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Assessment of Hot Mix Asphalt Performance Using Reclaimed Asphalt Pavement as a Sustainable Partial Replacement

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Abstract

Although Ethiopia's road network has expanded significantly in recent years, maintaining long-term pavement performance remains a major challenge. In response to increasing sustainability concerns, modern road construction practices emphasize the recycling and reuse of existing asphalt materials, an approach that has been successfully applied since the early 1900s and offers both technical and environmental benefits. This study investigates the laboratory performance of hot mix asphalt (HMA) incorporating varying proportions of reclaimed asphalt pavement (RAP) for binder course applications.

Comprehensive material characterization tests were conducted on all constituent materials to evaluate their suitability for asphalt mixture production. Marshall mix design and testing were subsequently performed on both conventional (control) and RAP-modified mixtures to assess key mechanical properties. To further evaluate field performance, moisture susceptibility, indirect tensile strength (ITS), and Hamburg wheel tracking tests were carried out on the prepared mixtures.

The results indicate that all RAP-containing mixtures satisfied the Marshall design criteria and performance specifications. Furthermore, the mixtures demonstrated acceptable resistance to moisture damage, adequate tensile strength, and satisfactory rutting performance under laboratory conditions. These findings confirm that binder course asphalt mixtures incorporating RAP can be successfully produced while meeting the required engineering and performance standards.

The study concludes that incorporating up to 40% RAP in HMA mixtures is technically feasible for binder course applications. Such mixtures can satisfy both Marshall and performance-based requirements while providing economic advantages through reduced material consumption and lower production costs compared with conventional asphalt mixtures. The findings support the broader adoption of RAP as a sustainable and cost-effective solution for pavement construction and rehabilitation.

Keywords: reclaimed asphalt pavement, Marshall properties, performance test, indirect tensile strength, Hamburg wheel tracking

1. INTRODUCTION

Road transport is the dominant mode of mobility in Ethiopia, accounting for more than 95% of freight and passenger movement (JICA, 2019). When the Road Sector Development Program (RSDP) began in 1997, the sector faced major challenges. Since then, Ethiopia's road network has expanded dramatically—from 26,550 km in 1997 to 165,863 km in 2023, reflecting an average annual growth rate of 7.5%. Consequently, road density increased from 24.1 km to 144.5 km per 1,000 km^2 over the same period, and the paved network rose from 3,708 km to 18,238 km (ERA, 2024). Despite these significant improvements, road conditions have shown only marginal progress. The proportion of federal asphalt roads rated as “good” increased modestly from 17% at the start of RSDP to just 22% in 2023. Notably, only 4.4% of total RSDP expenditure over the past 26 years was allocated to the maintenance of federal roads (ERA, 2024), indicating a substantial maintenance gap. This gap highlights the need for technically sound and environmentally responsible approaches to rehabilitating deteriorated pavements.

Sustainable road maintenance and rehabilitation have become essential components of modern infrastructure management (Hernan et al., 2019). Asphalt recycling and reclaiming, practiced in various forms since the early 1900s, has emerged as one such solution, offering technical, economic, and environmental benefits (Sadie, 2013). Advances in recycling technologies during the 1970s improved feasibility, particularly in regions with long, straight roadway segments (ARRA, 2015; Imran, 2007). The Federal Highway Administration (FHWA) further strengthened this trend by issuing policies that promote recycling nationwide (FHWA, 2002).

Asphalt recycling supports the construction of safe, durable, and cost-effective pavements while significantly reducing energy consumption and environmental impact. Around the world, the pavement industry has evolved considerably, yet challenges related to sustainability persist. Recycling with stabilizing agents aligns well with sustainability goals by allowing the reuse of existing pavement materials while delivering technical and economic advantages (Hernan et al., 2019). In Ethiopia, many asphalt pavements deteriorate prematurely, failing to reach their intended design life and creating an urgent need for efficient rehabilitation strategies (Adefris et al., 2022).

Given Ethiopia’s dependence on road transport, the performance and reliability of its road network are crucial for socio-economic development (ERA, 2021). The rising cost of virgin asphalt and energy has also encouraged greater interest in reclaimed asphalt pavement (RAP) (Elie Y. Hajj et al., 2007). A systematic review by Endale et al. (2022) identified full-depth reclamation (FDR) as one of three potential methods for sustainable rehabilitation, noting that recycling may achieve cost savings of up to 80% while preserving material quality. However, limited pilot applications and a narrow focus on specific regions and additives point to the need for broader trials and supportive policies. Adefris et al. (2022) further reported that RAP can improve pavement moisture susceptibility, rutting resistance, and tensile strength, while findings by Sadie (2013) reaffirmed the durability and moisture resistance of FDR-treated mixtures. Overall, the literature demonstrates that asphalt recycling offers multiple benefits across performance, cost, and sustainability dimensions.

The ERA Flexible Pavement Design Manual (ERA, 2013) states that unbound materials containing RAP may be used as base course materials provided, they meet grading, density, and CBR specifications. RAP’s advantages include reduced energy consumption, lower emissions, minimized landfill use, conservation of natural resources, and reduced disposal costs (Siddharth et al., 2020; Adefris et al., 2022). With maintenance and rehabilitation receiving renewed priority within the Ethiopian Roads Authority, increasing quantities of RAP will become available for reuse. The overall objective of this study is to evaluate the laboratory-based performance of hot mix asphalt mixtures incorporating different percentages of reclaimed asphalt pavement (RAP).

2. METHOD

Study Area

This study focuses on the laboratory evaluation of hot mix asphalt (HMA) mixtures incorporating reclaimed asphalt pavement (RAP) for use in asphalt binder course construction. The RAP material used in the research was sourced from Addis Ababa City, specifically from the Total–Ayertena road section, which had served traffic for more than eight years. The material consisted of milled RAP that had been stockpiled by the Addis Ababa City Roads Authority (AACRA). Milled RAP was selected because it is the form most used in practical HMA production and is generally preferred over core RAP for partial replacement in asphalt mixtures.

2.1.1. Source of Data and Sampling Techniques

RAP samples were obtained from the AACRA stockpile located near the Winget area in Addis Ababa. Since sampling accuracy directly influences the validity of laboratory test results, the material was collected with careful attention to established sampling protocols. As emphasized by Adefris et al. (2022), proper sampling is as critical as the testing process itself. The collected RAP material was then transported to the laboratory for preparation and subsequent evaluation.Bottom of Form

Figure 1 Source of RAP material from AACRA road project (photo taken during sampling)

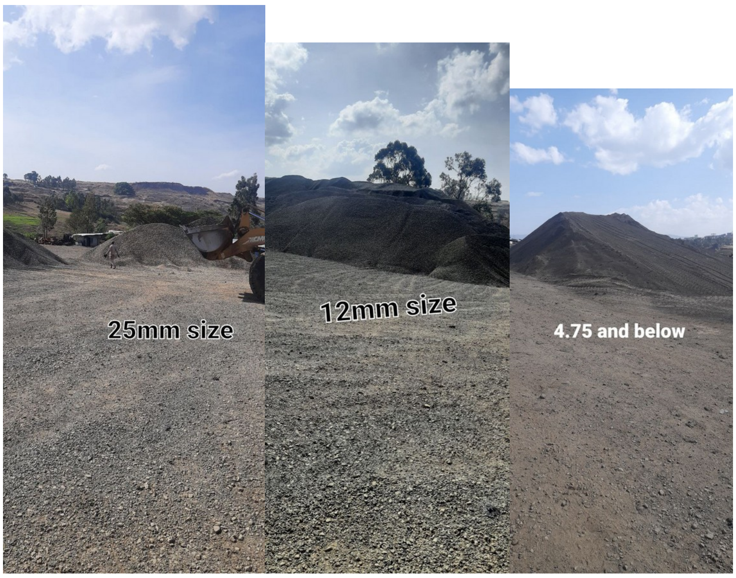

Figure 2 Source of virgin aggregate photo taken during data collection at AACRA batching plant

Sieve Analysis of Virgin Aggregate

The material sampled from the AACRA batching plant consists of four aggregate stocks with different sizes: 25 mm, 19 mm, 12.5 mm, and 4.75 mm.

Research Design and Procedure

This study focuses on the experimental investigation of RAP as a partial replacement material in HMA construction. In conventional HMA production, only virgin aggregates and bitumen are used. In this study, laboratory results of a mix containing RAP are compared with a specification developed for conventional HMA with 0% RAP, which serves as the control mix.

Figure 3 flow chart of the study

Mix Proportioning of RAP & Virgin Aggregate

The percentage of virgin aggregate required varied by 0% RAP, 15% RAP, 25% RAP, and 40% RAP. Therefore, a separate aggregate proportion was used for each RAP percentage in the total mix.

Indirect Tensile Strength Test

Strength is a fundamental property of HMA, used to evaluate the stress a material can withstand before deformation or failure occurs. The indirect tensile strength of HMA is a crucial parameter, as it strongly correlates with fatigue cracking and permanent deformation (rutting) in the bituminous mixture.

Figure 4 ITS test machine and test specimen respectively photo RRC central laboratory

For this study the Wheel Tracking Test (WTT) was carried out based on BS 598-110 to evaluate rutting resistance or performance of HMA. The test was run at a rate of 42 passes of a steel wheel per minute with a load of 520N. The test temperature was fixed at 50C* for sample temperature. The test temperature represents the high pavement temperatures. BS 598-110 specifies a test temperature of 45 or 60C. The WTT evaluates the permanent deformation of a mixture independently of the standard used. To determine the air void and thickness of slab several trial mixes were prepared at 10kg, 11kg and 12kg of total blend.

Figure 5 Core taking from lab compacted slab specimen (photo at RRC central laboratory)

3. RESULT AND DISCUSSION

Moisture Content of RAP Material

A representative sample of RAP material was oven-dried to a constant mass prior to the preparation of test specimens. The moisture content of each sample was determined separately following the AASHTO T265 standard, with an average value of 1.44% obtained. The results indicate that moisture had no significant effect on sample preparation or mix design. Additionally, the results from three trials were very consistent.

Extraction Test Results of RAP Material

Extraction testing is critical for mix designs that incorporate RAP as a partial replacement in HMA. Three extraction tests were conducted, and the average bitumen content of RAP was determined to be 5.03%.

Sieve Analysis

Gradation testing was performed for each extraction sample, and the average percent passing was calculated. This was compared with ERA specifications for binder course requirements. The results showed that the RAP aggregate gradation is close to the upper limit of the specification. Virgin aggregates were blended as needed to meet the ERA particle size distribution requirements for the binder course.

Figure 6 Final blending Curve for Combined Gradation

3.1. Blending Of Virgin Aggregate

The collected virgin aggregates were blended to satisfy the ERA binder course gradation requirements. The aggregates used for the preparation of hot-mix asphalt consisted of different particle sizes. Material sampled from the AACRA batching plant included four stockpiles with nominal sizes of 25 mm, 19 mm, 12.5 mm, and 4.75 mm, designated as aggregate A, aggregate B, aggregate C, and aggregate D, respectively. The results indicated that all gradation values for the blended aggregates fell within the target envelope for the binder course. After analysis, the optimum blend proportions were determined to be:

- Aggregate A: 30%
- Aggregate C: 15%

- Aggregate D: 45%
- Mineral filler: 10%

This combination provided the best gradation curve and was selected as the final blend for the control mix.

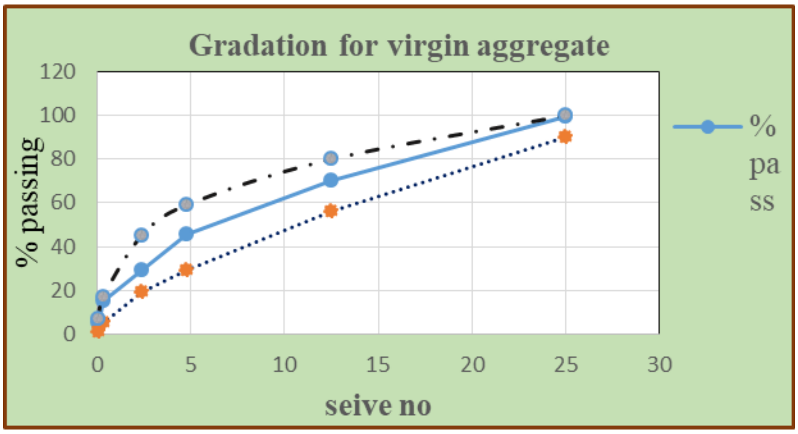

Figure 7 Blending curve for virgin aggregate with specification

3.2. Mix Design

After completing the mix design for the control Hot Mix Asphalt (HMA), different proportions of Reclaimed Asphalt Pavement (RAP)15%, 25%, and 40%—were incorporated into the control mix. A series of trial mix designs were then conducted to achieve a target mix compatible with standard specifications. Separate batches were prepared for both the control mix and the RAP-modified mixes. The optimum bitumen content (OBC) for each mixture was determined independently. First, the OBC of the control mix was established by evaluating the mix properties at different binder contents. For the RAP-containing mixes, the calculation of optimum bitumen content assumed of **100% binder contribution from the RAP material**. This assumption was adopted for the purposes of this study to simplify the estimation of total binder content in the RAP blends.

Table 1 RAP bitumen and RAP aggregate contribution for various % of RAP in HMAs.

Mix type	Aggregate contribution			Binder contribution		
	Fresh aggregate	RAP aggregate	Total	Fresh binder	RAP binder	Total
0% RAP	100	0	100	100	0	100
15% RAP	85.75	14.25	100	85.3	14.7	100
25% RAP	76.3	23.7	100	75.3	24.7	100
40% RAP	62	38	100	60.5	39.5	100

As shown in the table above, the RAP percentages represent the combined contribution of both RAP aggregate and RAP binder. For example, in the 25% RAP mixture, 5.03% of the material was RAP binder, while the remaining 94.97% represented RAP aggregate. This indicates that the actual aggregate contribution of RAP to the total aggregate blend is less than the nominal RAP percentage. The same principle applies to the other RAP levels (15% and 40% RAP). Therefore, in determining the total aggregate blend (% passing for each sieve size), only the effective RAP aggregate portion—excluding RAP binder—was used. As illustrated in the table below, the final blend of virgin aggregates and RAP material fell within the specified upper and lower gradation limits. Proper blending is a critical factor affecting HMA performance tests such as wheel tracking, indirect tensile strength, moisture susceptibility, and other durability assessments.

Overall, considering both **cost savings** and the **ability to meet specification requirements**, partial substitution of RAP in the HMA binder course can be recommended.

Table 2 Combined gradation for fresh and RAP aggregate

Sieve size(mm)	Specification	Target	Obtained gradation for control and RAP mix			
			0%	15%	25%	40%
25	90 - 100	95	99.8	99.9	99.7	97
12.5	59-80	69.5	70.2	67.9	71.5	70
4.75	29- 59	44	45.6	42.4	43	43
2.36	19- 45	32	29.2	28.3	28.2	27
.3	5-17	11	14.9	12.6	10.8	8
.075	1-7	4	6	3.8	4	4

Figure 8 Final blending Curve for Combined Gradation of RAP Material and Fresh Aggregates

Blending result for 0% RAP, 15%RAP, 25%RAP and 40% RAP almost overlapped which was so important for comparison study.

Marshall Property Result and Discussion

Control mix

Separated Marshall Property graphs for void in mix Vs bitumen content, stability Vs bitumen content, flow Vs bitumen content, VMA Vs bitumen and VFA Vs bitumen content were plot based on obtained laboratory test result respectively.

Figure 9 Marshall Property graph results for control mix 0% RAP

From the property curves presented above, the voids in mix (VIM) decrease as the bitumen content increases, and vice versa. This occurs because higher bitumen content fills the void spaces between aggregate particles, reducing the amount of air in the mixture. The stability increased as the bitumen content approached the Optimum Bitumen Content (OBC); however, after reaching a peak, the stability values began to decrease, reaching their lowest point at 6% bitumen content. This is a typical behavior, as excessive bitumen leads to a loss of internal friction and reduces the mixture's load-bearing capacity. The flow values increased with increasing binder content. Some flow values exceeded the specification limits, especially at 5%, 5.5%, and 6% binder content. This indicates that the HMA became more plastic at these higher binder levels, leading to a greater risk of plastic deformation or rutting. The voids in mineral aggregate (VMA) decreased up to 5% bitumen content and then increased as the bitumen content continued to rise. Initially, at 4% binder content, VMA decreased due to improved compaction and denser aggregate structure. Beyond 5%, however, the bitumen film thickened around the aggregate particles, reducing inter-particle contact and weakening the aggregate skeleton. This resulted in increased VMA values at higher bitumen contents.

3.2.1. RAP mix

If the flow value at the selected optimum binder content exceeds the upper specification limit, the mix is regarded as too plastic or unstable. Conversely, if the flow value is below the lower limit, the mix is considered too brittle. A summary of the volumetric and Marshall mix design results for the RAP-containing mixtures is presented as follows. A significant change in air voids was observed with the inclusion of RAP in the control mix. Despite these variations, all mixtures met the ERA air void requirement, falling within the acceptable range for binder contents between 4.7% and 5.6%. Overall, the stability values for all mixtures complied with

ERA specifications, with the 40% RAP mix exhibiting the highest stability—an expected outcome due to the harder binder present in the RAP. The increase in flow values at the optimum bitumen content for the 40% RAP mixture is also expected, as this mix required a higher optimum binder content compared to the 15% and 25% RAP mixes. Although most mixtures satisfied the ERA flexible pavement manual requirements for flow, the 40% RAP mix showed flow values slightly above the upper specification limit, indicating a tendency toward higher plasticity at its optimum binder content.

Table 3 Specification requirements for Asphalt binder course based on ERA manual

Marshall property	Acceptance criteria
Void in mix (VIM)	3 – 5
Stability in KN	≥ 8
Flow in mm	2 – 3.5
Void filled with aggregate	65 – 75
Void in mineral aggregate	≥ 12

Table 4 Marshall and volumetric Properties %, 15%, 25% and 40% RAP content of HMA

Binder content selection

	Bitumen content (%)	VIM (%)	Stability (KN)	Flow(mm)	VMA (%)	VFA (%)	Gmm	Gmb
0% RAP	4.5	5.4	12.35	3.0	14.9	63.6	2.547	2.409
	5	2.4	11.2	4.1	13.4	82	2.525	2.464
	5.5	2	9.88	4.2	13.8	85.4	2.515	2.464
	6	2	8.02	4.4	14.6	86.3	2.505	2.455
15% RAP	4.5	6.5	10.2	2.3	15.8	58.7	2.533	2.368
	5	4.5	11	2.9	14.69	69.3	2.525	2.411
	5.5	3.1	10.4	3	14.5	79	2.505	2.428
	6	2.5	9.8	3.8	14.5	83.8	2.500	2.441
25% RAP	4.5	7.2	10.3	2.5	16.5	56.6	2.525	2.344
	5	5.5	12.1	2.9	16	65.6	2.510	2.372
	5.5	3.5	10.8	3.2	14.9	76.2	2.503	2.416
	6	2.3	9.2	3.9	14.9	84.3	2.487	2.429
40% RAP	4.5	7.4	11.3	3.1	16.7	54.5	2.515	2.328
	5	6.0	13.1	3.2	16.2	61.5	2.510	2.358
	5.5	4.5	12.2	3.6	15.4	70.6	2.493	2.380
	6	2.6	10.2	4.2	14.9	82	2.470	2.406

The Optimum Bitumen Content (OBC) was determined using the smooth trend lines obtained from the plots of VMA, VFA, VIM, stability, and flow versus bitumen content. The results indicate that the OBC increased progressively with higher RAP content, rising from 0% to 40% RAP in the total mixture. Specifically, the OBC values for the control mix, 15% RAP, 25% RAP, and 40% RAP were 4.7%, 5.1%, 5.3%, and 5.6%, respectively. This increase is consistent with the stiffer aged binder present in the RAP, which requires more virgin binder to achieve the desired mixture performance and volumetric properties.

Table 5 Comparison of Marshall Properties RAP containing mix with fresh mix OBC

Mix property	0%	15%	25%	40%	Specification	Remark
OBC	4.7	5.1	5.3	5.6	3 -9	Satisfy
VIM	4	4	4	4.2	3 -5	Satisfy

Stability kn	11.9	10.8	11.3	12	≥ 8	Satisfy
Flow mm	3.35	2.9	3.1	3.5	2 – 3.5	Satisfy
VFA in %	68	71	71.5	73	65 -75	Satisfy
VMA in %	14.3	14.46	15.3	15.3	≥ 12	Satisfy

Retained Marshall Stability (Moisture Susceptibility)

The Retained Marshall Stability test was conducted to evaluate the moisture sensitivity of both the control mixture and the RAP-containing mixtures. For each mix, the ratio of conditioned stability to unconditioned stability was calculated, and the results are presented in the table below. All test specimens satisfied the ERA requirement, which specifies a retained stability greater than 75% as recommended in the ERA Flexible Pavement Manual. Among the mixtures, the 40% RAP mixture exhibited the highest resistance to moisture-induced damage. This improved performance is attributed to the characteristics of the aged binder present in the RAP and the increased RAP content in the mixture. Previous research also supports this finding: recycled binder blends tend to age more slowly than mixtures produced entirely with fresh binders. This is likely because the RAP binder has already undergone significant oxidation, which reduces its rate of further hardening. As a result, recycled mixtures generally demonstrate better resistance to moisture damage compared to fresh mixtures. Similar conclusions were reported by Spurti, Dheeraj, and Manjunath (2014), who found that RAP-containing mixtures perform better in moisture susceptibility tests.

3.2.2. Indirect Tensile Strength (ITS)

The minimum ITS value was observed in the control mix (0% RAP), whereas the maximum ITS value occurred in the 15% RAP mixture. The increase in ITS for RAP-containing mixtures can be attributed to the presence of stiffer (aged) binder in RAP. Aged binder possesses higher resistance to flow and exhibits better performance under tensile loading, thereby improving the tensile strength of the mixture. Overall, all mixtures including those containing RAP met the minimum indirect tensile strength requirements, indicating adequate tensile performance for binder course applications.

3.2.3. Wheel Tracking Test

The results indicate that rut depth decreases as the percentage of RAP increases. The highest rut depth was observed in the control mix, while the minimum rut depth occurred at 40% RAP substitution. The rutting test was conducted under a 520 N load with 5,040 repetitions at a sample temperature of 50 °C (Adefris et al., 2022). The reduction in permanent deformation with increasing RAP content may be attributed to the presence of stiff (hardened) bitumen in the RAP, which increases the overall stiffness of the mixture and enhances its resistance to rutting. These findings are consistent with previous studies in this area (Adefris et al., 2022).

Figure 10 Wheel tracking test result for 0%

4. CONCLUSION

The results of this study demonstrate that reclaimed asphalt pavement (RAP) can be successfully incorporated into hot mix asphalt (HMA) binder course mixtures while satisfying both Marshall design criteria and performance specifications. The RAP material was found to contain 5.03% asphalt binder, highlighting its potential as a valuable source of reusable materials. As RAP content increased up to 40%, the mixtures exhibited higher stability, flow, and VMA values, with optimum binder contents of 4.7%, 5.1%, 5.3%, and 5.6%

for the control, 15% RAP, 25% RAP, and 40% RAP mixtures, respectively. Performance testing indicated that increasing RAP content improved moisture damage resistance, indirect tensile strength, and rutting resistance, with the 40% RAP mixture showing particularly satisfactory performance. Furthermore, the use of RAP significantly reduced the demand for virgin aggregates and asphalt binder, contributing to resource conservation and sustainability. Overall, the study confirms that incorporating up to 40% RAP in HMA binder course mixtures is technically feasible and can produce mixtures that meet required specifications while reducing production costs compared with conventional asphalt mixtures.

Recommendations for Future Research

Future research should focus on the construction and long-term monitoring of trial pavement sections incorporating RAP to evaluate their actual field performance under traffic and environmental conditions, with comparisons made against conventional virgin mixtures. Further investigations are also recommended to assess the effectiveness of different recycling agents and additives in enhancing RAP mixture performance and modifying material properties. In addition, because aged RAP binder is generally stiffer than virgin binder and may negatively influence certain asphalt mixture characteristics, further studies should explore techniques for binder rejuvenation and stiffness reduction to improve the durability, flexibility, and overall field performance of RAP-containing asphalt mixtures.

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Availability of data and materials

All necessary data were included in this manuscript.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The author declares that there are no competing interests.

References

[1] AASHTO, 2004. Standard specifications for transportation materials and Methods of Sampling, and Testing, Washington DC, USA (2014).

[2] Adefris, K, Mpotdar A, Demeku S. (2022) Laboratory based performance evaluation of high content reclaimed asphalt pavement in hot mix. J Civ Eng Appl 2022; 3(1):12-19.https://doi.org/10.22271/27078388.2022.v3.i1a.10

[3] Asphalt Institute, 2014, Mix design methods for Asphalt Concrete and Others Hot-mix type, Asphalt Institute Manual Series No. 2 (MS-II)', seventh edition, Library of Congress, USA.

[4] BIBLIOGRAPHY Asphalt Recycling & Reclaiming Association (ARRA, 2016) Recommended Mix Design Guidelines for Cold Recycling Using Emulsified Asphalt Recycling Agent.

[5] Button, J. W., Estakhri, C. K., & Little, D. N. (1999). Overview of hot in-place recycling of bituminous pavements. Transportation research record, 1684(1), 178-185.

[6] Button, J. W., Estakhri, C. K., & Little, D. N. (1999). Overview of hot in-place recycling of bituminous pavements. Transportation research record, 1684(1), 178-185.

[7] Elie Y. Hajj, Peter E. Sebaaly, & Raghubar Shrestha (2007). A Laboratory Evaluation on the Use of Recycled Asphalt Pavements In Hma Mixtures.

[8] Endale, A.A., Ghataora, G.S. and Burrow, M.P.N. (2022) 'Asphalt Pavement Cold Recycling and Basic Characteristics of RAP Materials and Their Application', Journal of Civil Engineering and Architecture, 16, pp. 38–51. https://doi.org/10.17265/1934-7359/2022.01.004.

[9] Erica Ann Yeung (2017). Exploring Compaction

[10] Effects on Cold In-Place Recycling Mixtures using Emulsified Asphalt. (5-2017).

[11] Ethiopian Roads Authority (ERA) (2013). Pavement Design Manual Volume 1 Flexible Pavements, Ethiopia, Addis Ababa.

[12] Ethiopian Roads Authority (ERA) (2024) The Road Sector Development Program: 26 years RSDP Assessment. Addis Ababa: Ethiopian Roads Authority.

[13] Federal Highway Administration /FHWA, 1997, 'Pavement Recycling Guidelines for State & Local Governments-Participant's Reference Book', National Center for Asphalt Technology, Washington DC, USA. (1997).

[14] Frederico Vasconcellos Guatimosim (2015). Mechanical Behavior and Structural Performance of Recycled Foamed Bitumen Stabilized Materials. (Dissertation presented for the degree of Master of Science University of Sao Paulo (Engineering)

[15] Gidirsa, T. K. (2020). Evaluation of asphalt road pavement containing recycled asphalt pavement as a partial material in asphalt binder course mix in the laboratory (Case study: Ayertena – Alem Bank – Yeshi Debele Road Project). Addis Ababa: Addis Ababa Intuition of Technology.

[16] Harnan Gonzalo-Orden H, Linares-Unamunzaga A, Pérez-Acebo H, Díaz-Minguela J. Advances in the Study of the Behavior of Full-Depth Reclamation (FDR) with Cement. Applied Sciences. 2019; 9(15):3055. https://doi.org/10.3390/app9153055

[17] Nikolaides, A. (2014). Highway engineering: pavements, materials and control of quality. CRC Press.

[18] Paige-Green, P. (2010). Preliminary evaluation of the reuse of cementitious materials. (n.d.).

[19] Yatish Arvind Jakatimath (2000). Evaluation of Cold In-Place Recycling For Rehabilitation of Transverse Cracking.

[20] Z H Hussein, H Yaacob, S Abdulrahman, and R P Jaya (2019). Rejuvenation of Hot Mix Asphalt Incorporating High RAP Content: Issues to Consider Volume 2020, Article ID 8672654, 13 pages.