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Laboratory based performance evaluation of high content reclaimed asphalt pavement in hot mix

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Abstract

During maintenance, rehabilitation, or reconstruction operations removing existing asphalt pavement materials are common. This practice produces a large amount of reclaimed asphalt pavement (RAP), which contains valuable asphalt binder and aggregate. The road construction and maintenance works depend on the utilization of natural and industrial materials which is limited and scarce. As existing pavement diminishes, obtaining quarry sites is difficult.

The objective of this study is to conduct laboratory based- research that investigates and evaluates the performance of hot mix asphalt mixtures containing different amounts of RAP for binder course construction.

Quality test for all materials used in the mix was done separately. Marshall Parameter was done for control mix and mix containing RAP to evaluate the mechanical properties of the asphalt binder mixture containing RAP and control mix. To predict the field condition performance test such as moisture susceptibility, indirect tensile strength, and Humberg wheel tracking test was conducted.

The obtained result for all mixes is in terms of Marshall Parameter criteria and the performance test proves that the asphalt binder course mix can be successfully produced using RAP material within the specification limit. The study concluded that, using RAP in HMA up to 40% is possible to design a mix that satisfied the required specification for Marshall Property and performance test with low cost than the control mix.

Keywords: Reclaimed asphalt pavement, virgin aggregate, Marshall Property, hot mix asphalt, performance test, binder course

Introduction

In highway engineering, the evolution of the road industry has made many achievements throughout the world. However, this industry faces several challenges when it comes to pavement sustainability. Due to many reasons, the constructed asphalt pavements were seriously damaged without achieving the intended design life, which called for pavement maintenance and rehabilitation.

In a landlocked country like Ethiopia where the main transportation mode is through roads, the good performance of the road network in attending to road user needs is critical for both social and economic development. According to ERA (2021) in the viewpoint of Ethiopia, the road is the most vital infrastructure that gives access to the countryside and concrete areas within the country. The materials present in old asphalt pavements may have value, even when the pavements have reached the end of their service lives. Recognizing the value of those existing aggregate and asphalt resources increased the use of RAP in new asphalt pavements. Additionally, the increased prices of asphalts due to the escalating increases in crude oil prices as well as the cost of energy in general; raised the interest in the use of RAP in asphalt pavements (Elie Y. Hajj, *et al*. 2007) [6]. RAP is applicable to construct all types of road layers except runway surfaces. ERA (2013) [8] Flexible Pavement Design Manual Pp G-6, recommended that an unbound material containing RAP meets the specifications for grading, density, and CBR which are normally applied to fresh materials then it should be acceptable to use the RAP as a road base. Reclaimed Asphalt Pavement has many advantages including saving energy, emission reduction, optimize landfill disposal usage, conservation of natural resources, and for disposal waste reducing damping fees (Siddharth, *et al*., 2020). Due to its growing economy, the Ethiopian government through its road authority is investing a huge amount of budget in the road construction industry at the national and regional levels. After the construction of roads due to several reasons observing distress, asphalt pavement is becoming a common problem in Ethiopia.

This factors increases the demand for maintenance and rehabilitation of road pavements. The road construction and maintenance works dependent on the utilization of natural and industrial materials which is limited and scarce. As a result, major reconstruction or rehabilitation and maintenance work of asphalt Pavement are becoming a challenge for the road construction industry. The recycling of RAP material fills the gap exists between the road construction industry and construction material as well as the associated cost supplying of virgin material. Due to a lack of budget allocation Ethiopian road authority in the past decades mainly focused on expanding the road network throughout the country.

However, now the road authority is giving due attention to road maintenance and rehabilitation. Therefore, an extra amount of RAP will be available.

General objective

The main objective of this study is to conduct a laboratory-based research study that investigates and evaluates the performance of hot mix asphalt mixtures containing different amounts of RAP.

Method

This section deals with sample source, material characterization, estimation of the asphalt content in the RAP, conduct quality test for Virgin aggregate, Virgin bitumen, and RAP aggregate, standard and techniques used for material characterization, and mix design procedure.

Sampling and Data Collection

The RAP material was sampled from a stockpile found near the Winget area. The material was sampled carefully because sampling is very important and equivalent to testing. Some materials were removed from the top surface of the RAP stockpiles. The virgin crushed aggregate, that are required for the research work was obtained from AACRA batching plant found in the Akaki Kality sub-city. The aggregate was properly sampled from each gradation (25mm, 19mm, 12.5mm, 4.75mm, and below) from stocks prepared for conventional HMA that satisfy the specification or requirements of HMA.

Experimental Study and Test for Partial Substitution of RAP

After detailed reviews on previous related research and books including specification of the different standard in the study area, quality tests were conducted through experimental tests based on ERA, BS, AASHTO, and ASTM standards to know the property of individual material. The following procedures were used; Determination of history of old Pavement, Sampling of RAP, Extraction of bitumen from RAP, Sieve analysis of RAP aggregate, Sieve analysis of virgin aggregate, Mix proportioning of RAP & virgin materials, Laboratory batch preparation, mixing and compaction of test specimens determination of Marshall Property based on specification and finally conducting performance tests.

Mix Proportioning of RAP & Virgin Aggregate

The percentage of virgin aggregate needed for 0% RAP, 15% RAP, 25% RAP, and 40% RAP were different. Their fore a separated proportion of aggregate was used for each percentage of RAP in the total mix. The proportion shown in the table 1 below was selected after satisfying the gradation envelope for the binder course.

Table 1: Mix Proportioning of RAP & Virgin Aggregate

		Control mix	**15% RAP**	**25% RAP**	**40% RAP**
1	RAP	0	14.9	24.9	39.8
2	A	30	30	25	22.1
3	C	15	15	15	10
4	D	45	33.1	31.1	25.1
5	E (filler)	10	7	4	3
Total		100	100	100	100

Sample Preparation

After conducting all necessary quality tests for virgin and RAP material the next step is the production of specimen samples for Marshall Test.

Fig 1: Sample preparation

Mixing and Compaction of Test Specimens

The mixed samples were compacted with 75 blows on both faces of the specimen at compaction temperature using Marshall Compactor. ERA recommends a mixing temperature of 145±5 ℃ for 60/70 penetration grade bitumen. For a single mix design, a total of 18 Marshall Specimen was prepared.

Determination of Marshall Property

All prepared specimens were subjected to Marshall Test for stability, flow, void in mineral aggregate, and void filled with asphalt. From compacted specimen thickness, weight in the air, weight in water, and saturated dry weight (SSD) was measured using a caliper and balance.

Performance Test

Indirect Tensile Strength Test

Strength is a fundamental property of HMA that can be used to evaluate the stress that a material can resist before a deformation or failure can occur. The indirect tensile strength of HMA is very essential parameter because it highly correlates with fatigue cracking and permanent deformation (rutting) of the bituminous mixture.

Fig 2: Marshall and ITS test specimens

Moisture Sensitivity

Moisture sensitivity or susceptibility has been used to access moisture-induced damage of HMA.
To assess this performance parameter in the laboratory, strength ratio of the conditioned specimen to unconditioned specimen is an acceptable procedure (T. Anil Pradyumna, and Dr. P.K. Jain, 2016).

Wheel Tracking Test

Aggregates used in the RAP may be known to give good Marshall Test results when used in a new AC material.

Table 2: Wheel tracking test sample preparation

Load (N)	No of pass	Weight (gram)	Temperature	
			Chamber	sample
7000	21	10,000	120	60
7000	21	11,000	120	60
7000	21	12,000	120	60

Fig 3: wheel tracking test specimen

Result and Discussion

Gradation Test for RAP

Sieve analysis was done separately for each extraction test and the average percent pass was taken to compare with the ERA binder course graduation requirement. It was observed that the RAP aggregate gradation closed to the upper limit of the specification (it was fine due to the milling process). The collected virgin aggregate is blended together to satisfy the ERA binder course particle size distribution requirement.

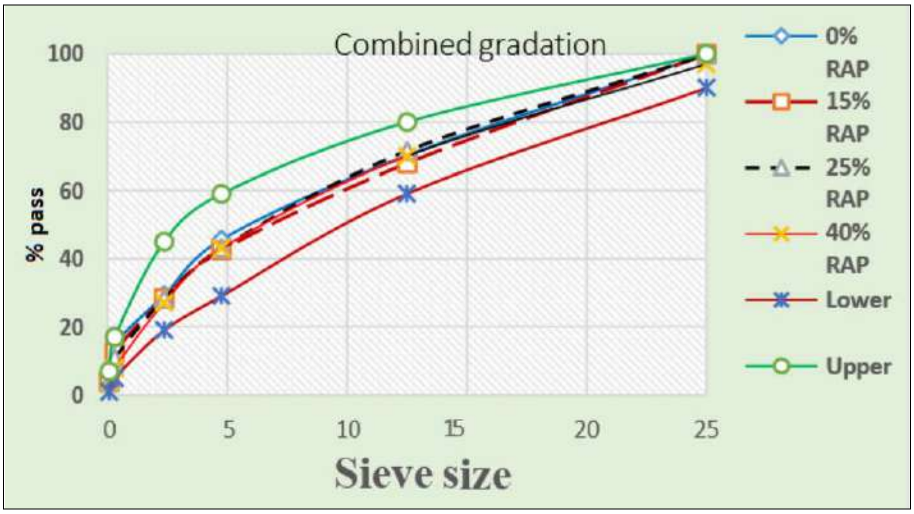

Fig 4: Final blending Curve for Combined Gradation

Mix Design

Control mix

After designing of HMA for control mix, different percentages of RAP (15%, 25% and 40%) were added to control mix. Various trial mix design was performed to achieve the target mix design that was compatible with the standard specification

Marshall Property Result and Discussion

The volumetric property of the control mix was determined @ 4%, 4.5%, 5%, 5.5% and 6% bitumen content. The results for air void, stability, flow, void in mineral aggregate, void filled with asphalt and Gmm at 4%, 4.5%, 5%, 5.5% and 6% bitumen content were present in the following section.

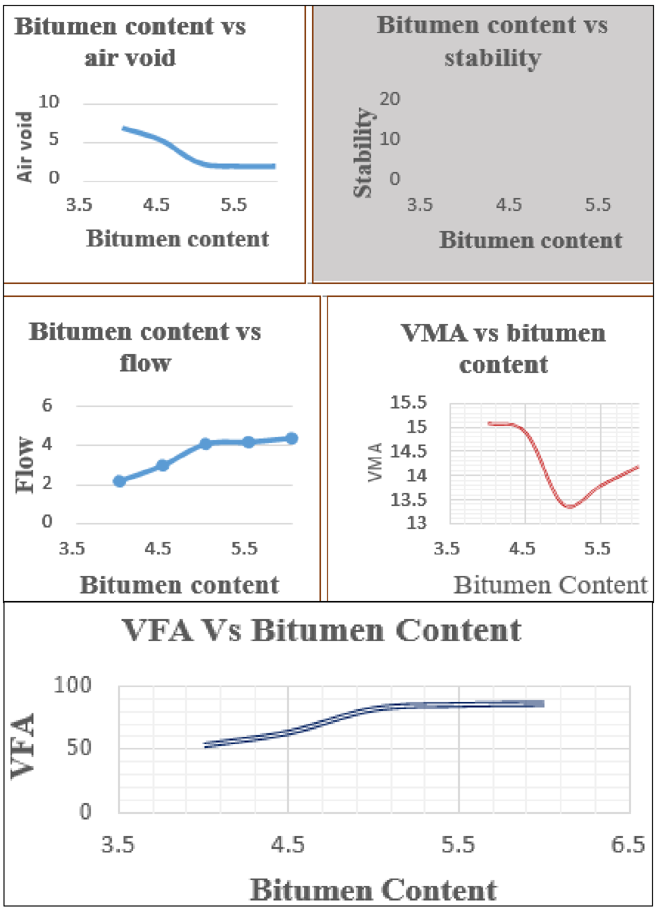

Fig 5: Marshall Property graph results for control mix

From the above property curve the following trends are noted. Void in mix (VIM), decreases with increasing bitumen content and vice versa. When bitumen content increases the void between aggregate is reduced, as a result air become reduced. In the case of stability different trend was observed. Up to near OBC the stability value was increased then the stability was decreasing to the minimum values at 6% bitumen content. From flow versus bitumen content curve the flow values increase together with increasing binder content. However some flow value were beyond the specification envelope. For 5%, 5.5% and 6% bitumen content the flow value were above the stated upper limit of ERA specification. It indicates the HMA asphalt at 5%, 5.5%, 6% were more plastic and results plastic deformation.

Voids in mineral aggregate (VMA) values were decreasing up to 5% bitumen content, then it was increased as the bitumen content increases. At the begging (4% bitumen content) the VMA value was decreased due to better compaction, beyond 5% bitumen content, the bitumen content between aggregate was increases and result poor bondage between aggregates result increase in VMA values. Void filled with asphalt (VFA) decreased when the bitumen content decreased. The VFA inversely related with air void, the VFA increases as the air void decreases. All Marshall Property were satisfied ERA requirements for a bitumen content between 4.5% and 5%. Their fore the OBC was expected between these ranges.

Mix Containing RAP

If the flow at the selected optimum binder content is above the upper specified limit, the mix is considered too plastic or unstable. If the flow is below the lower specified limit, the mix is considered too brittle. Summary of volumetric and Marshall Mix design results for a mix contain RAP was presented as follow.

Bitumen Content Vs Air void (VIM)

Excessive air void affects pavement performance by facilitating cracking due to lack of aggregate bonding, whereas too small air void results bleeding. The increased in air void together with the RAP percentage may be due to the stiffness of RAP binder. When compared and contrast air void of control and recycled mix, Very significant changes were observed on air void of the mix with the inclusion of RAP in the control mix. However, all mixes were satisfy ERA air void requirement criteria between 4.7% and 5.6% of bitumen content.

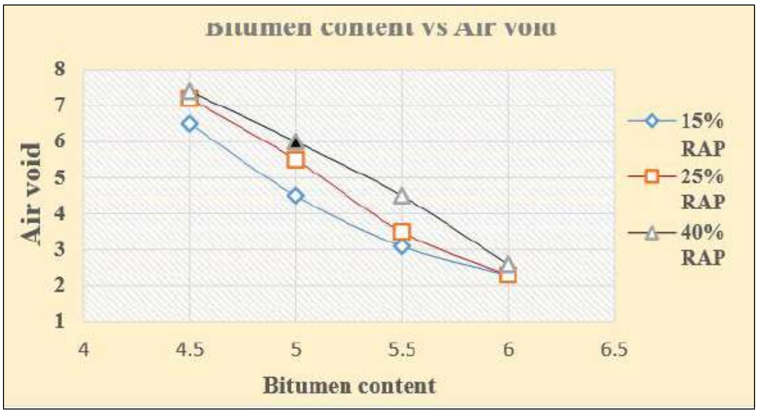

Fig 6: Bitumen content Vs Air void of mix containing RAP

Bitumen Content Vs Stability

The stability Vs bitumen content graph show that the stability increases with increasing bitumen content up to the 5% (near to the optimum bitumen content) and thereafter the stability decreases to minimum values. The stability values at optimum bitumen content were 11.9, 10.8, 11.3 and 12 KN, for 0%, 15%, 25% and 40% RAP respectively. In general it can be seen that the stability values for both mixes met the ERA specification, even if 40% mix have been better stability values (see figure 7 below). The increase in stability values improve bondage between aggregate and bitumen.

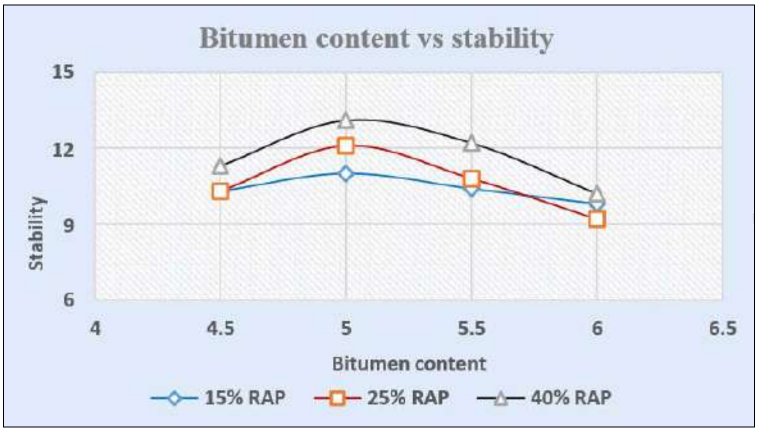

Fig 7: Stability Vs bitumen content of mix containing RAP test results

Bitumen Content Vs Flow

As it was presented in the graph below the flow values increase with increasing the bitumen content of the mix. The flow values at optimum bitumen content were 3.35, 2.9, 3.1 and 3.7 for 0%, 15%, 25% and 40% RAP respectively. Mix with 40% RAP have been highest flow values at OBC. The increase in flow values at optimum bitumen for 40% is expected due the highest optimum bitumen content values than 15 and 25%.

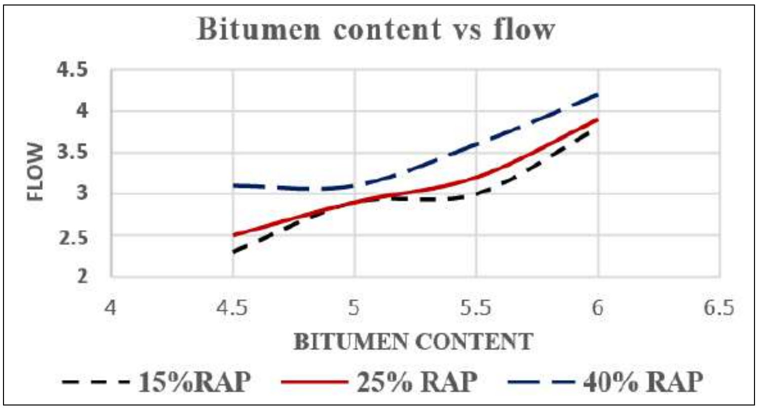

Fig 8: Flow values of RAP containing mixes

Optimum Bitumen Content Selection of Mixes

Optimum bitumen content (OBC) were taken from a smooth graph of VMA vs bitumen content, VFA vs bitumen content, VIM vs bitumen content, stability vs bitumen content and flow Vs bitumen content. The obtained result depicts that OBC were increase as the RAP content increased from 0% to 40% of the total mix. The OBC for control mix, 15% RAP, 25% RAP and 40% RAP were 4.7%, 5.1%, 5.3%, and 5.6% respectively.

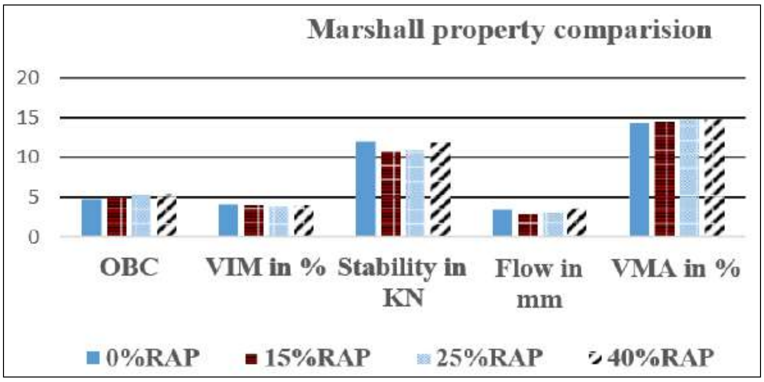

Fig 9: Graphical presentation of Marshall Property @ optimum bitumen content

Performance Tests Moisture Sensitivity

Measurement of retained stability or Retained Marshall Stability test was used to predict moisture sensitivity damages of both control and RAP-containing mix. The ratio of conditioned to unconditioned stability was calculated for both the control and RAP mix and the results were present in the table below. All test specimens were satisfy the ERA stability ratio requirement. ERA flexible pavement manual recommends Retained Marshall stability values of greater than 75%.

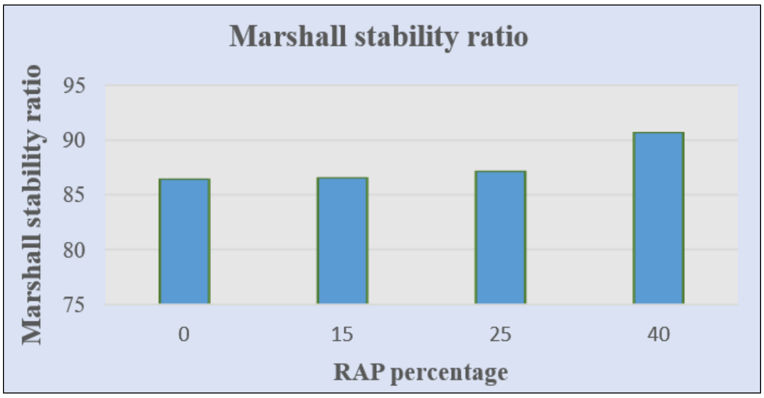

Fig 10: Marshall Stability ratio graph for moisture sensitivity A mixture containing 40% RAP performs well in resisting moisture-induced damage.

The properties of the recycled mixture are believed to be mainly influenced by the aged reclaimed asphalt pavement (RAP) binder properties and the amount of RAP in the mixture. Different scholars conducting research on RAP stated that mixtures prepared from the recycled binder blends generally age at a slower rate than fresh mixtures. This may be due to the fact that the RAP binder has already undergone oxidation which tends to retard the rate of hardening and the recycled mixtures withstands the action of water better than the Fresh mixtures. The research conducted on reclaimed asphalt by Spurti, Dheeraj, and Manjunath, 2014 agree this test result.

Indirect Tensile Strength

An Indirect tensile strength test (ITS) was conducted for three specimens and the average values were taken.

Table 3: ITS test Result

Percentage of RAP	Average Specimen diameter(mm)	Average thickness (mm)	Average Dial reading	Average ITS in Kpa
0%	101.3	62.75	195	841
15%	101.25	64.3	243	1023
25%	101.25	64.9	245	1020
40%	101.3	65.75	240	980

Minimum ITS value was obtained at 0% rap and maximum ITS values were obtained at 15% RAP. The increase of ITS values for a mixture containing RAP is due to the presence of hard bitumen in RAP. Hard bitumen has high resistance to flow; and performs well under tensile force. The mixture containing RAP performs better under tensile strength than the control mix. However, all mixtures satisfy the minimum indirect tensile strength requirements.

Wheel Tracking Test

The obtained result indicates the rut depth were decreasing as the percentage of RAP increases. The highest values of rut depth was found at control mix and the minimum values of rut depth was found at 40% RAP substitution in the control mix. The mix containing RAP performs well in rutting resistance than control mix. 520N load was applied for rutting test with 5040 repetitions and sample temperature of 50˚C. The reason of decreasing in permanent deformation or rutting as the RAP percentage increase may be due to the presence of stiff (hard) bitumen in RAP containing mix. Therefore as percentage of RAP increases the mixture will have higher stiffness and resistance to permanent deformation. These result was supported by previous studies conducted in this area.

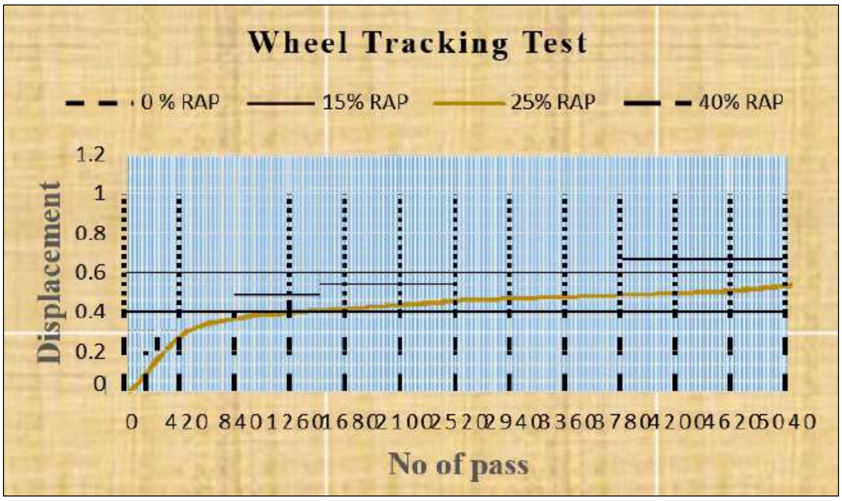

Fig 11: Wheel tracking test Rut depth at different percentage of RAP

Conclusion

This research study is conducted based on laboratory experiment and the obtained results are summarized as follow.

- The asphalt content of the RAP material was found to be 5.03% and aggregate obtained from extraction test was used for sieve analysis of RAP aggregate.
- Depending on the laboratory experiment carried out on RAP containing mix, the mix satisfy the specification criteria of hot mix asphalt.
- Based on the findings of the study stability, flow, and VMA values were increased as the percentage of RAP increased up 40%.
- The OBC was increasing as the RAP content increased from 0% to 40% of the total mix. The OBC for control mix, 15%RAP, 25%RAP and 40%RAP were 4.7%, 5.1%, 5.3%, and 5.6% respectively.
- The performance of the mix containing RAP was evaluated in terms of moisture susceptibility, indirect tensile strength, and rutting resistance or permanent deformation.
- As a percentage of RAP increases up to 40% the moisture susceptibility of the mix will be decreased. A mixture containing 40% RAP performs well in resisting moisture- induced damage.
- The RAP mix performs well under tensile force than the control mix.
- Data generated from the wheel tracking test indicates, that rutting resistance has been improved as the percentage of RAP increases.

- The partial substitution of RAP significantly decreases the demand of virgin aggregate and binder.
- The conducted study concluded that using RAP in HMA binder course up to 40% is possible to design a mix that satisfied the required specification for Marshall Property and performance test with low cost than the control mix.

Recommended Future study area

It is better to construct a trial section for the Actual field performance evaluation of RAP-containing mixes and compare it with the control mix. Use different recycling agents to know the effect of recycling agents on RAP performance and altered properties with the inclusion of additives. The RAP binder is very stiff and affects the same hot mix asphalt property, their fore it needs research on how to improve the RAP binder stiffness and improve its performance.

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