appendix D: Theoretical Maximum specific gravity of compacted mixture
TEST METHOD: ASTM DESIGNATION D: 2041-90

Table D1: Theoretical Maximum specific gravity of 0% RAPA trail 2

Bitumen Content (%)	**Ac 4.0%**		**Ac 4.5. %**		**Ac 5.0.%**		**Ac 5.5.%**		**Ac 6.0%**	
Trial Number	1	2	1	2	1	2	1	2	1	2
A. Mass of Dry Sample in Air	1230.2	1230.5	1232.5	1237.6	1243.3	1245.4	1226.7	1221.3	1235.1	1233.6
B. Mass of Jar Filled With Water	2427.6	2429.4	2427.6	2429.4	2427.6	2429.4	2427.6	2429.4	2427.6	2429.4
C. Mass of Jar Filled With Water + Sample	3159.8	3154.6	3157.4	3159.2	3162	3163.9	3150.7	3149.8	3150.4	3147.1
Maximum Theoretical Specific Gravity (Gmm) = K*A/(A+B-C)	2.470	2.435	2.452	2.437	2.443	2.438	2.436	2.438	2.411	2.391
Average of(Gmm)	**2.453**		**2.444**		**2.440**		**2.437**		**2.401**	

Table D2: Theoretical Maximum specific gravity of 10% RAPA

Bitumen content (%)	**Ac 4.0%**		**Ac 4.5.%**		**Ac 5.0.%**		**Ac 5.5.%**		**Ac 6.0%**	
Trial Number	1	2	1	2	1	2	1	2	1	2
A. Mass of Dry Sample in Air	1200.3	1210.5	1221.71	1207.5	1213.7	1215.5	1225.7	1227.3	1231.1	1232.9
B. Mass of Jar Filled With Water	2428	2430	2428	2430	2428	2430	2428	2430	2428	2430
C. Mass of Jar Filled With Water + Sample	3127.9	3134.2	3136.4	3131.8	3129.2	3133.1	3132.4	3132.8	3127.4	3128.1
Maximum Theoretical Specific Gravity (Gmm) = K*A/(A+B-C)	2.399	2.391	2.380	2.388	2.368	2.372	2.351	2.340	2.315	2.305
Average Maximum Theoretical Specific Gravity(Gmm)	**2.395**		**2.384**		**2.370**		**2.346**		**2.310**	

Table D3: Theoretical Maximum specific gravity of 20% RAPA

Bitumen content (%)	Ac 4.0%		Ac 4.5.%		Ac 5.0.%		Ac 5.5.%		Ac 6.0%	
Trial Name	1	2	1	2	1	2	1	2	1	2
A. Mass of Dry Sample in Air	1208.4	1212.7	1224.8	1213.2	1213.5	1216.7	1227.2	1228.3	1233.5	1231.9
B. Mass of Jar Filled With Water	2429	2431	2429	2431	2429	2431	2429	2431	2429	2431
C. Mass of Jar Filled With Water + Sample	3120.1	3130	3130.1	3125.1	3124.2	3126.1	3130.4	3133.6	3134.4	3133.5
Maximum Theoretical Specific Gravity = K*A/(A+B-C)	2.336	2.361	2.339	2.337	2.341	2.333	2.334	2.337	2.336	2.327
Average Maximum Theoretical Specific Gravity(Gmm)	**2.348**		**2.338**		**2.337**		**2.335**		**2.331**	

Table D4: Theoretical Maximum specific gravity of 30% RAPA

Bitumen content (%)	Ac 4.0%		Ac 4.5.%		Ac 5.0.%		Ac 5.5.%		Ac 6.0%	
Trial Number	1	2	1	2	1	2	1	2	1	2
A. Mass of Dry Sample in Air	1228.3	1226.3	1228.6	1217.5	1219.2	1222.3	1230.2	1238.3	1237.5	1236.9
B. Mass of Jar Filled With Water	2428	2430	2428	2430	2428	2430	2428	2430	2428	2430
C. Mass of Jar Filled With Water + Sample	3140.1	3145	3138.1	3132.4	3129.5	3131.1	3135.7	3135.8	3134	3132
Maximum Theoretical Specific Gravity = K*A/(A+B-C)	2.380	2.398	2.370	2.364	2.355	2.345	2.354	2.325	2.328	2.312
Average Maximum Theoretical Specific Gravity(Gmm)	**2.389**		**2.367**		**2.350**		**2.340**		**2.320**	

Table D5: Theoretical Maximum specific gravity of 40% RAPA

Bitumen Content (%)	**Ac 4.0%**		**Ac 4.5.%**		**Ac 5.0.%**		**Ac 5.5.%**		**Ac 6.0%**	
Trial Number	1	2	1	2	1	2	1	2	1	2
A. Mass of Dry Sample in Air	1218.1	1216.4	1217.7	1217.5	1219.8	1212.4	1228.3	1234.3	1235.8	1234.2
B. Mass of Jar Filled With Water	2427.4	2429	2427.4	2429	2427.4	2429	2427.4	2429	2427.4	2429
C. Mass of Jar Filled With Water + Sample	3127.1	3123.5	3132.1	3132.4	3126.5	3124.4	3131.9	3131.8	3138.8	3138
Maximum Theoretical Specific Gravity = K*A/(A+B-C)	2.350	2.331	2.374	2.368	2.343	2.345	2.345	2.322	2.357	2.350
Average Maximum Theoretical Specific Gravity(Gmm)	**2.340**		**2.371**		**2.344**		**2.334**		**2.353**	

Table D6: Theoretical Maximum specific gravity of 50% RAPA

Bitumen content (%)	**Ac 4.0%**		**Ac 4.5.%**		**Ac 5.0.%**		**Ac 5.5.%**		**Ac 6.0%**	
Trial Number	1	2	1	2	1	2	1	2	1	2
A. Mass of Dry Sample in Air	1227.3	1232.5	1224.7	1226.2	1233.8	1234.4	1227.6	1228.3	1231.7	1233.1
B. Mass of Jar Filled With Water	2428	2430	2428	2430	2428	2430	2428	2430	2428	2430
C. Mass of Jar Filled With Water + Sample	3139.9	3141.8	3138.1	3137	3140.2	3142.4	3136.2	3137.1	3139.8	3139
Maximum Theoretical Specific Gravity (Gmm) = K*A/(A+B-C)	2.381	2.367	2.380	2.362	2.365	2.365	2.363	2.357	2.369	2.353
Average Maximum Theoretical Specific Gravity(Gmm)	**2.374**		**2.371**		**2.365**		**2.360**		**2.361**	

APPENDIX E: Marshall Test Result for Control and Mix RAPA Proportion

Table E1: Marshall Test result of control mix for trail one

MARSHALL PROPERTIES OF BITUMINOUS MIXTURE ASTM D1559				All mix performed with 0% RAPA & 100%Crushed Aggregate by weight of the total mix	S.G of Aggregate & prop		
Tested by	Diriba A	Aggregate & bitumen source	ERA		Size (mm)	prop	Gsb
Test description	Binder course	Marshall compaction	2*75 Blow		a. (9-25 mm	25.6	2.618
Test purpose	research	Bitumen grade	60/70		b.2.36-9.5 m	36	2.612
T. lab. name	JiT, Highway la	Bitumen S.G	1.024		c.0-2.36mm	38.4	2.609
Bulk.s.G.ag	**2.612**	Test temp	60 ^{0}C		Total prop	100	
		The combined specific gravity of RAP & crushed aggregate (Gsb)					**2.612**

BC %	Spec. height	Gmm	Mass of specimen in			Volume Specimen	Gmb	VA (%)	VMA (%)	VFA (%)	Stability		Flow mm
			Air dry	water	Ai SSD						Pick Load	Stability	
A	B	C	D	E	F	G	H	I	J	K	KN	KN	
						F-E	D/G	(C-H)*100/C	100-[(100-A)*H/Gsb	(J-I)*100/J			
4	69.5		1227.8	699.9	1229.5	529.6	2.318	5.6	14.8	62.1	9.59	8.3	2.58
	68.9		1225.3	699.7	1227.4	527.7	2.322	5.5	14.7	62.8	9.33	8.2	2.54
	68.7		1226.6	698.6	1228.3	529.7	2.316	5.7	14.9	61.7	9.73	8.6	2.57
Av	69.0	2.456	1226.6	699.4	1228.4	529.0	2.319	5.6	14.8	62.2	9.55	8.4	2.56
4.5	69.1		1218.3	697.6	1220.8	523.2	2.329	4.5	14.9	69.8	10.41	9.1	2.59
	69.3		1217.4	696.2	1219.4	523.2	2.327	4.6	14.9	69.5	11.15	9.7	2.61
	68.7		1222.9	703.7	1223.3	519.6	2.354	3.5	14.0	75.2	11.20	9.9	2.63
Av	69.0	2.438	1219.5	699.2	1221.2	522.0	2.336	4.2	14.6	71.5	10.92	9.6	2.61
5.0	68.0		1223.7	701.1	1223.9	522.8	2.341	3.8	14.9	74.8	11.23	10.1	2.98
	68.5		1218.6	697.3	1219.6	522.3	2.333	4.1	15.2	73.2	11.82	10.5	3.04
	68.4		1217.4	699.7	1220.1	520.4	2.339	3.8	14.9	74.5	12.47	11.1	3.11
Av	68.3	2.432	1219.9	699.4	1221.2	521.8	2.338	3.9	15.0	74.1	11.84	10.6	3.04
5.5	68.3		1215.8	695.1	1216.6	521.5	2.331	3.8	15.7	75.9	10.98	9.8	3.18
	68.4		1214.7	694.2	1215.3	521.1	2.331	3.8	15.7	75.8	10.78	9.6	3.22
	68.2		1217.6	696.3	1219.1	522.8	2.329	3.9	15.8	75.4	10.17	9.1	3.37
Av	68.3	2.423	1216.0	695.2	1217.0	521.8	2.330	3.8	15.7	75.7	10.64	9.5	3.26
6.0	67.6		1218.2	698.4	1220.4	522.0	2.334	2.7	16.0	83.0	9.68	8.8	3.43
	67.9		1216.7	695.7	1218.2	522.5	2.329	2.9	16.2	81.9	9.53	8.6	3.47
	67.2		1219.5	699.2	1221.2	522.0	2.336	2.6	15.9	83.6	8.60	7.9	3.46
Av	67.6	2.399	1218.1	697.8	1219.9	522.2	2.333	2.8	16.1	82.8	9.3	8.4	3.45

Table E 2 Marshall Test result of control mix trail two

MARSHALL PROPERTIES OF BITUMINOUS MIXTURE ASTM D1559				All mix performed with 0% RAP & 100%Crushed Aggregate By weight of the total mix	S.G of Aggr & prop		
Tested by	Diriba A	Aggr & bitumen source	ERA		Size (mm)	prop	Gsb
Test disruption	Binder course	Marshall compaction	2*75blow		a. (9-25 mm)	31	2.618
Test purpose	Research	Bitumen grade	60/70		b.2.36-9.5 mm	37	2.612
					c.0-2.36mm	32	2.609
T. lab. name	JiT, Highway lab	Bitumen S.G	1.024		Total prop	100	
Bulk.s.G.agg	2.613	Test Temp	60 ^{0}C				2.613
		The Combined specific gravity of crushed aggregate (Gsb)					

BC %	Spec. height	Gmm	Mass of specimen in Air dry	water	Ai SSD	Volume Specimen	Gmb	VA (%)	VMA (%)		stability Pick Load (KN)	Stability (KN)	Flow (mm
A	B	C	D	E	F	G	H	I	J	K			
						F-E	D/G	(C-H)*100/C	100-[(100-A)*H/Gs	(J-I)*100/J			
4	70.2		1208.8	695.2	1220.7	525.5	2.300	6.2	15.5	59.8	10.47	8.9	2.58
	70.3		1212.1	696.7	1224.9	528.2	2.295	6.5	15.7	58.9	10.26	8.7	2.65
	70.0		1214.5	694.8	1221.7	526.9	2.305	6.0	15.3	60.6	11.12	9.5	2.61
Av	70.2	2.453	1211.8	695.6	1222.4	526.9	2.300	6.2	15.5	59.8	10.62	9.0	2.61
4.5	70.2		1216.2	695.1	1217.5	522.4	2.328	4.7	14.9	68.3	11.53	9.8	2.71
	70.3		1215.6	692.2	1215.7	523.5	2.322	5.0	15.1	67.2	12.38	10.5	2.67
	69.7		1213.9	692.7	1214.1	521.4	2.328	4.7	14.9	68.3	14.63	12.6	2.56
Av	70.1	2.444	1215.2	693.3	1215.8	522.4	2.326	4.8	15.0	67.9	12.85	11.0	2.65
5.0	70.2		1212.8	697.1	1213.5	516.4	2.349	3.7	14.6	74.4	14.82	12.6	3.06
	71.3		1210.6	693.3	1212.7	519.4	2.331	4.5	15.3	70.7	15.37	12.7	3.23
	69.5		1211.9	694.7	1212.1	517.4	2.342	4.0	14.8	73.0	16.29	14.1	3.03
Av	70.3	2.440	1211.8	695.0	1212.8	517.7	2.341	4.1	14.9	72.7	15.50	13.1	3.11
5.5	70.6		1208.2	695.1	1209.5	514.4	2.349	3.6	15.1	75.9	14.86	12.5	3.21
	70.3		1209.6	692.2	1210.7	518.5	2.333	4.3	15.6	72.7	14.51	12.3	3.32
	70.4		1208.9	692.7	1209.1	516.4	2.341	3.9	15.3	74.3	14.07	11.9	3.34
Av	70.4	2.437	1208.9	693.3	1209.8	516.4	2.338	3.9	15.3	74.3	14.48	12.2	3.29
6.0	68.7		1217.2	698.1	1217.5	519.4	2.343	2.4	15.7	84.7	12.00	10.6	3.35
	69.5		1216.6	696.2	1217.7	521.5	2.333	2.8	16.1	82.4	12.13	10.5	3.39
	69.7		1214.9	695.7	1215.1	519.4	2.339	2.6	15.9	83.7	12.08	10.4	3.31
Av	69.3	2.401	1216.2	696.7	1216.8	520.1	2.338	2.6	15.9	83.6	12.1	10.5	3.35

Table E3: Marshall Test Result of control mix trail three

MARSHALL PROPERTIES OF BITUMINOUS MIXTURE ASTM D1559				All mix performed with 0% RAPA & 100%Crushed Aggregate by weight of the total mix	S.G of Aggr & prop		
Tested by	Diriba A	Aggr & B. source	ERA				
Test description	Binder course	Marshall com	2*75 blows		F .size mm	prop	Gsb
Test purpose	Research	Bitumen grade	60/70		a.9-25mm	28.8	2.618
					B,2.36-9.5	36	2.612
T. lab. name	JiT, Highway lab	Bitumen S.G	1.024		c.0-2.36	35.18	2.609
Bulk.s.G.aggr .	2.613	Test Temp	60 ^{0}C		Total pro	100	2.613
		The combined specific gravity of crushed aggregate					

BC %	Spec. height	Gmm	Mass of specimen in			Volume Specimen	Gmb	VA (%)	VMA (%)	VFA (%)	stability		Flow
			Air d	water	Ai SSD								
A	B	C	D	E	F	G	H	I	J	K	Pick Load KN	Stab Lity KN	mm
						F-E	D/G	(C-H)*100/C	100-[(100-A)*H/Gsb	(J-I)*100/J			
4	71.5		1238.7	703.4	1245.7	542.3	2.284	7.2	16.1	55.1	10.46	8.6	2.53
	71.0		1232.1	702.7	1237.6	534.9	2.303	6.4	15.4	58.1	10.45	8.7	2.58
	70.6		1240.1	708.6	1246.3	537.7	2.306	6.3	15.3	58.6	10.58	8.9	2.61
Av	71.0	2.462	1236.97	704.9	1243.2	538.3	2.298	6.7	15.6	57.2	10.50	8.7	2.57
4.5	70.2		1233.4	704.1	1235.7	531.6	2.320	5.7	15.2	62.6	11.41	9.7	2.62
	70.4		1235.5	701.2	1236.9	535.7	2.306	6.2	15.7	60.2	11.71	9.9	2.64
	69.7		1232.9	703.7	1233.1	529.4	2.329	5.3	14.9	64.2	12.43	10.7	2.58
Av	70.1	2.460	1233.9	703.0	1235.2	532.2	2.318	5.8	15.3	62.3	11.85	10.1	2.61
5.0	70.0		1242.8	713.1	1243.7	530.6	2.342	4.2	14.8	71.4	12.76	10.9	2.89
	70.2		1248.6	715.3	1249.9	534.6	2.336	4.5	15.1	70.1	13.88	11.8	3.08
	69.2		1247.3	714.7	1249.1	534.4	2.334	4.6	15.1	69.7	13.41	11.7	3.01
Av	69.8	2.446	1246.2	714.4	1247.6	533.2	2.337	4.4	15.0	70.4	13.35	11.5	2.99
5.5	70.4		1241.2	713.1	1246.3	533.2	2.328	3.9	15.8	75.1	13.60	11.5	3.25
	69.7		1239.6	712.8	1243.2	530.4	2.337	3.5	15.5	77.1	14.29	12.3	3.29
	70.2		1238.6	711.7	1242.1	530.4	2.335	3.6	15.5	76.7	13.41	11.4	3.35
Av	70.1	2.423	1239.8	712.5	1243.9	531.3	2.333	3.7	15.6	76.3	13.77	11.7	3.30
6.0	69.7		1237.2	709.5	1240.5	531.0	2.330	3.4	16.2	79.0	11.85	10.2	3.39
	69.5		1238.3	710.4	1241.7	531.3	2.331	3.4	16.1	79.1	11.67	10.1	3.42
	69.4		1236.4	705.9	1237.1	531.2	2.328	3.5	16.3	78.5	11.06	9.6	3.48
Av	69.5	2.412	1237.3	708.6	1239.8	531.2	2.329	3.4	16.2	78.9	11.5	10.0	3.43

Table E4: Marshall Test Result of 10% RAPA mix proportion

MARSHALL PROPERTIES OF BITUMINOUS MIXTURE -ASTM - D1559				All mix performed with 10% RAPA & 90%Crushed Aggregate by weight of the total mix	S.G of Aggregate & proportion of aggregate size		
Tested by	Diriba A	Aggregate &bitumen source	ERA				
Test description	Binder course	Marshall compact	2*75 blow		Size (mm)	prop	Gsb
Test purpose	Research	Bitumen grade	60/70		a. 9-25	31	2.542
T. lab. name	JiT, Highway lab	Bitumen S.G	1.024		b.2.36-9.5	37	2.538
Bulk.s.G.agg	**2.535**	Testing temperature	60 ^{0}C		c. 0-2.36	32	2.525
					total	100	
		The combined specific gravity of RAP & Crushed aggregate					**2.535**

BC %	Spec. heigh	Gmm	Mass of specimen in Air dry	water	Ai SSD	Volume Specimen	Gmb	VA (%)	VMA (%)	VFA (%)	**Stability** Pick Load	**Stab Lity**	**Flow (mm)**
A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**			
						F-E	D/G	(C-H)*100 /C	100-[(100-A)*H/Gsb	(J-I)*100/J	KN	**KN**	
4.0	69.5		1231.1	695.4	1242.7	547.3	2.249	6.1	14.8	59.0	10.28	8.9	2.54
	70.3		1222.8	679.6	1231.0	551.4	2.218	7.4	16.0	53.8	10.73	9.1	2.61
	70.2		1227.0	687.5	1232.0	544.5	2.253	5.9	14.7	59.7	10.35	8.8	2.78
Av	70.0	2.395	1227.0	687.5	1235.2	547.7	2.240	6.5	15.2	57.5	10.46	8.9	2.64
4.5	69.4		1222.4	687.4	1228.1	540.7	2.261	5.2	14.8	65.2	12.69	11.0	2.74
	70.5		1222.9	686.3	1230.9	544.6	2.246	5.8	15.4	62.3	12.09	10.2	2.72
	69.7		1233.5	684.4	1230.2	545.8	2.260	5.2	14.9	65.0	11.03	9.5	2.95
Av	69.9	2.384	1226.3	686.0	1229.7	543.7	2.255	5.4	15.0	64.1	11.94	10.2	2.80
5.0	70.4		1230.1	693.2	1230.2	537.0	2.291	3.3	14.2	76.4	12.30	10.4	3.21
	70.5		1243.1	694.2	1243.3	549.1	2.264	4.5	15.2	70.5	12.21	10.3	2.93
	69.3		1236.5	691.6	1236.9	545.3	2.268	4.3	15.0	71.2	11.72	10.2	3.28
Av	70.1	2.370	1236.6	693.0	1236.8	543.8	2.274	4.0	14.8	72.7	12.08	10.3	3.14
5.5	70.4		1219.2	690.3	1220.4	530.1	2.300	2.0	14.3	86.2	11.12	9.4	3.34
	69.5		1211.1	678.2	1212.2	534.0	2.268	3.3	15.5	78.5	11.21	9.7	3.28
	69.7		1215.2	674.7	1217.3	542.6	2.240	4.5	16.5	72.5	10.22	8.8	3.44
Av	69.9	2.346	1215.2	681.1	1216.6	535.6	2.269	3.3	15.4	79.1	10.85	9.3	3.35
6.0	70.5		1215.2	679.6	1218.2	538.6	2.256	2.3	16.3	85.8	9.25	7.8	3.81
	70.2		1223.5	686.5	1228.5	542.0	2.257	2.3	16.3	86.0	9.53	8.1	4.22
	69.4		1219.4	684.6	1219.6	535.0	2.279	1.3	15.5	91.4	8.30	7.2	4.23
Av	70.0	2.310	1219.4	683.6	1222.1	538.5	2.264	2.0	16.0	87.7	9.0	7.7	4.09

Table E5: Marshall Test Result of 20% RAPA mix proportion

MARSHALL PROPERTIES OF BITUMINOUS MIXTURE ASTM D1559				All mix performed with 20% RAPA & 80%Crushed Aggregate by weight of the total mix	S.G of Aggr & prop		
Tested by	Diriba A	Agg & bitumen sourc	ERA		F .size (mm)	prop	Gsb
Test description	Binder course	Marshall compaction	2*75 blows		a. 9-25mm	31	2.510
					b. 2.36-9.5	37	2.508
Test purpose	Research	Bitumen grade	60/70		c. 0-2.36mm	32	2.503
T. lab. name	JiT, Highway l	Bitumen S.G	1.024		Total prop	100	
		Test temp	60^0C				
Bulk.s.G.ag	**2.507**	The combined bulk specific gravity of RAP & Crushed aggregate					**2.507**

BC %	Spec. height	Gmm	Mass of specimen in Air dry	Mass of specimen in water	Mass of specimen in Air SSD	Volume of Specimen	Gmb	VA (%)	VMA (%)	VFA (%)	Stability Pick Load KN	Stability Stab Lity KN	Flow mm
A	**B**	**C**	**D**	**E**	**F**	**G** F-E	**H** D/G	**I** C-H)*100/C	**J** 100-[(100-A)*H/Gsb	**K** (J-I)*100/J			
4.0	69.5		1216.4	684.7	1226.5	541.8	2.245	4.4	14.0	68.9	10.28	8.9	2.85
	68.7		1212.2	679.1	1229.6	550.5	2.202	6.2	15.7	60.4	9.73	8.6	3.29
	70.5		1214.4	680.9	1226.6	545.7	2.225	5.2	14.8	64.8	10.31	8.7	3.21
Av	69.6	2.348	1214.3	681.6	1227.6	546.0	2.224	5.3	14.8	64.7	10.11	8.7	3.12
4.5	68.4		1238.3	696.4	1243.1	546.7	2.265	3.1	13.7	77.3	10.78	9.6	3.42
	69.3		1163.4	658.1	1189.2	531.1	2.191	6.3	16.6	61.9	11.27	9.8	2.81
	68.3		1200.5	685.1	1213.1	528.0	2.274	2.8	13.4	79.5	11.09	9.9	3.39
Av	68.7	2.338	1200.7	679.9	1215.1	535.3	2.243	4.1	14.6	72.9	11.05	9.8	3.21
5.0	69.2		1179.3	666.1	1192.1	526.0	2.242	4.1	15.0	73.0	10.89	9.5	3.26
	69.3		1220.3	689.2	1226.0	536.8	2.273	2.7	13.9	80.3	11.27	9.8	3.37
	68.4		1206.1	679.3	1218.1	538.8	2.238	4.2	15.2	72.2	10.33	9.2	3.48
Av	69.0	2.337	1201.9	678.2	1212.1	533.9	2.251	3.7	14.7	75.2	11.83	9.5	3.37
5.5	68.8		1219.0	687.7	1219.7	532.0	2.291	1.9	13.6	86.3	10.33	9.1	3.45
	68.9		1216.3	676.5	1216.5	540.0	2.252	3.5	15.1	76.6	10.92	9.6	3.52
	68.6		1217.2	667.1	1218.6	551.5	2.207	5.5	16.8	67.4	10.05	8.9	3.81
Av	68.8	2.335	1217.5	677.1	1218.3	541.2	2.250	3.6	15.2	76.8	10.43	9.2	3.59
6.0	70.0		1233.2	683.2	1233.9	550.7	2.239	3.9	16.0	75.5	9.48	8.1	3.92
	69.3		1230.1	681.6	1230.8	549.2	2.240	3.9	16.0	75.6	9.08	7.9	4.01
	69.7		1234.5	691.4	1235.3	543.9	2.270	2.6	14.9	82.4	8.71	7.5	4.12
Av	69.7	2.331	1232.6	685.4	1233.3	547.9	2.250	3.5	15.7	77.8	9.1	7.8	4.02

Table E6: Marshall Test Result of 30% RAPA mix proportion

MARSHALL PROPERTIES OF BITUMIOUS MIXTURE ASTM D1559				All mix performed with 30% RAPA & 70%Crushed Aggregate by weight of total mix	S.G of Aggregate & proportion		
Tested by	Diriba A	Aggr & bitumen source	ERA				
Test description	Binder course	Marshall compaction	2*75blow		Fr .size (mm)	prop	Gsb
Test purpose	Research	Bitumen grade	60/70		a.9-25mm	31	2.573
T. lab. name	JiT, Highway la	Bitumen S.G	1.024		b.2.36-9.5	37	2.532
Bulk.s.G.agg	**2.538**	Test temp	60^0C		c.0-2.36	32	2.512
					Total prop	100	**2.538**
		Combined specific gravity of crushed aggregate					

BC %	Spec heig	Gmm	Mass of specimen in			Volume Specimen	Gmb	VA (%)	**VMA (%)**	VFA (%)	Stability		Flow (mm)
			Air dr	water	Ai SS						Pick Load (KN)	Stab Lity (KN)	
A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**			
						F-E	D/G	C-H)*100/C	100-[(100-A)*H/Gsb	(J-I)*100/J			
4.0	67.2		1208.2	664.1	1216.5	552.4	2.187	8.4	17.3	51.1	7.84	7.2	3.21
	68.0		1209.5	691.2	1219.7	528.5	2.289	4.2	13.4	68.7	8.56	7.7	3.22
	68.1		1208.9	688.7	1217.1	528.4	2.288	4.2	13.5	68.6	8.36	7.5	3.25
Av	67.8	2.389	1208.9	681.3	1217.8	536.4	2.255	5.6	14.7	62.8	8.25	7.5	3.23
4.5	67.2		1245.4	697.2	1246.6	549.4	2.267	4.2	14.7	71.2	9.36	8.6	3.29
	67.7		1213.4	684.0	1218.3	534.3	2.271	4.1	14.5	72.1	9.82	8.9	3.39
	68.4		1214.4	686.1	1218.2	532.1	2.282	3.6	14.1	74.7	9.77	8.7	3.45
Av	67.8	2.367	1224.4	689.1	1227.7	538.6	2.273	4.0	14.5	72.7	9.65	8.7	3.38
5.0	68.3		1213.3	680.0	1214.6	534.6	2.270	3.4	15.1	77.3	9.97	8.9	3.57
	68.5		1227.2	685.4	1227.7	542.3	2.263	3.7	15.3	75.8	10.67	9.4	3.49
	68.1		1220.3	684.7	1221.4	536.7	2.274	3.2	14.9	78.2	10.14	9.1	3.59
Av	68.3	2.350	1220.3	683.4	1221.2	537.9	2.269	3.5	15.1	77.1	10.26	9.1	3.55
5.5	69.1		1215.4	680.2	1216.2	536.0	2.268	3.1	15.6	80.1	8.81	7.7	3.85
	69.2		1223.9	684.3	1224.3	540.0	2.266	3.1	15.6	79.9	9.75	8.5	3.82
	68.9		1219.7	683.8	1220.4	536.6	2.273	2.9	15.4	81.4	9.22	8.1	3.81
Av	69.1	2.340	1219.7	682.8	1220.3	537.5	2.269	3.0	15.5	80.5	9.26	8.1	3.83
6.0	68.4		1215.2	683.1	1216.1	533.0	2.280	1.7	15.6	88.9	9.32	8.3	3.41
	69.5		1232.1	688.3	1233.7	545.4	2.259	2.6	16.3	83.9	7.97	6.9	4.54
	70.0		1246.1	690.5	1247.3	556.8	2.238	3.5	17.1	79.3	7.61	6.5	4.12
Av	69.3	2.320	1231.1	687.3	1232.4	545.1	2.259	2.6	16.3	84.1	8.3	7.2	4.02

Table E7: Marshall Test Result of 40% RAPA mix proportion

MARSHALL PROPERTIES OF BITUMINOUS MIXTURE ASTM D1559				All mix performed with 40% RAPA &60%Crushed Aggregate by weight of the total mix	S.G of Aggr & prop		
Tested by	Diriba A	Aggr & bitumen source	ERA		Fr.size mm	prop	Gsb
Test description	Binder cours	Marshall comp	2*75blow		a.9-25mm	31	2.517
Test purpose	Research	Bitumen grade	60/70		b.2.36-9.5	37	2.510
T. lab. name	JiT, Highway	Bitumen S.G	1.024		c.0-2.36	32	2.494
Bulk.s.G.ag	2.507	Testing temp	60^0C		Total prop	100	**2.507**
		The combined specific gravity of RAP and crushed aggregate					

BC %	Spec. heigh	Gm	Mass of specimen in			Volume of spe	Gmb	VA (%)	VMA (%	VFA (%	Stability		Flow (mm)
			Air dr	w	Ai SS						Pick Load (KN)	Stab Ility (KN)	
A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**			
						F-E	D/G	(C-H)*100/C	100-[(100-A)*H/Gsb	(J-I)*100/J			
4.0	70.5		1213.6	679.6	1225.1	545.5	2.225	4.9	14.8	66.7	8.65	7.3	3.51
	70.3		1214.6	689.2	1224.0	534.8	2.271	2.9	13.0	77.4	8.96	7.6	3.61
	70.2		1215.6	680.9	1224.1	543.2	2.238	4.4	14.3	69.5	8.59	7.3	3.68
Av	70.3	2.340	1214.6	683.2	1224.4	541.2	2.245	4.1	14.0	71.2	8.74	7.4	3.60
4.5	69.3		1214.8	691.9	1219.5	527.6	2.303	2.9	12.3	76.5	8.51	7.4	3.90
	69.3		1217.1	688.8	1223.0	534.2	2.278	3.9	13.2	70.4	8.62	7.5	3.82
	69.7		1216.0	691.0	1218.3	527.3	2.306	2.7	12.2	77.5	8.83	7.6	3.91
Av	69.4	2.371	1216.0	690.6	1220.3	529.7	2.296	3.2	12.9	74.8	8.65	7.5	3.88
5.0	69.5		1222.6	687.5	1222.8	535.3	2.284	2.6	13.5	81.0	8.43	7.3	3.95
	70.2		1208.5	682.6	1209.0	526.4	2.296	2.1	13.0	84.2	8.71	7.4	3.98
	69.7		1215.6	686.0	1215.8	529.8	2.294	2.1	13.1	83.8	8.25	7.1	3.92
Av	69.8	2.344	1215.6	685.4	1215.9	530.5	2.291	2.2	13.2	83.0	8.46	7.3	3.95
5.5	68.6		1228.1	695.2	1230.0	534.8	2.296	1.6	13.4	88.0	7.68	6.8	4.01
	68.4		1226.7	689.0	1226.9	537.9	2.281	2.3	14.0	83.7	7.52	6.7	4.12
	68.8		1227.4	691.6	1227.0	535.4	2.292	1.8	13.6	86.9	7.81	6.9	4.21
Av	68.6	2.334	1227.4	691.9	1228.0	536.0	2.290	1.9	13.7	86.2	7.67	6.8	4.11
6.0	68.9		1233.2	693.1	1233.9	540.8	2.280	3.1	14.5	78.7	7.39	6.5	4.35
	69.3		1230.1	708.2	1230.8	522.6	2.291	0.0	11.7	100.3	7.59	6.6	4.41
	69.0		1234.5	709.8	1235.3	525.5	2.284	0.2	11.9	98.6	7.30	6.4	4.34
Av	69.1	2.353	1232.6	703.7	1233.3	529.6	2.285	1.1	12.8	92.5	7.4	6.5	4.37

Table E8: Marshall Test Result of 50% RAPA mix proportion

MARSHALL PROPERTIES OF BITUMIOUS MIXTURE ASTM D1559				All mix performed with 50% RAPA & 50%Crushed Aggregate by weight of total mix	S.G of Aggregate & prop.		
Tested by	Diriba A	Aggr & bitu men source	ERA		F size	prop	Gsb
Test descriptio	Binder course	Marshall Compaction	2*75blow		a.9-25mm	31	2.608
					b.2.36-9.5	37	2.501
Test purpos	Research	Bitumen grade	60/70		c.0-2.36mm	32	2.491
T. lab. nam	JiT, Highway l	Bitumen S.G	1.024		Total prop	100	
Bulk.S.G.agg	**2.530**	Testing temp	60^0C				**2.530**
		Combined bulk specific gravity of RAP & crushed aggregate					

BC %	Spec heig ht	Gmm	Mass of specimen in			Volume Speci men	Gmb	VA (%)	VMA (%	VFA (%)	stability		Flow (mm
			Air dry	water	Air SSD						Pick Load (KN)	Stab Ility (KN)	
A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**			
						F-E	D/G	(C-H)*100/C	100-[(100-A)*H/Gsb	(J-I)*100/J			
4.0	69.5		1207.7	687.2	1208.5	521.3	2.317	2.4	11.2	78.5	8.78	7.6	4.15
	70.5		1220.5	691.6	1222.6	531.0	2.298	3.2	11.9	73.4	7.82	6.6	4.10
	70.4		1214.1	688.6	1215.6	527.0	2.304	3.0	11.7	74.8	7.69	6.5	4.20
Av	70.1	2.374	1214.1	689.1	1215.6	526.4	2.306	2.9	11.6	75.6	8.10	6.9	4.15
4.5	69.7		1237.8	699.8	1239.6	539.8	2.293	3.3	12.6	73.9	8.25	7.1	4.91
	70.0		1213.4	688.1	1214.4	526.3	2.306	2.8	12.1	77.2	7.49	6.4	4.38
	71.0		1200.6	687.5	1204.0	516.5	2.324	2.0	11.4	82.8	7.33	6.1	4.61
Av	70.2	2.371	1217.3	691.8	1219.3	527.5	2.308	2.7	12.0	78.0	7.69	6.5	4.63
5.0	69.4		1221.3	695.1	1222.4	527.3	2.316	2.1	12.2	83.0	7.03	6.1	4.84
	69.5		1220.3	686.9	1221.7	534.8	2.282	3.5	13.5	73.9	7.16	6.2	4.92
	69.7		1200.1	685.3	1201.1	515.8	2.327	1.6	11.8	86.2	7.32	6.3	4.98
Av	69.5	2.365	1213.9	689.1	1215.1	526.0	2.308	2.4	12.5	81.1	7.17	6.2	4.91
5.5	69.2		1219.0	699.7	1220.7	521.0	2.340	0.9	11.8	92.7	6.76	5.9	5.24
	68.6		1216.3	689.5	1217.1	527.6	2.305	2.3	13.1	82.3	6.55	5.8	5.56
	68.7		1217.9	689.1	1218.2	529.1	2.302	2.5	13.2	81.3	5.89	5.2	5.72
Av	68.8	2.360	1217.7	692.8	1218.7	525.9	2.316	1.9	12.7	85.4	6.40	5.6	5.51
6.0	68.3		1219.2	689.2	1220.9	531.7	2.293	2.9	14.0	79.4	6.72	6.0	6.77
	67.9		1217.1	699.4	1219.8	520.4	2.339	0.9	12.3	92.3	5.39	4.9	7.02
	67.6		1220.5	698.5	1222.3	523.8	2.330	1.3	12.6	89.6	6.05	5.5	7.12
Av	67.9	2.361	1218.9	695.7	1221.0	525.3	2.321	1.7	12.9	87.1	6.1	5.5	6.97

APPENDIX F: Procedure of determination OBC according to Asphalt instutute method

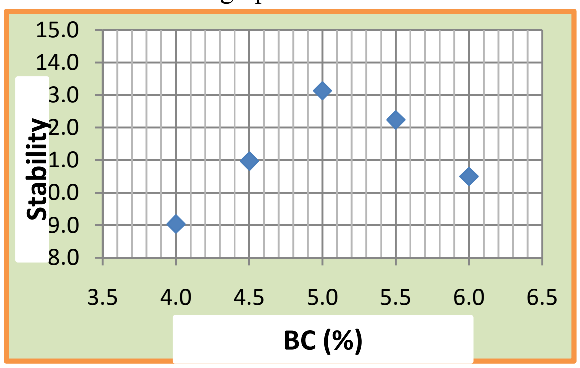
Table F1: Marshall Test result of control mix for the study (trail 2) OBC determination procedure

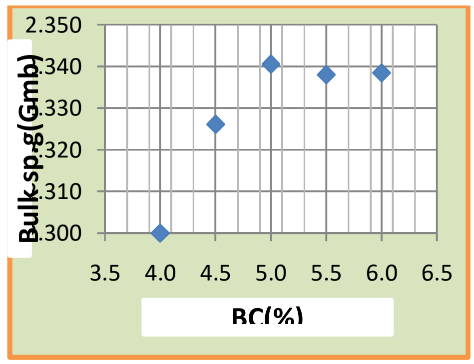
Summery of Volumetric properties and flow stablity result

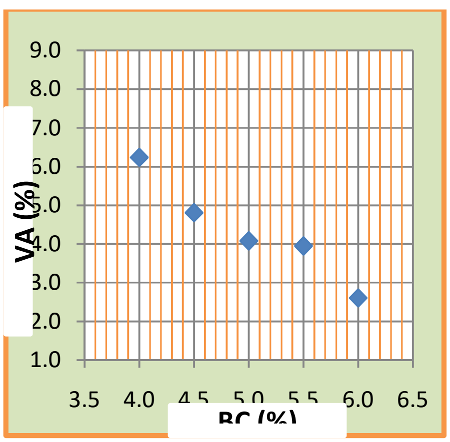
Bitumen content (BC) % by weight of total mix	Bulk specific Gravity of compacted specimen (Gmb)	Theorothical maximum specific gravity (Gmm)	Air Void in compacted mix (Va) %	Air Void In mineral Aggregate (VMA) %	Void Filled with Bitumen (VFB) %	Stablity (KN)	Flow in (mm)
4.0	2.300	2.453	6.2	15.5	59.8	9.0	2.61
4.5	2.326	2.444	4.8	15.0	67.9	11.0	2.65
5.0	2.341	2.440	4.1	14.9	72.7	13.1	3.11
5.5	2.338	2.437	3.9	15.3	74.3	12.2	3.29
6.0	2.338	2.401	2.6	15.9	83.6	10.5	3.35

To determine the Optimum bitumen content according to Asphalt institute Procedure

- 1st Plot the graph of Bitumen content versus stability and taken BC at maximum stability
- 2nd plot the Graph of Bitumen content versus bulk density and taken BC at max bulk Den
- 3rd Plot the graph of Bitumen content Versus Air void and taken BC at 4% air void







Since the BC at 4% VA is not getting directly from the table and graph we have interpolate and determine the BC at 4%VA

From the table above 4% VA exist between 4.1 VA @5BC&3.9VA@ 5.5BC

Interpolation

5=4.1
X=4
5.5=3.9
$\frac{5-x}{X-5.5} = \frac{4.1-4}{4-3.9}$
0.1(5-x) =0.1(x-5.5)
0.2x=1.05
X=5.25
So the BC@4%VA is 5.25

S/N	Bitumen at	BC%
1	BC at max stability (A)	5
2	BC at max bulk dens(B	5
3	BC at 4% air void(C)	5.25
OBC (%)=A+B+C/3		5.08

Bitumen content at max stability and max bulk density is gain from the table and plotted Graph directly. So the BC max stab=5% and Bulk D=5%

- After Optimum bitumen content is obtained we can determine Marshall Properties like flow, VMA, VFA air void, stability and etc with respect to Optimum bitumen content determined and compare to standard specification.

  Note: Optimum bitumen content of all RAP aggregate replacement and control mix is determined with the same procedure.

Appendix G: Some photos during Laboratory

Appendix F1: Selecting and preparation of Materials and test



(4:55 PM, June, 26, 2019) (12:19 PM, July, 26, 2019) (10:09 PM, July, 23, 2019)

Figure F1:1 RAP before crushing Fig F1.2 RAP after crushed and extracted (RAPA) Fig F1.3 washing of aggregate

(12:17 PM, July, 26, 2019)
Figure F1.3 Course aggregate prepared of both RAPA and crushed aggregates for the mix

(12:24 PM, July, 26, 2019)
F1.4 Fine Aggregate prepared of both RAPA and crushed aggregates for the mix

Appendix F2: some pictures of Test process

(6:38 PM, August, 14, 2019)
Figure F2.1 Gmm determination

(4:39 PM, August, 13, 2019)
Figure F2.2 Overnight cool of compacted mixture