

ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING



UTILIZATION AND LABORATORY EVALUATIONS OF MIXES
CONTAINING RECLAIMED ASPHALT PAVEMENT

By

Tedros Meles Abrha

A Thesis

Submitted in Partial Fulfillment of the Requirement for the Degree of Master of
Science in Road and Transportation Engineering

Habtamu Melese Zelelew (PhD, PE)

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Addis Ababa, Ethiopia

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Declaration

I hereby declare that research work entitled “UTILIZATION & LABORATORY EVALUATIONS OF MIXES CONTAINING RECLAIMED ASPHALT PAVEMENT” is my original work. The work has not been presented elsewhere for assessment and award of any degree. Statements and scientific concepts, which have been used from other sources, have been properly acknowledged/referred.

Name : Tedros Meles Abrha

Signature -----

Date -----

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Abstract

Developing technologies in the construction industry, that provide sustainable solutions for future pavement condition is vital given the ever-increasing demand on the supply of bitumen and good quality pavement construction materials. Reclaimed asphalt pavement (RAP) is formed by cold milling, heating, softening and removal of the existing aged asphalt pavement, full-depth removal of plant waste hot mixed asphalt (HMA) materials. The research investigates to efficiently utilize and assess the impact of RAP in asphalt mixes. The evaluation involved Nine mix designs of control mixes and partially substituted mixes. Out of the nine mixes, four are used as control mixes and the other five are checked for the comparative advantages of partially substituted mixes.

Laboratory testing was accomplished in the control mix with the production of Marshall compacted specimens to determine the performance of Hot Mix Asphalt using Marshall Mix design methods and parameters such as air voids, voids in mineral aggregate, voids filled with asphalt cement, Marshall Stability and flow are measured. Then after optimum bitumen content was obtained from the control mixes. Besides this, the optimum bitumen content is determined for a partially substituted mix.

For the selected optimum bitumen content, Three samples from each mix which partially substitution of RAP with (10, 20, 30 and 40) % by weight of RAP. To examine the rutting resistance of the RAP samples rutting test were conducted by wheel tracking. In addition to this Indirect Tensile Strength tests were conducted to evaluate the moisture susceptibility of the sample and the three samples (i.e. 10%,20%,30%) prevails that the samples were not susceptible to water and the figures were above the specification (80%).

Finally, the performance test result of laboratory RAP sample tests provided that using 20% by weight of RAP is strongly suggested. The laboratory result and other relevant parts of the thesis are illustrated.

Keywords: RAP, Indirect Tensile Strength. Marshal Stability and Flow, Rutting

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CHAPTER ONE: INTRODUCTION

The production of demolition and construction waste has been increasing at a gradual rate in recent years. The amount of landfill available to contain this material has been decreasing, and the need to find an appropriate disposal location has been of increasing concern. Recycling programs offer an available solution. Reclaimed asphalt pavement (RAP) is formed by cold milling, heating, softening and removal of the existing aged asphalt pavement, full-depth removal of plant waste hot mixed asphalt (HMA) materials. The collected RAP was milled, sieved and recombined in predetermined percent with new aggregates and asphalt grade. Reclaimed asphalt pavement (RAP) is one material that has been extensively recycled. It created when existing asphalt concrete surfacing is milled or completely removed.

Milling is the process of scraping and removing any distressed upper layers of the existing pavement to a specified depth. The process includes grinding by machine and loading of RAP into a truck for transportation. Here there is a result of allowing only 40% of RAP to be reused in HMA production, the quantity of unused RAP continually increases, creating opportunities for using RAP in other applications. (Larry Santucci,2007). RAP is being used more and more as a technology with RAP has increased. However, there is a strict specification for RAP use which limits the amount that can be used for each mix design. A recent survey has shown that the average of RAP used in new mixes is around 12 to 15 percent. Low consumption of energy for production and construction, low emission of a greenhouse, and conservation of natural resources help to make asphalt the environmental pavement of choice.

The material present in an old asphalt pavement may have value, even when the pavement has reached the end of their service lives, recycling the value of those existing aggregate and asphalt resources increased the use of RAP in new asphalt pavement. Additionally, the interest in the use of RAP has increased dramatically since the recent prices increases in crude oil and energy in general: by reusing aggregate and asphalt from the deteriorated pavement, the need for new materials is appreciably reduced and the overall cost of the improved pavement will be less.

The properties of RAP are largely dependent on the properties of the constituent materials i.e. aggregate and recovered binder properties. the RAP composition is also affected by the previous maintenance activities that were applied to the existing pavement.

The overall goal of the mix design process of HMA is to recommend a mix that can withstand the combined action of traffic and environment. Therefore, it is critical to assess the impact of various mixes. The component on the performance of the constructed pavement, i.e. resistance to rutting, fatigue, and thermal cracking. Currently, great emphasis is placed on sustainable construction and infrastructure.

The Leadership in Energy and Environmental Design (LEED) program has seen a dramatic increase in prominence in the past few years and public agencies across the country are modifying building construction requirements to lessen the effect of such construction on the environment. Although roadway construction is lagging in this area as compared to the building construction industry, the demand for sustainable and environmentally sound roads will increase in the future. One way to construct environmentally sound roads is through the use of recycled materials.

1.1. Statement of the Problem

Despite the increased opportunity of road construction, many miles of asphalt pavement need repair. As deteriorated pavement is replaced, millions of tons of used asphalt are generated. Asphalt reclamation techniques have been developed to reduce the amount of waste caused by the removal of aged asphalt. Despite the steady rise of prices of bitumen and the virgin material sources for pavement applications are becoming increasingly scarce, the volume of pavement materials routinely reclaimed from in-service pavements is increasing.

Following this, there is growing interest in using a significantly higher quantity of RAP in asphalt mix designs. All of this has attracted attention to the search for new means for the road construction sectors that are less expensive and environmentally friendly. Several modern methods of road construction appeared by recycling.

1.2. Objectives of the study

1.2.1. General objective

The main purpose of this research is to efficiently utilize and assess the impact of RAP in asphalt mixes.

1.2.2. Specific objectives

- ❖ To identify the optimum proportion of RAP in the asphalt mixes.
- ❖ To evaluate the impact of RAP and content on the properties of the Asphalt mixes (in terms of moisture sensitivity and resistance to rutting).
- ❖ To evaluate the performance of the mixes.

1.3. Scope and Significance

This experimental research mainly Asses the laboratory evaluation of mixes containing the recycled Asphalt Pavement at different Reclaimed Asphalt Pavement percentage and this research duly considered the performance of the surface course. Besides this, the utilization practice of AACRA also included in these investigations.

Stakeholders can be achieving this by reusing the old asphalt mixes again after grinding in different proportions in the new mix. This is done through designing a laboratory program include the asphalt mixes containing proportions of the old mixes and the other complementary asphalt mixes in ordinary asphalt.

1.4. Limitation of the Study

This research was limited to the investigation of the performance of RAP samples within the laboratory level only. Even though: in this research adheres to laboratory investigations, onsite performance evaluation of RAP needs to be done. Due to the lack of advance technology & laboratory apparatus and Solvent Recovery tests were not conducted and included in this experimental research. for this matter, it was difficult to characterize the rheology of bitumen in the reclaimed Asphalt Pavement.

CHAPTER TWO: LITERATURE REVIEW

2.1. Overview

Recycling materials have been reported to be utilized in different compositions in different layers of road structure from the top surfacing layer to the underneath layers. The processing cost, the engineering properties, the evidence that demonstrates the viability of the material and its positive impact on the long-term performance of the road construction works are what characterizes and favors the use of that specific recycled waste material. It is of the essence to properly understand the behavior of any recycled by-products and investigate the influence on the proposed inclusion with construction material to come with a suitable and viable utilization with regards to the type of material and the employed dosage.

The deficiencies and drawbacks in the quality of produced asphalt binder from native crude-oil producers have its repercussions on the performance of asphalt pavement under oscillating traffic loads. The quality and price of asphalt cement used in the road industry have been another pile of advocating the quest for another replacement.

Researches on existing recycling material were to valorize the utilization of recycled materials in road constructions and improve the long-term performance of asphalt pavement. any successful applications of recycled materials in road construction works oriented towards the efforts of achieving a sustainable pavement construction. (M. Abukhettala,2016). The materials present in old asphalt pavements have residual value even when the pavements themselves have reached the ends of their service lives. The use of RAP has proven to be economical and environmentally sound. In addition to the above, the performance of pavements with properly prepared recycled asphalt in terms of fatigue, rutting, thermal resistance, and durability proved to be satisfactory (Al-Qadi et al, 2007).

2.2. Recycled Asphalt Pavement

Recycled Asphalt Pavement (RAP) is old asphalt pavement that is milled up or ripped off the roadway. These RAP materials can be reused in the asphalt mixtures so that the bitumen and aggregates carry value. Also, hot mix asphalt or warm mix asphalt containing RAP can exhibit an outstanding performance as well as mixtures which are made of new materials. Since most of the roadways are constructed using high-type bituminous pavements, RAP materials, if properly processed, will consist of high quality, well-graded asphalt coated aggregates (Al-Rousan, Asi, Al- Hattamleh, & Al-Qablan, 2008).

The mechanical properties of the recycled mixtures were also investigated by researchers. Dunning & Mendenhall (1978), showed that the durability of recycled asphalt concrete mixtures was better than that of the conventional mixtures.

While RAP material is reused in a new asphalt pavement mixture, it is essential to take into account the properties of materials in the mixture. Following consideration of RAP materials properties, the aggregate from RAP has to be blended with virgin aggregates to meet certain gradation specifications as well as the old bitumen content of RAP that may need to be analyzed.

2.3. Recycling

Recycling is a quite simple and easily applicable method. Recycling of reclaimed asphalt materials obtains new pavement materials and this results in saving virgin bitumen, virgin aggregate, energy, and money. On the other side, the utilization of recycling helps to overcome the problem of disposal of old pavement waste. The advantages of recycling can be summarized as follows (Kandhal & Mallick, 1997):

- ❖ Saving of energy, bitumen, and aggregates;
- ❖ Protection of the environment;
- ❖ Preservation of the existing pavement geometrics;
- ❖ Cost reduction of construction;
- ❖ Less loss of time for users;
- ❖ Maintaining of existing roadway profile.

2.3.1. Objectives of recycling and recycling strategies

Recycling is one of the widespread pavement rehabilitation techniques. The recent increase in the price of bitumen is a major factor in promoting the development of recycling. On the other hand, the asphalt industry is constantly encouraging the development of cost-effective technologies, reduce energy consumption, and environmentally friendly (Hodo, Kvasnak & Brown, 2009). Over the years recycling has become one of the most desirable pavement rehabilitation alternatives. According to the continuous accumulation of performance data, field and laboratory evaluations of recycled mixes, it is expected that recycling will continue to be the most attractive rehabilitation technique.

The choice of rehabilitation technique should be based on energy conservation, economic consideration, engineering consideration, environmental effects

A) Energy Conservation

The road industry has years been seeking to minimize the amount of energy required to manufacture asphalt mixture and to lower asphalt plant emissions, combining energy savings and environmental benefits for many years (Romier, Audeon, David, Martineau & Olard, 2007). Recycling processes conserve energy. Reusing aggregates reduces the necessities of quarrying, transportation and the subsequent processing in recycling methods. Consequently, the cost of energy is saved in these processes. Recycled asphalt reduces the demand for new bitumen and saves energy at the refinery. Moreover, electric power consumption visibly decreases because of reduced demand for bitumen.

B) Economic Consideration

Recycling techniques can be reviewed in terms of the cost of the pavements. life cycle costs of the rehabilitation alternatives must also be considered in economic analysis. Life cycle costs include the initial construction cost as well as the cost of maintenance activities during the life cycle. This analyzing period consists of costs components which are given as:

- ❖ Initial and Future rehabilitation costs;
- ❖ Maintenance costs;
- ❖ Residual value;
- ❖ Engineering costs;
- ❖ Costs for travel time, vehicle operation, accidents, delays and extra operating.

C) Engineering Consideration

Before selecting a rehabilitation alternative, the engineer should take care of the environment, drainage factors and practical limitations. Engineering consideration also depends on the type of original surface where the new pavement layer will be replaced. The most important consideration should be the amount and severity of distress condition on the existing pavement because different recycling techniques can remedy different types of distresses, the most appropriate method should be considered.

D) Environmental Effects

Increasing environmental concerns have encouraged the development of using pollution-free, recyclable engineering materials that consume less energy to manufacture (Chiu, Hsu, & Yang, 2007). The most indispensable effect of recycling is the benefit to the environment. Before strengthening deteriorated urban

or rural roads, bituminous materials are generally removed and deposited outside of the way. This inevitability represents an economic loss and creates environmental problems. The utilization of recycling techniques can provide significant benefits to nature.

2.3.2. Asphalt recycling methods

Pavement recycling is a logical and practical way to conserve our diminishing supply of construction materials and to help reduce the cost of preserving our existing pavement network. When properly designed and constructed, recycled pavements have been found to perform as well as pavements built with all-new material several recycling techniques, such as hot mix recycling, hot in-place recycling, cold mix recycling, cold in-place recycling, and full-depth reclamation, have evolved over the past 35 years (Annapolis, 2001.).

A.Hot Mix Recycling is the most common method of recycling asphalt pavements. It involves combining RAP with new or “virgin” aggregate, new asphalt binder, and/or recycling agents in a central hot mix plant to produce a recycled mix. The amount of RAP allowed in a recycled mix and guidelines as to where the recycled mix can be used in the pavement structure varies by agency. Some agencies routinely allow 15% or less RAP while others permit larger amounts of RAP. Higher RAP concentrations require adjustments in a mix design and binder selection. Suggested guidelines relative to RAP content in a recycled mix are as follows (McDaniel, R.S. and A. Shah,2003):

- ❖ 15% RAP or less: PG binder is the same as that used in a virgin mix.
- ❖ 15-25% RAP: PG binder should be one grade lower on both high and low-temperature end
- ❖ >25% RAP: Test and blend the recovered asphalt from RAP with virgin asphalt as part of the design process to determine the amount of RAP to use.

For higher levels of RAP, proper material evaluation, mix design, construction, and quality control issues must be addressed. (Santucci, 2007).

Once RAP has been hauled to a central plant, it is processed and stored for future use. Processing may include crushing and screening the RAP before stockpiling. (APA,2007).

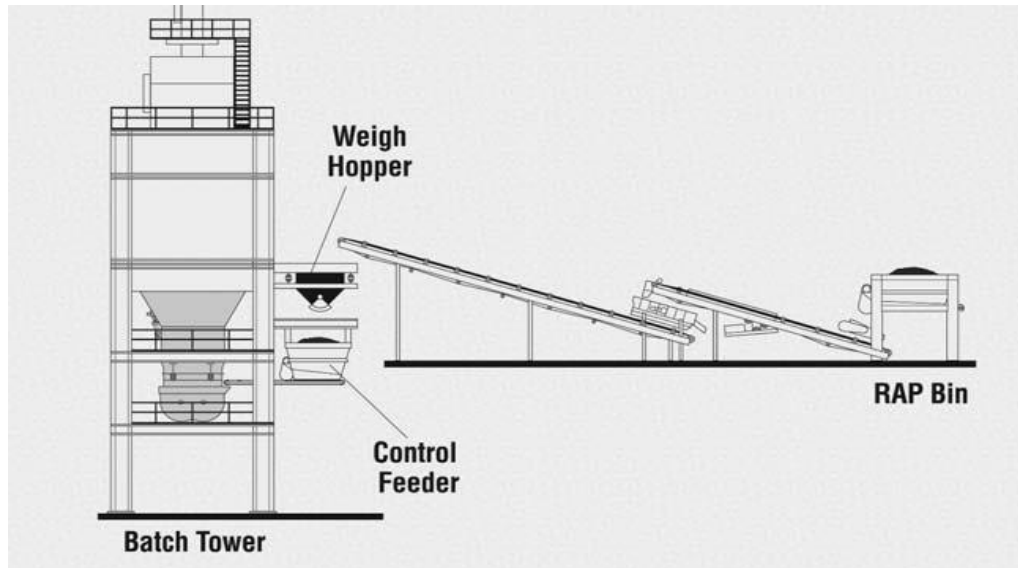


Figure 1. RAP Delivery System for Batch Plants

B.Cold Planning

CP is the controlled removal of an existing pavement to the desired depth, longitudinal profile and cross slope by special equipment. Also, CP can be used to rough pavements to restore low friction numbers and decrease slipperiness. There are various benefits of CP such as removal of wheel ruts, energy conservation and less disruption to the public compared to other reconstruction methods.

It is normally hauled to a hot mix recycling plant for processing and future incorporation into a recycled mix. RAP also can be used as base aggregate, ditch lining, or as a surfacing for untreated gravel roads or parking areas.



Figure 2. Typical Front-Loading Milling Machine

C. Hot In-Place Recycling consists of heating, scarifying, mixing, placing and compacting the upper layer of existing asphalt pavement on-site. Virgin aggregate, new asphalt binder, recycling agents, and/or new hot mix asphalt may be added as needed. Normally, 70 to 100 percent of the material in a mix, which has been recycled in-place comes from the existing pavement. This approach requires several pieces of equipment such as pre-heaters, heaters, scarifiers, mixers, pavers, and rollers. The combined equipment is often referred to as a “train”. Treatment depths range from $\frac{3}{4}$ to 3 inches depending on the Hot In-Place Recycling process used. The most common Hot In-Place Recycling processes are Surface Recycling, Remixing, and Repaving. (Park, 2007).

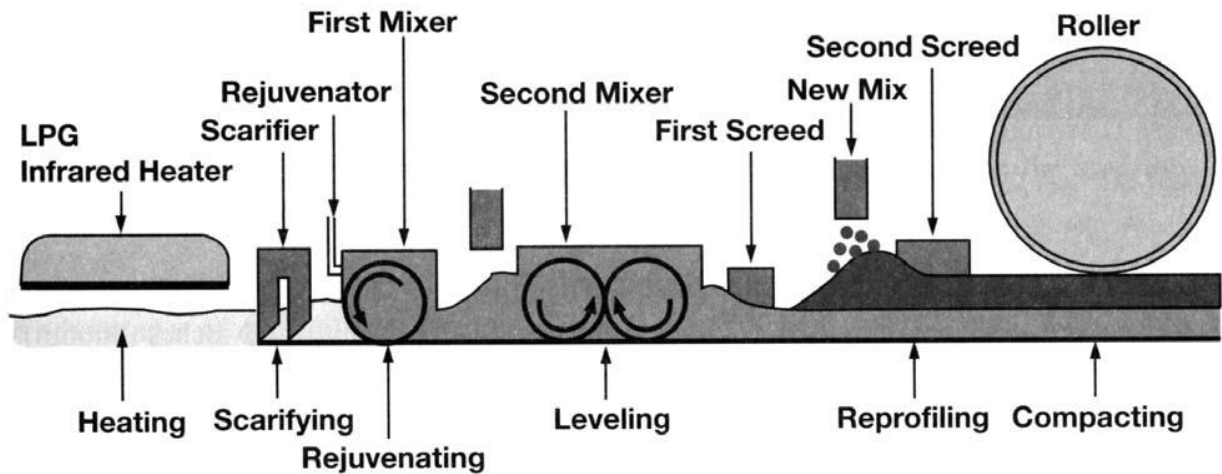


Figure 3. Hot In-Place Repaving Process and Equipment

D. Full Depth Reclamation (FDR)

Full Depth Reclamation is defined as a recycling method in which all parts of asphalt pavement and some amounts of the base material is treated to construct a stabilized base course. It is a cold mix recycling process in which different types of additives such as asphalt emulsions and chemical agents such as calcium chloride, Portland cement, fly ash, and lime is added to obtain an improved base course (Kandhall & Mallick, 1997).

The advantages of Full Depth Reclamation can be summarized as:

- ❖ Production of non-renewable resources;
- ❖ Energy conservation compared to other reconstruction methods;
- ❖ Less equipment is required;
- ❖ Elimination of bumps and dips, rutting, potholes, patches, and cracks;
- ❖ Problems with existing aggregate gradation can be corrected;
- ❖ The deteriorated base can be reshaped to restore surface profile and drainage;
- ❖ Significant structural improvement with the addition of stabilizations;
- ❖ Produces thick, bound layers that are homogeneous.

2.4. Effect of interaction between virgin and RAP bitumen

Since recycling hot mix asphalt results in a reusable mixture of aggregate and aged asphalt, using the old asphalt bitumen in the newly blended mixtures and, therefore, reducing the required new bitumen content makes the use of RAP in mixtures economically attractive.

From the laboratory tests indicate that the aged binder influences physical and rheological properties of the final blend due to an interaction with the virgin binder results of standard characterization test show an increasing in softening point and viscosity at 160^oc and a decrease in penetration grade as the RAP content in the mixture increase.

The rheology and bituminous samples were investigated with DSR analyzing the complex modulus and phase angle the result show a hardening and an increased elastic behavior of bitumen caused by the presence of RAP binder in the blended. Hence the aged bitumen has little influence on the rheology final blend when the RAP content in the asphalt mixture in equal or below 10% but the effect of the RAP binder is significant when the RAP content is above 20%.

2.5. Use of recycled materials in Road construction

With the evolution of the road industry and growing traffic on roads, construction materials have also been evolved and more unconventional ingredients have been incorporated.

The rate of utilizing reclaimed asphalt pavement in HMA and base material in Ontario has been reported to be as low as 8% of the total recycled material used between 2004 and 2006. The characteristics of RAP vary from one source to another according to the type and properties of aggregates material, binder content, binder stiffness, of the scarified pavement. The concentration of RAP in the new asphalt mixture is considered a pivotal factor influencing the performance of HMA. It has been reported that the performance of an asphalt pavement made of new material would be as equally satisfying as that composed of a low to an intermediate rate of 25% RAP.

Technically, modification to the binder grade in the asphalt mixture, especially the low-temperature grade, does not need much concern when RAP is used in less than 15% of the total weight of the mixtures. It has been reported that the performance of a new asphalt pavement would be as equally acceptable as that composed of a low to the intermediate rate of 25% RAP.

The implications of using a rate of more than 20% of RAP on the grade of the binder is significantly higher than that when the rate is in the low range (< 20%).

It was indicated in literature that between 15-25% of RAP in the mix needs a modification of reducing the grade on both low and high temperatures by 6°C. However, when a combination of an average rate of 20% RAP along with 3% RAS is used, a low-temperature grade of asphalt cement goes up by 6°C and a reduction in the low-temperature performance grade of asphalt cement was suggested.

Recycling is a kind of rehabilitation choice to apply for asphalt pavement. The selection of rehabilitation alternatives depends on many parameters such as observed pavement distress, laboratory, and field evaluation of existing material design parameters (Kandhal & Mallick, 1997). Since rehabilitation of pavement is needed for the following reasons:

- ❖ Reduction of surface friction;
- ❖ Unreasonable user costs;
- ❖ Maintenance requirements;
- ❖ Inadequate structural capacity;
- ❖ Inadequate pavement distress

2.6. Effect of RAP on the properties of Asphalt binders

Using Reclaimed Asphalt Pavement (RAP) not only reduces the cost of new asphalt mixtures but also conserve natural resources. To incorporate RAP in asphalt mix design, it is vital to know the amount and quality of the residual binder. In this research, both conventional and Superpave methods were used to determine the virgin and residual binder properties. The residual binders obtained from two RAP sources using solvent extraction and Absorbent recovery methods were blended with a virgin binder in different proportions. Penetration, ductility, dynamic modulus, stiffness and viscosity of the different blends were compared. Penetration, viscosity and PG grading blending charts were developed based on the corresponding test data.

2.7. Characteristics of RAP

Knowing well about the characteristics of RAP is helpful to describe RAP as a material for enough information during design, production or laying of the mixed asphalt material. Although different authors

have various approaches to discuss the characteristics of RAP, they have similarities in raising common matters that characterizes RAP as a construction material. At the 2nd International Symposium on Environment & Asphalt Pavement which was held during October 2012 in France, Gabriele Lebakli et al. (2012) discuss the characteristics of RAP from the perspective of RAP production, cleanness, moisture content, grading, and variability, bitumen content and aggregate properties. Similarly, Joel R.M. Olivera et al. (2013) on an International Journal of Pavement Research and Technology raised related concepts for the characterization of RAP as a construction material.

2.7.1. Cleanness of RAP

Cleanness relates to the mechanism of RAP production, storage and foreign matters like tar, asbestos & road markings. The production of recycling asphalt granulate is generally produced in two ways, either the pavement is milled with a milling machine or is removed in slabs with an excavator. The cold milling machine allows the separation of different layers with high precision and cleanness to obtain RAP of different types and quality. (Gabriele Lebakli et al, 2012) and (Joel R.M. Olivera et al, 2013)

2.7.2. Moisture Content of RAP

The concept of moisture content in RAP can be discussed from different perspectives like about its influence on the productivity of hot mix asphalt, the source of trapped moisture in RAP and its water draining character. Asphalt pavements are subjected to recycling when they are affected by extended distresses and deep degradations which alter the surface integrity to permit the entry of water into the body of the structure. In this case, the pavement to be reclaimed is potentially wet and depending on the surface damage it is crucial to choose the most suitable in-situ or in-plant recycling process (Gabriele Lebakli et al., 2012).

One of the criteria that need to be met to use a specific RAP material in the production of asphalt mixtures is its moisture content, which should not exceed approximately 5% (EN 13108-8). The moisture content specified, to the level of 5% is released by the RAP material while the drying process is undergoing before mixing with other components of pavement materials. Moreover, Edward J. Hoppe (2015) studied the behavior of RAP which had 3% to 3.5% moisture content to dry while it is exposed to varying temperatures to estimate the time required for the equilibrium weight of the material.

According to the results, it was possible to conclude that for the temperatures of 110 and 125°C, the moisture loss was stabilized after approximately 5 hours. But when the temperature was raised to 150 °C it took approximately 3.5 hours only, corresponding to a reduction of 30% on the drying period.

2.7.3. Grading of RAP

RAP is composed of crushed or milled asphalt concrete and as such is analogous to an aggregate produced by crushing stone that happened to be an asphalt-cemented conglomerate. Individual particles will range from those composed wholly of the original coarse aggregate of the asphalt concrete with adhered asphalt cement and mineral fillers. The mix of particles present in the RAP will depend on the nature of the asphalt concrete from which it was produced: open- or dense-graded, coarse or fine, etc. (Edward J. Hoppe, 2015). The gradation of RAP material is comparable to that of a crushed natural aggregate but, depending on the milling and stockpiling operations, it may contain a higher content of fines. This is due to the milling process of the surface layer from which the RAP was extracted.

2.7.4. Variability of RAP

One major factor that affects the mix design with high amounts of RAP materials is the variability of the stockpiles. Stockpiles that are not fractionated or split into more specific sizes can vary from being too coarse or too fine. Binder contents have also been shown to vary in stockpiles that have not been split. Varying stockpiles can cause varying mix designs which could be detrimental to future projects in the field (Russell Edgar Carlson IV, 2014) RAP derived from different sources can have a significantly different gradation, oil content, and density. This can be due to the milling process, rock source, type of oil, etc. Moreover, combined RAPs from several sources may change the quality of the product throughout the construction project because of this variation. One effective way to deal with this is to identify and segregate the various types of milled HMA.

However, this can add expense and would require major changes to the current practices for storing RAP (Russell Edgar Carlson IV, 2014).

Different researchers undertake multiples investigations on the issue of variability considering binder content, particle size distribution, maximum dry density, etc. and it was found that RAP materials are prone to variability. Two solutions are recommended for achieving a more uniform RAP product, such as segregating RAP piles by source or adding virgin aggregate to the RAP, which would most likely, can reduce the variability it has (Eric J. Mc Garrah, 2007).

On the other hand, Randy C. West (2010) proposed a third approach to minimize the degree of variability in RAP. Accordingly, materials from multiple sources that have different compositions must be processed to create a uniform material suitable for use in a new asphalt mixture. All around the world, contractors have found that they can make a very uniform and high-quality RAP from a combination of pavement rubble, millings, and wasted mix.

The key to achieving a consistent RAP from multiple sources is a careful blending as part of the processing operations. A bulldozer, excavator, or similar equipment should be used to blend materials from different locations in the multiple-source RAP stockpile as it is fed into the screening and crushing operation. This will tend to average out variations in the RAP from different sources.

2.8. Evaluation of RAP Properties

There are four components in hot mix recycling, such as RAP, virgin aggregate, virgin asphalt binder and in some cases, a recycling agent. In the mix designing of hot mix recycling, there are two basic issues raised, which are material evaluation and proportioning of component materials. The objective of the material evaluation process is to determine the important properties of the component materials to come up with an optimum blend of materials to meet the mix requirements (MS-20 of Asphalt Institute, 1986).

2.8.1. Sampling of RAP

The RAP to be used in the recycled mix may come from different layers of HMA with different compositions or stockpiles built with materials from different sources. Hence, representative samples must be obtained from existing pavements or RAP conveying trucks or RAP stockpiles to evaluate its properties (MS-20 of Asphalt Institute, 1986).

To obtain representative samples from RAP stockpiles, 10 samples from different locations in the stockpile should be obtained, and to minimize the effect of segregation, at least 150 mm of the material from the surface of the stockpile should be removed before sampling. Samples are scraped off and the material retained on the 50 mm sieve is discarded (MS-20 of Asphalt Institute, 1986). Sampled RAP materials should be used for extraction of aggregates and asphalt contained in the mix according to AASHTO T-164. AASHTO T2 Sampling of Aggregates (about the samples from a stockpile) can be used as guidance for sampling from the RAP stockpiles (MS-20 of Asphalt Institute, 1986). Besides, engineering judgment should always be used to develop an effective sampling plan.

2.8.2. RAP Aggregate Evaluation

The gradation of the aggregate may change due to degradation caused by traffic loads and the environment (MS-2 of Asphalt Institute, 1995). AASHTO T30, Mechanical Analysis of Extracted Aggregate, or AASHTO T27, Sieve Analysis of Fine and Coarse Aggregates, can be used to perform a sieve analysis of the aggregate extracted from the RAP (MS-20 of Asphalt Institute, 1986). Once the extraction is done the subsequent quality test on RAP aggregates can also be followed which include: aggregate crushing value, flakiness index, Los angles abrasion, etc.

2.8.3. RAP Asphalt Binder Evaluation

The bitumen part of RAP materials shall be evaluated before the actual mix design. This is because aging and oxidation are common with RAP. This includes loss of the lighter fractions and a corresponding increase in the proportions of the asphaltenes, hardening (increase in viscosity), and loss of ductility (MS-20 of Asphalt Institute, 1986).

The extracted asphalt can be recovered from the solution by ASTM D6847. Finally, AASHTO T 202 can then be used to check the consistency of the recovered asphalt binder by measuring its viscosity at 60°C, to estimate the amount and grade of virgin asphalt binder required in the recycled mix. At 25 °C of the recovered asphalt binder. If no more than 15-20 percent RAP is used in the recycled mix, testing of the extracted asphalt is not required by many highway agencies and the grade of the virgin asphalt binder is kept the same as that of the conventional mix (MS-20, 1986). In hot mix asphalt containing RAP, the aged bitumen in the RAP is often considered as a part of the bitumen in the new asphalt mixture.

Some agencies factor the contribution of the aged bitumen in the mix design while others do not consider the aged bitumen (Gabriele Lebakli et al., 2012). However, to reach on a reliable decision the property of old asphalt shall be tested first.

2.8.4. Mix Design of HMA Containing RAP

Hot mix recycling is the process in which reclaimed asphalt pavement materials are combined with new materials, sometimes along with a recycling agent, to produce hot mix asphalt mixtures. Like conventional HMA, recycled mixtures are expected to be designed properly to ensure the required performance. As a result of proper design, recycled mixtures can have properties similar to those of conventional hot mix asphalt mixtures (Pavement Recycling Guidelines of FHWA, 1997).

Therefore, the objective of mix design is to determine the well-proportioned aggregate, type & percentage of asphalt binder with the help of results from compacted trial mixes and finally selecting the optimum combination of mix components that meet the design criteria.

2.9. Performance evaluation of HMA mixtures with RAP

The overall objective for the design of asphalt paving mixes is to determine (within the limit of the project specification) a cost-effective blend and gradation of aggregate and asphalt that yields a mix having.

- ❖ Sufficient asphalt to ensure durable pavement
- ❖ Sufficient mix stability to satisfy the demand of traffic without distortion or displacement.
- ❖ Sufficient voids in the total compacted mix to allow for a slight amount of asphalt expansion due to temperature increases without flushing bleeding & loss of stability.
- ❖ A maximum void content to limit the permeability of harmful air & moisture into the mix.
- ❖ Sufficient workability to permit efficient placement of the mix without segregation and without sacrificing stability & performance.
- ❖ For surface mixes, proper aggregate texture & hardness to provide sufficient skid resistance in unfavorable weather conditions.

2.9.1. Marshall Test

To determine the optimum bitumen content for a particular gradation of aggregates by the Marshall method of mix design (ASTM D 1559), a series of test specimens were prepared for a range of different bitumen contents so that the test data curves showed a well-defined optimum value. Three test specimens were prepared for each bitumen contents used to provide adequate data. Thus, a warm-mix design study using four different bitumen contents normally required 12 test specimens. Before preparing mixtures, approximately 1200 grams of the mix aggregates, the filler and required quantity of the first trial percentage of bitumen was heated and thoroughly mixed at the desired temperatures. Besides, the compaction molds were cleaned and heated to a temperature of 145°C. The filter paper was inserted into the bottom of the mold to prevent adhesion between the mixture and the mold. The mix was placed in a preheated mold and compacted by a Marshall hammer with 75 blows (for wearing course) on either side at the desired temperatures. After the specimens had been removed from the mold, they were allowed to cool to room temperature. Since the Marshall Mix Design method is the most commonly used mix design method in the

World although criteria and practice vary in the selection of the optimum asphalt content (Kandhal and Koehler, 1985). The popularity of the Marshall method stems from its simplicity and portability.

The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute. The load is applied to the specimen till failure, and the maximum load is designated as stability. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) as a result of the loading. The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time when the maximum load is recorded

2.9.2. Rutting test

The loss of pavement serviceability is a common result of rutting which is defined as the formation of the longitudinal depressions under the wheel paths caused by the progressive movement of materials under traffic loading in the asphalt pavement layers. The wheel tracking device is designed to evaluate the rutting characteristics of bituminous mixtures by dint of aggregate structure, bitumen properties, moisture susceptibility and adhesion between bitumen and aggregates. The test is carefully contemplated to simulate the bearing capacity of pavement under actual wheel tracks.

2.10. International utilization of RAP

To know the state of practice and current experiences over the world, it also better to assess how countries are implementing asphalt pavement recycling.

2.10.1. Current status of RAP utilization in America

The use of RAP in the United States has continued to grow since it became more commonplace in asphalt mixtures in the 1980s. Originally, state highway agencies were concerned about mix design methodology and long-term performance, but researches have enhanced the state of the knowledge related to both of these topics.

In the early 1990s, FHWA and the U.S. Environmental Protection Agency estimated that more than 90 million tons of asphalt pavement were reclaimed (i.e., converted into material suited for use) every year and over 80 percent of RAP was recycled, making asphalt the most frequently recycled material. RAP was most commonly used as an aggregate and virgin asphalt binder substitute in recycled asphalt paving, but it was also used as a granular base or subbase, stabilized base aggregate, and embankment or fill material.

However, in the late 1990s, the consumption of RAP was limited to the introduction of the Super pave mix design method. There were two basic reasons for the occurrence of such minimized demand on RAP in HMA, such as the absence of guideline for the use of RAP in implementing the Super pave mix design method and due to the high fine content in RAP in contrary to the Super pave method of design which encourages the use of coarse-graded mixtures.

The highway community was reassessing the economic and environmental benefits of allowing higher percentages of RAP in premium pavements and asphalt surfaces while also maintaining high-quality pavement infrastructures. High RAP is defined as using 25 percent or more RAP in an asphalt mixture by weight of the total mix (FHWA, 2011).

2.10.2. Current status of RAP utilization in the Netherlands

The pushing factor in utilizing RAP for the people of the Netherlands was similar to the USA. The occurrence of the oil embargo in early 1970 was the driving force at that time to look for other ways to produce hot mix asphalt. Later on, environmental issues became another reason for implementing hot-mix recycling (TRB, 2014). Several developments have taken place since the first introduction of hot recycled asphalt. In 2012, around 4×10^6 tons of reclaimed asphalt was available for recycling. Of this amount, 80% is used in the production of HMA and 15% is used in cold recycling. In the Netherlands, hot RAP mixtures have to comply with the same specifications and requirements as are set for mixtures made of virgin materials. The requirements include stiffness, resistance to fatigue, resistance to permanent deformation, and moisture resistivity.

Moreover, the Netherlands has limited the level of RAP consumption up to 20% since increasing more than 20% has been challenged since with such level the mix it needs higher penetration grade bitumen. Therefore, achieving a high penetration mix might become a problem since the virgin aggregates have to be heated too much higher temperatures and it is, therefore, likely that the virgin bitumen rapidly hardens because of being exposed to a very hot virgin aggregates. However, to tackle such challenges, two new developments are either using a completely new system for heating and mixing recycled mixtures or using a bio-additive to upgrade RAP and on smart handling of RAP (TRB, 2014).

2.10.3. RAP utilization practices in Ethiopia

The history of asphalt pavement recycling counts more than a century, beginning in 1915 and became common practice since the 1970s in the developed world (Randy C. West, 2010). The performance, economic and environmental benefits from the technology has been proven since then.

In this year, 2017, the Ethiopian Defense Construction enterprise has started cold recycling technology at the Adigudem-Wukero road maintenance project, which stretches for 92Km crossing Mekele city (Hidasie Birehan, of Defense Infrastructure construction sector bulletin, 2017). In this project, the wearing surface with a base course layer is milled together for cold recycling, using cement stabilization by adding a defined amount of virgin aggregate to serve as a stabilized base course layer which will be further covered by new hot mixed asphalt layer. According to Hidasie Birhan bulletin, the company is claiming that the technology is the first introduction to the country for actual fieldwork. But before actual fieldwork, it has been tried to make a trial section for 200m and found to have good results (Hidasie Birehan, of Defense Infrastructure Construction Sector Annual Bulletin, 2017). Unless this record, the practice of such technology, specifically regarding hot recycling is not officially recorded at the institutional level in Ethiopia and seems unborn to this date and hence it is difficult to review literature. The economic and technological aspect of Ethiopia in the past decades might not permit to reach the level of advancement where the rest of the world is practicing today. History recorded that the first asphalt-paved road construction occurred during the Italians occupation 1936 to 1941 (Ibrahim Worku, 2011). During this period, approximately 2,500 Kms were covered with single asphalt surface treatment (Emmenegger Rony, 2012). Unless recently, from then asphalt paved road assets are not common in Ethiopia.

Though there was a difficulty to collect reliable data sources. Due to this, it is not difficult to conclude that HMA technology is still young in Ethiopia in contrast to the developed world.

Currently, different access roads, especially the route which follows Adama- Awash- Mille are under heavy maintenance/overlay works which are producing a large number of recyclable asphalt pavements. However, milled asphalt layers are not utilized properly. ERA has included asphalt recycling specification at Pavement Rehabilitation & Asphalt Overlay Manual - 2002 but the contract documents for these projects do not permit incorporating RAP as an alternative input and hence recyclable materials are withdrawn for landfills to the surrounding free spaces. As a part of this research, it is tried to assess the experiences of different companies regarding RAP utilization and ongoing researches towards asphalt recycling technologies in the country. (Samuel B.,2017)

2.10.4. Utilization practices of Addis Ababa City Roads Authority

In this study, the concerned stakeholders were asked about the utilization of RAP. Following this, the AACRA, own force maintenance gives their experience regarding this. Due to the milling machine, only milling was done last year. so, the summarized data for the year of 2017 G.C is presented as follows.

Table 1 milled and recycled Asphalt

Item	Milled Location	Amount in M ³	Purpose of RAP use
1	Different 5 roundabouts in Addis	19,603.00	As a sub-base for gravel road
2	Different road section in Addis, Out of the roundabout	10,243.00	As sub-base and base course
Total			29,846.00

Source (AACRA, 2017)

CHAPTER THREE: METHODOLOGY

This chapter illustrates different aspects of methodologies used during this experimental research. The different option was available to run the study and gives reasons. Why a particular method was selected at a different stage of the project and data collection and the way of collecting data also included. In addition to the materials, the different procedures also considered. All tests on aggregate, asphalt binder, control mixes, and partially mixes substituted by RAP were conducted according to respective ERA, AASHTO, and ASTM testing standards.

3.1. Materials and Methods

3.1.1. Aggregates

Aggregate is the major component in AC and the quality and physical properties of this material have a large influence on mix performance. Typically, the qualities required for aggregates are described in terms of shape, hardness, durability, cleanliness, bitumen affinity and porosity.

For this experimental research, many aggregate quality tests have been conducted, these tests include:

- ❖ Sieve Analysis (AASHTO T27-93 or ASTM C 136- 84a)
- ❖ Bulk specific gravity (AASHTO T 85)
- ❖ Aggregate crushing value (BS 812 Part 110)
- ❖ Moisture content
- ❖ Flakiness index (BS 8120 Part 105.1) and water absorption (AASHTO T 85) were done in the laboratory. Since the particle distribution test samples were collected from four hot bin of asphalt plant.

3.1.2. Asphalt binder

The bitumen used for this experiment was obtained from the Addis Ababa city road Authority Asphalt plant. The 85-100 penetration grades are a common type of asphalt used locally on the Addis Ababa road construction since as it is known the climate is relatively mild. To evaluate the bitumen properties number of laboratory tests have been performed. These tests include

- ❖ Penetration 100gm,5sec at 25°C (AASHTO T 49)
- ❖ Flashpoint °C (AASHTO T 48)
- ❖ Ductility(cm) at 25 °C (AASHTO T 51)

- ❖ Solubility in trichloroethylene (AASHTO T 44)

3.1.3. Reclaimed asphalt pavement

When HMA attains the end of its service life, milled materials already carried substantial value. RAP as the milled materials can be reused in virgin HMA to decrease the quantity of new material that needs to be used in the construction of the highway. During service, the blend of aggregates and bitumen undergo various physical and rheological changes that have to be considered in the design process to ensure that HMA mixtures with RAP perform as well as HMA produced with virgin materials. Before proceeding into the next section it conducted a different test to assess the quality of reclaimed asphalt pavement. During the Visual inspection, the RAP materials were subjected to severe aging and weathering on the site. The RAP chunks were crushed and screened into different sizes to meet the specified grading requirements. The RAPs, virgin aggregates, and virgin bitumen were used in this research to investigate the effects of RAP on the resulting mixture properties. RAP contents of 0, 10, 20, 30, and 40 % were evaluated in this study to see the effect of various RAP content on the mixture properties.

3.1.3.1. sampling of RAP materials

The sample acquired for this research was taken from Addis Ababa City Road Authority Korki plant from the stock that collected previously from the Lebu roundabout – Haile garment roundabout road section which serves for more than 15 years. Since the sampling was according to AASHTO T 248-95 / ASTM C 702-93 “reducing samples of the aggregate to testing size”. By this method, the reduction of large samples of aggregate to the appropriate size for testing employing techniques are intended to minimize.

3.1.3.2. Moisture content

The laboratory determination of moisture (water) content of RAP material was done according to AASHTO T 265 -93 “laboratory determination of moisture content “and the following procedures were applied.

- Weigh a clean, dry container and place the sample in the container and weigh them
- Place the container with the moist sample in drying oven at a temperature of 110 ± 5 °C and weigh it

$$\text{Moisture content} = \frac{\text{mass of moisture} * 100 \%}{\text{mass of oven dry}} \dots\dots\dots \text{Equation 1}$$

3.1.3.3. Extraction of bitumen from RAP

This method covers the quantitative determination of bitumen in hot mixed paving mixtures and pavement samples. Aggregate obtained by these methods may be used for sieve analysis using T 30 and performed according to AASHTO T 164-94 /ASTM D 2172-88.

In this method, approximately 1200 grams of re-graded RAP was heated up to 150°C in the oven for grains to easily separate the solvent that was about 200 ml. Trichloroethylene was poured on the sample through the fill point which was on the top of the container. This process was repeated until the solution is clear.

$$\% \text{ Extraction} = ((W1-W2) \backslash W) \times 100 \dots\dots\dots \text{Equation 2}$$

Where Wt. of the sample (W)gm, Wt. of the sample+ bowl (before extraction) (W1) gm, Wt. of the sample+ bowl (after extraction) (W2)

3.1.3.4. Sieve analysis for RAP aggregate

This method covers the determination of the particle size distribution of fine and coarse aggregate by sieving according to AASHTO T 27-93 / ASTM C 136- 84a.

This method is used primarily to determine the grading of RAP materials proposed for use as Aggregate or being used as aggregate. The result is used to determine compliance of the particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregate products and a mixture containing aggregate.

The gradation is obtained using 26.5-19mm, 19-12.5mm, 12.5-4.75mm, 4.75mm stone dust along with MoRTH specified gradation for Virgin and Reclaimed aggregates. The result of the sieve analysis is presented in the result and discussion section.

3.1.3.5. The bulk specific gravity of RAP aggregate

- ❖ Asphalt mixes with known aggregate properties were produced and aged in the laboratory to simulate RAP. The aggregate was recovered and the aggregate properties including G_{sb} ; were reassessed. The aged mixture was also tested to determine maximum theoretical specific gravity (G_{mm}) from which estimated G_{sb} values could be calculated.
- ❖ Once the mix design & determination of virgin aggregate, properties were completed, the laboratory mix was produced and aged to simulate RAP.

- ❖ Since the asphalt content was determined using extraction methods. The true asphalt content was assumed to be the target asphalt content. Since the actual asphalt content of the sample could not be determined

3.1.3.6. Maximum theoretical density for the mixes containing RAP materials

The maximum theoretical specific gravity (G_{mm}) test was conducted according to AASHTO T-209 for four RAP samples and table 4 summarizes the results for further consumption in the determination of bulk specific gravity of RAP aggregates and the results of this presented in chapter four.

3.1.3.7. Blending of RAP

The primary step in the design of recycling includes the determination of material properties of RAP and virgin materials, the selection of an appropriate blend percentage of RAP and virgin aggregate to meet gradation, the selection of an appropriate bituminous bitumen blend to satisfy specified viscosity and penetration requirements

3.2. Asphalt Mixes

3.2.1. Controlled mix

The design of asphalt paving mixes as with other engineering materials designs, in general, a matter of selecting & proportion materials to obtain the desired properties in the finished construction product. In general, the goal of mix design is to select unique design asphalt content that will achieve a balance among all of the desired properties since ultimate pavement performance is related to durability, impermeability, strength, stability, stiffness, flexibility, fatigue resistance & workability.

3.2.1.1. Marshall Mix Design method

For this study, the Marshall Mix Design method for HMA mixtures was used to identify the optimum asphalt binder contents for all mixtures. Therefore, preparing Marshall Specimens using the Marshall procedures for individual specimens is necessary. Dry and sieve aggregates into sizes and store in clean sealable containers. Separate enough material to make 12 specimens for the control mixes and 15 specimens for the partially substituted by RAP of approximately 1200gm each. Next, weigh out aggregate for each scenario of specimens placing each in a separate container and heat to mixing temperature determined from the asphalt property.

Then heat sufficient asphalt cement to prepare the total specimens on each step. Asphalt content should be selected at 0.5 percent increments with at least two asphalt contents above the expected design Asphalt content and at least two below the expected design Asphalt.

It is necessary to mix asphalt cement and aggregate until all the aggregate is coated. It is helpful to work on a heated table. The expected design asphalt content in percent by total weight of mix could then be estimated to be approximately equivalent to the percentage of aggregate in the final gradation passing the 75 μm (#200) sieve.

The approximate bitumen demands of the combined aggregates of the target wearing coarse mixtures containing RAP were calculated from the following empirical formula:

$$P_b = 0.035a + 0.045b + Kc + F \dots\dots\dots \text{Equation 3}$$

- Where a= % of mineral aggregate retained on 2.36mm sieve,
- b=% of mineral aggregate passing on 2.36mm sieve& retained on 75 μ sieve,
- c=% of mineral aggregate passing on 75μ sieve,
- K=0.15 for 11-15%passing 75μ sieve ,0.18 for 6-10 %passing 75μ sieve, 0.2 for 5% or less passing 75μ sieve,
- F=0-2% based on the absorption of light or heavy aggregate, 0.7 for other aggregates

To provide adequate data, at least 3 test specimens are prepared for each asphalt content selected.

3.2.1.2. Determination of Optimum Bitumen Contents

It is a common practice to design the mix using the Marshall Test (ASTM D1559) and to select the design binder content by calculating the mean value of the binder contents for maximum stability, maximum density, the mean value for the specified range of void contents and the mean value for the specified range of flow values. Two methods are commonly used to determine the optimum asphalt content from the plots. These two methods are NAPA Procedure and Asphalt Institute Method. Since the ERA manual recommends the second method, for this research the Asphalt Institute Method is selected to determine the optimum asphalt binder. In this method, the following cases of optimum values were determined

- A) Determine:
 - ❖ Bitumen content at maximum stability
 - ❖ Bitumen content at maximum density
 - ❖ Bitumen content at the midpoint of specified air void range

B) Average the three Bitumen contents of the above and Compare values with criteria for acceptability of other parameters.

3.3. Asphalt mixes with RAP

In this process, it is necessary to incorporate reclaimed asphalt pavement (RAP) into asphalt Mix design. It includes proportioning the reclaimed materials, selecting the grade and quantity of asphalt cement and preparing a final design for the recycled mixture. The Mix design assesses the Marshall method. Since the material from a reclaimed asphalt pavement is blended with a new aggregate that is required to obtain a combined aggregate gradation meeting the specification requirement once the relative aggregate proportions are determined a total asphalt demand is calculated.

For the Experimental investigations of four different % of RAP materials i.e. 10%, 20%, 30%, and 40% was conducted a Marshall mix by the optimum bitumen content (OBC) which get from the control mix and then we find out the air voids, stability, VMA, VFB. A total of 12 Marshall Specimens, 3 specimens each were prepared at OBC for RAP materials 10%, 20%, 30%, and 40% and tested for bulk density, stability, flow, air voids, VFB and VMA.

For making Marshall, they need to proportion the different materials used in the mixes like Virgin Aggregate, bitumen, and the RAP. Since the proportioning ratio was taken from the control mixes even to compare and to replace the Substitute RAP relative to the performance and other parameters.

Table 2 Proportion of RAP, virgin Aggregate and Bitumen

RAP (%)	0%	10%	20%	30%	40%
RAP WT.(gm)	0	120 gm	240 gm	360 gm	480 gm
Total V.AGG WT(gm)	1134 gm	1014 gm	894 gm	774 gm	654 gm
12.5 mm	238.14 gm	212.94 gm	187.74 gm	162.54 gm	137.34 gm
9.5 mm					
4.75 mm					
2.36 mm	351.54 gm	314.34 gm	277.14 gm	239.94 gm	202.74 gm
1.180 mm	544.32 gm	486.72 gm	429.12 gm	371.52 gm	313.92 gm
0.600 mm					
0.300 mm					
0.150 mm					
0.075 mm					
Pan					
Total	1200	1200	1200	1200	1200

3.4. Performance Evaluation

3.4.1. Marshal test

Marshal test was among the performance evaluation method for the Asphalt mixes. From the marshal test, each compacted test specimen is subjected to these tests and analysis in the order listed

- ❖ Bulk specific gravity
- ❖ Stability and flow test
- ❖ Density and void analysis

3.4.2. Indirect tensile strength

Moisture sensitivity of the HMA mixes is defined as the reduction in the internal strength of the mix due to moisture damage. Or Moisture damage in bituminous mixes refers to the loss of service ability due to the presence of moisture the extent of moisture damage is called the moisture susceptibility. As per to AASHTO T-283 test method was used to evaluate the moisture sensitivity of various mixes. Since the sensitivity expressed by tensile strength ratio

3.4.3. Tensile strength ratio (TSR)

The tensile strength ratio (TSR) is conducted in agreement with (AASHTO – (T283)), in this test method we measure the resistance of compressed mixtures of asphalt concrete to moisture damage. In this test, the sample is loaded at a stable deformation rate of (2inches) per (1 minute) or ((50mm) per (1minute) of vertical ram movement of the sample until failure (AASHTO, 2005).

The measure of water sensitive: It is the ratio of the tensile strength of water conditioned specimen, (ITS wet, 60 °C, and 24hr) to the tensile strength of unconditioned specimen (ITS dry). Higher TSR value typically indicates that the mixture will perform well with good resistance to moisture damage. The higher the TSR value, the lesser will be the strength reduction by the water-saving condition.

3.4.4. Wheel track Testing

Rutting is an important parameter for design as well as for the evaluation of the performance of a bituminous concrete mixture to check the rutting resistance of the mixtures. Tests were performed using a wheel tracking device since the test was conducted on a lab. With dimension 20x30x5cm compacted at OBC, for virgin as well as for different RAP percentage. The test was conducted as per AASHTO 324. The test applies 10,000 passes (5,000 cycles) of the rolling wheel at 45 °C & resulting rut depths were measured.

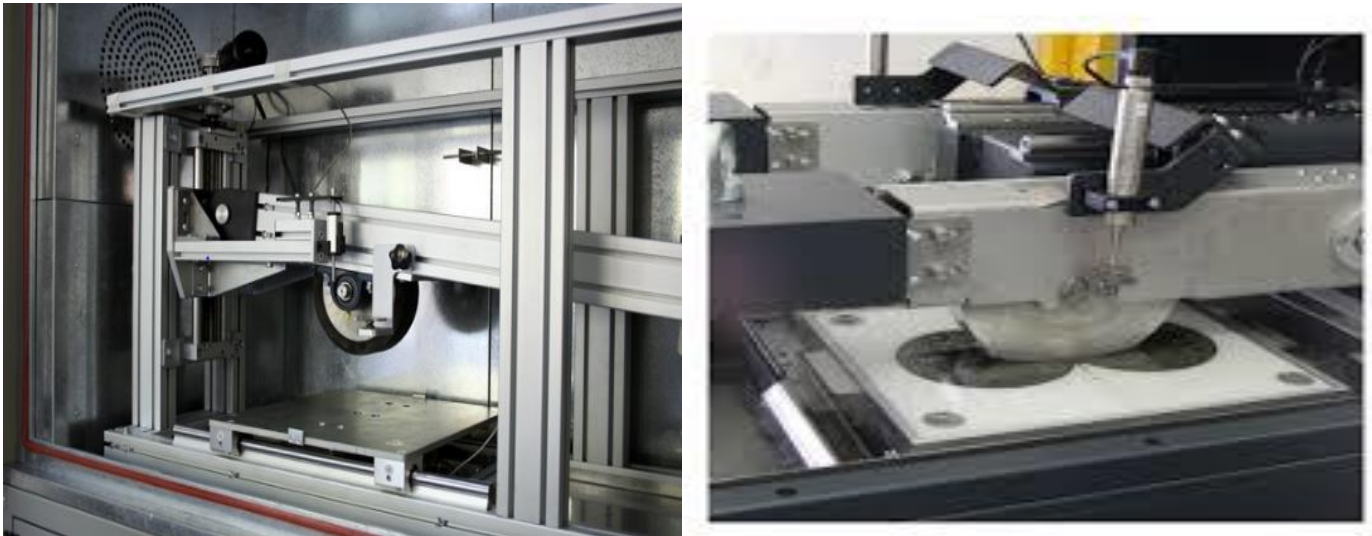


Figure 4 Wheel tracking machine @ AAIT

3.5. Statical Analysis

After proper completion of the laboratory procedures and data collection, statistical analysis was performed to evaluate the significance of mixes containing reclaimed Asphalt mixes in asphalt mixes using a one-way analysis of variance (ANOVA).

A one-way ANOVA uses two different estimates of sample variance. The first estimate is called the between-group variance, and it involves finding the variance of the means. The second estimate, the within-group variance, is made by computing the variance using all the data and is not affected by differences in the means.

The groups of independent variables were considered. For this analysis, the statistical model below is adopted.

$$Y_{ik} = \mu + \alpha_k + e_{ik} \dots\dots\dots \text{Equation 4}$$

Where Y_{ik} = ith score in the kth group

μ = Grand mean of the population.

$\alpha_k = \mu_k - \mu$ = effect of belonging to group k

e_{ik} = Random error associated with this group

This linear model is an estimation of the component of one score in the population.

❖ Testing the null hypothesis

In this research, the ANOVA consists of three random samples from each of the independent groups. And the null hypothesis (H_0) is that the control mix and the partially substitutes RAP are equally effective. This means, there is no performance change in asphalt mixture besides different percentages of RAP.

Therefore the null hypothesis $H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$

Whereas the alternative hypothesis $H_1: \mu_i \neq \mu_k$ for some i, k ; at least one percentage has a change in performance of asphalt mixture upon addition of RAP.

The null hypothesis is not rejected if the difference between the mean of each group is attributable only to random sampling fluctuation. Using this analysis testing of the hypothesis is done at 0.05 level of significance.

CHAPTER FOUR: RESULT AND DISCUSSION

This chapter concerned with the laboratory result and discussion to evaluate the laboratory mixes containing reclaimed asphalt pavement, which get from the material test, mix test/design and different performance tests. Generally, two types of laboratory tests were applied. The first type is qualification tests, which is conducted to identify the different property of materials used in the study. While the second type is the performance test used to measure the intended properties of the investigated mixtures such as Marshal test, indirect tensile test and rutting test.

4.1. Qualification Tests

4.1.1. Virgin Bitumen

Table 3. shows the qualification test for virgin bitumen of penetration grade of AC-85/100 used in this Laboratory Evaluation as per the AASHTO Standard. As a result, shows all the results are within the specification.

Table 3 Qualification test result for Bitumen

N O.	TEST TYPE	TEST METHOD	RESULT	SPECIFICAT ION	REM ARK
1	Penetration 100gm,5sec at 25°C	AASHTO T- 49	89	85-100	OK
2	Flash point °C	AASHTO T-48	275 °C	225 °C min	OK
3	Ductility(cm) at 25 °C	AASHTO T-51	146	Min 100	OK
4	Solubility in trichloroethyne	AASHTO T-44	99.62	Min 99.5	OK

4.1.2. For virgin aggregate

Table 4 Qualification test result for Aggregate

NO.	TEST TYPE	TEST MTD	RESULT	SPECIFICATION	REMARK
1	Aggregate crushing Value	BS 812	20.00%	Max 25 %	OK
2	Flakiness Index	BS 812	30.20%	Max 45 %	OK
3	Los Angeles abrasion	ASTM C-131	19%	Max 30 %	OK
4	Water Absorption	AASHTO T-85	1.83%	Max 2 %	OK
5	Specific gravity	AASHTO T-85	2.74	2.5 – 3.0	OK

In the above Table 4 shows the qualification test for virgin Aggregate used in this Laboratory Evaluation as per the AASHTO and British Standards. As the result shows all the results are within the specification. The average specific gravity of the three bins is presented by taking of the average individual specific gravity of each bin. Results of Average specific gravity of three Bins are tabulated in Appendix A of this research paper

The Maximum theoretical density at different Asphalt content was conducted. Following that Marshal test also experimented to get stability, flow, and volumetric parameter. Due to that the summarized result are here below. But the detail results are presented in Appendix C.

4.1.3. Summary Test result for the control mixes

Table 5. Summary Test result for the control mixes

B.C (%)	MTD (g/cm ³)	Bulk Density (g/cm ³)	Air Void (%)	VMA (%)	VFB (%)	Stability (KN)	Flow value (mm)
4.50	2.42	2.23	7.8	23.1	66.2	13.2	2.09
5.00	2.4	2.246	6.4	18.9	66.3	13	2.16
5.50	2.39	2.265	5.2	22.7	76.9	9.4	2.42
6.00	2.36	2.264	4.1	22.9	78.2	9.4	2.84

Table 5 presented that summarized test results for the control mixes including Bulk specific gravity, Stability and flow test, Density and void analysis parameters. From the above table to get optimum bitumen content. It was considered Bitumen content at maximum stability, Bitumen content at maximum density and Bitumen content at the midpoint of specified air void range. Then Optimum bitumen content of control Mixes =Avg (5.82, 5.0, 5.5) = 5.5 %

4.1.4. For RAP Material

4.1.4.1. Extraction Of Bitumen From RAP

From the extraction test, it easily understands that the bitumen content of old pavement was calculated as per the AASHTO T 164. The tabulated test results were illustrated in Appendix D. Finally the average bitumen content of the total weight was found at **4.43 %**.

4.1.4.2. Sieve Analysis Of RAP Aggregate

To determine the particle distribution of the extracted aggregate, sieve analysis was conducted as per the AASHTO T-27 using a wet method of analysis. The Gradation chart table of sieve analysis for RAP was attached in Appendix E.

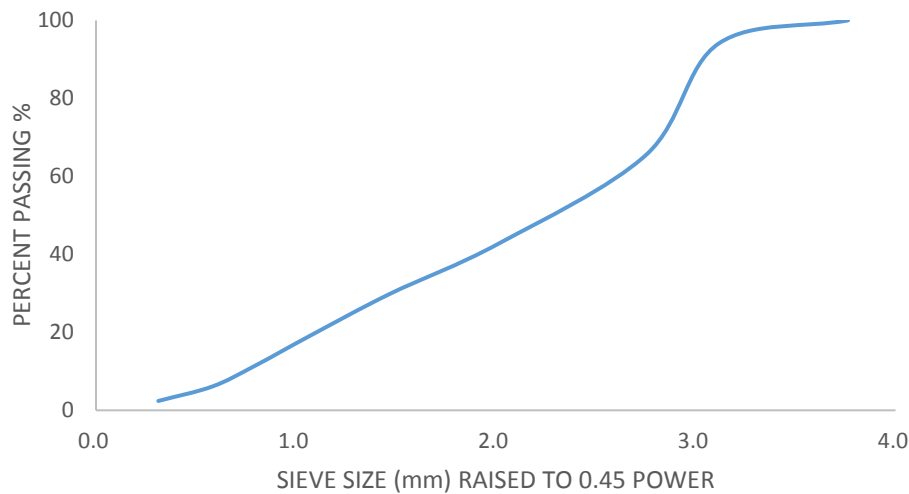


Figure 5. 0.45 Power Grading Chart

4.1.4.3. Maximum Theoretical Specific Gravity Of RAP Aggregate

The maximum theoretical specific gravity (G_{mm}) test was conducted according to AASHTO T209 for four RAP samples and summarizes the results for further consumption in the determination of bulk specific gravity of RAP aggregates as discussed in the methodology section of this research.

4.1.4.4. Marshal Test for Asphalt mixes with RAP

The marshal test result for Asphalt mixes with RAP different percentages are carefully conducted including Bulk specific gravity, Stability and flow test, Density and void analysis parameters and the laboratory test result are attached in Appendix F.

4.1.5. Statistical Analysis For Stability And Flow Test Results

Because we have two factors, we have hypotheses regarding each of the factors separately (called main effects) and then hypotheses regarding the interaction between the factors.

These two sets of hypotheses are:-

❖ Hypotheses for the stability

1. H0: There is no difference in population means among the levels of the stability factor.

H1: At least two population means are different among the levels of the stability factor.

2. H0: There is no difference in population means among the levels of the RAP % factor.

H1: At least two population means are different among the levels of the RAP % factor.

Table 6. Anova test result for stability and RAP %

Source of Variation	SS	MS	F	P-value	F crit	Decision
Stability	281.1561	93.71869	94.2555	1.31E-08	3.490295	H ₀ Rejected
RAP %	3.960773	0.990193	3.995865	0.006882	3.259167	H ₀ Rejected
Error	11.93166	0.994305				

The ANOVA result for stability test result indicates that the F value exceeds the critical value from the table for all RAP % at 0.05 level of significance. Therefore, the null hypothesis is rejected for RAP %. Hence this research accepted that the addition of RAP on asphalt mix affects the stability property of asphalt mix.

❖ Hypotheses for the flow

1. H0: There is no difference in population means among the levels of the flow factor.

H1: At least two population means are different among the levels of the flow factor.

2. H0: There is no difference in population means among the levels of the RAP % factor.

H1: At least two population means are different among the levels of the RAP % factor.

Table 7. ANOVA test result for Flow and RAP %

ANOVA							
Source of Variation	SS	df	MS	F	P-value	F crit	Decision
Flow	0.444	2	0.222	6.434783	0.021593	4.45897	H ₀ Rejected
RAP %	2.18	4	0.545	15.7971	0.000726	3.837853	H ₀ Rejected
Error	0.276	8	0.0345				

The decision to accept or reject the null hypothesis is made by comparing the test statistics computed F with the critical value from the table. If the computed F value exceeds the critical value, the hypothesis is rejected; if not, the hypothesis is not rejected.

The ANOVA result for the Flow test result indicates that the F value exceeds the critical value from the table for all RAP % at 0.05 level of significance. Therefore, the null hypothesis is rejected for RAP %.

Hence this research accepted that the addition of RAP on asphalt mix affects the flow property of asphalt mix.

4.2. Performance Test of the Mixes

4.2.1. Marshal Property

4.2.1.1. Air Voids (VIM)

The air void is an important factor that must be considered in designing of asphalt mixture. Since the total volume of air expressed as a percentage of the bulk volume of the compacted mixture, which is distributed throughout a compacted paving mixture and is located between the coated aggregate particles. The limit is in the range of 4-8 % but for design purposes, we choose 4-5 % of the total mix volume. When air void lower than 4 % bleeding of asphalt will occur especially with higher temperature causing a decrease of asphalt in the pavement with time. This decrease in asphalt content will already cause pavement cracking. On the other hand, for air void more than 5 % of the mix, the pavement will be weak and unstable. For these considerations, the asphalt binder is a very sensitive element in the pavement design.

In figure 6 below show that the Air void in mix showed a decreasing trend with increasing RAP content up to 30 %. The trends could be attributed to the existing bitumen in RAP which influences the properties as its percentage increases. Besides this, the 40 % RAP percentage addition will not meet the least requirement of the ERA flexible pavement design manual, 2013(4-8 %). Because the air void percentage is crucial for mixture design, it excluded from further analysis to avoid bleeding. For those mixes having low void, it mitigates by adding coarser aggregate and for a high void, increase the amount of minerals filler in the mix.

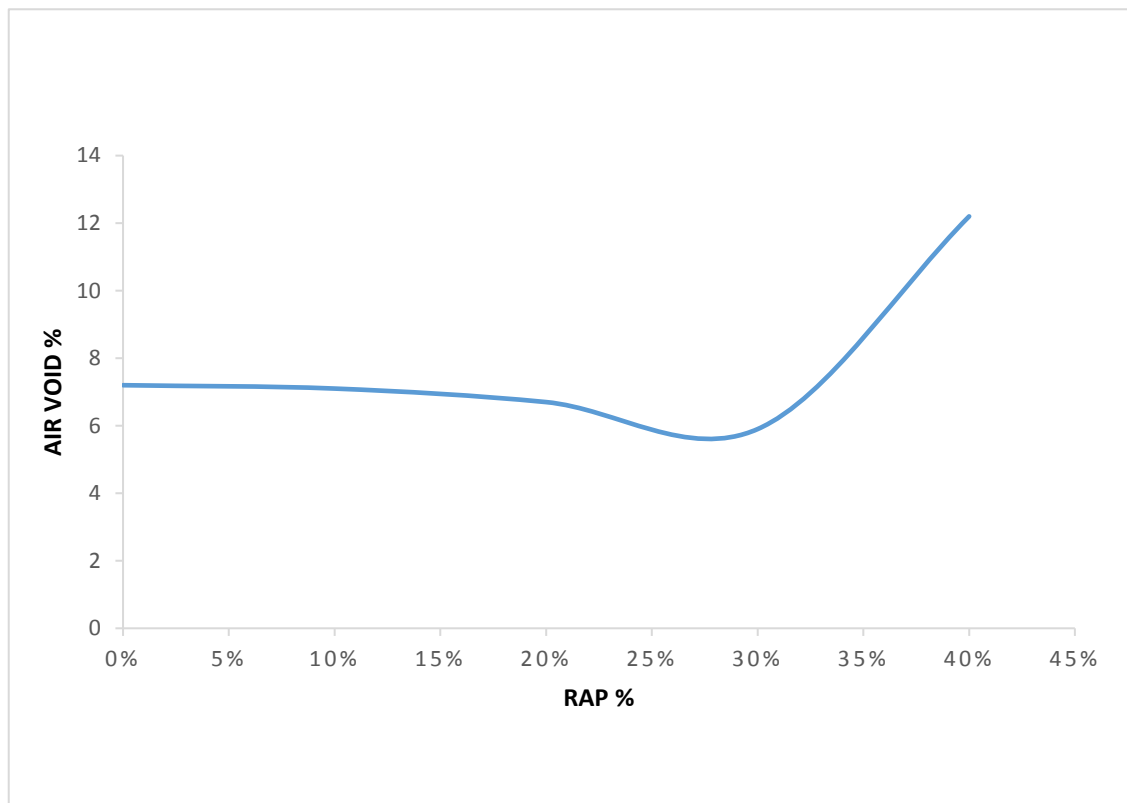


Figure 6 Air Void Vs RAP % age

4.2.1.2. Voids in the Mineral Aggregate (VMA)

Figure 7 below shows that the voids in mineral aggregate for all the investigated mixes. From the experimental result, it can be concluded that, the void in mineral aggregate increase as the RAP percent increase achieving values in the range between 0% and 30% for the mixes. This may be due to ineffective old asphalt in the aggregate pores which prevent the new asphalt from occupying deeply the aggregate pores. It is obvious that the increase in VMA is of low rate up to reclaimed percent of 30 %

.For this reason, it is concluded that the recycled aggregate percent must not exceed 30 % for satisfactory.

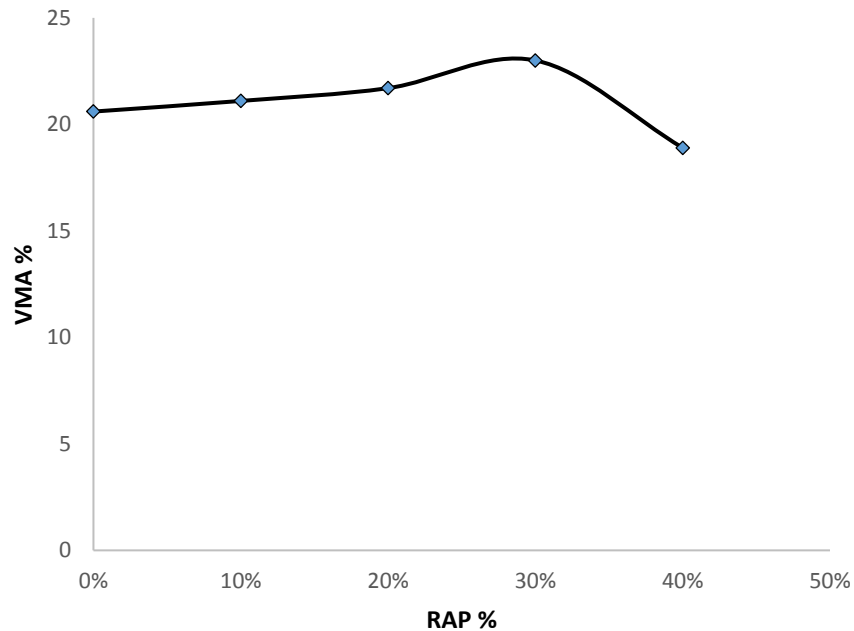


Figure 7 VMA Vs RAP % age

4.2.1.3.Voids Filled with Bitumen (VFB)

This is the portion of the volume of void space between the aggregate particles (VMA) that is occupied by the effective bitumen. To determine volumes, the specific gravities of the mix components must also be determined. From the investigation, Figure 8 pointed that, the effect of RAP mixture percentage was increase as the void filled with the asphalt increase. This may be due to the presence of the old asphalt in the mixes.

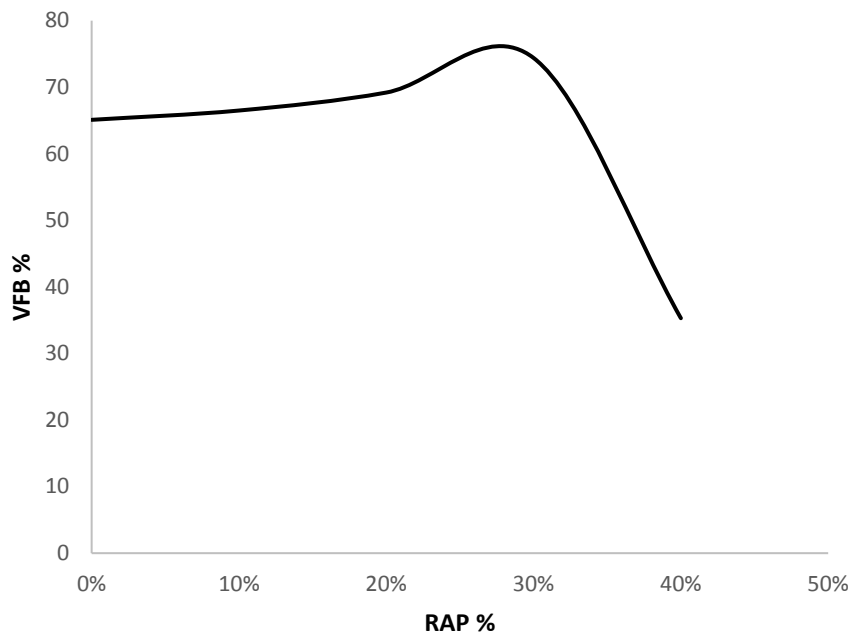


Figure 8 VFB Vs RAP % age

4.2.1.4. Mix Flow

Mixes flow value gives an indicator of the resistance of permanent deformation. Based on the flow value obtained for all the investigated mixture. Generally, the mix flow increase as the RAP percentage increases. When the RAP percentage increase from 0 % to 30 %, the flow increases from 2.23 mm to 2.79 mm, by 20.07 %., this increment happened may be due to the presence of additional asphalt in the RAP especially during high temperature.

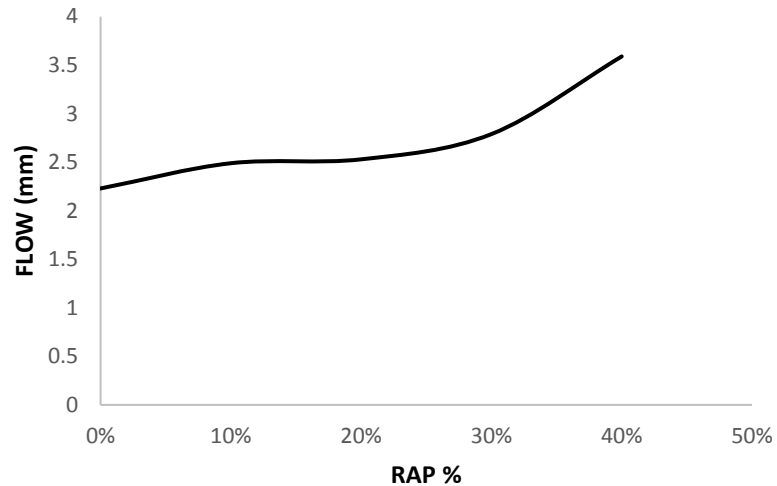


Figure 9 Flow Value Vs RAP %age

4.2.1.5. Mix stability

Mix stability is an important parameter for resisting pavement distress. The stability presented in Figure 10 below noticed that the mix stability has increased as RAP increased to 20 % then they tend to decline up to 30 %. Since all the mixes give an acceptable value and a sudden decrease is occurred for more than 30 % .

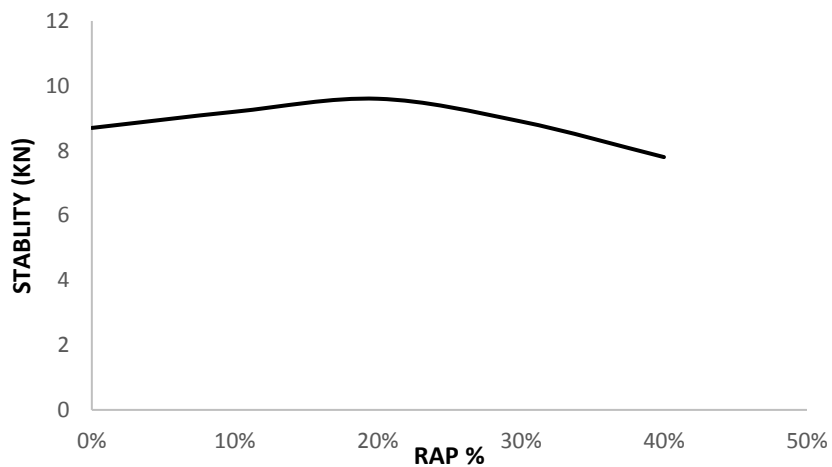


Figure 10 Stability Vs RAP % age

4.2.2. Moisture Sensitivity

This test is conducted as per the ASTM D-4867 specification. The prepared samples were divided in to conditioned and unconditioned, the first one maintained in dry while the second one is subjected to partially saturated with water and moisture conditioned. The potential for moisture damage is indicated by the ratio of the tensile strength of the wet to that of the dry one. The dry samples are soaked in a water bath for 20 min at 25 °C and for the conditioned of wet, the samples are placed in a water bath at 60 °C for 24 hr. and placed in a water bath for 1 hr. at 25 °C. HMA mixtures may be considered susceptible to moisture if the internal asphalt binder-to-aggregate bond weakens in the presence of water.

Table 8 Indirect test result

Property	Type of Mix					Specification as per MoRTH,2001
	0 % RAP	10% RAP	20% RAP	30% RAP	40 % RAP	
Indirect tensile strength (dry)/ unconditioned	6.2	6.3	6.34	5.33	6.48	>80 %
Indirect tensile strength (wet) conditioned	5.264	5.166	5.08	4.01	4.73	
Tensile strength ratio	84.9	82.0	80.2	75.23	73.00	

In the above table 8 summarizes the moisture/water sensitivity properties of the various mixture with different RAP percentages. All the mixes meet the least requirement as per the specification except for the 30 % and 40 % RAP substitution.

The tensile strength ratio of reclaimed asphalt and virgin mixes can be observed that reclaimed mix as lower tensile strength ratio when compared to virgin mix. However, even reclaimed asphalt pavement mix fulfilled the minimum criteria (80 %). This indicated reclaimed mixes are moisture susceptibility.

4.2.2.1. Statistical Analysis of Indirect strength test result Using ANOVA

This analysis testing of the hypothesis is done at 0.05 level of significance. The test statistics for two-way ANOVA are the F ratio i.e. the ratio of between the group variance and the within-group variance. The results are summarized in the table below.

❖ For ITS at different RAP percentage,

H0: There is no difference in the population mean of ITS at different RAP percentages.

H1: At least four have a different population mean of ITS RAP percentage.

Table 9. ANOVA test result for ITS and RAP %

Source of Variation	SS	MS	F	P-value	F crit	Decision
ITS	45.05852	45.05852	325.7608	0.000371	10.12796	Rejected
RAP %	0.414953	0.138318	1	0.5	9.276628	Accepted
Error	0.414954	0.138318				

The ANOVA result for the ITS result indicates that the F value exceeds the critical value from the table for all number of cycles at 0.05 level of significance. RAP percentage the reverse is true; the critical value from the table exceeds the calculated F value. Therefore, the null hypothesis is rejected for ITS and it is accepted for RAP percentage. Hence this research accepted that the addition of RAP on asphalt mix doesn't affect the moisture sensitivity of asphalt mix.

4.2.3. Rutting Resistance

Rutting resistance measured by wheel tracking apparatus, which consists of a loaded wheel, which bears on a sample held on a moving table. The table reciprocates with simple harmonic motion through a distance of 230 mm with a frequency of 53 pass/minute. The wheel is fitted with a solid rubber tire outside diameter 200mm. The wheel load under standard condition 700N and fitted with 60°C temperature and the 20 % RAP substitution showed the least rut depth among the other samples.

Table 10 deformation at different RAP percentage

No, of cycle	Deformation at different RAP percentage				
	0%	10%	20%	30%	40%
1000	2.5 mm	2.36 mm	2.43 mm	2.22 mm	2.15 mm
2000	3.34 mm	3.06 mm	3.2 mm	2.81 mm	2.8 mm
3000	4.5 mm	3.87 mm	4.185 mm	3.73 mm	3.6 mm
4000	6.19 mm	6.11 mm	6.15 mm	5.82 mm	6.03 mm
5000	8.44 mm	7.82 mm	7.6 mm	8.12 mm	8.69 mm

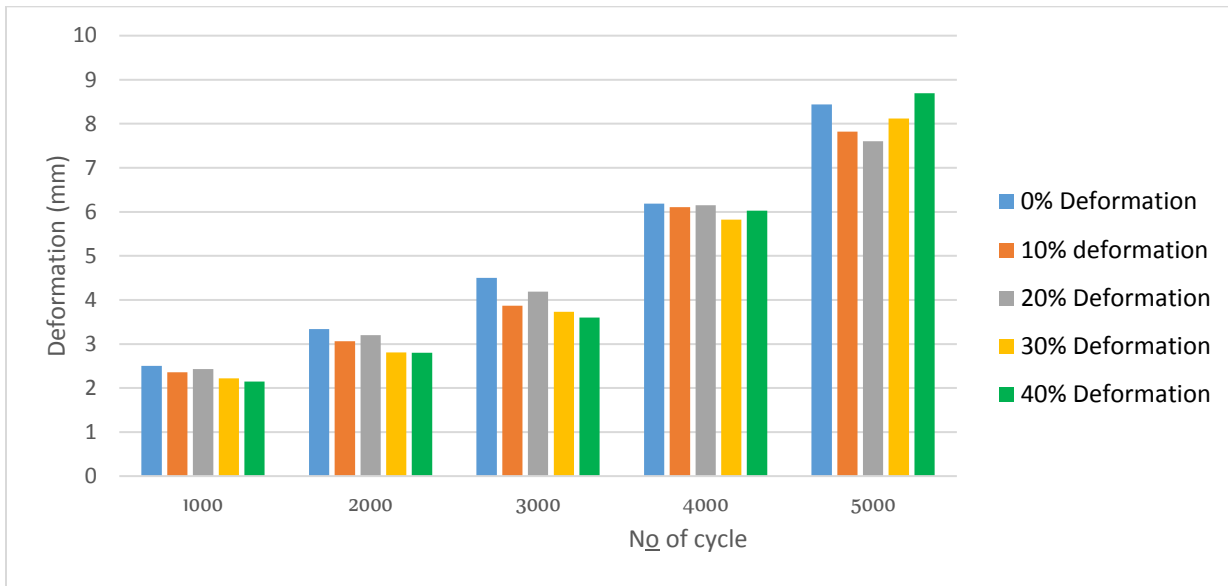


Figure 11 deformation at different RAP percentage

Figure 11 illustrated that the rut depth (mm) with many cycles at different RAP percentages. From the graph, the higher rut depth indicates that the mixes with higher RAP content have lower resistance to rutting.

4.2.3.1. Statistical Analysis of Rutting Depth Result Using ANOVA

After pursuing the laboratory procedures and data collection, statistical analysis was performed to evaluate the significance of the addition of RAP and the Number of cycles to asphalt mix using two-way analysis of variance (ANOVA).

The five groups of independent variables i.e. 0%,10%,20% 30% and 40% were considered. This analysis testing of the hypothesis is done at 0.05 level of significance. The test statistics for two-way ANOVA are the F ratio i.e. the ratio of between the group variance and the within-group variance.

❖ For Deformation at different RAP percentage,

H0: There is no difference in population mean rutting depth by deformation at different RAP percentages.

H1: At least four have a different population mean rutting depth by deformation at different RAP percentages.

❖ For Number of cycles,

H0: There is no difference in mean Rutting depth for the different number of cycles.

H1: At least four number of cycles give different mean rutting depth.

Table 11 deformation at different RAP percentage

Factors	F-value	P-value	F critical	Decision
Number of cycles	398.737	0.000	3.007	Rejected
RAP percentage	2.072	0.132	3.007	Accepted

The decision to accept or reject the null hypothesis is made by comparing the test statistics computed F with the critical value from the table. If the computed F value exceeds the critical value, the hypothesis is rejected; if not, the hypothesis is not rejected.

The ANOVA result for the Rutting depth result indicates that the F value exceeds the critical value from the table for all number of cycles at 0.05 level of significance. RAP percentage the reverse is true, the critical value from the table exceeds the calculated F value. Therefore, the null hypothesis is rejected for the Number of cycles and it is accepted for RAP percentage. Hence this research accepted that the addition of RAP on asphalt mix doesn't affect the rutting property of asphalt mix.

4.3. Optimum RAP percentage

Table 12. Summarized performance test result @ different RAP %

RAP %	ITS	Rutting Depth(mm)	stability(KN)	Flow(mm)
0%	84.9	8.44	8.7	2.23
10%	82	7.82	9.2	2.49
20%	80.2	7.6	9.6	2.3
30%	75.23	8.12	8.9	2.79
40%	73	8.69	7.8	3.59

Based on the laboratory result carried out on virgin mixes and mixes with 10 %, 20 %, 30 %, and 40 % RAP, it was found that the addition of RAP improves all the properties of the bituminous mixes. Thus, indicates that mixes with 20 % RAP would perform better than the virgin and other mixes under similar condition.

CHAPTER FIVE : CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The performance of the control and RAP mixes were evaluated in terms of their resistance to moisture damage, rutting resistance and marshal property including volumetric analysis.

- ❖ A mix made from only virgin material was selected as the control mix for investigation and Adding the reclaimed asphalt to new asphalt mixes, with the aggregates & the old bitumen performing the same function as in their original application
- ❖ Increasing RAP has an unpronounced effect on the mix weight. however, increasing RAP from 0 to 30 % decrease the mix density
- ❖ Mix stability increase from 0 to 20 % then decreases. This may be due to fatigue of such material by aging
- ❖ Adequate mix stability to prevent unacceptable distortion and displacement when traffic load applied is needed and adequate void in the total compacted mixture to permit a small amount of compaction when traffic load is applied without bleeding and loss of stability.
- ❖ Based on the finding of this study, it is possible to design acceptable quality mixes with 20 % RAP substitution that meets the required volumetric, mechanical properties and the desired performance criteria.
- ❖ There is the poor practice of utilized RAP as a substituting material in Addis Ababa. Besides this, there is a fear of using in asphalt surface course. This may come from lack of experience, technology, and research.
- ❖ The addition of RAP improves different Hot Mix Asphalt as the proportion increase. the optimum binder content demand gradually reduced when the RAP content was increasing
- ❖ Recycling of asphalt pavement is an available approach for technical, economical & environmental reasons. Using RAP has been favored over virgin materials in light of the increasing cost & asphalt.

5.2. Recommendation

- ❖ To investigate, examine and to improve the mechanical characteristic of different RAP mixes respect to our country, it should be better to enforce law and policies by the cooperation of different governmental and non-governmental institutes.
- ❖ The RAP material should better handle and store properly. This may be affected by moisture and seasonal weather condition.
- ❖ Further investigation can be carried out for more than 40% of the RAP materials concerning reducing the Virgin materials and their Marshall Properties, ITS and Fatigue test behavior can be evaluated.
- ❖ From the study, the RAP increases the stability of the mixes .it recommended to use the improved aggregate quality. This may improve by using different aggregate or use cement coated aggregate
- ❖ The educational institute, training and research center are recommended to do more in this study area and to be equipped with different laboratory facilities.
- ❖ Last but not least there need further study to be done regarding the rheological characteristics of RAP, environmental impact, current practices on the utilization of RAP in the different state of Ethiopia and the advantage in road construction as a sub-base and base layers

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7. APPENDICES

APPENDIX A. BULK SPECIFIC GRAVITY FOR BIN 1, BIN 2 AND BIN 3

FOR BIN 1	Sample A	Sample B	Average
Mass of Saturated Surface Dry specimen(S) in gm	500.0	500.0	500.0
Mass of Pycnometer filled with water (B) in gm	1688.5	1688.5	1688.5
Mass of Pycnometer + specimen+ water(C) in gm	2004.5	2004.0	2004.3
Mass of Oven Dry specimen (A) in gm	476.0	475.0	475.5
Bulk Specific Gravity (dry basis) $A/(B+S-C)$	2.587	2.575	2.6
Bulk Specific Gravity (SSD basis) $S/(B+S-C)$	2.717	2.710	2.71

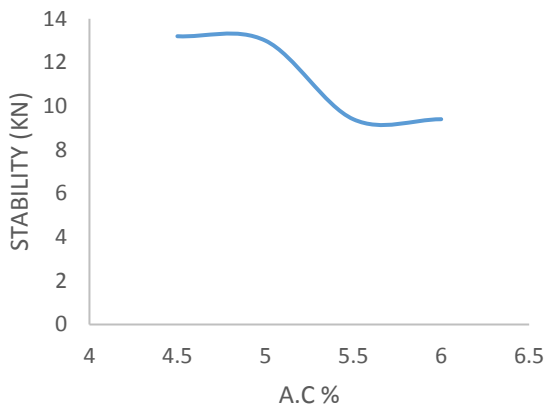
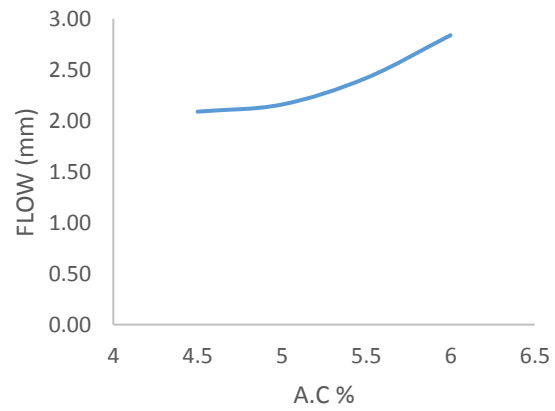
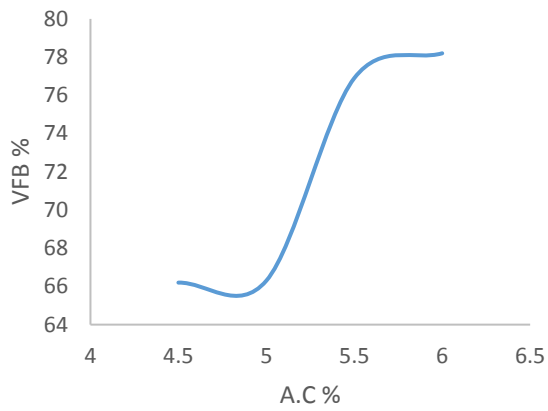
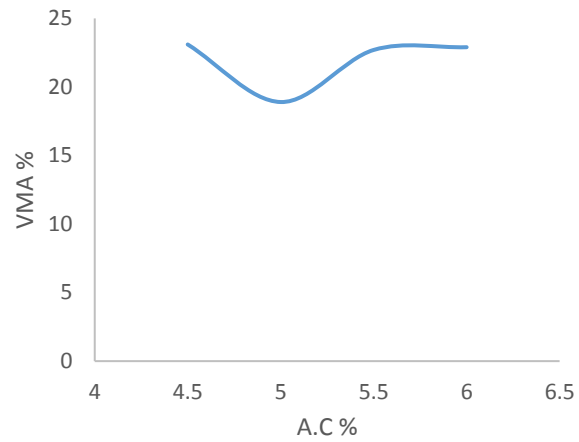
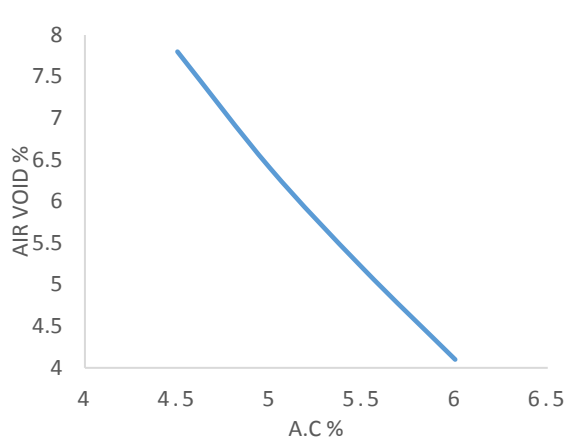
FOR BIN 2		Sample A	Sample B	Average
1	Mass of saturated-surface-dry in air=a, gm	2346.0	2314.0	2330.0
2	Mass of oven-dry test sample in air=b, gm	2269.0	2241.0	2255.0
3	Mass of test sample in water=c, gm	1496.0	1476.0	1486.0
4	Bulk Specific Gravity (SSD) $\{a/(a-c)\}$	2.76	2.76	2.76

FOR BIN 3		A	B	Average
1	Mass of saturated-surface-dry in air=a, gm	2413.0	2490.0	2451.5
2	Mass of oven-dry test sample in air=b, gm	2356.5	2431.5	2394.0
3	Mass of test sample in water=c, gm	1564.5	1608.5	1586.5
4	Bulk Specific Gravity (SSD) $\{a/(a-c)\}$	2.64	2.82	2.74

Table 13 Average specific gravity of three Bins

Bin No.	Bulk specific gravity	Percentage	Average Gsb
Bin 3 (4.75-12.5 mm)	2.748	31.0%	2.74
Bin 2 (4.75-2.36mm)	2.757	21.0%	
Bin 1 (0-2.36mm)	2.714	48.0%	

APPENDIX B. GRAPHICAL REPRESENTATION OF MARSHAL TEST RESULT FOR GETTING OPTIMUM B.CONTENT



APPENDIX C. RESULT FOR THE CONTROL MIXES (MTD AND MARSHAL TEST) FOR THE CONTROL MIXES

A. MTD for controlled mixes

Asphalt Content	4.5 %		5.0 %		5.5 %		6.0 %	
	1	2	1	2	1	2	1	2
(A) Weight of Flask	460	460	460	460	460	460	460	460
B) Weight of Flask + Water	1688.5	1688.5	1688.5	1688.5	1688.5	1688.5	1688.5	1688.5
C) Weight of Sample	500	500	500	500	500	500	500	500
D) Weight of Flask + Sample + Water	1996.0	1997	1992.5	1992	1996.0	1997	1992.5	1992
E) Temperature of Water	25	25	25	25	25	25	25	25

UTILIZATION AND LABORATORY EVALUATIONS OF MIXES CONTAINING RECLAIMED ASPHALT PAVEMENT

G) Weight of Replaced Water (B+C) – D	208.4	206	208	208.5	208.3	208	211	212.5
(H) Max. Sp. Gravity of Material	2.401	2.43	2.404	2.398	2.398	2.404	2.369	2.353
Average Max Specific Gravity of Material	2.42		2.4		2.39		2.36	
STD	0.021		0.004		0.004		0.011	

B). Marshal Test result of the control mixes

Specimen	% AC	Specimen height	Wt. Of Specimen in air (gm)	Wt. Of Specimen in Water (gm)	SSD Wt. Of Specimen in air (gm)	Vol. Of Specimen (D-C) cc.	Bulk Density (gm/cc) B/E	Gm m	% Air voids	% VMA = 100 – (F x % AC)	% VF B	Stability in KN	Corrected Coeff.	Corrected Stability in kgf LxM	Flow value (mm)
									(G– F) x100	Gsb	(I– H)x 100				
									G	I					
	A	B	C	D	E	F	G	H	I	J	K	M	N	O	
1A	4.5 %	63.0	1196.0	669.0	1199.5	530.5	2.254	6.8	22.3	69.3	11.80	1.04	12.3	2.3	
1B		63.5	1195.5	665.8	1199.5	533.7		2.240	7.4	22.8	67.3	12.68	1.04	13.2	2.2
1C		62.5	1196.0	655.0	1199.5	544.5		2.197	9.2	24.3	61.9	13.67	1.04	14.2	1.8
Avg.								2.230	7.8	23.1	66.2			13.2	2.09

UTILIZATION AND LABORATORY EVALUATIONS OF MIXES CONTAINING RECLAIMED ASPHALT PAVEMENT

A	5.0	63.0	1190.0	660.0	1198.2	538.2	2.211	2.40	7.9	20.2	61.0	12.63	1.0	12.6	2.2
B		63.5	1194.0	666.0	1195.2	529.2	2.256		6.0	18.6	67.7	13.13	1.0	13.1	2.39
C		62.5	1194.5	668.0	1194.0	526.0	2.271		5.4	18.0	70.2	13.21	1.0	13.2	1.88
Avg.							2.246		6.4	18.9	66.3			13.0	2.16
A	5.5	63.0	1189.0	668.0	1192.0	524.0	2.269	2.39	5.1	20.6	77.6	9.63	1.04	10.0	1.9
B		63.5	1192.2	667.0	1196.0	529.0	2.254		5.7	19.5	75.3	9.03	1.04	9.4	2.3
C		62.5	1190.0	670.0	1194.0	524.0	2.271		5.0	20.5	77.9	8.46	1.04	8.8	3.0
Avg.							2.265		5.2	20.2	76.9			9.4	2.42
A	6.0	63.7	1194.0	669.0	1196.5	527.5	2.264	2.36	5.3	23.2	77.2	9.63	1.04	10.0	1.9
B		62.8	1186.5	666.1	1193.4	522.9	2.269		5.1	23.0	78.0	9.03	1.04	9.4	2.8
C		62.4	1194.5	670.0	1194.0	524.0	2.280		4.8	22.6	79.6	8.46	1.04	8.8	3.8
Avg.							2.264		5.0	22.9	78.2			9.4	2.84

APPENDIX D. RESULT FOR THE CONTROL MIXES (MTD AND MARSHAL TEST)

Table 14 Extraction test result

Wt. of Mix before test (A) gm		1200
Wt. of Filter paper before test (B) gm		8.0
Wt. of filter + sediment (C) gm		8.5
Wt. of Sediment (D) = (C – B) gm		0.5
Wt. of filler after burn (E) gm		7.5
Wt. of Aggregate (F) gm		1130.0
Total Wt. of Aggregate (G) = (D + E+F) gm		1148.0
Wt. of Bitumen (H) = (A – G) gm		62.0
Bitumen Content	4.33	4.43 %
In Mix H/A %		
In Agg. H/G %	4.53	

UTILIZATION AND LABORATORY EVALUATIONS OF MIXES CONTAINING RECLAIMED ASPHALT PAVEMENT

Nominal Sieve Size (mm)	Weight Retained (gm)	Cumulative Weight Retained (gm)	Cum.% Retained (%)	Percent Passing %	Acceptable Limits	
					Lower	Upper
19.0	0.0	0	0.0	100.0	100	100.0
12.5	0.0	0	0.0	100.0	100	100.0
9.5	62.5	62.5	5.9	94.1	90	100.0
4.75	303.0	365.5	28.5	65.6	55	85.0
2.36	243.0	608.5	22.9	42.8	32	67.0
1.180	137.0	745.5	12.9	29.9		
0.600	112.0	857.5	10.5	19.3		
0.30	84.0	941.5	7.9	11.4		
0.150	56.5	998	5.3	6.1	7.0	23.0
0.075	40.0	1038	3.8	2.4	2.0	10.0
Pan	25.0	1063	2.4			

APPENDIX E. RESULT FOR THE GRADATION OF RAP

Table 15. MTD for Asphalt Content 5.5% with 10% RAP

Asphalt Content 5.5% with 10% RAP			
(a) Weight of dry Sample in air	(gm)	500	500
(b) Weight of Flask + Water	(gm)	1690	1690
(c) Weight of Flask + Sample + Water	(gm)	1988	1988.8
Temperature of Water	°C	25	25
(d) Weight of Replaced Water (a+b) – c	(gm)	202	201.8
Max. Sp. Gravity of Material=a/d		2.475	2.487
Average Max Specific Gravity of Material		2.48	

Table 16 MTD for Asphalt Content 5.5% with 20% RAP

Asphalt Content 5.5% with 20% RAP			
(a) Weight of dry Sample in air	(gm)	500	500
(b) Weight of Flask + Water	(gm)	1690	1690
(c) Weight of Flask + Sample + Water	(gm)	1990.5	1990.5
(d) Weight of Replaced Water (a+b) – c	(gm)	199.5	199.5
Max. Sp. Gravity of Material=a/d		2.506	2.506
Average Max Specific Gravity of Material		2.50	

Table 17 MTD for Asphalt content 5.5% with 30% RAP

Asphalt Content 5.5% with 30% RAP			
(a) Weight of dry Sample in air	(gm)	500	500
(b) Weight of Flask + Water	(gm)	1690	1690
(c) Weight of Flask + Sample + Water	(gm)	1986	1984
(d) Weight of Replaced Water (a+b) – c	(gm)	204	206
Max. Sp. Gravity of Material=a/d		2.45	2.43
Average Max Specific Gravity of Material		2.44	

Table 18 MTD for Asphalt Content 5.5% with 40% RAP

Asphalt Content 5.5% with 40% RAP			
(a) Weight of dry Sample in air	(gm)	500	500
(b) Weight of Flask + Water	(gm)	1690	1690
(c) Weight of Flask + Sample + Water	(gm)	1989.5	1990.8
Temperature of Water	°C	25	25
(d) Weight of Replaced Water (a+b) – c	(gm)	200.5	199.5
Max. Sp. Gravity of Material=a/d		2.494	2.506
Average Max Specific Gravity of Material		2.50	

APPENDIX F. COMBINED GRADATION

Table 19. Combined gradation

Sieve Dimension	12.5-9.5mm	9.5-4.75 mm	< 4.75 mm	(Combination Grading)	Specification	
					Max	Min
25.00 mm	100.0	100.0	100.0	100.0	100.0	100.0
19.00 mm	100.0	100.0	100.0	100.0	100.0	100.0
12.50 mm	99.8	100.0	100.0	100.0	100.0	100.0
9.50 mm	62.0	99.8	99.7	91.8	100.0	90.0
4.75 mm	1.3	29.1	98.3	56.5	75.0	45.0
2.36 mm	0.1	3.8	71.7	35.6	58.0	30.0
1.18 mm	0.1	1.9	53.4	26.2	44.0	20.0
0.60 mm	0.1	1.2	36.7	18.0	32.0	13.0
0.30 mm	0.1	1.0	24.4	12.0	23.0	9.0
0.150 mm	0.1	0.8	16.6	8.2	16.0	6.0
0.075 mm	0.1	0.7	11.4	5.7	8.0	4.0
RATIO	21.0%	31.0%	48.0%	100.0%		

Table 20: Marshal Test result for different RAP percentage

Specimen	% RAP	Specimen height	Wt. Of Specimen in air (gm)	Wt. Of Specimen in Water (gm)	SSD Wt. Of Specimen in air (gm)	Vol. Of Specimen (D-C) cc.	Bulk Density (gm/cc) B/E	G _{mm}	% Air voids	% VMA = 100 - (Fx% A C)	% VFB	Stability in KN	Corrected Coeff.	Corrected Stability in kgf LxM	Flow value (mm)
									(G-F) x100	G _{sb}	(I-H)x 100				
	A		B	C	D	E	F	G	H	I	J	K	M	N	O
1A	0%	63.7	1182.0	678.5	1185.5	507.0	2.331	2.50	6.7	20.2	66.6	9.2	1.04	9.568	2.3
1B		62.8	1180.0	675.5	1184.0	508.5	2.321		7.2	20.6	65.1	8.4	1.04	8.736	2.1
1C		62.4	1174.5	673.0	1181.5	508.5	2.310		7.6	20.9	63.7	7.6	1.04	7.904	2.2
Avg.							2.321		7.2	20.6	65.1				8.7

UTILIZATION AND LABORATORY EVALUATIONS OF MIXES CONTAINING RECLAIMED ASPHALT PAVEMENT

1A	10%	64.0	1182.5	678.5	1190.2	511.7	2.311	2.48	6.8	20.9	67.4	6.41	1.04	7.7	2.3
1B		63.5	1182.0	675.5	1189.6	514.1	2.299		7.3	21.3	65.8	9.34	1.04	9.7	2.1
1C		63.8	1176.3	673.0	1183.5	510.5	2.304		7.1	21.1	66.5	10.00	1.04	10.4	3.1
Avg.							2.305		7.1	21.1	66.5			9.2	2.49
1A	20%	65.0	1181.8	678.5	1191.4	512.9	2.304	2.50	2.5	21.1	88.2	10.26	1.04	10.7	2.5
1B		63.0	1188.5	675.5	1200.2	524.7	2.265		9.4	22.5	58.2	9.34	1.04	9.7	2.4
1C		66.0	1184.0	673.0	1189.6	516.6	2.292		8.3	21.5	61.4	8.15	1.04	8.5	2.7
Avg.							2.287		6.7	21.7	69.2			9.6	2.53
1A	30%	64.0	1191.8	665.0	1198.4	533.4	2.234	2.44	2.5	23.5	89.4	8.01	1.04	8.3	3.1
1B		63.0	1190.6	667.2	1194.6	527.4	2.257		7.5	22.7	67.1	9.34	1.04	9.7	2.1
1C		63.5	1188.4	668.0	1195.0	527.0	2.255		7.6	22.8	66.8	8.20	1.04	8.5	3.2
Avg.							2.249		5.9	23.0	74.4			8.9	2.79
1A	40%	63.0	1188.2	653.5	1190.0	536.5	2.215	2.6	13.5	20.0	32.7	6.92	1.04	7.2	3.6
1B		63.5	1190.0	656.0	1185.0	529.0	2.250		12.1	18.8	35.4	7.12	1.04	7.4	3.4
1C		62.5	1196.5	655.0	1180.4	525.4	2.277		11.0	17.8	37.9	8.46	1.04	8.8	3.8
Avg.							2.247		12.2	18.9	35.3			7.8	3.59

