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SCHOOL OF GRADUATE STUDIES

PARTIAL REPLACEMENT OF RECLAIMED ASPHALT PAVEMENT, (RAP) AND EXTRACTED BINDER IN HMA USING MARSHAL METHOD

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DECLARATION

I, the undersigned, declare that this thesis is my original work, and has not been presented in any University for a degree, and that all sources of materials used for this thesis have been duly acknowledged.

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ABSTRACT

The shortage of road construction materials and supplies along with the increase in processing and hauling cost has encouraged the use of Reclaimed Asphalt Pavement (RAP) materials in hot mix asphalt (HMA). The use of RAP is becoming a common practice around the world and involved a regular improvement in various countries. RAP has only limited application in Ethiopia.

The aim of this study is to evaluate the effect of RAP in HMA in the form of Solid aggregate weight and extracted binder using Marshall Method based on laboratory experiment by applying Direct and Extracted RAP methods. The binder was extracted by using Trichloroethylene to separate the bitumen and the aggregate. Marshall Mix design is used for the analysis based on 0%, 15%, 25%, 35% and 45% of RAP by weight of the mix. Nine mixes were tested; four RAP materials without extraction, four extracted aggregate with RAP binder and recovered RAP binder one Control/Virgin Mixes. Each mix has been tested on four different percentages of RAP 15%, 25%, 35% and 45%.

The Marshal Test result in both methods indicates that when the RAP percentage increases the Air voids, Stability, VMA and VFA increase accordingly. On the other hand, the Bulk Density, Dust to binder Ratio and flow decrease. Based on laboratory results as well as Marshal Criteria properties and performance, it has been recommended it is possible to reuse the RAP up to 45% with improved performance as compared to control /virgin mix In addition by using both methods it was justified that all RAP mixtures results found to be adequate and meets the minimum requirements as per MS-2 Criteria.

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1. INTRODUCTION

1.1. Background

Road is one of the key foundations of economic growth for all sectors. Currently Ethiopia has 200,000kms paved road in 2020 [1] followed by increasing in cost of construction material there is significant budget shortage for new road construction maintenance of old road and rehabilitation. Usage of RAP can be a sustainable solution for scarcity of construction material and also it will have significant advantage by reducing environmental impact.

The use of reclaimed asphalt pavement (RAP) in the construction of new flexible pavements has increased in recent years. In most third world countries, like Ethiopia, where technological development is still growing, some regions especially large urban areas already have a problem in obtaining adequate aggregate supplies at reasonable cost and reasonable amount of bitumen. At the same time, increasing quantities of demolished asphalt pavement materials from road reconstruction projects are generated as a waste material close to these areas. These waste asphalt pavement materials are usually plowed back as sub-base material during the reconstruction process or used as embankment fill material which does not represent the most suitable use for the RAP. One of the possible ways to enhance the ample use of RAP would be to incorporate the material into hot mix asphalt.

Different manuals and guidelines were developed to incorporate RAP use in the Pave mix design procedures in different countries and there is also some description on RAP in Ethiopian roads authority manual. Once RAP materials are selected for use in a new HMA, the effect of binder stiffness on the HMA must be quantified. The designer must first determine the amount of RAP materials to be used in the HMA. Low RAP percentages in the mix appear to have insignificant effects on the blend of virgin and RAP binder. However, when an intermediate or high amount of RAP is used, the effect of the RAP binder on the mix properties becomes significant. Hence, it is crucial to quantify the RAP's contribution to HMA design and its behavior. ERA recommended the use of RAP percentage 20% to 50% and also can be used as a capping layer and sub base layer. A better understanding of the volumetric properties and physical characteristics of HMA containing RAP is necessary to ensure quality pavements.

1.2. Statements of Problems

Due to the end up of its design life and traffic loads, asphalt pavements may badly deteriorate the re-construction of the pavement may become an economical and feasible solution. Reconstruction of a pavement requires removal of pavement surfaces. Waste asphalt removed from a failed pavement surface is a mixture of aggregate coated with bitumen and is collected from failed asphalt pavement surfaces and has been used as flexible layer construction material for more than 20 years [1].Successive road improvement and expansion of road network play the crucial role in economic development and to maintain sustainable development of our country.

The major problems facing transportation agencies is the need to maintain and upgrade the level of service that highways provide, while copies with rapidly escalating costs and a nearly fixed level of highway funding. Asphalt pavement recycling can be a part of the solution to this multi-faceted problem. If an existing pavement with a base failure is reconstructed by conventional methods, then the existing pavement material must be excavated and hauled from the site. This produces additional hauling costs, consumes fuel for transportation, provides additional wear on nearby roads, and wastes valuable landfill space. Also, the construction of the replacement, pavement uses virgin aggregate and bitumen, hauled over the same roads, using additional fuel for transportation and construction.

The use of cheaper construction materials without loss of performance is crucial for developing country like Ethiopia. Hence a continuous increase in the cost of conventional construction materials, the researcher explored possible alternative and cheaper in the overall cost of construction without compromising performance. However, using Reclaimed Asphalt Pavement is not common in Ethiopia. While several factors influence the use of RAP in Asphalt pavement, such as costs and scarcity of virgin materials are motivating to use recycled pavement materials in pavement construction by blending with virgin materials. Currently, the production of demolition and construction waste has been increasing at a gradual rate. The use of RAP material in road construction has been proven to reduce both the rate of depletion of natural resources and the amount of construction debris reaching the urban landfills.

1.3. Research Objectives

1.3.1. General Objective

This research is expected to point out major explanation to examine the properties RAP and extract bitumen from RAP will obtain bitumen content by laboratory tests and come up with conclusion how to use the RAP in hot-asphalt mixture.

1.3.2. Specific Objectives

1. To carry out laboratory study on the asphalt mixes with RAP material and compare their properties with virgin asphalt mixes.
2. To estimate the optimum RAP percentage that can fulfill aggregate demand and gradation within specific asphalt bitumen grade.

1.4. Research Questions

- What are the effect of the variation in properties of the bitumen in RAP and how this will be taken to account in the mix design process
- What is the optimum amount of RAP in the mix

1.5. Scope of the study

This study has been confined in the laboratory test to investigating the use of Reclaimed Asphalt. And evaluate the extraction of RAP material to get RAP bitumen and aggregate. The virgin bitumen and aggregate it will be work relevant laboratory tests which are planned to conduct were Gradation test, Specific gravity, test particle shape test, on the aggregate extracted from the RAP. Penetration test, specific gravity test, density and void analysis test stability, flow, and RTFO test on the bitumen extracted from the RAP. And also, determination of the RAP mixture, Marshal is going to be studied.

1.6. Organization of the Thesis

The organization research paper is as follows. In Chapter 1; Introduction, problem statement, objectives and scope of the research are outlined. In Chapter 2, literature review on use of RAP is discussed. Chapter 3 covers materials and methods during research design and experimental process. Chapter 4 deals with the presentation and discussion of test results from laboratory experiments. The last Chapter of the paper provides the conclusion from the study and recommendations for further study.

2. LITRATURE REVIEW

The history of asphalt begins thousands of years ago. Asphalt occurs naturally on both asphalt lakes and rock asphalt (a mixture of sand, limestone and asphalt). The first documented use of asphalt as a road construction material was Babylon, circa 615 BC. Under the control of King Nabopolassar BC. In the 1992 World's Columbian Exposition the Story of Hot Mix Asphalt, published by the National Asphalt Pavement Association, author Hugh Gillespie said: Asphalt and baked bricks in the city.

As we all know, the ancient Greeks knew about asphalt and its properties. The word asphalt comes from the Greek; (asphalt). The Romans used the word Aspirin and used it to seal their baths, reservoirs, and aqueducts. Several centuries later, Europeans exploring the New World discovered natural deposits of asphalt. Writing in 1595, Sir Walter Raleigh described an asphalt "plain" (or lake) on the island of Trinidad, off the coast of Venezuela. He used this asphalt to mend his ships [2].

Today, due to good infrastructure and well-equipped road structures, the demand for aggregates is increasing, and due to the limited amount of aggregates, recycling of asphalt pavement is the best option with benefits and good results. Several factors drive the use of RAPs, but the main drivers are cost savings and environmental benefits. Aggregates make up the majority of the materials required for bituminous concrete pavement. As a natural material, aggregate is rapidly depleted and requires significant resources for rapid infrastructure development. On the other hand, in accordance with a new trend in the construction industry, solid waste is generated in the form of buildings torn down.

Today, science and technology are driving new trends that are economical and environmentally friendly. Recycling reduces the amount of construction waste going to landfills. Recycle asphalt to use natural resources and maintain asphalt pavement. Old and destroyed concrete structures can be recycled to produce Recycled Aggregate (RA). It can be effectively used together with natural aggregates in various infrastructures, reducing the impact on nature while balancing the supply and demand of building materials [3].

2.1. Reclaimed Asphalt Pavements

Recycling is the process of converting or reusing waste to obtain new products that reduce energy consumption by reducing the use of fresh materials. Most materials are non-renewable, reducing air and water pollution. Today's trend is to reduce energy and new material consumption. As a result, the world creates a hierarchy for reduction, reuse, and recycling. Recyclable materials include many types of glass, paper, metals, plastics, textiles, and electronics. Similar effects, but composting and other reuse of biodegradable waste such as food and garden waste is considered recycling [4].

Recycled materials can be used to make new pavements, but the pavement strength is weaker than unused materials. When refurbishing an existing pavement, it is best to mix several chemicals and use recycled materials, depending on the type and application of the refurbishment. Sidewalk recycling can be categorized based on the type of material used. It generally falls into three main categories: flexible pavement recycling, hard pavement recycling, and waste recycling for road construction. Most of the recycling processes used today involve hot mixed asphalt pavement [5].

Determining the amount of RAP used in the new mixture must follow the design of the mixture. In any case, the design of the mixture made with RAP is expected to have the same properties as the mixture of unused materials. The asphalt cement contained in RAP is considered active, but its age and results require special attention during construction. Primarily with the addition of new, softer asphalt cements, special additives, and / or rejuvenating agents, the entire binder of the final HMA mix has the properties required for the pavement location and traffic density where the mix is placed [5].

To recycle an HMA into a new HMA, recycled asphalt pavement (RAP) must be used to manufacture the new HMA. There are two ways to get the RAP. One is to remove the plaster and then crush it to a proper size facility for transportation, and the other is to crush it in place and crush it. The latter is well achieved with the large number of milling machines available today. However, the ground material is usually screened at the factory to provide the required grading. Special care should be taken when removing the RAP to avoid contamination from the underlying road surface. The use of RAP may not be desirable if the aggregate of the existing mixture does not meet the minimum specifications required for the new mixture in the grinding process [5].

2.2. Asphalt Recycling Process

2.2.1. Sources of RAP

RAPs are collected from a variety of sources. RAPs are usually created by milling, complete removal of pavement and HMA scrap materials produced at the facility. An important consideration in RAP management is when to separate the RAP from the new source and when to combine the RAPs from different sources. Milling machines are an important part of pavement rehabilitation to remove problematic top layers of existing pavement to a certain depth.

2.2.2. RAP Fractionation (Separation)

Separation is the act of processing a RAP to separate it into at least two sizes, usually coarse and fine. According to a study conducted by ODOT in September 2008, more RAPs can be used if one of the reasons for the required sensibleness is thought to improve RAP consistency. However, the data collected by NCAT from US contractors in 2008 and 2009 showed that the partial RAP inventory was less consistent than the processed unfractionated RAP inventory. Therefore, it is better to create a final result specification for the RAP inventory that requires regular QC testing of the RAP, rather than calling the RAP management method specification.

2.2.2.1. Variability of RAP

RAPs are usually either broken due to plastic deformation and mostly either materials containing relatively soft bitumen or heavily cracked asphalt containing very hard bitumen. Therefore, it is important to identify variations in the RAP bitumen characteristics and how this is taken into account in the mixed design process.

2.2.2.2. Moisture Content of RAP

Asphalt pavement is recycled when exposed to heavy loads and deep degradation that change the integrity of the surface so that water can penetrate the body of the structure. In this case, the surface to be refurbished is potentially wet, so it is important to choose the best site or implant recycling method, depending on the surface damage [6]. One of the criteria that must be met in order to use a particular RAP material in the production of asphalt mixtures is its water content, which should not exceed about 5% .The specified moisture content of 5% is released by the RAP material during the drying process before being mixed with the other components of the flooring.[7]

2.3. RAP Categories

RAPs originating from a specific project or packaging type are considered classified or traceable sources. Restriction to allow only traceable RAP sources in new binders, full use of RAPs. Therefore, the guidelines should have a technical basis to meet this requirement, not a ban. The material quality of RAP can and should be verified through routine testing as part of RAP quality testing and blend design.

2.4. Recycled asphalt pavement

RAP is made from crushed or crushed asphalt concrete and as such is similar to aggregate produced by crushing rock that has been treated as a cementations aggregate of asphalt. The individual granules consist of those entirely made up of the initial coarse aggregate of asphalt concrete with a binder asphalt cement and mineral filler. The mixture of particles contained in the RAP will depend on the nature of the asphalt concrete from which it is produced: open or solid, coarse or fine, etc. The grain form of the RAP material is comparable to that of the naturally ground aggregate, but depending on the crushing and storage operations, it may contain higher fine particles. This is due to the grinding process of the surface layer from which the RAP is extracted.

The amount of RAP used in the asphalt mixture determines the properties you need to know before using the RAP. Knowledge of asphalt binder content and grade is required for all RAP levels. Higher RAP levels require the physical properties of the asphalt binder, so a mix chart can be used to select the appropriate grade of primary or newly added asphalt binder.

2.4.1. RAP Aggregate Properties

RAP devices, like base devices, must meet the consensus requirements set out in AASHTO M323 [8]. It is important to remember that consensus requirements do not apply specifically to individual aggregates, but rather to primary and RAP aggregate blends. Some institutions allow mix design technicians to test individual aggregate components and mathematically combine them in the appropriate proportions to obtain the value of the combined aggregate. To test the RAP device individually, it must first be split into coarse and fine by sample separation. 4.75mm sieves (#4 sieves are used to test the angle of coarse aggregates and flat/long grains. Materials finer than 2.36mm (#8) sieves are used to test the angles of fine aggregate test.

The blending process for blends containing RAP is similar to the blending process for all virgin materials. Once the RAP is characterized, it can be combined with virgin aggregate to calculate a blend grade for development purposes. The composite properties of gradient, specific gravity, and consistency are used to determine the acceptability of a mixed aggregate. It is important to note that the grade of the RAP particles is not the original grade of the aggregate used in the RAP because the binder film on the RAP increases the aggregate size. However, the original gradient of the reconstructed RAP unit is used for design purposes. Typical design software (i.e., a spreadsheet program) describes the difference between the "true" gradient and shading material of a RAP material, as well as the binder contained in the RAP material [9].

2.4.2. RAP bitumen properties

Because recycling hot asphalt produces recyclable aggregate and aged asphalt mixtures, the use of old asphalt bitumen in freshly mixed mixtures to reduce the required new bitumen content makes the use of RAP in mixtures economically attractive. Laboratory tests show that the aged binder affects the physical and rheological properties of the final mixture due to its interaction with the original binder.

2.4.3. RAP percentages and binder grade selection

The percentage of RAP used in the blend can be selected by determining the proportion of RAP in the total blend by weight, or by determining the proportion of RAP binder in the blend by weight while maintaining bulk requirements. Due to the stiffness effect of the old binder in RAP; It may be necessary to adjust the specified binder grade. There are three levels of the most recent national guidelines for determining binder content adjustments for HMA blends containing RAP. Each level has a percentage range representing the contribution of RAP to the total mixture by weight [26].

Some government transport departments have changed the percentage ranges based on local conditions and/or additional testing (e.g. increasing the percentage of RAP that can be used before choosing a softer binder. Binder selection guidelines, the recommended values of RAP mixture is listed in the following Table 2-1.

Table 2-1: Recommended Values of RAP AASHTO M 323

Recommended Virgin Asphalt Binder Grade	RAP Percentage
No change in binder selection	< 15
Select Virgin Binder One grade softer than normal(e.g. select a PG 58-28 If a PG 64-22 would normally be used)	15-25
Follow recommendations from blending charts	> 25

2.5. RAP Processing

RAP processing involves one or more steps to create a homogeneous material that can be used in high proportions and meets standards for high-quality asphalt mixtures. Screening is used to separate dimensions. As mentioned earlier, grinding materials from traceable sources can be very consistent and may not require further processing. In some cases, it may be desirable to sieve or fractionate the traceable source RAP to remove coarse particles, or to separate the RAP into coarse and fine stacks to maximize the amount of RAP available for a particular blend. Separating RAPs by size increases control and decreases variability. It also allows for the variability of the RAP mix as well as the virgin aggregate mix to be tuned. An example of a special classification of RAP Typically, RAPs are divided into two (rough or shallow) or three (rough, coarse or shallow) piles. With special sorting equipment, up to # 4 sieves (4.75 mm) or #8 sieves (2.36 mm) can be sieved.

For stockpiles of RAP from different sources, such as ours, crushing the material to generate RAP with an acceptable top size for use in fresh asphalt mixes may be essential, especially for stockpiles containing huge pieces of RAP or concrete slabs. If numerous sources RAP is fed into the crusher machine from different places of the unprocessed stockpile, crushing can increase the uniformity of the produced RAP. Horizontal impact crushers hammer mill impact crushers, and jaw/roll combination crushers are among the several types of crusher systems available. Recycling Hot Mix Asphalt Pavements has further information on crusher possibilities. Choosing the appropriate top size.

2.6. Asphalt recycling methods

Five broad categories have been defined to be describing the various asphalt recycling methods. These categories are: -

1. Cold Planning
2. Hot Recycling or Hot Recycling at central plant
3. Hot In-Place Recycling
4. Cold Recycling
5. Full Depth Reclamation

2.6.1. Cold Planning

This is the controlled removal of existing pavement to the desired depth, longitudinal section and lateral slope using specially designed equipment. Cold planning can be used to roughen or texture pavements to restore a low coefficient of friction and eliminate slippage. Mowers are equipped with replaceable tungsten "tooth's" or "tools" specifically designed to remove or "crush" existing pavement. A small amount of water is used in the milling process to control the amount of dust generated and prolong the service life. The milling machine is self-propelled/ self-propelled and is of sufficient size to provide the necessary traction and stability to remove pavement at the specified cross-section and horizontal slope [10].

Figure 2-1: Cold planer or milling machine

Figure 2-2: Hot recycling utilizes the heat-transfer method

2.6.2. Hot Recycling

The process of combining RAP with fresh or "virgin" aggregate, new asphalt binder and/or recycle agent in a central plant to produce a recycled mixture. High-temperature recirculation uses heat transfer methods to soften the RAP so that it mixes with virgin aggregate and asphalt binder and/or recycle agent. Hot RAP recycling is currently the most widely used asphalt recycling method in the world. About 33% is used for high-temperature recycling, 47% is used for other asphalt recycling or reuse, and less than 20% is emitted. Aggregate hierarchy in RAP, physical properties of bituminous binders in RAP, and emissions regulations. The ratio of RAP to coarse aggregate used in hot recycling is 85 to 90%. However, this ratio is usually around 15 to 25% for batch plants and 30 to 50% for empty mix plants [10].

2.6.3. Hot in Place Recycling

With HIR, 100% recycling of the existing asphalt pavement is completed on-site. Typical treatment depths range from 3/4 to 2 inches (20 to 50 mm). The process involves heating and softening the existing asphalt pavement, allowing it to be cleaned or ground hot to the point of boiling. Regulatory depth Primary, new asphalt binder, recycler and/or new HMA may be added as needed generally the percentage of virgin aggregate or the rate of addition of HMA is limited by constraints force of the device to less than 30 percent, by mass, of the HIR mixture. Addition rates of various additives are determined from analysis of existing asphalt pavement properties and subsequent laboratory mix designs to confirm conformance to specifications requirements mix technique [10].

Virgin hot mix can also be added to correct recycled asphalt pavement (RAP) defects, such as during remixing. Punching of existing asphalt pavement is necessary to determine the material properties of existing asphalt pavement. This allows you to evaluate the necessary adjustments to the aggregate grade to develop the voids required for mineral aggregates and to select the right binder for asphalt cement. Recycle existing coatings into one of the following subcategories described below using a hot swap process [1].

Recycling is the process of heating, softening, and then crushing existing asphalt pavement. Recycling agent is added and the material is thoroughly mixed and placed on a standard screed. Crushing the existing asphalt pavement by heating to a certain depth; the hardened material is combined with aggregate and/or recalculating agents and recalculated. A new coating or treatment is placed on the recycled mixture.

<u>Remixing</u> is similar to recycling by adding virgin aggregate or new hot blended asphalt to the recycled material. Then the ingredients are thoroughly mixed and placed on a standard screed.

Simultaneous placement and compression of HMA coatings and simultaneous combination of surface recycling.

<u>Repaving</u> combines reprocessing or remixing with the application of fresh HMA placed immediately after the reprocessed mixture. The new HMA layer is placed directly on the recycling layer and both are compressed simultaneously.

Figure 2-3: Hot In Place Recycling (HIR)

Figure 2-4: Cold in Place Recycling (CIR)

2.6.4. Cold in Place Recycling

On-site cold recycling is the reuse of existing packaging materials without the application of heat. With the exception of recalculating agents, there is generally no material transportation required, and aggregates can be added, resulting in very low transportation costs. Asphalt emulsions are usually added as a recycling agent or binder. The ratio of the emulsion to the RAP weight. These additives are effective for over-asphalted mixtures and poorly stable mixtures. The use of recirculation lines consisting of crushing, screening, crushing and mixing devices is very common. Working depth is usually 75-100mm. Benefits of on-site cold recycling include significant structural handling of most packaging damage, improved ride comfort, minimal transport and air quality issues, and the ability to expand coverage.

2.6.5. Full Depth Reclamation

Full depth reclamation was defined as a recycling method that processes an entire section of asphalt pavement and a predetermined amount of foundation material to produce a stabilized foundation layer. It is essentially a cold mix recycling process in which various types of additives such as asphalt emulsions and chemicals such as calcium chloride, Portland cement, fly ash and lime are added to create an improved base. Insufficient internal material to provide the desired depth of the base to be machined. This processing method is usually performed to depths of 100mm to 300mm. Execute regenerative training in full depth. The benefit of landfill is that most packaging damage is repaired and shipping costs are minimized [11].

2.7. Advantage of RAP in HOT Mix

There are several benefits of using recycled materials in pavements indeed even though they have some limitations. Here are listed some of the advantage of RAP in HOT mix.

- Reuse and Preservation of non-renewable vitality sources
- Conservation of the environment and lessening in arrive filling
- Vitality preservation and made strides asphalt smoothness
- Cost sparing over conventional recovery strategies
- Made strides asphalt physical properties by adjustment of existing total degree and black-top cover properties.
- Avoids encourage smashing of total particles in RAP, which may permit higher RAP substance blends.
- Most reduced fetched of RAP preparing choices
- Millings from expansive ventures are likely to have a consistent degree and black- top substance
- Limits smashing of total particles in RAP, which decreases tidy era
- Utilizing distinctive measured RAP stockpiles gives more prominent adaptability in creating blend plans

Limitations

Different projects have used different RAP percentages, but there is no optimal RAP percentage to use. The RAP percentage depends on many parameters, including:

- Age of RAP materials
- Binder content,
- Availability of RAP
- Viscosity of binder

These factors require more research, so more research is needed. The following are major limitations, which require further research to narrow the scope of RAP for use in different types of mixtures. The age of the RAP and other factors such as residual binder, percentage, etc. should also be corrected.

Some points that need to be given concern while using RAP in the HMA are as follows.

- Quality concerns.
- Consistency of RAP.
- Binder grade and blending.
- Mix design procedures.
- Volumetric requirements

2.8. Studies on the Use of RAP in HMA

There are many and different laboratory studies/literatures performed in order to assess the impact of RAP in HMA.

- Structural performance of recycled mixes is equal and, in some instances, better than that of the conventional mixes.
- The use of RAP in asphalt mixtures could produce important benefits in terms of performance and economics.
- The properties of the recycled mixture are believed to be mainly influenced by the aged reclaimed asphalt pavement (RAP) binder properties and the amount of RAP in the mixture.
- Mixtures prepared from the recycled binder blends generally age at a slower rate than fresh mixtures. This may be due to the fact that the RAP binder has already under gone oxidation which tends to retard the rate of hardening and the recycled mixtures with stands the action of water better than the Fresh mixtures.

In addition to testing the volumetric properties, it may be desirable to evaluate the performance of an engineered asphalt mix containing RAP, especially a high RAP content, to ensure that the mixture is resistant to cracking. at low temperatures and fatigue or rutting if a softer pure binder has been used in the composite design. A variety of performance tests are available. Possible failure mechanisms that should be evaluated include long-term fixation (i.e. rutting), sensitivity to moisture, fatigue, and thermal cracking.

T. Chandra Sekaraiah, K.M.Mallesh & Sunil S [12] carried out the experimental investigations on the laboratory performance of Bituminous Mixes with Reclaimed Asphalt Pavement RAP Materials. Their objective was to carry out the Marshall Mix design with conventional materials added by controlled RAP and evaluation of the mechanical properties of the bituminous mix with various proportions of the RAP. They concluded that the aged bitumen has shown the available paving material at different percentages of the virgin binder and there has been consistent increase in the physical properties (Penetration, Ductility, softening point etc.) of the old bitumen when rejuvenated with Virgin VG-30. B) The proportioning of the aggregates with reclaimed aggregates at all specified percentages of 10, 20, 30 and 40 have given correct blending of the aggregates meeting the specification requirements. C) More than I0% and less than 40% RAP can be suitable adopted in making the new roads with the RAP.

A.Veeraragavan conducted an Investigation on Laboratory Performance of Bituminous Mixes with Reclaimed Asphalt Pavement Materials. His Primary objectives were to estimate the bitumen and aggregate demand to fulfill the gradation and volumetric requirements of recycled mix, for a typical highway project, to carry out mix design with recycled and virgin materials and compare the mix properties and finally to investigate the influence of recycled materials on the mechanical behavior, tensile strength, durability and performance of bituminous mixes through laboratory experiments. After carrying out the investigations he concluded that the use of recycled materials brings about 78% reductions in the optimum bitumen content required for air voids level of 4% for a typical road project considered in the present investigation, Indirect tensile strength results confirm that the use of recycled materials in bituminous mix offers high fatigue cracking resistance similar to that of virgin mixes, The bituminous mixes with recycled materials are found to offer higher resistance to rutting when compared with virgin materials. [13]

Widyatmoko used three different levels of addition of RAP (10%, 30% and 50%). Rigorous control of the grading of the source materials (i.e. RAP and virgin aggregate) is required, as small variations in grading could result in the target recycled mixture having a combined aggregate grading outside the specification hence a graph necessitates to study the composition of aggregate and binder in the target mixes weather for wearing course or base course. The results suggested that rejuvenated binders properties show similar results of 60/70 bitumen properties [5].

Alex K. Apeagyeiet al, 2012 studied on the production of high-RAP mixes (i.e., mixes with more than 20% for surface and intermediate, and 25% for base mixes) to evaluate the stiffness characteristics of asphalt-concrete mixtures containing different RAP amounts to achieve a better understanding of how high RAP (>20%) affects the mixture performance properties that are important for more durable and cost-effective asphalt. The use of higher RAP percentages with locally available binders was adopted as an approach to reduce the demand, on specialty more expensive Fresh binder and Fresh aggregates in Virginal [14].

Recent researches have established that RAP replacement at proportions above 50% is feasible to produce new HMA mixtures, obtaining satisfactory results in the mechanical properties. It is universally recognized that an important benefit of asphalt as a pavement construction material is its ability to be recycled. This factor is becoming more relevant as the use of RAP in asphalt mixtures could produce important benefits in terms of performance and economics.

The properties of the recycled mixture are believed to be mainly influenced by the aged reclaimed asphalt pavement (RAP) binder properties and the amount of RAP in the mixture. A literature showed that mixtures prepared from the recycled binder blends generally age at a slower rate than fresh mixtures. This may be due to the fact that the RAP binder has already undergone oxidation which tends to retard the rate of hardening and the recycled mixtures withstands the action of water better than the Fresh mixtures. The above studies have clearly evaded the utilization of recycled materials towards the sustainable and economic development of infrastructure. The gaps in the studies were explored; hence an attempt has been made to study the performance of RAP.

2.9. Manuals Practices of using RAP in HMA.

As mentioned earlier, a major challenge when using recycled asphalt in hot mix asphalt is to account for the effects of binder and aggregate aging. Therefore, it is very important to understand these properties when using RAP in hot mixed asphalt. Various guidelines and researchers are trying to study their effectiveness and suggest some corrective actions in blend design.

2.9.1. Pavement Rehabilitation and Asphalt Overlay Design/ERA/2013

Obviously, the biggest cost savings come from using RAP to produce quality bituminous bonding materials. RAP is usually a plastically deformed material that contains mostly relatively soft bitumen or heavily cracked asphalt that contains very hard bitumen. Therefore, it is important to determine the change in bitumen properties in RAP and how this is accounted for during the blend design process. The guidelines provide two options when modifying options for bitumen properties in the RAP.

Anti-aging agents were used in RAP to change the properties of bitumen to make it look like new bitumen. However, these agents can alter the aged bitumen to achieve the desired viscosity; Different agents produce binders with different temperature sensitivity and compatibility between aged bitumen and anti-aging agents. Once the softer bitumen is added to bring the mixed bitumen to specification, Equation 2.1 can be used to calculate the fresh bitumen penetration.

$$\text{Log}\,P = (A \log P_a + B \log P_b) / 100 \tag{2.1}$$

Where:

P : Specified penetration of final blend

P_a : Penetration of RAP bitumen

P_b : Penetration of virgin bitumen

A : Percentage of RAP bitumen in the final blend

B : Percentage of virgin bitumen in the final blend

In this relationship, the blended is the total quantity of bitumen only, i.e. .A+B=100.

It is recommended that RAP be used to produce binders or packaging mixtures according to the appropriate specifications in the Packaging Design Guide to ensure mixing consistency and design tolerances. These recycled materials must be sealed or covered with a new bitumen coating [1].

2.9.2. MS-2 Asphalt Mix Design Methods

The binder grade selected will depend on several factors such as the climate and the expected traffic load on the construction site. Due to the time and testing costs involved in determining RAP binder properties for blending, many asphalt mixers prefer to use RAP percentages that do not require binder properties, and indirectly convert mixing diagrams and/or equations to RAP percentages is usually 25% lower. If other binder specifications are used, only an absolute viscosity test at 60°C is usually required to determine the viscosity of the recovered RAP bitumen binder [15].

2.9.3. Asphalt Recycling and Reclaiming Association (ARRA)

HMA blend projects should consider the mechanisms that affect the performance of the original blend and efforts to correct deficiencies in the refined blend. Renewal of existing asphalt binders is one of the key mechanisms and there are several perspectives on how to do this. Some points are summarized as follow.

- Rejuvenating agent for restoration/rejuvenation of existing properties of bituminous binders. This suggests that the recycle agent is effectively combined with the existing asphalt binder in the HIR process.
- Use new mild bitumen binders, not recycled ones. This suggests that the recirculation agent cannot fully bond with the existing asphalt binder and that the new soft asphalt binder combined with the original binder will produce a suitable "intermediate" binder.
- Rejuvenating the old asphalt binder by using a recalculating agent and a new soft asphalt binder with virgin aggregate.
- Use properties of recycled blends such as modulus of elasticity, stability, etc., rather than those of bituminous binders, to determine the choice of final blend. This acknowledges the uncertainties associated with adjusting the properties of bituminous binders in the laboratory and the fact that the overall performance of the recycled mix reflects the true effectiveness of the chemical rejuvenation bitumen adhesive.

2.10. Challenges for Increasing the Use of RAP

Despite the similarities between the production of virgin asphalt mixes and the production of asphalt mixes using RAP, there are still challenges in maximizing the use of RAP and using high RAP on a regular basis. According to AASHTOM-323, the current binder selection guidelines for RAP blends were originally formulated with the assumption that thorough mixing takes place between the binder and the RAP binder. It is understood that the degree of mixing that occurs between the original and the RAP binder lies somewhere between complete mixing and no mixing at all. However, there is no direct way to accurately quantify the amount of mixing that occurs. Researchers are currently developing a method to determine whether proper mixing has occurred using the properties of the mixture to evaluate the properties of the blended binder using properties such as dynamic modulus and to compare the expected properties of the measured blended binders. We are conducting continuous research for Binder properties [9, 15].

For blends with high RAP content, the blend table can be used to accurately determine the quality of the primary binder. If the purity of the binder is known, it can be used to optimize the amount of RAP used. However, the mixing diagram requires a costly and time consuming procedure followed by binder recovery and recovery procedures using hazardous solvents and testing of recovered binders. As a result, many countries are reluctant to allow RAP content that requires this test. Additionally, many contractors do not have binder recovery and recovery equipment or subsequent binder testing. In some cases, countries set limits on the amount of RAP that can be used based on previous bad experiences with RAP. According to a 2007 NCDOT study, the four most common barriers to using complementary RAPs are:

- Specification limitations
- Lack of processing (i.e., variability of RAP)
- Lack of RAP availability
- Past experience

2.11. Best Practices for increasing RAP use

In general, there is little difference in the development of RAP asphalt mixtures and virgin asphalt mixtures until a high RAP content is used. However, when increasing the use of RAP, you should consider the following:

- Additional processing.
- Characterizing RAP
- Changing the virgin binder grade
- Preparing materials for mix design.
- Blending/comingling the virgin and RAP binders.
- Performance

2.12. Effect of Laboratory mixing methods and RAP performance HRA mixtures.

Mixing procedures include Black Rock, full mixing procedures, and newly developed field simulation methods. The main difference between these methods is the mixing mechanism. The BR case means a situation in which there is no interaction between the RAP and the primary binder. In contrast, in the case of complete blending, the RAP and the primary binder fully interact. The mixing procedure for BR and CB bodies is the same as for conventional asphalt mixtures. However, BR hull bitumen is pure virgin bitumen. CB bitumen is also a mixture of RAP and primary binder. The RAP/primary binder ratio is 4/6. In contrast, in the FS method, the mixing procedure is the same as in the asphalt mixing plant. RAP is mixed several times with superheated virgin aggregate (215°C) before being mixed with virgin bitumen at 130°C for 2 minutes. The mixing time for RAP/superheated virgin aggregate starts with a short mixing time, gradually increasing until the change in the RAP chunk size is negligible when the RAP is still present at approximately its original size [16].

Experimental results indicate that the four-way stiffness measurement can indicate non-uniformity of the recycled mixture. The diffusion of stiffness values in different directions of measurement is important for heterogeneous mixtures and not for homogeneous reused mixtures. The results show that there is a relationship between the mixing force, homogeneity and stiffness values for the recycled asphalt mixture. Longer mixing times improve homogeneity and reduce dispersion of recycled mixture stiffness. Also, as more RAP and primary binder are added, the recycle stiffness generally increases with increasing mixing time.

Since the transparent binder has a reddish color with 15% of by wt iron oxide, the proportion of the pigment clearly changes the flow characteristics of the binder. This can affect the mixing process and the regeneration effect between the clean and old binder. Therefore, we further investigated the effect of mixing method and RAP size on the mechanical performance of hot regenerated asphalt mixtures using 80/100 Pen plain straight run bitumen as the main binder. Evaluation indicators include stiffness modulus, fatigue damage resistance and permanent deformation resistance.

Experimental result results show that conventional laboratory mixing methods (SHRP) tend to overestimate the mechanical properties of recycled asphalt mixtures. Long warm-up times not seen in the industry accidentally intensify the reaction between the RAP and the primary binder. Long RAP warm-up times also slightly change the properties of RAP binders.

For the FS method, increasing the mixing time significantly improves the homogeneity level of the recirculation mixture. The level of uniformity is also strongly affected by the size of the RAP and is usually more uniform than that made with a larger RAP. The more homogeneous the mixture, the stronger the interaction between the RAP and the primary binder. As a result, the machined mixture becomes harder and more resistant to permanent deformation and fatigue failure. A slight linear increase in stiffness can exponentially increase the fatigue life of the treated mixture.

The mechanical properties, including the modulus of stiffness, resistance to fatigue damage, and resistance to permanent deformation of hot recycled asphalt mixes are not similar to those of BR or CB mixes, even under favorable conditions where RAP was preheated for 2 h at 110°C in the SHRP Method and 8 min in the FS method. This implies that RAP does not behave like Black Rock. In addition, it is assumed that the RAP and pure binder are completely mixed also never exist in the recycling asphalt production process.

2.13. Blending of RAP and Virgin Binders

The mixing ratio of the old and new binders is one of the major issues with the performance of HMA blends. A negligible change in viscosity was observed when low proportions of RAP were used (up to 15%). At higher percentages (e.g. 45%), the RAP effect is more pronounced. Studies have shown that old binders do not behave like black stone, nor do they completely mix the old binder with the default binder [17].

Experiments were conducted on the process of mixing RAPs screened through a control experiment in different proportions from the primary mixture. The results of this experiment indicate that in the RAP, only a small fraction of the aged asphalt mixed with the premix, while the other part forms a hard mat around the RAP aggregate and the RAP functionally acts as a "composite black rock". They also found that the RAP multilayer system helped reduce stress concentrations in the HMA mixture and improve road surface performance [18].

3. MATERIAL AND METHODOLOGY

This chapter describes the materials, methodology and process of the thesis. For this work, an experimental method was used. The experimental work has two parts. The first part covers the preparation of materials, mix design for bituminous binders' aggregates and various amount of recycled bitumen coatings. The second part covers the sensitivity of the mixture to the optimum asphalt content at the RAP. The guidelines and manuals used for this study are the 2013 ERA manuals, namely the flexible pavement design manuals and standard specification, MS-2 asphalt organization, standard specifications ASHTO standards and other documents.

Figure 3-1: RAP Asphalt Pulverizing Equipment

3.1. Sample Source

The restored asphalt pavement was extracted from the RAP stockpile located around Megenagna to the CMC road in Addis Ababa. Extracted RAP is a full depth pavement that involves the use of heavy equipment to break the pavement structure into slabs. The slabs are then transported from various renovation projects carried out around Addis Ababa to this place, where they are disposed of as they are no longer in use. Representative samples were collected using the AASHTO T-2 methodology for sampling.

For the RAP samples, the bituminous binder content was determined according to AASHTO T308. "Recovery of bitumen from solution using a rotary evaporator" or ASTM D7906, "recovery of bitumen from solution using Toluene and a rotary evaporator". The combined extraction and recovery procedure is given in AASHTO T319 [19]. Abrasion resistance and friction property tests were performed as specified by ERA manual. The materials used in this study and their properties are discussed hereunder.

Figure 3-2: Sampling RAP from the stockpile

3.1.1. RAP Binder and Aggregate Properties

a) RAP Binder After Extraction

The properties of RAP binder are tested and the results are presented in the table below.

Table 3-1: RAP binder property test after extraction

Test	Standard	Test result	AASHTO Criteria
Solubility in Trichloroethylene, (%)	AASHTO T 44	97.8	Min 98%
Loss on Heating, (%)	AASHTO T 47	-0.9	Min 1%
Flash Point, ^{o}C	AASHTO T 48	275	232
Penetration at 25^{o}C, 100g, 5sec	AASHTO T 49	81	80-100
Ductility at 25^{o}C (cm)	AASHTO T 51	100+	100+
Penetration of residue percent of original, at 25^{o}c,100g, 5sec	AASHTO T 51	91	------
Ductility of residue, cm	AASHTO T 51	65+	Min 50+
Softening Point (^{o}c)	AASHTO T 53	42	42-52
Specific gravity at 25^{o}C (kg/m^{3})	AASHTO T 228-06	1016	-------

b) RAP Coarse Aggregate

Once the asphalt binder was separated from the aggregate, the properties of the RAP aggregate were determined. The gradation of the RAP was determined after solvent extraction and was shown in above Table 3.2. The bulk specific gravity, effective specific gravity, fine aggregate angularity (FAA), and absorption of the RAP aggregates were then determined. Summary of soundness and specific gravity for RAP extracted aggregates are shown in Tables 3.3 and 3.4, respectively.

Table 3-2: RAP Aggregate Properties

RAP Source	G_{sb}	G_{se}	FAA(FI)	Absorption
Megenagna to CMC	2.505	2.697	38.2	1.35

Table 3-3: Summary of Soundness Test for Rap Aggregates

Aggregate type	Result	ERA 2013 Requirement
Coarse Aggregate (> 4.75mm up to < 25mm)	8.1	< 16%
Fine Aggregate(< 4.75mm)	9.3	< 10%

Table 3-4: Specific Gravity for RAP extracted aggregates

Parameter	Size (2.5mm - 4.75mm)	Size < 4.75mm
Bulk Specific Gravity [oven-dry]	2.722	2.743
Bulk Specific Gravity [SSD]	2.741	2.771
Apparent Specific Gravity	2.768	2.788
Water Absorption [%]	0.88	1.35

Moreover, for coarse aggregates, strength tests (Flakiness Index, Aggregate Crushing Value, Ten Percent Fine Value, Aggregate Impact Value, Los Angeles Abrasion Value and Coating and Striping) were performed and the results are shown in Table xx.

Table 3-5: Strength test results for RAP extracted aggregates

Property	Types of Tests	Test Results	ERA 2013 Requirement
Strength	Aggregate Crushing Value (ACV), %	19.3	< 25%
	Aggregate Impact Value (AIV), %	23.4	< 25%
	10% FACT (dry) kN	254	160 kN
	10% FACT (wet) kN	217	-
	10% FACT (wet/dry ratio), %	85.4	> 75%

As shown in the above table, all the test results of RAP aggregate the requirement set on ERA 2013 PDM.

c) RAP Extracted Fine Aggregate

For RAP fine aggregates, sand equivalent and plastic index tests were performed and the results are shown in the table below.

Table 3-6: RAP Extracted fine aggregates quality test results

Property	Test	Test Method	Specification as per ERA 2013 PDM	Test Result
Cleanliness	Sand equivalent: for < 4.75mm fraction	AASHTO T-176	> 40	----
	(Material passing 0.425mm Sieve) Plastic Index	ASHTO T-89	< 4	NP
Water Absorption	Water absorption fine aggregate	AASHTO T-85	< 2	1.35
Bitumen affinity	Static Immersion Test	AASHTO T-182	> 95% coating retained	> 95%

3.1.2. Virgin Materials

Materials that are used for this study are aggregate and bituminous binder. Both materials for this research are taken from Tulu Dimtu (Azita Crusher). The aggregate samples were collected on the 26th of February 2021. Both aggregate and bitumen are prepared in accordance with the AASHTO Standard Specification for Transportation Materials and Methods of Sampling and Testing.

a) Virgin Bitumen

The property of the virgin bitumen is shown in the table below

Table 3-7: Test Results of Virgin Bitumen-80/100

No.	Test	Method	Test Results
1	Penetration of bituminous material	AASHTO T 49	87
2	Flash and fire point by Cleveland open cup	AASHTO T 48	315°C
3	Ductility of bituminous material	AASHTO T 51	100+
4	Softening point of bituminous material by ring and ball apparatus	AASHTO T 53	48
5	Solubility of bituminous material	AASHTO T 44	99.8
6	Specific gravity	AASHTO T 228	1.021
7	Loss on Heating	AASHTO T 47	0.2%

The test result shows the values conformed to ERA 2013 pavement design manual and AASHTO Standard Technical Specification M20-70.

b) Virgin Coarse Aggregates

Particle shape, strength and other properties of the virgin coarse aggregates is shown in Table 3.11. Summary of soundness and specific gravity for virgin aggregates are shown in Tables 3.3 and 3.4, respectively. Moreover, strength test result is shown in Table 3.5.

Table 3-8 : Virgin Coarse Aggregate Quality Test Result

No.	Property	Test	Method	Requirement	Test Results
1	Particle Shape	Flakiness Index	British Standard 812, Part 105	< 35%	26%
2	Strength	Aggregate Crushing Value (ACV)	British Standard812, Part 3	< 25%	18%
3		Aggregate Impact Value (AIV)		< 25%	17%
4		10% FACT (dry) kN		> 160kN	260kN
5		Los Angeles Abrasion (LAA)	ASTM C131 and C535	< 30%	18%
6	Water absorption	Water absorption	British Standard812, Part 2	< 2%	0.70%
7	Soundness (5 cycles, % loss)	Sodium Sulphate Test:	AASHTO T104-99	< 10%	5.40%
8	Bitumen affinity			> 95% coating retained	> 95%

As shown in the above table, the test results satisfied the requirements set in different standards.

Table 3-9: Soundness Test for Virgin Coarse Aggregates

Aggregate type	Result	ERA 2013 Requirement
Coarse Aggregate (> 4.75mm up to < 25mm)	5.4	< 16%
Fine Aggregate(< 4.75mm)	6.3	< 10%

Table 3-10: Specific Gravity for virgin coarse aggregates

Parameter	Aggregate Size			
	25mm - 10mm	10mm - 4mm	4mm - 0mm	Stone Dust Filler
Bulk Specific Gravity [oven-dry]	2.835	2.733	2.761	2.922
Bulk Specific Gravity [SSD]	2.871	2.768	2.788	
Apparent Specific Gravity	2.895	2.771	2.799	
Water Absorption [%]	0.45	0.53	1.21	

Table 3-11: Summarize strength aggregate test results for Virgin aggregates

Property	Types of Tests	Test Results	ERA 2013 Requirement
Strength	Aggregate Crushing Value (ACV), %	16.3	< 25%
	Aggregate Impact Value (AIV), %	19	< 25%
	10% FACT (dry) kN	298	160 kN
	10% FACT (wet) kN	263	-
	10% FACT (wet/dry ratio), %	88.3	> 75%

As shown in the above table 3.11, the test results satisfied the requirements set in different standards.

c) Virgin Fine Aggregates

Properties of fine aggregates such as cleanness, water absorption tests are shown in Tables 3.12 and 3.13, respectively.

Table 3-12 : Virgin Fine Aggregate Quality Test Results

No.	**Property**	**Test**		**Method**	**Requirement**	**Test Results**
1	Cleanliness	Sand equivalent for < 4.75mm fraction		AASHTO T176-86	< 40%	22%
2		Plasticity Index	Material passing 0.425mm sieve	British Standard 1377: Part 2	< 4%	NP
3		Linear shrinkage			< 2%	NP
4	Water absorption	Water absorption		BS 812, Part 2	< 2%	1.2%
5	Soundness (5 cycles, % loss)	Sodium Sulphate Test:		AASHTO T104-99	< 16%	7.42%

NP- Non Plastic

As shown in the above table, the test results satisfied the requirements set in different standards. Moreover, for fine aggregates, additional tests (sand equivalent and plastic index) were performed and the results are shown in the table below.

Table 3-13: Virgin fine aggregates quality test result

Property	Test	Test Method	Specification (ERA 2013 PDM)	Test Result
Cleanliness	Sand equivalent: for < 4.75mm fraction	AASHTO T-176	> 40	95%
	(Material passing 0.425mm Sieve) Plastic Index	ASHTO T-89	< 4	NP
Water Absorption	Water absorption fine aggregate	AASHTO T-85	< 2	1.21
Bitumen affinity	Static Immersion Test	AASHTO T-182	> 95% coating retained	> 95%

3.2. Aggregates Gradation

The gradation curve for both Virgin Aggregate and RAP extracted aggregate is shown in Figure below.

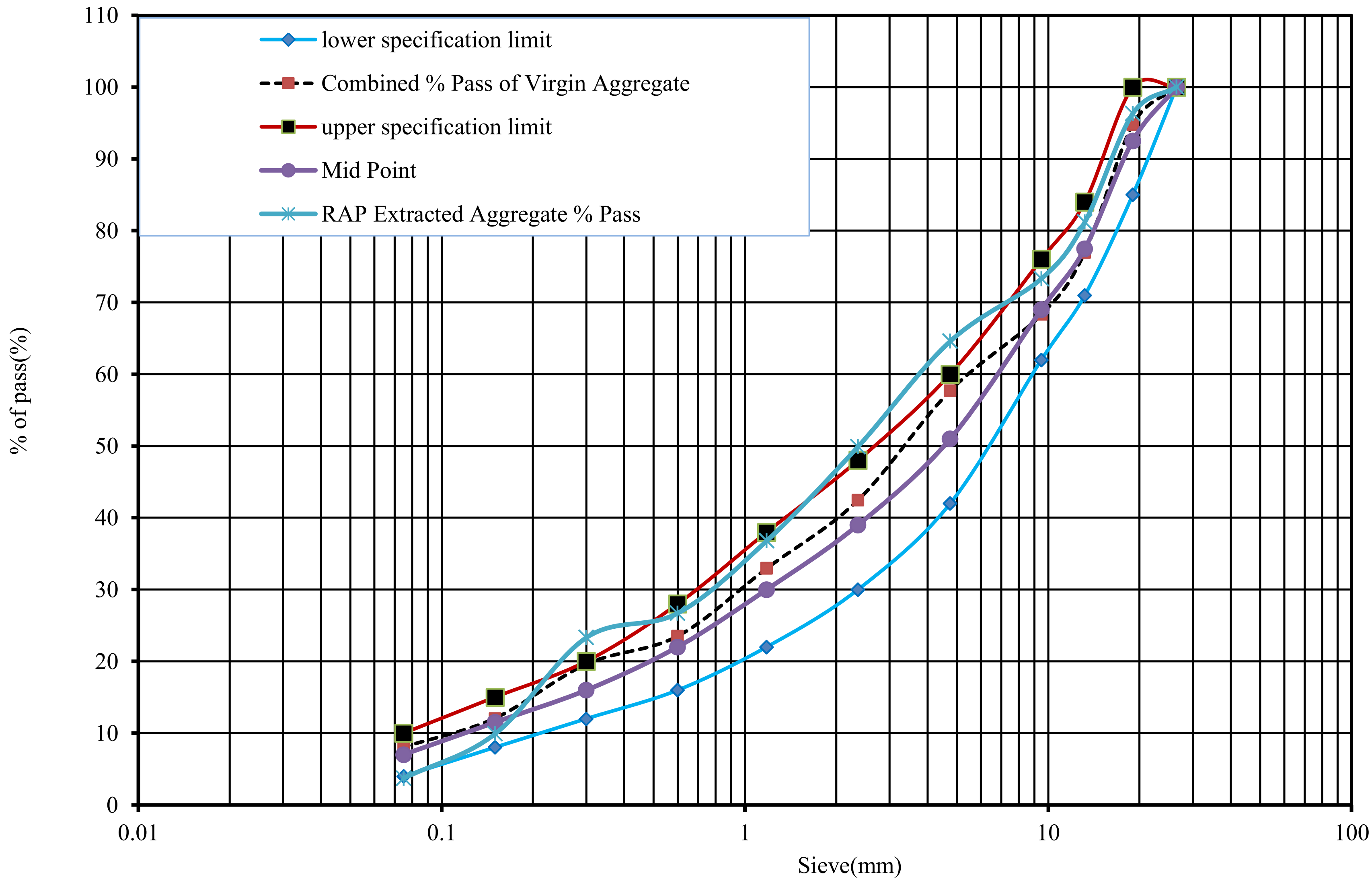

Figure 3-3: Combined grading of control/virgin and extracted RAP aggregates

3.3. Material Sample Preparation and Quantities

Representative samples of aggregate and asphalt should be obtained to complete the required number of tests prior to testing the mixture design. The bitumen composition stares from 3.5 up to 5.5 bitumen content for the mix. RAP with different percent composition were considered, the following composition are: -

1. 15% RAP and 85% virgin aggregate
2. 25% RAP and 75% Virgin aggregate
3. 35% RAP and 65% Virgin aggregate
4. 45% RAP and 55% Virgin aggregate

For each case, different percentage of RAP and Virgin aggregate contents has been considered. Detailed marshal sample quantities and the corresponding mix designs are attached in the ANNEX. The mix design is performed based on ASTM MS-2 Design Standard Manual.

3.4. Materials Characterizations

The materials used for this experimental are recycled asphalt pavement, bitumen and aggregate. The source of RAP was from ongoing rehabilitation project in Addis Ababa Megenagna to CMC in Addis Ababa pointed from AACRA whereas the bitumen grade 80/100 and aggregates from Core Consulting Engineers. A variety of tests were necessary to facilitate volumetric properties of each of the neat RAP. Before using RAP into the mix design the following quality test of RAP conducted to check the RAP Properties/characteristics.

- RAP flow and Stability
- RAP Bulk Density
- RAP Air Void, VMA and VFA
- RAP G_{mm}(Maximum Theoretical Density)
- RAP Sieve Analysis (after Extracted)
- RAP Binder quality test (After Extracted)

To determine the properties of this aggregate, general quality tests were performed to confirm the suitability of the grading source, several laboratory tests were performed and compared to specifications according to ERA [1] guidelines. These tests include:

During service, the blend of aggregates and bitumen undergoes various physical and that have to be considered in the design process to ensure that HAM mixtures with RAP perform as well as HMA produced with virgin materials. Before proceeding in to the next section we conducted different test to assess the quality of recycled asphalt pavement.

Once the data were obtained from these tests, each material was characterized using the American Association of State Highway and Transportation Officials (AASHTO), ASTM and ERA 2014, Standard Technical Specification. All quality test results of RAP material before starting the research are attached in the ANNEX.

3.5. Research type and strategy

Research can be classified as a type of applied research and descriptive research, as it can be done and explored on its own. It is also descriptive in an attempt to explore and provide insight into the existing recycled asphalt pavement in the hot mix versus the maximum strength of RAP used in the mix. Qualitative approaches seek to better understand and understand people's perceptions, while quantitative approaches attempt to investigate how precise it is to achieve desired outcomes.

3.6. Research Design

This study is designed to answer research questions and achieve experimental discovery goals. Sample preparation was the first step in the work. At this stage, samples of the materials that make up recycled asphalt pavement, crushed aggregate and bitumen were collected.

The second step was a laboratory test. This step contained three major steps.

- Step I:Quality testing
- Step II: Mix design and

The detailed methodology of the study is summarized in Figure below.

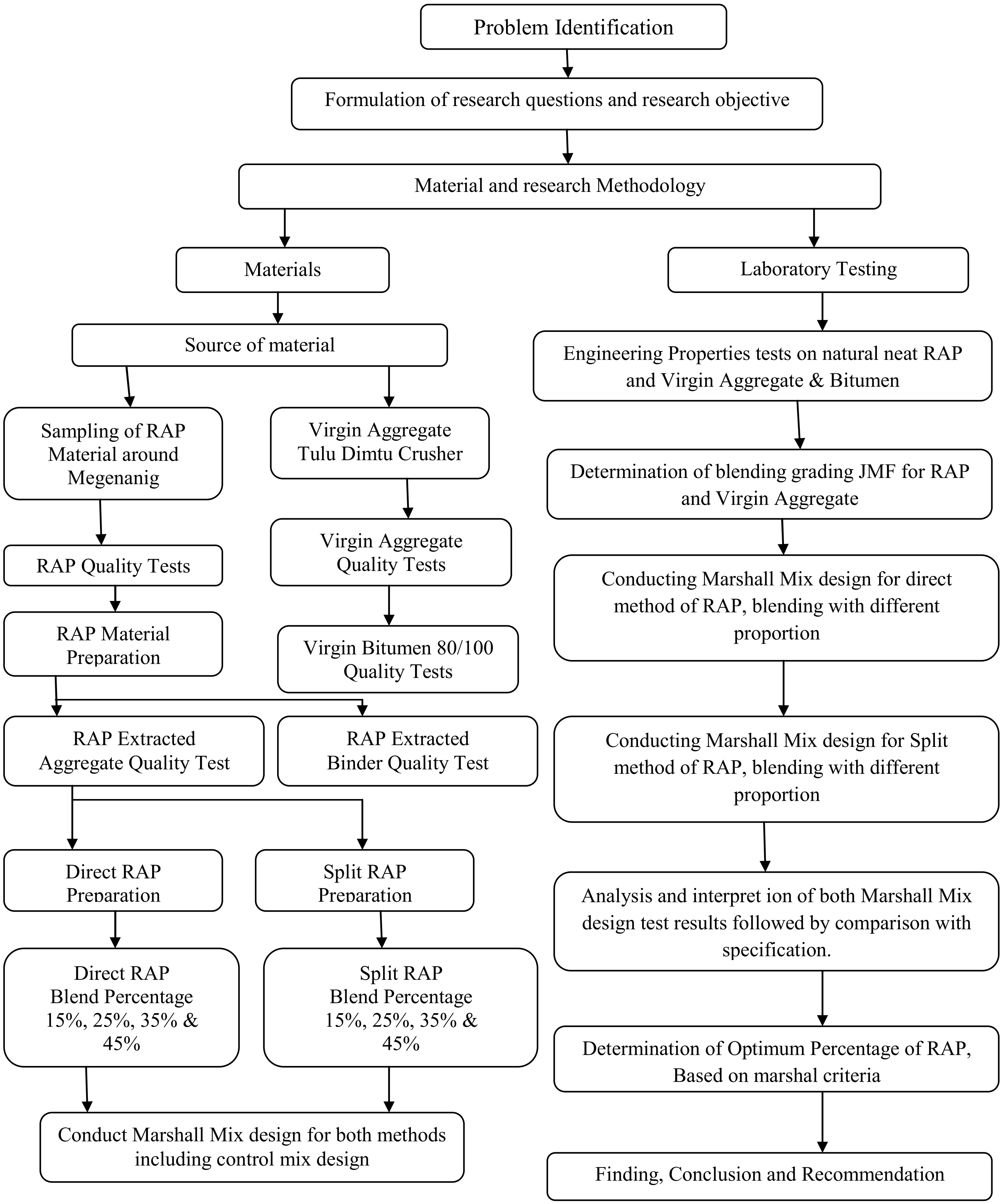

Figure 3-4: Flow chart showing general outline of the study

Step:-1 RAP material Sampling and Preparation

- ✓ After rap sampling before start the research identified the actual rap material the following tests has been conduct to verified the actual rap within the specification or not.

  - RAP Extraction test: - this can identified the sieve analysis and the bitumen content.
  - RAP Stability, flow, Bulk density, VMA, Air Void and VFA
  - RAP Bitumen Content
  - Gmm, Maximum Theoretical Density

Step:-2 RAP Preparation and testing

- ✓ Before starting marshal mix design preparing the rap material in two ways. The first one is direct rap method of material and the second is split the rap material in two ways extracted rap aggregate and extracted rap binder/bitumen. After splitting the rap material conducting the following quality tests for both the split materials.

  - RAP Extracted Aggregate the following Quality test conduct
    - Sieve Analysis
    - Aggregate Crushed Value, ACV
    - Aggregate Impact Value, AIV
    - Soundness
    - Specific Gravity
    - Water Absorption
    - Ten Percent Fine Value, TFV
  - RAP Binder/Bitumen the following Quality test conduct
    - Loss on Heating
    - Ductility
    - Residue on Ductility
    - Penetration
    - Residue on Penetration
    - Specific gravity
    - Solubility of bituminous
    - Softening point
    - Flash and fire point

Step:-3 Virgin Aggregate and Virgin Bitumen 80/100 Sampling, Preparation and testing

- ✓ Before starting marshal mix design identified the quality of the virgin aggregate and also the following quality test conduct to verified weather the material have good quality or poor quality.

- Virgin Aggregate the following Quality test conduct
  - Sieve Analysis
  - Aggregate Crushed Value, ACV
  - Aggregate Impact Value, AIV
  - Soundness
  - Specific Gravity
  - Water Absorption
  - Ten Percent Fine Value, TFV
- Virgin Bitumen 80/100 the following Quality test conduct
  - Loss on Heating
  - Ductility
  - Residue on Ductility
  - Penetration
  - Residue on Penetration
  - Specific gravity
  - Solubility of bituminous
  - Softening point
  - Flash and fire point

Step:-4 Virgin Aggregate and RAP Extracted Aggregate blending preparation

- ✓ Before start the marshal mix design blending each material to fulfill ERA wearing curse specification with using different percentage of rap material.

Step:-5 Marshal Mix design for Direct method of RAP

- ✓ In this method conducting marshal mix design using different percentage of rap. The following percentage listed below.
  - ➢ 15% of Direct RAP material, 85% of virgin aggregate and conduct marshal mix design.
  - ➢ 25% of Direct RAP material, 75% of virgin aggregate and conduct marshal mix design.
  - ➢ 35% of Direct RAP material, 65% of virgin aggregate and conduct marshal mix design.
  - ➢ 45% of Direct RAP material, 55% of virgin aggregate and conduct marshal mix design.

**Note: on the direct method during the mix design when adding the calculated virgin bitumen 80/100 in the one specimen mix must consider the rap bitumen content.

Step:-6 Marshal Mix design for Split/Separate method of RAP

- ✓ In this method conducting marshal mix design using different percentage of Extracted rap aggregate, Extracted binder/bitumen and virgin aggregate and virgin bitumen 80/100

- 15% of Extracted RAP aggregate, 15% of Extracted Binder and 85% of virgin aggregate, 85% of Virgin Bitumen and conduct marshal mix design.
- 25% of Extracted RAP aggregate, 25% of Extracted Binder and 75% of virgin aggregate, 75% of Virgin Bitumen and conduct marshal mix design.
- 35% of Extracted RAP aggregate, 35% of Extracted Binder and 65% of virgin aggregate, 65% of Virgin Bitumen and conduct marshal mix design.
- 45% of Extracted RAP aggregate, 45% of Extracted Binder and 55% of virgin aggregate, 55% of Virgin Bitumen and conduct marshal mix design.

**Note: on the Split/Separated method during the mix design on the blending on bitumen (for example the marshal mix design bitumen content start from 3.5 up to 5.5 so from 3.5% using RAP extracted binder 15% used and 85% virgin bitumen 80/100 used in the mix.)

Step:-7 Analysis, Interpretation and discussion on the test results

- ✓ In this steps determine all the tests starting from step 1 up to step 6 and analysis based on standard/specification identified the optimum rap percentage which fulfills the Marshall criteria.

Step:-8 Conclusion and Recommendation

- ✓ In this steps based on the finding of the research laboratory test results recommend and discuss the research finding.

4. RESULTS AND DISCUSSIONS

This chapter concentrates on the test results utilized from the laboratory evaluations. The results obtained show the impact of RAP on the overall physical properties of compacted HMA and compared with virgin HMA. This study used two different RAP methods and each method has five different types of percentages: 0%, 15%, 25%, 35% and 45%, which were mixed with primary and reclaim asphalt pavement (RAP). Summary of detailed test results are presented and interpretation of the test results are discussed in this Chapter.

4.1. Marshall Mix Test Results

4.1.1. Marshall Test for Virgin Aggregates and Virgin Bitumen

At each gradation and aggregate type, Marshall Test specimens of 101.6mm diameter and 63.5mm thick were prepared as per AASHTO T245-82 by varying the RAP percentage mixing by using direct RAP or Split the RAP blending with virgin aggregate.

The aggregate bitumen trial mixes were prepared for both methods at five different binder contents. The first trial was made with 3.5% and the last with 5.5% bitumen contents. The summary of the test results is shown in Table 4.1 and the detailed is presented in Appendix. To determine the optimum asphalt content (OBC), two methods are used [28].

Table 4-1: Control Marshall Mix design (with virgin aggregate and bitumen)

Item No	% AC by wt.	Bulk S.G. Comp. Mix (gm/cc)	Air Void (%)	Voids in Mineral Aggregate V.M.A. (%)	Voids filled with Bitumen V.F.A (%)	Stability, kN	Flow (mm)	Optimum bitumen content (%)
1	3.50	2.428	8.40	15.93	47.28	10.96	1.83	4.91
2	4.00	2.465	6.25	15.10	58.67	11.42	2.97	
3	4.50	2.488	4.70	14.81	68.26	12.46	3.14	
4	5.00	2.515	2.72	14.39	81.14	13.17	3.34	
5	5.50	2.476	2.12	16.20	86.90	12.21	3.73	

4.1.2. Marshall Test for RAP blended with Virgin aggregate and Bitumen

Different percentages of RAP are blended with virgin aggregates and virgin bitumen (80/100 bitumen) and the corresponding Marshall test results are summarized in Tables 4.1 to 4.5. The gradation envelope for different percentages from Mid-Point of virgin Aggregate % pass is attached in the Annex.

Table 4-2: Marshall Test for 15% RAP blended with virgin aggregate and bitumen

Item No.	% AC by wt.	Bulk S.G. Comp. Mix (gm/cc)	Air Void (%)	Voids in Mineral Aggregate V.M.A. (%)	Voids filled with bitumen V.F.A(%)	Stability in, kN	Flow in, (mm)	Optimum bitumen Content (%)
1	3.50	2.430	8.13	15.85	48.72	10.74	1.68	4.90
2	4.00	2.461	6.18	15.26	59.72	11.28	1.88	
3	4.50	2.492	4.21	14.66	71.30	12.30	2.15	
4	5.00	2.517	2.48	14.31	82.81	13.12	2.63	
5	5.50	2.490	1.97	15.74	87.52	12.05	3.13	

Table 4-3 : Marshall Test for 25% RAP blended with virgin aggregate and bitumen

No.	% AC by wt.	Bulk S.G. Comp. Mix (gm./cc)	Air Void (%)	Voids in Mineral Aggregate V.M.A.(%)	Voids filled with Bitumen V.F.A(%)	Stability in, kN	Flow in, (mm)	Optimum bitumen Content (%)
1	3.50	2.424	8.18	16.06	49.06	10.96	1.86	4.91
2	4.00	2.449	6.43	15.68	59.03	11.38	2.16	
3	4.50	2.475	4.45	15.27	70.96	12.41	2.33	
4	5.00	2.499	2.44	14.94	83.94	13.21	2.74	
5	5.50	2.472	2.30	16.35	86.19	12.11	3.20	

Table 4-4 : Marshall Test for 35% RAP blended with virgin aggregate and bitumen

No.	% AC by wt.	Bulk S.G. Comp. Mix (gm/cc)	Air Void (%)	Voids in Mineral Aggregate V.M.A.(%)	Voids filled with Bitumen V.F.A (%)	Stability in, kN	Flow in, (mm)	Optimum Bitumen Content (%)
1	3.50	2.417	8.15	16.32	50.12	11.11	1.96	4.92
2	4.00	2.438	6.44	16.04	59.91	11.78	2.21	
3	4.50	2.463	4.56	15.66	71.66	12.67	2.40	
4	5.00	2.488	2.59	15.31	83.16	13.42	2.83	
5	5.50	2.465	2.19	16.59	87.37	12.90	2.99	

Table 4-5 : Marshall Test for 45% RAP blended with virgin aggregate and bitumen

Item No.	% AC by wt.	Bulk S.G. Comp. Mix (gm./cc)	Air Void (%)	Voids in Mineral Aggregate V.M.A.(%)	Voids filled with Bitumen V.F.A.(%)	Stability, kN	Flow in, (mm)	Optimum bitumen Content (%)
1	3.50	2.401	8.35	16.85	50.65	11.21	2.11	4.90
2	4.00	2.427	6.35	16.41	61.57	12.05	2.34	
3	4.50	2.451	4.40	16.07	72.65	12.78	2.46	
4	5.00	2.480	2.04	15.56	87.29	13.58	2.88	
5	5.50	2.455	2.00	16.92	88.37	13.05	3.30	

4.1.3. Extracted RAP (aggregate and binder) blended with Virgin aggregate and Bitumen

In this section, test results for different percentages of extracted RAP aggregate and binder with virgin aggregate and virgin bitumen are presented and discussed. The corresponding Marshall Test results are summarized in Tables 4.6 to 4.9. The gradation envelope for different percentages of extracted RAP aggregate % pass is attached in the Annex.

Table 4-6 : Marshall Test for 15% (extracted RAP aggregate and binder) blended with virgin aggregate and bitumen

Item No.	% AC by wt.	Bulk S.G. Comp. Mix (gm./cc)	Air Void (%)	Voids in Mineral Aggregate V.M.A (%)	Voids filled with Bitumen V.F.A.(%)	Stability in, kN	Flow in, (mm)	Optimum bitumen Content (%)
1	3.50	2.435	8.60	15.68	45.17	12.33	1.85	4.93
2	4.00	2.466	6.48	15.08	57.04	13.01	2.21	
3	4.50	2.494	4.49	14.62	69.28	13.96	2.76	
4	5.00	2.519	2.59	14.25	81.60	14.30	3.25	
5	5.50	2.498	2.26	15.64	85.41	13.87	3.71	

Table 4-7 : Marshall Test for 25% (extracted RAP aggregate and binder) blended with virgin aggregate and bitumen

Item No.	% AC by wt.	Bulk S.G. Comp. Mix (gm./cc)	Air Void (%)	Voids in Mineral Aggregate V.M.A (%)	Voids filled with Bitumen V.F.A. (%)	Stability, kN	Flow (mm)	Optimum bitumen Content (%)
1	3.50	2.429	8.67	15.87	45.37	12.47	1.98	4.91
2	4.00	2.457	7.04	15.40	54.26	12.56	2.27	
3	4.50	2.492	4.99	14.67	66.00	13.25	2.83	
4	5.00	2.511	2.69	14.53	81.52	13.71	3.47	
5	5.50	2.479	2.52	16.11	84.35	12.51	4.12	

Table 4-8 : Marshall Test for 35% (extracted RAP aggregate and binder) blended with virgin aggregate and bitumen

Item No.	% AC by wt.	Bulk S.G. Comp. Mix (gm./cc)	Air Void (%)	Voids in Mineral Aggregate V.M.A (%)	Voids filled with Bitumen V.F.A. (%)	Stability in, kN	Flow in, (mm)	Optimum bitumen Content (%)
1	3.50	2.398	8.64	16.95	49.03	11.39	2.01	4.92
2	4.00	2.430	6.70	16.34	59.01	12.02	2.52	
3	4.50	2.454	4.85	15.98	69.70	13.03	2.68	
4	5.00	2.484	2.68	15.45	82.69	13.68	3.19	
5	5.50	2.457	2.31	16.85	86.30	11.93	3.26	

Table 4-9: Marshall Test for 45% (extracted RAP aggregate and binder) blended with virgin aggregate and bitumen

Item No.	% AC by wt.	Bulk S.G. Comp. Mix (gm./cc)	Air Void (%)	Voids in Mineral Aggregate V.M.A (%)	Voids filled with Bitumen V.F.A. (%)	Stability in, kN	Flow in, (mm)	Optimum bitumen Content (%)
1	3.50	2.401	8.35	16.85	50.65	11.21	2.11	4.90
2	4.00	2.427	6.35	16.41	61.57	12.05	2.34	
3	4.50	2.451	4.40	16.07	72.65	12.78	2.46	
4	5.00	2.480	2.04	15.56	87.29	13.58	2.88	
5	5.50	2.455	2.00	16.92	88.37	13.05	3.30	

4.1.4. Comparison of Direct Method RAP and Split/Separate methods

4.1.4.1. Effect of Bulk Specific Gravity Compacted Mix in both method of RAP

Analysis of the obtained bulk specific gravity data showed that the bulk specific gravity (density) of a mixture in OBC was dependent on the gradient and maximum nominal size, observing some variation for each mixture; different ratios of RAP, different RAP methods were used. The previous chapter shows the sample densities for all mixtures. As the laboratory test results show, the density increases slightly as the nominal size of the aggregate increases. The highest density was achieved at a nominal size of 19 mm, with a fine gradation indicating that the mixture was denser. And the lowest value was reached at the coarse gradation of 12.5mm, as shown in Figure 4.1 shows results [40] also suggest that increasing aggregate size increases specific gravity for given asphalt content.

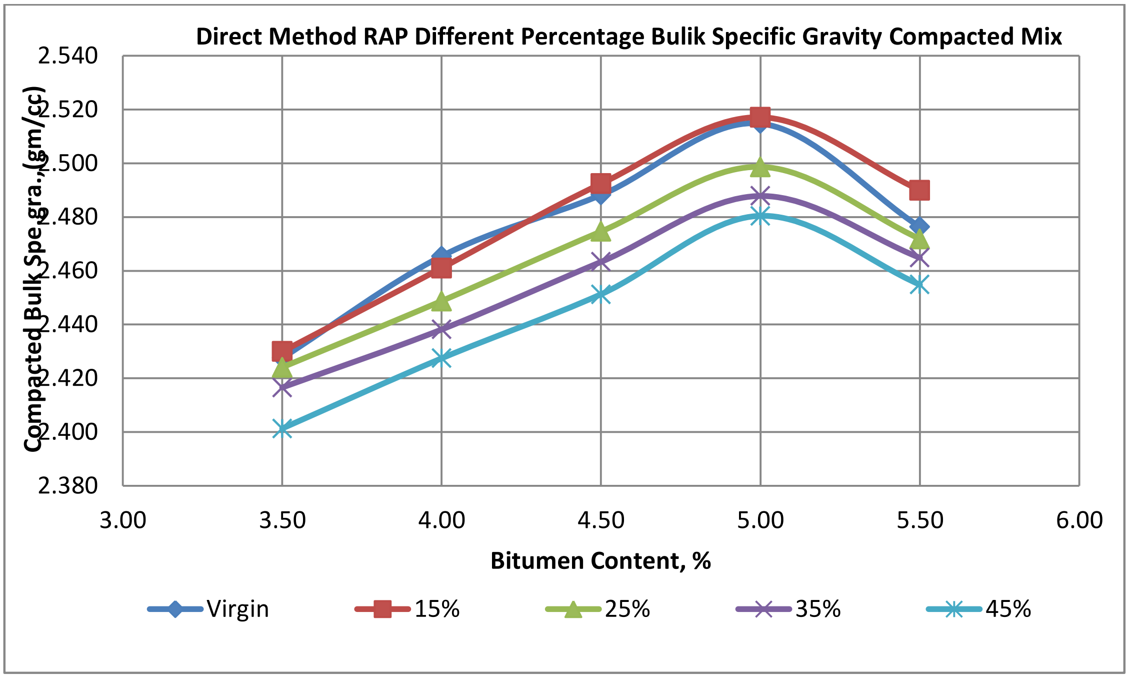

Figure 4-1: Bulk Specific Gravity for Direct Method RAP using Compacted Mix

As it can be seen from the above figure 4-1, the test results of bulk density in the use of direct method increasing the RAP percentage decrease the compacted bulk specific gravity. This is due to the fact that as the mix becomes finer, almost all the main components of the mix become finer graded aggregate particles.

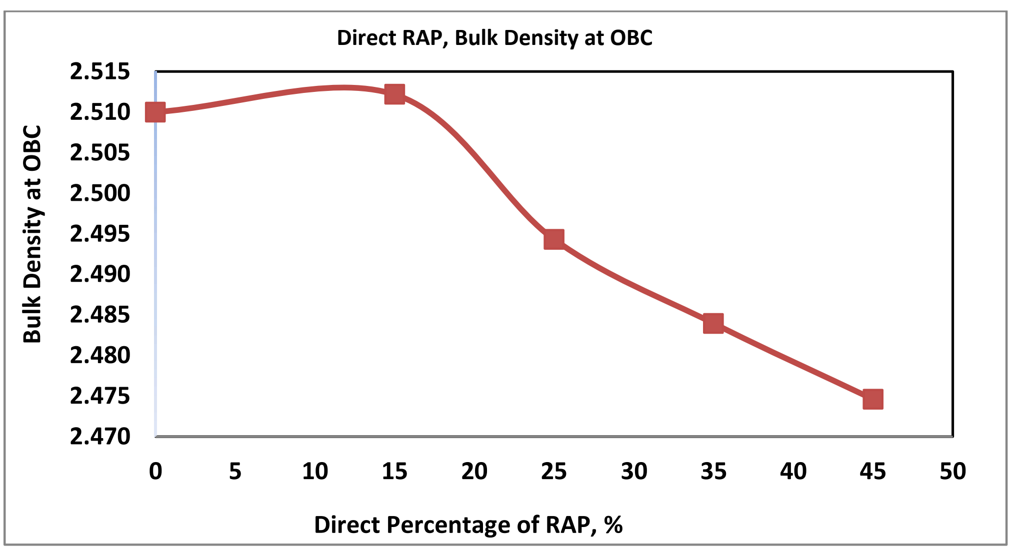

Figure 4-2: Bulk Specific Gravity for Direct Method RAP using Compacted Mix

Due to this fact, the voids created by a very low percentage of coarse aggregate are filled with fine aggregate, the particles are tightly packed, the contact between the particles is increased, and the voids in the mineral aggregate are reduced, resulting in a density, increase. In addition, the total surface area of the fine mixture is greater than the total surface area of the coarse mixture. The larger surface is made up of fine aggregate, so the fine aggregate works among the coarse aggregates.

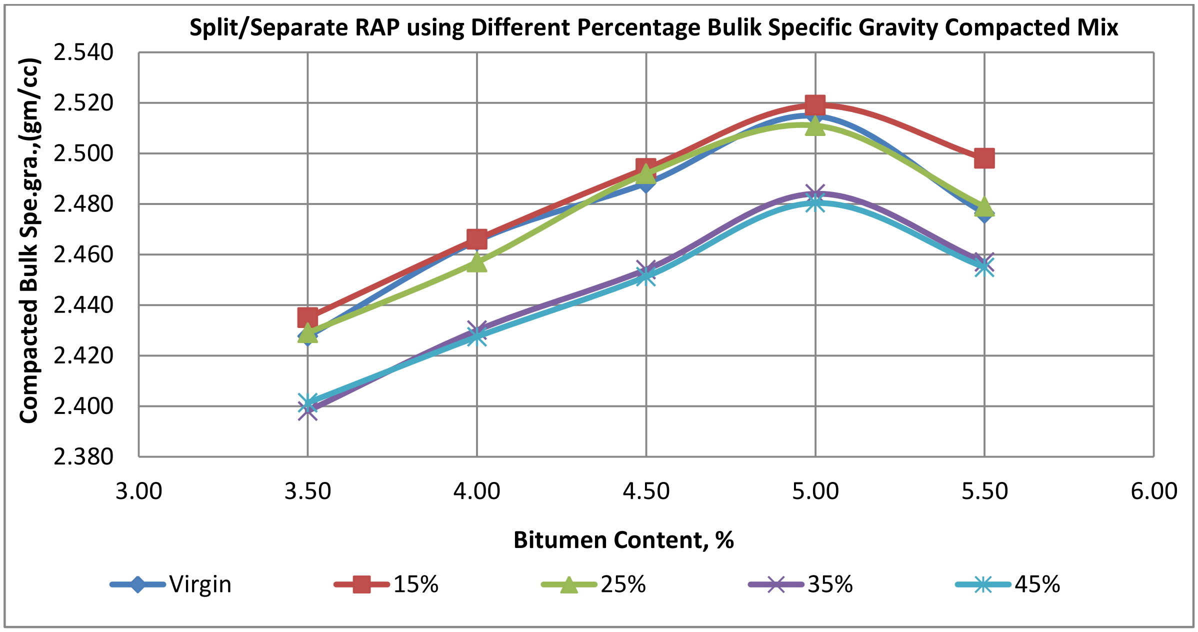

Figure 4-3: Bulk Specific Gravity for Direct Method Split/Separate using Compacted Mix

As it can be seen from the above figure 4-3 the test results of bulk density at the optimum bitumen content in the use of Split/Separate method increasing the RAP percentage decrease the compacted bulk specific gravity except 15% of RAP Extracted mix increase the bulk density when compare with virgin mix density. This is due to the fact that as the mix becomes finer, almost all the main components of the mix become finer graded aggregate particles.

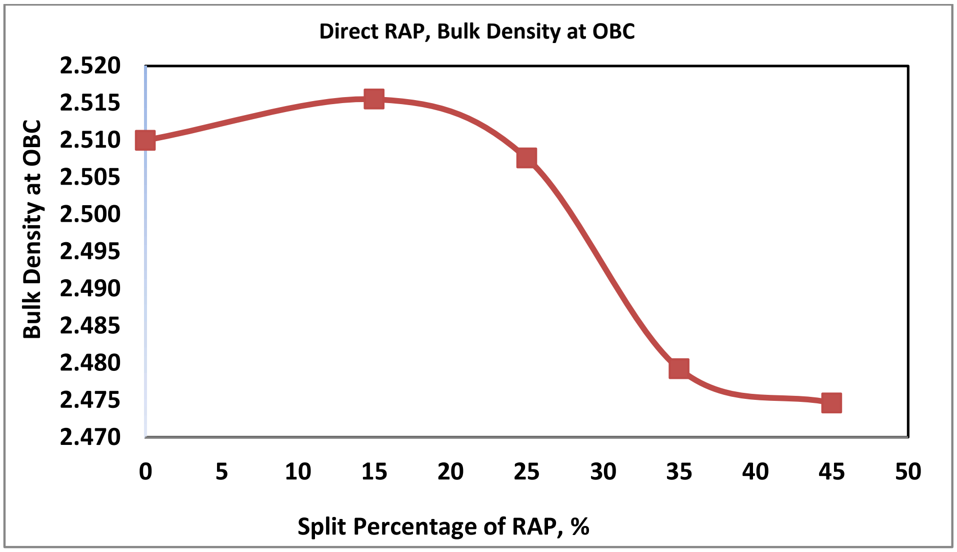

Figure 4-4: Bulk Specific Gravity for Direct Method Split/Separate using Compacted Mix

4.1.4.2. Effect of Stability Compacted Mix in both method of RAP

The results of the martial test are shown in the chapters and appendices above. The results showed that all blends were more stable than the minimum tolerance i.e. 8kN and 9kN compliant with MS2 or ERA 2013 PDM. According to the Asphalt Institute, heavy traffic mixtures require a minimum intensity of 8 kN. However, this value increases to 9kN in ERA 2013 PDM. All mixes presented in this study in both processes achieved the minimum requirement of Marshall Stability. As can be seen from the results of the stability test, both methods have a slight improvement in stability.

As shown in the following figure, the highest stability value was achieved with the 15% RAP split / separation method and the lowest value was achieved with the 15% RAP direct method. Stability is generally a measure of the volumetric viscosity of an asphalt cement mixture and is greatly influenced by the angle of internal friction of the rock. As the size of the aggregate increases, the contact between the aggregates increases, which increases the internal friction between the particles Therefore, the reason for this large nominal size, which has a coarse gradient, is its high stability value.

If the amount of very fine dust in the mixture is somewhat high, this will cause the asphalt cement/dust mixture to act as a more viscous binder, thereby increasing its resistance to combat. Therefore, due to this fact, the highest stability can be observed in both Rap methods. This result is consistent with Marshall's stability being affected by gradation changes, with finer gradations producing the highest stability and finer coarse gradations being the lowest[25]. There was little difference in stability values between the two processes, the difference in RAP proportions and the stability of all blends were very high compared to the specification requirements.

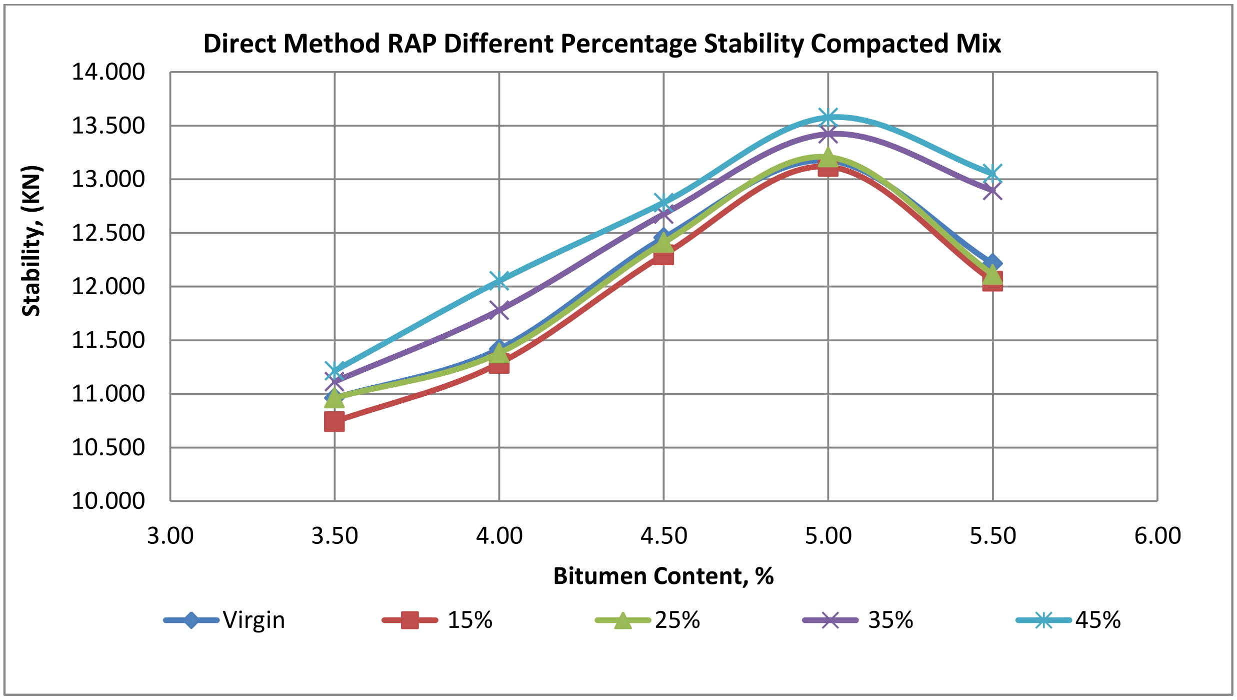

Figure 4-5: Direct Method RAP different percentage Stability Compacted Mix

As we can see the above Figure 4-5 in the direct method during the marshal mix design at different percentage of bitumen content each stability test results and the stability in two percentage 35% and 45% of RAP increase the stability results.

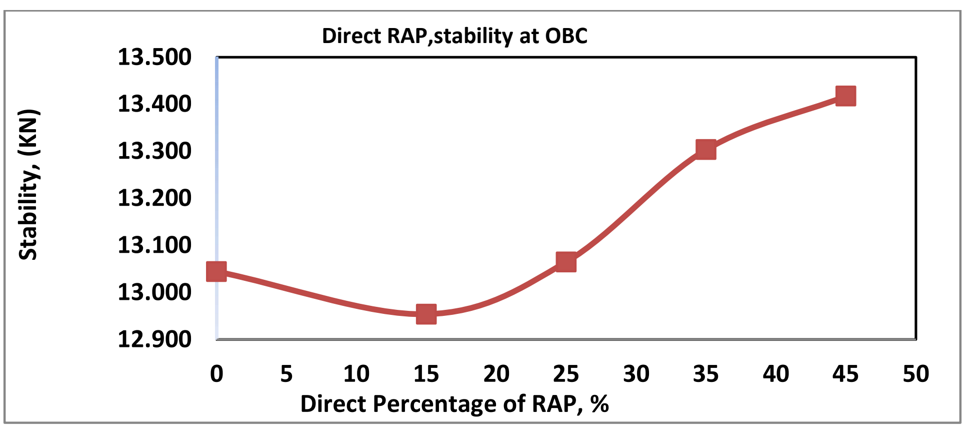

Figure 4-6: Direct RAP using different percentage Stability Compacted Mix

As it can be seen from the above figure the test results of stability the higher percentage of direct RAP increase the stability results at the optimum bitumen content.

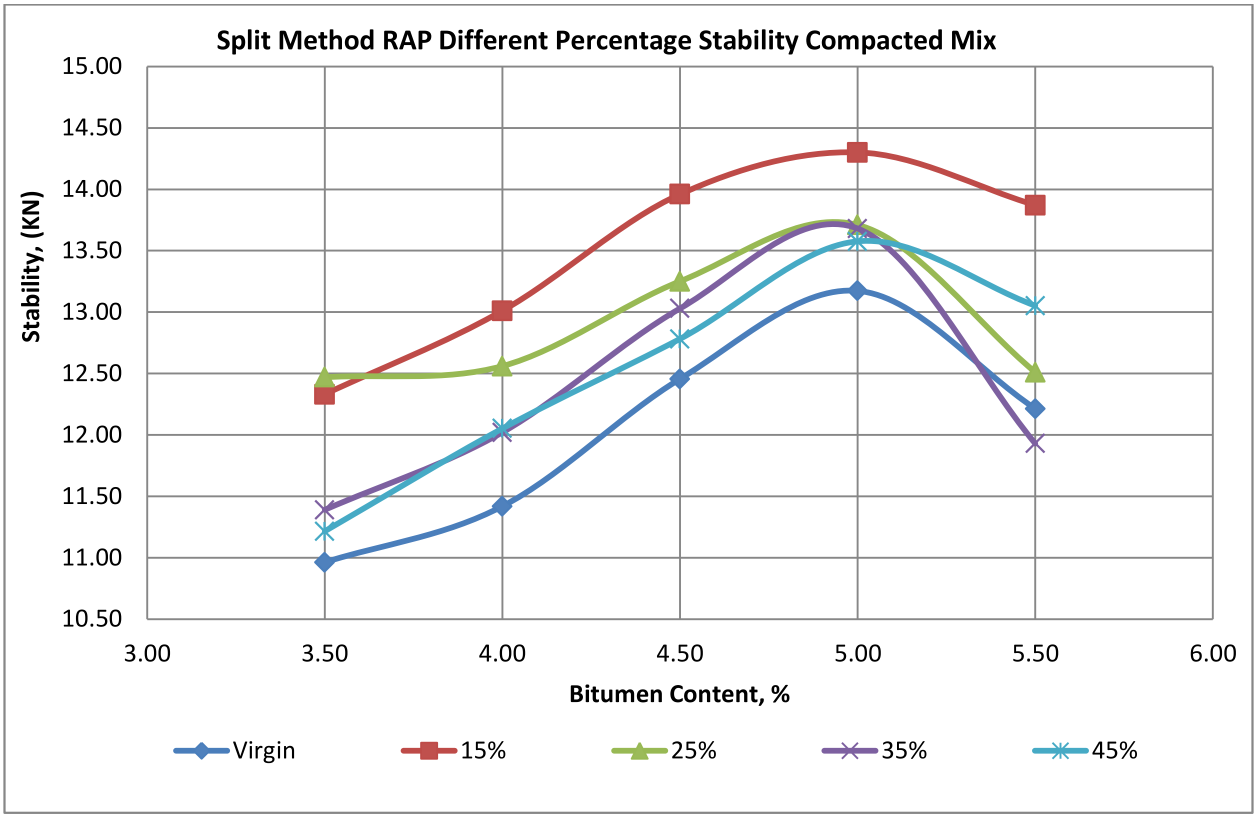

Figure 4-7: Split Method RAP different percentage Stability Compacted Mix

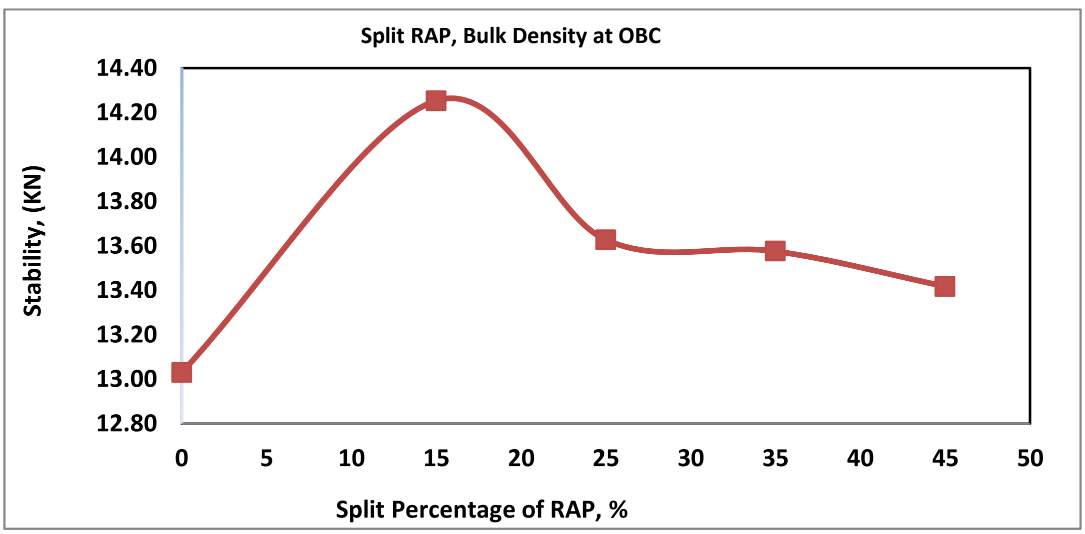

Figure 4-8: Split RAP using different percentage Stability Compacted Mix

4.1.4.3. Effect of Flow Compacted Mix in both method of RAP

Flow values were measured for all mixtures and the influence of the percentage of RAP, size, and classification of the RAP aggregates was assessed. Since the flow is the longitudinal strain of the sample in percent cm, it seems that the larger aggregate (19mm) in the asphalt still retains the highest yield value (more longitudinal strain), showing the flexibility increases as the aggregate size increases. The flow rate value is within the specification defined in the ERA 2013 PDM. The user manual suggests that the flow rate value for heavy traffic is in the 2-3.5mm range. Regarding the effect of RAP in both methods, the flow value decreases as the proportion of RAP in both aggregation methods changes with a finer gradient in the course. However, both methods do not differ significantly in flow rates between different classification types and different RAP procedures in the mix. Reducing the flow value for subtle gradations can involve using a higher percentage of pass number 200 (Fillers) in the mix, which creates mix stiffness.

At 4% air void the trend of stability with bitumen based on the OBC. However, some variation has been observed in flow value. Flow value decreases as gradation of aggregate changes from course to finer gradation as well as from each method changing the RAP percentage. Since flow is vertical deformation of the specimen in hundredths of an inch, is appears that larger aggregate in an asphalt concrete mix produced more vertical deformation, which indicates increased flexibility with increased aggregate size.

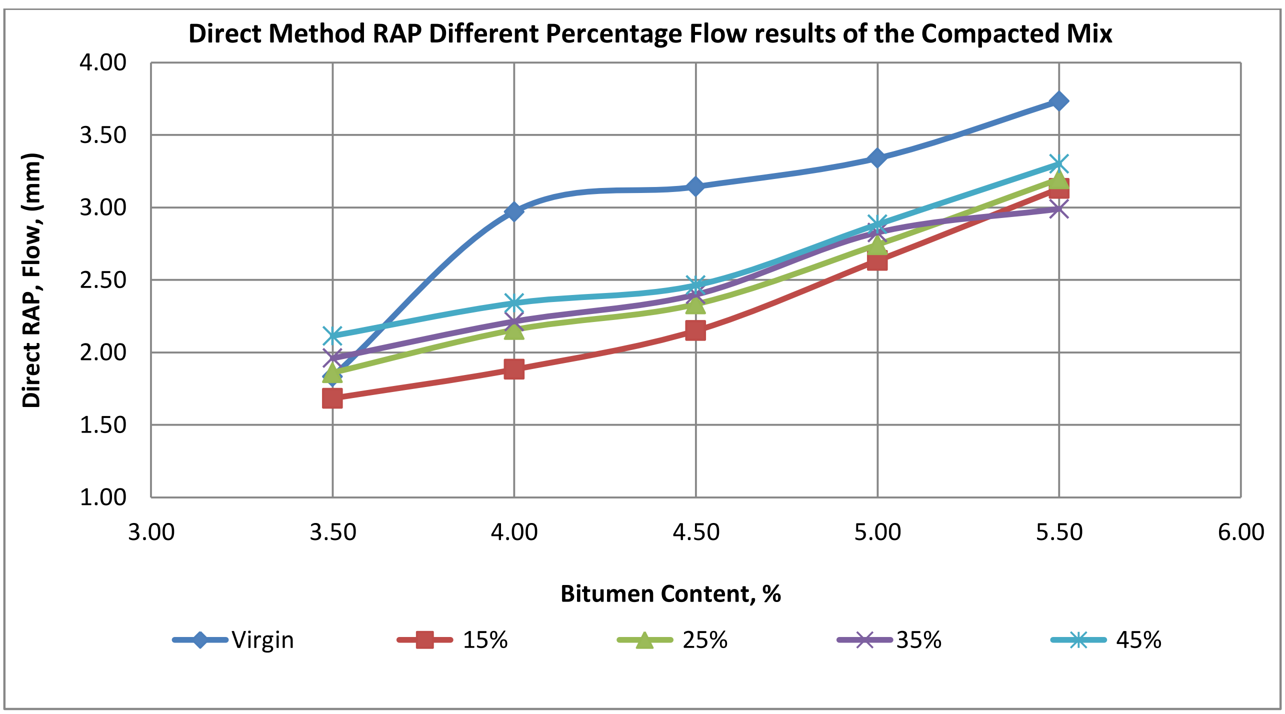

Figure 4-9: Direct Method RAP different percentage flow Compacted Mix

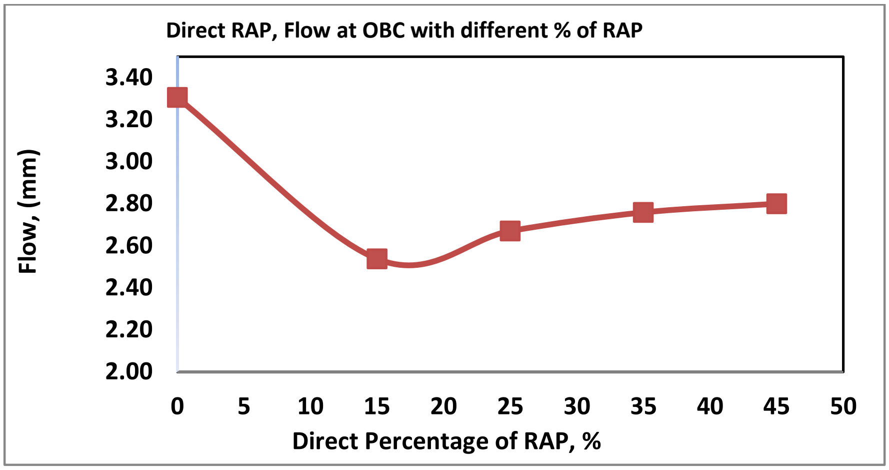

Figure 4-10: Direct RAP using different percentage flow Compacted Mix

As it can be seen from the above Figure 4-10 the test results of flow when increase the percentage of RAP direct method during the marshal mix design the flow results are decrease compare to the Control/Virgin mix. And also at the selected optimum bitumen content for different percentage of rap use in the mix the flow results also decrease.

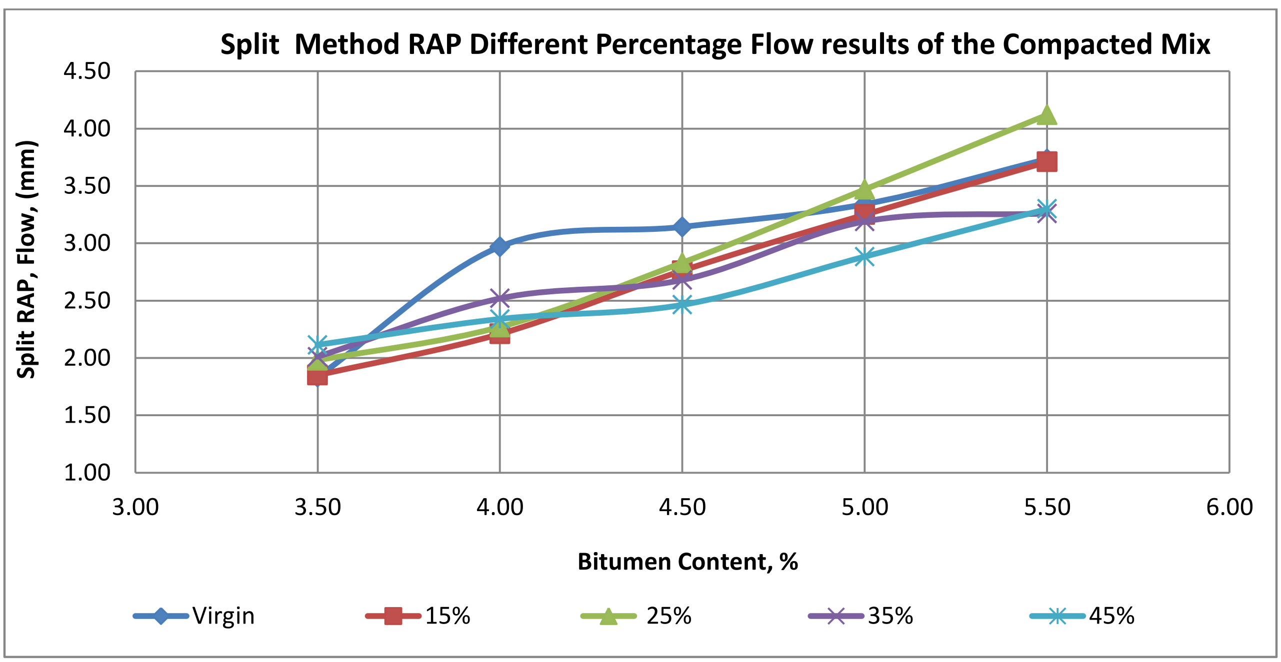

Figure 4-11: Split Method RAP different percentage flow Compacted Mix

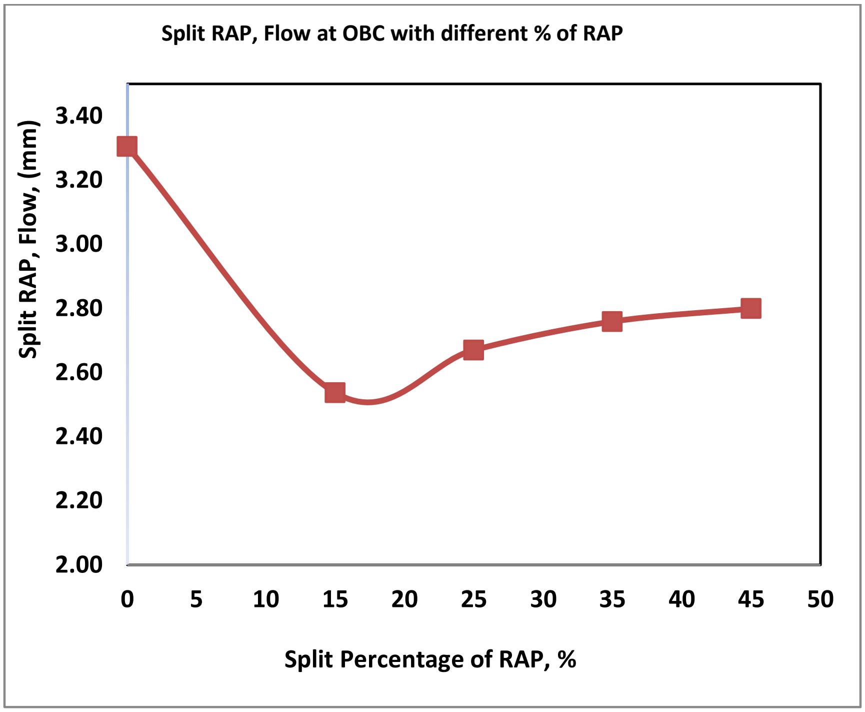

Figure 4-12: Split RAP using different percentage flow Compacted Mix

4.1.4.4. Effect of RAP and Virgin Aggregate gradation Size on Dust to binder ratio

The dust to binder ratio recommended range is 0.6-1.2 according to Asphalt Institute 7th edition, (2015) and AASHTO, (2004). However, in this study the ratio exceeds the limit. In this study, all grading fulfills the specification grading requirement when using Split/Separate Extracted RAP method and also in the direct RAP method we cannot control the grading of the mix since grading is the major criteria in the marshal mix design. High mineral filler content may cause the mix to be dry or gummy, hard to handle, and not durable.

Table 4-10 : Split/Separate Method RAP different percentage dust binder Ratio

Type of Tests	Grading % Pass	OBC (%)	Dust to Binder Ratio at OBC (%)
Virgin Aggregate% Pass at 0.075mm	8.1	4.91	1.65
15% of Extracted RAP % Pass at 0.075mm	7.4	4.93	1.50
25% of Extracted RAP % Pass at 0.075mm	7.0	4.91	1.43
35% of Extracted RAP % Pass at 0.075mm	6.5	4.92	1.32
45% of Extracted RAP % Pass at 0.075mm	6.1	4.90	1.24

As it can be seen from the laboratory test result, increase the Extracted RAP with different percentage, the dust to binder ratio decrease slightly when compare to Control/Virgin mix. The highest value of Filler to bitumen ratio was achieved at the virgin/control mix. The fact that the virgin mix higher filler to bitumen ration during the mix of virgin aggregate i used to select the median envelop grading at 0.075mm 8.1% pass due to this the filler to bitumen ration a slightly higher when compare with the specification. But in the mix using split/separate extracted method of RAP all the mix with different percentage of extracted RAP the filler to bitumen ratio decrease when compare to the virgin mix. This is apparent and due to the fact that as the mix becomes finer.

In this study, all grading fulfill the specification grading requirement when using Split/Separate Extracted RAP method and also in the direct RAP method we cannot control the grading of the mix since grading is the major criteria in the marshal mix design. As shown in the above chapter, the virgin aggregate gradations have more fine materials and dust compared to the other percentage of Extracted RAP grading. The recommend gradation envelope for this study which is adopted from ERA 2013 and MS-2the optimum bitumen content for the mix in the study are the nearly equal/found within a narrow range of RAP this decrease dust to binder ratio when the ratio is relatively lower, a coarser mix will be obtained.

The Asphalt Institute Manual associated the workability problems with mineral filler. If the mix has a low mineral filler content, the pavement may experience tender mix or highly permeable. High mineral filler content may cause the mix to be dry or gummy, hard to handle, and not durable.

4.1.4.5. Effect of Gradation on Optimum Bitumen Content

The results of the RAP test mixed with the two methods for optimal bitumen content are presented in the table below. In both RAP methods mixed with primary aggregates, the optimal bitumen content is almost the same when choosing OBC. They found that for a given aggregate, the OBC was higher for aggregates with fewer types of filler and lower for aggregates with more filler. In addition, some publications also indicate that more bitumen is required to cover the surface of smaller NMAS aggregates. However, even if the area of the lower NMAS (Nominal Maximum Aggregate Size) is higher, less/moderate amount of bitumen is required to fill the voids to achieve the required air gap.

OBC decreases as the gradient changes from course to fine. However, similar to the nominal size, the fine aggregate is expected to have a higher surface area, but in this particular study less bitumen is required to fill the voids to achieve the voids needed. This fact may be due to the high density of the gradient. Dense asphalt mixtures generally contain fewer voids. Therefore, BC obtained by the NAPA method was slightly higher than that of the MS2 method. However, in the case of the extracted RAP Split/Separate method, it greatly increases. There was no difference in RAP method in this particular study/case, and nominal size showed an inverse correlation compared to [10].

Table 4-11: RAP blended with both methods the optimum bitumen content.

Blend Percentage from RAP, (%)	Split/separate Extracted RAP Optimum Bitumen Content, (%)	Direct RAP Optimum Bitumen Content, (%)
0	4.91	4.91
15	4.93	4.90
25	4.91	4.91
35	4.92	4.92
45	4.90	4.90

According to Asphalt Institute guidelines, excessive asphalt can cause scratches and bleeding, which affects pavement stability and low skid resistance. On the other hand, a lower asphalt content results in a thinner asphalt film, leading to premature aging. Low asphalt content can also promote drying and cracking. As a result, both effects can lead to the fact that the road surface becomes brittle and impermeable. Both RAP blends were in the MS2 recommended bitumen range. From an economic point of view, both marshaling mixes have the lowest OBC, which makes them really economical to use in construction.

4.1.4.6. Effect of gradation and Nominal Size on VMA

Table and figure presented in below to show the effect Extracted RAP and without extracted /Direct RAP of aggregate gradation for each nominal aggregate size used in this study. Results show that the VMA were mainly affected by gradation rather than Nominal Size. The result mentioned on listed below noticed that when using direct rap method except 15% Direct RAP all others blend percentage 25%,35% and 45% Increases the VMA results when compare with control/virgin mix.

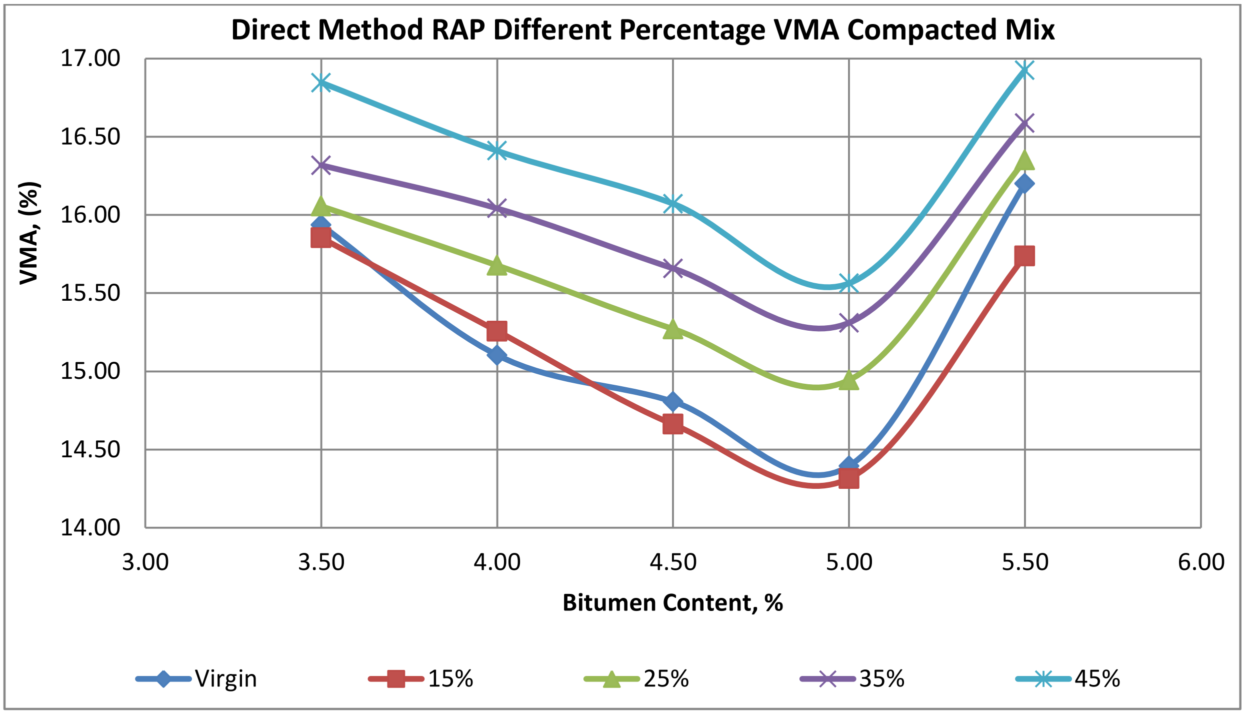

Figure 4-13: Direct Method RAP different percentage VMA Compacted Mix

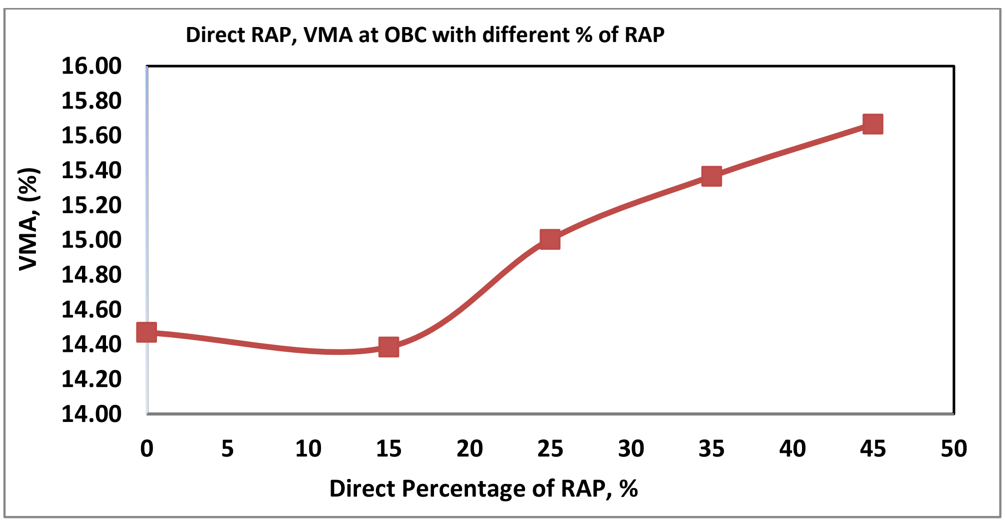

Figure 4-14: Direct RAP using different percentage VMA at OBC.

As can be seen from the Figure 4-14 above, the VMA test results increase when using the RAP percentage is increase. In terms of size for this study, the nominal size variations do not cause significant changes in the VMA. For the mixes tested, the direct method of RAP would be judged to be most detrimental because it resulted in acceptably higher VMA contents. As per MS-2, it is suggested that deviating from the maximum density line in either the coarse or fine direction tend to cause an increase in VMA. However [10] stated that the amount fine increase, increase surface area and tends to decrease VMA for the same level of compaction. .

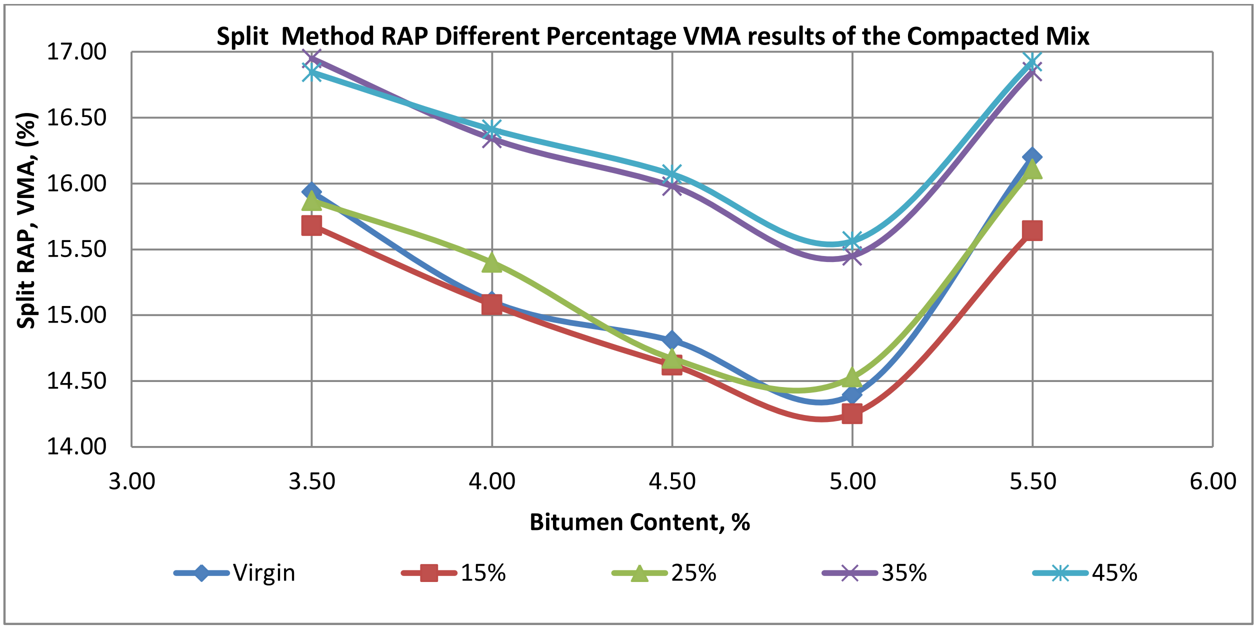

Figure 4-15: Split Method RAP different percentage VMA Compacted Mix

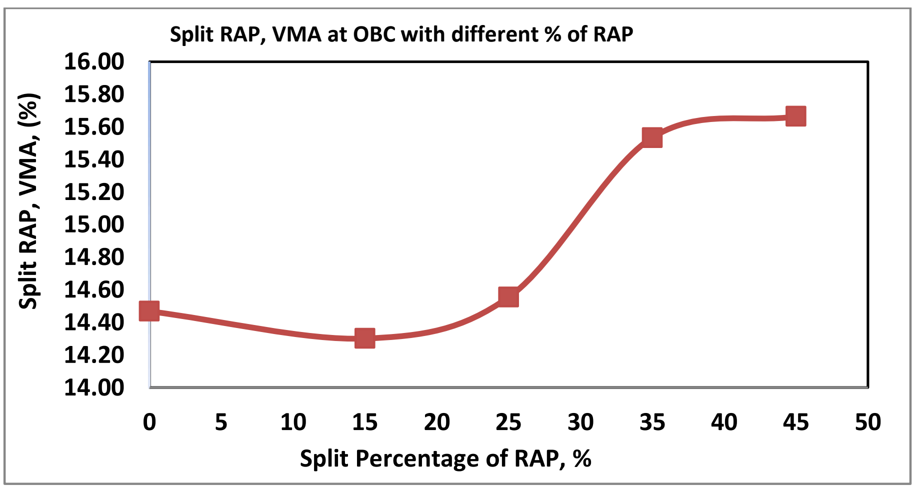

Figure 4-16: Split RAP using different percentage VMA at OBC

As it can be seen from the above figure 4-16, the split/separate method of RAP the VMA usually increase as the percentage of RAP higher and gradation of aggregate changes from course to relatively finer gradation. In a coarser graded aggregate, voids are created in between aggregate particles which are to be filled by fine aggregate fractions. In spite of this fact, there will be voids left unfilled by fine aggregate as aggregate won't pack 100% on mixing and compaction. As the aggregate becomes finer, they are closely packed in such a way that the void space left unfilled by filler particles will be minimized. At 4% air void, the VMA verses BC follows similar trend with the OBC. However, the VMA at 4% air void is slightly higher compared to the OBC obtained from MS-2 method. The total amount of void significantly affects the performance of mixture because if the VMA is too large, in this study, the void in the mineral aggregate, VMA, for both methods of RAP and nominal size met the minimum requirement of the marshal mix design specified on MS-2 with acceptable value.

4.1.4.7. Effect of Voids Filled with Bitumen

Void filled with bitumen in the percent of the volume of the VMA that is filled with asphalt cement. Both RAP methods have no significant impact on VFB of compacted samples at OBC. The VFB slightly increase when compare to control mix. When the direct RAP method percentage increase the VFA value slightly increase compare to Virgin/Control mix value. The computation of VFB is dependent on VMA and bitumen content. Based on the test result in terms of gradation, the highest value of VFB was achieved at 45% of direct RAP method.

Table 4-12: Direct Method RAP different percentage VFA Compacted Mix

Bitumen Content (%)	VFA Comp. Mix (%)				
	Virgin/ Control Mix	Direct 15% of RAP	Direct 25% of RAP	Direct 35% of RAP	Direct 45% of RAP
3.50	47.28	48.72	49.06	50.12	50.65
4.00	58.67	59.72	59.03	59.91	61.57
4.50	68.26	71.30	70.96	71.66	72.65
5.00	81.14	82.81	83.94	83.16	87.29
5.50	86.90	87.52	86.19	87.37	88.37

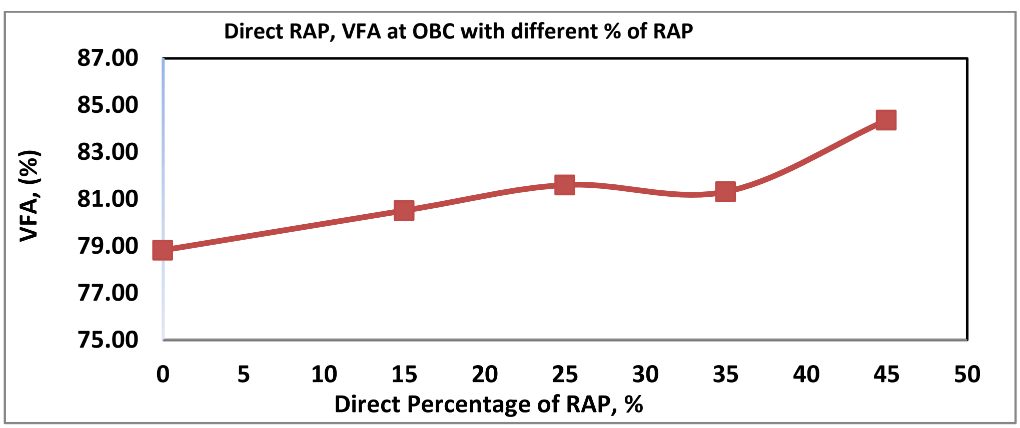

Figure 4-17: Direct Method RAP different percentage VFA at OBC

As shown in the above table 4-12, the lowest value was achieved in the control mix. For this particular thesis, using direct RAP have relatively dense graded which is closely follow the maximum density line (fuller curve). This agrees with most literatures, manuals and findings of [10] who stated as the aggregate becomes dense graded, they are closely packed in such a way that the void space left unfilled by particles will be minimized. This will minimize the VMA in turns the VFB of the mixture. However, at 4% air void, the highest value of VFB was achieved at 45% of direct RAP method. The lowest VFB value was achieved in control mix.

The effect of voids filled with bitumen is experimentally tested and the results are shown in Table 4.13 below.

Table 4-13: Split Method RAP different percentage VFA Compacted Mix

Bitumen Content (%)	VFA Comp. Mix (%)				
	Virgin/ Control Mix	Split 15% of RPA	Split 25% of RPA	Split 35% of RPA	Split 45% of RPA
3.50	47.28	45.17	45.37	49.03	50.65
4.00	58.67	57.04	54.26	59.01	61.57
4.50	68.26	69.28	66.00	69.70	72.65
5.00	81.14	81.60	81.52	82.69	87.29
5.50	86.90	85.41	84.35	86.30	88.37

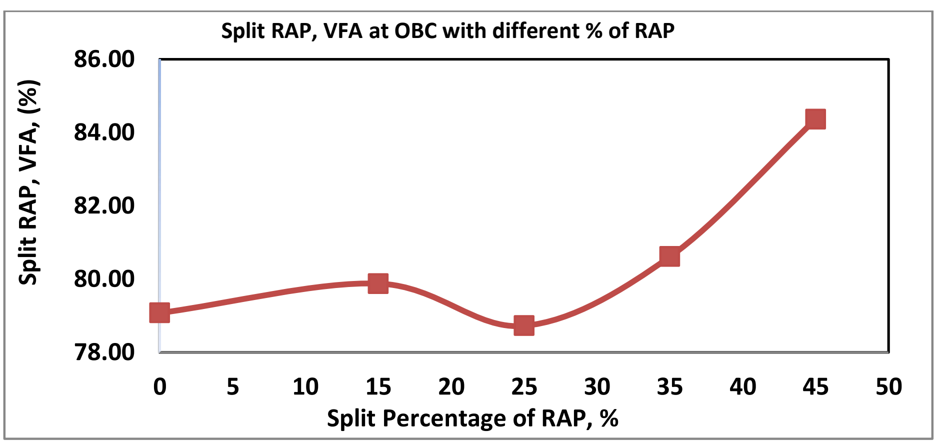

Figure 4-18: Split Method RAP different percentage VFA at OBC

Results show that the VFA were mainly affected by gradation rather than Nominal Size. The result mentioned on listed below noticed that when using extracted RAP split method except 25% of extracted RAP all others blend percentage 15%,35% and 45% Increases the VFA results when compare with control/virgin mix.

Based on this it can be concluded that analysis of all the data indicated significant effects on VFB attributable to aggregate gradation type but no significant effect weather using direct RAP or Extracted split RAP method on the VFA value. Over- all, the VFB at OBC used in this study, direct RAP method can produce relatively higher VFB compared to Extracted RAP Split method and Control mix. The lowest VFB value was achieved in the control mix and Extracted RAP split method. However, there is no clear (significant) difference can be seen between in both methods.

4.1.4.8. Effect of Bitumen Film thickness

Because of the importance of asphalt film thickness to HMA durability, the asphalt film thickness was estimated for all mix design. Asphalt film thickness describes the asphalt binder coating the aggregate particles. As per ERA 2013 pavement design manual, the value of the film thickness for an asphalt mix is in the range of 7-9μm.

The film thickness estimates along with the corresponding bitumen content are described in listed below. To calculate the film thickness, surface area and effective asphalt content are the two-basic parameter. The simple equation presented in ERA 2013 pavement design manual is used to predict the surface area of aggregate. The effective asphalt content for the corresponding asphalt content was estimated from the formula recommended on asphalt institute.

The film thickness results shown in the table show that, the film thickness is slightly lower when the percentage of RAP increases. In terms of gradation, film thickness of the mix decreases substantially as gradation of aggregate changes from course to finer gradation. This is due to the fact that the fine graded mix has a greater total surface area and therefore a lower film thickness. The analysis of the film thickness shows trends similar to results as [10] showed. They reported for given asphalt and aggregate mixture, the durability is enhanced if adequate film thickness is attained. For given effective asphalt content, the film thickness will be greater if the aggregate gradation is coarser. This can most effectively be accomplished by decreasing or minimizing the percentage of fines.

The test result showed that in both RAP method had the lowest film thickness. It can be seen that the both RAP method has no significant impact on film thickness of compacted samples at OBC. The film thickness very slightly decreases as the RAP percentage of the mix increase. Therefore, based on this it can be concluded that significant effects on film thickness related to aggregate gradation but no significant effect caused by RAP material.

The film thickness revealed that on the split/separate extracted RAP method 15% and 25% has sufficient film thickness. However, the remaining percentage of split method and all the direct method including control/virgin mix is found smaller film thickness compared to most specification. According to [25] inadequate film thickness can create a lack of cohesion between aggregate particles and create a dry mix. Also, if the asphalt film is too thin, air which enters the compacted HMA can more rapidly oxidize, causing the pavement to become brittle. Additionally, if the aggregate are hydrophilic, thin asphalt films are more easily and rapidly penetrated by water than thick ones causing striping or deboning of the asphalt binder from the aggregate.

Table 4-14: Bitumen Film Thickness, FT

Types of tests	**Direct RAP Method**				**Control /Virgin**
	15% of Direct RAP	**25% of Direct RAP**	**35% of Direct RAP**	**45% of Direct RAP**	
Bitumen Film Thickness, FT	5.83	5.45	5.30	4.83	5.93

Table 4-15: Bitumen Film Thickness, FT

Types of tests	Split/Separate Extracted RAP method				Control /Virgin
	15% of Direct RAP	25% of Direct RAP	35% of Direct RAP	45% of Direct RAP	
Bitumen Film Thickness, FT	6.09	6.15	5.58	5.01	5.93

The film thickness results shown in the table show that, the film thickness is slightly lower when the percentage of RAP increases.

Generally, the Marshall properties such as stability, flow, specific gravity, VTM, VMA, VFA, effective asphalt content, optimal asphalt content, binder to dust ratio and mixture film thickness are evaluated comparatively according to the Marshall method for mix design.

The trends all the different gradation has exhibited with the bitumen content are normal of the HMA. That is:

- Stability increases with bitumen content. Moreover, the peak was also reached at the testing bitumen content;

- The flow and VFB values also increase with increase in the bitumen content;
- The air-void continuously decreases with increasing bitumen content;
- The VMA curve shows an upward parabola shape; and
- The unit weight increases until the peak point and decreases thereafter.

Since this study only consisted of a laboratory evaluation, field performance of the various asphalt mixtures was not established.

4.1.4.9. Selection of Optimum RAP Percentage

The optimum percentage of RAP is selected in both direct and split method based on marshal criteria. Here are summarized listed below in the table.

Direct RAP						
Types of tests	Criteria	Control	15% of RAP	25% of RAP	35% of RAP	45% of RAP
Stability	>9KN	13.04	12.95	13.06	13.3	13.42
Air Void	3-5%	3.07	2.82	2.80	2.91	2.51
VFA	65-75 %	78.81	80.51	81.6	81.32	84.36
VMA	>14%	14.47	14.38	15	15.37	15.66
FLW	2-4 mm	3.30	2.54	2.67	2.76	2.80
Split/Separate RAP						
Types of tests	Criteria	Control	15% of RAP	25% of RAP	35% of RAP	45% of RAP
Stability	>9KN	13.03	14.25	13.63	13.58	13.42
Air Void	3-5%	2.99	2.87	3.10	3.03	3.30
VFA	65-75 %	79.08	79.88	78.73	80.61	81.2
VMA	>14%	14.47	14.3	14.56	15.53	15.66
FLW	2-4 mm	3.30	3.18	3.35	3.11	2.79

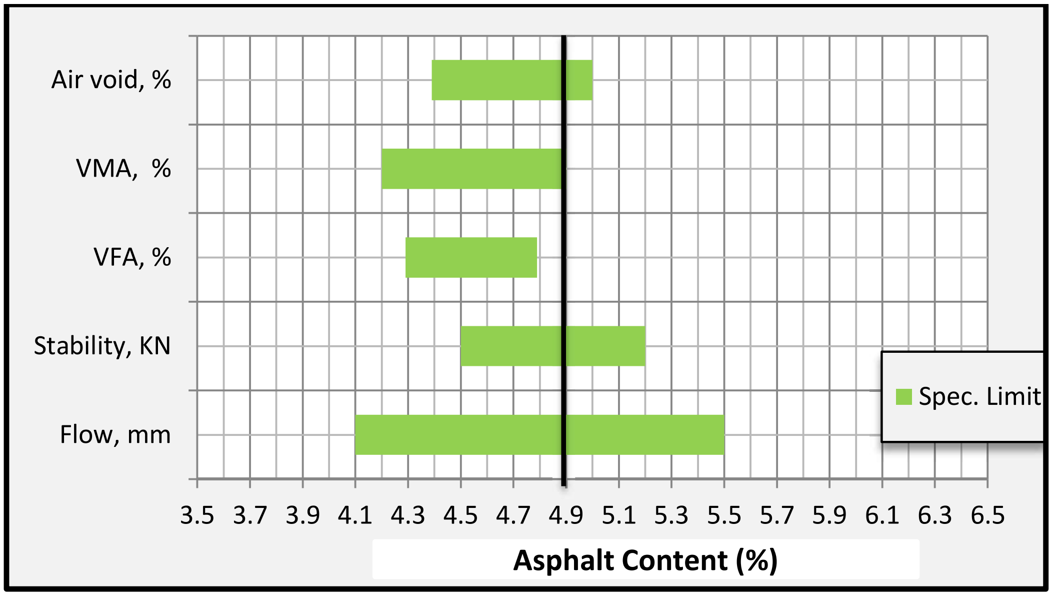

Figure: 4.1.4.9.1, Optimum 15% of RAP Percentage,(Direct Method)

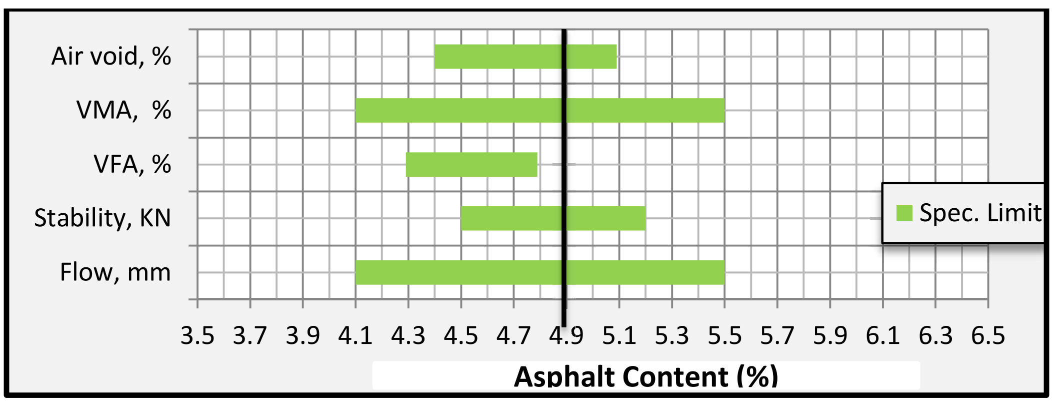

Figure: 4.1.4.9.2, Optimum 25% of RAP Percentage,(Direct Method)

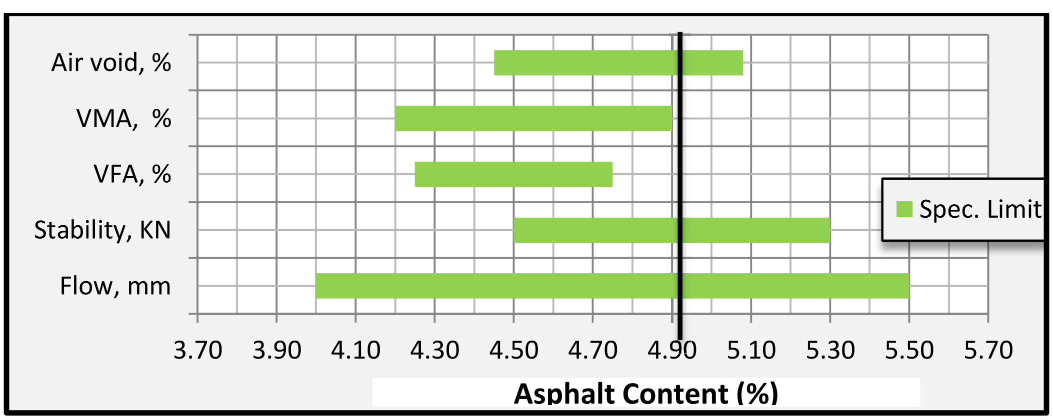

Figure: 4.1.4.9.3, Optimum 35% of RAP Percentage,(Direct Method)

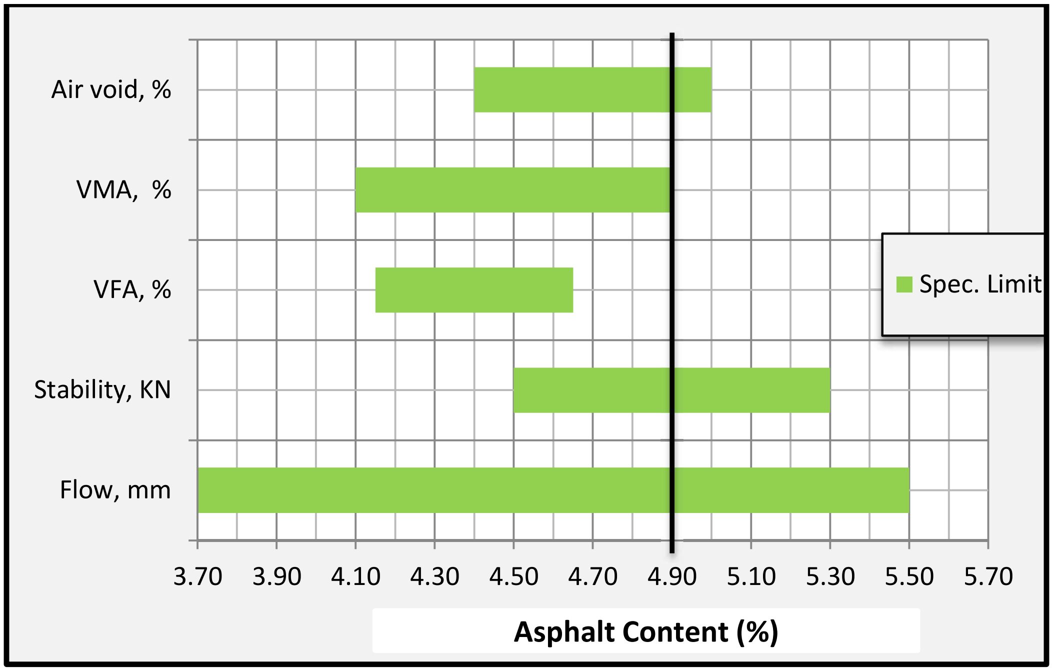

Figure: 4.1.4.9.4, Optimum 45% of RAP Percentage,(Direct Method)

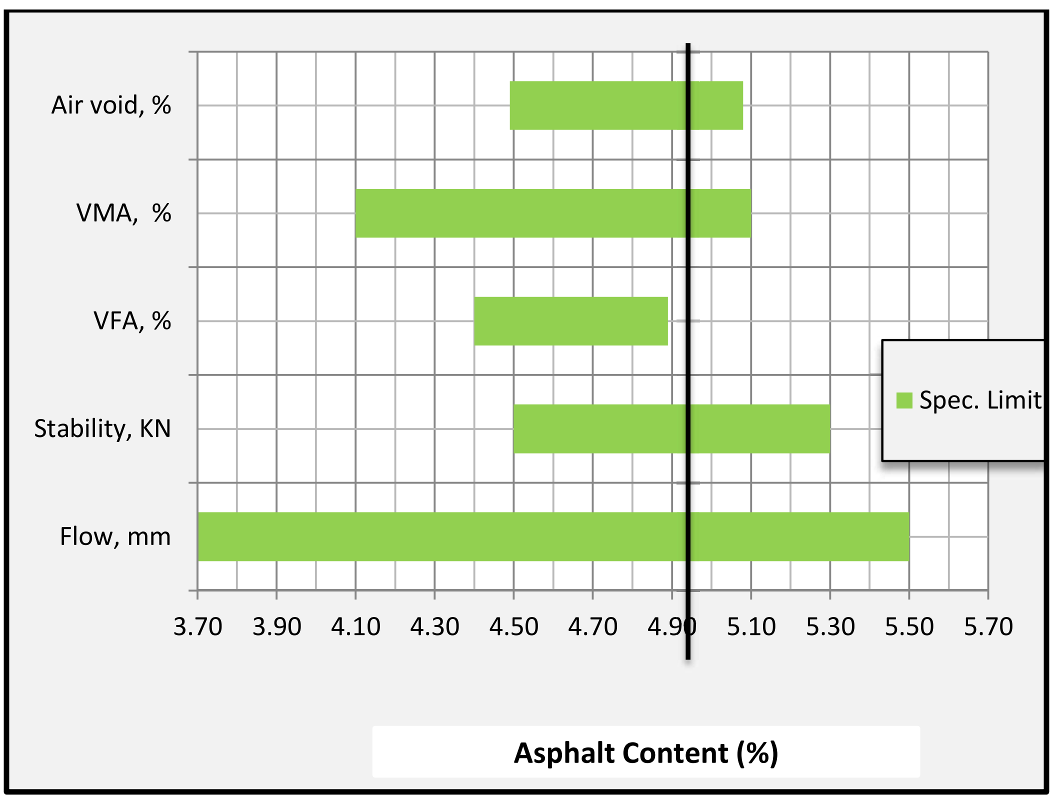

Figure: 4.1.4.9.5, Optimum 15% of RAP Percentage,(Split Method)

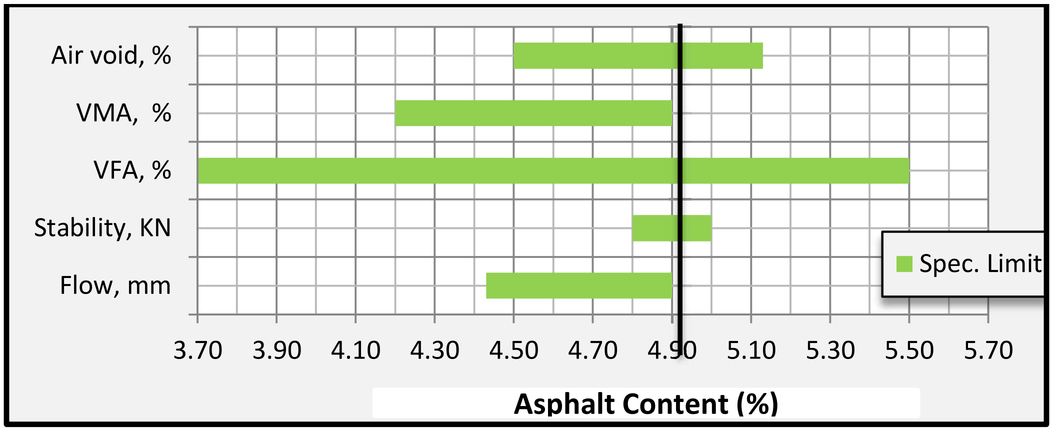

Figure: 4.1.4.9.6, Optimum 25% of RAP Percentage,(Split Method)

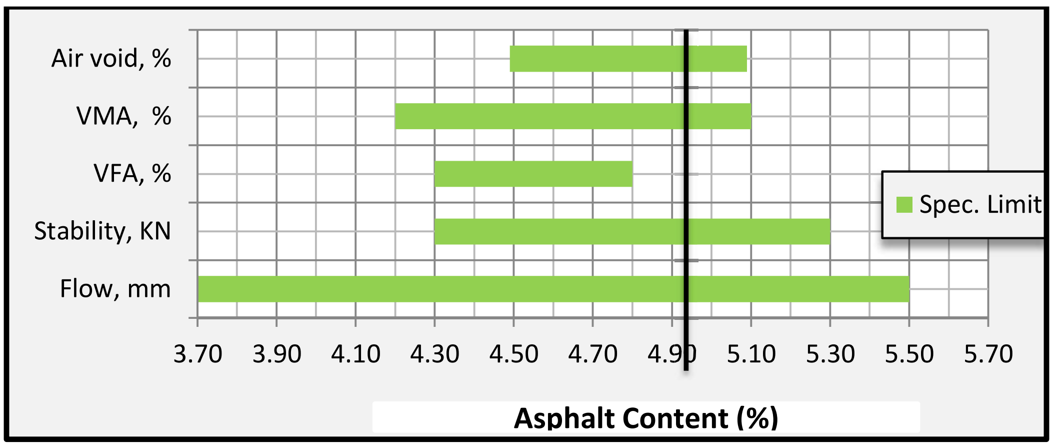

Figure: 4.1.4.9.7, Optimum 35% of RAP Percentage,(Split Method)

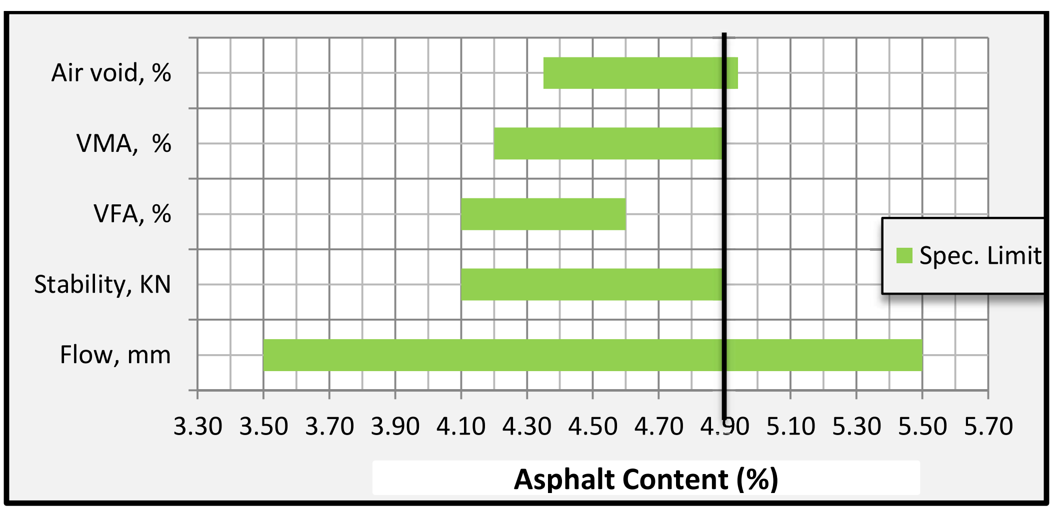

Figure: 4.1.4.9.8, Optimum 45% of RAP Percentage,(Split Method)

5. FINDINGS AND CONCLUDING

The following findings and conclusion have been made based upon the experimental results obtained from a laboratory investigation of various HMA mixtures which contain both RAP and virgin Material on the marshal mix design.

- ✓ Based on the Bitumen Centrifuge Extract Test Bitumen Content in RAP material was 4.21% which indicates that binder content in RAP was in lower percentage and based on recycled aggregate properties result it shows all test result are within specification limits.
- ✓ The bitumen needed is getting lesser as the RAP percentage increases in both methods. Even though, the surface area for lower RAP percentage is higher, less/moderate bitumen is needed to fill the voids in order to get the required air void for this particular study.
- ✓ The Marshall Stability Values of HMA for both methods of the mixes prepared with RAP material of 0%, 15%, 25%, 35% and 45% at 155°C shows all the Marshall Test values of the mixes are well and within the specified limit.
- ✓ It has been also seen that there was very less difference in the Marshall Properties values of different percentage of RAP mixes in both methods.
- ✓ In direct method the sieve analysis/grading cannot be control this can affect the marshal mix properties as well as the performance.

5.1 From the above findings the following conclusions can be drawn:

- As the RAP Percentage increases, martial stability, flow, VMA, Bulk Specific Gravity, Dust to binder ratio and the bitumen content slightly increase when compare the control/virgin mix.
- Specimen prepared with Virgin Mix (0%) sample has lower marginal Air Void value than specimen prepared with RAP mixes indicates that Air Voids value decreases while increasing the RAP content.
- In both methods the volumetric properties of air void and VFA slightly decrease as the RAP percentage increases.
- Based on the laboratory test results blended RAP tends to have slightly higher Stability than those from control mixtures without RAP.
- Base on the laboratory results in when increasing the RAP percentage the Gmm, Bulk Density and Flow results in both method slightly decrease when compare with control mix.

- While asphalt film thickness is a very important parameters with regard to pavement durability. Based on the above finding in both method of RAP including control mix slightly lower Film thickness when compare to the standard specification due to selection of the grading types before starting the mix. The gradations have sufficient film thickness and ensure durable in the pavement mix.

5.2 From the above Conclusion the following Recommendation can be drawn:

- Based on the Marshall Test results criteria, the split/separate method recommended for using reclaim asphalt pavement, (RAP). Since the gradation of each material can be controlled on this method.
- While asphalt film thickness is a very important parameters with regard to pavement durability. Based on the above finding in both method of RAP including control mix slightly lower Film thickness when compare to the standard specification due to selection of the grading types before starting the mix. The gradations have sufficient film thickness and ensure durable in the pavement mix.
- The recommended mix based on Marshall Criteria is 45% of extracted split/separated method of RAP mixtures results found satisfied all the minimum requirements.
- From workability point of view 25% and 45% of extracted Split/separate RAP method is recommended based on Marshall Criteria.
- In order to further validate the findings of this research, additional researches have to be conducted. Here are some of the research topics recommended
  - Dynamic Shear Rheometer (DSR)
  - Effects of surface texture
  - Economic Analysis of the RAP

REFERENCES

[1]. ERA, Ethiopian Road Authority, 2013, Pavement Design Volume I Flexible Pavements and Gravel Roads Manual Appendix, Addis Ababa, Ethiopia

[2]. www.asphalt pavement.org

[3]. L.D.R.P Institute of Technology Research, recycling of asphalt pavements, 2018

[4]. ERA. The federal democratic republic of Ethiopia ministry of infrastructure. Midterm review of RSDPII assessment of accomplishment .Addis Ababa: Road sector development program, 2005

[5].IswandaruWidyatmoko,"Mechanistic-empirical mixture design for hot mix asphalt pavement recycling",Elsevier, Construction and BuildingMaterials2008

[6] Gabriele Lebakli et al., 2012

[7] (EN 131 088).

[8].The Asphalt Institute, Mix Design Methods for Asphalt Concrete and other Hot Mistypes, MS-2, Sixth Edition, 1995

[9].AudreyCopelandReclaimedAsphaltPavementinAsphaltMixtures:State of the Practice, Turner-Fairbank Highway Research Center Federal Highway Administration 6300 George Town Pike Mclean, VA22101-2296April2011

[10]. Federal Highway Administration, Basic Asphalt Recycling Manual, ARRA, Second Edition, 2001

[11].International Research Journal of Engineering and Technology (IRJET

[12].T.Chandrasekaraiah ,K.M.Mallesh & Sunil S, Experimental Investigations on the Performance of Bituminous Mixes with Reclaimed Asphalt Pavement (RAP), International Journal of Research in Engineering and Technology,3(6),May2014,297-303

[13].Dr.Veeraraghavan, Investigations on laboratory performance of bituminous mixes with reclaimed asphalt pavement material, IRC20 12

[14].S.KKhanna and C.E.G.Justo, Highway Material Testing (Laboratory Manual),Nemchand and Bros, Roorkee (1997).

[15].The Asphalt Institute.(2007). The Asphalt Handbook: MS-2, 7thEd.The Asphalt Institute, Lexington, KY

[16].Nguyen, Viet Hung (2009) Effects of laboratory mixing methods and RAP materials on performance of hot recycled asphalt mixtures. PhD thesis, University of Nottingham

[17]. AI-Qadi, I. L., Carpenter, S. H.; Roberts, G., Ozer, H., Aurangzeb, Q., Elseifi, M.; &Trepanier, J. (2009). Determination of Usable Residual Asphalt Binder in RAP.Illinois Center for Transportation (ICT), FHWA-ICT-09-031

[18]. Huang, B., Li, G., Vukosavljevic , D., Shu, X., & Egan B. K. (2005). Laboratory investigation of mixing hot- mix asphalt with reclaimed asphalt pavement. Transportation Research Record: Journal of the Transportation Research Board, 1929, 37-45

[19]. Federal Highway Administration.(1993).A Study of the Use of Recycled Paving Materials: A Report to Congress, Report No.FHWA-RD-93-147, Federal Highway Administration, Washington, DC.

[20].Daniel, J. S. & Lachance, A. (2005). Mechanistic and volumetric properties of asphalt mixtures with RAP. Transportation Research Record: Journal of the Transportation Research Board, 1929, 28-36.

[21].Saad EI-Hmrawey, Ahmed Ebrahim Abu EI-Maaty and Abdulla Ibrahim El mohr , DurabilityofHotAsphaltMixturesContainingReclaimedAsphaltPavements,may2015

[22].Al-Qadi, I.L., Kern,J.,andMeister,J. (2010)."Warm Mix Asphalt Study"-Illinois Center for Transportation Report (JCT), R27-SP17, Rantoul, Illinois (in preparation)

[23].Jie Han BA, Jitendra K. Thakur, and Robert L. Parsons. On-site Use of Recycled Asphalt Pavement Materials with Geo cells to Reconstruct Pavements Damaged by Heavy Trucks. Washington, D.C: Mid-America Transportation Center, 2011; 25-1121 - 0001 -462.

[24].Texas Department of Transportation, Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges item 358, November 2014

[25].Roberts, F.L., P.S. Kandhal, E.R. Brown, Dah - Yinn Lee, and T.W.Kennedy. "Hot Mix Asphalt Materials, Mixture Design and Construction", NAPA Education Foundation Lanham, Maryland, 1991.

[26].American Association of State Highway and Transportation Officials. (2010). "AASHTOM 323: Standard Specification for Superpave Volumetric Mix Design," Standard Specifications for Transportation Materials and Methods of Sampling and Testing,

[27]."AASHTO T 308: Determining the Asphalt Binder Content of Hot Mix Asphalt by the Ignition Method," Standard Specifications for Transportation Materials and Methods of Sampling and Testing, 30th Ed., AASHTO, Washington, DC.

[28].National Asphalt Pavement Association. (2007). Information Series 123: Recycling Hot Mix Asphalt Pavements, NAPA, and Lanham, MD. American Association of State Highway and Transportation Officials (2010).

[29].American Association of State Highway and Transportation Officials.(2010). "AASHTOM 323: Standard Specification for Super pave Volumetric Mix Design," Standard Specifications for Transportation Materials and Methods of Sampling and Testing, 30th Ed., AASHTO, Washington, DC

[30].American Association of State Highway and Transportation Officials. (2010)."AASHTOT 2: Sampling of Aggregates," Standard Specifications for Transportation Materials and Methods of Sampling and Testing, 30th Ed., AASHTO, Washington, DC.

[31].American Association of State Highway and Transportation Officials. (2010). "AASHTOT27: Sieve Analysis of Fine and Coarse Aggregate," Standard Specifications for Transportation.

[32].AmericanAssociationofStateHighwayandTransportationOfficials. (2010). "AASHTOT 164: Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt," Standards Specifications for Transportation Materials and Methods of Sampling and Testing, 30th Ed., AASHTO, Washington, DC.

[33].American Association of State Highway and Transportation Officials. (2010).'AASHTO T-30 Mechanical Analysis of Extracted Aggregate" Standard Specifications for Transportation Materials and Methods of Sampling and Testing,30th Ed,

[34].American Association of State Highway and Transportation Officials. (2010). "AASHTO T 209: Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)," Standard Specifications for Transportation Materials and Methods of Sampling and Testing, 30th Ed., AASHTO, Washington, DC.

[35].Imad L. AI-Qadi, MostafaElseifi and Samuel H. Carpenter , Determination of Usable Residual Asphalt Binder in RAP, 2017

[36].Newcomb, D., Brown, E.R., and Epps, J.A. (2007). Quality Improvement Series 124: Designing HMA Mixtures with High RAP Content: A Practical Guide, National Asphalt Pavement Association, Lanham, MD.

[40].Mohammad, L. (2006). Performance Tests for HMA Including Fundamental and Empirical Procedures, STP 1469, ASTM International, West Conshocken, PA.

[41]. Qazi Aurangzeb1, JeffKern2, etl. Q. (2009) ."Laboratory Evaluation of Warm Mix Asphalt and Asphalt Mixtures with Recycled Materials, presented at 88th Annual Meeting of the Transportation Research Board, Washington, DC

[42].National Asphalt Pavement Association. (2007). Information Series 123: Recycling Hot Mix Asphalt Pavements, NAPA, Lanham, MD.

[41].Kim, Y.R., Kim, N., and Khosla, N.P., "Effect of Aggregate Type and Gradation on Fatigue and Permanent Deformation of Asphalt Concrete" "," Effect of Aggregates andMineralFillersOnasphaltMixturesPerformance,"ASTMSTP1147,RichardC.Meininger,Ed.,AmericanSocietyforTestingandMaterial,Philadelphia,1992


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